On the Urban Heat Island in Beirut
Noushig Kaloustian

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L’îlot de chaleur urbaine à Beyrouth
On the urban heat island in Beirut

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Abstract

Replacement of natural surfaces with artificial surfaces, anthropogenic heat emissions and urban geometry can lead to one of the more widely documented phenomena of climate change known as the urban heat island (UHI). In Beirut, there is no evidence that the UHI has been investigated or even considered in relevant policies or construction standards.

In this research, the UHI is investigated across Beirut to find the most suitable mitigation solutions within urban planning and design disciplines. The methodology adopted included using the Town Energy Balance model of Météo France (Masson, 2000) which parameterizes the surface-atmospheric energy exchanges. Simulations determined that raising the solar reflectance of roof materials had the highest impact on alleviation of the UHI followed by increasing garden fractions.

Improvements could be made in the Urban Planning Law #69 (dated 1983), the Building Code #646 (dated 2004) and the existing institutional framework to ensure protection of the urban microclimate. Transfer of urban climatic knowledge amongst all relevant stakeholders could also be beneficial in this regard. Indeed, TEB could be an important decision-making tool and a means to promote evidence-based planning and design practices in Beirut.

Limitations included limited data availability, which were accordingly extrapolated using aerial imagery. TEB also requires simplified architectural data requirements and does not have the option to include street orientations in its simulations.

Future research could include investigation of the impacts of cooling by increasing evaporation, and cooling by implementation of water-film surfaces, as well as
the investigation of the actual possibility of intervention and implementation of proposed mitigating actions for Beirut, taking into consideration economic and social conditions.

*Key words:* Urban Heat Island, Beirut, Town Energy Balance, Urban Planning, Building Code
Résumé

Le remplacement des surfaces naturelles par des surfaces artificielles, les émissions de chaleur anthropique et la géométrie urbaine peut résulter au phénomène plus ou moins documenté du changement climatique, aussi connu sous le nom de l’Îlot de Chaleur Urbain (ICU). Il n’y aurait pas de preuves que ce phénomène a été le sujet d’enquêtes approfondies ou même encore pris en considération dans l’élaboration des politiques nationales relatives ou des standards de construction.


Des améliorations pourraient être introduites à la loi sur la planification urbaine 69 de 1983, le code de construction 646 de 2004 et le cadre institutionnel existant pour assurer la protection du microclimat urbain. Le transfert de connaissance sur le climat urbain entre les différents acteurs pourrait aussi être bénéfique à ce sujet. Au fait, TEB pourrait être un outil de prise de décision important et un moyen pour promouvoir une planification fondée sur les preuves et des pratiques de conception à Beyrouth.
Les limites dont a souffert cette étude ont été les informations disponibles limitées, qui ont été tout de même extrapolées à travers l'utilisation de l’imagerie aérienne. Le EVV requit aussi des exigences d’information architecturale simplifiées et ne fournit pas l’option d’inclure le sens des rues dans la simulation.

Les recherches à l’avenir pourraient inclure des enquêtes sur l’impact du refroidissement à travers l’augmentation de l’évaporation et le refroidissement à travers l’installation de surfaces de films d’eau, ainsi que la considération de la possibilité pratique d’intervention et la mise en place des mesures d’atténuation suggérées pour Beyrouth, en prenant en considération les conditions socio-économiques.

*Mots clés :* L’îlot de chaleur urbain, Beyrouth, Town Energy Balance, planification urbaine, loi sur la construction.
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<tbody>
<tr>
<td>AUB</td>
<td>American University of Beirut</td>
</tr>
<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
</tr>
<tr>
<td>CAS</td>
<td>Central Administration of Statistics</td>
</tr>
<tr>
<td>CDR</td>
<td>Council for Development and Reconstruction</td>
</tr>
<tr>
<td>CNRM</td>
<td>Center National De Recherche Météorologique</td>
</tr>
<tr>
<td>CNRS</td>
<td>Conseil National de Recherches Scientifiques</td>
</tr>
<tr>
<td>COM</td>
<td>Council of Ministers</td>
</tr>
<tr>
<td>DGUP</td>
<td>Directorate General of Urban Planning</td>
</tr>
<tr>
<td>EIA</td>
<td>Environmental Impact Assessment</td>
</tr>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>GBA</td>
<td>Greater Beirut Area</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gases</td>
</tr>
<tr>
<td>FVM</td>
<td>Finite Volume Model</td>
</tr>
<tr>
<td>HCUP</td>
<td>Higher Council of Urban Planning</td>
</tr>
<tr>
<td>HIR</td>
<td>Heat Island Reduction</td>
</tr>
<tr>
<td>IAUC</td>
<td>International Associations for Urban Climate</td>
</tr>
<tr>
<td>INVS</td>
<td>Institut de Veille Sanitaire (French Institute for Public Health Surveillance)</td>
</tr>
<tr>
<td>ISBA</td>
<td>Integration with Soil Biosphere and Atmosphere</td>
</tr>
<tr>
<td>IPCC</td>
<td>International Panel on Climate Change</td>
</tr>
<tr>
<td>LAI</td>
<td>Leaf Area Index</td>
</tr>
<tr>
<td>LARI</td>
<td>Lebanese Institute for Agricultural Research</td>
</tr>
<tr>
<td>LCCEC</td>
<td>Lebanese Center for Energy Conservation</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
</tr>
<tr>
<td>LEDO</td>
<td>Lebanese Environment and Development Observatory</td>
</tr>
<tr>
<td>LGBC</td>
<td>Lebanese Green Building Council</td>
</tr>
<tr>
<td>LIBNOR</td>
<td>Lebanese Standards Institution</td>
</tr>
<tr>
<td>MOE</td>
<td>Ministry of Environment</td>
</tr>
<tr>
<td>MOEW</td>
<td>Ministry of Energy and Water</td>
</tr>
<tr>
<td>MOI</td>
<td>Ministry of Industry</td>
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<td>MOIM</td>
<td>Ministry of Interior and Municipalities</td>
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<td>MOPWT</td>
<td>Ministry of Public Works and Transport</td>
</tr>
<tr>
<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
<tr>
<td>NOAA</td>
<td>National Oceanic Atmospheric Administration</td>
</tr>
<tr>
<td>NPMPLT</td>
<td>National Physical Master Plan of the Lebanese Territory</td>
</tr>
<tr>
<td>OEA</td>
<td>Order of Engineers and Architects</td>
</tr>
<tr>
<td>PCM</td>
<td>Phase Change Materials</td>
</tr>
<tr>
<td>RGM</td>
<td>Regional Climatic Model</td>
</tr>
<tr>
<td>SDATL</td>
<td>Schéma d’aménagement du territoire Libanais</td>
</tr>
<tr>
<td>SEA</td>
<td>Strategic Environmental Assessment</td>
</tr>
<tr>
<td>SEB</td>
<td>Surface Energy Balance</td>
</tr>
<tr>
<td>SOER</td>
<td>State of the Environment Report</td>
</tr>
<tr>
<td>SVF</td>
<td>Sky View Factor</td>
</tr>
<tr>
<td>TEB</td>
<td>Town Energy Balance</td>
</tr>
<tr>
<td>UHI</td>
<td>Urban Heat Island</td>
</tr>
<tr>
<td>UNDP</td>
<td>United Nations Development Program</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Carbon</td>
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### Latin Letters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_L$</td>
<td>Upper leaves area</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$A_p$</td>
<td>Tree ground planting area</td>
<td>m$^2$</td>
</tr>
<tr>
<td>$c_f$</td>
<td>Cloud fraction</td>
<td>-</td>
</tr>
<tr>
<td>$D$</td>
<td>Diffuse short-wave radiation (D)</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$e_a$</td>
<td>Actual vapor pressure</td>
<td>Pa</td>
</tr>
<tr>
<td>$j$</td>
<td>Total energy radiated</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$K^*$</td>
<td>Net short-wave radiation</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$K\downarrow$</td>
<td>Total short-wave radiation received at the earth surface</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$L\uparrow$</td>
<td>Outgoing long-wave radiation from the surface</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$L\downarrow$</td>
<td>Counter radiation or downward long-wave radiation which arrives at Earth’s surface</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$P$</td>
<td>Pressure</td>
<td>Pa</td>
</tr>
<tr>
<td>$Q^*$</td>
<td>Net all wave radiation</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$\Delta Q_A$</td>
<td>Net energy (sensible and latent) advection; rate per unit volume (per unit horizontal area)</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$Q_E$</td>
<td>Latent heat flux</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$Q_G$</td>
<td>Energy exchange between the canopy and the underlying soil.</td>
<td></td>
</tr>
<tr>
<td>$Q_F$</td>
<td>Anthropogenic heat and represents “man-made’ heat generated by buildings, machinery or people</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$Q_H$</td>
<td>Sensible heat flux</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$\Delta Q_S$</td>
<td>Net energy storage; rate per unit volume (per unit horizontal area)</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$q_a$</td>
<td>Humidity of the air at the first atmospheric level</td>
<td>-</td>
</tr>
<tr>
<td>$R_R, R_e, R_w$</td>
<td>Aerodynamic resistance of roofs, roads and walls</td>
<td>s.m$^{-1}$</td>
</tr>
<tr>
<td>$S$</td>
<td>Direct-beam short-wave radiation</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$S\downarrow$</td>
<td>Direct sunlight</td>
<td>W.m$^{-2}$</td>
</tr>
<tr>
<td>$T$</td>
<td>Temperature</td>
<td>°C, °F, or K</td>
</tr>
<tr>
<td>$T_a$</td>
<td>Air temperature in the first atmospheric level</td>
<td>°C, °F, or K</td>
</tr>
<tr>
<td>$T_R, T_r, T_w$</td>
<td>Temperature of roofs, roads and walls</td>
<td>°C, °F, or K</td>
</tr>
<tr>
<td>$T_s$</td>
<td>Temperature of the surface</td>
<td>°C, °F, or K</td>
</tr>
<tr>
<td>$U$</td>
<td>Wind speed</td>
<td>W.m$^{-2}$.K$^{-1}$</td>
</tr>
<tr>
<td>$U_a$</td>
<td>Wind speed measured in the inertial sub-layer</td>
<td>m.s$^{-1}$</td>
</tr>
<tr>
<td>$u^*$</td>
<td>Friction velocity</td>
<td>W.s$^{-1}$</td>
</tr>
<tr>
<td>$W$</td>
<td>Width of road</td>
<td>m</td>
</tr>
<tr>
<td>$z$</td>
<td>Height</td>
<td>m</td>
</tr>
<tr>
<td>$z_0$</td>
<td>Roughness length</td>
<td>m</td>
</tr>
</tbody>
</table>
## Greek Letters

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\alpha)</td>
<td>Albedo</td>
<td>-</td>
</tr>
<tr>
<td>(\varepsilon_a) or (\varepsilon)</td>
<td>Emissivity</td>
<td>-</td>
</tr>
<tr>
<td>(\varepsilon_g, \varepsilon_s)</td>
<td>Emissivity of ground and surface</td>
<td>-</td>
</tr>
<tr>
<td>(\lambda_R, \lambda_c, \lambda_w)</td>
<td>Thermal conductivity of roofs, roads, and walls</td>
<td>W.m(^{-1}).K(^{-1})</td>
</tr>
<tr>
<td>(\sigma)</td>
<td>Stefan Boltzmann constant</td>
<td>W.m(^{-2}).K(^{-4})</td>
</tr>
<tr>
<td>(\phi)</td>
<td>Zenith angle of sun</td>
<td>Degrees ((^{\circ}))</td>
</tr>
</tbody>
</table>
PART I: INTRODUCTION
In this introductory chapter of this thesis, background information on the country of Lebanon and its capital city of Beirut is given. This includes, existing and projected urban populations, urbanization and impacts on the surrounding environment and urban microclimate or more specifically on the urban heat island (UHI) phenomenon, which is the context of this research. As such, the significant impacts of the UHI related to human health, deterioration of the quality of life and heat-related mortality is deliberated which justify the need to conduct detailed research and analysis for the densely populated city of Beirut. The choice of scale at which the data collection and numerical analysis of this research is carried out is also discussed. Finally the research objectives and the thesis structure are all outlined in this chapter.

1.1 Background Information on Lebanon

Lebanon is the second smallest country in the Middle East after Bahrain, covering an area of 10,452 km\(^2\) with an estimated local population of about 4,223,553 (World Bank, 2013). The urban density\(^1\) is one of the highest in the world with an estimated ratio of about 21,000 inhabitants / km\(^2\) (Population and Development Strategies Programme Lebanon, 2014; MOE/LEDO/ECODIT, 2001). Latest available figures show that 87 % of actual population lives in urban to suburban\(^2\) areas of which 64 % resides in large urban agglomerations namely in the cities of Beirut, Tripoli, Sidon, Tyr and Baalbek (United Nations Centre for Human Settlements [UN-HABITAT], 2009). This is by far the highest urban to rural population in the region ahead of Jordan (78.5 %) and Syria (54.6 %).

\(^1\) Except in Australia, the authorities use a minimum urban density definition of 400 persons per square kilometer (Demographia World Urban Areas, 2015)

\(^2\) Suburban area refers to an area lying immediately outside of a city or a town, especially a smaller residential community
According to UN-HABITAT (2011), the Lebanese population is expected yet to
grow to reach 4,587,000 capita by year 2020, of which 89 % will be an urban population. Therefore, built environment or built-up areas\(^3\) are also expected to grow accordingly over the next 3 decades at a rate of 10 km\(^2\)/year (CDR-NPMLT/DAR-IAURIF, 2004).

**1.2 Urbanization Effects on UHI and implications for Beirut city**

Urban populations are increasing due to rural exodus, which is a growing trend worldwide and which is generally found to be the result of a combination of factors including greater job opportunities, wider choices in education, improved infrastructure, and higher expectations in overall quality of life, and for the case of Beirut, due to the combined effect of an influx of refugees. Urban areas consequently become major consumers of energy and materials generating vast amounts of harmful waste such as carbon dioxide (CO\(_2\)), from the burning of fossil fuels for heating and cooling purposes, industrial processes, and transportation of people and goods. Although there is much contention on this issue, they contribute to a certain extent to greenhouse gas (GHG) forced global climate change (Emmanuel & Krüger, 2012; Grimmond, 2007).

Urban areas also contribute to urban microclimate effects at the city scale. Therefore, increasing urban populations are also responsible for the gradual modification of surfaces at city scales where natural vegetation is replaced with buildings and roads (Akbari, 2005). As such, the urban microclimate is affected. The term Urban Heat Island (UHI) describes this phenomenon which is related to higher urban temperatures in the city centers as compared to the surrounding rural or suburban areas (Figure 1). The UHI

\(^3\) Built-up areas or a built environment is a human-made landscape, as distinguished from the natural environment. It is a material, spatial and cultural product made by man that combines physical elements and energy in forms of living, working and playing. It has been defined as “the human-made space in which people live, work, and recreate on a day-to-day basis” (Roof & Oleru, 2008).
phenomenon is mainly related to the high density of buildings and urban structures that absorb solar radiation, the use of highly absorbing materials, the lack of green spaces, the characteristics of the urban canyons, and the production of anthropogenic heat (Santamouris, Synnefa & Karlessi, 2011). In fact, research studies conducted in the Mediterranean region other than Beirut, like in the city of Athens for example, have shown the strong positive correlation that exists between the aforementioned parameters and the UHI (Giannopoulou, Livada, Santamouris, Saliari, Assimakopoulos, and Caouris, 2011; Santamouris, et al, 2011; Santamouris, et al, 2012). Urban densification therefore increases the proportion of impervious artificial\textsuperscript{4} surfaces and changes the urban fabric morphology (Bozonnet, Musy, Calmet, & Rodriguez, 2013) resulting in higher urban temperatures. While predicting climate change and its impacts at a global scale is still highly uncertain, the effects of urbanization on the climate at the city scale have long been recognized and documented (Landsberg, 1981; Oke, 1987).

![Figure 1. Schematic representation of the urban heat island profile in Paris. Source: Descartes Team Grand Paris, 2009](image)

The question of what the repercussions of urban heating are on city dwellers therefore arises. Indeed it has been found that urban heating may cause many problems for urban populations including deteriorating living environments and associated

\textsuperscript{4} Artificial surfaces infer impermeable man-made surfaces common in urbanized areas as opposed to natural areas covered by vegetation and which are accordingly permeable
qualities, increasing energy consumption, growing health concerns, and even rises in 
mortality rates (Rizwan, Dennis, & Chun-Ho, 2009) as in the case of the summer 2003 
heat wave, which resulted in an estimated 70,000 additional deaths in Europe. In France 
alone, which was hit the hardest, approximately 14,000 heat-related deaths occurred 
during the 2003 summer heat wave according to the French National Institute of Health 
(Bozonnet et al., 2013; Chagnon, Kunkel, and Reinke 1996; French Institute for Public 
Health Surveillance [INVS], 2015; Masson, 2006; Meehl and Tebaldi, 2004; Poumadère, 
Mays, Le Mer, and Blong, 2005). Settlements are continually expanding to accommodate 
the influx of migrants from rural areas not to mention the natural increase of urban 
populations. This makes the study of urban climates doubly important; first to ensure a 
pleasant and healthy environment for urban dwellers, and second to see that the effects of 
urbanization do not have harmful repercussions on larger scale climates (Oke, 1978). For 
the case of Beirut city, which as previously mentioned is experiencing rural exodus, and 
associated developments and constructions, not to mention major traffic congestions, 
dramatic impacts on the UHI are increasing which is why it is imperative to conduct a 
detailed investigation and analysis of this phenomenon in Beirut and find mitigating 
solutions in urban planning policies and practices.

1.3 Scale of Study for Beirut City

The complex morphology of urban areas results in a range of effects on the 
surface-atmosphere energy exchange balance. In order to understand the physical 
mechanisms responsible for the urban modifications to the local climate it is necessary to 
first comprehend the spatial scale upon which these physical processes act. According to 
Oke (1987), there are four classifications of scales in which atmospheric phenomena can
occur; these include micro-scale ($10^{-2}$ to $10^3$ m), local scale ($10^2$ to $5 \times 10^4$ m), meso-scale ($10^4$ to $2 \times 10^5$ m) and macro-scale ($10^5$ to $10^8$ m ) classifications. This research focuses on the effects of urbanization in Beirut at the city scale or meso-scale level, while micro-scale essentially refers to street level, local scale to neighborhood level and macro-scale to larger regional levels.

It is worth noting that a key aspect of urban meteorology studies concerns the description and classification of the surface on the relevant spatial scale which is why it is important to first identify the scale at which the research will be conducted. Therefore, the meso-scale level of study is selected because the aim of this research is to identify urban parameters that have the most significant impact on UHI at the city-scale of Beirut in the view to propose mitigation measures from an urban planning perspective for the city.

1.4 Research Objectives

This research therefore aims to investigate the UHI phenomenon within the Beirut context to accordingly propose solutions to minimize the impacts on the UHI in Beirut city in the view to improve the overall living conditions of the city dwellers. As such, this research uses the Town Energy Balance (TEB) model to substantiate and measure the effects of Urban Heat Island (UHI) within Beirut administrative boundaries taking into consideration the main urban artificial or man-made surfaces including buildings, and roads as well as existing urban vegetated surfaces. It then assesses the extent to which UHI is being considered in current planning policies and practices, and finally, it provides recommendations for appropriate mitigation measures and required actions deliberated from an urban planning perspective.
The main objectives of this research are therefore listed as follows:

1. To measure and model the effect of UHI in Beirut and identify major contributing factors

2. To assess whether and to what extent the urban microclimate is considered in urban planning processes for Beirut

3. To find most suitable measures to alleviate the effects of UHI in Beirut from a technical perspective

4. To assess implications for urban planning process from an institutional and administrative perspective

5. To find opportunities at all planning and design levels to help achieve more sustainable design and planning practices in Beirut

1.5 Thesis Structure

This dissertation is organized into five parts. The first part consists of one chapter which gives background information on Lebanon and the densely populated urban capital city of Beirut which accordingly modifies and replaces existing natural surfaces with man-made artificial surfaces thus affecting the UHI. It also gives an overview of the UHI phenomenon in Beirut, its adverse effects on the urban microclimate and human health, and discusses the scale of study for this research and finally provides an outline of the research objectives as well as the thesis structure.

The second part is the literature review chapter on the UHI phenomenon which is divided into three chapters; the first chapter gives a detailed account of the history and definition of UHI as well as the causes of this phenomenon. The second chapter discusses the relationship between climate change and the urban heat island, as well as the impacts
and characteristics of the UHI and the energy balance. The third and final chapter of this second part is dedicated to measurement and mitigating methods of the UHI according to the existing literature on the topic giving light to methods selected for the Beirut case.

The third part is comprised of one chapter on the Beirut case study and gives details on the physical characteristics of the city, the urban planning of the city, the land-cover and land uses, the urban morphology, and urban populations and accordingly justifies the need to investigate the UHI phenomenon in the city of Beirut.

The fourth part is on the UHI in Beirut and is comprised of two chapters; the first chapter is on the research methodology of the thesis and gives a detailed account of the data collection process, and the measurement and modeling schemes adapted for this research. The second chapter gives an outline of the numerical analysis results based on the simulation results and the selected scenarios.

The fifth and final part of this thesis is divided into three chapters where the first chapter discusses in detail the numerical analysis results; the second chapter addresses and discusses the objectives of this research and how they were achieved, and; the third and final chapter is the concluding chapter of this thesis and provides a summary of the findings of this research and makes recommendations for future works within the context of Beirut city. Figure 2 is a flow chart illustrating the structure of this thesis.
Figure 2. Flow chart showing thesis structure
PART II: LITERATURE REVIEW AND ANALYSIS OF THE URBAN HEAT ISLAND
Part II of this thesis gives a comprehensive account and analysis of the literature review on the topic of the urban heat island phenomenon. It is divided into three chapters as follows: 1) history and causes of the UHI; 2) climate change, impacts and characteristics of the UHI and the energy balance equation, and 3) measuring, modeling and mitigation measures of the UHI. It is worth noting that in these chapters comparisons are made to the Beirut case as necessary depending on the relevance of the specific UHI topic being discussed.

Chapter 2: Urban Heat Island: History and Causes

In this chapter of the thesis, a detailed account of the history and definition of the urban heat island is provided as well as the different types of heat islands that exist, such as the urban canopy layer, the urban boundary layer and the surface heat islands, all based on the available literature on the topic. In addition, this chapter discusses the underlying causes that lead to the formation and exacerbation of the heat island, namely natural factors such as geographic locations, proximity to major water bodies, climatic conditions and so on, and anthropogenic factors such as industrial and traffic-associated heat emissions, as well as urban geometry of cities, solar reflectivity of urban materials and presence or absence of vegetation.

2.1 History and Definition

In 1818, Luke Howard - a chemist turned meteorologist, renowned for his seminal work on clouds’ classification - published the first volume of “The Climate of London”, a documentation of the urban climate of London with continuous daily meteorological records of wind direction, temperature, precipitation, and atmospheric precipitation (International Association for Urban Climate [IAUC], 2014). Howard was the first to recognize that urban areas can have significant effects on the local climate by identifying
how London’s urban climate was much hotter than that of the English countryside, a phenomenon that was later coined as the “Urban Heat Island (UHI)”.

Similar observations were then made in Paris in the second half of the 19th century, in Vienna in the early 20th century, and in the U.S. in the first half of the 20th century (Gartland, 2008). Thereafter, several investigations have been made uncovering the causes that contribute to the UHI effect, putting forth various methods to modeling the UHI, and suggesting effective measures to mitigate and alleviate the negative impacts of UHI on cities and their dwellers.

The term "heat island" therefore 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. 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. At the building scale, dark roofs heat up more, thus increasing the summertime cooling demands of buildings. For example, a study conducted in the city of Athens, with an urban heat island intensity of 10°C, showed that the cooling load, or cooling energy demand, of urban buildings may be doubled thus reflecting the strong impact of the UHI on energy demands in urbanized areas (Santamouris, et al, 2001). Similar effects can be expected in Beirut due to the resemblances in urban characteristics between these two Mediterranean cities. It is therefore important to study the effects of urbanization on the urban heat island in Beirut to determine to what extent energy demands are affected and what the potential consequences are on the surrounding environment and urban microclimate.
Moreover, dark surfaces and lack of vegetation collectively warm the air over urban areas leading to the creation of urban heat sinks. It has been reported, that on a clear summer afternoon, the air temperature in a typical city is as much as 2.5°C higher than in the surrounding rural areas (Akbari, Pomerantz, & Taha, 2001). This urban heating or UHI can therefore also result in mortality like in the case of the 2003 summer heat wave in Paris which caused over 10,000 heat-related deaths as recorded by the French National Institute of Health thus reflecting the strong impact of the UHI on human health and quality of living in urbanized areas (INVS, 2015). In Beirut, the number of hot days\footnote{Hot days are defined as the number of days each summer that daily maximum temperature (Tx) exceeds 31°C (close to the 95\textsuperscript{th} percentile).} has increased during the second half of the last century, at a rate of about two days per decade. In fact the largest number of hot days has been recorded from the late 1980s onwards, during which time urbanization developments and urban population records in Beirut increased significantly making the living thermal conditions extremely uncomfortable and unhealthy for the city dwellers. Hot summer days can accordingly have negative effects on human comfort levels and can contribute to significant heat stress. The number of hot summer days has increased significantly in Beirut in this past decade (Hatzaki, Giannakopoulos, Hadjinicolaou, & Kastopoulou; CIRCE project, 2010), which lowers thermal comfort levels dramatically consequently affecting human health and overall quality of life (this is described in more detail in Part III of this thesis – climatic conditions).

2.2 Types of heat islands.

Looking closely at this phenomenon, Oke (1982) distinguished 3 types of heat islands; these are: the urban canopy layer (UCL), the urban boundary layer (UBL), and
the surface heat island (SHI). It's important to distinguish between these different heat islands as their underlying mechanisms are also different. The first two layers refer to a warming of the urban atmosphere and are referred to as “atmospheric urban heat islands” whereas the last refers to the relative warmth of urban surfaces (see Figure 3).

![Figure 3. Schematic depiction of the main components of the urban atmosphere. Source: Voogt, 2004](image)

The UCL is the layer of air closest to the surface in cities, extending upwards to approximately the mean building height. It is in fact within this layer, the urban canyon layer, in which numerical analysis for this research is carried out by using the Town Energy Balance (TEB) urban surface exchange model developed by Masson (2000) which aims to realistically represent the energy balance of the 3-dimensional urban canyon representing roofs, walls and roads (Masson, 2006) (see Chapter 3 for more details on existing modeling tools of the urban heat island).
Above the urban canopy layer lies the UBL, which varies in thicknesses from 1 kilometer or more during the day to hundreds of meters or less at night. It is a dome-shaped heat sink of warmer air that extends downwind of the city which may sometimes take a plume shape depending on the wind gust. Atmospheric heat islands are typically weak during the late morning and throughout the day but become more pronounced after sunset due to the slow release of heat from urban mineralized surfaces. Also, atmospheric heat islands vary much less in intensity than SHIs. On an annual mean basis, air temperatures in cities might be 1 to 3°C warmer than their rural surroundings. On the other hand, SHIs are typically present throughout the day and night but tend to be strongest during the day. On average, the difference in daytime temperatures between urban and rural areas is about 10 to 15°C while the difference in surface temperatures during the nighttime is typically smaller, between 5 to 10°C showing therefore a greater intensity than atmospheric heat islands (USEPA, 2014).

It is also worth noting that heat islands may vary in spatial form or shape, in temporal characteristics, and in some of the underlying physical processes that contribute to their development. Air temperatures at the UCL and UBL are measured directly using thermometers; whereas, the SHI is measured either indirectly using remote sensing techniques and technologies or directly through handheld or aircraft mounted thermal scanners (Voogt, 2004).

Therefore, out of the three types of urban heat islands identified, this research focuses on the urban canyon layer (UCL). More specifically, investigations in this research within the context of Beirut are concentrated on the effects of the various complex interactions of the existing urban conditions on the urban heat island air
temperatures, as opposed to surface temperatures or boundary layer air temperatures, in the urban canyon layer. A canyon is defined as a street which is flanked on both sides by buildings and therefore investigations in an urban canyon layer extends upwards to the average building height in a street. This specific layer was selected since the purpose of this research is to ultimately find mitigation solutions to ensure the thermal comfort of the urban dwellers who are more directly affected by air temperatures within the canyon layer in which they frequent as opposed to the boundary layer. While surface temperatures may also have an impact on surrounding air temperatures, measurements for urban surfaces require thermal remote sensing data which is somewhat limited for Beirut city as explained in more detail in Chapter 4 of this thesis.

2.3 Causes of the Heat Island

There is no single cause of the heat island phenomena. Instead, many factors combine to increase urban and suburban temperatures including 1) meteorological or natural factors and 2) urban or anthropogenic parameters examples of which are described in more detail as follows:

1) Meteorological parameters such as temperature, cloud cover and wind have a significant impact on the UHI. The natural location of a city also plays a role since its physical characteristics that include topography, mountain ranges and hills, rivers and/or other water bodies can determine the extent to which UHI can be affected.

2) As for anthropogenic factors, these include urban parameters such as city size, influenced by urban populations and densities, density of built-up areas including land coverage, distance between buildings and average height of buildings, urban geometry that includes street orientations, aspect or height (H) to width (W) ratio (H/W) of
buildings, and sky view factor (SVF), which is the visible area of the sky from a given surface. Other urban parameters that exacerbate the UHI include man-made surfaces including buildings and pavements that are generally composed of dark materials that readily absorb and store the sun’s heat. Most building materials are also impermeable thus further exacerbating the warming trend in cities. Other man-made reasons for the heat island formation include urban heat generations as well as high levels of urban air pollution. These natural and man-made causes of the heat island, which are relevant for the Beirut case, are described in more detail in the following sections.

2.3.1 Natural factors. Meteorological factors such as winds and cloud cover also have an impact on the development of UHI. For instance, during periods of calm winds and clear skies, UHI may be intensified by the amount of solar energy retained by urban surfaces which is not easily convected away from the city, whereas the opposite effect occurs during periods of strong winds and increased cloud cover (Che-Ani, Shahmohamadi, Sairi, Mohd-Nor, Zain, and Surat, 2009). Alonso, Labajo & Fidalgo (2003) defined five weather types based on variations of wind speeds and cloud cover (see Table 1) and found that the UHI is more intense under conditions of atmospheric stability than under conditions of instability. Cloud cover and wind speed can also exacerbate the UHI by intensifying pollution and smog episodes in cities since particles in the air absorb and emit heat to a city’s surfaces.

The time of day can also affect the UHI intensity. Oke (1982) and Voogt (2004) demonstrated that the heat island intensity increases from the sunset hours till the predawn and typically reaches its maximum values when the temperature is at a daily minimum (Karl, Diaz, & Kukla, 1988). Alonso et al. (2003) also studied the intensity of
the UHI during a three year period between 1996 and 1998 in the city of Salamanca in Spain comparing the temperatures in an urban area and those in a nearby rural area and found that the UHI is more intense during the night-time hours. A similar study carried out in Athens which studies the hourly variability of the UHI effect also shows that the hottest temperatures are recorded in the afternoon hours (Kourtidis, et al., 2015). It is expected that Beirut city would have similar variability of the UHI effect during the day. This is attributed to the fact that the city of Beirut has urban characteristics similar to those of Athens; they are both coastal situated along the Mediterranean Sea, they are both characterized by a dense built environment with mainly artificial dark urban surfaces, few green or natural spaces, major road networks, a skyline that is gradually changing with the construction of newer and taller buildings\(^6\), and both are densely populated (Beirut has a population density of about 21,000 persons/km\(^2\) while Athens has a population density of about 23,000 persons/km\(^2\)). Indeed this research aims to investigate the UHI effect in the city of Beirut in the view to identify the urban parameters that have the most significant effect on the UHI diurnal variability and to consequently find mitigating solutions from an urban planning and design perspective (see Part IV of this research).

Therefore the available literature shows that the natural factors that characterize a city play an important role on impacting the UHI. For the case of Beirut, which is a coastal city and which is characterized by a relatively flat topography with two hill-tops at 90m elevations above sea-level (A.S.L.), and a mild winter season with typically low

\(^6\) A “tall building” is a multi-story structure in which most occupants depend on elevators to reach their destinations. The most prominent tall buildings are called ‘high-rise buildings’ in most countries. A high-rise building can be defined as follows: 1) “Any structure where the height can have a serious impact on evacuation”; 2) “For most purposes, the cut-off point for high-rise buildings is around seven stories. Sometimes, seven stories or higher define a high-rise, and sometimes the definition is more than seven stories. Sometimes, the definition is stated in terms of linear height (feet or meters) rather than stories (Craighead, 2009). For the purpose of this research, a similar definition for a “tall building” having seven stories is applied.
average wind speeds throughout the year, the UHI effect can be exacerbated especially when these natural factors are combined with the existing artificial (as opposed to natural) urban fabric and the characteristic geometry of the city (see subsequent sections).

The natural factors characterizing the city of Beirut, namely the defining weather characteristics like minimum and maximum temperatures and wind speed and so on, are described in more detail in Part III of this thesis.

Table 1: Five weather types based on variations of wind speed cloud cover adapted from Alonso et al, 2003

<table>
<thead>
<tr>
<th>Weather Type</th>
<th>Mean daily wind speed (v) (km/h)</th>
<th>Cloudiness (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>v≤ 4</td>
<td>2/8 of cloudy sky</td>
</tr>
<tr>
<td>Type II</td>
<td>v≤ 4</td>
<td>3/8 of cloudy sky</td>
</tr>
<tr>
<td>Type III</td>
<td>4≤ v≤ 22</td>
<td>2/8 of cloudy sky</td>
</tr>
<tr>
<td>Type IV</td>
<td>4≤ v≤ 22</td>
<td>3/8 of cloudy sky</td>
</tr>
<tr>
<td>Type V</td>
<td>v&gt;22</td>
<td>For all cases of C</td>
</tr>
</tbody>
</table>

2.3.2 Urbanization and anthropogenic heat. Increasing urban populations and associated urbanization and land use practices are taking their toll on the environment and its climate. According to the World Bank and the U.S. Central Bureau of Statistics, the global population is currently estimated at about 7 billion and it is expected to grow further to reach between 7.5 and 10.5 billion by year 2050. The United Nations World Urbanization Prospects Report (2003) expected that world population growth between 2000 and 2030 will happen in urban areas and that the world urban population is expected to rise by over 2 billion persons to reach 4.9 billion in 2030. With growing urban populations naturally vegetated and permeable surfaces become replaced with concrete impermeable urban surfaces thus expanding urbanization. Such changes are coupled with an ever-growing consumption of natural resources and burning of fossil fuels for power generation resulting in increasing air polluting emissions that contribute to the greenhouse gas (GHG) effect or climate change at the global scale. Human induced
activities in cities also generate urban heat or anthropogenic heat at the local scale which comes from many sources including car emissions, use of air-conditioning both in summer (for cooling) or winter (for heating), and industrial facilities (Che-Ani et al., 2009) and which accordingly have tremendous impacts on the environment and associated ecosystems. Anthropogenic heat varies by urban activity and infrastructures, where urban canyons characterized by energy-intensive buildings and high traffic congestion produce more heat (EPA [Environmental Protection Agency], 2014).

Furthermore, Landsberg (1981) posits that the heat island is present in every town and city and is the most obvious climatic manifestation of urbanization (as cited in Santamouris, 2013, p. 48). Beirut city also falls under this category especially when considering the considerable rise in city residents during the last fifty years and the respective high fraction of impermeable and mineralized urban surfaces (see Part III case study for Beirut). To this effect, the impact of urbanization on long-term temperature records has been observed for cities with populations less than 10,000 even (Karl, Diaz, and Kukla., 1988). Urbanization therefore results in changes in land uses and practices thus affecting the intensity and scale of the UHI formation. For example, industrial areas, with their anthropogenic heat emissions, can have significant exacerbating effects on the UHI while residential areas with large open spaces would potentially have much lower impacts on the UHI.

In fact, Rizwan et al. (2009) highlighted the significant role of anthropogenic heat on UHI, while Emmanuel and Fernando (2007) highlighted anthropogenic heat or heat waste from combustion and metabolism as being one of the major contributors to urban microclimate modifications. In another similar study, Giannopoulou, Livada,
Santamouris, Saliari, Assimakopoulos, and Caouris (2011) showed that increased urbanization, industrialization and increased anthropogenic heat all play a significant role in exacerbating high urban temperature trends and accordingly urban heat islands. In this aforementioned study, the characteristics of the UHI phenomenon were analyzed during the summer season by using 25 fixed temperature stations which were spread out across the major Athens area. The city was then divided into five geographic zones where higher air temperatures were found in the western industrial part of the city and the center, where anthropogenic heat emissions are highest, while lower values were found in the less urbanized areas in the northern and eastern parts. Another study conducted in Athens (Katsoulis & Theoharatos, 1985), showed similar results to those of Giannopoulou et al. (2011), and indicated a close correlation between growth of the city and the UHI effect. Beirut is a city in the Mediterranean region, with similar urban characteristics to those of Athens, namely the very dense built-up areas, the high population concentrations within the city, and the high traffic congestion, which can all also contribute to an intense urban heat island effect when compared to the more rural, and less populated and congested surrounding areas.

Urbanized and dense city centers characterized by tall buildings and high traffic volumes will also add to the intensity of the UHI as seen for example in the works of Alonso et al. (2003) in the city of Salamanca, who found maximum temperature records in areas characterized by higher percentage of built-up area while the opposite was found in areas with a much higher percentage of green areas. These higher urban temperature trends are attributed to increasing urban populations, urbanization trends and corresponding generation of anthropogenic heat.
Therefore urbanization and anthropogenic heat sources have been found to have significant impacts on the UHI effect according to the available literature. The city of Beirut, which is a dense city with many road networks, significant traffic congestion, and haphazardly located industrial areas which generate uncontrolled and high levels of air polluting emissions (MOE/UNDP/ECODIT, 2011), is without doubt a major source of anthropogenic heat emissions. However this research focuses primarily on the artificial urban surfaces and their respective impacts on the UHI in Beirut as opposed to anthropogenic heat sources since the aim of this research is primarily to identify the urban planning and design schemes that can be modified or corrected in future sustainable planning solutions for the city. Having said this, the effects of anthropogenic heat on the UHI in Beirut can be a potential topic of research to be considered in future works for the city.
2.3.3 Albedo and urban surface materials. Another significant anthropogenic factor that has a major impact on the UHI phenomenon is the albedo property of urban surface materials. Simply put, the “albedo” - from Latin “albus” meaning whiteness - is the ratio of the amount of light or energy that is reflected back into the atmosphere by any particular surface. A low albedo means a surface reflects a small amount of the incoming radiation and absorbs the rest, for example for trees the albedo ($\alpha$) is between 0.15 and 0.18. On the other hand, a high albedo means a surface absorbs a small amount of the incoming radiation and reflects the rest, for example a white paint albedo ($\alpha$) may range between 0.5 and 0.95 (see Table 2). Therefore, depending on the type of urban material and its associated albedo property, the UHI phenomenon can be affected significantly.

The albedo value of mineralized surfaces in a typical city is typically low. This is because cities are usually composed of tall and medium-sized buildings which have dark concrete surfaces. Access roads and transportation networks in these cities also tend to be comprised of similar materials. These dark hard impermeable surfaces, including stone, concrete and asphalt that typically replace the vegetative surfaces (also resulting in changes in land use) are usually characterized as “warm” materials, have low “albedo” or reflective properties with high heat retaining properties, and typically result in higher urban temperatures as compared to their surrounding rural areas.

Thus urban surfaces with particular geometrical effects, multiple reflections, or with darker colours, intensify the UHI. In turn it is possible that “higher urban air temperatures increase city-scale cooling loads as well as the frequency of smog episodes” (Taha, et al., 1992). Therefore, by taking into consideration the albedo properties of urban surface materials in urban design and planning measures including roofing or paving,
there can be better control over urban microclimates and energy consumption, resulting in an overall improved quality of life (Akbari, Pomerantz, and Taha, 2001; Rosenfeld, Akbari, Bretz, Fishman, Kurn, Sailor, and Taha, 1998; Synnefa, Saliari, and Santamouris, 2013; Taha, Sailor, and Akbari, 1992; Taha, 1997). As such, in order to implement sustainable urban designs that have optimal impacts on the microclimate and UHI, it is necessary to calculate the albedo values of typical urban materials. The available literature gives light to certain studies carried out in this regard that propose new computer web based applications for example as well as systems to calculate the albedo properties of urban surface materials (Chimklai, Hagishima, and Tanimoto, 2004; Tsangrassoulis & Santamouris, 2003).

Other studies investigate the impact of weathering and cleansing on the albedo values of existing urban materials (such as roofing and paving materials) and consequently on the climatic conditions of urbanized area. For instance, Berdahl, Akbari, Levinson and Miller (2008) and Levinson, Berdahl, Berhe, and Akbari (2005) assessed the albedo effects and thermal properties of roofing materials, in weathered, clean and soiled conditions. They found that roofing materials in an unweathered and clean state were cooler than the same materials in soiled and weathered conditions. Furthermore, Doulos, Santamouris, and Livada (2004) and Asaeda, Ca, and Wake (1996) assessed the albedo values and associated thermal properties of paving materials of different colours, textures, and sizes and confirmed that light coloured surfaces are cooler than dark coloured surface. Whereas, Asaeda et al. (1996) found that heat storage for asphalt was significantly higher than that for concrete or bare soil. In Beirut, asphalt is the main material used in road surfaces. Thus, as per Oke (1987), considering the very low albedo
property of this material, the limited urban vegetated surfaces and the existing dense urban fabric, the impacts on UHI can be felt ever more clearly, which is why it is important to conduct in-depth investigations that can indicate and determine these impacts clearly in the view to find good mitigative solutions.

In addition, many studies have been carried out to measure the temperature of urban surfaces to determine their effect on the UHI. Doulos et al. (2004) used an infrared camera to measure the surface temperature of urban paving materials as well as a precise contact thermometer in order to take into account minor errors associated with the infrared thermography procedures. Hendel, Colombert, Diab and Royon (2014) also used infrared camera measurements of pavement surface temperatures in their study on the potential use of pavement-watering methods to mitigate the urban heat island phenomenon in the city of Paris. Asaeda et al (1996) on the other hand showed the temperature distribution in pavements using experimental procedures that involved installing 1mm diameter copper tubes along the central axis of pavement samples (including asphalt and concrete slabs, and bare soil) through which thermocouples were inserted. Santamouris et al. (2011) assessed in detail the thermal performance and benefits of materials for buildings and urban structures with high solar reflectance and infrared emittance, “cool materials”, such as cool roofing materials, cool-paving materials, phase change materials (PCM), and thermo-chromic materials and found that materials with high reflectivity and high emissivity contribute highly to UHI mitigation.

In a similar study, Synnefa, Santamouris and Livada (2005) investigated 14 types of reflective coatings which are commonly used in the urban environment’s external surfaces, like building walls and roofs, sidewalks, pavements, and parking lots, and with
the use of surface temperature sensors, and infrared thermography procedures, they were able to demonstrate that the use of reflective coatings with high solar reflectance properties, can significantly reduce surface temperatures.

Therefore the available literature shows that techniques used to measure temperature distribution of urban surface materials are diverse and help to determine albedo properties of construction materials used for urban surfaces including paving, roofing and facades. While this technique is not applied for this research, since the available literature on albedo properties for specific materials is abundant and generally unanimous, it can be considered as a potential future approach to more accurately determine the solar reflectivity or albedo of the urban materials in the city of Beirut.

In addition, the available literature points to the fact the use of low reflective cool materials (for example for facades, rooftops and roads) is considered the norm nowadays for a sustainable architecture, design and planning of cities in hot climatic zones and this can also be considered for the Beirut context. Indeed, Beirut is a city which is characterized mainly by low albedo urban surfaces for rooftops and road surfaces (see Part III –Beirut Case Study for more details on the land cover land uses and albedo values of dominating urban surfaces within the Beirut context). Therefore the albedo or solar reflectivity of an urban material is a very important factor that needs to be considered when devising sustainable solutions for mitigation of the UHI impact in a city (see Chapter 4 on mitigation measures).
Table 2: Albedo values for various urban surfaces according to NASA, 2012 and Oke, 1987

<table>
<thead>
<tr>
<th>Surface</th>
<th>Typical Albedo (α) Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass</td>
<td>0.25 - 0.30</td>
</tr>
<tr>
<td>Trees</td>
<td>0.15 - 0.18</td>
</tr>
<tr>
<td>Corrugated roof</td>
<td>0.10 - 0.15</td>
</tr>
<tr>
<td>Highly reflective roof</td>
<td>0.60 - 0.70</td>
</tr>
<tr>
<td>Colored paint</td>
<td>0.15 - 0.35</td>
</tr>
<tr>
<td>White paint</td>
<td>0.50 - 0.90</td>
</tr>
<tr>
<td>Tar and gravel</td>
<td>0.03 - 0.18</td>
</tr>
<tr>
<td>Red/brown tile</td>
<td>0.10 - 0.35</td>
</tr>
<tr>
<td>Brick/stone</td>
<td>0.20 - 0.40</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.10 - 0.35</td>
</tr>
<tr>
<td>Asphalt</td>
<td>0.05 - 0.20</td>
</tr>
</tbody>
</table>

2.3.4 Urban geometry. Urban geometry is another important anthropogenic factor contributing to urban temperature variations (Lindberg, Eliasson, and Holmer, 2003; Ando, Morishima, Yokoyama, and Akasaka, 2009). It refers to the shape, dimension and spacing of buildings within a city, which together add to the amount of radiation received, reflected and emitted by the urban infrastructure. In urbanized areas, spaces and structures are often obstructed, either fully or partially, by building blocks that quickly become large thermal masses triggering the build-up of UHI (EPA, 2014). Che-Ani et al. (2009) found that development of UHI is sometimes partially due to unplanned urban geometries. This section describes the importance of the effects of building heights, sky view factor, height to width ratio and street orientations on the UHI impact.
2.3.4.1 Height and Sky View Factor. Researchers often focus on an aspect of urban geometry called urban canyons which refer to relatively narrow streets lined by tall buildings. Urban canyons can have different effects on the UHI during the day time whereby the tall buildings can provide shading thus reducing temperatures while the incoming solar radiation that reaches inside the canyon is reflected and absorbed by the walls of buildings thus lowering the overall albedo of the city and accordingly raising the urban temperatures. During the night time, the buildings and other artificial man-made surfaces in the urban canyon obstruct the heat being released thus generally impeding cooling effects. As previously mentioned, this research focuses on the UHI effect within the urban canyon in Beirut therefore it would potentially be interesting to investigate the effects of tall buildings on urban canyon temperatures as carried out and discussed in Chapter 7 of this thesis.

Another important aspect of urban geometry which is frequently studied is the sky view factor (SVF) described as the ratio of the amount of the sky ‘seen’ from a given point on a surface to that potentially available (i.e. the proportion of the sky hemisphere subtended by a horizontal surface). Therefore an urban canyon that is characterized by tall closely spaced buildings would have a low SVF as opposed to an open space parking lot or field with few obstructions which would accordingly have a high SVF. As such, during the night-time, due to dense developed areas characterized by low SVF, urban areas cannot easily release radiation into the cooler open sky and therefore this trapped heat contributes to the urban heat island. Oke (1981) used the SVF to characterize the urban geometry of a city by using the following formula:

\[ \Delta T_{\text{max}} = 15.27 - 13.88 \times \text{SVF} \] (°C) (Equation 1)
This formula assumes that the urban heat island effect is due mainly to the reduced heat loss in narrow streets compared to more open environments. In a study on urban design factors that have the greatest influence on heat island intensity in high-rise high-density environment of Hong Kong, 12 variables were used\(^7\), including the SVF, for 17 coastal area residential developments. Figure 4 shows images of these 17 coastal developments where the measurements were carried out showing the close relation between SVF and UHI. In this study therefore, statistical method analysis was carried out to identify the most critical variables that can be used to mitigate UHI in high-rise high-density environments. Among other variables like albedo, altitude and vegetation, it was found that the SVF is a critical variable in mitigating both daytime and nocturnal UHI (Giridharan, Lau, Ganesan, and Givoni, 2007). For the case of Beirut, the average height of buildings is about 15-18m (or 6-storeys high) although this trend is currently being altered due to limited land space availability within the city with a resulting rise in the average height of buildings which could potentially lower the SVF and thus trap more heat in the canyons and accordingly exacerbate the UHI. Indeed old buildings are being demolished and replaced by taller and more modern buildings, such as in Ashrafiyeh and Ras Beirut areas\(^8\) which can potentially have significant impacts on the UHI of the city. Therefore, the SVF is not assumed to play a significant impact on the UHI in Beirut at the present time although given the limited land availability and increased demand for housing this may change in the near future with the resulting construction of taller buildings.

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\(^7\) Other variables included solar radiation intensity, wind velocity, average height (H) to floor area (A) ratio (HA), surface albedo (SA), altitude, and proximity to sea, vegetation below and above 1m in height, total non-residential to total floor area ratio, location quotient (is an analytical statistic and is a way of quantifying how concentrated a particular industry, cluster, occupation, or demography group is in a region as compared to the nation), emission index-day, and emission index night.

\(^8\) Refer to Part III on “Beirut Case Study” of this thesis which identifies the administrative areas of Beirut and the respective geographical locations of these areas.
buildings throughout the city. It is worth noting however that this factor is not considered as a scenario in the numerical analysis chapter of this research since the modification of the height of buildings has already been selected as one of the scenarios taken into consideration to make the necessary assessments in this regard (see Chapter 7).

In another study in the Swedish city of Malmö, Bärring, Mattsson, and Lindqvist (1985) concluded that air temperature was not strongly correlated to street canyon geometry as surface temperature was. In Japan however, a relatively strong relationship was found between air temperature and SVF in cities such as Fuchu and Higashimurayama (Yamashita et al., 1986). Eliasson and Svensson (2003) have demonstrated that both land use parameters and the SVC are important for spatial variations of air temperature within an urban environment. Therefore there appear to be different views held on whether SVF is related to air temperature but this can be attributed to the range of analytical methods that are used in these aforementioned studies (Svensson, 2004).

**Figure 4.** Site characteristics of highest mean daytime UHI location in each estate. *Source: Giridharan et al, 2007, pp. 3673*
2.3.4.2 Height to Width Ratio and Street Orientations. This section discusses some research works conducted on the significance of the impacts of height to width ratio and street orientations on the UHI effects. For example, Ali-Toudert and Mayer (2006) carried out investigations on the contribution of street design toward the development of a comfortable microclimate for pedestrians during the hot and dry summertime of Ghardaia in Algeria. The main factors investigated in the study comprised: aspect ratio or height (H) to width (W) ratio (H/W), street orientation, overhanging facades, and the use of galleries and rows of trees. As per Oke (1981), the H/W ratio can be used to find the correlation between maximum urban heat island intensity and urban geometry by using the following formula:

$$\Delta T_{\text{max}} = 7.54 + 3.97 \ln (H/W) \quad (^\circ \text{C})$$

(Equation 2)

In the aforementioned study therefore, by using a three dimensional model and the physiologically equivalent temperature (PET) to assess thermal comfort level, Ali-Toudert and Mayer were able to determine that street orientation and height-width ratio (H/W) of streets have the most significant impact on the microclimate in urban canyons. In the case of street orientations in Beirut which lies in the Northern Hemisphere, east-west orientations of streets will be more significantly affected by the incoming solar rays thus lowering thermal comfort levels as opposed to north-south orientations which provide shade in the morning and in the afternoon on at least one side of the street thus improving thermal comfort levels. Therefore, N-S street orientation leads to less heat stress within the street both in its duration and its intensity but it is important to note that the time of day also plays an important role in this respect. While the effects of street orientations in Beirut is not considered in the numerical analysis for this research due to
the selection of the TEB modeling scheme which considers only one direction for all street orientations in the urban canyons, it is important to consider this factor in future research works within the context of devising more sustainable urban planning solutions for the city of Beirut.

As for height to width ratio of streets, in an urban street design that is characterized by wide streets this can result in a stressful thermal environment thus requiring shading strategies. In the case for Beirut, streets are not generally wide (approximately 4-6m for local roads and 5-8m for secondary roads), while primary and international roads are generally moderately wider (approximately 8-10m for primary roads and 10-14m for international roads). As for the height of buildings, these are typically not high (average height of approximately 15m) although this trend is fast changing what with the increased demand for more housing, associated with the corresponding rise in urban populations, resulting in taller building constructions (see Chapter 5 for more details on heights of buildings). Therefore, the aspect ratio or H/W ratio is not typically very high for Beirut ranging between 0.5 and 0.8 and therefore effects on UHI are not expected to be significant at present time although there is an increasing probability for this to increase in the near future in Beirut.

Other studies on the effects of urban geometry on the UHI include the works of Fahmy and Sharples (2008) who carried out a research on the thermal behavior of three different types of traditional and modern street canyons with varying densities, orientations, and clusters, in the hot dry semi-arid city of Cairo (see Table 3). They deemed such an investigation essential in establishing an urban planning tool to develop passive cooling policies, which would help reduce thermal stress on internal building
conditions, provide ease of movement for people and reduce UHI effects. Only buildings form and green surfaces were simulated so that the effect of different urban pattern forms on the temporal heating of an urban canyon were assessed. Results showed that street orientation and urban geometry, namely street and building compactness, are the most significant parameters for alleviating outdoor thermal comfort levels since as previously mentioned, not choosing optimal street orientations, typically N-S, can retain and trap the incoming solar radiation resulting in a higher heat stress in urban canyons. As for the compactness of each urban pattern case, in terms of SVF, aspect ratios and urban pattern design details, it was found that a medium compact fabric that can produce medium SVF and medium aspect ratios can experience enough wind and solar access to allow for passive cooling and comfortable thermal conditions.

The influence of urban vegetation, building density and height to width ratio on the urban microclimate of the hot and humid city of Taichung in Taiwan were also investigated by Sun et al. (2009) using air temperature data collected in two streets, which represented differences in street geometry. Vegetation density and building density were also included in the investigation. Results showed a close relationship between street geometry and air temperature at street level. The most comfortable thermal levels were found to occur in the street areas with low building density, low height to width ratio and high vegetation density.

**2.3.4.3 Other urban geometric parameters.** Several other studies have also been conducted to examine the types of urban fabric, urban street designs, and building forms that provide comfortable or optimal thermal levels for city dwellers. For example, Ratti, Raydan, & Steemers (2003) examined six different building archetypes including
courtyards and pavilions with variations on building height, site coverage and total floor space, and discovered that courtyards performed best in terms of built potential and daylighting criteria in arid climates. Within the context of Beirut, housing is typically in the form of apartment buildings (and not single villa type homes) which have an average height of 15m. Due to the limited land availability there are typically no courtyards associated with the apartment buildings but rather limited asphalted parking areas around the perimeter of the buildings and/or sidewalks. To assess the potential impact of courtyards on the UHI phenomenon would therefore not be a realistic scenario for the case of Beirut. In addition, Ratti’s research attempts to determine the most suitable building archetype from the perspective of individual buildings while this PhD research attempts to understand the impact of UHI for the whole city scale of Beirut since the objective of this research is to propose mitigating solutions from an urban planning perspective and therefore a larger scale. In their study, Ratti et al. (2003) also stressed on the importance of specifying the climatic zone in which an environmental research on urban form is being considered or undertaken as this may play a key role in identifying most suitable building architectural form for a particular city from an UHI perspective. The city of Beirut is a coastal city located along the Mediterranean Sea and has in fact been classified as having a coastal climate. Indeed a road map for thermal standards of buildings has already been developed for Beirut in collaboration with the Ministry of Energy and Water (MOEW) but this is still in the process of being approved (see Chapter 5).

Street geometry can also affect the dispersal of anthropogenic pollutants, which in turn can affect urban microclimates. Gromke and Ruck (2007) studied the dispersion of
traffic exhaust pollutants in urban street canyons with and without tree plantations. Although his model proved insufficient for distinguishing between varying canopy densities, the presence of single row of trees hindered airflow in certain areas, leading to increased pollution levels compared to open areas with no trees. Although the impact of trees on increasing pollution levels may seem counterintuitive, another study by Gromke and Ruck (2010) shows the distinction between single-row avenue plantings and larger tree groves emphasizing the latter’s significant impact on heat, wind and pollution which act both as a pollution filter and a heat sink (Gromke & Ruck, 2010).

There appears to be poor interdisciplinary work carried out between urban designers, architects and urban climatologists (Alcoforado et al., 2009; Ali-Toudert & Mayer, 2006; Grimmond et al., 2010; Ng, 2012). As such, urban temperatures are affected, especially in the summer time, thus impacting the comfort, quality, and health of urban dwellers. In order to improve outdoor thermal comfort levels, especially in hot arid zones (or semi-arid zones as in the case for Beirut), it becomes essential to understand the intricate relationship that exists between climatic conditions and urban form (Fahmy and Sharples, 2008).

In Beirut, information on the potential connection that exists between urban geometry of the city and the urban microclimate is lacking or limited. This is firstly because investigations in this regard have not previously been conducted and in addition because there is insufficient transfer of urban climatic knowledge to urban designers, and planners or policy makers in Beirut. It is not enough to investigate the significant relationship that potentially exists between factors of urban geometry that contribute the most to urban microclimate impacts in Beirut. It is also necessary to improve the
communication channels between the concerned disciplines and provide the necessary “evidence” or results to urban planners and decision-makers in the view to find the best mitigation solutions from an urban planning, urban design and even building design perspective (see Chapter 9 for recommendations and solutions in this regard for the Beirut case).

Table 3. Description of three different urban patterns examined for optimal thermal conditions Source: Fahmy and Sharples, 2008

<table>
<thead>
<tr>
<th>Urban Pattern No.</th>
<th>Sites Description</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1</td>
<td>High density, compact, multi-family, low income apartment housing with a ground floor and four other floors</td>
<td>Central urban area northeast of metropolitan Cairo</td>
</tr>
<tr>
<td>#2</td>
<td>Mixed, clustered dot, multi-family, high-income apartments with a ground floor and three other floors</td>
<td>Sheraton Heliopolis urban area of metropolitan Cairo</td>
</tr>
<tr>
<td>#3</td>
<td>Dot single and multi-family high income villas and apartments with a ground floor and three other floors</td>
<td>Suburban area of metropolitan Cairo outside the first ring road of greater Cairo as part of new Cairo town</td>
</tr>
</tbody>
</table>

2.3.5 Lack of vegetation. The landscape in rural areas is typically dominated by large vegetated surfaces or open spaces. Rural temperatures are therefore lower and cooler than their surrounding urban areas due to 1) shading provided by the trees and vegetation, and 2) the process of evapotranspiration in which plants release water from the earth’s surface and accordingly dissipate ambient heat into the air thus helping to keep a city cool. In contrast, urban areas are characterized by dry, impermeable and dark mineralized surfaces consisting primarily of roofs, pavements, roads and parking lots that typically reflect less and absorb more of the sun’s energy. As urbanization expands therefore, more vegetation is lost, and more surfaces become paved and covered with buildings thus resulting in lower levels of moisture and accordingly heat loss. Akbari,
Kurn, Bretz, and Hanford (1997) illustrated the relevance of the cooling impact of shading by trees in urban areas in their works on the assessment of peak power and cooling energy savings of shade trees; their results showed substantial cooling energy savings in two houses after shading them with 16 trees. Moreover, Huang, Akbari, and Taha (1990) showed that air temperature in urban areas is reduced by up to 2°C on average both by the direct shading of dark surfaces with dense canopies and by evapotranspiration. In another similar study, Loughner, Allen, Zhang, Pickering, Dickerson, and Landry (2012), showed how the presence of urban trees lowered surface and near-surface air temperatures because of shading and evapotranspiration whereby the addition of trees in the simulations caused maximum daytime and minimum nighttime urban canyon air temperatures to decrease by 4.1 and 2.5°C respectively. The removal of trees and vegetation therefore has dire consequences on the ecosystem, the local climate, as well as overall human comfort levels and therefore their role in alleviation of the urban heat island phenomenon is crucial.

In general, investigations carried out on the topic of urban heat islands indicate in one way or another the important role that urban trees, vegetation, and green roofs play, to alleviate uncomfortably high urban thermal conditions of especially hot arid or semi-arid dense urban cities (Akbari, Pomerantz, & Taha, 2001; Akbari, 2005; Che-Ani et al., 2009; Oliveira, Andrade, & Vaz, 2011; Rosenfeld et al., 1998). In the study of the most optimal urban street designs on thermal microclimate for example, Ali Toudert and Mayer (2006) highlighted the importance of having rows of shade trees in urban canyons due to the important role they play in enhancing thermal comfort levels of urban streets.
The leaf area index (LAI) of urban trees, which is the ratio of total upper leaf surface of vegetation divided by the surface area of the land on which the vegetation grows (leaf area / ground surface) is another important parameter that is considered within the context of urban vegetation and their respective impacts on the urban heat island phenomenon (Fahmy, Sharples, and Yahiya, 2010). By definition, LAI can be represented as follows:

\[
\text{LAI} = \frac{A_L}{A_p} \quad (\text{m}^2/\text{m}^2)
\]

(Equation 3)

where \(A_L\) is the upper leaves area, and \(A_p\) is the tree ground planting area.

The larger the LAI of an urban tree the larger the shading and cooling provided in an urban canyon. Ideally therefore, urban trees must have a large LAI for maximum shading, latent heat exchange (or evapotranspiration) and pollutant deposition and in addition they must be durable, and must be able to thrive in an urban environment. Trees in fact play a very important role in pollution removal by uptake of gaseous air pollution via leaf stomata (opening or apertures on outer leaf skin layer). Trees are also capable of intercepting airborne particles by either absorbing them into the tree or retaining on the plant surface. Having said this, it is worth noting that some of the intercepted particles are typically released back into the atmosphere, washed off by rain or dropped onto the ground by leaf or twig fall thus not being completely or permanently removed by the urban vegetation. Finally, when choosing the most ideal types of urban trees or vegetation for mitigation of the urban heat island, it is necessary to consider their biogenic volatile organic carbon or VOC emitting properties. Urban trees must not be emitters of VOCs, since this plays a significant role in the formation of one of the most damaging pollutants – ground-level ozone (O\(_3\)) – which is a major component of smog.
While planting urban trees is an important urban heat island mitigative strategy, a recent study at Yale University showed that high albedo properties of urban surfaces influenced a larger area of the city than the vegetative methods (Mackey, Lee and Smith, 2012). Indeed in this study, recent vegetated and reflective surfaces in LANDSAT images of Chicago, a city which has deployed a variety of heat island mitigation measures over the last 15 years, were analyzed. Results accordingly showed that the new reflective surfaces that were implemented in Chicago in 1995 produced a clear impact on the citywide albedo, raising it by 0.016, while citywide NDVI$^9$ increase was found to be at around 0.007.

Moreover, it is worth noting that it is simply not enough to plant any type of urban trees for summertime urban cooling because special consideration should be given to their various properties like LAI, evapotranspiration, VOC emissions, and durability. As previously mentioned, the LAI of trees plays a significant role in urban microclimatic effects as seen in the works of Fahmy et al. (2010) where urban trees were selected for urban developments in Cairo depending on their respective LAI based thermal performances. In addition, the evapotranspiration rate of trees should be considered which vary with different tree types. The VOC of trees is also important as it can have significant detrimental effects on air quality via smog formation in cities resulting in human health and respiratory problems. Finally the durability of trees is an important factor when selecting urban trees for urban cooling where certain species of trees cannot adapt to the temperate to semi-arid climatic conditions of the city of Beirut.

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$^9$ NDVI or Normalized Difference Vegetation Index (NDVI) is a numerical indicator that uses the visible and near-infrared bands of the electromagnetic spectrum and is adopted to analyze remote sensing measurements and assess whether the target being observed contains live green vegetation or not.
By acquiring the input of relevant experts, ensuring an organized institutional framework, and implementing proper sustainable urban planning strategies, it is possible to achieve optimal thermal conditions by planting urban trees in dense cities as seen in the positive modeling results for the cities of Sacramento, Houston and Salt Lake City for example (EPA, 2014). Upon taking the city of Sacramento as an example, it was found that Lawrence Berkeley National Laboratory (LBNL) used aerial photos to characterize the area fraction of various surface types including roofs, sidewalks and vegetation cover, and concluded that although Sacramento is a fairly green city, the potential for additional urban vegetation is large. Considering that trees can shade 20% of the roof area, 20% of roads, 50% of sidewalks, and 30% of parking areas, Sacramento could increase additional tree cover by approximately 15%. A pilot study was accordingly conducted with the placement of eight mature deciduous shade trees around residential buildings, eight shade trees around office buildings, and four shade trees around commercial buildings, and further to modeling experiments, LBNL calculated that there would be 26 million U.S.D. savings in 1997 (EPA, 2014).

Therefore according to the available literature, vegetation planting in urban areas can have significant cooling effects and is therefore an important mitigation strategy for urban heat island in dense cities, but the extent to which this is in fact impacted depends on several factors including LAI, VOC, evapotranspiration, and durability of the trees. For the case of Beirut, it is important that the existing urban trees and overall vegetation are examined first to determine the extent of their cooling impact on the UHI effect. Therefore, considering the importance of this scenario that involves increasing urban
vegetation fraction to combat UHI in cities, this scenario is also considered for the Beirut case in this research. (see Chapter 7 of this thesis for more details).
Chapter 3: Climate Change, Impacts and Characteristics of Urban Heat Islands and the Energy Balance Equation

In this chapter, the potential relationship that may or may not exist between climate change and urban heat islands is discussed based on the available literature on the topic. Moreover, the various negative effects of urban heat islands is discussed that include mainly impacts to quality of life of city dwellers, modification to thermal comfort levels and even heat-related mortality. This chapter also discusses the various underlying characteristics of the urban heat island that are important to help understand why urban heat islands form in cities. Finally the energy balance equation which explains the transfer of energy to and from the Earth’s surfaces giving an understanding as to the fundamental mechanisms by which urban heat island phenomenon functions is discussed in this chapter.

3.1 Climate Change and Urban Heat Islands

Within the context of urban heat islands, it is also essential to discuss the widely deliberated topic of climate change. While this research does not attempt to analyze the relationship that may or may not exist between urban warming and global climate change, it does conduct a literature review on the topic to discover expert views, arguments and researches that assess and analyze the relationship between these two phenomena. Indeed the distinction between the two was outlined briefly in the introductory chapter of this thesis, but this section provides further elaboration on the definition of global climatic changes.

As such, upon referring to the Fourth Assessment Report on Climate Change (IPCC, 2007), one of the more widely known reports that documents such information, projections of future changes in climate show that in the next two decades there will be a
global warming of about 0.2°C per decade. Even if the concentrations of all greenhouse gases (GHG)\(^\text{10}\) and aerosols levels had been kept constant at year 2000, a further warming of about 0.1°C per decade would be expected (IPCC, 2012). Indeed GHSs from human activities are the most significant drivers of observed climate change since the mid-20\(^{\text{th}}\) century (EPA, 2014).

The link between these two phenomena is found to be discussed in numerous articles and publications. In one such example, Sànchez-Rodríguez et al. (2005, as cited in Grimmond, 2007, pg. 83), argues that the relationship between urbanization and global climate change is not obvious, is complex and may create two broad categories of impacts: those originating in urban areas that have a negative effect on global environmental change, and global environmental changes that have negative effects on urban areas. According to UN-HABITAT global report on cities and climate change (2011), cities are responsible for 75 per cent of global energy consumption and 70% of GHG emissions while occupying only 2% of its land. However, the analyses of emission inventories carried out by Dodman (2009) shows that in most cases per capita emissions from cities are lower than the average for the countries in which they are located (Dodman, 2009, p.6). Moreover, Grimmond (2007) claims that the direct contribution of urban warming to global climates is not considerable, arguing that cities and urban areas cover only a small fraction of the earth’s surface and that their moisture and thermal effects extend only a few kilometers downwind and that the gases from urban areas are the dominant anthropogenic emissions. She concludes that warmer conditions in many

\(^{10}\) Gases that trap heat in the atmosphere are called greenhouse gases (GHGs). Examples of such gases include carbon dioxide (CO\(_2\)) which enters the atmosphere through the burning of fossil fuels (coal, natural gas and oil). Methane (CH\(_4\)) is another GHG which is emitted during the production and transport of coal, natural gas and oil, livestock, and other agricultural practices. Nitrous oxide (N\(_2\)O), another GHG, is emitted during agricultural and industrial activities as well as during combustion of fossil fuels and solid waste.
cities result in greater energy consumption by inhabitants to offset the heat which in turn exacerbate the UHI effect and makes the urban populations more vulnerable to heat waves and other extreme conditions (p.87). Upon application of this argument for the case of Beirut, which is a small city that covers only about 20 km$^2$, it can be concluded that urban warming may also have negligible effects on global climate change although impacts on the city-scale are expected to be significant considering the high population density and congestion of the city.

Similarly, Emmanuel and Kruger (2012) argue that since urban areas cover only about 2.8% of the Earth’s land area it is unlikely that cities have a direct bearing on global climate change (p.138). However, they do emphasize that cities contribute indirectly to global warming on account of their unquenchable appetite for energy and natural resources and associated waste and pollution. Moreover, when urban population grows the expansion of land covered by cities equally grow on the expense of non-urbanized areas to a point where the direct influence of cities on regional and perhaps global climate becomes more significant (Grimmond, 2007).

On the other hand, some experts in the field have shown that the effects of UHI may be exacerbated in the future due to climate change. McCarthy et al. (2010) for example quantified the impact of large-scale and local-scale drivers of climate change on the urban environment and found that simulated heat islands respond to climate change involving cloud or soil moisture feedbacks that influence important components of the urban surface-energy balance. More specifically, they found that climate change has the capacity to modify the climatic potential for urban heat islands, with increases of 30% in some locations as well as increases in the disparity in extreme hot night conditions
between rural and urban areas (p.1). Che-Ani et al. (2009) also argues that climate change has the potential to significantly alter the intensity and spatial extent of heat islands in urban environments. As global climatic temperatures warm, the frequency with which UHI conditions occur could grow.

Other contradicting theories however have shown that indeed urban warming can play a significant role in exacerbation of global climatic changes as seen in the works of McKitrick and Michaels (2007) for example who reject the hypothesis that the spatial pattern of temperature trends in global climate data is independent of extraneous effects that include urbanization. In their paper, McKitrick and Michaels use a new database for all available land-based grid cells around the world to test the null hypothesis that the spatial pattern of temperature trends in a widely used gridded climate data set is independent of socioeconomic determinants of surfaces processes and data inhomogeneities. As such in their interpretation of global climate data, they find that extraneous effects such as urbanization and other land surface effects and data quality problems that may arise due to inhomogeneities in the temperature series are removed by adjustment algorithms and therefore do not affect the large-scale climatic trends. McKitrick and Michaels accordingly reject this hypothesis based on their findings which show that trends in the gridded climate data are in part driven by the varying socioeconomic characteristics of the regions of origin.

Therefore, the available literature on this topic indicates that there are two schools of thought on the relationship between global climatic changes and urban warming. The first argues that anthropogenic heat emissions at the city-scale have negligible effects on global climate change but that the impacts on urban microclimates can be significant as a
result of global climatic changes while the second school argues that indeed anthropogenic heat emissions do have a significant impact on global climatic changes.

As mentioned, this research does not aim to analyze which school of thought is indeed the correct one. However, in so far as assessing measures that are being taken to protect the urban climate, it is found that for Beirut city, anthropogenic heat emissions from various sources, including industrial areas and the transportation sector for example, are above the national and permissible standards (MOE/UNDP/ECODIT, 2011). As such adaptation measures have been recommended by the Lebanese Ministry of Environment (MOE) in a very important document as part of Lebanon’s Second National Communication in a document otherwise referred to as “Climate Change Vulnerability and Adaptation” (MoE/UNDP, 2011). In this document the sensitivity of human settlements and infrastructure to climate change has been assessed and recommendations have accordingly been given for implementation of adaptation measures. Indeed the report identified a great risk with respect to buildings and structures especially in urban areas by emphasizing that the increase in hot summer days may very well lead to intensification of existing phenomena such as the urban heat island. Some important adaptation measures were accordingly recommended including the adoption of a better design of building envelopes through the use of suitable design techniques and building materials with the aim to reduce cooling demand and render constructions capable of withstanding more extreme climatic conditions (www.moe.gov.lb) although details are not provided as to the means by which these objectives can be achieved. Therefore some important preliminary steps have been taken in this regard although actual implementation is still in the preliminary stages as seen around the city such as a few new
constructions in the Ashrafiyeh area which have building envelopes with visibly lighter coloured facades and therefore have less impacts on the surrounding urban microclimate. Having said this, new building constructions are typically being designed which are much higher than the average building height in Beirut (in general over 10 storeys high or approximately 30m or above), which in itself can be have potentially significant effects on the UHI by minimizing the SVF and trapping more heat in the urban canyons but this is discussed in more detail in Chapter 5 of this thesis.

3.2 Impacts and Characteristics of the Urban Heat Island.

3.2.1 Impacts of the Urban Heat Island. Human discomfort is one of the main impacts of the UHI phenomenon, leading at times to disease and even mortality. Higher temperatures result in higher energy consumption levels with greater emissions from power plants and consequently increased levels of ozone (O3) resulting in smog formation, and also higher emissions of carbon dioxide (CO2) which both raise urban temperature trends. These higher thermal levels have an adverse effect on human health especially in dense urban areas including general discomfort, heat cramps and exhaustion, respiratory difficulties, non-fatal heat strokes and heat-related mortality (EPA, 2014; Met Office, 2012; Rainham and Smoyer-Tomic, 2003; ). Moreover, given the global warming forecasts, both frequency and intensity of heat wave episodes will increase and these will accordingly be exacerbated by the UHI effect as witnessed in the excess mortality of 15,000 people in Paris and a death toll in excess of 50,000 people in Europe during the heat wave of summer 2003 (Figure 5 and Figure 6) (Bozonnet et al., 2013; Chagnon, Kunkel & Reinke, 1996; Masson, 2006).

Therefore, the urban heat island can have significant impacts on human thermal comfort levels, on the quality of life, and can even lead to heat-related mortality. For the
case of Beirut, a study was conducted which aimed to show the relationship between heat mortality and increased air temperatures showing a positive correlation between the two factors (El-Zein, Tewtel-Salem & Nehme 2004). However, another study on temperature rises in the Greater Beirut Area (GBA)\textsuperscript{11} and their implications on heat-related premature mortality (El-Fadel and Ghanimeh, 2013) found that during the first half of the twenty-first century, the expected life losses due to high temperatures in hot days are offset by expected life gains due to improved temperatures in cold days, but by the year 2095, the annual average all-cause premature mortality is expected to increase by 3-15%.

Therefore, having said this, there remains a very strong positive relation between rising temperatures and mortality, as emphasized in the existing literature, which is why it is important to investigate the urban parameters that play the most significant role in aggravating the UHI to find immediate mitigating solutions for the case of Beirut especially from an urban planning perspective which can be modified and accordingly improved thus lowering effects on human health and even heat-related mortality as has been successful carried out in many similar dense cities (see Chapter 4 mitigation measures).

\textsuperscript{11} The Greater Beirut Area (GBA) which is generally identified by planners as such, extends between the rivers of Damour and Nahr el-Kalb (or between the Dbayeh and Hadath areas), therefore lying outside Beirut administrative boundary, although there is no official jurisdiction of public recognized boundaries for this metropolitan area (Fawaz, 2013).
Figure 5. UHI associated deaths in Paris. Source: INVS, 2015

Figure 6. Heat storm and heat island during the summer of 2003. Source: Akbari, 2014
3.2.2 Characteristics of the Urban Heat Island. Based on the existing literature, the urban heat island phenomenon is characterized by the following key features:

- Higher air temperatures in urban areas in comparison to the surrounding semi-rural or rural areas;
- Warmest urban temperatures after sunset and coolest temperatures after sunrise in urban areas in comparison to the surrounding semi-rural or rural areas;
- More heat absorbing urban surface materials and less overall vegetative surfaces in urban areas in comparison to surrounding rural areas resulting in higher urban surface temperatures;
- Under stable weather conditions (low/minimal wind speeds and clear skies) the urban heat island effect is exacerbated;
- Heat island effect intensifies with increasing development of cities and urban areas;
- In addition to the UHI effect on temperatures in the “urban canopy layer” (below the tops of buildings and trees), the heat island also affects air temperatures above the trees and buildings of urban areas in what is known as the “urban boundary layer” by a process known as thermal inversion. This is when a warm layer of air covers a layer of cooler air and keeps the cool air from moving.

Table 4 also gives a list of UHI generalizations adapted from the comprehensive review of urban climatic research (Arnfield, 2003) and correlates each of these characteristics to the Beirut case.
Therefore, these underlying characteristics of the urban heat island help in understanding the mechanisms of this phenomenon and within the context of this thesis, they are especially important upon analyzing the simulations results and devising suitable mitigation strategies for the Beirut case as discussed in more detail in later chapters (see Part IV of this thesis).

Table 4. *UHI empirical generalizations adapted from Arnfield, 2003*

<table>
<thead>
<tr>
<th>Items</th>
<th>Empirical generalization</th>
<th>Beirut case</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>UHI intensity decreases with increasing wind speed</td>
<td>Average day-time winter wind speed records of 18-20m/s are typical for Beirut and are much less between 5-10m/s in summer. Average night-time winter wind speeds range between 13-20m/s while during the summer they range between 2-10m/s.</td>
</tr>
<tr>
<td>2</td>
<td>UHI intensity decreases with increasing cloud cover</td>
<td>Cloud cover typically increases during the winter season in Beirut</td>
</tr>
<tr>
<td>3</td>
<td>UHI intensity is greatest during anticyclonic conditions</td>
<td>Anticyclonic events are not typical in Beirut Mediterranean climate</td>
</tr>
<tr>
<td>4</td>
<td>UHI intensity is best developed in the summer or warm half of the year</td>
<td>This research investigates this specific characteristic of the UHI and finds that indeed UHI intensity is best developed in the summer season (see Chapter 7 Numerical Analysis)</td>
</tr>
<tr>
<td>5</td>
<td>UHI intensity tends to increase with increasing city size and/or population</td>
<td>At the beginning of the 20th century Beirut surface area was at around 5 km² but due to rural exodus Beirut surface area grew to about 20 km² with a population density of approximately 21,000 inhabitants/km² where artificial surfaces increased and UHI impacts also increased (see Chapters 5 and 7)</td>
</tr>
<tr>
<td>6</td>
<td>UHI intensity is greatest at night</td>
<td>This research investigates this specific characteristic of the UHI and indeed finds that UHI intensity is greatest at night when trapped heat is released back into the atmosphere by the impermeable and low solar reflectivity surfaces (see Chapter 7 Numerical Analysis)</td>
</tr>
<tr>
<td>7</td>
<td>UHI may disappear by day or the city may be cooler than the rural environs</td>
<td>This research investigates this characteristic of the UHI but finds that areas with lower density urban fabrics are typically cooler than dense urban fabrics because of the higher artificial and low solar reflectivity urban surfaces (see Chapter 7 Numerical Analysis)</td>
</tr>
</tbody>
</table>
3.3 The Energy Balance

The UHI phenomenon therefore occurs due to a combination of natural as well as man-made factors, which alter or impact the energy and water cycles of the Earth-Atmosphere systems by which energy and mass are transferred, converted and stored. As such, the earth’s energy balance and accordingly its physical climate are modified. According to Oke (1987), the relationship between energy flow and the climate can be explained by the First Law of Thermodynamic where energy can be neither created nor destroyed but only converted from one form to another (Energy Input = Energy Output). In fact, the physical processes of heat energy transfer occur through radiation, convection, and conduction and play a key role in the earth’s energy balance and accordingly its climate and these are discussed in more detail in the sections below.

3.3.1 Radiation characteristics. All bodies possessing energy or whose temperatures are above absolute zero emit radiation. The total energy emitted by each body can be calculated according to Stefan-Boltzmann’s Law (Oke, 1987) that states that the total energy radiated (j) per unit surface area of a black body across all wavelengths per unit time is directly proportional to the fourth power of the black body’s thermodynamic temperature as shown in the below equation:

\[ j = \sigma T^4 \]

where \( \sigma \) is Stefan-Boltzmann’s constant (Equation 4)
If the body is not a full radiator, the value of the surface emissivity ($\varepsilon$) will be included

$$j = \varepsilon \sigma T^4_0$$  \hspace{1cm} \text{(Equation 5)}

The process by which radiation absorption takes place at the earth’s surface as well as its reflection back into the atmosphere is fully explained by Oke (1987). First, incoming solar beam encounters clouds and other atmospheric constituents like water vapor, salt crystals, dust particles and various gases as it travels through the atmosphere; Since these constituents have their own set of radiative properties with respect to the short-wave radiation, part of this beam is reflected, part is absorbed and the rest is transmitted to the Earth’s surface. In fact, almost 47% of the solar energy input is absorbed at the Earth’s surface. This considerable amount of energy is converted from radiation into thermal energy which warms the surface. The portion of the incoming solar radiation that is reflected and scattered gives diffuse short-wave radiation (D), while the portion of the incoming solar radiation that arrives at the Earth’s surface, without being absorbed or diffused, is called the direct-beam short-wave radiation (S). The total short-wave radiation received at the earth surface ($K_\downarrow$) is the sum of the diffuse and direct-beam short-wave radiation ($K_\downarrow = D + S$).

At all levels the atmosphere emits long-wave radiation consistent with its temperature ($T_a$) and emissivity ($\varepsilon_a$). The processes of absorption and re-emission take place on a continuous basis through the atmosphere but quantitatively, they are most important in the lowest layers where the concentrations of water vapour and carbon dioxide are greatest (Oke, 1987). The net portion that emerges from the top of the atmosphere is lost to space; and that which arrives at the Earth’s surface is sometimes
referred to as “counter-radiation (L↓)” because it counteracts the outgoing long-wave radiation from the surface (L↑).

3.3.2 Convection and conduction. Another physical process of heat energy transfer occurs through convection which is the energy that is transferred from a solid surface to a fluid and in this case from the earth’s surface to the air above it. Convection increases with higher wind speeds, when air becomes more turbulent over rougher surfaces and when there is a significant variation in temperature between the surface and the air (Gartland, 2008). If the gain or loss of energy to a body is sensed as a rise or fall in its temperature then this is referred to as sensible heat or “heat energy that is able to be sensed (with a thermometer)”. On the other hand, to enable a substance to change from liquid at a given temperature to vapour at the same temperature requires the addition of heat. This heat that is not sensed as a temperature change is called latent heat or the “heat released or absorbed per unit mass by a system in changing phase” (Oke, 1987). Convection transports heat to and from the atmosphere in both its sensible and latent forms. When surfaces are warmer than the surrounding air, sensible heat is transferred to the cooler air while the reverse transport occurs when the air is warmer than the surface. As for latent heat transport, this is tied up with that of water vapour.

Thermal conductivity is another physical process of heat energy transfer and is defined as the energy that is transferred within a substance by the collision of rapidly moving particles. This usually occurs in solids and less so in liquids and gases. It is negligible in atmospheric applications but it is important to the transport of heat beneath the surface. The conduction of heat is dependent on the thermal properties of the substrate in question (Oke, 1987). Therefore, materials with high thermal conductivity are
more able to direct heat into their depths. As more heat is stored, the temperature of the material rises (Gartland, 2008).

Convection and conduction are therefore important physical processes of heat energy transfer and should be considered when analyzing the UHI simulation results for the case of Beirut.

**3.3.3 Modification by urban areas.** When an existing landscape is replaced by a building or number or buildings in an urbanization process, modification of the radiative, thermal, moisture and aerodynamic properties of the surrounding environment occurs and the natural solar and hydrologic balances are affected. This is because with the process of urbanization urban construction materials increase, trapping and storing more heat and waterproofing the surface. In addition, the block-like urban geometry causes radiation trapping and air stagnation while man-made activities release excess heat and water in the form of ‘waste’ which further affects the energy balance. Therefore buildings have a significant impact on the urban microclimate and also on air pollution dispersal but wind and turbulence also play a role on the dispersion of air pollutants. For example, in urban canyons characterized by low buildings, the height to width ratio of streets plays an important role in the exchange between street level, where pollutants are emitted by cars, and above roof-level, so if the streets are narrow, air exchange is restricted (Figure 7a). On the other hand, urban canyons characterized by wider streets allow for the flushing of these street level pollutants into the air (Figure 7b). Sometimes, where an air-polluting source is placed in the suction zone above the roof of a tall building, the flow of air removal becomes restricted (Figure 7c) but this can be alleviated by constructing a taller stack so that effluent is carried downwind in what is known as the displacement zone. Air
pollution dispersal is also stagnated when an-air polluting source is placed near the surface in the eddy of a cavity zone (Figure 7d). Lee eddies are semi-enclosed circulation systems and therefore poor locations for a pollutant source. There is no simple remedy for this latter case except to eliminate the polluting source.

Figure 7. The influence of building air flow on pollution dispersion. Source: Oke, 1987, pp.273

3.3.4 The energy balance equation. In order to measure heat island effects, it is necessary to measure the energy flowing in and out of surfaces which gives a further understanding into the origins of the heat island. An equation called the ‘energy balance’ explains the transfer of energy to and from the Earth’s surfaces through the physical processes of radiation, conduction and convection (Convection + Evaporation + Heat storage = Anthropogenic heat + Net radiation). There are two sources of energy entering the Earth’s surface: 1) man-made or anthropogenic sources including buildings, machinery and people, or 2) net radiation which is defined as the amount of the incoming solar energy that is absorbed, not reflected or emitted away. At any moment in time, anthropogenic heat and net radiation must be convected away by the wind, dissipated by
the evaporation of moisture or evapotranspiration from vegetation, or stored in the surface itself (Gartland, 2008; Oke, 1987). The energy balance equation is written as follows:

\[ Q^* + Q_F = Q_H + Q_E + \Delta Q_S + \Delta Q_A \quad (\text{W.m}^{-2}) \quad \text{(Equation 6)} \]

Where:

- \( Q^* \) is the net all wave radiation which encompasses four separate radiation processes taking place at the Earth’s surface: Net radiation = Incoming solar – Reflected solar + Atmospheric radiation – Surface radiation.

- \( Q_F \) is anthropogenic heat and represents “man-made’ heat generated by buildings, machinery or people

- \( Q_H \) is sensible heat

- \( Q_E \) is latent heat

- \( \Delta Q_S \) is the net energy storage; rate per unit volume (per unit horizontal area)

- \( \Delta Q_A \) is the net energy (sensible and latent) advection; rate per unit volume (per unit horizontal area)

Moreover, the energy balance of a building-air volume is given by a relation similar to that for a single building, as written in Equation 6. The term \( \Delta Q_S \) refers to heat storage changes in the ground, the buildings and the air contained within the volume, and \( Q_F \) refers to heat sources in the city associated with combustion, and which are directly controlled by human decisions responding to the activity rhythms only indirectly related to the solar cycle. Finally, \( \Delta Q_A \) refers to the net horizontal transfer of sensible and latent heat through the sides of the building-air volume. Figure 8 is a schematic representation of the fluxes involved in the energy balance of an urban building air volume. This has
been referred to in numerous related researches and is indeed the basic figure in climatology.

Figure 8. Schematic depiction of the fluxes involved in the energy balance of an urban building air volume. *Source: Oke, 1987, pp.275*
Chapter 4: Measuring, Modeling and Mitigating Heat Islands

This chapter of the literature review covers the different types of techniques typically adopted to measure the urban heat island phenomenon in dense cities worldwide and discusses the choice of selection for the most suitable technique for the purpose of this research for the Beirut case. In addition, the available literature on the various different modeling schemes available for simulation of the urban heat island is also discussed at length as well as some brief discussions on the choice of selection for the most suitable modeling scheme for this research for Beirut. However more details on the selections made for measurement and modeling techniques for UHI in Beirut including elimination processes can be found in Chapter 6 (Research Methodology) of this research as this chapter covers primarily the literature review content of UHI measurement types and modeling schemes.

4.1 Measuring the Urban Heat Island

The available literature shows that there have been many advances in measuring UHI intensity. Methods used to quantify the effects of urbanization on urban microclimate include: 1) fixed or mobile weather stations, handheld or mounted thermal scanners; 2) aerial orthophotography; and 3) remote sensing thermal images and techniques and these are explained in more detail in the subsequent sections.

4.1.1 Weather stations. To date, air temperatures records from meteorological stations is the most conventional way used to detect the occurrence and profile of the UHI over cities across the globe. (Colacino & Lavagnini, 1982; Eliasson, 1996; Giannopoulou et al., 2011; Katsoulis & Theoharatos, 1985; Vez, Rodríguez, and Jiménez, 2000). Data are typically acquired from existing weather stations or from micro-weather stations setup purposefully at specific locations with different land use and land cover
such as: coastline, dense inner city, commercial or office area, residential area, etc. To that end, day and night time minimum and maximum temperature records are monitored and compared for specific times of the day over a determined period (day, month or season). Records are then compared to historical temperature records and trends to identify unusual climatic pattern and any associated impact on the UHI.

For example, Giannopoulou et al. (2011) monitored temperature data from 25 fixed meteorological stations during the summer season of year 2009 in the major Athens area in order to study the characteristics of the UHI phenomenon. The greater area of Athens was divided into 5 geographical parts each being characterized by its own specific urban morphology and land uses. Results showed that each of these 5 areas had different temperature conditions; the higher air temperatures were found in the industrial western part of the city and also the central dense urbanized area, while the lower temperature values were presented at the northern and eastern parts characterized by their higher percentage of green areas and the absence of industrial zone and identified UHI intensity close to 5°C. In general, it was found that this method of using fixed weather stations to study the UHI in Athens was successful in that it helped to draw important conclusions as follows:

1. the development of high summer air temperatures is mainly as a result of the presence of high mountains (over 1000m a.s.l.) surrounding the Athens area; and
2. the urban heat island during the night period was observed mainly in the industrial western part of the city.
Another example where weather stations were used to study the UHI can be seen in the works of Alonso et al. (2003) for the city of Salamanca in Spain. In these works, the experts: 1) investigated the temporal evolution of UHI intensity for the period 1996 to 1998; and 2) compared temperature records between an urban area and a nearby rural area. To this purpose, the spatial distribution of the UHI was analyzed by using the transect selection method for two measuring transects in the city. For the measurement of temperature along these two selected measuring transects, a digital thermometer with a resolution of 0.1°C was used. In general the results indicated that the Tormes River in relation to the city of Salamanca played a significant role in determining the city’s thermal characteristics. In addition, results showed that the UHI was more intense under conditions of atmospheric stability as compared to conditions of atmospheric instability.

In the city of Granada in Spain, Vez, Rodríguez, and Jiménez (2000) studied the effects of the UHI by investigating weather station records. Here however, it is worth noting that reference was made to the historical temperature evolution of the last century for only one meteorological station, namely Cartuja station, and analysis was carried out by application of statistical methods. However, comparisons between both rural and urban temperature records were also carried out but over a much smaller time-scale, probably due to lack of data for previous years. For the rural temperature records a military airdrome site uninfluenced by urbanization was selected. Using the time series of temperature differences, daily maximum and minimum temperature records were obtained for annual and seasonal periods with results showing maximum differences occurring only during the winter months. It is important to note that the results also
showed that population growth was very closely related to the trends in temperature records.

On the island of Taiwan, air temperature data were also collected for the purpose of analyzing the thermal environment in two urban street canyons in the hot and humid city of Taichung (Sun, Kato, Sung, Lin, Wang, and Ou, 2009). Again, this method of study helped to find important correlations between the urban fabric, including building density, street height to width ratio and vegetation, and the urban heat island phenomenon.

Therefore, as can be seen in the available literature, the application of this method of analysis for urban atmospheric temperatures is quite common in cities worldwide although it has proven to be time-consuming, is weather-dependent, can be quite costly depending on the choice of instruments, and requires good coordination amongst all involved parties to reduce the margin of error to the extent possible.

For the case of Beirut, there are several weathering stations that exist which are associated either with academic institutions, like for example the station at the American University of Beirut (AUB)\textsuperscript{12} or governmental agencies, like stations that are operated by the Lebanese Institute for Agricultural Research (LARI)\textsuperscript{13} and that are spread out across

\textsuperscript{12} 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. A new station was set up after the end of the Civil War although the old station still remains and is referred to the “AUB Old Observatory”. As such, 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), another private French academic institute. These institutions typically provide data only to their students or upon official request from governmental authorities and are associated with fees.

\textsuperscript{13} LARI is a governmental organization under the Minister of Agricultural supervision. The institute conducts applied and basic scientific research for the development and advancement of the agricultural sector in Lebanon and has accordingly been measuring weather data since 2009 at stations spread out across the country.
the country including Beirut, or like the station at Rafik Hariri International Airport\textsuperscript{14}. However, there is no available information, documentation or publication to indicate that these aforementioned sources have conducted any works on the UHI phenomenon in Beirut. Having said this, reference is made to these aforementioned stations within the context of this research for Beirut, to collect historical climatic records and to accordingly conduct numerical analysis of historical weather patterns, namely maximum and minimum temperature trends (see Chapter 6 of this thesis for more details).

\textbf{4.1.2 High resolution aerial ortho-photos.} High-resolution aerial orthophotography is also a commonly used method in the study of the urban heat island phenomenon. As the term suggests, aerial photographs are images that are taken of the ground from an elevated position that are of high quality, sharp and finely detailed and among other purposes are very useful for studying the effects of the urban heat island.

In their study of the urban heat island phenomenon, Akbari, Shea-Rose and Taha (2003) used high-resolution aerial colour photography to characterize the area fraction of various surface types and vegetation fraction in the city of Sacramento. They stressed the importance of carrying out this characterization when estimating the impact of various urban surfaces (roofs and pavements) on the UHI. As such, they examined five land use types including: 1) downtown and city center; 2) industrial; 3) offices; 4) commercial; and, 5) residential. Their results showed the urban surface area fractions of these five different land use areas, which could essentially be very useful when comparing UHI effects in these areas of Sacramento city.

In another similar study, Akbari and Rose (2008) investigated urban surface type distributions and urban-fabric makeup using aerial colour orthophotography for four

\textsuperscript{14} Weather records began in the year 1932 at the Rafik Hariri International Airport
metropolitan areas in the US, including Chicago, IL, Houston, TX, Sacramento, CA, and Salt Lake City, UT. The major land use types examined included: commercial, residential, industrial, educational and transportation. Each aerial orthophoto was visually inspected using ERDAS/Imagine software (ERDAS, [Earth Resources Data Analysis System, 1997) to identify qualitatively all surface-types and land-covers that can be seen at the resolution of the data. In this study, Akbari and Rose found that it is possible to characterize the fabric of a region of interest accurately and cost-effectively using aerial orthophotography further stating that between, 10 to 50 km² of aerial photography would suffice for reasonably good characterization of the fabric. As a result of these investigations, Akbari and Rose were able to conclude that there is large potential for additional urban vegetation as well as increasing albedo for these four metropolitan areas.

In their works on the modeling of the urban environmental quality in Hong Kong, Nichol and Wong (2005) apply satellite-based sensing systems to depict parameters of environmental quality over large areas. In their methodology, they use colour orthophotography to give specific and clearer details of the area under study. By applying this method, they are able to accurately identify the various characteristics of the area being studied determining that it is a small park within a densely built area of Mongkok district in Hong Kong.

Aerial orthophotos therefore play an important role in the investigation and in-depth study of urban heat islands and environmental quality. However, according to the existing literature, aerial orthophotos are used primarily to determine the fraction of various surface types and vegetation to indicate areas most sensitive to the impacts of the UHI as opposed to actually measuring the UHI intensity in a city. This is still
advantageous however since the information can accordingly help to devise solutions at the city scale as to the areas which would benefit the most through implementation of mitigating solutions, such as the plantation of more urban trees along asphalted roads of low solar reflectivity or in areas which are characterized by a high fraction of artificial surfaces. Therefore they can be very helpful in this respect. Aerial orthophotos do exist for Beirut although they are difficult to obtain as only the military has access to them and in addition they are quite costly. Having said this, the most recent aerial orthophoto that exists for Beirut, which is dated 2008, was obtained and accordingly used to identify main areas of vegetation, densely built areas and roads. Although it is 7 years old, comparison with the recent satellite image (from Google Earth) showed only very minor changes since 2008. It is worth also noting that for the purpose of this research, ArcGIS software was used to inspect more closely and in more detail the aerial orthophoto for Beirut administrative area and to extrapolate necessary information regarding urban surfaces from it (see Part IV of this research for more details).

4.1.3 Thermal remote sensing. With the advent of high-resolution earth-monitoring satellites, these last two decades or so have witnessed a significant increase in the application of thermal remote sensing to study urban effects on meteorology, climate, and urban heat islands, as opposed to the more traditional in-situ measurements that are carried out in isolated locations. Thermal remote sensing is a method used to study urban surface temperatures by observing surface temperature which varies in response to the surface energy balance (Voogt and Oke, 2003). It is that branch of remote sensing that deals with the acquisition, processing and interpretation of data acquired primarily in the thermal infrared (TIR) region of the electromagnetic (EM) spectrum where the radiations
‘emitted’ from the surface of the target are measured as opposed to optical remote sensing where radiations ‘reflected” by the target under consideration are measured (Gupta, 1991). Satellite images have therefore made it possible to study the effects of the UHI both remotely and on continental or global scales (Streutker, 2002.) and are typically used to study land surface temperatures (Parlow, 1999; Qin & Karnieli, 1999).

There do, however, appear to be some limitations in the application of thermal remote sensing images to study urban heat islands. For example, thermal remote sensing is not able to capture the thermal properties of tall vertical surfaces and facades such as trees and buildings (Streutker, 2002; Voogt and Oke, 2003). Therefore it is limited in its ability to identify the features that dominate the landscapes of urban areas (Akbari and Shea-Rose, 2008).

According to Voogt and Oke (2003), while some progress has been made in the application of thermal remote sensing of urban areas, it has in fact been “slow to advance beyond qualitative description of thermal pattern and simple correlations”. Akbari and Shea-Rose (2008) also find that “while advances in techniques in the fusion of GIS data and remote sensing among others are promising, they have yet to characterize disaggregated urban features in a manner that is practical and accurate enough for applied city planning”. Voogt and Oke (2003) suggest applying the advances made in the remote sensing measurements of vegetative surfaces to urban areas, while Akbari et al. (2003) find that when comparing the various available data resources (including thermal remote sensing images), high resolution colour digital orthophotos offer the best means for obtaining accurate estimates of urban fabric to accordingly study the urban heat island phenomenon.
In his study of the urban heat island in the city of Houston Texas, Streutker (2002) also identifies some limitations of remotely sensed data used in making temperature determinations: “remotely sensed derived temperatures are surfaces temperatures of the emitting materials, and not air temperatures, as in situ measurements often are”. As such, this can cause surface temperatures to exhibit a much greater spatial variation than the concurrent air temperatures (Streutker, 2002). This shortcoming is further emphasized by Arnfield (2003) who explains that remotely sensed UHIs are usually stronger and exhibit greatest spatial variability by day, the opposite to air temperature UHIs. As further explained by Roth et al (1989), the reason for this is because remote sensing tends to oversample roofs, treetops, and roads and open horizontal areas while it neglects areas below tree crowns. Having said this, the application of thermal remote sensing to study UHIs is fast spreading with continual suggestions and applications for improvements. For example, in their study of the assessment of the urban heat island effect for 37 dense cities across the U.S.A. and their respective nearby rural regions, Gallo, McNab, Karl, Brown, Hood and Tarpley (1993) used data from the NOAA (National Oceanic Atmospheric Administration) Advanced Very High Resolution Radiometer (AVHRR) and derived a vegetation index and radiative surface temperature for these urban-rural areas. By comparing urban-rural differences in computed versus observed situations in minimum air temperatures, Gallo et al. were able to determine that the difference in the surface properties between the two environments is the main reason for the resulting differences in urban and rural minimum temperatures (Gallo et al., 1993). The use of the remotely sensed data was therefore very suitable for these large areas under study as opposed to the application of in-situ measurements.
From 1998 to 1999, Streutker (2002) studied the urban heat island effects of the highly populous city of Houston, which covers a large geographic area. His study was based on temperature maps from AVHRR data. In the application of this approach to study UHI, and after carrying out the radiometric correction, cloud and water rejection, rural subtraction, and UHI characterization as necessary for the interpolation of the required temperature data, Streutker concluded that the application of this type methodology showed that satellite radiance data can be used to characterize both the magnitude and spatial extent of an urban heat island with suggestions to carry out future studies for more prolonged periods of time as well as over several urban areas in a given region.

Recently, in Beijing, Yang, Gong, Zhou, Huang, and Wang (2010) evaluated the suitability of using thermal infrared (TIR) data from satellite imagery for detecting UHIs. This was validated against a previous study carried out in Beijing. The study essentially demonstrated that the application of thermal remote sensing is successful in studying surface UHIs. Others have applied thermal remote sensing in combination with another methodology (hybrid methodology) to study UHIs, such as Geographic Information System (GIS), as done for the Kawasaki, Japan case (Iino and Hoyano, 1996). Here it was found that it was possible to construct urban thermal images accordingly giving a clear idea as to where energy problems potentially occur and how this information could be employed in proper urban development planning.

In general, the application of thermal remote sensing methods to study UHI (in combination, or not, with GIS or other similar tools) appears to be quite popular, according to the authors mentioned, who generally compare the results of their studies to
other case studies representing temperature records of cities. Having said this there still seems to be room for improvement for application of this type methodology for measurement of UHI. This choice for UHI measurement was not selected for the purpose of this research however mainly since the available thermal remote sensing images are limited for Beirut city or are not very clear for easy extrapolation of surface thermal data (see Chapter 6 for more details on choice of selection for measurement technique of UHI).

4.1.4 Summary. Based on the literature review on the different measurement types for UHI measurements in cities it is found that all approaches equally have advantages as well as limitations as outlined in Table 5. This table below helps in the selection process of this research for the most feasible approach for the Beirut case although as a preliminary assessment it is found that all these measurements types may not be suitable. Rather, the collection of weather data from existing weather stations in Beirut may potentially be the most feasible approach thus avoiding all the limitations associated with the outlined measurement types.
Table 5. Limitations and advantages of various existing measurement types for UHI (prepared by author)

<table>
<thead>
<tr>
<th>Measurement type</th>
<th>Limitations</th>
<th>Advantages</th>
<th>Examples of cities/countries of implementation</th>
</tr>
</thead>
</table>
| Fixed and mobile weather stations| - time-consuming  
- weather-dependent  
- can be quite costly depending on the choice of instruments  
- requires good coordination amongst all involved parties | - gives accurate climatic data and recent / new data  
- allows for the choice of selection for location of weather stations or path to be taken in the case of mobile traverses | Athens, Greece  
New York City, U.S.A.  
Taiwan, China  
Salamanca, Spain |
| High resolution aerial-orthophotos| - they do not actually measure UHI intensity but rather help determine areas that could benefit the most from UHI mitigation strategies | - high quality, sharp and finely detailed  
- used to accurately characterize the area fraction of various surface types and vegetation fraction in cities | Chicago, IL,  
Houston, TX, Sacramento, CA, and Salt Lake City, UT, U.S.A.  
Mongkok., Hong Kong |
| Thermal remote sensing           | - thermal remote sensing is not able to capture the thermal properties of tall vertical surfaces and facades such as trees and buildings  
- remotely sensed derived temperatures are surfaces temperatures of the emitting materials, and not air temperatures, hence can cause surface temperatures to exhibit a much greater spatial variation than the concurrent air temperatures | - it is a fast process and therefore is time efficient  
- gives indications of the impact of surface temperatures on air temperatures and accordingly UHI impacts | Beijing, China,  
37 dense cities across the U.S.A (Gallo et al., 1993)  
Houston, Texas |
4.2 Modeling the Urban Heat Island

Modeling of urban heat islands is useful to both help understand how the UHI works and to estimate how effective application of different mitigation measures types can be. As such, after reviewing the existing literature on the topic, it is important to select the most suitable modeling scheme for the Beirut case in order to conduct simulations across the city that could potentially provide feasible solutions for mitigation of the UHI from an urban planning and design perspective.

Numerous models have been developed which vary widely with regard to both their physical basis and spatial/temporal resolution (Emmanuel & Fernando, 2007). The available literature on this topic shows many comparative studies that assess and evaluate urban land surface schemes that have been developed to model the distinct features of the urban surface and the associated energy exchange processes. While most of the applied models show relatively successful simulation results, each is specific to the scale it which it can be used. Therefore, in this section of the literature review, out of the numerous models developed worldwide to study the effects of UHI (Grimmond, et al., 2010; Grimmond, et al., 2011), the modeling schemes most commonly mentioned in the available literature are discussed based on the scale at which they are used i.e., whether micro-scale, local-scale, meso-scale or macroscale. As such, for micro-scale and local-scale modeling schemes, the NARPS-LUMP, SM2-U, ENVI-met and SOLENE models are discussed and compared. For meso-scale models, the Town Energy Balance (TEB) model and the Finite Volume Model (FVM) are discussed and compared. As previously mentioned at the beginning of this chapter, while the choice of selection of the most
suitable modeling scheme of UHI in Beirut is briefly discussed here, more details for the elimination and respective selection process can be found in Part IV of this thesis.

4.2.1 Micro-scale and local scale modeling schemes. In this section, details on four modeling schemes that are used typically for UHI simulations at the micro-scale or local scale i.e., building level or neighborhood level, are discussed, which include NARP-LUMPS, SM2-U, ENVI-met, and SOLENE.

4.2.1.1 NARP-LUMPS. The NARP-LUMPS model (Net All-Wave Radiation Parameterization / Local-scale Urban Meteorological Pre-processing Scheme) which was developed by Grimmond and Oke (2002), is an empirical model that is used typically for small-scale studies. It is used to assess the energy balance of a city but it simplifies the energy balance equation without incorporating the anthropogenic heat flux produced by combustion processes, metabolism and waste heat (QF) and by ignoring the advective heat flow (QA) and thus considers the following formula:

\[ Q^* = Q_H + Q_E + \Delta Q_S \text{ (W.m}^{-2}\text{)} \]  

(Equation 7)

Where:

- \( Q^* \) is the net all wave radiation
- \( Q_H \) is sensible heat
- \( Q_E \) is latent heat
- \( \Delta Q_S \) is the net energy storage; rate per unit volume (per unit horizontal area)

NARP-LUMPS is based on several stages as indicated in flow chart of the structure of LUMPS in Figure 9, which shows that it is driven by relatively easily obtained meteorological and surface data. Heat storage by the urban fabric is parameterized from net all-wave radiation and surface cover information.
According to Masson (2006), NARP-LUMPS is adequate if the observational field data are sufficient and well understood. The main asset of this model is its simplicity since it needs very few inputs and its computation is very efficient although its main weakness is that it is only valid in the range of conditions observed in the field (Hidalgo, Masson, Baklanov, Pigeon, & Gimeno, 2008). Indeed in their paper introducing this empirical model, Grimmond and Oke (2002) acknowledge that their model is very simplistic and would potentially need additional input requirements with special consideration of the effects of wind and anthropogenic heat. In addition, they emphasize

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15 The Monin-Obukhov length is used to describe the effects of buoyancy on turbulent flows, particularly in the lower tenth of the atmospheric boundary layer.

16 The friction velocity is used to represent fluctuations in wind speed.
that LUMPS is unlikely to perform well in areas of greater spatial variability of land cover and/or morphology such as at the urban-rural edge, near coasts or in complex terrain.

Therefore, the available literature shows that NARP-LUMPS is a simple empirical model that is used mainly for micro-scale studies of the UHI. This model is therefore not feasible for the purpose of this research which aims to study the UHI effect at the mesoscale level, for the entire city of Beirut, in the view to find solutions from an urban planning perspective.

**4.2.1.2 SM2-U.** The SM2-U (Soil Model for Sub-Mesoscale Urban) model, developed by the Ecole Centrale de Nantes, calculates heat flux at the canopy-atmosphere interface across a district. It can be coupled with SUBMESO, which is a non-hydrostatic model also developed by the Ecole Centrale de Nantes. SUBMESO simulates atmospheric flows with a resolution up to a few meters to several kilometers (Leroyer et al, 2004). SM2-U is a single canopy layer models built on a physical basis from the Integration with Soil Biosphere and Atmosphere (ISBA) rural soil model (Noilan and Orderly, 1989) by including urban surfaces to evaluate the heat and humidity fluxes at the urban canopy-atmosphere interface and provides the lower boundary condition of the computational domain in simulations of the urban boundary layer (Mestayer, Dupont, Calmet, Leroyer, Mahura, and Penelon, 2004). SM2-U has the advantage of being a unique model covering both rural and urban soils. Furthermore, the physical processes inside the urban canopy, such as heat exchanges, heat storage, radiative trapping, water interception or surface water runoff, are integrated in a simply way. In the SM2-U model therefore, the surface dynamic influence is represented through roughness lengths and displacement heights.
The horizontal exchanges inside the urban canopy are not considered except radiation reflections and water runoff from saturated surfaces the wind advection between urban surfaces is also not considered.

According to Mestayer et al. (2004), SM2-U considers eight types of surfaces including: bare soil without vegetation; bare soil located between sparse vegetation elements; vegetation over bare soil; vegetation over paved surfaces (e.g., trees on the road side), paved surfaces located between the sparse vegetation elements, paved surfaces located under the vegetation, building roofs, and water surfaces, respectively denoted as bare, nat, vegn, vega, pav, cova, roof and wat as illustrated in Figure 10.

Figure 10. (a) Scheme of the SM2-U energy and water budget models with 8 surface types (pav, cova, bare, nat, roof, vega, ven, wat) and 3 layers of soil. (b) Energy budget of paved surfaces. Source: Mestayer, et al., 2004, pp.3

In each computational cell, each surface type is characterized by its area density fi, the index I corresponding to one of the 8 surface types. Three soil layers are
considered: a surface layer for the natural surfaces, allowing evaluation of the evaporation fluxes from the bare soils; a root zone layer representing the influences area of the vegetation roots; and a deep soil layer used as a water reservoir which provides water to above soil layer by diffusion in dry periods (Mestayer et al., 2004). In each cell, the model determines 1) for each type surface its surface temperature, specific humidity and energy fluxes, 2) the deep soil temperature, 3) the mean potential surface temperature and the mean energy flux, and 4) the water content of each soil layer and the water amount intercepted by roofs, vegetation and paved surfaces. SM2-U does not evaluate the energy budget of building walls to avoid introducing a questionable parameterization of the wind velocity inside the canopy (Mestayer, et al., 2004).

Bozonnet et al. (2013) describes the SM2-U model as a “simple” model which can be used to illustrate the influence of alternative mitigation techniques on the urban microclimate. In his paper, Bozonnet et al. (2013) uses the SM2-U modeling scheme to assess the impact of two alternative rainwater management mitigation techniques and is accordingly able to provide feasible recommendations based on the simulation results of SM2-U. Hence he considers this to be a reliable simulation tool although he does recommend the need for the model to consider additional urban morphology parameters and material properties for improvement of this particular modeling scheme. Therefore, according to the available literature, SM2-U is a fairly simple model and has been proven to be useful in devising feasible recommendations for mitigation tools. However, since SM2-U model is used typically for neighborhood scale studies, it is not found to be feasible for the purpose of this research which aims to study the effect of UHI at the city-scale.
4.2.1.3 **ENVI-met.** ENVI-met (Environmental Meteorology) was developed within the Research Group of Climatology (RGC), Department of Geography at the University of Buchum in Germany by Michael Bruse (Bruse, 1999). ENVI-met is a three-dimensional micro-climate model designed to simulate the surface-plant-air interactions in urban environments with a typical resolution of 0.5 to 10m in space and 10 seconds in time. Therefore, ENVI-met is applied typically for micro-scale projects at the building scale or neighborhood levels for example and is not used for large-scale studies (www.envi-met.com).

ENVI-met is a prognostic model based on the fundamental laws of fluid dynamics and thermodynamics. The model has many uses and indeed includes the simulation of the following processes: flow around and between buildings; exchange processes at the ground surface and at building walls, building physics, impacts of vegetation on the local microclimate and pollutant dispersion. Since its first official release more than 10 years ago, ENVI-met model is constantly being developed further, and has accordingly undergone numerous upgrades as seen in its most recent Version 4.0 (Huttner and Bruse, 2009). In prior versions of ENVI-met, the atmospheric boundary conditions of the simulation could only be adjusted by setting some initialization values from which ENVI-met deduces directly (incoming radiation) or indirectly (wind speed, air temperature, humidity) the diurnal variation of the boundary conditions of the simulation. Although this approach facilitates the use of ENVI-met for non-scientists, unfortunately it allows only very limited influence on the development of the boundary conditions on which the results of a micro-scale model strongly depend. The most recent version of ENVI-met (Version 4.0) has taken into consideration these limitations and has made it possible to
define the diurnal variation of the atmospheric boundary conditions and the incoming radiation. This allows a more accurate comparison between measurements and simulations of ENVI-met and allows the development of much more detailed weather scenarios for testing purposes (Huttner and Bruse, 2009). Figure 11 shows the basic data structure of ENVI-met. Figure 12 shows a typical output of ENVI-met for a linear park in Phoenix, Arizona, where the darker colours (dark blue in this case) typically reflect cooler surfaces (Ozkeresteci, Crewe, Brazel, and Bruse, 2003). In this aforementioned study, these linear parks were investigated in ENVI-met first to evaluate the practical applications of the model and second, to assist Phoenix metropolitan area planners in advancing their open space and park planning strategies.

Figure 11. Design of the ENVI-met database system in Version 4.0. Source: www.envi-met.info/
Numerous studies for analysis of UHI have been conducted using ENVI-met. Ali-Toudert and Mayer (2006) applied ENVI-met to study the effects of aspect ratio and solar radiation toward the development of a comfortable microclimate at street level for pedestrians in the town of Ghardaia in Algeria (Bruse, 2004). Their argument for using this specific modeling scheme was that it requires few input data parameters to calculate all important meteorological factors; it has the ability to reproduce major processes in the atmosphere that affect the microclimate, and it has high spatial and temporal resolution enabling a fine understanding of the microclimate at street level. According to Emmanuel and Fernando (2007) however, this modeling scheme does have some major shortcomings since buildings which are modeled as blocks have no thermal mass and have constant indoor temperatures and the albedo for walls and roofs are the same for all buildings. Having said this, ENVI-met modeling scheme was used also in the works of Emmanuel and Fernando (2007) where the effects of UHI mitigation options were analyzed within the heavily built up street canyons of the city of Pettah in Colombo and the central business district of Phoenix.
Yu and Hien (2006) also used the ENVI-met model to explore the patterns of energy consumption of a typical commercial building near to a nature park in Singapore and different thermal conditions of an area with and without a neighborhood park. Yu and Hien accordingly found that the ENVI-met simulations supported the data generated from field measurements which indicated that the park has significant cooling effects on the surroundings both during the day and night. Also, the simulations results on ENVI-met illustrated the truth that the loss of greenery may cause bad thermal conditions not only in the original park area but also in the surroundings especially when greenery is replaced by buildings and hard surfaces.

Therefore according to the available literature it is found that the use of ENVI-met model is widespread in UHI associated works where results appear to be acceptable in all cases but the only drawback within the context of this research is that it is used typically for micro-scale or local-scale studies and is therefore not feasible for the purpose of this research which aims to find mitigation solutions for UHI at the city of scale of Beirut as opposed to neighborhoods or individual buildings.
4.2.1.4 Solene. SOLENE is a modeling software which is used to simulate solar, luminous and thermal radiation parameters for urban and architectural spaces. It was developed by CERMA (Center for Methodological Research in Architecture) in Nantes in France and facilitates the evaluation of climatic designs in urban and architectural projects whereby simulations of the microclimatic solar fittings of buildings and other urban forms for example can be conducted (www.cerma.archi.fr/). SOLENE is therefore capable of simulating the influence of various choices of urban designs and urban architectural projects on the microclimate at the micro-scale or neighborhood scale and can accordingly provide some solutions to building designs and urban forms that can have least impacts on the microclimate.

According to Groleau, Fragnaud, and Rosant (2003), SOLENE is based on a 3D modeling scheme and takes into account the interactions between urban form and its environmental dimensions including the climate by correlating geometric data of urban form (such as layout, density, street orientations, type of building…) with the physical properties of the built environment (roughness length, sky view factor, solar radiation). The application of SOLENE is varied and can be used for example to assess the temperature of surface walls and outdoor comfort levels, air temperatures 1.5m above ground and surface temperatures. Two factors not taken into account by SOLENE include anthropogenic heat and the latent heat flux (Ringenbach, 2004). Figure 13 shows the outputs of SOLENE with simulations for surfaces temperatures and solar flux calculated at building surfaces, trees and on the ground. This therefore assists in drawing urban designs and building designs that have low or nominal impacts on the microclimate with respect and is therefore a useful modeling tool for micro-scale projects.
In a study conducted by Bozonnet et al. (2013), the UHI phenomenon and its effects on energy demand at the building scale were assessed. SOLENE modeling scheme was selected whereby the model’s capabilities, in a coupled approach, were investigated. In this study therefore, SOLENE was used to investigate the impact of trees and natural soil against the impact of the mineral environment on buildings’ energy demand in the city of Lyon in France. It was accordingly found that the coupling procedures for SOLENE had a weak but non-negligible impact on the energy consumption assessment of buildings. This is an important factor when designing buildings as energy demand and associated gas emissions from air conditioning use and heating use can potentially contribute significantly to the heat island effect. Therefore, SOLENE has been used in mainly the architectural domain to design buildings with least impact on the microclimate but it is used for micro-scale or local scale studies and is therefore not feasible for the purpose of this research for Beirut.
Therefore, all four micro-scale and local-scale modeling schemes discussed above are deemed unsuitable for the purpose of this research which aims to analyze UHI effects at the city-scale of Beirut in order to propose recommendations and mitigation strategies from an urban planning point of view. Having said this more details regarding the selection of most suitable modeling scheme for the Beirut case can be found in Chapter 6 of this thesis.

4.2.2 Mescoscale modeling schemes. In this section of the literature review, two models which are typically used to conduct simulations at the mescoscale or city-scale are discussed namely the Town Energy Balance (TEB) and the Finite Volume Module (FVM). The mechanisms by which these two modeling schemes function are therefore discussed and compared in the view to determine the most suitable modeling scheme for UHI simulations for the Beirut case.

4.2.2.1 Town Energy Balance (TEB). Due to the extensive literature on the Town Energy Balance (TEB), this section is divided into the following sections: 1) the first section gives an introduction to TEB and the various hypothesis the modeling scheme is built upon; 2) the second section discusses the mechanism by which this scheme fundamentally functions; 3) the third section gives an outline of the vegetation (veg) scheme which was recently integrated into TEB and discusses the associated advantages of this new approach, and; 4) the fourth and last section discusses the new Building Energy Model (BEM) which was also recently integrated into the TEB scheme and gives an account of the various advantages associated with this new option for this model.
Introduction to TEB

The Town Energy Balance (TEB) model was developed by Masson (2000) at Centre National De Recherches Météorologiques (CNRM) at Météo-France in Toulouse, France and is used to parameterize town-atmosphere dynamic and thermodynamic interactions. It is included in the SURFEX land-surface modeling system (www.cnrm.meteo.fr/surfex), which means “surface externalisée” and is a code that represents the energy exchange processes that occur between the atmosphere and the urban surfaces. SURFEX is “externalized” which means that the code can be used inside a meteorological or climate model or in a stand-alone (offline) mode. SURFEX is divided into 4 main tiles including NATURE, WATER, SEA and TOWN, which are all treated by different models whereby the town tile is represented by the Town Energy Balance (TEB) model while the vegetation tile is represented by the Integration with Soil Biosphere and Atmosphere (ISBA) model (see Figure 14).

![Figure 14. Representation of surface fluxes. Source: Colombert, 2008](image)

TEB is built following the canyon approach and is applicable for mesoscale atmospheric models (a grid mesh larger than a few hundred meters). It simulates the turbulent fluxes into the atmosphere at the surface of a mesoscale atmospheric model by treating the urban area as a series of urban canyons whereby each grid mesh is considered
to be comprised of a single road bordered by facing buildings. It should be noted that TEB requires spatial averaging of town characteristics as well as its effect on the atmosphere. As such, individual shapes of each building are not taken into account, and in this way it is based on the canyon geometry approach. Therefore TEB incorporates canyon geometry with three typical surfaces – roof, road, and wall – in order to reproduce the effects produced by buildings and is a single-layer urban canopy model where there is direct interaction between one atmospheric layer above the uppermost roof layer.

TEB is “forced” with atmospheric data and radiation recorded above roof level and incorporates detailed representation of the urban surface (canyon geometry) to simulate energy balances for each of the three surfaces including roofs, roads and walls. “Force” is the terminology used in SURFEX to describe the climatic conditions that are prominent in the city, including for example temperature, and wind, and that are accordingly used to carry out the simulations. TEB therefore considers the following hypotheses for city representation:

- The buildings have the same height and width (in the model mesh), with the roof level at the surface of the atmospheric model;
- Buildings are located along identical roads, the length of which is considered far greater than their width; the space contained between two facing buildings is defined as a canyon;
- Any road orientation is possible and all exist with the same probability. This hypothesis allows the computation of averaged forcing for road and wall surfaces.

These hypotheses therefore allow for the development of a relatively simple scheme but which still allow for most of the physical effects associated with the urban
energy balance to be reproduced. The advantage of such a simple scheme for the Beirut case for example is that since the available data on urban form is limited, the dominating urban characteristics (including urban form and material composition) for roads, rooftops and wall surfaces can be considered in the numerical analysis process. This also includes dominating building height and street orientations. However, this can cause a small margin of error in the analysis since if there are for example a total of 20 buildings within a grid mesh for Beirut and 7 out of these 20 buildings are taller than the rest, their respective impact on UHI will not be precisely considered in the simulations. In this case the trend in urban form is taken into consideration in TEB as opposed to individual building specifications.

**TEB Mechanism**

Fundamental to the mechanism by which TEB functions therefore is the concept of the urban surface energy balance (see Figure 15) as defined by Oke (1987) (see Equation 6 in Chapter 3), which is applied in TEB to an entire urban area. The TEB scheme therefore computes the surface energy budget for each of the roofs, roads and walls surfaces treating each grid mesh as an urban canyon comprised of a street, walls and roofs (Lemonsu and Masson 2002; Lemonsu, et al., 2004; Masson, et al., 2002). In Figure 15 it is seen that the roofs, roads and walls are represented in terms of four layers as presented by subscripts \( R, r, \) and \( w \) for roofs, roads and walls respectively and by this TEB takes into account the process of heat conduction into these artificial materials. Regarding surface temperatures, the model does not use one urban surface temperature but rather three surface temperatures representative of roofs, roads and walls \((T_R, T_r, T_w)\) hence it uses a complex surface consisting of multiple explicit energy budgets. In this
figure it is also seen that the model is forced with a temperature \( (T_a) \), humidity \( (q_a) \), and wind speed \( (U_a) \) measured in the inertial sub-layer. The rooftop level is the surface of the atmospheric model so the TEB computed sensible heat flux \( (Q_H) \) for the urban canopy is assigned at the base of the first atmospheric grid box. The aerodynamic resistances are also represented by the thick lines in Figure 15 and include the aerodynamic road resistance \( (R_r) \), aerodynamic roof resistance \( (R_R) \), and aerodynamic wall resistance \( (R_w) \). Therefore based on the surface energy balance of Oke (1987) the surface energy budget of each of the roof, road and wall surfaces in a grid mesh representing an urban canyon are computed.

Thus TEB takes into account the processes that influence mainly the urban-atmosphere energy exchanges in which the urban or town part is defined by roads, roofs and wall surfaces. It carries out fast numerical simulations for large urban areas and does not require reproduction of each building with the exact specifications of either geometry or orientations. The city is divided into grid meshes of identical dimensions each defined by three geometric parameters including dominating width and height of the buildings and width of the streets that are kept constant within each grid box of the model with identical street orientations. The approach is relatively simple but still allows most of the physical effects associated with urban energy balance to be reproduced, including long-wave and shortwave radiative trapping, the momentum flux, the turbulent sensible and latent heat fluxes, and heat storage uptake and release. Anthropogenic heat fluxes due to traffic and industry are also considered in TEB but it is worth noting that anthropogenic heat flux is not prescribed in the analyses since the objective of this research is make
recommendations for the urban planning of the city and not anthropogenic heat emissions.

Figure 15. Schematic representation of surfaces (roof, wall, road indicated by subscript R, w, and r, respectively), prognostic temperatures (T) and aerodynamic resistances (R) used in TEB and the output fluxes. Resistances are shown with thick lines. Source: Masson et al., 2002, pp.1015

**TEB-Veg**

The TEB model was recently improved to include vegetation directly inside the canyon. According to Lemonsu, Masson, Shashua-Bar, Erell, and Perlmutter (2012), this new version of TEB with integrated vegetation, including ground-based vegetation inside the canyons such as private gardens and backyards as well as trees inside the streets and green roofs and walls, performs better than if vegetation is treated outside the canyon. This is mainly because it allows for shadowing of grass by buildings; it provides a better representation of urban canopy form and gives a more accurate simulation of the canyon
air microclimate. Before vegetation was integrated directly into TEB and in the presence of vegetation in the canyons, SURFEX was run with TEB and ISBA models. This latter design however was found to present some problems since vegetation was considered an open area not subject to the shadow effect of buildings and to radiation trapping within the canyon. In addition, the canyons were assumed to be narrower than they were in reality as the vegetation was placed outside the canyon hence unrealistic geometric parameters were prescribed for TEB (for more detailed discussions refer to Lemonsu et al., 2012). Figure 16 presents the comparison of tiling approaches in TEB-ISBA (top) and TEB_Veg (bottom) to compute surface fluxes and as can be seen the TEB_Veg approach considers the buildings, roads and gardens fractions all within the TEB tile. With respect to the functional processes, TEB_Veg model does not require implementation of new mechanisms but needs only adjustment of descriptive parameters such as the leaf area index (LAI) or tree height.
Therefore, SURFEX tile dedicated to urban covers is now associated to the TEB_Veg model and includes short-wave and long-wave radiation calculations inside the canyon that take into account the shadow effects and multiple reflections of buildings. The contribution of gardens takes place through the long-wave emission received by roads and walls (for other calculations refer to Lemonsu et al., 2012). Figure 17 represents the new modeling approach that leads to a new architecture of the code.

Within the context of Beirut, the consideration of urban vegetation and their respective impact on UHI is necessary because this would potentially be an important mitigation strategy for the city, especially when considering that Beirut is predominantly covered by artificial surfaces as opposed to natural surfaces (see Chapter 5 for land cover land uses in Beirut). The existing urban vegetation of Beirut city and their impact on UHI
could also be analyzed and compared to areas without any vegetative surfaces within the context of this research. This new integrated version of TEB_Veg is therefore deemed very useful for the purpose of this research.

Figure 17. Diagram describing the inclusion of urban vegetation in the TEB’s code within the tiling approach of SURFEX. Source: Lemonsu et al, 2012, pp. 1380
**Building Energy Model.**

The energy consumption of heating, ventilation and air-conditioning (HVAC) systems in buildings has become an important factor in the design and analysis of urban areas (Bueno, Pigeon, Norford, Zibouche, and Marchadier, 2012). As such, a new building energy model (BEM) was recently integrated into the TEB scheme. Given the increased use of air conditioning systems as a consequence of global-scale and urban-scale climate warming, the integration of the BEM scheme into TEB is considered to be very beneficial as it can help determine and identify those urban geometric and radiative characteristics that result in highest energy demands. Thus, BEM-TEB makes it possible to represent the energy effects of buildings and building systems on the urban climate to estimate the building energy consumption at the city scale with a resolution of a neighborhood (~100m). This approach for TEB was based on an improvement of previous models developed to integrate new building energy models in urban canopy models which are essentially able to capture the mean heat transfer processes that occur inside buildings thus calculating building energy demand, HVAC energy consumption and waste heat emissions (Kikegawa, Genchi, Yoshikado and Kondo, 2003; Salamanca et al., 2010, cited in Bueno et al., 2012). According to Bueno et al., (2012), previous models considered idealized HVAC systems not taking into account passive building systems. The new BEM-TEB model that has been developed overcomes the limitations of these previous models. As such, BEM uses a heat balance method to calculate indoor thermal conditions and building energy demand and accounts for solar radiation through windows, heat conduction through the building enclosure, internal heat gains, infiltration and ventilation. An energy balance is thus applied to each indoor surface including wall,
window, floor, roof and internal mass, accounting for conduction, convection and radiation heat components.

The same geometric principles applied in TEB are also used by BEM and these include firstly a homogenous urban morphology, where the building enclosure is defined by an average-oriented façade and a flat roof; and second a glazing ratio where BEM assumes that all building facades have the same fraction of glazed surface with respect to their total surface.

In addition, buildings in BEM are assumed to be in a single thermal zone where all buildings in a particular urban area have the same indoor air temperature and humidity thus calculating the overall energy consumption of a building or neighborhood as opposed to a building zone. BEM also assumes an internal thermal mass which represents the thermal inertia of the construction materials inside a building such as the separation between building levels. Finally, BEM assumes that the surface of the building in contact with the ground is well-insulated (see Figure 18 which represents the main physical processes included in BEM-TEB).

Within the context of UHI analysis in Beirut therefore, the TEB-BEM is potentially very useful for assessment of the diurnal energy demand of buildings in the city since heat emissions from HVAC systems can indirectly impact the UHI. This option for BEM could also be useful for example for simulation of future scenarios for a specific mitigation strategy, like urban greening, being considered for Beirut city. It is therefore a good indicator of whether the selected mitigation scenario has a cooling effect on the city or not.
Conclusions

TEB has been validated in several measurement campaigns (Lemonsu and Masson, 2002; Lemonsu et al., 2004; Masson et al., 2002) and investigations are continuously underway to improve the model by taking into consideration other relevant urban parameters characterizing a typical town or city. It is worth noting that TEB is being used widely in the field of urban climatology modeling and is even now incorporated in the French operational Numerical Weather Prediction (NWP) model (www.cnrm.meteo.fr/). Compared to the other models thus far, TEB is the most suitable modeling scheme for the Beirut case because it is a simplified model that considers the
dominant thermal and radiative properties for urban surface parameters in its simulations within a grid cell and does not require detailed data (as in the case for the Finite Volume Model which is discussed in the subsequent section), and second because it takes into consideration surface-atmospheric energy exchanges at the city scale and not micro-scale or local-scale (see Chapter 6 of this thesis for more details on the elimination and accordingly selection process for TEB for the Beirut context).

4.2.2.2 Finite Volume Model. Martilli, Clappier, and Rotach (2002) developed an atmospheric modeling scheme that moved away from the traditional approach typically adopted in mesoscale models (which consist of modifying the roughness length at the surface and the thermal properties of the ground) since they failed to reproduce the vertical structure of the turbulent momentum fluxes and the urban heat island effects. According to Martilli, et al. (2002) these failures are due mainly to the fact that the shadowing and radiation effects of buildings are neglected. Another reason is attributed to the fact that the only sink of momentum is at the ground and is not distributed up to the higher buildings. Martilli accordingly developed a new model that corrected these failures capable of representing the impact of urban buildings on airflow at the mesoscale (see Martilli et al., 2002 for a complete description of the model). The model is referred to as the Finite Volume Model (FVM) and represents the city as at least one urban class that is characterized by the following parameters (Roulet, 2004):

- Shape of the street canyon, expressed in terms of the distance between building rows, and shape of the buildings, expressed in terms of roof width and wall height (see Figure 19)
• Building height distribution, expressed in terms of the probability $\gamma$ of having buildings with a certain height $z$ and a density $\Gamma$ of buildings higher than given values of $z$ (see Figure 19); $\gamma$ and $\Gamma$ are linked by the following equation:

$$\Gamma(z_{iu}) = \sum_{j_u=i_u} \gamma(z_{ju})$$

(Equation 8)

Where $nu$ is the highest level in the urban grid.

• Street orientation (several orientations per class are possible)

• Properties of the materials (thermal diffusivity, heat capacity, albedo, and emissivity for the three urban element types, i.e., street, wall, and roof.

Figure 19. Illustration of the numerical grid in the urban module and the geometrical urban parameters: street canyon width (WS), building width (WB), $iu$ are the face and IU the center of the urban model levels and building height distribution in terms of $\gamma$ and $\Gamma$. Source. Martilli, et al. 2002, pp. 267

The module therefore calculates turbulent fluxes and meteorological scalars for any given street direction while allowing for the specified building height distribution, and then averages over all defined street directions. This urban parameterization scheme is implemented as a sub-grid of the mesoscale grid in the FVM mesoscale model. The horizontal resolution is identical with the resolution of the mesoscale grid, while the vertical resolution must be finer than the mesoscale resolution and is usually selected to
be of the order of 2 to 5 meters (the sub-grid extends vertically only up to the highest building). After their calculation in the urban grid, the fluxes and meteorological variables must then be vertically interpolated in the mesoscale grid (Roulet, 2004).

According to the available literature the TEB and FVM appear to be similar in their modeling approach although the TEB model is described as a single layer urban canopy model as opposed to the FVM which is described as a multi-layer urban canopy model. In a paper by Masson (2006) which compares the various different modeling schemes that have been developed for study of urban energy surface-atmosphere exchange processes, he recommends using single-layer urban canopy models for the surface energy balance (SEB), such as the Town Energy Balance (TEB) scheme of Masson (2000), where there is direct interaction with one atmospheric layer above the uppermost roof layer but recommends using multi-layer models, such as the FVM developed by Martilli, et al. (2002), for more specific analysis objectives such as the impact and feedback between canyon air and air-condition (see Figure 20). Hidalgo et al. (2008) explain the workings of the FVM modeling scheme as the “buildings of different height” approach since all building heights must be identified within a grid cell (see Figure 19).

Therefore, due to the higher complexity involved in the FVM scheme, which requires more detailed urban data values (like for the case of determination of each building height within a grid cell), the TEB scheme is perceived to be the more feasible of the two mesoscale models discussed thus far for the Beirut case especially when considering the limited data available for buildings as well as general associated data on urban form in Beirut (see Chapter 6 of this thesis for more details).
4.2.3 Other modeling schemes: mesoscale and macroscale. This section of the literature review gives an outline of three other modeling schemes mentioned in the available literature. One of these is developed by Kusaka, Kondo, Kikegawa, and Kimura (2001) and is in fact an urban canopy model similar to that developed by Masson (2000) and is also used for meso-scale studies. In their paper, Kusaka et al. (2001) introduce this simple single-layer urban canopy model for use in atmospheric models and compare it to two sets of observations concentrating mainly on air temperatures and net longwave radiation in Vancouver, British Colombia. While both Kusaka et al. (2001) and Masson (2006) mention the similarities of their two models, the differences are also explicitly defined. Kusaka et al. (2001) explains that as opposed to Masson’s model, his model includes the canyon orientation and diurnal change of solar azimuth angle, and the surface consists of several canyons with different orientations whereas Masson’s urban canopy model is based on only one single orientation. Kusaka’s model also uses several

Figure 20. Schematic view of multi-layer urban surface schemes: the interactions between the surface scheme and the atmosphere are drawn in thick-dashed lines. Source: Masson, 2006, pp. 40
canyons which are all treated differently making the modeling scheme more complex than Masson’s TEB scheme.

Another numerical modeling scheme mentioned in the existing literature is the numerical multi-layer canopy layer developed by Ca, Asaeda, and Ashie (1999) which is also used for meso-scale studies. It exhibits workings similar to that of Martilli’s multi-layer urban canopy model although according to Masson (2006), Ca’s model more accurately takes into account the volume occupied by buildings.

The Soil Vegetation Transfer Scheme (SVTS) is another modeling scheme that has been developed for climatic studies but it is used for much larger scale studies at the macro level or global scale. SVTS is in fact a numerical model adapted to take into account the specific effects of urban surfaces on the exchanges of momentum. Therefore for large scale global climatic simulations, Masson (2006) recommends application of existing vegetation schemes, like the SVAT, that would have to be adapted to take into account the specific effects of urban surfaces on the exchanges of momentum such as roughness length, albedo of individual surfaces, water via evaporation, heat via conduction, radiation and convection, and anthropogenic heat fluxes. Modification of such parameters would be necessary since urban areas behave very differently to vegetation schemes with their natural environments.
4.2.4 Summary. As can be seen from the above literature review on the existing urban surface exchange models therefore, most of these modeling schemes are based in one form or another on the surface energy–atmosphere balance equation, with some variations as to the specific urban parameters that are considered in the models simulations such as anthropogenic heat, street orientations, building heights, wind velocity, and so on. Another main difference lies in their scale of use, where some are used at the building or neighborhood scales while others are used for city scale or even global scale climatic simulations.

Based on this literature review therefore, the most suitable choice for the UHI modeling scheme for Beirut was found to be the TEB model since it is the most adequate model for analyzing UHI in large scale studies. In addition, TEB does not require data for individual buildings which is advantageous within the context of this research since data of this sort is limited in Beirut (see Chapter 6). Table 6 is a summary of the various urban surface exchange modeling schemes described above.
<table>
<thead>
<tr>
<th>Urban surface exchange modeling schemes</th>
<th>Characteristic / type of modeling scheme</th>
<th>Specific features of modeling scheme</th>
<th>Reference</th>
</tr>
</thead>
</table>
| NARP-LUMPS (Net All-Wave Radiation Parameterization / Local-scale Urban Meteorological Pre-processing Scheme) | Statistical model | - For small scale local studies  
- It is an urban meteorological parameterization scheme  
- This model is adequate if observational field data are sufficient and well understood  
- Needs very few inputs  
- Computation is very efficient  
- Main weakness: only valid in the range of conditions observed in the field | Grimmond and Oke, 2002  
Hidalgo et al, 2008  
Masson, 2006 |
| SM2-U | “Bulk” model or simple model (as opposed to a “canopy” model) | - This model carries out simulations at the micro-scale  
- It represents an urban fragment extending from the street scale to a district composed of different types of surfaces including buildings, soil and vegetation with explicitly defined urban geometric parameters and relative positioning | Bozonnet et al, 2013  
www.ec-nantes.fr  
Mestayer, et al, 2004 |
| ENVI-met | Three-dimensional numerical microclimate model | - Simulates the surface-plant-air interactions in urban environment with a typical resolution of 0.5 m in space and 10 sec in time therefore it is applied for micro-scale projects  
- It requires few input data parameters  
- It has the ability to reproduce major processes in the atmosphere that affect the microclimate  
- It has high spatial and temporal resolution | www.envi-met.com  
Ali-Toudert and Mayer, 2006  
Bruse, 2004  
Emmauel & Fernando, 2007  
Yu and Hien, 2006  
Bozonnet et al, 2013  
Huttner and Bruse, 2009 |
<table>
<thead>
<tr>
<th>Model Name</th>
<th>Model Description</th>
<th>Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Vegetation Transfer Scheme</td>
<td>Numerical model adapted to take into account the specific effects of urban surfaces on the exchanges of momentum</td>
<td>Applied for global climatic simulations</td>
</tr>
<tr>
<td>(SVTS)</td>
<td></td>
<td>Ozkeresteci, et al, 2003</td>
</tr>
<tr>
<td>Town Energy Balance (TEB)</td>
<td>Single layer urban canopy numerical model for the surface energy balance (SEB)</td>
<td>Carries out simulations at the meso-scale for assessment of the influence of cities urban characteristics on the urban microclimate</td>
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<td></td>
<td>Considers one canopy layer characterized by a simplified urban fabric</td>
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<td>There is direct interaction with one atmospheric layer above the uppermost roof layer</td>
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<td>Masson 2006</td>
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<td>Bozonnet et al, 2013</td>
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<td>Lemonsu &amp; Masson, 2002</td>
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<td>Urban canopy model</td>
<td>Single layer urban canopy model</td>
<td>Used for meso-scale studies</td>
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<td>Column model of energy and momentum exchange between an urban surface and atmosphere</td>
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<td>It includes the influence of street canyons</td>
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<td>It includes shadowing from buildings and reflection of radiation</td>
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<td>It estimates both the surface temperatures of and heat fluxes from roof, wall and road</td>
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<td>Although very similar to TEB, this model includes the canyon orientation and diurnal change of solar azimuth angle</td>
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<td>The surface consists of several canyons with</td>
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<td>Model Description</td>
<td>Features</td>
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<tr>
<td>Finite Volume Model (FVM)</td>
<td>Multi-layer urban canopy numerical model</td>
<td>- Carries out simulations at the mesoscale</td>
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<td>- Applied for more specific analysis objectives such as the impact and feedback between canyon air and air conditioning</td>
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<td>- This model uses the “buildings of different height” approach”</td>
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<td>Numerical model</td>
<td>Multi-layer urban canopy numerical model</td>
<td>- Carries out simulations at the mesoscale</td>
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<td>- Accurately takes into account the volume occupied by buildings</td>
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<td>SOLENE</td>
<td>Three-dimensional thermo-radiation model</td>
<td>- Carries out simulations at the micro-scale</td>
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<td>- Analyzes interactions between urban form and environmental dimensions and climate by correlating geometric data of urban form with physical properties of space structure like roughness, sky view factor, and sun exposure</td>
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4.3 Mitigation Strategies to Combat Urban Heat Island

The available literature on measures and schemes to mitigate or minimize the impacts of UHI is exhaustive as plenty of work and research has been carried out in this regard in densely populated cities worldwide. While this aspect of the literature review does not attempt to cover all the existing literature on this topic, it does provide a classification of these measures into three main categories commonly implemented and practiced and gives examples of successful results and researches conducted based on these respective categories of mitigation measures. These categories include 1) implementation of urban vegetation; 2) implementation of cool surfaces; and 3) implementation of both urban vegetation and cool surfaces. Figure 21 presents these three aforementioned UHI mitigation strategies showing the associated processes that are accordingly affected as well as the results on the overall urban environment and quality of life.

![Figure 21. Methodology for energy and air quality. Source: Akbari, 2005, pp. 13](image-url)
Therefore, cool roofs and pavings and vegetation all help to cool urban spaces. A fourth and more recent category for mitigation of the UHI includes pavement-watering although this has not been investigated or referred to in the available literature to the same extent as the three aforementioned mitigation measures. All 4 mitigation measures are therefore discussed in more detail below:

4.3.1 Planting of urban vegetation. Planting of urban vegetation: the benefits of urban trees can be divided into direct and indirect effects: a) shading of buildings, and; b) ambient cooling. Shade trees intercept sunlight before it is able to warm a building and urban forests cool the air by evapotranspiration (Akbari, et al., 2001). Wind speed is also decreased under the tree canopy of shade trees which are also able to shield buildings from cold winter breezes. The energy demand for air-conditioning use is also reduced by urban shade trees, air temperatures are lowered and the overall urban air quality is improved by reducing smog. On the other hand, trees planted along streets and in parks where they do not offer direct shade to air conditioning buildings exert an ambient cooling effect sufficient to have a substantial impact on smog formation (Gartland, 2008). Green roofs have also been shown to have significant mitigating effects on urban heat islands. In a study on the effect of rooftop gardens on energy consumption of a building in Singapore, Wong et al. (2003) were able to show the major difference in surface temperatures of surfaces with and without vegetation (Figure 22). This is therefore an important mitigation scenario for the UHI in Beirut. (see also Chapter 2 literature review of this thesis for more details on urban vegetation and their role in cooling surrounding urban environments). Table 7 gives examples of successful implementation of this mitigation measure.
4.3.2 Implementing cool surfaces. Implementing cool surfaces (including rooftops and pavements); implementation of “cool roofs” or roofing surfaces with high solar reflectivity (like white coated roofs), has resulted in very low differences between the surface and ambient air temperatures, only up to about 10°C. On the other hand, for dark roofs which are highly absorptive and which have low albedo properties, the difference between the surface and ambient air temperatures may be as high as 50°C. At the building scale, a dark roof is heated by the incoming solar radiation which directly raises the summertime cooling demand of the building beneath it. However, cool surfaces are capable of reducing the summertime cooling energy use of the buildings (Akbari, et al., 2001; Akbari, 2005). Cool pavements also have the advantage of lowering urban heat islands because more of the incoming light is reflected back into space resulting in cooler surfaces and ambient temperatures. In contrast, dark pavements (typically asphaltered) increase heating of the city by sunlight because a dark surface absorbs a lot of the incoming solar radiation thus getting warmer. The pavements then heat the ambient air
temperature and help create the urban heat island. Figure 23 shows the temperature differences 1.5m above the ground between dark asphalted pavings and cooler granite pavings. This UHI mitigating scenario is therefore considered to be an advantageous one for Beirut (see also Chapter 2 literature review part of this thesis for more details on albedo and solar reflectively of urban materials). Table 7 gives examples of successful implementation of this mitigation measure.

![Figure 23. Comparison of environmental conditions at 1.5m above the ground on a typically summer day with two ground surface materials. Source: Akbari, 2014](image)

### 4.3.3 Combination of urban vegetation planting and cool surfaces implementation.

A combination of urban vegetation planting and implementation of “cooler surfaces” with higher solar reflective properties (or albedo) have been shown to have more beneficial effects in lowering UHI effects at the city scale as well as lowering the energy cooling load of buildings and improving the overall quality of life of urban dwellers (see Table 7).

**4.3.4 Pavement watering.** Pavement-watering has been studied since the 1990s and is currently considered to be a promising tool for urban heat island reduction and climate change adaptation. Indeed a recent study in the city of Paris showed that application of this specific technique reduced street surface temperatures by several
degrees further to analyses carried out using infrared camera measurements which therefore had positive effects on pedestrian comfort (Hendel, et al, 2014). In Japan, this method for cooling of urban spaces has been studied since the 1990s and has also shown overall positive effects (Kinouchi & Kanda, 1998). Having said this it is worth noting that future water resource availability must be considered and accordingly optimized should this strategy be selected as a suitable UHI mitigation measure (Hendel, et al, 2014). The cooling effect is attributed to the transpiration process of water which helps to release the trapped heat in asphalted pavements (especially during periods of intense incoming solar radiation) which is the type of material typically used for pavements in Beirut for example. For the case of Beirut, given the widespread awareness for more sustainable use of water resources as a result of the water deficit across the country (MOE/LEDO/ECODIT, 2001; CDR. NPMPLT /DAR-IAURIF, 2004)\textsuperscript{17}, this scenario is not suitable for the Beirut context\textsuperscript{18}.

\textbf{4.3.5 Summary.} Hence, these aforementioned mitigation strategies not only improve the thermal comfort levels of urban dwellers, but also reduce energy demand levels thus also minimizing air polluting emissions or anthropogenic heat and therefore also indirectly lower impacts on the UHI effect of a city. For the case of Beirut, implementation of these mitigation strategies may have significant impacts in reducing urban canyon temperatures and cooling energy loads of buildings. As such, except for the

\textsuperscript{17} The average annual volume of water input in Lebanon via rainfall and snowfall amounts to \(\sim 9,300 Mm^3\) and the losses which occur via evapo-transpiration, surface flow in streams, and groundwater (with losses outside the national boundaries into the sea and to neighboring countries, and un-exploitable groundwater and sea-springs) leaves \(\sim 1,830 Mm^3\) or only 20\% of the incoming water volume (CDR. NPMPLT /DAR-IAURIF, 2004).

\textsuperscript{18} It could be argued that the planting of urban vegetation scenario previously discussed also essentially requires water intake which would therefore not be a sustainable strategy for Beirut. However the existing urban tree types in Beirut (namely \textit{ficus nitida} and \textit{pinus pinea}), which would also be proposed in future planting strategies for the city should this be found to be a suitable mitigation scenario for the city (see Chapter 7), do not require high water intakes per day (see Chapter 6 for details on existing vegetation).
pavement watering scenario, this research considers the aforementioned mitigation measures in scenarios devised specifically for the purpose of this research to find measures most suitable for alleviation of UHI of Beirut city from an urban planning and design perspective (see Chapter 7 of this thesis).

Table 7 gives examples of case studies worldwide that involve implementation of one or more of the aforementioned UHI mitigation measures and with successful results.
<table>
<thead>
<tr>
<th>Category of mitigation measure</th>
<th>Location of case study</th>
<th>Brief description of successful case study</th>
<th>References</th>
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<tbody>
<tr>
<td>Planting of urban vegetation and/or green roofs</td>
<td>Lisbon, Portugal</td>
<td>This paper analyzes the thermal performance of a small green space (0.24 ha) and its influence on the surrounding environment of a densely urbanized area in Lisbon. It was found that the garden was cooler than the surrounding areas, either in the sun or in the shade. These differences were higher in hotter days. Besides the local weather conditions, the low wind speed, the sun exposure and the urban geometry are the potential factors that explain these differences. It was concluded that green spaces in urban areas can therefore create a cooling effect which is more pronounced in cities with UHI and during hot and dry days in cities with a Mediterranean climate.</td>
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<td>Oliveira, Andrade, and Vaz, 2011</td>
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<td>Singapore</td>
<td>This research discusses a mobile survey (via vehicles equipped with observation tubes consisting of temperature and datalogger) which was conducted to explore both the severity of UHI and cooling impacts of green areas in Singapore. Highest temperatures were measured in industrial areas and the airport which have less green areas compared with other land uses. Lowest temperatures were detectable in residential areas with more greenery indicating that within developments plants can cool the surroundings and generate lower ambient temperature. The study indicated the presence of UHI effect in Singapore with a maximum difference of 4.01°C between planted areas and the central business district area and confirmed the cooling effect of green areas in Singapore.</td>
<td>Wong and Yu, 2005</td>
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<td>Location</td>
<td>Description</td>
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<td>Singapore</td>
<td>This study carried out simulations to determine the effects of rooftop garden on the annual energy consumption and cooling load of a five-story hypothetical commercial building in Singapore. In these simulations, three different types of roof (exposed roof, typical flat roof, roof with rooftop garden) were simulated and the effects of the rooftop garden with different types of vegetation and the variation in thickness of soil were also considered. The study accordingly showed that the installation of rooftop garden in a five-storey commercial building could result in a saving of 1-15% in the annual consumption and 17-79% in the space cooling load. The optimum type of rooftop garden was found to be rooftop garden with shrubs (300mm thick soil and shrubs) could achieve a saving of 15% in the annual energy consumption and 79% in the space cooling load. This type of rooftop could achieve a saving of 3% in the annual energy consumption and 64% in the space cooling load.</td>
<td>Wong, et al., 2003</td>
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<td>Athens, Greece</td>
<td>Application of 4,500 m² of reflective pavements in an urban park in the greater Athens area. The aim was to improve thermal comfort conditions, reduce the intensity of heat island, and improve the global environmental quality in the considered area. It is concluded that the use of reflective paving materials is a very efficient mitigation technique to improve thermal conditions in urban areas.</td>
<td>Santamouris, et al., 2012</td>
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<td>Not specific to any one city or case study</td>
<td>This paper is a review aiming to present the actual state of the art on the development and assessment of cool materials for buildings and urban structures. Four categories of cool materials are assessed: 1) highly reflective and emissive light coloured materials; 2) cool coloured materials; 3) phase change materials; and, 4) dynamic cool materials. It is concluded that the wide use of cool materials can contribute significantly to the mitigation of the heat island effect and improvement of urban environmental quality.</td>
<td>Santamouris, Synnefa, and Karlessi, 2011</td>
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<td>Not specific</td>
<td>This paper presents the results of a comparative study aiming to investigate the suitability of paving materials to lower heat island effect. The study involved 93 commonly used paving materials outdoors and was performed during the summer period in 2001. The study therefore contributes to the selection of the most appropriate materials for outdoor urban applications that can help to combat the UHI.</td>
<td>Doulous, Santamouris, and Livada, 2004</td>
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<td>Athens, Greece</td>
<td>A modeling study was undertaken to assess the urban heat island effect over Athens, a densely populated city, by trying to analyze the impacts of large-scale increase in the albedo of building rooftops on ambient temperatures. The study showed that adopting large-scale high albedo measures by using building materials with high solar reflectance can significantly reduce ambient temperatures. In addition, city-scale application of cool materials will result in a reduction in energy consumption by reducing both direct radiative heating of buildings and ambient temperature and will improve thermal comfort levels in outdoor spaces.</td>
<td>Syneffa, Dandou, Santamouris, and Tombrou, 2008</td>
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<td>Not specific</td>
<td>This paper quantifies the effect of increasing the albedo of urban areas on global warming. Although it focuses on global warming and not specifically the urban heat island, the concept remains valid also for mitigation of urban heating. The paper emphasizes that in many urban areas, pavements and roofs constitute over 60% of urban surfaces. As such, increasing the albedo of urban surfaces (including roofs and pavements) can reduce the summertime urban temperature and improve urban quality. The paper concludes that using cool roofs and cool pavements in urban areas, on an average, can increase the albedo of urban areas by 0.1.</td>
<td>Akbari, Menon, and Rosenfeld, 2008</td>
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Using cool roofing and/or cool paving materials

Sacramento, CA - This paper conducts a study for the city of Sacramento and shows that it is possible to raise the overall albedo of urban surfaces, namely roofs, accordingly producing significant energy savings and at the same time increasing comfort within the city. First the study shows that there is indeed potential to increase the overall albedo of roofing within the city by identifying that 20% of the 96 square miles area is dark roofing and 10% is dark pavement. Some programs that would support solar-reflect urban improvement are also identified in this paper such as labeling of paints and roofing materials according to their temperature in full sun; marketing programs and information materials to aid consumers in the selection of solar-reflective materials; low-coast loans for solar-reflective surfacing and so on. The paper concludes that the albedo of Sacramento city can be increased by 18% overall. Bretz, Akbari, and Rosenfeld, 1998

U.S. cities including Los Angeles, CA; San Ramon, CA - Data were collected and analyzed from two U.S. cities where cool surfaces and shade trees were implemented to reduce energy use and to improve air quality in urban parks. The study showed that cool surfaces (cool roofs and cool pavements) and urban trees can have a substantial effect on urban air temperature and hence can reduce cooling-energy use and smog. 20% of national cooling demand can be avoided through large-scale implementation of heat-island mitigation measures. Akbari, Pomerantz, and Taha, 2001

Implementation of urban vegetation, green roofs and cool materials

Los Angeles, CA - ‘Cool communities’ strategies were adopted for the city of L.A. which involved reroofing and repaving in lighter colours and planting shade trees that can effect substantial energy savings, both directly and indirectly. The analysis indicated that the L.A. heat island can be reduced by as much as 3Oc. Cooler roof and paving surfaces and 11 million trees which were planted should reduce ozone air pollution exceedence by 12% in L.A. and by slightly less in other smoggy cities. Rosenfeld, Akbari, Romm, and Pomerantz, 1998
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<th>Location</th>
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<th>Mitigation Measures</th>
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<td>Tehran, Iran</td>
<td>The densely populated city of Tehran is the area of concern; it is characterized by having high emissions of anthropogenic heat, low sky view factor, dominating concrete and asphalted surface areas which all play a significant role in exacerbating the UHI. For the mitigation of the UHI effect it is proposed to increase the albedo or solar reflectively of building materials, to place vegetation on buildings, to use green roofs and to also use cool roofs as these measures are seen to be the most effective solutions for lowering of UHI impacts.</td>
<td>Che-Ani, et al., 2009; Shahmohamadi, Che-Ani, Etessam, Maulud, and Tawil, 2011</td>
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<td>Not specific to any one city or case study</td>
<td>This study was carried out to review and summarize various mitigating measures that are applied through an investigation of the most important feature of UHI. It is found that the heat re-radiated by the urban structures plays the most important role. Mitigating measures are categorized as: 1) related to reducing anthropogenic heat release (e.g. by switching off air conditioners); 2) related to better roof design (e.g., green roofs, roof spray cooling, reflective roofs, etc.); 3) other design factors (e.g., humidification, increased albedo). It is also concluded that future research should be focused on design and planning parameters for reducing the effects of UHI.</td>
<td>Rizwan, Leung and Chunho, 2008</td>
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<tr>
<td>Not specific to any one city or case study</td>
<td>The study proposes that simple ways to cool the cities are the use of reflective surfaces (rooftops and pavements) and planting of urban vegetation and attempts to show it by illustrating case study examples in U.S. cities. On a large scale, evapotranspiration from vegetation and increased reflectin of incoming solar radiation by reflective surfaces will cool a community a few degrees in the summer. This study therefore suggests that heat island mitigation is an effective air pollution control strategy, more than paying for itself in cooling energy cost savings.</td>
<td>Akbari, 2005</td>
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This paper proposes to implement heat island mitigation strategies such as urban forestry, green roofs, and light surfaces for the city of New York. The paper therefore analyzes and models the UHI in New York city and tests the impacts of each of the aforementioned mitigation strategies on surface and near-surface temperatures in the city. It then evaluates the effects of the changes in land-surface cover in six case study area. The paper concludes that the mitigation strategies tested can reduce surface and near-surface air temperatures. Although street trees provide the greatest cooling potential per unit area, light surfaces provide the greatest overall cooling potential because there is more available area in which to implement this strategy compared to the other strategies.

An urban heat island pilot project was conducted for the Salt Lake City of Utah by the Lawrence Berkeley National Laboratory (LBNL) and U.S. Environmental Protection Agency (EPA). Thermal aerial photos were first taken to identify the main “hot spot” areas (or areas which generally correspond with urban developments). Surface cover data also helped scientists to indicate that Salt Lake City’s heat island can reach 4°C at night and about 2°C during the afternoon. The area extent of Salt Lake City’s heat island was also found to be greater in the afternoon compared to earlier in the day. LBNL concluded that Salt Lake City could increase their additional tree cover by approximately 13%. In addition, LBNL found that with 49% of the city’s surfaces being impermeable (roofs and pavement), there is a large potential for solar reflectance modification starting with the impermeable surfaces. Similar pilot projects were conducted for the cities of Chicago, Baton Rouge, Houston and Sacramento.
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<th>Location</th>
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<td>Paris, France</td>
<td>Street temperatures were investigated on Rue du Louvre in Paris, France during the summer of 2013. Watered and control weather stations were erected although only data from the watered site were studied. Surface temperature measurements were made using an infrared thermal camera which was placed on the roof terrace of Rue du Louvre, approximately 20m above street level. The pavement was watered over a total of 10 days during the summer. Pavement watering was found to reduce morning temperatures between 2-4°C and between 6-13°C for afternoon surface temperatures. Surface wetting is indeed found to decrease pavement albedo thus lowering reflected shortwave radiation which can otherwise negatively affect pedestrian comfort. However this approach is expected to increase air humidity caused by watering which may negatively affect pedestrian comfort. In all it was found that watering pavements helps reduce formation of UHI in Paris.</td>
<td>Hendel, et al., 2014</td>
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<td>Japan</td>
<td>In this study, the effect of watering on the road and the retention in porous pavement is investigated. Watering on the pavement is considered to produce significant urban cooling. Watering on the surfaces of pavements was conducted using watering pipes buried in the center of roadways. The field observation was accordingly conducted on August 13 from 9AM to 3PM for two sites, one within the area to be watered (site A) and the other about 30m away from this site (site B). Watering was conducted from 10AM to 2PM. Observations showed that the average temperature measured at Site B was higher than that at Site A during the time of the watering. For the experiment performed to see the effect of water retention in porous pavements it was found that during the period of watering which was supplied to the pavement once a day from 13 until 15 August, the maximum temperature decreased by 14-18°C. When there was no water supply after 15 August, the surface temperature rose again to around 55°C due to the reduced suction water in the porous pavement therefore highlighting the significant effect of watering on alleviation of surface porous pavement temperatures.</td>
<td>Kincouchi and Kanda, 1998</td>
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PART III: BEIRUT CASE STUDY
Part III of this thesis is comprised of one chapter and gives a detailed description of the case study area including its physical characteristics, climatic conditions, and urban populations. In addition, it gives an historic overview of urbanization and urban planning processes in Beirut, since these processes helped shape the urban morphology of Beirut as we know it today thus giving a clearer understanding of how the city has been planned and where planners, architects and engineers have channeled their main focus of attention for the development and growth of the city or lack thereof. The land cover and land uses are also outlined here, along with the city’s zoning scheme which has been adopted. The relevant legal framework is also discussed as well as the key players in the urban planning sector in Beirut. Finally, the dominating urban surfaces in Beirut and their respective solar properties are determined in this chapter.

The aim of this chapter is to identify the urban parameters of the city, based on the aforementioned assessment of the city’s urban characteristics, which contribute to the urban heat island effect thus raising the thermal discomfort levels of urban dwellers and accordingly lowering the overall quality of life. This chapter therefore justifies why there is a need to carry out measurements and modeling of the UHI in Beirut in the view to emphasize the importance of this phenomenon in Beirut and to accordingly propose mitigation strategies from an urban planning perspective.
Chapter 5: Beirut Case Study

5.1 Introduction

While the history of urbanization of the city of Beirut shows a marked expansion of the city from the 1800s to present day, there is no evidence showing that the environment, urban climate or the UHI for that matter were ever considered by architects, engineers or even urban planners while European cities like London and Stuttgart for example analyzed the climatic conditions of the study from as far back as 1818 and 1938 respectively in order to better understand the relationship between urban development and climate and to take action accordingly. This disregard for the UHI in Beirut/Lebanon could be attributed to the fact that major advances were made in the study of this phenomenon only recently and more specifically within the last three decades when the first publication of the International Journal of Climatology took place soon after its establishment in 1981 (Arnfield, 2003). The civil war could be regarded as another reason for this delay or disregard for such a significant urban climatic phenomenon where other more pressing issues like survival and safety were top on the list of priorities for the citizens of Beirut.

Urbanization, when not planned, controlled or managed in a sustainable manner, can contribute to shaping an urban morphology which can have exacerbating effects on the UHI phenomenon. This in turn can have serious implications on thermal comfort levels and human health leading even to mortality (Bozonnet et al., 2013; Chagnon, Kunkel & Reinke, 1996; Che-Ani et al., 2009; Dhainaut, Claeseens, Ginsburg, and Riou, 2003; Hartz, Golden, Sister, Chuang, and Brazel, 2012; Masson, 2006; Oliveira,
Andrade, and Vaz, 2011; Santamouris, Synnefa, & Karlessi, 2011; Colombert, Diab, Salagnac, and Morand, 2011).

The following sections therefore give an account of the history of urban planning of Beirut, as well as the physical, climatic and urban factors that characterize the city and that accordingly contribute to the exacerbation of the urban heat island phenomenon of Beirut.

5.2 Physical and Climatic Characteristics of Beirut City

5.2.1 Physical Characteristics. Beirut is a Mediterranean coastal city located at Latitude 33.8809° North and Longitude 35.5131° East. It has a triangular shape and sits on a peninsula that extends westward into the Mediterranean Sea. The city is relatively flat with two distinct hilly areas namely in Ashrafiyeh and Moussaytbeh where elevations reach their peak at approximately 95m above sea-level (ASL). There is one seasonal river that runs through a concrete channel along the eastern edge of the city’s administrative boundary known as Nahr19 Beirut (see Figure 24).

5.2.2 Climatic Conditions. Beirut’s geographical situation, in the Mediterranean coastal zone, determines its climatic conditions including temperature, precipitation, wind speed, wind direction and sun path. The average annual temperature in Beirut varies between 19.5 and 21.5 °C. January is the coldest month, with an average daily temperature of 17°C, while July and August are the warmest months of the year with daily averages reaching up to 33°C. The day and night temperature variations range between 6 to 8°C. In fact records from the Rafik Hariri Beirut International Airport (BIA) show an increase in summer maximum temperatures especially during the last decade where an intense warming appears to have taken place; an increase of 0.12°C per decade

19 “Nahr” means river in Arabic
is virtually certain to have occurred (>99% likelihood of occurrence) (Hatzaki, Giannakopoulos, Hadjinicolaou, & Kastopoulou; CIRCE project, 2010) (see Figure 25). Historical temperature records also show that there has been a marked increase in average minimum temperature (TMIN) and maximum temperature (TMAX) records during this past century and especially in TMIN records, which is a clear indication of the manifestation of the UHI.

Annual rainfall levels in Beirut vary between 700 to 1000mm and occur between the months of October and April. An increase in annual precipitation levels in Beirut has also been recorded from 1999 to 2011. The prevailing winds in Beirut travel in a southwesterly direction and annual average wind speeds are low ranging from 2 to 5 m/s. As for the sun path, since Beirut lies in the northern hemisphere, it is hit by the sun from the south. The north orientation receives no sun except in the very early and late hours of the winter season with 21 December being the most extreme case (see Appendix I for figures illustrating the prevailing climatic conditions for Beirut city). These climatic records are important factors to be considered in urban planning, and architecture and design especially when proposing a specific design or location for buildings as they can significantly affect their thermal performance.

Therefore weather conditions in the city are mild during the winter season but quite warm in the summer season, especially when considering the escalating number of hot days in the city. Wind speeds are also typically quite low in Beirut except during extreme situations. These natural climatic conditions of the city of Beirut play an important role on UHI and they are accordingly deliberated in the numerical analysis scheme of this research (see Chapter 6 of this thesis).
Figure 24 Map showing physical characteristics of the city of Beirut. Source: Directorate of Geographic Affairs, 25-30cm pixel, 2008
Figure 25. 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
5.3 Cadastral Districts of Beirut

Beirut city is made up of 12 cadastral districts covering an area of approximately 21.47 square kilometers and all fall under the administration of Beirut municipality. These cadastral areas include: Ain El-Mreisse; Ras Beirut; Zokak El Blat; Minet El Hosn; Ashrafieh; Bachoura; Saife; Port; Remeil; Medawar; Moussaytbeh; and Mazraa (see Figure 26). For the purpose of this research that aims to provide recommendations for UHI mitigation from an urban planning perspective, and therefore for the whole city, the UHI simulations are carried out across the entire administrative area of the city of Beirut thus including all 12 cadastral areas (see Chapter 6).

Figure 26. The administrative areas of Beirut. Source. Department of Geographic Affairs, 25-30cm pixel (aerial photograph)
5.4 Population of Beirut City

Urban population growth directly impacts the surrounding environment and microclimate (McCarthy, Best, and Betts, 2010). Data for population figures prior to the 1800s for Beirut is sparse or not available. However, available data after the 1800s shows that population figures in the capital city soared during this period for many reasons but mainly due to instability in the region and business opportunities. Lebanon’s last population census was conducted in 1932 and since then all population estimates have been based on surveys and extrapolations (MOE/UNDP/ECODIT, 2011). Lebanon’s resident population was 3.7 million in the year 2007, excluding an estimated 425,000 Palestinian refugees (CAS, 2008; UNRWA, 2008). The total population in 2008 including refugees was therefore about 4.2 million. As for Beirut city, the population was at about 400,000 in 2007 (CAS, 2008).

According to Yassin (2012), Lebanon witnessed a gradual population growth from 1896 to 2005 with a distinctive rise in its capital city of Beirut. Figure 27 is an illustration of this population rise in Beirut in comparison to the country’s overall population growth. When this population growth in Beirut is correlated against maximum and minimum temperature trends it is found that there is a very strong positive correlation between these two parameters with an $R^2$ value of 0.97 (see Figure 28). This rural exodus continues to present day and is in part attributed to greater job opportunities, improved and better municipal services as well as wider choices for education within the capital city of Beirut.

As such, rural exodus can have potentially significant impacts on the surrounding environment and specifically the UHI due to a greater demand for housing needs,
increased modification of natural surfaces, and more pressure on energy demands, on road infrastructure and accordingly increased anthropogenic heat emissions and so on.

Although this thesis does not investigate the direct impact of urban populations on the UHI, it does carry out analysis indirectly via the effects of the urban form and material compositions of the artificial city as a result of the rising urban populations in Beirut.

![Figure 27. Growth of Beirut and Lebanon Population from 1896 to 2005 adapted from Yassin, 2012](image)

![Figure 28. Population versus Tmax and Tmin. Source: Saliba 1998 (population) and AUB 2013 (climatic data) (prepared by author)](image)
5.5 Beirut, an artificial city

After having discussed the various underlying physical and climatic factors and demography of Beirut city, this section gives an account of the history of urbanization, urban planning and urban zoning processes that have shaped the urban form of Beirut as it exists today, and the legal and institutional framework of the urban planning sector in Beirut, which all contribute to the effects of the UHI of this city.

This section also assesses the main land cover and land uses of the city, its urban morphology, the dominating urban surfaces of the city and their respective albedo or solar reflectivity properties. What makes these factors important within the context of the UHI study for the city is first the characterization of the main land uses and therefore the assessment of the extent of artificial versus natural surfaces and second the identification of the material composition of the respective urban surfaces within specific land covers and land uses along with their respective radiative and thermal values. For example, in areas primarily defined as artificial surfaces the majority of these urban surfaces like rooftops and pavements are impermeable with predominantly low solar reflectivity or albedo properties (since these surfaces are primarily asphalted in Beirut) that can significantly aggravate the UHI. In contrast, land uses that are characterized or defined as parks or vegetated surfaces have the reverse effect with important cooling impacts on the UHI as a result of the evapotranspiration processes of trees and plants. Moreover, the urban morphology of a city contributes significantly to exacerbation of the UHI where for example building heights, street width, height/width ratios, street orientations, all factors of urban geometry, contribute to UHI effects as discussed in Chapter 2. This section is therefore divided into the following six parts: 1) an historic account of the urban planning
and urbanization events which helped shape the urban morphology of the city of Beirut; 
2) zoning extent and specifications of Beirut; 3) the legal and institutional urban planning 
framework; 4) assessment of land use-land covers characterizing the city of Beirut, 5) the 
urban morphology of Beirut, and; 5) the albedo or solar reflectivity of the dominating 
urban surfaces including buildings and roads. The main aim of this chapter is to identify 
the main urban factors that can potentially have the most significant effects on UHI.

5.5.1 History of Urbanization, Urban Planning and Environmental 
Considerations in Beirut. There are numerous important references on the historical 
evolution of Beirut city with emphasis on the impact of governing mandates and sectarian 
diversities on the respective urbanization and molding of the morphology of Beirut as 
well as the more specific details on the urban, suburban, peri-urban and rural areas in and 
around Beirut (Davie, 2001; Khalaf & Said, 1998; Rowe & Sarkis, 1998; Saliba, 1998; 
Yassin, 2012). Within the context of the aim of this research to identify the urban 
geometric parameters that have the most significant contribution to the effects of UHI, it 
is important to understand the history of urbanization of the city that has resulted in the 
development of an urban morphology that characterizes the city as it exists today. One 
central and recent reference (Yassin, 2012) which aims to illustrate the evolution of 
Beirut, explains the marked expansion of the city from the 1800s to present day with 
development that took place in almost all directions (see Figure 29). According to Yassin 
(2012), within the context of urban planning and development, the city of Beirut passed 
through five main stages of development as follows: 1) the Ottoman Empire(1840s-
1920); 2) the French Mandate (1920-1943); 3) the Independent Era (1943-1970); 4) the 
civil war period (1970-1991), and; 5) the post-war period (1992-present). Table 8 gives a
detailed outline of the history of the key urbanization and urban planning practices that took place within these five development stages and identifies whether any respective environmental considerations were given as such, specifically to the urban microclimate.

In summary, based on Table 8 and the available literature on the topic it can be concluded that in fact urban planning took place haphazardly in Beirut with very little consideration being given to the environment or urban microclimate. Urban planning of Beirut was therefore offset by the various different development stages mentioned previously which are linked primarily to the political situation of the country (mandating powers, wars, and so on). For example, in 1948, Lebanon witnessed a large influx of Palestinian refugees into the country as a result of the political instability in their territories which resulted in the establishment of numerous camps across the country including Beirut (see section 1.5.1.1 for more details on these Palestinian camps). In addition, as a result of the widespread unaffordable housing situation, informal settlements also started to materialize but mainly outside of the city’s boundaries starting in the 1960s (see section 1.5.1.2 for more details on informal settlements in the city). Moreover, after the Lebanese civil war period, the private company “Solidere” became highly involved in the reconstruction and reshaping of the city center (see section 1.5.1.3 for more details on Solidere’s associated works for the city center). These aforementioned events that include the mandating powers and regional or civil wars, the establishment of Palestinian refugee camps, and the associated important works of Solidere all helped shape the urban form of the city as it exists today.

Therefore these urbanization events that took place are very important when considering the main events which molded the urban form of Beirut city and which
resulted in the choice or selection of the dominating urban surface materials of the city that potentially have a significant impact on UHI and which is the main context of this research.
Figure 29. Beirut phases of urbanization. Source: Yassin, 2012, pp. 67
<table>
<thead>
<tr>
<th>Period</th>
<th>Population</th>
<th>Urbanization</th>
<th>Urban Planning/ Construction</th>
<th>Environmental Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ottoman Period (1840s-1920s)</td>
<td>80,000</td>
<td>-Flow of immigrants into Beirut due to political unrest in the country and the region</td>
<td>-1868 election of the first municipal council took place</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>-First building code was implemented by Beirut municipality known as the <em>Defter Khan</em> system</td>
<td></td>
</tr>
<tr>
<td>French Mandate (1920-1943)</td>
<td>200,000</td>
<td>-Political Arab refugees started traveling to Beirut as well as locals for business opportunities</td>
<td><em>Danger brothers</em> drafted the first master plan for Beirut city but this was never implemented</td>
<td>None</td>
</tr>
<tr>
<td>Independent Era (1943-1970s)</td>
<td>900,000</td>
<td>-Urbanization sprawl and the creation of the “misery belts around the city center took place coupled with a rapid demographic growth and a massive rural to urban migration -Influx of Palestinian refugees in 1948 and the establishment the refugee camps across Beirut known as <em>Shatila</em>, and <em>Mar Elias</em></td>
<td><em>Ecochard</em> drafted the first master plan for Beirut in 1943 but this was never implemented. - <em>Ernst Egli</em>’s plan for the city was approved in the 1950s which was inspired by Ecochard’s plans linking the city to major highways leading to Damascus, Sidon &amp; Tripoli. - In 1961, under the <em>Fouad Chehab</em> Era (1958-1964), a new Planning Ministry was created, the first Town Planning law was passed in 1962, and the GDUP and HCUP were created. -A second master plan was drafted by <em>Ecochard</em> in 1963 which included Beirut Greater Area also</td>
<td>None</td>
</tr>
<tr>
<td>Civil War Period (1970s to 1991)</td>
<td>1,400,000</td>
<td>-Refugees, and rural migrants, in addition to</td>
<td>-In January of 1977, the Council for Reconstruction and Development</td>
<td>NEPA issuance in the U.S.A. in 1969 and worldwide</td>
</tr>
<tr>
<td>Period</td>
<td>Population</td>
<td>Urbanization</td>
<td>Urban Planning/ Construction</td>
<td>Environmental Context</td>
</tr>
<tr>
<td>---------------------</td>
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<td>------------------------------------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td></td>
<td>1,750,000</td>
<td>-During and after the civil war era, Lebanon witnessed an unprecedented urbanization due to lacking control and regulation mechanisms. -Slum dwellers and informal settlements continued to increase during this time.</td>
<td>-The National Emergency Reconstruction Plan (NERP) and Plan Horizon 2000 were prepared under CDR - Solidere was commissioned to design and implement a new plan for Beirut Central District after the end of the Civil War. -In 2005 the National Physical Master Plan Land of the Lebanese Territory (NPMLT) or “Schéma d’aménagement du territoire Libanais (SDATL), was prepared by DAR/IAURIF for CDR. -The Council of Ministers (COM) endorsed the NPMLT as Decree No. 2366 (dated 20/6/09) and this is the most recent urban plan for</td>
<td>-The Ministry of Environment (MOE) was created according to Decree 216 ratified in April, 2, 1992. -No. 667 ratified on Dec.29, 1997, gave the Ministry full power to operate. -During the 1990s many organizations dealing with the environment were created under the national union -Environmental Law 444 was approved in 2002 which was considered to be the legal instrument for environmental protection and management - Strategic Environmental Assessment (SEA) Decree</td>
</tr>
<tr>
<td>Period</td>
<td>Population</td>
<td>Urbanization</td>
<td>Urban Planning/ Construction</td>
<td>Environmental Context</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
<td>--------------</td>
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<td>-----------------------</td>
</tr>
<tr>
<td></td>
<td>Lebanon including Beirut city.</td>
<td></td>
<td></td>
<td>8213 was ratified in May 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Environmental Impact Assessment (EIA) Decree</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>8633 was ratified in August 2012</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Solidere’s works take into consideration promotion of natural environment with implementation of green areas and parks</td>
</tr>
</tbody>
</table>
5.5.1.1 Refugee camps. In Beirut, there exist two Palestinian Refugee Camps known as “Shatila”, and “Mar Elias” (see Figures 30 and 31). Established in the 1950s as temporary settlements for a large refugee population, these camps eventually turned into permanent elements of the urban context of the city of Beirut and formed a base from which urbanization spread to surrounding areas whenever the possibilities of expansion were available (Fawaz, 2013). Thus, according to Fawaz, some of these camps have increased their area since they were first established becoming part and parcel of the urbanization of the city and affecting the overall transformation of Beirut. Indeed the housings within these camps do not follow modern standards of building and urban regulations. Table 9 provides brief information on these camps including the year in which they were established and their respective populations (Fawaz and Peillen, 2002; Fawaz, 2013; Martin; 2015). While this thesis does not investigate specifically the extent to which the buildings or structures within these camps impact the UHI, it can potentially be an interesting and important topic to consider for future researches within the context of UHI for Beirut city. Having said this, these camps are integrated within the overall analysis of the UHI for Beirut city.
Figure 30. Location of Palestinian refugee camps in Beirut. Source: Google Earth, 2015

Figure 31. Image of haphazardly construction buildings in a Palestinian refugee camp in Beirut. Source: UNRWA, 2015

Table 9. Palestinian refugee camps in Beirut adapted from Fawaz and Peillen, 2002

<table>
<thead>
<tr>
<th>Name of Palestinian Refugee Camp</th>
<th>Year of establishment</th>
<th>Population of camp</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar Elias</td>
<td>1952</td>
<td>1,411</td>
<td>Mar Elias is the smallest Palestinian refugee camp and covers approximately 5,400m².</td>
</tr>
<tr>
<td>Shatila</td>
<td>1949</td>
<td>12,235</td>
<td>Shatila was established by the International Committee of the Red Cross to accommodate the hundreds of refugees who poured into the area in 1948.</td>
</tr>
</tbody>
</table>
5.5.1.2 Informal settlements. Like other cities in the Third World, Beirut’s recent urbanization has largely occurred around the tight framework of urban regulations giving rise to the so-called informal settlements, neighborhoods which have developed since the 1960s through the efforts of their current or prospective dwellers, in violation of urban and building regulations/ and or property rights (Fawaz, 2013). The informal settlements in Lebanon have been established due to a combination of factors but mainly due to local and regional history of violent conflicts such as the Lebanese civil war and the Arab-Israeli war, as well as the absence of affordable housing options especially for low-income families (for a more extensive account of the associated contributing factors that have resulted in these informal settlements see Fawaz, 2013). Most of these informal settlements lie in the suburbs of Beirut. Houses in these informal settlements are typically haphazardly constructed, are no more than two to maximum three storeys, have asphalted rooftops and with almost no space in between the buildings. Road conditions and infrastructure are also extremely poor; the roads are poorly paved, and are narrow where two cars in opposite directions can just barely pass by. These closely packed asphalted buildings can have significant impacts on the UHI of the city of Beirut due to their low solar reflective properties and poor or indeed non-existing urban planning. Again as previously mentioned, while this thesis does not attempt to analyze the specific impact of these types of informal buildings on the UHI of Beirut, it could be recommended as a topic for future research work. Having said this, they are integrated into the overall UHI analysis of the city of Beirut, without concentrating specifically on these informal settlement areas.
5.5.1.3 Solidere. Another important event worth mentioning here, which is contributing to the shaping of the urban form of Beirut is associated with the developmental and urban planning activities of the private company “Solidere”.

Following the civil war period, Solidere became actively involved in master and urban planning projects primarily for the Beirut Central District (BCD) area which covers approximately 1.9 km$^2$ (Figure 32) of Beirut administrative area. Their activities include the establishment of guidelines and detailed plans defining the rules and regulations of construction and urban development and these also include defining land uses and land covers (http://www.solidere.com/corporate/services/master-urban-planning). Figure 32 represents the Master Plan for BCD where most of these projects have been implemented, such as the marina area currently referred to as “Zaytouna Bay” (no. 9 on the map) and the traditional old souks area known as “Beirut Souks” (no. 5 on the map), with a few others still in progress. Within the context of the UHI, the urban development activities of Solidere may or may not be contributing to the exacerbation of the UHI of the city of Beirut especially as Solidere is involved in land uses and land covers within the 1.9 km$^2$ of land owned by Solidere. In fact, Solidere undertook a major project which involved the reclamation of vast areas of land in “Biel” which can have significant impacts on the UHI due to obstruction of wind patterns for example as a result of the newly constructed buildings on this reclaimed piece of land (labeled as “Reclaimed Zone” in Figure 32). On the other hand, Solidere is planning public parks and squares within the city (labeled no. 7 in Figure 32) which can have major cooling effects of the urban vegetation on the city’s UHI. While this thesis does not aim to specifically investigate the impacts of Solidere’s construction and planning works on the UHI effect, it can be considered as an interesting
and important topic for future research work for the city of Beirut. While the reclaimed zone is not considered in this thesis due to unattainable data, the rest of Solidere’s land is integrated along with the overall UHI analysis of the city.

Figure 32. BCD Master Plan: A-Treelined sea-side promenade, B-Seaside park, 1-Public & Religious Buildings, 2-Preserved historic core of the city, 3-Financial district mixed use of offices, recreational & shopping facilities, 4-Traditional old souks area, 5-Mixed use area, 6-Residential area, 7-Public parks & squares, 8-Archeological excavation area, 9-Marinas. Source: http://www.lebanon.com/construction/beirut/masterp.htm
5.5.1.4 Beirut’s urban zoning. In the year 2000, decreed master plans covered 1,091 km$^2$ (10.4%) of Lebanon, while un-decreed master plans covered an additional 614 km$^2$ (5.8%) – these master plans await their corresponding decree. Therefore, until 2004, the total area of Lebanon covered by master plans (approved/decreed and approved/non-decreed) was about 1,705 km$^2$. The remaining area (83.8%) is unplanned and only partially surveyed. Therefore this implies that from a land use point of view, the most complex areas (i.e., coastal zone, urban poles and their suburbs), including the Beirut case study area, are already zoned (MOE/UNDP/ECODIT, 2011).

The urban planning and zoning for the city of Beirut was originally developed by Michel Ecochard in 1963 (see Table 8) to which some minor modifications, not pertaining to the zoning specifications per se, were made in the year 2007. This urban plan divides the city into 10 zones (see Figure 33), each with its own specifications for surface area of building plots, lots subdivisions and so on.

Out of the various zoning specifications, the specification of relevance for the purpose of this research is the building height, where higher buildings reduce the sky view factor thus significantly impacting the UHI of a city. For zones I and II, reference is made to Decree 5714 (under Solidere ownership) where the maximum permissible heights for buildings under these zones are listed. For zone 3 a calculation is provided for the building height (H=2.5[R1+L+R2]$^{20}$), while zones 4, 5, 6 and 7 have no specified building heights in which case reference is made to the Building Code#646 (see subsequent section for more details on Building Code #646) which provides the methodology for calculation of building height, typically around twice the width of the street and pavements on which the building is to be constructed, similar to the calculation

\[ H = 2.5[R1 + L + R2] \]

\[ 20 \text{ In this calculation for building height, “R” refers to the pavement width and “L” refers to the road width.} \]
provided for zone 3 above. Therefore if the road is 6m wide for example, the building can go up to maximum 12m height.

Zone 8, which falls primarily in Moussaytbeh cadastral area, is divided into 6 additional sub-zones and has the most detailed zoning specifications and the reason for this could potentially be because the most recent urbanization in the history of Beirut took place in this part of the city (see Figure 29) and therefore it was possible to integrate more zoning criteria within these undeveloped areas at the time of Ecochard (see Appendix II for a full list of the zoning specifications for Beirut). Indeed, specifications for building heights are listed for some but not all zones including zone 8, where for example the maximum building height is 17m for subzones 8.A.I and 8.A.I.4 while there are no height specifications for the other 4 subzones.

As for zone 10, which falls under Ras Beirut cadastral area, and which is subdivided into six subzones, only subzones I, II, and IV have specified heights for buildings where in subzone I, maximum permissible floor number is 7 and subzones II and IV have maximum permissible building height of 9m. Finally, for Zone 9, Zone 10. III and Zone 10.V these are listed as “servitude non-aedificandi totale” which implies that they are non-constructible zones reserved mainly for public utility such as pathways, areas in the sea port or airport, or any right-of-way passage.

In the case of the aforementioned high rises which are fast becoming more prominent features in the skyline of the city, these require special permits from the Council of Minsters (COM) which accordingly issues a decree in order for the developer to proceed with the construction works for buildings who’s heights surpass the maximum permissible limit.
Within this zoning scheme for Beirut therefore, the main specification of relevance within the context of UHI analysis is the building height because as discussed in the literature review chapter of this thesis, buildings that are relatively high and spaced close to each other can have a more significant impact on trapping incoming solar radiation thus preventing the emitted heat from escaping back into the atmosphere and accordingly aggravating the heat island. Indeed this scenario is considered in the numerical analysis chapter of this thesis (Chapter 7) in order to illustrate the potentially significant effects of these high rises on the UHI of the city in the view to propose sustainable design and planning recommendations accordingly (see Chapter 7).
Figure 33. Zoning for Beirut administrative area. Source: Ecochard, 1963
5.5.1.5 Legal and institutional urban planning framework of Lebanon. Strategic urban planning is very important in ensuring sustainable utilisation of land available in urban areas and in minimizing degradation of the environment. This section therefore gives an outline of the legal urban planning framework of Lebanon comprised of the Urban Planning Law #69 and the Building Code #646. The various parties involved in the institutional framework for urban planning in Lebanon are also outlined. The aim of this section is to identify any weaknesses and opportunities for potential improvements in the existing Urban Planning Law #69 and Building Code #646 of Lebanon and to identify the key players who can make this difference.

**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 (see Appendix III for a full copy of Urban Planning Law 69/1983 in Arabic). 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 as detailed below (MOE/UNDP/ECODIT, 2011):

- Article 7: urban planning should consider the relationship between communities and surrounding areas including agricultural areas, forested areas, and the **protection of the environment**.

- Article 8: Urban master plans must specify the criteria for land use by taking into consideration the agricultural value of the land and the possibility or implementation of irrigation canals. These should be specified prior to
construction otherwise no construction is permissible. Non-construction zones can also be determined.

- Article 9: zones that have not been planned can be placed under study for a period of up to two years further to a decision made by the Ministry of Public Works and Transport, and after consultation with the HCUP and the relevant municipality. During these two years however no construction is to be permitted. Forested areas are not allowed to be destroyed and the natural landscape of the area should not be changed.

- Article 17: no monetary compensations will be provided for changes to any restrictions on building coefficients, including setbacks, number of floors, building height, and colour, which plays an important role in protecting public health and safety or the natural environment.

- Article 19: relevant authorities may expropriate private land for the benefit of the public good by compensating the respective landowner(s) with a nearby land of equal value.

- Article 20: relevant authorities may carry out re-parceling of previously zoned areas in order to facilitate urban planning.

- Article 23: government or relevant municipality may ask the landowners of residential areas nearby forested areas or natural open spaces to swap their land with another piece of land.

- Article 24: municipalities or union of municipalities can agree with landowners of forest or natural sites to open these areas as public areas or parks and municipalities can accordingly change admission fees for maintenance or upkeep.
As can be seen, the Urban Planning Law #69 of 1983 took important foresight with regards to urban planning measures to help protect the environment although there is still room for improvement within the context of implementation of urban planning practices to minimize impacts on UHI or urban microclimate but these are discussed in more detail in later sections (see Chapter 9).

**Building Code #646**

Moreover and more recently, another relevant law was issued in the building and construction sector, namely the Construction Law 646 (dated 2004) also known as the Building Code (see Appendix IV for a copy of extracts from the Building Code #646 of Lebanon in Arabic). 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 #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. These specific changes that are advantageous for the safeguarding of the environment are listed in Table 10 below (MOE/UNDP/ECODIT, 2011):
Table 10. Environmental implications of Building Code #646 adapted from MOE/UNDP/ECODIT, 2011

<table>
<thead>
<tr>
<th>Changes introduced</th>
<th>Environmental implications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in the validity period of a construction permit from 4 to 6 years with the possibility of another 2 years extension</td>
<td>This article implies that the construction period is extended for a longer period of time so for example in cities this affects neighbors and pedestrians for a longer time via the generation of dust, noise, and prolonged obstruction of sidewalks. As for villages, unfinished buildings can have a negative impact on the landscape. Fortunately, Article 3 of this law issues fines for buildings that are not completed within the permit period of a maximum of 8 years, although this period is still relatively long where associated impacts on the environment including the urban microclimate are prolonged and linger.</td>
</tr>
<tr>
<td>Every additional underground car park, above and beyond what is prescribed in the construction law, will be exempt from taxes:</td>
<td>This article is an incentive for developers to maximize underground floor space thus having lower impacts on natural lands if available. Unfortunately though, in practice, underground construction is expensive and although impacts on ambient air are minimized, the incentive to increase car ownership for a single family is maximized with associated impacts on UHI via anthropogenic heat emissions (although the latter is not investigated in this research since the focus lies primarily on urban fabric and form and their respective impacts on UHI in the view to find urban planning mitigation solutions)</td>
</tr>
<tr>
<td>Article 13 of the construction law requires that construction and demolition activities comply with environmental regulations pursuant to Environmental Law 444/2002 (see Appendix V)</td>
<td>This article identifies conditions for not granting construction permits such as safety, public health, landscape and architectural components. It also allows for urban planning authorities to require developers to provide additional infrastructure including wastewater treatment plants (WWTPs) and green areas. whereby the latter requirement is an advantage within the context of UHI mitigation</td>
</tr>
<tr>
<td>Staircases and elevator shafts are excluded from the calculation of building coefficients on the condition that they consume less than 20m² floor space</td>
<td>In practice, this implies that buildings exceed the legal building coefficient by 20m² which reduces water infiltration further. Small parcels are now more attractive to developers. Reduction in water infiltration increases water runoff and may even cause flooding especially during the rainy season. Increasing impermeable surfaces exacerbates the urban heat island</td>
</tr>
</tbody>
</table>

Looking at Table 10 therefore it is evident that there are no specific building codes to minimize impacts on the urban microclimate such as the specific requirement for
“cool materials” for rooftops and facades of building for example although it does mention implementation of green areas in Article 13 as seen in Table 10 which can potentially have significant alleviating effects on UHI of Beirut if indeed applied. Some other obvious green elements in the current version of this amended construction or Building Code #646 include the requirement to plant trees, to properly ventilate all areas of buildings, and to encourage installation of solar hot water systems for all building owners. Therefore it does consider some green elements although unfortunately, this Building Code in its entirety, and not specifically for the selected articles in Table 10 above, is not regimentally applied by the concerned professionals in the field, including architects and engineers, since it does not allow for flexibility in design and due to a major deficiency in a robust implementation and reporting regime by the relevant authorities. Recommendations and suggestions within the context of UHI mitigation strategies are discussed in later chapters of this thesis (see Chapter 9).

**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.
Table 11 provides a list of these aforementioned stakeholders involved in the urban planning sector in Beirut with a description of their associated responsibilities in this respect. The key purpose of this table is to identify the main role of these various parties and whether their responsibilities include any consideration of the protection of the urban microclimate of Beirut.

Table 11. Key authorities and other non-governmental authorities involved in the urban planning process in Beirut

<table>
<thead>
<tr>
<th>Name of Authority</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beirut Municipality</td>
<td>• Permits for constructions in Beirut administrative area must be issued from the Municipality of Beirut and all ultimate decisions related to urban planning within the city are taken with the approval of the Municipality of Beirut</td>
</tr>
<tr>
<td>Directorate General of Urban Planning (DGUP) (under the Ministry of Public Works and Transport or MOPWT)</td>
<td>• DGUP develops urban regulations and coordinates urban planning activities. • It prepares and reviews urban master plans all over the Lebanese territory except Beirut and Tripoli and three federations of municipalities (Jbail, Keserouan and Metn) which have their own urban planning/engineering units. • It is involved in the building permit application process. • Urban master plans are either prepared by the DGUP or by a private urban planning office. • Completed master plans are submitted to the concerned municipality which has one month to respond. • If accepted, the plan is sent to COM for endorsement. • DGUP is also involved in the protection of archaeological and cultural heritage.</td>
</tr>
<tr>
<td>Regional Departments of Urban Planning (under the MOPWT)</td>
<td>• Established in every <em>caza</em> to review construction permits and ensure compliance with urban planning regulations issued by DGUP and/or HCUP. • They are usually comprised of one director and several civil engineers (CE) or architects who assume responsibility for a specific area within the <em>caza</em>. • Regional departments act as technical advisor to local municipalities on urban planning and construction related matters.</td>
</tr>
</tbody>
</table>
Higher Council of Urban Planning (HCUP) (under the MOPWT)

- The HCUP was established in 1962 by Legislative Decree 69 dated 24/09/1962.
- It is responsible for the management of the entire Lebanese territory as follows:
  - Review and approval of urban master plans and large-sized projects >3,000m² in Beirut and >10,000m² outside Beirut
  - Draft decrees related to establishment of real estate companies, land expropriation and land parceling.
  - Review decisions related to licenses for construction and parceling; and
  - Review proposed amendments to urban planning and construction legislation.
- The Council is chaired by the Director General of Urban Planning.
- Based on the Urban Planning Law Legislative Decree 69/1983 and its amendments, the Council consists of 12 members: DGUP, Justice, Interior and Municipalities, Public Works and Transport (Roads and Buildings), Housing, Environment, Director of Programs at CDR, President of OEA in Beirut and Tripoli, and sociology, urban planning and environment, and architecture experts.

Order of Engineers and Architects (OEA)

- Lebanon has two OEsAs in Beirut and Tripoli.
- They were established in the 1950s with the chief purpose of formalizing the profession of engineers and architects in Lebanon.
- Members have different areas of expertise namely: architects, civil engineers (CE), electrical, mechanical, telecommunication, and agriculture.
- Construction permits and execution plans can only be signed by architects or CEs.
- The other members of the OEA (electrical, mechanical, etc.) can only participate in preparation of execution plans but these cannot be signed without first obtaining approval from the lead architect or CE.

Ministry of Interior and Municipalities (MOIM)

- The Ministry of Interior and Municipalities is involved in matters concerning the development, coordination and execution of Lebanon's internal policy.
- It is involved in ensuring law and order, and for overseeing all relevant cases in mohafazas²¹, cazas²².

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²¹ Mohafaza means “governorate” or “region”
²² Caza means “district” which falls within a governorate boundary
municipalities, union of municipalities, independent municipal funds, mokhtars\textsuperscript{23} screening councils, and the rest of the elected or assigned local councils, villages, gathering places, political parties, and unions.

- It also takes administrative control of citizens and refugee personal information, matters of civil defense, motor vehicles, traffic, and executes everything to do with law and order.

<table>
<thead>
<tr>
<th>Lebanese Standards Institution (LIBNOR) (attached to the Ministry of Industry)</th>
<th>LIBNOR is a public institution attached to the Ministry of Industry.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It was established by a law dated 23.7.1962 as the sole authority to prepare national standards and gives the right to use the Lebanese Conformity Mark;</td>
</tr>
<tr>
<td></td>
<td>National standards cover all products including codes of practices and structural rules for buildings.</td>
</tr>
<tr>
<td></td>
<td>LIBNOR is a member of the International Organization for Standardization (ISO) (<a href="https://libnor.gov.lb">https://libnor.gov.lb</a>).</td>
</tr>
</tbody>
</table>

Therefore as can be seen from Table 11, there are several key stakeholders involved in the urban planning sector in Beirut but unfortunately communication amongst and between 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 and therefore not listed in Table 11 is the Lebanese Green Building Council (LGBC)\textsuperscript{24}. LGBC 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. Indeed most of the incentives towards achieving a more environmentally conscious city are being taken by such NGOs

\textsuperscript{23} “mokhtar” is a person who is the head of a local government of a town

\textsuperscript{24} LGBC acts on market, educational and legislative issues to achieve its goals (www.lebanon-gbc.org). It offers a Lebanese certification system for buildings, known as “Arz”, that adopts environmental parameters and transforms the way buildings and communities are designed into a prosperous and sustainable environment.
which do not have as much influencing power as the governmental authorities like the
Municipality of Beirut or the Directorate General of Urban Planning. There is therefore
much room for improvement in this respect and this is discussed in more detail in later
chapters (see Chapter 9).

### 5.5.2 Land cover-land use in Beirut.

Having assessed the various urbanization development stages which helped shaped the urban form of Beirut within the context of UHI analysis the next step involves the assessment of the main land cover and land uses in Beirut from which the dominating urban surfaces and material compositions can be extrapolated. Thus, a visual assessment of the most recent aerial orthophoto of Beirut city (Department of Geographical Affairs, 2008) showed that Beirut is primarily a dense built environment with extensive road networks. Figure 34 shows the built-up and predominantly artificial city of Beirut where roads and buildings cover the majority of the city’s surfaces. In fact, the main land cover land uses in Beirut city include primarily buildings, roads, and asphalted spaces (which serve mainly as parking lots), with a lower fraction of vegetated surfaces.

A land cover-land use study for Lebanon was carried out by DAR-IAURIF in the year 2004, as a project for the Council of Development and Reconstruction (CDR). The findings of this study are documented in what is referred to as the “National Physical Master Plan of the Lebanese Territory” (NPMPLT) or “Schéma Directeur d’Aménagement du Territoire Libanais” (SDATL) ([http://www.cdr.gov.lb/study/SDATL/sdatlf.htm](http://www.cdr.gov.lb/study/SDATL/sdatlf.htm)). This document was later endorsed by the Council of Ministers (COM) as Decree No. 2366 dated 20/06/2009 and is therefore an important document commonly referred to in the urban planning sector in Lebanon. The
NPMLT or SDATL distinguishes four levels of land covers where level 4 is the more detailed and descriptive classification with over 20 subcategories (see Table 12). In general however, to identify directly the main categories of existing land covers, Level 1 is referred to which classifies the existing land covers in Lebanon into 6 main categories as follows (see Figure 35):

1. *Territoire artificialisé* or urban or built environment (or built-up area);
2. *Territoire agricole* or crop land or farm land;
3. *Surface boisée* or forested areas;
4. *Surface à végétation herbacée* or rangeland;
5. *Terrain naturel sans ou avec peu de végétation* or natural land without or with little vegetation;
6. *Surface en eau* or water bodies.

According to the NPMLT classification of land uses and land covers, Beirut is a predominantly artificial area (as per item 1 listed above). It is worth noting here that the NPMLT of DAR-IAURIF is based on the land cover-land use report prepared by the Lebanese Environment and Development Observatory (LED) and Management Support Consultant-Investment Planning Program (MSC-IPP Environment) dated June 2003. In this report, again four levels of land use-land cover types have been distinguished where level 4 is the most detailed of the four. Although this report does not identify the land cover-land uses of Beirut city to the same detail as the NPMLT, it does distinguish useful terminologies, which are referred to as necessary throughout this thesis.

As such, according to this latter classification, Beirut is again described as an “artificial area” (level 1 classification), comprised of both “urban areas” and “activity
areas” (level 2 classification). Table 13 gives a clear outline of the various levels of land use land cover categories. Based on these classifications therefore, it is concluded that Beirut is an “artificial area” with a mix of all level 2 classifications that include “urban areas”, “activity areas”, “non-built-up artificial areas” and “artificial, non-agricultural vegetated areas”.

Consequently, “urban areas” in Beirut are indeed comprised of both a “continuous urban fabric” and a “discontinuous urban fabric”. Within the predominantly continuous urban fabric characterizing the city of Beirut, there is typically a mix of largely dense urban fabrics and dense informal urban fabrics (namely the Palestinian refugee camps). Within the remaining smaller fraction of areas defined as discontinuous urban fabrics within Beirut, there is typically a mix of medium density urban fabrics, some tourist resorts and a few scattered archeological sites.

As for Level 2 areas identified as “activity areas”, the city of Beirut includes all categories listed in Table 13 except for railways, since only remnants of these remain as they have not been operational since around the 1970s. Under level 2 areas identified as “non-built-up artificial areas” there are no mineral extraction sites, or landfill sites, or airport, which lies outside of the administrative boundary of the city of Beirut toward the south. Moreover urban vacant lands are typically asphalted areas which serve primarily as parking lots.

Therefore upon comparing these two sources that classify land uses and land covers in Beirut it is seen that in fact there is not much difference between the two, considering that the more recent one, the NPMPLT, is based on the one prepared prior to that by the MSC-IPP Environment. Having said this, the NPMPLT classifications consist
of more broken down and explanatory descriptions of the specific land cover categories. Reference is thus mainly made to the NPMLT classifications in this thesis since this is a more recent document and has in fact been endorsed as a decree hence is considered as a more official reference.

Figure 35 presents the main category of land uses within the city of Beirut, according to the NPMLT classification, which categorizes Beirut primarily as *territoire artificialisé* or artificial/built-up/urban area comprised of a combination of residential, commercial and industrial zones. Some green urban areas are also seen on this map of Beirut where the largest ones exist namely at the AUB institutional campus grounds and the pine trees public garden known as Horsch Beirut. These urban parks/gardens cover approximately 2% and 1.75% of the entire Beirut administrative area respectively. There are however no water bodies (artificial or otherwise) within the city of Beirut. There is only one seasonal river which runs just outside the eastern boundary of Beirut administrative area (see Figure 35) but this remains mostly dry during the summer season. Therefore, the majority of the land cover land use in Beirut is artificial (>90%) (buildings and roads) with a small percentage of the remaining land being covered by urban vegetation..
<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban or built-up land</td>
<td>Area of activity and infrastructure</td>
<td>Road infrastructure</td>
<td>Highway</td>
</tr>
<tr>
<td></td>
<td>Urbanized zone</td>
<td>Discontinuous urban fabric</td>
<td>Urban sprawl</td>
</tr>
<tr>
<td></td>
<td>Urban or built up land</td>
<td>Urban sprawl</td>
<td>Vacant urban land</td>
</tr>
<tr>
<td></td>
<td>Undeveloped urban land</td>
<td>Vacant urban land</td>
<td>Dense urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Continuous urban fabric</td>
<td>Dense informal urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Industrial or commercial area</td>
<td>Moderately dense urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Port area</td>
<td>Moderately dense informal urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Railway station</td>
<td>Sparse urban fabric</td>
</tr>
<tr>
<td></td>
<td>Diverse sports and leisure equipment</td>
<td>Diverse equipment</td>
<td>Industrial or commercial area</td>
</tr>
<tr>
<td></td>
<td>Urban sprawl on sparse forest</td>
<td>Diverse sports and leisure equipment</td>
<td>Port area</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Urban sprawl on sparse forest</td>
<td>Railway station</td>
</tr>
<tr>
<td>Rangeland</td>
<td>Artificial green area</td>
<td>Urban green space</td>
<td>Diverse equipment</td>
</tr>
<tr>
<td>Crop land or farm land</td>
<td>Intensive cultivation</td>
<td>Intensive crop fields</td>
<td>Diverse sports and leisure equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intensive protected crops (greenhouses)</td>
<td>Archeological site</td>
</tr>
<tr>
<td>Water bodies</td>
<td>Continental surface water</td>
<td>River or stream</td>
<td>Tourist resort</td>
</tr>
<tr>
<td></td>
<td>Beach</td>
<td>Beach</td>
<td>Urban sprawl on sparse forest</td>
</tr>
<tr>
<td>Forested areas</td>
<td>Sparse forest</td>
<td>Reclaimed sea</td>
<td>Reclaimed sea</td>
</tr>
<tr>
<td>Natural land without or with</td>
<td>Bare rock</td>
<td>Bare rock</td>
<td>Bare rock</td>
</tr>
<tr>
<td>little vegetation</td>
<td>Moderately dense herbaceous vegetation</td>
<td>Shrublands</td>
<td>Shrublands</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderately dense herbaceous vegetation</td>
<td>Moderately dense herbaceous vegetation</td>
</tr>
</tbody>
</table>

*Source: CDR· NPMPLT /DAR-IAURIF, 2004*
Table 13. Levels of land cover-land use classifications

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Artificial area</td>
<td>Urban area</td>
<td>Continuous urban fabric</td>
<td>Dense urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discontinuous urban fabric</td>
<td>Dense informal urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Medium density urban fabric</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>Medium density informal urban fabric</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Medium density informal urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low-density urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low-density informal urban fabric</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tourist resort</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Diverse equipment</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Archeological site</td>
</tr>
<tr>
<td>Activity area</td>
<td>Industrial or commercial area</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Port area</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Airport</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Railway station</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non built-up artificial area</td>
<td>Mineral extraction sites</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dumpsites</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Landfill site</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urban extension and/or construction site</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Urban vacant land</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Artificial, non-agricultural vegetated areas</td>
<td>Green urban area</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Sport and leisure facilities</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: MSC-IPP Environment, 2003*
Figure 34. Map of Beirut city showing built environment including road networks (prepared by author)
Figure 35. Land use-land cover map. Source: CDR. NPMPLT/DAR-IAURIF, 2004
5.5.3 Urban Morphology of Beirut. An urban area’s characteristics including its development densities, street widths, general pattern of building height, transportation corridors, and open spaces, and green spaces, all play a combined role in shaping the urban morphology or urban form of a city. As mentioned, the history of urbanization of Beirut and the various associated ‘development stages’ played a key role in shaping the urban form of the city as we know it today. While a detailed account of these urbanization stages has already been given, this section is dedicated to the key urban morphological characteristics that formed as a result of these development stages. These characteristics are deemed important for the purpose of this research as they can contribute significantly to the UHI effect of the city as mentioned in the literature review chapter of this thesis and can accordingly affect the results of the simulations.

For the case of Beirut, the urban morphology was molded and shaped by the two main governing and ruling authorities at the time namely, the Ottomans (1840s – 1920), who left their mark on the city’s architecture and design, but only a couple of these structures are left standing today like the Grand Serail situated in the downtown Beirut area, and the French (1920-1943) who also played a role to this effect as reflected in the buildings architectures and the city’s planning attempts by Ecochard and the Danger Brothers. The Independent Era (1943-1970), especially under the presidency of Fouad Chehab (1958-1964), also witnessed major transformations of the urban morphology of the city with significant improvements in infrastructure combined with major development and construction projects. However, during this period, the Arab-Israeli war resulted in the influx of many Palestinians into the country and the consequent establishment of refugee camps which had a significant impact on the urban morphology.
of the city (see previous section 1.5.1). The civil war period (1970s-1991) on the other hand was a destructive period and resulted in massive internal displacements of hundreds of thousands of inhabitants who fled their original rural areas of residence and settled in informal squatted settlements which expanded and grew in an unorganized and sporadic manner, taking up land surfaces and producing small low-quality housings in the outskirts of large cities such as Beirut and Tripoli. Beirut received the largest share as the main urban center of the country, with fleeing residents settling down mainly in the outskirts of Beirut in the ‘misery belts’ of Beirut suburbs. At around this time, the Council for Development and Reconstruction (CDR) was established, in order to better control and govern the various urban developments and planning that the city was in such dire need of. This period also witnessed the ratification of Urban Planning Law 69 which was issued further to modification of the previous Urban Planning Law of July 24 1962 (see Appendix III for a full copy of Urban Planning Law 69/1983 in Arabic).

Finally, the post-civil war period (1991 to present) witnessed gradual changes in the urban morphology due to increasing population densities of the city, with about 21,000 inhabitants / km² (Population and Development Strategies Programme Lebanon, 2014; MOE/LEDO/ECODIT, 2001). These changes involved mainly improvements in road transportation networks as well as development projects that include typically tearing down and replacement with newer and taller buildings. Throughout its history of urbanization, the environment has not been considered in the planning of the city, although in the summer of 2012, the Ministry of Environment’s (MOE) environmental impact assessment (EIA) and strategic environmental assessment (SEA) decrees were finally ratified, which oblige consideration of environmental as well as climatic effects of
new proposed development projects as well as policies (see Table 8 for history of urbanization and environmental considerations in urban planning in Beirut).

A closer look at the urban morphology of the city shows that upon taking a grid cell of 200x200m size in Mazraa area for example (see Figure 36 where the grid cell is represented in red), which is situated toward the south of the city in what is identified primarily as Zone 4, the urban fabric is defined by a large mass of closely spaced buildings of heights up to 12m or less (or 4 storeys) and primary and secondary roads with widths ranging between 8-10m, and with very little urban vegetation (represented in green). Upon looking closely at this image, it seen that there are three buildings with red-tiled rooftops, which are typically lower in height reaching up to a maximum of 5-6m (or 2 storeys) but as clearly seen these are not the dominating building types in this area of Mazraa or even in the entire Beirut city area. There is also a significant surface area of open spaces, characterized mainly by paved parking lots hence this area is characterized as a dense urban fabric. According to the urban plan of the city there are no specifications for maximum building height in this specific zone of Beirut in which case reference is typically made to the Building Code #646 of Lebanon.
Upon looking at a cell size of similar size in Ras Beirut on the other hand, situated along the coastline and primarily in Zone 10, the urban fabric is found to be less dense than the inner and eastern areas of the city, with a lower density of buildings but these are again closely spaced just as in the Mazraa area, although roads or highways are more clearly defined here and again urban vegetation is sparse (Figure 37). This area could therefore be described as having a medium density urban fabric. Furthermore, Ras Beirut is characterized by average buildings heights that are almost twice that in Mazraa, reaching up to and over 20m in most cases. The maximum allowable height for buildings in this zone is in fact limited to 7 storeys which is equivalent to approximately 20m height.
Another area in Beirut was selected which shows the urban morphology of informal settlement areas as indicated in Figure 38; this is in fact the Palestinian refugee camp of “Mar Elias” in Beirut, situated primarily in Zone 8 II.B (where the specification for building height is not specified), where the urban fabric can clearly be defined as a dense informal urban fabric. The stark contrast in the urban morphology of this informal fabric is clearly apparent upon comparison with the medium density urban fabric to the west of this image where buildings are haphazardly orientated and very closely spaced together. Building heights typically do not go above 4-5m (or 2 storeys) in such areas. Roads in such informal areas are typically in poor condition, are quite narrow (not more
than a total of 3-4m width for both lanes) and are not officially part of the public domain\textsuperscript{25} but are haphazardly paved by the informal residents in the area.

Figure 38. Dense informal urban fabric in Moussaytbeh

Beirut is therefore typically characterized by a combination of dense to medium urban fabrics and dense informal urban fabrics (such as the “Shatila” and “Mar Elias” Palestinian refugee camps). Green urban areas are scarce and scattered throughout the city and the transport networks are widely distributed throughout the city making up for a large fraction of the city’s urban surface. Therefore the predominantly dense urban fabric of Beirut city which is comprised primarily of artificial surfaces and with varying street orientations, building heights as well as height to width ratios, can all play a significant role in exacerbating the UHI of the city. Some of these latter urban geometric

\textsuperscript{25}Public domain is State owned land and protection consists of forbidding construction, quarries, cutting of trees, and grazing (CDR- NPMPLT /DAR-Iaurif, 2004)
characteristics are indeed investigated in this research as discussed in later chapters (see Chapter 7). However, the intensity of the UHI impact can also be highly impacted by the solar reflectivity or albedo of the material compositions of this dense urban fabric which is discussed in the subsequent section.

5.5.4 Albedo values of dominating artificial urban surfaces in Beirut. As mentioned previously, the dominating artificial urban surfaces in Beirut (as opposed to natural surfaces) which can potentially have a significant impact on the UHI or urban microclimate are comprised of buildings, which include facades and rooftops, and roads. Depending on the albedo property of these surface urban materials, the impact on UHI can be significant whereby the lower the albedo the higher impact and vice versa. This section focuses primarily on the main material composition and accordingly albedos of the dominating artificial surfaces in Beirut. As such, regarding the typical wall materials in Beirut, as illustrated in Figures 39 and 40, the majority of new as well as old buildings in the Beirut area have light coloured walls composed primarily of beige/white paint or plaster. According to Oke (1987), these materials have a high albedo (α) typically as high as 0.7. Thus walls are not expected to have significant impacts on UHI in Beirut.

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26 It is worth noting that within the context of this thesis and with respect to radiation properties (namely albedo [α] and emissivity (ε)) and thermal properties (mainly heat capacity and thermal conductivity) of urban materials, reference is made primarily to Oke (1987) as this is the most comprehensive and reliable source of information in this respect and has indeed been referred to in numerous studies on UHI analysis (Akbari, 2001; Montavez, et al., 2008; Taha, 1997).
Figure 39. a) Building constructed circa 1940s in Ras Beirut area with light-coloured facades with approximate albedo ($\alpha$) of 0.7; b) Recently constructed building with light-coloured façade with approximate albedo of 0.7 (photographs taken by author)

Figure 40. a) Building constructed circa 1950s in Zokak El Blat with light-coloured facades with approximate albedo ($\alpha$) of 0.7; b) Building constructed circa 1950-1960 but recently painted over with light-coloured façade with approximate albedo of 0.7 (photographs taken by author)

Regarding rooftops, a visual assessment of the aerial orthophoto of Beirut, and a further more detailed extrapolation on ArcGIS, shows that the majority of these rooftops are gray because they are predominantly covered by concrete slab. Figure 41 is a photograph of a building constructed in the 1980s which is covered by concrete slab; in
fact, most developers opted for concrete covered rooftops during the construction boom in Beirut which took place mainly during the Independent Era between 1940s and 1970s, concrete covered rooftops in contact with the ambient air can significantly raise the internal building temperatures and additionally affect the UHI of the city. Having said this, it is not uncommon to find that recently some owners of old building in Beirut are replacing their rooftops with lighter coloured coatings, typically white in colour such as limestone or white paint, which generally have higher albedos; the main purpose of this is because owners are suffering from the internal heating effects of the low solar reflectivity of these concrete covered rooftops and have found that this approach can lower the heat stress significantly. Having said this, the majority of the buildings still appear to have concrete covered rooftops. According to Oke (1987) the albedo ($\alpha$) for concrete is 0.225 which is quite low therefore rooftops in Beirut are considered to have significant impacts on UHI.
Finally, the third dominating urban surfaces in Beirut, roads, are comprised mainly of asphalted surface layers which have an albedo (\(\alpha\)) of 0.2 (Oke, 1987). In fact, in Beirut there are three classifications of roads including primary, secondary and tertiary and the main material composition of all three of these road classifications is asphalt. Therefore since asphalt has a very low albedo value of 0.2, it is expected that the impact on UHI of Beirut is significant.

Hence rooftops and roads, the dominating urban surfaces in Beirut and with highest exposure to incoming solar radiation, have very low albedo (\(\alpha\)), as compared to the facades of buildings in Beirut, and accordingly play a major role in exacerbating the UHI. The extent to which these urban surfaces impact the UHI is one of the chief
objectives of this research with the aim to find mitigating solutions for the urban planning of the city as such. Scenarios are accordingly devised and analyzed and these are discussed in detail in Chapter 8 of this thesis. Table 14 is a summary list of the albedo ($\alpha$) of the material composition of the outer layer of the dominating urban surfaces in contact with the ambient air in Beirut city as adapted by Oke (1987).

Table 14. Albedo ($\alpha$) of dominating artificial urban surfaces in Beirut adapted from Oke (1987) (prepared by author)

<table>
<thead>
<tr>
<th>Description of dominating urban surfaces in Beirut</th>
<th>Material compositions in contact with ambient air</th>
<th>Albedo ($\alpha$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facades of buildings</td>
<td>Beige/white paint and plaster</td>
<td>0.7</td>
</tr>
<tr>
<td>Rooftops</td>
<td>Grey concrete slab</td>
<td>0.225</td>
</tr>
<tr>
<td>Roads</td>
<td>Asphalated road surfaces</td>
<td>0.2</td>
</tr>
</tbody>
</table>

5.6 Importance of Investigating Urban Heat Island in Beirut

Based on the above detailed account of the predominantly artificial land cover of Beirut, the small percentage coverage of urban vegetated surfaces, the dense urban fabric and haphazard urban morphology of the city, and the low albedo values of the dominating urban surfaces in Beirut, it is evident that these all contribute to the urban heat island of the city and the respective deterioration of a good quality of life of urban dwellers. This section aims to show that while sustainable urban planning practices are being implemented in many densely populated cities worldwide and with successful results, very few efforts have been made for Beirut. The need to investigate and find solutions for UHI in Beirut is discussed in this section, which is divided into the following sub-sections: 1) sustainable urban planning practices worldwide; 2) haphazard urban planning practices in Beirut; 3) previous climatic and UHI studies in Beirut, and; 4) conclusions and justification for UHI analysis in Beirut.
5.6.1 Sustainable urban planning practices in developing countries

While it is clear that urbanization and industrialization activities improve our material lives and daily comfort they also induce many problems to the surrounding environment, and consequently human health. Consideration of the environmental discipline in urban planning is fast becoming the norm around the world especially with the ever increasing demands and pressure from a legal perspective (EIAs, SEAs and the like). Architects, planners, and environmental experts are joining forces to implement sustainable practices and measures for the future growth and development of cities. Voluntary programs like green building programs are also becoming increasingly popular with rewarding results. As such, cities in developed as well as developing countries worldwide are making major efforts in their quest toward reducing air pollution levels, implementing green areas, gardens and parks, improving public transportation systems, implementing green buildings, and organizing campaigns for raising overall environmental awareness. Examples of such cities include Thailand, Bogota, Curitiba, Denmark, London, Vancouver, Sydney, Barcelona and many more (UNEP [United Nations Environmental Program], 2010). Such sustainable steps are necessary especially when considering the significant rise in population growth, depletion in natural resources, the resulting impacts on the urban microclimate and the consequent effects on the health and comfort of urban citizens.

5.6.2 Haphazard urban planning practices in Beirut. For the case of Lebanon, a small country situated along the Mediterranean Sea, increasing urbanization trends and expansion of its major metropolitan cities of Beirut and Tripoli are being witnessed. Unfortunately, an overview of the history of urban planning practices in Beirut clearly
shows that the existing urban morphology of this city has been molded primarily as a result of the wars and governing mandates that lasted for relatively short periods hence interrupting and disturbing certain urban planning trends initially being practiced and or implemented. For example, regional strife in the 1940s resulted in the influx of Palestinians who accordingly resided in informal refugee camps in the city and across the country thus affecting the existing urban morphology of the city. In such instances, very little consideration was given to the protection of the environment or sustainable planning due mainly to the urgency of the situation to accommodate and house the refugees. These haphazard planning events are the cause of a fast decline in the surrounding environmental quality, including air quality, and urban microclimate (SOER, MOE/UNDP/ECODIT, 2011). Table 8 which provides an overview of the history of urban planning in Lebanon has clearly shown that the environmental context only recently started to be considered in relevant laws and regulations while implementation of protection measures is just barely taking place.

As such, when considering these haphazard trends of urban planning practices in Lebanon, the increasing urban populations (Yassin, 2012), the dominating artificial land cover land uses, and the dense urban fabric and complicated urban morphology, it is evident that impacts on the urban microclimate are significant what with the increasing warming trends\(^\text{27}\), and the resulting increases in heat-related deaths (El-Zein et al., 2004).

Vulnerability to the impacts of urban microclimatic changes in Beirut is therefore high. Upon considering the importance being given to climatic adaptation measures in similar dense cities worldwide, like Athens, the Abu Dhabi, Paris, London, and so on, it

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\(^{27}\) As previously mentioned within the context of the CIRCE studies conducted for Beirut showed an increase in the number of hot days especially during this past decade in Beirut
is concluded that it is important to quantify the UHI in Beirut to identify areas of greatest impacts and to determine the urban parameters that play the most significant role in this regard. The objective is to provide recommendations for mitigation of the UHI from an urban planning perspective in order to improve the overall quality of life and to prevent heat-related deaths (see Figure 42). However, some investigations on climate change and to a certain extent on UHI in Beirut have been conducted as discussed in the subsequent sections.

5.6.3 Previous climatic and UHI studies in Beirut. There exist a few studies and reports related to climate changes and UHI in the existing literature for Beirut. One such report was prepared as part of Lebanon’s Second National Communication on the assessment of future climate risks, vulnerability, and adaptation (MOE/UNDP/ELARD
2011), the sensitivity of human settlements and infrastructure (including wastewater, solid waste, and transport) to climate change is also assessed. As such, although not emphasized per se, the issue of the urban heat island effect is briefly mentioned where the study explains that the increase in hot summer hot days due to climate change will result in intensification of the urban heat island phenomenon (Chapter 9, Table 9-3, pp. 9-14). The major urban agglomerations coupled with the drastic land use changes are listed as being the major reasons giving rise to the UHI. Although it has been recommended to carry out dynamical downscaling experiments to provide more accurate data input for sector impact studies in future works, it has not been mentioned that it would be helpful to actually include urban heat island investigation as part of this downscaling exercise.

Another study worth mentioning within the context of the urban heat island and urban design disciplines in Lebanon includes two UNDP reports on “Climatic Zoning for Buildings in Lebanon” and the “Thermal Standard for Buildings in Lebanon (UNDP/GEF and MPWT/DGU 2005)”. In the first study, Lebanon is divided into four climatic zones (Coastal, Western Mid-Mountain, Inland Plateau and High Mountain) where Beirut falls under the Coastal zone area. These climatic zones were established based upon the review and assessment of four main climatic parameters including temperature, humidity, solar radiation and wind, which all play a major role in impacting the heating and cooling energy requirements in buildings. The second study establishes the thermal standards for buildings in Lebanon based upon their respective climatic zones although one drawback of this study is that it is applicable only to new residential buildings and complexes and does not offer solutions to improve the building envelope of existing residential...
buildings. Having said this, considering that there are significant numbers of “old” buildings that are being demolished and replaced by new buildings (~0.6%), like in Ashrafiyeh, Moussaytbeh, Minet El Hosn, and Ras Beirut areas amongst others, these energy-efficient building standards are important and can prove to be very effective. It is worth noting that these studies indeed mentioned that the reason for the hot microclimate of Beirut is the UHI phenomenon without elaborating any further as this was not the aim of these studies. Two other related studies include the Energy Efficiency Building Code Study and Energy Efficiency Building Road Map (MED-ENEC/EU, 2012) which emphasize the importance of making energy efficiency a fundamental part of the building design and construction process and which accordingly provide the roadmap for successful implementation for Beirut case. Unfortunately these thermal standard codes for buildings and the road map have not yet been approved by the relevant authorities and have therefore not yet been properly adapted. Implementation of these energy efficient thermal building codes would be a major milestone for a sustainable and green development of buildings in Beirut.

A study on the health impacts of urban warming was also carried out focusing on heat-related mortality for the city of Beirut (El Zein, Tewtel-Salem, & Nehme, 2004). This study concluded that there exists a very strong positive correlation between heat related mortality at moderately high temperatures in Beirut and is therefore a serious public health risk in this city which is experiencing increasing hot summer days.

Finally, an important study worth mentioning involved climatic model simulations to investigate the extent of the urban heat island of the Mediterranean cities

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29 This research does not aim to investigate the specific number of buildings that are demolished and replaced by new buildings although the total number of buildings that are being constructed within each cadastral area of Beirut is determined via Google Earth satellite imagery (see Table 21)
of Athens, Alexandria, and Beirut (McCarthy, 2009). In this study, the Met Office Hadley Regional Climate Model (RCM) was used to downscale climate change projections from the Hadley Center Global Climate Model. The RCM typically runs at 25km for a limited area and provides high resolution climate projections. However, even at 25km, variations in land surface types are poorly resolved. To resolve this problem for weather forecasts and climate change studies, the Met Office developed “tiled” surface scheme (similar to TEB) to conduct simulations of the urban heat island in the aforementioned Mediterranean cities. This tiled scheme allows for sub-grid scale variations at the model surface. Each model grid box is composed of a varying mix of five vegetation types (broadleaf tree, needle leaf tree, grass and shrub), and four non-vegetation surfaces (bare soil, inland water, ice, and urban). The transport of heat and water (and consequently near-surface temperature, and humidity) between the atmosphere and surface is then calculated explicitly for each surface type within the grid cell as shown in the schematic in Figure 43.

![Diagram of MOSES2 surface tile scheme](source)

*Figure 43. Schematic representation of the MOSES2 surface tile scheme representing land surfaces within a single model grid cell. Source: McCarthy, 2009; Report on CIRCE, urban heat island simulations*

The urban tile within the MOSES2 is utilized to provide representation of cities at sub-grid resolution. In this study therefore, the urban tile is modeled in a simple way by
introducing a canopy that has the thermal properties of urban elements. This canopy is radiatively coupled to the underlying soil scheme. Figure 44 is a schematic representation of the surface energy balance of the urban canopy model (Best, Grimmond, & Villani, 2006).

\[ Q^* = K^* + \varepsilon_s L \downarrow - \varepsilon_s \sigma T_s^4 \]  
(Equation 9)

Where:
- \( Q^* \) is the net all-wave Radiation,
- \( K^* \) the net shortwave radiation,
- \( L \downarrow \) the downward long-wave radiation,
- \( \varepsilon \) is the emissivity and
- \( \sigma \) the Stefan Boltzmann\(^{30} \) constant.

\( \sigma \) The Stefan Boltzmann law describes the power radiated from a black body in terms of its temperatures. The Stefan Boltzmann constant is the constant of proportionality in the Stefan-Boltzmann law.
In addition, the emissivity of the ground (subscript g) and the surface (s) are assumed to be 1. The terms $Q_H$ and $Q_E$ are the turbulent sensible and latent heat fluxes respectively, and $Q_G$ is the energy exchange between the canopy and the underlying soil.

There are relatively few parameters used for the urban tile and these include surface albedo, aerodynamic roughness length, and heat capacity (as opposed to TEB which considers many more parameters as highlighted later). In addition the urban surface is considered impermeable, increasing surface runoff, and limiting evaporation to water lying on the surface following precipitation. If the urban surface is dry there is no evaporation. It is also worth noting that the model contains no information about the true morphology of cities, and the tile scheme cannot describe the spatial distribution of different surface types within a grid cell.

Therefore, although this tiled scheme is somewhat similar to the TEB scheme, which is selected as the most suitable model for conducting UHI analysis for the Beirut case as discussed in more detail in Chapter 6 of this thesis, in that they are both tiled schemes and function on the basis of the surface energy exchange equation, it is in fact a much simpler model which does not consider the energy exchange between the main urban surfaces that characterize the city such as walls, rooftops and roads (as considered in TEB) and in addition it does not consider important urban parameters like heat conductivity or emissivity of these urban surfaces, not to mention that it is based on a much larger regional scale of study. Moreover, it is worth noting that the model aimed to replicate the results of previous studies conducted for characterization of urban heat island as in the case of the city of Athens for example (Kassomenos & Katsoulis, 2006). Furthermore, the model assumed that the Mediterranean region has low soil moisture
resulting in low heat capacity of soil and vegetation surfaces which in turn yield a large
diurnal temperature range in the region. The urban tile therefore reduces the night cooling
rate resulting in a larger night time urban island for the Mediterranean in the summer as
seen for the case of Beirut for example where a large summer diurnal temperature range
for non-urban areas around Beirut resulted in a large UHI in excess of 7°C during the
summer season (July and August), while in Athens and Alexandria, the simulated average
night time UHI was found to be much less, at an order of 2°C to 3°C, bearing in mind that
the model was aiming to also replicate the results of previous studies. Figure 45 shows
the UHI magnitude of minimum temperatures of these three modeled cities and illustrates
the large UHI magnitude found for Beirut in comparison to the cities of Alexandria and
Athens for the aforementioned reasons, namely the low soil moisture characteristics
assumed for the Mediterranean region.

Figure 45. Annual difference in UHI magnitude between three Mediterranean cities adapted from
McCarthy, 2009: Report on CIRCE, urban heat island simulations

Hence, McCarthy’s simulations showed that Beirut exhibited the largest summer
heat island out of the three cities indicating the significance of this phenomenon in this
dense Mediterranean city but mainly because of the nature of the data input into the tiled
scheme not to mention that approach that was used to replicate data from previous studies. Nevertheless, this was the first study that was conducted for the UHI in the Mediterranean region including Beirut where the simulations provided a preliminary indication for the growing significance of this phenomenon over Beirut (and Alexandria and Athens) and its associated implications on the environment although it applied a rather broad and simplified scheme for its simulations.

5.6.4 Conclusions and justification for UHI analysis in Beirut. Based on the above overview of the haphazard urbanization trends in Beirut, the rising urban populations due to rural exodus, the low albedo of the dominating urban materials, the rising number of hot summer days especially over this past decade, and the associated human health impacts and heat-related mortality, it is imperative that more detailed studies are carried out to investigate the urban parameters of the existing urban form of the city which have the most significant effect on UHI. Although a preliminary analysis of UHI in Beirut was previously conducted (McCarthy, 2009), this study adapted a very simple scheme for conducting the analysis, based on a regional climatic model, which did not take into consideration the main urban parameters that can exacerbate the UHI effect as such and which can accordingly be corrected if the proper urban planning measures are implemented. In addition this analysis did not consider different scenarios which could potentially be implemented to identify the best mitigation solutions and actions from an urban planning perspective for the city of Beirut. This is in fact the context of this thesis therefore which first assesses and identifies the urban characteristics of greatest significance on the UHI of Beirut and which accordingly proposes mitigation measures within the context of the sustainable urban planning of the city.
PART IV: UHI IN BEIRUT
Part IV of this thesis on the UHI in Beirut is comprised of the following two main chapters: 1) the research methodology adopted for this research including the rationale for the selections made with regards to measurement type and modeling scheme for the Beirut case, and 2) the numerical analysis which includes the simulation results of the UHI in Beirut based on the collected data which are run on TEB and the specific scenarios devised for the purpose of this research and the results.

**Chapter 6: Research Methodology**

This chapter describes the specific methodology adopted by this research to conduct an analysis of the urban parameters that play the most significant role in exacerbating the UHI in Beirut to consequently recommend feasible mitigating solutions from an urban planning perspective. The chapter is accordingly divided into four main sections: the first and second sections explain the rationale made for the selection of the most suitable measurement type and modeling schemes for UHI analysis in Beirut respectively; the third section identifies the nature of data required to carry out the simulations on TEB in Beirut, and; the fourth and final section of this chapter describes the data collection process, the gap between the required data and the availability of data and respective measures taken to overcome this gap giving an account of some associated challenges during this process.

**6.1 Selection of Measurement Type for Beirut Case**

The literature review part of this thesis gave an outline of the various type methodologies typically employed for UHI measurement and these included fixed and/or mobile traverses, high resolution aerial orthophotos and thermal remote sensing techniques. In this chapter, several criteria are selected and used upon which the decision for most feasible type-methodology for temperature measurements for the Beirut case
was based. These criteria include namely: 1) associated costs; 2) coordination with relevant authorities; 3) permitting processes; 4) equipment availability; 5) training requirements; 6) timeline; 7) traffic congestion; and 7) allocation of suitable equipment set-up locations as necessary (see Table 15). This section is therefore divided into two parts: the first describes the elimination process and the second describes the collection of data from existing weather stations which are selected for the purpose of this research.

Table 15. Criteria for comparison of various available measurement tools

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Fixed traverses</th>
<th>Mobile traverses</th>
<th>Aerial orthophotos</th>
<th>Thermal remote sensing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Associated costs</td>
<td>High</td>
<td>High</td>
<td>Very high</td>
<td>Low</td>
</tr>
<tr>
<td>Coordination with authorities</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Permitting</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Availability of equipment</td>
<td>Not available</td>
<td>Not available</td>
<td>Not available</td>
<td>Not available</td>
</tr>
<tr>
<td>Training requirements</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Not applicable</td>
<td>Required</td>
</tr>
<tr>
<td>Timeline</td>
<td>Long</td>
<td>Long</td>
<td>Moderate</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Traffic congestion</td>
<td>Expected</td>
<td>Expected</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Allocation of set-up locations</td>
<td>Required</td>
<td>Required</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

6.1.1 Elimination process. First, the choice of using fixed or mobile traverses to measure the urban diurnal temperature patterns over a set period of time be it winter or summer season, or both, was not found to be feasible. This was due to the high associated costs required to purchase the necessary measuring instruments; although specific quotations were not obtained for these instruments, some inquiries showed that this would indeed prove to be the case. Another constraint involved the potential difficulty in finding suitable locations to set up the instruments since this would require coordination.
and official no-objection certificates or permits from the relevant authorities, involved property owners and concerned municipalities. The application of this type-methodology would have been time-consuming and the results may in all probability not have been very reliable especially given the uncertain political situation in the country as well as in the region, and where sectarian strife may have potentially prevented or interrupted continuous and proper measurements. Similar obstacles were associated with mobile traverses where such equipment that can typically be installed on bicycles or cars for example would have been difficult to obtain due to the associated costs, unavailability, and potentially long shipment times if purchased. Traffic congestion would have been another one of the main problems encountered if measurements were to be conducted by application of this methodology at a specified time of day or night taking into consideration the significant traffic congestions in and around Beirut whether during or off-peak hours.

Second, the choice of using high resolution aerial orthophotos also proved to be challenging, the reasons being partly due to even higher estimated costs associated with either the purchase of the high resolution photos themselves, which are not available for sequential years, and which would have been necessary to carry out an in-depth study of the UHI. If the choice of renting aircraft were to be considered, this would have proved to be even more difficult as aircraft in Lebanon with the necessary equipment are not open for public use, not even for post-graduate students for that matter, as they generally are in the U.S.A. or other more advanced cities across Europe. Use of aircraft in Lebanon for such cases is restricted to military use.
Finally, regarding thermal remote sensing data, according to the remote sensing department at the CNRS (National Council for Scientific Research or Conseil National de Recherches Scientifiques), the availability of the required data is not sufficient with many apparent gaps in data. Remote sensing data is typically obtained from LANDSAT or MODIS. Figure 46 is a LANDSAT image taken in May of 2000 at 08h12min showing relatively high surface temperatures, for this early time of the day, represented by yellow and red ranging from 33 to 47°C in Beirut as opposed to the lower surface temperatures ranging from 18.5 to 30°C represented by green in the suburban and rural areas to the east and south of Beirut city. It is expected that a thermal remote sensing image taken at midday in Beirut would show much higher surface temperature records. Recent thermal images and data are unavailable, discontinuous, or unclear. It is also worth noting that thermal images provide data for surface temperatures as opposed to air temperatures and since this research is focused primarily on the latter this method for temperature measurements was eliminated.
Figure 46. Surface temperatures dated 21 May 2000 at 8h12min courtesy of LANDSAT 7 ETM+
6.1.2 Selection of records from existing weather stations in Beirut. The aforementioned methodologies were not found to be feasible for the Beirut case given the associated time constraints, required permitting and coordination requirements with relevant authorities, not to mention the curiosity factor and/or suspicious nature of local inhabitants which might have been cause for even further unexpected delays in work progress and discontinuity in results.

Hence, it was found that the most feasible measurement approach in this regard was to collect pre-existing historical as well as recent present climatic records from the relevant authorities, institutions and concerned parties in order to analyze their relevance for the UHI case of Beirut. As such, climatic records were gathered from two pre-existing weather stations for the purpose of this research including:

1) **The old observatory at the AUB** located at sea-level on the campus of the university at Latitude 33°54’2.09”N and Longitude 35°28’48.34”E (see Figure 47). This station, surrounded by a dense urban fabric, but which is in fact located in a low-density urban fabric with numerous green spaces, began its operation in 1875 up until 1975, which marked the start of the civil war in Lebanon. Since then, two additional weathering stations have been installed at the AUB campus however it was not possible to attain any records from these university weather stations during the time of this research study even though several unsuccessful attempts were made. Such records are typically provided to AUB students or to authorities that officially request the data but are associated with fees. Having said this, the records obtained from the old observatory, which is readily available in all relevant authorities, was sufficient for investigation of
historical or climatic maximum and minimum temperature trends in the Beirut area.

2) *The Fanar station*, located at approximately 3.5 km to the east of Beirut River at Latitude 33° 52’ 49.95” and Longitude 35° 33’ 59.09” at an elevation of 90 m ASL, in a medium density urban area (see Figure 47). This station, which is operated by the Lebanese Institute for Agricultural Research (LARI), started its operation in 2009. Records were collected and accordingly compiled from the year 2009 to 2012 for the numerical analysis section of this research (see Chapter 7).

It should be noted that there are indeed three other weather stations situated within or outside Beirut city which were considered (see Figure 47) but which were not found to be suitable for the purpose of this research as explained in Table 16. As a concluding remark therefore, it is worth noting that the weather records from the old observatory at AUB and the Fanar weather station were obtained without any difficulty which made it possible to accelerate the data collection process for at least this part of the research. The records were found to be fully comprehensive without any missing records or information. There was however a difference in the parameters provided whereby for example the records for Fanar were more comprehensive consisting of relative humidity, solar radiation, wind speed, and many other parameters deemed useful for the purpose of this research, while for AUB the records were comprised mainly of minimum and maximum temperature records but dated back from over a century ago which allowed for assessment of historical weather patterns.
Figure 47. Location of five weather stations within and outside of Beirut. *Source:* Google Earth, 2013
Table 16. Data on climatic stations within and outside Beirut administrative area

<table>
<thead>
<tr>
<th>Stations</th>
<th>Coordinates</th>
<th>Location with respect to Beirut</th>
<th>Years data available</th>
<th>Applicability</th>
</tr>
</thead>
<tbody>
<tr>
<td>AUB old observatory</td>
<td>x=35.480094 y=33.900581, z=25m</td>
<td>In Beirut</td>
<td>1875-1975</td>
<td>Recent records are not available however this station was selected and climatic records were used to study historic weather patterns and relation to population growth.</td>
</tr>
<tr>
<td>Fanar</td>
<td>x=35.55230556 y=33.88411667, z=90m</td>
<td>3.5 km east of Beirut</td>
<td>2009-2012</td>
<td>This station was selected and records were used for TEB atmospheric forcing</td>
</tr>
<tr>
<td>Bir Hassan</td>
<td>x=35.49125278 y=33.85714167, z=40m</td>
<td>1 km south of Beirut</td>
<td>2009-2012</td>
<td>Operation not continuous and relevant records were not sufficient for analysis =&gt; not selected</td>
</tr>
<tr>
<td>Abdeh</td>
<td>x=35.98777778 y=34.52083333, z=15m</td>
<td>60 km north of Beirut</td>
<td>2009-2012</td>
<td>Situated at a significant distance from study area therefore not used for the purpose of this thesis =&gt; not selected</td>
</tr>
<tr>
<td>Rafik Hariri International Airport</td>
<td>x=35.4883 y=33.8211, z=0</td>
<td>3 km south of Beirut</td>
<td>1931- Present</td>
<td>Records were not accessible for collection or purchase =&gt; not selected</td>
</tr>
</tbody>
</table>

6.2 Selection of Modeling Scheme for Beirut Case

Modeling was deemed necessary for the purpose of this research to identify areas of significant UHI intensity in Beirut and to accordingly recommend mitigation measures to reduce the UHI impacts as such. The simulation results help to determine urban geometric parameters that play a key role in exacerbation of the UHI. Thereby, any deficiencies existing in the urban planning, environmental, engineering and architectural sectors would be identified thus giving credibility to future recommendations that would
essentially be made for these sectors for alleviation and control of UHI. The concept of
UHI modeling and simulations is in itself a novelty for Beirut city.

As such, regarding the choice of the most suitable model to carry out the
necessary simulations for the UHI of Beirut, as a start, a rigorous review of the available
literature on the topic showed that there are numerous numerical as well as empirical
models that have been developed worldwide for the purpose of analyzing UHI (see
Chapter 4). Several important comparative studies have also been previously conducted
in this regard including the works of Bozonnet et al. (2013), Colombert (2008),
Grimmond et al. (2011), Hidalgo et al. (2008), and Masson (2006), as well as many
others. In this research, an assessment of nine urban surface modeling schemes was
carried out whereby the various advantages and disadvantages of these models was
assessed and/or highlighted and it was found that in a preliminary step, the Town Energy
Balance (TEB) was the most suitable of these models.

In this chapter, the choice for the most suitable modeling scheme for the Beirut
context was carried out by a process of elimination. As a start, based on the scale of
simulations criterion, three out of the nine modeling schemes that are applied typically
for small scale or microscale simulations were eliminated from the list including SM2-U,
ENVI-met, and NARPS-LUMPS since the aim of this research is to conduct simulations
for the whole city of Beirut and therefore at the mesoscale or the urban planning/town
scale. The SVTS model applied for global scale simulations was also eliminated for the
same purpose. Then, SOLENE, developed by CERMA laboratory, was also eliminated
since it is applied typically for small scale analysis and also due to its weaknesses in
assessment of energy consumption of buildings (Bozonnet et al., 2013), a very important
factor when considering analysis of UHI intensity in dense urban areas. For the remaining four mesoscale urban modeling schemes, including the two single layer urban canopy models developed by Masson (2000), and Kusaka et al. (2001), and the two multi-layer urban canopy models developed by Ca et al. (1999), and Martilli et al. (2002), the selection was made by assessing the nature of data as well as the availability of the data required to run the simulations. This was deemed to be an important criterion for the selection process since as previously mentioned there is limited data in the Beirut study area. As such, regarding the single-layer canopy models, it was found that the urban canopy model developed by Kusaka et al. (2001) requires reproduction of an urban surface consisting of several canyons with different orientations, and therefore more specific data, whereas the Town Energy Balance (TEB) model, developed by Masson (2000) considers only one canopy layer characterized by a simple urban fabric, and therefore less data input. As for the multi-layer urban canopy models, it was found that the model developed by Martilli et al. (2002) is typically applied for specific analysis objectives such as the impact and feedback between canyon air and air conditioning while the model developed by Ca et al. (1999) needs very accurate and detailed data on the volume that is occupied by each building in the canyons for example. Thus, based on this approach and considering the limited data availability for Beirut, the TEB model was selected, which is not attached to the details between existing buildings but rather to the overall characteristics of the urban fabric, and is therefore the most suitable urban surface exchange modeling scheme for the Beirut case. Having said this, this architectural simplification of TEB can in itself be seen as a limitation.
In a similar study comparing six modeling schemes for the city of Paris, including ENVI-met, SOLENE, NARP-LUMPS, SM2-U, TEB and FVM, the application of five select criteria focusing on the nature of data entry and outputs of the model again showed that TEB was the most feasible modeling scheme for analysis of UHI in the city for similar reasons as those discussed above (Colombert, 2008). These criteria primarily included: fine representation of the built environment; representation of the whole city; consideration of vegetation; heat flux of anthropogenic origin; and, consideration of thermal and radiative characteristics of urban materials. The TEB modeling scheme was found to be sufficient as an indicator for main urban parameters of concern to be considered for the urban planning of Paris just as it was found to be suitable in this research for the case of Beirut. Therefore TEB, which considers mainly building, road, and vegetation fractions, was selected for the purpose of this research.

Figure 48 below is a flow chart showing the elimination process carried out for the most suitable modeling scheme for UHI analysis for the Beirut case.
Further assessment of the TEB model for the Beirut case was carried out based on: validity; availability; associated costs; and, training requirements as listed below. This was done to plan the feasibility and timeline for each stage of the project.

*Figure 48.* Flow chart showing elimination process for modeling schemes and selection of TEB for UHI simulations in Beirut (prepared by author)
1. Validity: the use of this model has been validated in several important studies (Lemonsu and Masson, 2002; Lemonsu, Grimmond, and Masson, 2004; Masson, Grimmond, and Oke, 2002);

2. Availability: the model can be made available from Météo France further to obtaining recommendations and filling out all necessary paperwork;

3. Associated costs: the offline version of TEB/SURFEX can be downloaded for free further to receiving the special code and login or alternatively it can be obtained without any associated fees directly from Météo France with recommendation from affiliated academic institutions.

4. Training requirements: an intensive three-day training course at CNRM at Météo France in Toulouse, France.

6.3 Data Collection and Compilation for Beirut

After having selected the TEB model to conduct the UHI simulations for the city of Beirut, the next step required the actual collection of the data based on the identification of the exact nature of data required to run the simulations on TEB. This section of the research therefore provides details on: 1) determination of the nature of the data required for the assessment and analysis of the UHI in Beirut using the TEB model; 2) the data collection process for the Beirut case; 3) the data which are required but which are not available, and 4) respective measures taken to compile, manage and finalize the required data for analysis of UHI in Beirut using TEB. The flow chart in Figure 49 below illustrates these various steps taken in the data collection process:
6.3.1 Nature of data required to run simulations on TEB. This section therefore describes the nature of data required to run the simulation on TEB. To recap, the SURFEX model is comprised of four main cover fractions (Equation 10) where the TOWN or TEB cover fraction is the tile of relevance for the purpose of this research for Beirut. The TEB tile is comprised of three types of cover fractions representing urban towns including buildings, roads, and gardens (Equation 11). In TEB, the relevant data associated with these covers can be entered within cells or grid sizes that range from 200 x 200m up to 1000 x 1000m. For the Beirut case the smallest cell size was selected in order to more accurately simulate the required data.

As for the garden part, this includes three types of vegetation covers including high vegetation (HVEG) such as trees for example, low vegetation (LVEG) such as grass, and no vegetation (NVEG) represented by bare soils (Equation 12). Table 17 is a compilation of the nature of data required to run the simulations for analysis of UHI using the TEB/SURFEX model.
NATURE + WATER + SEA + TOWN = 1  
(Beginning of Equation 10)

BLD + ROAD + GARDEN = 1  
(Equation 11)

HVEG + LVEG + NVEG = 1  
(Equation 12)

Climatic records are also required to run or “force” the simulations on TEB. In Beirut city, the weather is fairly moderate during the winter season although records show a warming trend for the summer season over the past decade. Humidity levels are relatively high especially during the summer period considering that Beirut is a coastal city and wind speeds are quite low in general during both winter and summer seasons. Table 18 is a list of the climatic parameters that are required to force the simulations on TEB for the case of Beirut and generally include wind speed, air temperatures, direct short-wave radiation, and long-wave radiation amongst others. Of course it is worth noting that snow and is not applicable for Beirut as explained in Table 18 below.
Table 17. Nature of data required to run TEB

<table>
<thead>
<tr>
<th>Cover Type</th>
<th>Description of data required for TEB cover fractions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buildings</td>
<td>Walls: Area of walls; number of layers; thicknesses; albedo; thermal conductivity; heat capacity. Floors: Internal floor area; number of layers; thicknesses; thermal conductivity; heat capacity. Roofs: Area of roofs; number of layers; thicknesses; albedo; thermal conductivity; heat capacity. Windows: Glass Ratio. Others: Building height.</td>
</tr>
<tr>
<td>Roads</td>
<td>Roads areas; number of layers; thicknesses, albedo; thermal conductivity; heat capacity; fraction of roads.</td>
</tr>
<tr>
<td>Gardens</td>
<td>Type of vegetation: bare soil, low (NVEG) vegetation (LVEG) or high vegetation (LVEG); leaf area index (LAI) of different vegetation types; fraction of gardens.</td>
</tr>
</tbody>
</table>

Source: Masson, 2000; [www.cnrm.meteo.fr/surfex-lab](http://www.cnrm.meteo.fr/surfex-lab)

Table 18. Forcing / climatic data / files required for TEB/SURFEX and necessity for Beirut case

<table>
<thead>
<tr>
<th>Forcing file name</th>
<th>Forcing file description</th>
<th>Units</th>
<th>Necessity for Beirut case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forc_DIR</td>
<td>Wind direction</td>
<td>Degrees from N, clockwise</td>
<td>Required (obtained from Fanar weather station)</td>
</tr>
<tr>
<td>Forc_DIR_SW</td>
<td>Direct short-wave radiation</td>
<td>W/m²</td>
<td>Required and calculated with assistance from Valéry Masson Météo France</td>
</tr>
<tr>
<td>Forc_LW</td>
<td>Long-wave radiation</td>
<td>W/m²</td>
<td>Required (obtained from Fanar weather station)</td>
</tr>
<tr>
<td>Forc_PS</td>
<td>Atmospheric pressure</td>
<td>Pa</td>
<td>Not required</td>
</tr>
<tr>
<td>Forc_QA</td>
<td>Atmospheric humidity</td>
<td>kg/kg</td>
<td>Required (obtained from Fanar weather station)</td>
</tr>
<tr>
<td>Forc_SCA_SW</td>
<td>Diffuse short-wave radiation</td>
<td>W/m²</td>
<td>Required (obtained from Fanar weather station)</td>
</tr>
<tr>
<td>Forc_SNOW</td>
<td>Snow precipitation</td>
<td>kg/m²/s</td>
<td>Not required</td>
</tr>
<tr>
<td>Forc_TA</td>
<td>Atmospheric temperature</td>
<td>K</td>
<td>Required (obtained from Fanar weather station)</td>
</tr>
<tr>
<td>Forc_WIND</td>
<td>Wind speed</td>
<td>m/s</td>
<td>Required (obtained from Fanar weather station)</td>
</tr>
<tr>
<td>Forc_RAIN</td>
<td>Rain precipitation</td>
<td>kg/m²/s</td>
<td>Required (obtained from Fanar weather station)</td>
</tr>
</tbody>
</table>

Source: [www.cnrm.meteo.fr/surfex-lab](http://www.cnrm.meteo.fr/surfex-lab)
6.3.2 Collected data for Beirut case. During the data collection process it was found that in general there is no single authority in Beirut administrative area that has complete compilation of data as they pertain to buildings, roads or vegetation for example. In addition, obtaining the relevant data was a challenging task because generally the concerned parties were either hesitant to part with the data unless a considerable payment was made or because the data was not considered to be open for public or personal use. A collaborative approach may have been more successful in this regard. Having said this, some authorities were willing to provide the requested data and were helpful. Table 19 is a compilation of the data collected from various governmental authorities and academic institutions in Lebanon.

Table 19. Physical data collected for TEB analysis for Beirut from relevant authorities and institutions in Lebanon

<table>
<thead>
<tr>
<th>Names of Governmental Agencies</th>
<th>Data Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direction des Affaires</td>
<td>Aerial image 2008, 15-20 cm pixel identifying number of floors for buildings in Beirut.</td>
</tr>
<tr>
<td>Geographiques</td>
<td></td>
</tr>
<tr>
<td>Council for Development &amp;</td>
<td>Land use classifications in Beirut</td>
</tr>
<tr>
<td>Reconstruction (CDR)</td>
<td></td>
</tr>
<tr>
<td>Central Administration of</td>
<td>Data on number of buildings in Beirut (2004)</td>
</tr>
<tr>
<td>Statistics (CAS)</td>
<td></td>
</tr>
<tr>
<td>Lebanese Agricultural Research</td>
<td>• Meteorological mean monthly records from the 5 weather stations for the period from 2009 to present:</td>
</tr>
<tr>
<td>Institute (LARI)</td>
<td>1. Ain el Abou</td>
</tr>
<tr>
<td></td>
<td>2. Akoura</td>
</tr>
<tr>
<td></td>
<td>3. Byr Hassan</td>
</tr>
<tr>
<td></td>
<td>4. Ghazir</td>
</tr>
<tr>
<td></td>
<td>5. Tarchich</td>
</tr>
<tr>
<td></td>
<td>• Meteorological records for Fanar station from the period 2000 to 2012.</td>
</tr>
</tbody>
</table>
6.3.3 Data extrapolation for Beirut case. At this stage, after having identified the nature of data required to run the simulations on TEB and after having obtained relevant data from various governmental authorities and academic institutions in Lebanon depending on their availability, the data that was still missing was identified. This included for example data urban geometric parameters as well as material compositions which are necessary to run the urban heat island simulations on TEB. After consulting with the Central Administration of Statistics (CAS), the authority in charge of collecting and gathering all data and statistics of this nature in Lebanon, it was discovered that although this type of data is not available at present time, a campaign for collection and digitization of this type of data on buildings is being planned for the near future.

Deficiency of this type of data was further confirmed by consulting with the Order of Engineers and Architects. As for the roads and vegetation parameters, again data was found to be limited. Therefore by meeting with concerned authorities, consulting with the relevant experts, conducting site visits and using the general available information from satellite and aerial images, the required data was collected and compiled and prepped to run simulations on TEB although it is worth noting that since absolute values were not
available the data that was collected and compiled was based on extrapolations rather than precise values. In fact, data extrapolation was facilitated by using ArcGIS software. The processes for data preparation of the required urban parameters for analysis on TEB, missing or otherwise, are described in more detail in the sections below.

6.3.3.1 Buildings. Due to limited data on existing buildings in Beirut in general, it was found that the most suitable way to gather relevant data was to first determine the age of buildings. As such, all other associated data, including façade and roof materials, and internal floorings, would be able to be determined since respective contractors used typical materials for construction purposes at specific time periods during the history of urbanization of Beirut. For example, during the 1970s, contractors used mainly concrete masonry units for the facades of buildings and painted over them with a thin layer of either white or beige coloured layers of coatings. As for the roofs, no insulation or waterproofing was used at this time, as these were introduced later in the mid to late 1980s. As such, the roofs were either painted with a very thick coating over a relatively thick concrete roof slab (20-30cm) or were just left as is.

Hence, based on historical urban development of Beirut dating from the early 20th century, the age of buildings in Beirut administrative area was categorized into the following age groups: i) <1948; ii) 1948-1970; iii) 1970-1992; and iv) >1992. Accordingly, aerial images of Beirut were obtained from the military department “Direction des Affaires Geographiques” for the years 1971, 1998 and 2008 (1:20,000 scale and digital for 2008). These years were deemed sufficient for this step of the analysis although earlier images were available for the 1956 and 1962 but at much smaller scales.
(1:3750 and 1:5000 respectively). The images were therefore overlaid in the ArcGIS software program and by extrapolation it was possible to match the available digitized version of the existing buildings to one of the aforementioned age groups (see Figure 50). Those built prior to the year 1948 are few in number, are sparsely scattered, and are generally easily identifiable hence did not require application of this type-methodology. Instead, site visits were conducted for validation purposes. Since buildings belonging to this age group are few in number, impacts on thermal levels are not considered to be significant. All data that was collected pertaining to buildings was confirmed with the concerned experts and professionals in the field. Table 20 is a list of all data compiled relevant to building facades in Beirut based on their respective age group.

![Figure 50. Identification of building age groups in Beirut by extrapolation on ArcGIS of aerial images for the years 1971, 1998, 2008. Source (aerial images): Direction des Affairs Geographiques.](image_url)
Since the aerial image which was used in the data management process for building is dated from the year 2008, some changes are expected to have taken place since then in terms of development and demolition of buildings and structures in Beirut but these are in fact only minor changes as confirmed by recent satellite imagery on Google Earth (dated 2014). As such, any potential effects on the numerical analysis process are expected to be negligible. It is worth noting that upon comparing the satellite image of Beirut dated 2009 with that dated 2014 it is found that the highest fraction of new building constructions took place in the Moussaytbeh and Mazraa areas toward the south, followed by Minet el Hosn, near the Port area to the north, and Ashrafiyeh, again toward the north. All administrative areas witnessed new building constructions except for Rmeil and Medawar to the east. This could be attributed to lower demand and land availability in these two areas.

In all, it was found that there are a total of 34,746 buildings in Beirut administrative area for all age groups (see Table 21) where the bulk or approximately 90% of the buildings in Beirut were constructed during the Independent Era from the 1940s to 1970s what marked the start of the civil war in Lebanon. New building constructions account for 0.6% of the total new building stock of Beirut city.
Table 20. Data on building wall layers in Beirut depending on building age group adapted from Oke (1987) (prepared by author)

<table>
<thead>
<tr>
<th>Building Age Group</th>
<th>Number of wall layers</th>
<th>Description of wall materials</th>
<th>Thickness of wall materials (cm)</th>
<th>Albedo ($\alpha$) of first layer in contact with ambient air</th>
<th>Emissivity ($\varepsilon$) of first layer in contact with ambient air</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1948</td>
<td>2</td>
<td>Beige/white paint and plaster Sandstone</td>
<td>4</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>1948-1970</td>
<td>2</td>
<td>Beige/white paint and plaster Hollow block/ cementitious with sand and gravel</td>
<td>4</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>1970-1992</td>
<td>2</td>
<td>Beige/white paint and plaster Concrete masonry unit (CMU)</td>
<td>4</td>
<td>0.7</td>
<td>0.9</td>
</tr>
<tr>
<td>&gt;1992</td>
<td>5</td>
<td>Limestone White/beige paint and plaster Hollow block Plaster Natural stone</td>
<td>3</td>
<td>0.275</td>
<td>0.9</td>
</tr>
</tbody>
</table>


Table 21. Building count in each age group (prepared by author)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Ashrafieh</td>
<td>5,634</td>
<td>296</td>
<td>25</td>
<td>21</td>
<td>5,976</td>
<td></td>
</tr>
<tr>
<td>Ain el Mreisse</td>
<td>6</td>
<td>959</td>
<td>85</td>
<td>67</td>
<td>1,123</td>
<td></td>
</tr>
<tr>
<td>Bachoura</td>
<td>1,030</td>
<td>17</td>
<td>5</td>
<td>7</td>
<td>1,059</td>
<td></td>
</tr>
<tr>
<td>Mazraa</td>
<td>6,923</td>
<td>737</td>
<td>107</td>
<td>53</td>
<td>7,820</td>
<td></td>
</tr>
<tr>
<td>Medawar</td>
<td>882</td>
<td>336</td>
<td></td>
<td></td>
<td>1,218</td>
<td></td>
</tr>
<tr>
<td>Minet el Hosn</td>
<td>1</td>
<td>517</td>
<td>60</td>
<td>26</td>
<td>27</td>
<td>631</td>
</tr>
<tr>
<td>Moussaytbeh</td>
<td>5,459</td>
<td>598</td>
<td>54</td>
<td>64</td>
<td>6,175</td>
<td></td>
</tr>
<tr>
<td>Port</td>
<td>2,48</td>
<td>23</td>
<td>44</td>
<td>7</td>
<td>322</td>
<td></td>
</tr>
<tr>
<td>Ras Beirut</td>
<td>13</td>
<td>4,317</td>
<td>571</td>
<td>128</td>
<td>19</td>
<td>5,048</td>
</tr>
<tr>
<td>Rmeil</td>
<td>3,132</td>
<td>73</td>
<td>13</td>
<td></td>
<td>3,218</td>
<td></td>
</tr>
<tr>
<td>Saife</td>
<td>1</td>
<td>512</td>
<td>44</td>
<td>54</td>
<td>1</td>
<td>612</td>
</tr>
<tr>
<td>Zoukak el Blatt</td>
<td>1,334</td>
<td>188</td>
<td>21</td>
<td>1</td>
<td>1,544</td>
<td></td>
</tr>
<tr>
<td>Grand Total</td>
<td>21</td>
<td>30,947</td>
<td>3,028</td>
<td>544</td>
<td>206</td>
<td>34,746</td>
</tr>
<tr>
<td>% Bldg. Stock</td>
<td>0.06%</td>
<td>89.1%</td>
<td>8.7%</td>
<td>1.56%</td>
<td>0.59%</td>
<td></td>
</tr>
</tbody>
</table>

6.3.3.2 Internal floors. Data on internal flooring was also required to run the simulations on TEB-BEM. While flooring materials have no direct contact with outside ambient air temperatures and accordingly UHI, their thermal properties, namely thermal conductivity \((k)\) and heat capacity \((C)\), can have indirect effects on UHI since for example the warmer the effects of the respective flooring materials on indoor air temperatures the more significant the demand on energy use via operation of air conditioners, resulting in higher releases of air polluting emissions into the atmosphere thus exacerbating the warming effects of the UHI especially during the summer season. On the other hand, the cooler the effects of the flooring materials the higher the energy consumption demands during the winter season for domestic heating purposes. The activation of the internal flooring thermal data in TEB falls under the BEM (building energy model) application of SURFEX.

Therefore, once the age of the buildings was verified, it was then possible to determine the internal flooring materials, their respective number of layers, thicknesses
and thermal properties which were adapted from Oke (1987) (see Table 22). As before, contractors used typical flooring materials at specific time periods, but not much change was found in this regard from the late 1940s to present day. In fact, contractors typically used and continue to use 5 layers of floorings comprised primarily of the lowermost layer of concrete slab, followed by soft gravel, plaster, terrazzo (from the 1940s to 1970s), replaced more commonly by ceramic, marble or natural stone from the 1970s to present day, followed by the uppermost layer of plaster coating. As reference was being made to Oke (1987) for the respective thermal values of the flooring materials in question, there was no listing found for ‘terrazo’ and ‘soft gravel’. Approximate values were therefore applied based on other similar materials types. The lower the thermal conductivity ($k$) of the flooring material, the better the product is at unblocking unwanted heat gain whereas the opposite applies to materials with higher $k$ values. In addition, the higher the heat capacity ($C$) of a specific material the greater the ability of that material to trap and retain the heat making it more suitable for construction purposes in cold climates. Table 22 is a list of the internal flooring materials typically applied for buildings in Beirut. As can be seen these are generally similar in all age-groups and have generally low to moderate heat capacities and thermal conductivities thus their heat retaining properties are moderate.
Table 22. Data on internal floor materials of buildings in Beirut based on age group category (prepared by author)

<table>
<thead>
<tr>
<th>Age-group</th>
<th>Number of layers</th>
<th>Materials</th>
<th>Thicknesses (cm)</th>
<th>Heat capacity (Jm⁻³K⁻¹)</th>
<th>Thermal conductivity (Wm⁻²K⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1948</td>
<td>5</td>
<td>Concrete slab (aerated)</td>
<td>35</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soft gravel</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>4</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terrazzo</td>
<td>2.5</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>1.4</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td>1948-1970</td>
<td>5</td>
<td>Concrete slab</td>
<td>35</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soft gravel</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>4</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Terrazzo</td>
<td>2.5</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>1.4</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td>1970-1992</td>
<td>5</td>
<td>Concrete slab</td>
<td>30</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soft gravel</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>4</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ceramic/marble/natural stone/terrazzo</td>
<td>1.4</td>
<td>2.25</td>
<td>2.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>0.3</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td>1992-present</td>
<td>5</td>
<td>Concrete slab</td>
<td>30</td>
<td>0.28</td>
<td>0.08</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Soft gravel</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>4</td>
<td>1.4</td>
<td>0.46</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ceramic/marble/natural stone/terrazzo</td>
<td>1.4</td>
<td>2.25</td>
<td>2.19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Plaster</td>
<td>0.3</td>
<td>1.4</td>
<td>0.46</td>
</tr>
</tbody>
</table>

6.3.3.3 Windows. Data on windows was also necessary to run simulations on TEB because glass has a relatively low heat capacity (1.66Jm⁻³K⁻¹ x 10⁶) and can therefore raise temperatures and trap heat inside buildings thus raising internal building temperatures. This in turn sets off the use of air-conditioning systems which impacts the UHI via anthropogenic heat emissions. In TEB-BEM, the parameter of relevance in this regard is the glazing thermal transmittance (KmW⁻²) of glass windows, also typically referred to as the U-value, which is the overall heat transfer coefficient that describes how well a building element conducts heat. Typically, the higher the U value the worse
the thermal performance of the building material while a low U value usually indicates high levels of insulation and therefore lower heat emissions and accordingly lower impacts on the UHI.

In Beirut, approximately 90% of the existing building stock was constructed between the 1940s – 1970s (see Table 21) but it was not until after the 1970s when double-paned windows started to become more widely used by developers and contractors. Typically however, although the precise statistics is not available, house-owners in Beirut are opting for double-paned windows due to its higher insulation properties and therefore higher energy savings, in which case the single paned windows are being replaced by the double-paned windows. For the purpose of this thesis, it was considered that the majority of the buildings belonging to the 1940-1970 age-group are comprised of double-insulated windows in which case the value $3\text{ KmW}^{-2}$ is applied in TEB-BEM as opposed to $6\text{ KmW}^{-2}$ which is the typical U value for single-paned windows.

Another important variable for windows is the fraction of glass in relation to the total area of walls of a building. In TEB-BEM, typically the fraction 15% is applied for buildings described as residential housings while the 40% fraction is applied for multi-family buildings. Since most of the buildings in Beirut are described as multi-storey family / residential buildings, the 40% value is applied. However, it is worth noting that areas of Beirut dominated primarily by hangars (as in the port area and industrial areas) have a lower glass ratio than residential buildings whereby the 15% value would apply. However, since such areas makes up only approximately 5-7% of the entire Beirut
administrative surface area, they are not expected to have significant impacts on the simulation results hence the 40% value is applied for the control simulation runs.

6.3.3.4 Roofs. Regarding roofs of buildings, three main types of roofs are identified in Beirut including: 1) white roofs; 2) grey roofs; and 3) red-tiled roofs. ArcGIS software program was used to identify these three classifications of roofs by extrapolation on ArcGIS (see Figure 51). These data were validated through site visits as well as meetings with roof contractors, engineers and architects. Table 23 lists the general information for roofs along with their respective thermal properties and here again reference is made to Oke (1987) for $\alpha$ and $\varepsilon$ values of the dominant roof materials as well as $k$ and $C$.

![Figure 51](image.png)

*Figure 51. Classification of roof types in Beirut based on extrapolations on ArcGIS.*
Table 23. Data regarding rooftops in Beirut adapted from Oke (1987) (prepared by author)

<table>
<thead>
<tr>
<th>Roof type</th>
<th>Number of roof layers</th>
<th>Description of roof materials</th>
<th>Thickness of roof materials (cm)</th>
<th>Albedo (α) of first layer in contact with ambient air</th>
<th>Emissivity (ε) of first layer in contact with ambient air</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grey</td>
<td>1</td>
<td>Dense concrete roof slab</td>
<td>20</td>
<td>0.225</td>
<td>0.805</td>
</tr>
<tr>
<td>White</td>
<td>2</td>
<td>White/white wash paint (insulation) Dense concrete roof slab</td>
<td>0.15</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Red-tiled</td>
<td>3</td>
<td>Red clay tiles Polystyrene Dense concrete roof slab</td>
<td>4.5</td>
<td>0.225</td>
<td>0.9</td>
</tr>
</tbody>
</table>

6.3.3.5 Roads. As for roads, three categories of roads were identified in Beirut based on the number of existing lanes again by extrapolations of aerial images on ArcGIS as follows: 1) primary; 2) secondary; and 3) tertiary roads by extrapolations using the aerial image and discussions with relevant experts. Primary roads are comprised of three lanes, secondary roads of two lanes, and tertiary or local roads primarily of one lane. All road categories are typically asphalted in Beirut area except for the port area (covering a surface area of approximately 1.2 km² out of a total of 21.47 km²) which is covered in basalt. Asphalt has a low albedo (α) value of 0.2 while its emissivity (ε) value is high at 0.97 (Oke 1987). Basalt on the other hand has a much lower α at 0.11 and ε of 0.72. Primary roads are comprised of one layer of asphalt with 7cm thickness, secondary roads of two layers of asphalt with 5cm and 7cm thicknesses respectively, and tertiary roads of three layers of asphalt with 5cm, 7 cm and 8cm thicknesses respectively. This information was again confirmed with the relevant experts and professionals in the field.
For the purpose of this research, the thermal properties of asphalt were considered in the simulation runs since this is the dominating road surface material used typically for Beirut road surfaces. Open spaces in Beirut area were also identified consisting mainly of parking spaces or other vacant lands with no vegetation or paving. All asphalted open spaces were merged with road cover fraction while those with bare soils were listed under the no-vegetation category with gardens as described in the subsequent section (see Figure 52).

![Figure 52. Road classification into primary, secondary and tertiary roads by extrapolation using aerial image dated 2008. Source: Direction des Affaires Geographiques](image)

6.3.3.6 Vegetation. Finally, for urban vegetation, all existing vegetation types, whether high vegetation (trees), low vegetation (grass), or no vegetation (bare soils), were identified by extrapolations on ArcGIS using the available aerial image dated 2008. These again were validated by conducting random site visits along the streets of Beirut.
In general, trees or high vegetation are mainly comprised of *Ficus nitida* trees, with heights reaching up to 8m, and *Pinus pinea* trees, with heights of up to 10m (see Figures 53 and 54), while lower vegetation types are mainly comprised of grass found typically in educational institutions and the limited number of public parks in the city. Having said this, it is important to note that there were numerous other vegetation types, including palm trees, olive trees, jacarandas and so on\(^3\), that were identified across Beirut and which were included in the simulations (see also Appendix VII for a full database on the various tree types identified and included in the simulations in Beirut). The Leaf Area Index (LAI) of these identified vegetation types was then determined. LAI, which is defined as the ratio of total upper leaf surface of vegetation divided by the surface area of land on which the vegetation grows (leaf area / ground surface), determines the interaction between the vegetation surface and the atmosphere. It is considered to play a significant role in UHI, whereby, the larger the LAI of an urban tree for example the larger the shading and cooling provided in an urban canyon thus having greater impact in alleviating the effects of UHI. Generally, the LAI can range considerably from 2 to 5. The LAI of the identified dominating urban trees in Beirut have values ranging typically between values of 2 and 3 which are considered to be relatively low. It is also worth noting that these urban trees typical in the landscaping of Beirut do not require high quantities of water intake (typically between 1-2mm of rainfall per day).

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\(^3\) High vegetation types identified across Beirut included: *Jacaranda mimosifolia* (deciduous), *Pinus pinea* (coniferous), *Ficus nitida*, *Altea altissima* (deciduous), *Phoenix dactylifera* (perennial), *Brachychiton populneus* (deciduous), *Albizia julibrissen* (deciduous), *Olea oleacea* (perennial), *Cupressus sempervirens* (coniferous), *Eucalyptus globulus* (perennial), among others; low vegetation types identified in Beirut included: *Ricinus communis, Nerium oleander* among others
Figure 53. *Ficus Nitida* vegetation type typically found in Beirut garden/green areas and street trees with LAI of 2 (photographs taken by author)

Figure 54. *Pinus Pinea* vegetation type typically found in Beirut garden/green areas with LAI of 2 (photographs taken by author)
6.3.3.7 Forcing data. Finally, the climatic records were prepared to act as atmospheric forcing data based upon which the simulations would be run on TEB. As previously mentioned “forcing” describes the prominent climatic conditions in the city that are used to define the boundary conditions for the simulations. Climatic records from the Fanar weather station were extrapolated and computed with the assistance of Météo France experts. These forcing atmospheric data at any given day or time of year were uniform across the entire Beirut administrative area. For the purpose of this research therefore, the months of February and July were selected to represent the results of the simulations during the winter and summer seasons respectively since temperature records show that January and February are typically the coldest months in Beirut while July and August are the hottest months in Beirut (refer to Appendix V for a list of the forcing atmospheric data used for TEB simulations for the months of February and July).

6.3.3.8 Finalization of data compilation. Once all the relevant data were compiled they were implemented into the TEB modeling scheme to run the simulations based on existing conditions and on various devised scenarios. Table 24 is an example of six sample cells within the Beirut administrative area showing their respective cover fractions calculated during the data collection process on ArcGIS. As can be seen, each cell is characterized by a distinct urban coverage where each has its specific impact on the UHI of Beirut. Therefore, the data related to the respective urban surfaces, including thermal and radiative characteristics, material thicknesses, vegetation types and LAI values, were identified for each cell within the Beirut administrative area. These were then forced with atmospheric forcing data previously discussed giving simulations for specified output parameters for each cell across Beirut (see Chapter 7).
Table 24. Sample grid cells in Moussaytbeh and Mazraa areas showing summation of town cover fractions

<table>
<thead>
<tr>
<th>Cell land use/land cover description</th>
<th>BUILDING</th>
<th>GARDEN</th>
<th>ROAD</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low density urban fabric in Moussaytbeh</td>
<td>0.07</td>
<td>0.52</td>
<td>0.40</td>
<td>1.00</td>
</tr>
<tr>
<td>Low density urban fabric in Moussaytbeh</td>
<td>0.10</td>
<td>0.50</td>
<td>0.40</td>
<td>1.00</td>
</tr>
<tr>
<td>Low density urban fabric in Moussaytbeh</td>
<td>0.10</td>
<td>0.60</td>
<td>0.30</td>
<td>1.00</td>
</tr>
<tr>
<td>Low density urban fabric in Moussaytbeh</td>
<td>0.10</td>
<td>0.27</td>
<td>0.63</td>
<td>1.00</td>
</tr>
<tr>
<td>Medium density urban fabric in Mazraa</td>
<td>0.39</td>
<td>0.03</td>
<td>0.57</td>
<td>1.00</td>
</tr>
<tr>
<td>Dense urban fabric in Mazraa</td>
<td>0.48</td>
<td>0.03</td>
<td>0.49</td>
<td>1.00</td>
</tr>
</tbody>
</table>

6.4 Challenges during the data collection process

It is worth noting that some difficulties were encountered during the data collection process mainly because of the limited data availability in Beirut. While TEB does not require precise accuracy for data related to individual urban surfaces as compared to the other modeling schemes, the data was still challenging to collect and compile. The reason for this is attributed to the fact there is no documentation or digital information regarding the required data for urban surfaces in Beirut. In addition, not all parties are willing to part with the data they may have since this is usually reserved for collaborative-type works. Accordingly, the data collection and preparation phase was considerably time-consuming. A full list of the compiled data which were prepped for analysis for TEB can be found in Appendix VII of this thesis in a digital CD copy.
Chapter 7: Numerical Analysis

This chapter provides a detailed account of the results of the numerical modeling and analysis of the UHI phenomenon carried out for Beirut city using the TEB urban surface exchange modeling scheme. The collected and compiled data characterizing the existing urban context of Beirut are initially used to run the simulations, in what is henceforth referred to as the ‘control run’, to observe temperature patterns in different parts of Beirut during both winter and summer seasons. Simulation runs are also conducted for scenarios devised specifically for the purpose of this research. The respective outputs from the ‘control run’ are then compared against the simulated outputs for the formulated scenarios to assess their significance for the Beirut context. Since the majority of the data was extrapolated, the focus of this numerical analysis is to assess the pattern of the simulated results, as opposed to the real values, to give recommendations for the urban planning and urban development of the city of Beirut with focus primarily on urban geometric characteristics and urban design of the city (see Chapter 8 Discussion).

7.1 Control Run

The ‘control run’ refers to the simulation runs that were carried out using the existing data characterizing the present urban context of Beirut. These include the current dominating urban surface materials and their respective radiative and thermal properties (see Chapter 6). The data were accordingly run on TEB for one entire year using the 2009 forcing data of Fanar weather station with one hour time steps for all grid cells across Beirut city (or that fall within the administrative boundary of Beirut) meaning that

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33 In this research, there are a total of 446 cells of 200 x 200m dimensions across Beirut in which simulations using TEB are run. These were prepped using ArcGIS software and the most recent aerial image dated 2008.
outputs were simulated for every hour of every day starting from 0000UTC (equivalent to 3:00AM local standard time) for one entire year. For the purpose of presentation in this chapter all output result for the months of February and July are selected. The choice for February was to allow enough time for TEB to balance out its simulations seeing as these are initiated from the month of January and in addition these months are considered to represent relatively extreme weather conditions for Beirut city although August tends to be the hottest month in Beirut and the coldest months are usually recorded between the months of January and February. Furthermore, it is important to investigate the difference in temperature output simulation results in winter and summer seasons.

7.1.1 Selected cells for simulation runs. Simulations were carried out across the entire Beirut administrative area (covering 21.47 km²), but for the purpose of this research and for distinct comparisons, several grid cells were also selected for assessments and analyses between areas of contrasting cover fractions. Figure 55 presents the location of these selected cells and Table 25 distinguishes the town cover fractions within each of these cells including the buildings, roads and gardens fractions (which add up to 1.0), all of which are entered into TEB to run the simulations. Results are presented either in the form of graphs for the selected cells or for the entire city of Beirut.
Figure 55. Selected cells for the purpose of distinct comparison of simulation results

Table 25. Selected cells with contrasting cover fractions

<table>
<thead>
<tr>
<th>Grid cell #</th>
<th>Grid cell description of general land use / land cover and district</th>
<th>Cover Fractions</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Building</td>
<td>Garden</td>
</tr>
<tr>
<td>1</td>
<td>American University of Beirut (AUB) in Ain El Mreisseh</td>
<td>0.28</td>
<td>0.61</td>
</tr>
<tr>
<td>22</td>
<td>Port area predominantly with hangars</td>
<td>0.23</td>
<td>0.00</td>
</tr>
<tr>
<td>220</td>
<td>Dense urban area Bachoura</td>
<td>0.32</td>
<td>0.12</td>
</tr>
<tr>
<td>261</td>
<td>Seaside non-dense Ras Beirut</td>
<td>0.12</td>
<td>0.43</td>
</tr>
<tr>
<td>439</td>
<td>Cemetery with gardens Mazraa (Horsch Beirut)</td>
<td>0.02</td>
<td>0.73</td>
</tr>
</tbody>
</table>
7.1.2 Selected outputs for the control run. The outputs of interest for the purpose of this research study were also selected as follows:

- canyon temperatures,
- surface rooftop temperatures,
- surface road temperatures,
- surface wall temperatures,
- internal building temperatures,
- cooling energy demands, and
- heating energy demands.

These output results are assessed and analyzed in more detail in the subsequent sections.
7.1.2.1 Canyon Temperatures. The figures below (Figures 56 and 57) show the canyon temperature simulations across Beirut at 12:00hrs. when the incoming solar radiation is at its peak over Beirut, during both winter and summer seasons. Therefore, the temperature differential (ΔT) across Beirut is clearly marked in these figures, highlighting the areas of highest and lowest temperatures. Indeed the cells characterized by highest building fractions, like in Mazraa, Bachoura, and Ashrafiyeh areas for example, have higher temperatures inside the canyon. Lowest canyon temperature simulations are seen especially over the garden areas, such as “Horsh Beirut”, toward the south of Beirut, the largest urban public garden in Beirut that covers approximately 0.375 km<sup>2</sup> or 1.75% of the entire Beirut administrative area, thus showing the significant alleviating effects of these areas on the UHI. In February, or during the winter season, ΔT across Beirut is 2°C, ranging from 15.9 to 17.3°C, but this ΔT is much higher, at 6°C, in July or during the summer, ranging from 37.6 in garden areas to 44.6°C in high density urban fabrics thus reflecting the more significant cooling effect of vegetation on canyon temperatures during the summer season. These simulations showing significant temperature during winter and summer seasons also reflect the main characteristics of the UHI which typically decreases with increasing wind speed and cloud cover during the winter (where average maximum wind speed of 10-12 m/s have been recorded in Beirut) and which is best developed in the summer or warm half of the year (where lower wind speeds of 0.4m/s have been recorded in Beirut). However, it is to be noted that the summer simulation results are generally higher than the average maximum temperature records during this time of the year (at about 35°C) and these results could be attributed to the sensitivity of the TEB modeling scheme to the very low albedo properties of the
roofs and roads in Beirut (see Chapter 7). Having said this it is important to emphasize that this research study does not focus on the exact values of the simulations per se but rather on the pattern of the results obtained.

Comparison between five of the selected cells are also presented in the graphs below (Figures 58 and 59). These show clearer distinctions in simulations for areas with differing town cover fractions where higher canyon temperatures are found in the dense urban fabric areas as opposed to the lower density urban fabrics and garden areas. The night-time UHI is also evident in these figures during both winter and summer seasons with higher night-time canyon temperatures in the higher density urban fabrics. This is indeed one of the main characteristics of the UHI intensity which is typically greatest at night.

Therefore, for the control run, the results of the simulations for the canyon temperatures are indicative for the purpose of this research. In general, however, it is expected that the areas of higher elevation in Ashrafiyeh and Moussaytbeh (at >90 m above sea-level) would have cooler temperatures than similar dense urban fabric areas at lower elevations, but indeed not much difference is observed in the simulations for canyon temperatures during both winter and summer. This could be attributed to the similar urban geometries of urban morphologies at both elevations that do not maximize the effects of local climatic conditions. It is also expected that buildings in the dense urban fabric areas would cause a greater shadow effect especially during the winter season due to the lower path of the sun in the sky and the lower intensity of the sun in winter with cooler results than lower density urban fabrics but the shadowing effect of buildings during the winter season is not so significant and occurs only for short periods
during the early morning and late afternoon hours and certainly not at peak hours, and in addition the evaporative and cooling effect of urban vegetation on canyon temperatures appears to be far more significant.

Figure 56. Canyon temperature simulations for the Control Run across Beirut on 01-February at 1200 UTC

Figure 57. Canyon temperature simulations for the Control Run across Beirut on 01-July at 1200 UTC
7.1.2.2 Roof Temperatures. The output results for surface roof temperatures show that the highest surface roof temperatures are found in areas with larger building fractions, like in Bachoura area for example, while lower roof temperatures are found in areas with lower building fractions like in the institutional green campus grounds of the American University of Beirut (AUB) situated in Ain El Mreisseh. As discussed previously, the dominating roofs in Beirut are comprised primarily of grey concrete roof
slabs which have a very low solar reflectivity ($\alpha=0.225$) and a high thermal capacity ($C=2.11$) accordingly raising their surface temperatures significantly more than areas with higher urban vegetation (Oke, 1987). Hence, upon comparison of the simulations between these two aforementioned areas a significant $\Delta T$ of approximately $20^\circ C$ is found (see Figures 60 and 61). In this output therefore, TEB results indicate that areas with higher building fractions have the highest rooftop surface temperatures while areas with higher vegetation fractions and lower building fractions, have lower rooftop surface temperatures across Beirut (see Figures 62 and 63). Considering that TEB requires input for each building, road and vegetation cover fractions (where the total of these fractions must add up to 1.0 within each grid cell), these results are expected.

Surface roof temperatures are found to go up to $70^\circ C$ in areas of dense urban fabric during the summer season (see Figure 61) reflecting the significantly high thermal capacities and low albedo of the concrete roof slab material ($C=2.11$), which consequently have high impacts on the UHI effect. Again as before, this research focuses on the pattern of the simulation results and not on the exact temperatures per se. Validations were not carried out to measure the real temperature values of the surface roof materials in this research however this can be recommended in future works when using TEB to compare the results.
Figure 60. Evolution of surface roof temperatures for two selected cells on 01-February

Figure 61. Evolution of surface roof temperatures for two selected cells on 01-July

Figure 62. Roof temperature simulations for the Control Run across Beirut on 01-February at 1200 UTC
7.1.2.3 Road Temperatures. Simulations are run across the entire Beirut administrative area with outputs for surface road temperatures at 12:00hrs. As previously discussed, asphalt, which is the dominating road surface material used in Beirut, has a very low albedo ($\alpha=0.2$), a relatively high thermal conductivity ($k=0.75 \text{ Wm}^{-1}\text{K}^{-1}$) and a high heat capacity ($C=1.94 \text{ Jm}^{-3}\text{K}^{-1} \times 10^6$) thus being more significantly impacted during the summer season when the intensity of incoming solar radiation is high resulting in high surface temperatures (reaching up to $60^\circ\text{C}$ or greater).

Results across Beirut therefore show that during the winter day, surface road temperatures are highest in areas with higher road fractions like in Bachoura, Mazaraa and Ashrafiyeh but the $\Delta T$ across Beirut is found to be small at this time (at about $1^\circ\text{C}$), ranging from about $16^\circ\text{C}$, like the seaside, AUB, and Horsch Beirut areas, to $17^\circ\text{C}$ in the higher road fraction areas (see Figure 64). During the summer day, again simulations for
surface road temperatures are highest in areas wherever main or primary road fractions are highest but the ΔT is found to much larger across Beirut at this time (at about 30°C), ranging from about 43.5 to 73.5°C (see Figure 65). These results are expected due to the higher intensity of the incoming short-wave radiation especially during the summer season and the higher angle of the sun over the horizon thus having a greater effect on areas with higher road fractions and lower vegetation fractions. Indeed such areas have more exposure to the incoming high intensity solar radiations because of the lower shading and cooling effect provided by trees. The latter is represented by the LAI values input parameter in TEB. These results also reflect the important shading effect of trees on surface road temperatures especially during the summer season.

Figures 66 and 67 represent the differences in surface road temperature evolutions between selected cells characterized by high road fractions, like the Port and Bachoura areas, and low road fractions, like the Gardens/Horsch Beirut area, during winter and summer days. Indeed the daily temperature evolutions show that during the winter month of February, there is a ΔT of approximately 2°C between the Bachoura and garden areas throughout the day, except at midday when there is almost no difference. In July, there is not much difference in ΔT between the port and gardens areas throughout the day except at around midday and during the late afternoon and night-time hours with a ΔT of around 2°C. These results are attributed to the important shading and evaporative effects of trees during periods of the day when intensity of incoming short-wave radiation is high and during the late afternoon and night-times when air temperatures drop but this impact is not so significant at midday during the winter season and this is because of the lower intensity (and thus lower temperatures) of the incoming short-wave radiation at this time.
of the year. In addition, the temperature evolution of surface road temperatures is much lower during the winter (rising from about 4 to 18°C) as compared to the summer (rising from approximately 18 to 70°C) and once more this can be attributed to the lower intensity of the incoming solar radiation during the winter season thus not having significant effects on raising the surface temperature of roads. Again, this research focuses on the pattern of the simulation results as opposed to real road surface temperatures. Validations could however be considered in future works associated with TEB with real-time measurements.

Therefore, simulation results across Beirut indicate that areas with lower road fractions and higher vegetation covers have lower road surface temperatures reflecting the more significant shading effect of trees in these areas. In addition, according to the daily temperature evolutions during winter and summer, there is not much difference in the simulations between these areas during the winter at around midday while the difference is more significant at this time during the summer. This is expected due to the lower intensity of incoming short-wave solar radiation at winter, while during the summer intensity of incoming solar radiation is higher and the evaporative effect of trees is consequently also higher at midday resulting in the more significant cooling effect of trees at this time of day. At night time when temperatures drop due to the lower intensity of incoming solar radiation trees also further provide shading thus further lowering road surface temperatures.
Figure 64. Surface road temperature simulation results for Control Run across Beirut on 01-February at 1200 UTC

Figure 65. Surface road temperature simulation results for Control Run across Beirut on 01-July at 1200 UTC
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7.1.2.4 Wall Temperatures. The dominating façade material of buildings in Beirut is beige/white paint and plaster (see Chapter 6) and as per Oke (1987), this latter material has a high albedo value ($\alpha=0.7$) and is therefore considered to be a cool material in contrast to the road surface materials (comprised primarily of asphalt with $\alpha=0.2$) and rooftops (mainly grey concrete slab with $\alpha=0.225$). With such a high albedo, it is expected that walls would have the lowest impact on the UHI of Beirut. However, since the mechanism by which TEB functions is based upon the principle of the energy balance equation, and the specific town cover fractions (for buildings, road and vegetation), the combined effect of the radiative properties of the artificial surfaces and the low vegetation covers in some of the street canyons of Beirut city defined as such, results in greater exposure of the walls/facades to the incoming short-wave solar radiation, especially at peak hours, thus increasing wall temperatures comparatively more than areas with higher vegetation fractions (like at AUB campus grounds or the Horsch Beirut park). This pattern is apparent across Beirut during both the winter and summer seasons although during the winter season the temperature differential at midday is small, between about 16 to 19°C, while during the summer season it is much larger ranging between around 40 and 55°C as illustrated in Figures 68 and 69.

*Figure 67. Evolution of surface road temperatures for two selected cells on 01-February*

*Figure 66. Evolution of surface road temperatures for two selected cells on 01-July*
Figures 70 and 71 below show the distinct comparison between the evolution of wall temperatures for selected cells in the dense urban area of Bachoura and the lower density urban fabrics of the AUB institutional campus and the seaside area. During winter, the temperature differential between these areas at around 12:00hrs, when incoming short-wave radiation is at its peak, is only at about 1°C and this difference remains more or less constant throughout the day and even night-time. During the summer day the ΔT is slightly more especially at midday at about 2°C owing to the more distinct and effective cooling impact of vegetated surfaces at AUB (with 61% garden fraction) and the seaside (43% gardens) and also during the late afternoon and night-time which is expected due to the lower intensity of the incoming solar radiation at these hours of the day enhanced further by the shading effect of trees.

*Figure 68*. Wall temperature for the Control Run across Beirut at midday on 01-February at 1200 UTC
For internal building temperature outputs, simulation results showed that just as in the case of the canyon temperatures, areas with higher garden fractions lower internal building temperatures of buildings as opposed to the higher urban density fabrics which typically increase internal building.
temperatures, especially between 11:00 and 14:00 hours during both winter and summer seasons. Figure 72 and Figure 73 show the temporal evolution of the internal building temperatures for five selected cells across Beirut during one winter and one summer day respectively. During the winter it is seen that the HVAC_HT energy system is initiated earliest in areas with highest garden fractions like the AUB campus or Gardens/Horsch Beirut areas because of the respective cooler internal building temperatures in these areas. During the summer season however, the evolution of diurnal internal building temperature simulations shows that the HVAC_CL is initiated first in areas with higher density urban fabrics like in Bachoura, seaside, port and industrial areas because of the higher internal buildings temperatures in these areas characterized by higher artificial surface coverage. It is expected that internal flooring materials also impact the internal building temperatures. The majority of the building stock across Beirut typically have similar flooring materials (see Table 22) with low to moderate heat retaining properties and are therefore expected to have a comparatively higher impact on energy savings in the winter in areas of dense urban fabrics as opposed to more vegetated areas with lower building fractions (see Figure 72). During the summer again the heat retaining properties of the internal flooring materials across Beirut are expected to have higher impacts on energy demands as seen in the simulation results below (see Figure 73).
Figure 72. Temporal evolution of internal building temperature for five selected cells at midday on 01-February

Figure 73. Temporal evolution of internal building temperatures for five selected cells at midday on 01-July
7.1.2.6 Cooling Energy Demand. In Beirut, annual cooling energy demands take place typically between the months of May to October. After this period, energy demands switch from cooling to heating. Thus, upon simulation of the heating-ventilating air-conditioning system (HVAC) or the cooling energy demands (HVAC_CL) across Beirut during summer in July, it is found that as expected, cooling demands are highest in areas defined by a dense urban fabric, such as Bachoura that is defined by a 32% building cover fraction, a low garden fraction of 12% and a high road fraction at 56%, as opposed to the AUB institutional area for example, that is defined by a 28% building fraction, a road fraction of 11% and a significantly high garden fraction of 61% (see Figure 74 and Figure 75).

Diurnal peak cooling energy demands are found to take place between the hours of 11:00 and 15:00 when the intensity of the incoming solar radiation rises, reaching up to 360W/m² in the Bachoura area as opposed to 120W/m² in the AUB campus area for example, showing a significantly lower cooling energy demand in the latter due to the higher fraction of urban vegetation thus reflecting the noteworthy cooling effect of the green spaces on the UHI and accordingly the lower cooling energy demands. Cooling energy demands taper off typically in the cooler evening hours. During the winter season in Beirut, starting from around the months of November/December to May, there is no demand for cooling energy in Beirut as confirmed in the simulation results for HVAC_CL.
7.1.2.7 Heating Energy Demand. Upon running the simulations for heating energy demands (HVAC_HT) for three selected cells including Bachoura, the seaside and AUB campus areas, it is found that during the winter season, heating consumption levels are highest in the high density urban fabric of Bachoura (32%), in comparison to the...
lower density urban fabric along the seaside (12%) and the AUB campus (28%). In Bachoura, results show heating energy demands that go up to 160W/m$^2$, at the seaside up to 150W/m$^2$, and at AUB up to only 30W/m$^2$. These differences can be attributed to the higher building fraction in the Bachoura neighborhood and therefore a greater residential population requiring energy for domestic heating purposes especially during the cold early morning hours of the day. At the seaside however, although the building fraction is significantly lower than at Bachoura, heating energy levels are still closely correlated to the latter area and this could be attributed to the cooler conditions resulting from the relatively larger fraction of the vegetation surfaces (43%). In AUB however, which has the highest garden fraction of the three cells (61%) and much lower resident populations, although an almost similar building fraction to Bachoura at 28%, heating energy demands are found to be the lowest of the three selected cells due to lower living residents (see Figure 76 for comparison of cooling energy demand between the three aforementioned cells and Figure 77 for simulation results across the entire city of Beirut).

In addition, upon assessing the diurnal patterns and trends for heating energy demands, highest levels of energy consumption are found to take place especially during the late night hours when home owners return to their residences after work, the early morning hours before setting off to work, and the early afternoon hours starting from around 15:00, after the incoming solar radiation is no longer at its highest peak. During the summer season, starting from around the month of May to October / November, there is no demand for heating energy as confirmed by the simulation results for HVAC_HT.
Figure 76. Evolution of heating energy demand for three selected cells on 01-February

Figure 77. Heating energy demand for Control Run across Beirut on 01-February at 2000 UTC
7.1.3 Summary of control run results in Beirut. The simulations for the control run across Beirut with outputs for canyon temperatures, surface roof temperatures, surface road temperatures, wall temperatures, internal building temperatures, and cooling and heating energy demands were as expected for areas with differing town cover fractions in Beirut. In general, it was seen that TEB is particularly sensitive to roof temperatures and also to cooling and heating energy demands. This is further clarified in the subsequent section on developing scenarios.

7.2 Developing Scenarios

Six scenarios were devised to better understand the contribution of each of the previously tested outputs to the overall effect on UHI in Beirut and to make recommendations accordingly for the urban planning of the city. It is worth noting that these devised scenarios to reduce the impacts of UHI of Beirut are realistic considerations for mitigation actions that can indeed be deliberated for a more sustainable approach to the urban planning of the city, particularly where it concerns modifications to the existing urban geometry of the city which is the context of this research. Out of the five previously selected cells therefore and for the purpose of presentation, one cell is selected from the scenarios results and compared against the control run results for the same selected cell with the objective to carry out distinct comparisons and numerical analysis although it is important to note that simulations were carried out for all 446 cells developed across the Beirut administrative boundary. These cells in the following sections were selected randomly to simply illustrate the significance in the extremes in the output results. Table 26 provides a description of these devised scenarios for this thesis. It is worth noting that these devised scenarios are simply modifications or
exaggerations of the existing conditions so for example in the case of Scenario 4 (Table 26), the glass ratio is increased from 40% (which is the value applied to the existing glass ratio of existing buildings in Beirut and to run the simulations on TEB – see section 6.3.3.3) to 80% to determine the effect of increasing the glass fraction of buildings in Beirut and their respective impact on UHI of the city. Similar approach is applied to the remaining scenarios.

Table 26. Devised scenarios run on TEB

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>Albedo of roofs increased to 0.7 (previously $\alpha = 0.2$) in all grid cells across Beirut</td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Albedo of roads increased to 0.8 (previously $\alpha = 0.225$)</td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Glass ratio increased from 40% to 80%</td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Building height was increased from 15m to 35m and the roughness length was accordingly modified from 1.5 to 3.5m</td>
</tr>
<tr>
<td>Scenario 5</td>
<td>Increase in vegetation height from 10m to 25m height</td>
</tr>
<tr>
<td>Scenario 6</td>
<td>Increase in garden fraction by same amount by which road fraction was decreased (50%)</td>
</tr>
</tbody>
</table>

7.2.1 Scenario 1: Modification of Roof Albedo. For Scenario 1, the roof albedo is increased from 0.2 to 0.7 to assess the impacts of ‘cool’ materials or high reflecting roof surface materials on the UHI in Beirut since this is a commonly practiced mitigation measure in other similar dense cities (Akbari, 2014). The outputs for these simulations included canyon temperatures, roof temperatures, road temperatures, wall temperatures, internal building temperatures, and cooling and energy demands (see Figures 78 to 89). Simulation results showed that modification of the roof albedo lowered the canyon temperatures by 0.28% during the winter day in February however, during the summer day in July, a much more significant temperature differential of 1.7% or 0.7°C was found.
at around 10:00AM when the incoming short-wave solar radiation is at its peak. In the case of surface roof temperatures, simulations during the winter showed temperatures that were lower by 38% (or 15°C) when results were compared against the control run, while during the summer, simulations showed temperatures that were lower by about 30% or a ΔT of 20°C. For surface road temperatures, again temperatures were lowered by about 0.17% during midday hours of the winter day, while this decrease was much more significant during the summer day lowering temperatures by approximately 7.5%, especially during the early morning and late afternoon hours. For wall temperatures, these were again lowered by about 0.3% during the winter day at midday, but during the summer day, the impact was found to be more significant where temperatures decreased by about 1% at around 10:00AM. The internal building simulations were lowered by about 1.26% during the winter day and by negligible amounts during the summer day. However, regarding the heating energy demands during the winter day, these were found to be slightly higher when compared against the control run due to the more significant cooling effect of the roofing materials with their higher albedo properties under this scenario where heating energy demands were raised by about 11.5W/m². Regarding the cooling energy demands during the summer day, these were found to be lower by around 50W/m² when compared against the control run, again due to the more significant cooling effect of the higher albedo roofing material under this scenario. Therefore, simulation results under this scenario were as expected.

The results of these scenarios versus the control run are presented in Figures 78 to 89 below. It is to be noted that some of these differences will not appear so significant in
the form of graphical presentations but in all cases there is a positive difference, albeit not always substantial, as previously discussed.

Therefore based on these results it is concluded that this scenario is a desirable and feasible mitigation strategy for the Beirut context with generally positive effects on alleviation of the UHI of the city and accordingly the quality of life of urban dwellers.

Figure 79. Comparison of canyon temperatures between Scenario 1 and Control Run on 01-February

Figure 80. Comparison of roof temperature between Scenario 1 and Control Run on 01-February

Figure 78. Comparison of canyon temperatures between Scenario 1 and Control Run 01-July

Figure 81. Comparison of roof temperature between Scenario 1 and Control Run on 01-July
Figure 82. Comparison of road temperature between Scenario 1 and Control Run on 01-July

Figure 83. Comparison of road temperature between Scenario 1 and Control Run on 01-Feb

Figure 84. Comparison of wall temperature between Scenario 1 and Control Run on 01-February

Figure 85. Comparison of wall temperature between Scenario 1 and Control Run on 01-February

Figure 86. Comparison of internal building temperature between Scenario 1 and Control Run on 01-July

Figure 87. Comparison of internal building temperatures between Scenario 1 and Control Run on 01-February
7.2.2 Scenario 2: Modification of Road Albedo. For Scenario 2, the road albedo was increased from 0.225 to 0.8 to assess the impact of “cool” road surface materials on the UHI effect of Beirut city as such since this is another commonly implemented mitigation strategy in other similar dense cities (Santamouris, et al., 2011). Again, as for the previous scenario 1, the outputs selected for these simulation runs included canyon temperatures, roof temperatures, road temperatures, wall temperatures, internal building temperatures, and cooling and energy demands (see Figures 90 to 101).

There were no significant impacts observed in canyon temperature results during the winter however during the summer canyon temperatures were reduced by approximately 0.7%. For surface road temperatures, significant changes were observed where road temperatures were reduced by 2.5°C (or 14%) during the winter and much more at 25°C (or 36%) during the summer emphasizing the important cooling effect of road surfaces upon increasing its albedo properties. As for roof temperatures however, an approximate 2% increase in simulations was observed during the winter and about a 1% increase during the summer; this could be attributed to the higher reflective properties of the roads and their potential direct effects on the facades and roofs of the buildings inside the canyon thus raising their respective temperatures. Regarding wall temperatures again

Figure 88. Comparison of HVAC_HT between Scenario 1 and Control Run on 01-February

Figure 89. Comparison of HVAC_CL between Scenario 1 and Control Run on 01-July
simulations showed higher temperatures which were raised by about 0.75% during the winter and about 1% during the summer. The simulations for the internal building temperatures were also raised but by negligible amounts. As for heating energy demands, these were lowered by a maximum of $5 \text{W/m}^2$ (or 55%) upon comparison with the control run and this could be potentially attributed to the higher wall and roof and internal building temperatures as a result of the higher reflecting properties of the road surfaces affecting the internal building temperatures in the street canyons under this scenario while the cooling energy demands during the summer day were raised by about $90 \text{W/m}^2$ (or 28%) for similar reasons. Again, results under this scenario for increased road albedos were as expected.

Figures 90 to 101 present the comparison of the simulations between the control run and scenario 2. Although some of these presented graphs do not show a significant comparative difference, in all case there is a difference, as previously discussed.

Therefore, based on these results it is concluded that this scenario is not a feasible mitigation strategy for alleviation of the UHI in Beirut due to its associated undesirable effects which occur such as increasing internal building temperatures because of the higher solar reflectivity of the road surfaces and the respective rises in the cooling energy demands of buildings during the summer.
Figure 90. Comparison of canyon temperatures between Scenario 2 and Control Run on 01-February

Figure 91. Comparison of canyon temperatures between Scenario 2 and Control Run on 01-July

Figure 92. Comparison of road temperatures between Scenario 2 and Control Run on 01-February

Figure 93. Comparison of road temperatures between Scenario 2 and Control Run on 01-July

Figure 94. Comparison of roof temperatures between Scenario 2 and Control Run on 01-February

Figure 95. Comparison of roof temperatures between Scenario 2 and Control Run on 01-July
Figure 96. Comparison of wall temperatures between Scenario 2 and Control Run on 01-July

Figure 97. Comparison of wall temperatures between Scenario 2 and Control Run on 01-Feb

Figure 98. Comparison of internal building temperatures between Scenario 2 and Control Run on 01-February

Figure 99. Comparison of internal building temperatures between Scenario 2 and Control Run on 01-July

Figure 100. Comparison of heating energy demand between Scenario 2 and Control Run on 01-July

Figure 101. Comparison of cooling energy demand between Scenario 2 and Control Run on 01-February
7.2.3 Scenario 3: Modification of Glass Ratio. For Scenario 3, the glass ratio of buildings was increased from 40% (0.4) to 80% (0.8) to assess the effects of buildings with higher glass ratios on the UHI impact in Beirut as new architectural designs in Beirut tend to favor this option. Considering the relatively low solar reflectivity of glass (according to Oke, 1987), it is expected that increasing glass ratio of future building designs can have detrimental impacts on the UHI in Beirut.

Therefore, as before the outputs selected for these simulations included canyon temperatures, roof temperatures, road temperatures, wall temperatures, internal building temperatures, and cooling and energy demands. The respective results were compared to those of the control run to assess the sensitivity of the model to modification of this specific parameter and the consequent impact on Beirut’s urban microclimate. The results showed an increase in canyon temperatures of approximately 0.35°C (or 3.65%) mainly during the early morning and late afternoon hours of the winter day but simulations were similar to the control run data throughout the rest of the day. During the summer day, canyon temperatures were again raised by 0.4°C (or 1.25%) during the early morning and late afternoon hours of the day. This can be attributed to the low reflective properties of clear glass, where $\alpha=0.08$ for clear glass with zenith angle less than $40^\circ$ and $\alpha=0.09-0.52$ for clear glass with zenith angle 40 to $80^\circ$ (Oke, 1987). Regarding road temperatures, simulations showed a small decrease of 0.1°C (or 1%) when compared against the control run during the winter day but there was increase in road temperatures during the summer day by about 0.5°C (or 2.5%) especially during the early morning late afternoon hours. For roof temperatures, simulations were higher than the control run by 0.7°C (or 5%) during the winter day and by 0.9°C (or 3.45%) during the summer day both at around
16:00 hrs. Regarding wall temperatures, a higher temperature differential of 0.4°C (or 4.75%) was observed throughout the whole day during the winter, and during the summer day the simulations were higher by about 0.2°C (or 0.95%) when compared against the control run especially in the early morning hours. As for the internal building temperatures, during the winter day the simulations showed warmer results than the control run data by about 0.15°C (or 0.75%) but during the early morning hours of the winter day (between 04:00 and 08:00) the simulations were found to be lower than the control run by about 0.01%. During the summer day the internal building temperatures were only slightly warmer than the control run by about 0.01°C (or 0.04%). As such, the heating energy system (which is preset in BEM to initiate when internal temperatures are below 19°C) is activated just before the control run between the hours of 08:00 and 14:00 during the winter day while the cooling energy system (which is preset to initiate when internal temperatures are above 24°C) begins again just before the control run between the hours of 12:00 and 18:00hrs. Regarding the cooling energy demands, these were found to be higher than the control run by up to 180W/m² especially when the incoming short-wave solar radiation is at its peak and this is attributed to the good insulating property of glass and the relatively low heat capacity of the increased glass ratio of the buildings (1.66 Jm⁻³K⁻¹ x 10⁶) (Oke, 1987) thus raising quickly the temperatures inside the buildings and consequently keeping the temperatures inside the buildings fairly constant. As for the heating energy demands, these are again found to be higher than the control run by about 25W/m² especially during the early morning hours of the day and late evenings and this can be attributed to the combined effect of the lower intensity of
the incoming solar radiation at these times and the fairly low conductivity of clear glass
\( (k=0.74 \text{ Wm}^{-1}\text{K}^{-1}) \) (Oke, 1987).

Therefore the simulations for the outputs under this scenario with increased percentage of building glass ratio were as expected. Since some of these differences in results are not so significant, they will not be clearly visible if presented in the form of graphs, therefore for presentation purposes only the simulations results for heating and cooling energy demands are presented here (see Figures 102 and 103).

Based on these results therefore, it is concluded that increasing the glass ratio of buildings is not a suitable design measure for buildings in Beirut since it exacerbates the overall UHI of the city and accordingly lowers the quality of life and thermal comfort level of urban dwellers.

7.2.4 Scenario 4: Modification of Building Height. For Scenario 4, modification of the building height and accordingly the roughness length from 15m to 35m for all cells across Beirut was carried out to reflect the effect of raising the height of buildings which is becoming an increasingly more attractive business scenario for most developers in
Beirut on the UHI of the city. Simulations therefore showed an increase of 0.07°C (or 0.7%) in canyon temperatures during the winter and an increase of 0.55°C (or 1.25%) during the summer especially during the late afternoon and night-time hours. What happens is that the sensible heat flux from the incoming solar short-wave radiation that reaches deep inside the urban canyon gets reflected back up at the reflective walls of the buildings. These buildings absorb the heat and then release it back into the surrounding area causing the areas between the tall buildings to retain more heat thus raising canyon temperatures. As for road temperatures these are also increased by about 0.5°C (or 12%) during the whole winter day under this scenario but the difference in these simulations against the control run went up to 2.65°C (or 17%) during the summer day mainly because of the higher angle of the sun over the horizon and therefore the more significant impacts on road surfaces at this time of the year. As for roof temperatures, simulations decreased by up to 0.2°C (or 1%) during the winter day and similar trends were observed during the summer day also with decreases of up to 0.35°C (or 0.75%) owing potentially to the lower sky view factor caused by the taller buildings whereby the resulting radiative exchanges occur mainly between the roads and the walls of the buildings. The wall temperature simulations increased by up to 0.07°C (or 0.8%) during the winter day, again due to the increased radiative exchanges occurring between the walls and the roads, and the same was observed during the summer day whereby in general the temperature of the building facades increased by up to 0.15°C (or 0.6%) especially during the early morning and late afternoon hours when the angle of the sun is lower over the horizon thus resulting in higher impacts over the walls of the buildings. Internal building simulations also increased both during the winter day (by 0.08°C or 0.46%) and summer day (by
0.003°C or 0.0013%). Therefore simulation results under this scenario for increased building height were as expected.

As for the heating and cooling energy systems, the raised canyon temperatures resulted in higher cooling energy demands when compared against the control run by approximately 40W/m² (or 12%) especially at midday when the intensity of the incoming short-wave radiation is at its peak. During the winter day however, due to the raised canyon temperatures, heating energy demands were approximately 10W/m² (or 10%) less than the control run. The simulations for the heating and cooling energy demands were as expected and it appears that activation of the BEM option in TEB has the highest impact on the heating and cooling energy demand simulations under all 4 scenarios thus far.

Therefore under this Scenario 4, considering that TEB is a single layer canopy model where there is direct interaction between one atmospheric layer above the uppermost roof layer, these results were generally as expected although they were not significant enough for graphical presentation therefore only the simulations for heating and cooling are presented here (see Figures 104 and 105).

Based on the above discussed results therefore, it is concluded that this scenario is not a desirable design measure for the future development and planning of the city of Beirut due to its overall negative effects on the UHI of the city and therefore overall lowering of thermal comfort levels of Beirut’s urban dwellers.
7.2.5 Scenario 5: Modification of HVEG height. For Scenario 5, the height of high vegetation (or trees) was modified from 10m to 25m to consider the effect of replacing the existing trees along the streets and in the parks of Beirut with much higher trees to test their overall effect on UHI impact. This could be a potential mitigation strategy for Beirut UHI if simulation results show a cooling effect under this scenario.

Simulations therefore showed lower canyon temperatures during the winter day by up to 0.05°C (or 0.37%) when compared against the control run and by up to 0.03°C (or 0.1%) during the summer day. Road temperatures results also decreased by up to 0.76°C (or 10%) during the winter day and by up to 0.33°C (or 0.9%) during the summer day thus showing the more significant effect in alleviation of road and canyon temperatures as a result of increased trees height during the winter season. Roof temperatures again decreased under this scenario by negligible amounts of up to 0.004°C and 0.002°C during both winter and summer days respectively. As for wall temperatures simulations, these also decreased by up to 0.04°C (or 0.36%) during the winter day and by up to 0.015°C (or 0.04%) during the summer day. Regarding internal building temperature simulations, again these were lowered by 0.02°C (or 0.11%) during the
winter day but during the summer day no changes were observed. Finally, heating energy demands were about 6W/m$^2$ higher when compared against the control run during the winter day but the cooling energy demands were found to fluctuate during the summer day whereby they increased by up to 35W/m$^2$ at around midday but decreased again by up to 35W/m$^2$ between the hours of 04:00 to 07:00 and 14:00 to 18:00.

Since some of these differences in results are not so significant, they will not be clearly visible if presented in the form of graphs, therefore for presentation purposes only the simulations results for heating and cooling energy demands are presented here (see Figures 106 and 107).

In conclusion therefore, this scenario for increased tree heights seems to have overall positive impacts on alleviation of the UHI effect in Beirut with increased heating energy demands during the winter but mixed impacts on cooling energy demands during the summer which could be because increasing the height of trees to alleviate canyon temperatures is not nearly so effective as increasing the fraction of the trees which is considered in Scenario 6 below. In addition it is worth investigating the costs associated with purchase and planting and maintenance of suitable trees that grow to such heights and that would easily adapt to Beirut’s Mediterranean climate not to mention that this approach would require removal and replacement with new tree types which might not necessarily adapt and might require many years for any effects on canyon temperatures to take place. Indeed this mitigation strategy is not found to be feasible for the Beirut context.
7.2.6 Scenario 6: Modification of Garden Fraction. For Scenario 6, the garden fraction was increased by the same amount by which the road fraction was decreased (50%), in order to consider this potential mitigation strategy for the city of Beirut which has been found to give positive results in mitigating the UHI impacts in many other similar dense cities worldwide. The simulation results showed that for the case of the canyon temperatures for example, there were no changes during the winter and a decrease in temperatures of up to 0.02°C (or 0.07%) during the summer day. Road temperatures also decreased by about 0.006°C but this was more significant during the summer day where road temperature decreases of up to 0.14°C (or 0.71%) were observed. Regarding roof temperatures, these decreased by up to 0.03°C (or 0.08%) during the winter day and up to 0.08°C (or 0.12%) during the summer day. As for wall temperatures, simulations under this scenario decreased by 0.14°C (or 1%) during the winter day but up to 0.62°C (or 1.8%) during the summer day. Internal building temperatures decreased by 0.04°C (or 0.2%) during the winter day and up to 0.03°C during the summer day. Finally, regarding heating energy demands these increased by about 7W/m² as a result of the raised cooling
effects of the increased garden fractions under this scenario while during the summer day cooling energy demands decreased significantly by about 40W/m² mainly between the hours of 04:00 and 07:00 and 14:00 and 18:00.

Again, as for the previous scenarios three scenarios, since results will not appear so significant in graphical presentations, the simulations for heating and cooling energy demands are only presented here which show a small yet positive difference in energy demands under this scenario especially during the summer season (see Figures 108 and 109).

Therefore, simulation results were generally as expected, with an overall decrease in canyon temperatures, internal building temperatures, and cooling energy demands of the city. The small significance in the output results however is seen later in the discussion section to be because of the lower sensitivity of the TEB modeling scheme to variations in cover fractions as compared to the radiative properties of urban surfaces for example (see Chapter 8). In general however the results were desirable and more suitable for the Beirut context than Scenario 5 and therefore this scenario is considered to be a feasible mitigation strategy for the future sustainable urban planning of Beirut. It is worth noting however that while this scenario might prove to be a very attractive solution for the Beirut case indeed it may cause undesirable effects in increasing traffic congestions, which accordingly brings to attention the dire need to improve the existing public transportation system of Beirut which is discussed in later chapters (see Chapter 8).

\[34\] While this research does not aim to find solutions for a more sustainable transportation networking system for Beirut it does bring to attention the important need to consider this recommendation for future sustainable planning solutions for the city.
7.3 Summary of developing scenarios results for Beirut

Out of the six scenarios analyzed for the Beirut case, it was found that Scenario 1 with increased roof albedos had the most significant effect on alleviation of canyon temperatures. Scenario 2 with increased road albedos also increased canyon temperatures but had generally undesirable effects on internal building temperatures which accordingly increased cooling energy demands. Scenario 3 with increased glass ratio of buildings and Scenario 4 with elevated building heights both increased canyon temperatures and cooling energy demand and therefore gave undesirable results. Scenario 5 with increased tree heights resulted in cooler canyon temperatures. Finally Scenario 6 with increased garden fractions across also had a positive cooling impact on canyon temperatures and was indeed found to be more suitable than Scenario 5 for implementation for the Beirut context as this approach could be regarded as a continuation and expansion of the existing garden fraction while the latter would require replacement and adaptation of new tree types. Based on the simulation results it is concluded that the most suitable UHI mitigating solutions for the Beirut context are Scenarios 1 and 6.
Table 27 is a summary list of the output results for all 6 scenarios in comparison with the control run (CR) during both winter and summer seasons.

<table>
<thead>
<tr>
<th>Outputs for Scenario 1</th>
<th>Impact during winter</th>
<th>Impact during summer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canyon temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Roof temperatures</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Road temperatures</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Wall temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Internal bldg. temps.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Heating energy demand</td>
<td>+</td>
<td>++</td>
</tr>
<tr>
<td>Cooling energy demand</td>
<td>++</td>
<td>++</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs for Scenario 2</th>
<th>Winter results</th>
<th>Summer results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canyon temperatures</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Roof temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Road temperatures</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>Wall temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Internal bldg. temps.</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Heating energy demand</td>
<td>+</td>
<td>--</td>
</tr>
<tr>
<td>Cooling energy demand</td>
<td>++</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output for Scenario 3</th>
<th>Winter results</th>
<th>Summer results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canyon temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Roof temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Road temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wall temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Internal bldg. temps.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Heating energy demand</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Cooling energy demand</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Outputs for Scenario 4</th>
<th>Winter results</th>
<th>Summer results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canyon temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Roof temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Road temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wall temperatures</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Internal bldg. temps.</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Heating energy demand</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Cooling energy demand</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
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<table>
<thead>
<tr>
<th>Outputs for Scenario 5</th>
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<th>Summer results</th>
</tr>
</thead>
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<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Roof temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Road temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Wall temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Internal bldg. temps.</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>Heating energy demand</td>
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<td>+</td>
</tr>
<tr>
<td>Cooling energy demand</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Outputs for Scenario 6</td>
<td>Winter results</td>
<td>Summer results</td>
</tr>
<tr>
<td>------------------------</td>
<td>----------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Canyon temperatures</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Roof temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Road temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Wall temperatures</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Internal bldg. temps.</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Heating energy demand</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Cooling energy demand</td>
<td></td>
<td>--</td>
</tr>
</tbody>
</table>
PART V: DISCUSSION, RESEARCH OBJECTIVES AND CONCLUSIONS
This final part of this thesis is divided into three chapters as follows: 1) discussion of the simulation results of the numerical analysis carried out on TEB for the Beirut case; 2) discussion of the achievement of objectives of this research; and 3) the conclusions and the contributions this research makes to the field of urban microclimatic studies in Beirut.

**Chapter 8: Discussion**

This chapter provides a summary outline of the methodology adopted to investigate the UHI in Beirut, and discusses the outcome of the numerical analysis results, and their significance and meaning.

**8.1 Overview of Research Methodology**

The aim of this research is to determine the nature of the existing urban characteristics of Beirut that have the most significant impact on the UHI of the city. As such, the Town Energy Balance (TEB) urban surface exchange modeling scheme (Masson, 2000), which is a single layer urban canyon model used for mesoscale studies, is selected to carry out simulations of the urban climate in Beirut. TEB is chosen, out of a choice of 9 potential models considered and assessed for the purpose of this research, due mainly to its successful application for large-scale studies of the UHI at the city-scale and due to the nature of the data required to run the simulations which are possible to obtain and extrapolate for the Beirut case.

The city of Beirut covering approximately 21.47 km$^2$ is accordingly divided into cells of equal dimensions (200 x 200 m) across Beirut, where those cells that fall within the boundaries of the Mediterranean Sea are eliminated since this study focuses primarily on the town part of the city and its associated impacts on the UHI. Within each of these
cells the urban characteristics comprised of building height, dominating façade, roofing and road materials along with their corresponding thicknesses, thermal and radiative properties, and vegetation types (whether high or low vegetation or bare soil) and their respective LAI values are defined. The urban boundary conditions are forced with meteorological records obtained from the Fanar weather station located approximately 3.5 km to the east of the Beirut administrative boundary in what is defined as a medium to dense urban fabric. This station is chosen due to the similarity of its location to the Beirut urban fabric, due to its relative proximity to the city as compared to the other existing weather stations spread out across the various regions of the country, and finally due to the continuity of the weather records.

Simulations are accordingly run on TEB across Beirut for one entire year, with one hour time steps (or outputs at every hour). Comparisons are carried out for specified outputs like canyon temperatures or internal building temperatures and so on during February and July days, to determine the effects of existing urban characteristics on UHI during these different times of the year in Beirut in the view to recommend the most suitable mitigation action for alleviation of UHI from an urban planning and design perspective.

8.2 Discussion of Numerical Analysis Results

Analysis of the collected data confirms that the city of Beirut is characterized by a predominantly dense urban fabric with over 80% of the land cover being occupied by impermeable buildings and roads and with less than 20% being covered by garden or green areas although these are mostly scattered across the city. The TEB numerical simulation results for the control run reflect the strong impact of the dominating and
commonly used artificial urban surface materials on UHI particularly in the high density urban fabrics of Beirut. Canyon temperatures are higher in these latter areas as compared to higher garden fraction areas like Horsch Beirut and AUB areas, both during the winter and summer seasons although the cooling effect of the gardens is more apparent during the summer season. Thus, the importance of gardens in alleviating urban temperatures is made apparent from these simulation results under the control run.

Six scenarios are subsequently devised which are compared against the control run data. The purpose of this exercise is to find the most suitable UHI mitigation strategy within the urban planning and design disciplines for the city. Below is a discussion of the output results for these scenarios as follows:

**Scenario 1**

For Scenario 1, the strong impact of the low albedo ($\alpha$) or solar reflectance of the commonly used concrete roofing surfaces is made apparent when the solar reflectance or albedo of concrete is raised from 0.2 to 0.7 and compared against the control run data. Simulation results show generally lower street canyon temperatures and significantly lower roof temperatures as well as lower cooling energy demands during the summer but higher heating energy demands during the winter especially in the dense urban fabrics of the city. Although this scenario results in a higher heating energy demand by about 11W/m$^2$ during the winter when compared to the control run simulations, which is not a desirable result under this scenario, it is seen that indeed these are offset by the lower cooling energy demands of about 50W/m$^2$ during the summer, which is almost five times more than the heating energy loss, thus rendering this heating loss as negligible.

Therefore results show that Scenario 1 is a feasible mitigation strategy for the UHI in
Beirut and can indeed be implemented for Beirut city by painting roofs with white
coloured coatings or limestone for example but this will be discussed in more detail in
later sections.

**Scenario 2**

For Scenario 2, the solar reflectance of road surfaces is raised from 0.225 to 0.8
and upon comparison with the control run data it is found that the temperatures of road
surface and canyon temperatures are lowered. On the other hand, the temperature of
facades, roofs and internal building temperatures are raised. These results can be
attributed to the higher reflective properties of the road surfaces and the resulting
increases in radiative exchanges that accordingly take place predominantly between the
roads and walls of the buildings accordingly affecting their temperatures. Hence, the
cooling energy demands are raised during the summer due to the warmer wall
temperatures while during the winter the heating energy demands are lowered. Therefore,
while Scenario 2 might have significant cooling impacts on road surface temperatures,
the overall effect on walls and internal building temperatures are undesirable resulting in
increased cooling energy demands during the summer season and therefore higher gas
emissions thus exacerbating the UHI effect in the street canyons of Beirut even further.
Selection of this scenario is therefore not a suitable mitigation strategy for Beirut.

**Scenario 3**

Under Scenario 3, which involves raising the percentage of the glass ratio of
buildings, it is confirmed that such a scenario exacerbates the UHI effect but especially
during the summer season during peak hours of incoming shortwave solar radiation
between the hours 11:00 and 14:00 hrs. All output results under Scenario 3 show a
tendency to increase urban surface temperatures and accordingly impact the heating and cooling energy demands of buildings. Therefore Scenario 3 confirms that increasing the glass ratio of buildings is not a sustainable architectural approach for new buildings designs especially due to their significant effect on canyon temperatures thus reducing thermal comfort levels of city dwellers.

**Scenario 4**

As for the modification of building heights from 15 to 35m under Scenario 4, simulations show a resulting increase in canyon temperatures during both the winter and summer seasons. Taller buildings reduce the sky view factor, and reflect the incoming solar radiation to the walls of the buildings thus preventing outgoing long-wave radiation from escaping into the atmosphere. Thus the radiative exchanges occur mostly between the roads and facades of the buildings in the street canyon accordingly raising canyon temperatures. Of course the angle of the sun over the horizon also contributes to the intensity of the solar radiation that is received over urban surfaces which also affects canyon temperatures. The results are therefore more significant during the summer as compared to the winter (see Figure 110) which is why it is important to find sustainable mitigation solutions to alleviate these UHI effects especially during this time of the year. Regarding other output results therefore, under Scenario 4, the simulations for surface road temperatures also increased during the winter season as expected and also during the summer season. Surface roof temperatures under this scenario decreased, since with increased building heights and a reduced sky view factor, most of the radiative exchanges for the incoming short-wave solar radiation take place between the roads and walls of the building. Wall temperatures also increased during the winter and summer seasons as
expected due to the higher radiative exchanges that take place between roads and facades as a result of the lower sky view factor. Internal building temperatures also increased during both winter and summer seasons under this scenario as expected due to the reduced sky view factors. Finally, heating energy demands decreased slightly during the winter season while the cooling energy demands increased during the summer as expected. Therefore, this scenario showed the major disadvantage in constructing higher buildings in Beirut due to their undesirable effects in raising canyon temperatures and cooling energy demands thus lowering the thermal comfort levels for urban dwellers.

Having said this, there is limited available space for new buildings constructions and given the increasing demand for real estate all over Beirut, developers and architects alike are finding that the best solution to maximize space and meet the real estate demand is to increase the height of building but unfortunately this is having significantly negative effects on the UHI of the city as seen in the simulation results in this scenario.

*Figure 110. Solar radiation received in a canyon perpendicular to the sun direction; left hand: sun low over the horizon ($\lambda > \lambda_0$); right hand: sun high over the horizon ($\lambda < \lambda_0$). Source: Masson, 2000, pp.368*
Scenario 5

Concerning scenario 5, where the height of high vegetation or trees is increased, canyon temperatures results decreased slightly during both winter and summer seasons and this can be attributed to the increased shading and consequent cooling effect of trees via evapotranspiration on buildings and corresponding canyon temperatures. Road, roof, and wall temperatures were lowered as well as internal building temperatures under this scenario. Consequently, the heating and cooling energy demands were affected as expected. Although in general this scenario shows overall cooling tendencies, it is not considered to be a very feasible solution for the Beirut context mainly due to the difficulty in finding the appropriate vegetation types of heights greater than 25m (whereas the height of native trees reaches up to about 10m) that could easily acclimatize to Beirut weather conditions and which may potentially take years to show positive effects on canyon temperatures after removal of existing trees and replanting.

Scenario 6

Finally, in the case of modification of the garden fraction under Scenario 6, which is increased by the same fraction by which the road fraction is decreased (50%), the output results show a tendency to decrease canyon temperatures, road, roof and wall temperatures, and internal building temperatures during both winter and summer seasons. The cooling and heating energy demands are also consequently affected with lower cooling demands during the summer (40W/m²) but higher heating demands during the winter (7W/m²) when compared against the control run simulations. Again as for Scenario 1, while the latter is not a desirable result of this scenario it is seen that the energy savings during the summer is almost six times more than the heating energy loss
during the winter thus making this loss negligible. Moreover, it is worth nothing, that the effects under Scenario 6 are not as significant as they are for Scenario 1 for example under which the solar reflectance property of roof surfaces is increased. In fact, according to Lemonsu et al. (2004), the impact of variations of the cover fractions on the fluxes computed by TEB is not very important and is always under 6W/m² as seen in the case of the simulation results under this scenario 6 although they were somewhat higher for the Beirut context (up to 35W/m²). Therefore, due to the generally favourable results of the simulations, Scenario 6 is recommended as a suitable mitigation strategy for the Beirut case and is in fact considered to be an important step toward achieving more suitable thermal conditions for urban dwellers, with increased energy savings in Beirut especially during the summer season not to mention the many other aesthetic benefits of implementing a bigger fraction of urban trees and vegetation around the city. However, it is worth noting while this scenario is a promising solution for Beirut, it will essentially increase traffic congestions around the city due to the reduced road fractions. This therefore brings to attention the important need to improve the existing public transportation of the city, which is quite poor in its existing state as private cars far surpass public transport, with implementation of for example dedicated bus lanes, and even railroads or tramways which were in fact operational in Beirut from the time of the Ottoman rule, and during the French mandate, up until the 1960s. These tramway tracks have unfortunately been covered by layers of asphalt material therefore in the event where operation of tramways is indeed considered in future sustainable planning scenarios for Beirut, tramway tracks will have to be reconstructed. Therefore, this scenario has to be strategically planned by urban planners, transportation and landscaping
engineers and architects to maximize the cooling effect of the city of Beirut under this specific scenario which is indeed a promising solution for the city.

Table 28 is a summary of the results of the 6 scenarios devised for the purpose of this research and the respective determination of their suitability for the Beirut context.

Table 28. Summary of results for the devised scenarios and their suitability for the Beirut context

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Suitability for Beirut case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1</td>
<td>Increasing the albedo of roof surfaces reduced canyon temperatures especially during the summer season thus lowering overall cooling energy demands -&gt; <strong>suitable mitigation strategy for Beirut</strong></td>
</tr>
<tr>
<td>Scenario 2</td>
<td>Increasing the albedo of road surfaces reduced canyon temperatures during the summer but raised the wall temperatures and internal building temperatures accordingly raising cooling energy demands significantly -&gt; <strong>not a suitable mitigation strategy for Beirut</strong></td>
</tr>
<tr>
<td>Scenario 3</td>
<td>Increasing the glass ratio of buildings significantly affected the canyon temperatures, internal building temperatures and cooling energy demands -&gt; <strong>not a suitable mitigation strategy for Beirut</strong></td>
</tr>
<tr>
<td>Scenario 4</td>
<td>Increasing building heights increased canyon temperatures and cooling energy demands -&gt; <strong>not a suitable mitigation strategy for Beirut</strong></td>
</tr>
<tr>
<td>Scenario 5</td>
<td>Increasing heights of vegetation reduced canyon temperatures during winter and summer but this approach would require removal and replacement with new tree types which might not necessarily easily adapt to Beirut’s Mediterranean climate -&gt; <strong>not a suitable mitigation strategy for Beirut</strong></td>
</tr>
<tr>
<td>Scenario 6</td>
<td>Increasing the garden fraction and reducing the road fraction resulted in cooling of canyon temperatures and lowering of overall cooling energy demands. This strategy was found to be more suitable than Scenario 5 as it is considered to be a continuation and expansion of the existing situation using similar tree types that have already adapted to Beirut’s Mediterranean climate. However this scenario may have potentially negative effects on the traffic congestions. It will therefore be necessary to address the improvement of the public transportation of the city with implementation of dedicated bus lanes and even operation of tramways. It requires strong coordination between urban, transportation and landscape planners for successful results -&gt; <strong>suitable mitigation strategy for Beirut</strong></td>
</tr>
</tbody>
</table>
Chapter 9: Achieving Research Objectives

Based on the numerical analysis results of this research, the five key objectives initially outlined in the introductory chapter of this thesis are accordingly discussed in this chapter to assess whether and how this research was successful in achieving these objectives for the Beirut context.

9.1 To measure and model the effect of UHI in Beirut and identify major contributing factors

The first objective of this research was to determine whether it would be possible to measure and model the effects of the UHI in Beirut. To measure directly the effect of UHI in Beirut it would have been necessary to select and obtain relevant measurement equipment from abroad, as they are not available in the country, and which are not only costly and time consuming to ship but also require special permits from the relevant authorities. Considering the unstable situation of the country this attempt would have been futile not to mention time-consuming. Hence, climatic records from the AUB old observatory station were obtained to investigate historical climatic trends in Beirut.

As for modeling of UHI across Beirut, it was first necessary to identify the most suitable modeling scheme for the Beirut context. Out of a choice of nine possible modeling tools in the available literature, including numerical and empirical models developed by Martilli et al. (2002), and Kusaka et al. (2001) for example, and after application of several criteria to assess the suitability of these models for the Beirut context, including nature of data and scale at which these models are used, the Town Energy Balance (TEB) urban surface exchange numerical model (Masson, 2000) was selected. TEB was therefore selected because it requires the least detailed data entry
while still making it possible to carry out accurate parameterization of the atmosphere and surface energy exchanges as validated in numerous studies in this regard for other similar dense cities. In addition, TEB is applied largely for mesoscale studies of the UHI and with successful results (Lemonsu et al., 2004; Masson et al., 2002; Masson, 2006). Therefore, considering that TEB is the most adequate tool to conduct UHI simulations for large scale studies, and considering that TEB does not require data for individual buildings in the city, which is advantageous when considering that data of this nature is limited in Beirut, TEB was found to be the most suitable of the nine modeling schemes considered for the Beirut case.

As such, by using the TEB urban surface exchange modeling scheme, and by using forcing climatic records from Fanar weather station, it was possible to run simulations across the entire administrative area of Beirut for twelve consecutive months for the year 2009 to simulate temperature differences and accordingly impacts on UHI across varying town cover surfaces of Beirut. While >80% of the city is characterized as dense to medium density urban fabric, through TEB, it was possible to identify the major contributing factors of UHI in Beirut (Kaloustian & Diab, 2015).

Therefore, while direct measurements of UHI were not possible, modeling of the UHI using TEB modeling scheme was, giving realistic and justifiable results which were consistent with current studies. Indeed, the scientific findings of this research confirmed that TEB is a very important decision-making tool and can be used as a means to promote evidence-based planning and design practices in Beirut, which is a new trend in urban planning and design disciplines where designers and planners use tangible facts about the environment in order to design more sustainable and healthier environments for cities.
(Faludi and Waterhout, 2006). It therefore involves integration of the best possible research evidence with design and planning experiences as well as knowledge of the needs of the target populations whereby surveys and/or scientific findings or evidence become part of the classic planning traditions (Davoudi, 2006; Faludi and Waterhout, 2006). Indeed, according to Krizek, Forysth, and Slotterback (2009) there is a valuable role for research-generated evidence to inform decision-making. This recommended approach is discussed in more detail in subsequent sections.

The flow chart in Figure 111 below illustrates the various stages involved in the first objective of this research.

![Flow chart of first objective of this research](image)

**Figure 111.** Flow chart of first objective of this research
9.2 To assess whether and to what extent the urban microclimate is considered in urban planning processes for Beirut

The second objective of this research was to assess whether urban microclimatic issues are considered in the urban planning processes for Beirut/Lebanon. To this end therefore it was necessary to review the history of urban planning practices to present day as well as the legal documents of relevance in this regard. Throughout the history of architectural design, engineering, infrastructure, transportation, urban design, and urban policies of Beirut and Lebanon, available literature shows that very little consideration has been given to protection of the environment whether at national or city scale level (Fawaz, 2005; Rowe, P.G. & Sarkis, H, 1998) (Table 8). In fact, according to the latest report on the state of the environment of Lebanon, Beirut and its immediate surroundings have been and continue to be experiencing haphazard or uncontrolled planning which are accordingly having irreversible effects on the surrounding environment including climate (MOE/UNDP/ECODIT, 2011). Considering the unstable political situation of the country this is understandable however upon closer examination it is found that such negative effects are further aggravated as a result of deficiencies in the existing legislations, policies and regulations, and weak institutional and administrative frameworks.

This section therefore investigates the extent to which the environment is considered in the Urban Planning Law, the Building Code and the zoning of Beirut whereby the two former legal documents include designs and policies at the national scale and not specifically at the city scale of Beirut. While it would be useful to also investigate any policies associated with transportation and infrastructure design and networks, it is important to note that this research focuses its investigations primarily on
the effects of the existing urban geometric characteristics on the UHI of the city, which therefore includes building heights, building construction materials, building glass fractions, thermal and radiative properties of construction materials as well as garden fractions. To this end, assessment in this research is restricted to the aforementioned legal policies and zonings as they pertain to their impacts specifically on the urban climate.

As such, as previously mentioned, the key parties involved in the urban planning process in Lebanon, and more specifically for the Beirut case study area, include the Municipality of Beirut, the Directorate General of Urban Planning (DGUP), the Higher Council of Urban Planning (HCUP), the Regional Departments of Urban Planning, and the Order of Engineers and Architects and so on (see Chapter 5). These aforementioned parties are therefore responsible for all issues pertaining to management of the urban planning system, which consists of the Urban Planning Law #69 for Lebanon dated 1983, the zoning specifications of Ecochard dated 1963 which was amended in the year 2007 with some minor modifications, and the Building Code or Construction Law #646 dated 2004.

Although drafted and approved during a time of great civil unrest, the Urban Planning Law #69 does in fact consider the environmental dimension to a certain extent in 8 of its directives as discussed previously (Chapter 5) and as highlighted again in Table 29 below. These directives are generally geared toward the protection of the environment, natural landscapes and sites and do not specifically mention consideration or protection of the urban microclimate. Due to a lack of reinforcement and reporting regime, unfortunately such considerations are often overlooked by the governing authorities. This could be attributed to the fact that these institutions are generally
understaffed and/or do not have skilled personnel; this is typical in governing agencies across Lebanon and is primarily due to the low associated salaries. In addition, there is no direct or efficient coordination between the aforementioned authorities concerned with the urban planning process of Lebanon and the Ministry of Environment (MOE), which is responsible for all issues pertaining to the environment and climate in Lebanon as per Environmental Law 444/2002 (see Appendix VI). Moreover, coordination with the Municipality of Beirut, the key authority in charge of all permitting issues for building constructions, urban planning and so on, is limited.

Regarding the urban zoning specifications the city of Beirut is divided into 10 zones, where each zone has specific zoning requirements for land subdivisions, surface areas permissible for construction in the plots, allowable height for buildings, and so on. Within the urban planning process for Beirut, the zoning specifications do not take into consideration the environmental dimension but rather focus more on the building specifications themselves depending on their respective zones. Having said this the building height is an important factor in terms of its potentially significant impacts on the UHI of a city whereby the taller the building the more significant the reduction in the sky view factor with more heat being trapped in the canyons thus elevating street temperatures and the UHI and this factor is indeed investigated in this research (see Chapter 7 and subsequent sections). As for the Building Code #646, this does include some obvious green elements such as planting trees, ventilation of specific areas of buildings that do not have a view (window/air passage), and it encourages installation of solar hot-water systems for all house owners.
Moreover, the National Physical Master Plan of the Lebanese Territory (NPMPLT) or SDATL, which was issued as a decree in the year 2009, is one of the first official urban planning documents, which emphasizes the importance of considering the environmental dimension but it should be emphasized that this is a master plan at the national scale and not for the city scale per se and therefore has a more general approach toward recommending measures to protect the environment. More detailed works are accordingly required to find recommendations more specific to the city scale (meso-scale) of Beirut case study area, which is one of the objectives of this research. Also, Solidere, although a private company, is taking major steps to implement environment and microclimatic factors in its urban planning and architectural designs although these are focused only in the BCD area which is owned by Solidere. Finally, thermal standards for buildings in Lebanon were also established by the Ministry of Public Works and Transport (UNDP/GEF and MPWT/DGU 2005) based upon their respective climatic zones and an energy efficiency building code road map was also accordingly established for Lebanon (MED-ENEC/EU, 2012). Unfortunately these thermal standards for energy efficient buildings in Beirut have not yet been approved by the relevant authorities and have therefore not yet been adapted.

In addressing the second objective of this research therefore, it is concluded that throughout its history, some important achievements have been made to consider the environmental dimension but mainly at the national level and not the city scale or meso-scale level of Beirut case study area. However, these environmental issues are not rigorously implemented within the urban planning processes (Fawaz, 2005; MOE/UNDP/ECODIT, 2011). These can be achieved by improving and strengthening
the existing institutional frameworks to ensure a rigorous implementation of green and sustainable urban planning and design practices in Lebanon. In addition, there still remains an important need to consider the urban microclimatic factor in the urban planning and design policies.

Table 29 is a summary of the assessment of environmental and urban microclimatic considerations within the existing urban planning framework of the city.
Table 29. *Summary of assessment of environmental and urban microclimatic considerations in urban planning context of Beirut*

<table>
<thead>
<tr>
<th>Legal documents, institutional framework and urban planning developers in Beirut</th>
<th>Assessment of environmental and urban microclimatic considerations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban Planning Law #69 (1983)</td>
<td>Considers the environmental dimension to a certain extent in several articles 7, 8, 9, 17, 19, 20, 23 &amp; 24. These directives are generally geared toward protection of the environment, natural landscapes and sites but there is no mention of protection of the urban microclimate. Also, due to a lack of reinforcement and reporting regime, such considerations are often overlooked by the governing authorities.</td>
</tr>
<tr>
<td>Building code #646 (2004)</td>
<td>This code does include some obvious green elements such as planting trees, ventilation of specific areas of buildings that do not have a view (window/air passage), and it suggests installation of a solar hot-water system for house owners but it is not regimentally applied by the concerned professionals in the field, including architects and engineers, since it does not allow for flexibility in design.</td>
</tr>
<tr>
<td>Urban zoning of Beirut (Ecochard) (1963)</td>
<td>This divides Beirut into 10 zones and focuses more on the building specifications themselves depending on their respective zones as opposed to any environmental considerations.</td>
</tr>
<tr>
<td>NPMPLT - Decree No. 2366 (2009)</td>
<td>The NPMPLT emphasizes the importance of considering the environmental dimension in the master planning of the country, and not at the city scale, requiring therefore more detailed goals and objectives.</td>
</tr>
<tr>
<td>Institutional framework</td>
<td>Concerned authorities are generally understaffed and/or do not have skilled personnel; this is typical in governing agencies across Lebanon and is primarily due to low associated salaries.</td>
</tr>
<tr>
<td>Solidere</td>
<td>The private company of Solidere is involved in important urban planning and design works in Beirut Central District implementing sustainable and environmentally friendly practices that take into consideration the urban microclimate such as soft landscaping and environmentally friendly green building designs and planning.</td>
</tr>
<tr>
<td>Thermal standards for buildings across Lebanon (2005)</td>
<td>Thermal standards for buildings were established for Lebanon based on their climatic zones where Beirut falls within the coastal climatic zone but these standards have not yet been approved or adapted.</td>
</tr>
<tr>
<td>Energy Efficiency building code road map (2012)</td>
<td>An energy efficiency building code road map was also established for Lebanon by</td>
</tr>
</tbody>
</table>
9.3 To find most suitable measures to alleviate the effects of UHI in Beirut from a technical perspective

Since urban planning is a technical and political process concerned with the use of land and design of the urban environment, including buildings, water and energy and transportation infrastructures, the process to alleviate the impacts of the UHI effect can be devised by targeting one or more of these branches of the urban planning discipline, both from a technical and political approach. For proposed technical solutions to take effect it would be necessary to ensure support from a legal and political perspective.

As such, from a technical perspective, this research was able to achieve its third objective which involved the determination of the most suitable measures to alleviate the effects of UHI of Beirut. Again it is important to emphasize that this research focused primarily on technical solutions from the perspective of the urban design and geometry of the city while transportation and infrastructure dimensions were not included.

Indeed, the TEB simulation results for the devised scenarios helped identify and provide the evidence for the urban parameters that play the most significant role in exacerbating the UHI effect in Beirut, namely the low solar reflectance properties of roofs and the low percentage of garden fractions spread out across Beirut.

This research therefore recommends replacing existing roofing materials with cooler building materials, either by coating existing roofs with white-coloured paints or by spreading limestone layers across the rooftops. Existing roofing materials have a low $\alpha$ value of 0.2. Research shows that cool roofs and/or white roofs save 10%-20% air-conditioning for an area under roofs therefore resulting in significant cooling energy savings (Akbari, 2014) (see Figure 112). Moreover, a materials measurement
performance tests for roofs show that upon testing and comparing the surface temperature of varying roofing materials over a course of four days (26-29 August 2004), cool white roofs have the lowest surface temperatures, at around 30°C, as compared to concrete roofs, at about 45°C (see Figure 113). According to Synnefa, Saliari, and Santamouris (2012), increasing either reflectance and/or emittance lowers a surface’s temperature and contributes to the decrease in temperature of the ambient air as the heat convection intensity from a cooler surface is lower. In fact, under peak solar conditions (about 1000W/m²) the temperature of a black surface with solar reflectance of 0.05 is about 50°C higher than ambient air temperature. For a white surface however with a higher solar reflectance of 0.8, the temperature rise is only about 10°C. Therefore, among heat island mitigation strategies, the use of cool materials has gained a lot of interest due to their efficiency, low-cost and easy to apply solution (Akbarai et al., 2001; Doulos et al., 2004; Rosenfeld et al. 1995, 1998; Santamouris et al., 2011, Santamouris et al., 2012). To ensure implementation of this strategy however it would be necessary to coordinate with architectural and engineering sectors under the Order of Engineers and Architects (OEA) for example but this is addressed in more detail in the fourth objective of this research in the following section.
Figure 112. Mexican researchers modeled significant cooling energy savings from cool roofs. *Source:* Akbari, 2014

Figure 113. Materials performance testing for roofs from 26 to 29 August. *Source:* Akbari, 2014
This research also recommends increasing the percentage of vegetative surfaces. According to the available literature, trees and green spaces contribute significantly to cooling cities and saving energy (Santamouris, 2013). Shade trees intercept sunlight before it warms a building while the urban forest cools the air by evapotranspiration. Trees also decrease the wind speed under their canopy and shield buildings from cold winter breezes (Akbari et al., 2001). Evapotranspiration is the major mechanism through which trees contribute to decreasing urban temperatures. Trees also help mitigate the greenhouse effect, filter pollutants, mask noise, prevent erosion and have a calming effect on people (Santamouris, 2013). They also improve quality of life, increase value of properties, decrease rain run-off water and hence also protect against floods (McPherson et al., 1994). The effectiveness of vegetation in an urban area depends on its intensity, shape, dimensions and placement. But in general, any tree, even one bereft of leaves, can have a noticeable impact on energy use (Akbari and Taha, 1992). However, a study on the measurements of the ambient temperature in and around an urban area in Athens, Greece showed that upon leaving the park an immediate temperature increase of about 1K occurred showing that there is no constant gradient of temperature increase with distance from the park but rather a step function (Santamouris, 2013) thus reflecting the very localized effect of urban trees and vegetation on ambient temperatures as opposed to a wider effect at the city scale. In fact, the control run results for canyon temperature simulations across the entire city of Beirut showed that just outside of the boundaries of the pine tree garden of Horsch Beirut in Mazraa, in the south of Beirut for example, the temperatures immediately shoot up again from around 38 to 42°C. Having said this, according to TEB simulation results, there are some overall energy savings during the
summer season thus highlighting the more significant shading effect of trees on buildings. Numerous studies show the substantial energy savings due to planting of shade trees or urban forests (Akbari, Romm and Pomerantz, 1998; Akbari, Pomerantz and Taha, 2001; Rosenfeld, Santamouris, 2013). Therefore existing literature highlights the successful results upon implementation of this mitigation measure resulting in alleviation of UHI effects and energy savings (Akbari et al., 2001; Oliveira et al., 2011; Rosenfeld et al., 1998). As for the case of the first recommended mitigation strategy, it is necessary to ensure implementation by communicating and coordinating with all concerned urban planning authorities. The evidence provided by the TEB modeling tool in this research can be used to facilitate this communication process and this is addressed in the fourth objective of this research in the subsequent section.

Therefore, the third objective of the thesis was achieved in this research whereby the most suitable technical measures for mitigation of the UHI for the Beirut context were determined and accordingly recommended based upon the simulation results of the devised scenarios on TEB. For the recommendation to raise the solar reflectivity of rooftops, this could easily and successfully be achieved by applying white coatings of paint on the rooftops of existing as well as new buildings in Beirut. The second recommendation on the other hand, to increase the fraction of urban gardens and vegetation, can be considered to be an optimistic scenario, although it could essentially be achieved by ensuring close coordination and communication between and amongst all relevant authorities and by selecting for example pilot areas in which to test the success of this mitigation strategy for the Beirut context. The present condition of roads may also need to be considered which may not have enough pavement or median spaces to plant
vegetation, in which case such sections may need to be eliminated with more focus on increasing the solar reflectivity of the rooftops here, although it would be interesting to conduct a study to investigate the total length of such roads in Beirut which could help in determining the suitability of this proposed scenario. On the other hand, those roads with sufficient pavement spaces could be the focus of attention for tree or vegetation planting in Beirut. In addition, the sufficiency of water supplies to maintain increased garden fractions across Beirut would also need to be considered if one is to ensure the success of such a scenario. In this case it is important to emphasize that although Lebanon is rich in water resources there is the concerning problem of sustainable management of water resources in the country. Having said this, the national water strategy of Lebanon (Ministry of Energy and Water, 2010) is the gateway to ensure sustainable water supply to all areas of Lebanon including Beirut through the construction of dams and reservoirs that can also help to ensure successful implementation of this scheme for Beirut. Specifically for Beirut, it has been proposed to construct the “Bisri Dam”, which has a capacity of 125 million cubic meters to supply water to approximately 1.8 million inhabitants residing in Beirut and Greater Beirut Area (www.cdr.gov.lb). Therefore, according to the simulation results from TEB, significant positive steps will be taken to alleviate the impacts of UHI in Beirut city.

9.4 To assess implications for urban planning process from an institutional and administrative perspective

The previous objective of this research was achieved whereby technical solutions to alleviate the effects of the UHI for the Beirut context were found based on the numerical analysis results of the devised scenarios using TEB. However, this in itself is
not enough to ensure proactive implementation and successful results across Beirut. Coordinated efforts from the responsible authorities are necessary to ensure implementation of the scientific findings of this research for improvements in planning and design practices in Beirut and accordingly mitigation of the UHI impacts. Indeed this could be managed by the potential establishment of a council or agency that could deal solely with urban climatic issues and that could include one member from each of the concerned stakeholders and that could be under the responsibility of the Ministry of Public Works or Transport of the Ministry of Environment. In addition, the evidence-based planning approach could be implemented for successful application of the recommended mitigating actions.

As previously mentioned evidence-based planning is a new approach in the planning and design sectors that is being implemented nowadays in decision-making processes. Evidence contributes to the sustainable development of a city acting as a common language that facilitates communication between the various involved parties thus tying the measurement process more closely to planning. Unfortunately, in Lebanon, urban planners and architects have little or no knowledge of the urban microclimate and the impact of urban planning and urban design parameters on the UHI and this is due mainly to little or no climatic information awareness. In addition, there is no existing legislation or code that can at a minimum provide guidance in this regard, be it at national scale or city scale, as discussed in the second objective of this research. There is therefore a need for systematic dissemination of climatic information by providing evidence to urban planners and designers which can accordingly help in promoting informed decision-making.
There are also authorities and parties worth mentioning that are already involved in this field in Lebanon such as the climatic department of the MOE (http://climatechange.moe.gov.lb/home) and which can therefore be a great source of knowledge for topics associated with the climate in Beirut. The Lebanese Center for Energy Conservation (LCEC) is another national organization affiliated to the Lebanese Ministry of Energy and Water (MOEW) and which addresses end-use energy conservation and renewable energy at the national level (www.lcecp.org.lb). The LCEC could therefore also provide knowledge on urban design parameters and buildings designs for example to help minimize exacerbation of the UHI as well as adaptation measures. Indeed the LCEC was recently involved in a very important energy-savings campaign whereby it provided incentives through subsidies to homeowners to implement solar water heating which achieved successful results across the city of Beirut (see LCEC webpage).

LIBNOR or the Lebanese Standards Institution is another important authority attached to the Ministry of Industry (MOI) that is involved in preparing national standards for structural codes for buildings, amongst others, and could therefore be another very useful source of knowledge in the communication network that is proposed in this research (www.libnor.gov.lb). Moreover, the Lebanon Green Building Council or LGBC (www.lebanon-gbc.org), which is a Non-Governmental Organization (NGO), is another source of climatic knowledge which provides incentives for a variety of relevant parties, including consulting engineers, architects, building contractors, real estate owners and promoters, manufacturers, educational institutes, and research organizations, by offering a Lebanese certification system for buildings, known as “Arz”, that adopt
environmental parameters and transform the way buildings and communities are designed into a prosperous environment that improves the quality of life (www.arzrating.com). Currently, LGBC is not involved as a stakeholder in urban planning decisions and could indeed prove to be a very useful source of knowledge in decision-making processes in this regard. Finally, academic researchers in the field could also be involved in this process of transferring urban climatic knowledge. However, it is also important to emphasize that there should be robust and continuous implementation of the knowledge and/or evidence that has been gained through TEB in all future urban plans and designs of the city. In order to achieve this it is recommended that all relevant parties employ properly skilled, certified and trained staff that can carry this through and ensure best practice at all times.

Therefore, the successful communication between and amongst these parties and the urban planning authority would be an essential first step toward mitigating the UHI in Beirut and this could be achieved by first establishing an urban climate agency at the city scale, by strengthening the existing institutional framework (see Figure 114) and finally by ensuring support through the evidence-based planning approach through integration of the scientific findings, by TEB, into each stage of the decision-making processes (see Figure 115).
Figure 114. Recommended organization chart for the transfer of urban climatic knowledge amongst all parties involved in urban planning process in Beirut and institutional strengthening.
9.5 To find opportunities at all planning and design levels to help achieve more sustainable design and planning practices in Beirut

The previous objective of this research was to propose successful methods for the administrative and institutional disciplines to implement successfully the technical solutions as per TEB for alleviation of the UHI of Beirut. The assessment of opportunities from a legislative point of view however still remains unanswered. What are the regulatory gaps and what can be done to include and enforce sustainable measures to protect the urban climate within the context of the existing legislations, designs and planning processes of Beirut city?
As previously discussed, the existing Urban Planning Law #69 considers protection of the overall environment and natural landscapes within 8 of its directives. There is however a gap in the existing legislation with respect to the need to consider climatic issues in urban planning schemes. Therefore there is an opportunity for modification and amendment of this Urban Planning Law #69 to take into account the climatic dimension however it is important to note that any modifications made to the UP law can only be at the large-scale where more detailed specifications could be provided at building scale in the Building Code for example which is discussed next. In addition, any recommendations are restricted specifically to urban geometric and design parameters and do not include transportation and infrastructure sectors. Table 30 therefore recommends improvement of the Urban Planning Law #69 to consider more rigorously protection of the urban microclimate at the national scale.

Indeed there is also a gap in the consideration of “green” initiatives in the existing Building Code #646 (or construction law) for Lebanon thus again there exists an opportunity for modification of building design codes to reflect green building designs which could be more specific to meso-scale. Sustainable design is fast becoming the norm for architects around the world accelerated by the advent of green building rating systems and standards. Categories of sustainability that can be incorporated into the existing Building Code #646 of Lebanon could potentially include planning and design, energy efficiency, and environmental quality dimensions. More specifically, elements of sustainability that could be incorporated into the Building Code #646 include orientation of buildings and their impact on energy consumption, natural daylight and view, insulations, green roofs, energy conservation measures, indoor environmental quality and
coordination with the Environmental Law 444/2002 (LGBC, 2012). It is worth noting that although Law 444/2002 mentions the need to control and mitigate environmental degradation, it is actually the work plan prepared by the MOE for the period 2010-2012 which specifically mentions climate change and its importance at the urban scale (MOE/UNDP/ECODIT, 2011). Therefore, in this respect, reference should be made to both these documents.

As such, changes in the Building Code #646 are necessary as there is a much needed alternative for advancing environmentally responsible architecture as can be seen in the numerous building rating systems developed worldwide like BREEAM (Building Research Establishment Environmental Assessment Methodology), LEED (Leadership in Energy and Environmental Design), and Estidama (the Arabic word for sustainability and the sustainability initiative of the Abu Dhabi Urban Planning Council), and so on. Upon looking into more detail regarding the workings of the Estidama rating system in Abu Dhabi for example it is found that it is not just a rating method but it is a vision and a desire to achieve a new sustainable way of life in the Emirate. The reason why Estidama is so successful in Abu Dhabi is because of the large awareness and educational campaigns carried out for all developers, engineers, architects and urban planners to think and act in a sustainable manner. However, these are all voluntary programs similar to the previously mentioned “Arz” building rating system for Lebanon the implementation of which is encouraged by the Lebanon Green Building Council NGO. A much stronger approach would be required in Lebanon for awareness and incentives in order to achieve successful results similar to the Abu Dhabi case in which case robust implementation of the green building requirements at the building design level for the Beirut case is
recommended. However, the question of how to go about making this change arises. Should it first be adopted as a voluntary green code program to allow adequate time for all concerned parties to become educated and more familiar with it, or should the green code be adopted as mandatory as a way to achieve environmental benefits on a large-scale? In the case of the latter, those who are familiar with sustainable design practices would experience an easy transitional phase but others would need to pay more attention to the building performance measures to ensure code compliance while a few others might perceive this as a dramatic change (Building Energy Forum, 2012). In addition, a new green building code would potentially mean new training requirements for architects and engineers alike that would essentially incorporate another layer of expertise on the fundamentals of environment and climate that form the basis of the licensed practice. Having said this it is worth noting that writing codes that apply with equal rationale to a variety of building types in different geographic locals and climatic zones is difficult which is why it would be necessary to establish building codes that target the respective climatic zones in which they lie. Thus, for the case of Beirut city, this would fall under the coastal climatic zone.

Assuming that the choice for modification of the existing Building Code #646 of Lebanon is made therefore, it would accordingly be necessary to implement requirements for these green building elements, such as the need for cooler materials for rooftops of buildings including white-coated paintings or limestone which could be spread out across the entire roof area of a building. These are common methods that are being practiced in many similar dense cities experiencing the undesirable effects of UHI (Akbari, 2014). Therefore it is recommended to improve the existing Building Code #646 to include an
additional section listing the requirements for green buildings in Beirut under which the general criteria outlined in Table 31 below could be added.

Opportunities also exist for the modification of zoning specifications to specify for example surface area requirements for green surfaces within building plots, or to revise height requirements for buildings within each zone as not all the zones have specifications for building height, namely zones 4, 5, 6 and 7. Given the numerous high rises spreading across the city of Beirut like the Marina Tower\textsuperscript{35} in Ain El Mreisseh and the Sama Tower\textsuperscript{36} in Ashrafiyeh (see Figure 116 below), implications on the UHI can be quite significant as seen in Scenario 4 of this research (see Chapter 7). Once the specifications have been made, stringent measures would be necessary from the side of the planning authorities to forbid the issuance of building permits unless they meet the specifications as per the modified “sustainable or green” zoning plan. Should this requirement not be met due to limited space availability or otherwise, there should be a requirement for the implementation of cool building materials, higher fraction of green surfaces, low glass ratio and so on before permits are finalized.

\textsuperscript{35} The Marina Towers is a residential complex in Beirut Central District and is built on over 7,000m\textsuperscript{2} of land with the main tower reaching a height of 150m.

\textsuperscript{36} Sama Beirut is an upcoming residential, commercial and office tower in the Sodeco region of Ashrafiyeh in Beirut. It is a 50-storey high-rise with a height of approximately 187m.
Figure 116. View of Sama Beirut Tower in Ashrafiyeh as well as five more high rises under construction as seen in the background (photograph taken by author)
Table 30. Environmental dimensions considered within the Urban Planning Law #69 (dated 1983) and corresponding weaknesses and opportunities in terms of climatic issues

<table>
<thead>
<tr>
<th>Article #</th>
<th>Directive</th>
<th>Weaknesses and Opportunities</th>
</tr>
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<tbody>
<tr>
<td>7</td>
<td>Urban planning should consider the relationship between communities and surrounding areas including agricultural areas, forested areas, and the protection of the environment and to consider the use of the land for the benefit of the public good aiming toward achieving sustainable development</td>
<td>There is very little or no evidence for sustainable development taking place within the Beirut context although major attempts and works are being carried out toward achieving this goal as per “1er atelier urbain vers une politique d’aménagement durable des espaces publics de Beyrouth” (<a href="http://www.bt-ville.org">www.bt-ville.org</a>). It is recommended to modify Article 7 to include also protection of the climate aiming toward achieving sustainable development.</td>
</tr>
<tr>
<td>8</td>
<td>Urban master plans must specify the criteria for land use by taking into consideration the agricultural value of the land and the possibility or implementation of irrigation canals. These should be specified prior to construction otherwise no construction is permissible. Non-construction zones can also be determined</td>
<td>As there are no agricultural lands within Beirut and as most of the land is already built-up, this directive does not apply for the Beirut case therefore there are no perceived opportunities here.</td>
</tr>
<tr>
<td>9</td>
<td>Zones that have not been planned can be placed under study for a period of up to two years further to a decision made by the Ministry of Public Works and Transport (MOPWT), and after consultation with the HCUP and the relevant municipality. During these two years however no construction is to be permitted. Forested areas are not allowed to be destroyed and the natural landscape of the area should not be changed</td>
<td>All zones within the Beirut administrative area are planned. There is no longer any remaining natural landscape within the boundaries of Beirut. In Beirut there is the Horsch Beirut public garden which is comprised of pine trees and was created as an urban park in the early 2000s. Therefore this specific article could be elaborated to say that all existing urban gardens should also not be changed especially due to the positive role they play in alleviating the urban microclimate.</td>
</tr>
<tr>
<td>17</td>
<td>No monetary compensations will be provided for any changes to building coefficients including setbacks,</td>
<td>This directive could be elaborated to mention the important role the specified building parameters play</td>
</tr>
<tr>
<td>Number</td>
<td>Paragraph</td>
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<tr>
<td>19</td>
<td>Relevant authorities may expropriate private land for the benefit of the public good by compensating the respective landowner(s) with a nearby land of equal value. The expropriation of private land for the benefit of the public good could be further elaborated to include examples of such types of public good particularly where they relate to the incorporation of urban parks for example since these are not only aesthetically pleasing but also help improve the urban microclimate thus improving the overall quality of life therefore benefiting the public good.</td>
<td></td>
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<tr>
<td>20</td>
<td>Relevant authorities may carry out re-parceling of previously zoned areas in order to facilitate urban planning. Again this specific article is beneficial especially if the relevant authorities are planning to re-parcel to incorporate green areas in their newly zoned areas. An opportunity exists here in that this article could be further elaborated to express that it is not only to facilitate urban planning but sustainable urban planning which would again benefit the public good.</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Government or relevant municipality may ask the landowners of residential areas nearby forested areas or natural open spaces to swap their land with another piece of land. Again there is another opportunity here in that this article could be further elaborated to express the need for the government or relevant municipality to protect these forested or natural open spaces especially due to the role they play in cooling urban microclimates and improving the overall quality of life.</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Municipalities or union of municipalities can agree with landowners of forest or natural sites to open these areas as public areas or parks and municipalities can accordingly charge admission fees for maintenance or upkeep. An opportunity exists here whereby this article could also mention the importance of ensuring maintenance and upkeep especially due to the significant role they play in improving quality of life and the urban climate.</td>
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### Table 31. Recommendations for modifications of the Building Code #646 (dated 2004) of Lebanon

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Description of requirements</th>
<th>Actions</th>
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<tbody>
<tr>
<td>Increase solar reflectivity</td>
<td>All rooftops in Beirut must have albedo values 0.6-0.8</td>
<td>Cool roof materials include white-coloured paint or limestone paint</td>
</tr>
<tr>
<td>of rooftops</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increase solar reflectivity</td>
<td>All facades in Beirut must have albedo values &gt; 0.7</td>
<td>Cool facades include white/beige paint or plaster</td>
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<tr>
<td>of facades</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Decrease glass ratio</td>
<td>All buildings in Beirut must have glass ratio &lt; 0.4 (40%)</td>
<td>Building designs should ensure that while buildings are properly ventilated and have natural lighting they should not have glass ratios &gt; 40%</td>
</tr>
<tr>
<td>Height of buildings</td>
<td>All buildings in Beirut must have heights not more than twice the width of roads on which they will be built and should strictly comply with Building Code #646 requirements (Appendix IV)</td>
<td>More stringent efforts should be made to abide by the maximum permissible height for buildings and leniency should not be permitted unless the building can be classified as a green building following a specific rating system like Arz for example</td>
</tr>
<tr>
<td>Landscaping / vegetation</td>
<td>All buildings must ensure planting of one row of urban trees (preferably pine trees or ficus nitida) around the building perimeter</td>
<td>Landscape architects and urban planners must coordinate to ensure maximizing garden areas around building perimeter</td>
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<tr>
<td>around buildings</td>
<td></td>
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</tbody>
</table>

In conclusion therefore, it is found that there are indeed opportunities for improvement of urban planning and design policies or codes in Lebanon for better consideration of the urban microclimatic issues at national scale and accordingly city-scale.
Chapter 10: Conclusion

Urban areas tend to have warmer air temperatures than their rural counterparts as a result of gradual land surface modifications that include replacing natural vegetation with buildings and roads. The urban heat island or UHI which describes this phenomenon arises mainly as a result of the higher solar absorptive capacity of the artificial urban surfaces that replace the naturally vegetated surfaces, which accordingly become extremely hot, thus warming the surrounding air. This is cause for concern especially where the thermal comfort level and well-being of urban dwellers is concerned, not to mention the strong link that exists between heat stress and mortality as seen in the case of the Paris heat wave of 2003, for example, which was responsible for the death of thousands of urban residents. The issue of urban climate and more particularly urban heat island is part of the more general subject of adapting to climate change impacts. Local communities are showing an increasing demand for knowledge on the impacts but also on the means of available local solutions as such.

This research had 2 core objectives: 1) to find the main causes of urban planning and building design characteristics that exacerbate the UHI within the context of the densely populated city of Beirut; and, 2) to propose the most suitable mitigating actions from an urban planning and design perspective with the aim of reducing urban warming in Beirut.

For the 1\textsuperscript{st} objective, simulations were carried out for the existing urban conditions across the entire administrative area of Beirut using the Town Energy Balance or TEB model. This numerical model, which was developed at Météo France, parameterizes the surface-atmospheric energy exchanges at the city scale or meso-scale. For the 2\textsuperscript{nd} objective, realistic and feasible mitigating scenarios were devised for the
Beirut context and were accordingly run on TEB. The simulation results helped to recommend urban heat island mitigating actions for the urban planning and design sectors in Beirut.

This thesis was therefore organized into 5 main sections as follows: 1) introduction and scale of study; 2) literature review and analysis; 3) Beirut context; 4) numerical analysis; 5) discussion and conclusions.

Within a city, the various complex interactions between the existing urban components can have a significant impact on the urban climate, which can be analyzed at various different scales as discussed in the 1st section of this research. At the micro scale, or what is otherwise known as street-scale, the main physical mechanisms involved in influencing the urban climate include air circulation strongly influenced by evaporation, the contributions of anthropogenic heat, radiative or thermal heat due mainly to the geometry of the city, and the radiative properties of building materials.

All these physical mechanisms at the street scale can lead to the UHI phenomenon at the scale of the city. These are expressed through the radiation balance where all the associated processes are affected by the urban environment because of its geometry, radiative properties of its materials, and air pollution, all of which help to explain the formation of the urban heat island.

As the 2nd section details therefore, the city has a rather significant influence on the urban heat island, although it is important to note that the geographical factors and topographic situation of the city (such as mountains, valleys, lowlands, etc.) also play a vital role in this respect.
Other factors that contribute to the formation of the urban heat island as seen in the 2nd section of this research include:

- natural factors: wind speed and intensity of cloud cover, time of year (season) and time of day; and,
- anthropogenic factors: increased urbanization and replacement of natural surfaces with artificial surfaces that have typically low albedo or solar reflectivity properties, air polluting emissions from industrial activities, transportation and air-conditioning and domestic heating, and urban geometry that includes heights of buildings, orientations, sky view factor, and height to width ratio of buildings.

Indeed the urban heat island is one of the more noticeable aspects of urban climate. Numerous studies show the various techniques and criteria that are being implemented to measure and reduce urban warming effects. For measurement techniques, some of these include, for example, direct measurements using fixed or mobile traverses, while others include application of either high resolution orthophotography or thermal remote sensing imagery. As for mitigating actions, some of these include implementation of larger fractions of gardens while others include increasing the albedo of urban surfaces, for example. Indeed, for the purpose of this research in the Beirut context, the identification of these various techniques for measurement and mitigation of UHI were deemed important.

In the 3rd section of this research, an assessment of the existing urban situation within the Beirut context including land cover and land uses, urban zoning, urban morphology, and albedo of dominating artificial surfaces, confirmed that Beirut is an
artificial city with a very low percentage of vegetation cover. Indeed >85% of the urban surfaces, namely roofs and roads, have low albedo properties or solar reflectivity. The average height of buildings has also been gradually increasing, especially over this last decade. These urban characteristics of Beirut can all contribute to the exacerbation of the urban heat island phenomenon.

What is interesting and based on the aforementioned findings is the fact that urban policies in Lebanon do not consider or mention protection of the urban climate. An assessment of the legal context in the 3rd section showed that the Urban Planning Law #69 (dated 1983) and the Building Code #646 (dated 2004) are the two main legal documents that are of utmost relevance within the urban planning and design disciplines for Beirut, although neither mention or provide relevant codes that take into consideration the urban climate. Additionally, the National Physical Master Plan of the Lebanese Territory (NPMLT) or the Schéma Directeur d’Aménagement du Territoire Libanais” (SDATL) (prepared in 2005 and later ratified as Decree #2366 on 20/06/2009), is another important document typically referred to for guidance for urban planning and for existing and proposed land uses in Lebanon. Although, here again, there is no reference for measures to be taken to reduce the impacts on the urban climate.

The zoning plan of Ecochard (dated 1963) is another important document referred to for guidance by architects and planners with respect to specific limitations for building plots within each of the 10 respective zones of Beirut. However, some deficiencies are also found here, such as in the implementation of allowable building heights by developers; this is relatively lax as evidenced by the process of obtaining permits for buildings above maximum permissible heights which has been somewhat facilitated due
in part to weaknesses in the existing administrative framework, including the low number of skilled staff and low salaries. In addition, the relevant authorities and/or parties are not adequately informed of the significance of protecting the urban climate.

Having conducted an extensive literature review and assessment of the existing Beirut context, simulations of the existing urban conditions for Beirut city were carried out as seen in the 4th section of this thesis. To enable better awareness policies, be it as developers, planners, architects or simply citizens who have a relative influence on some of the factors affecting the climate, it is necessary to present the results related to the temperature of the city. Simulations using TEB modeling scheme were therefore carried out. The goal was initially to model the UHI from a description of Beirut (based on the aerial orthophotograph of Beirut dated 2008) with a grid mesh having a scale of 200 x 200m. Results of the simulations confirmed the predominant role played by the radiative parameters in the energy balance of the city in the summer. During the winter, on the other hand, it is the thermal insulation that has the greatest influence, as seen, for example in the results under the scenario which modifies the glass ratio of buildings. Although simulation results for modification of vegetation fractions were not as significant as expected, all results were consistent with current studies, which showed that increasing both the albedo of surface materials and vegetation fraction in cities have a great advantage in reducing the impacts of the urban heat island phenomenon, specifically on urban dwellers.

The form of the built environment influences the amount and fraction of wall surfaces, roads and roofs. Thus, changes in this form results in modifications to the energy balance due not only to a change in the exposure to solar radiation of different
surfaces, but also due to a change in their fraction, considering that each surface
possesses its own physical characteristics and therefore has a different thermal behaviour.
The influence of the shape or form of the built environment on the energy balance is
therefore a complex one.

Finally, in the 5th and last section of this thesis, recommendations are made for
improvements in the communication network that currently exists between the various
relevant authorities and parties, most notably the Municipality of Beirut, the Higher
Council for Urban Planning (HCUP) and the Directorate General of Urban Planning
(DGUP) since urban climatic knowledge amongst these parties is relatively limited.

Currently the Lebanese Green Building Council or LGBC – an NGO that is quite
actively involved in raising awareness on thermal standards for energy efficiency of
buildings – has no influence on the decisions made by the relevant urban planning
authorities. However, their participation and involvement as a stakeholder could be
highly beneficial in transmitting the necessary knowledge on urban climatic issues due to
the organization’s involvement in providing a Lebanese certification system for buildings
known as “Arz” that adopt environmental parameters and transform the way buildings
and communities are designed into a prosperous environment that improves the quality of
urban life. Academic institutions could also be actively involved in the transfer of urban
climatic knowledge especially when considering the numerous works being conducted in
these institutions that are paying increased attention to the topic of climate change, urban
climate and adaptation measures. Of course multi-disciplinary coordination would be
required at all times between all the relevant disciplines to ensure strategic and
sustainable urban planning for Beirut and this could be achieved through the establishment of an urban climate agency or council.

Recommendations are also made in this 5th section for the need to modify relevant urban policies in the Urban Planning Law #69 (dated 1983) and Building Code #646 (dated 2004) of Lebanon. For example, for the case of the UP Law, the environmental elements already considered in the existing 8 out of 43 articles should be further elaborated to emphasize the importance of also protecting the urban climate. By introducing this specific requirement in the urban planning law under which Lebanon functions today, the preliminary vital step that identifies the need to protect the urban climate would have been achieved. As for the Building Code, this should also be further elaborated upon to introduce new components that more specifically target the construction of new buildings, which make up 0.6% of the existing building stock in Beirut, as well as the rehabilitation of the existing building stock in Beirut, with the aim to mitigate the impacts of the urban heat island. As such, the modified building code should specify the following: 1) new buildings should adhere to the maximum allowable building height limitations as per the zoning specifications; 2) new as well as existing buildings should implement cool roof strategies, with albedo ranging between 0.6-0.8, which has the most significant impact on alleviating urban heat island as per the simulations results on TEB; 3) new buildings should have a glass ratio of less than 40% so as to avoid exacerbation of the urban heat island; and, 4) all buildings, new and existing, must ensure planting of at least one row of urban trees (preferably *pinus pinea* or *ficus nitida* which are considered to be native trees and which require minimal water
intake) around the building perimeter in order to increase the fraction of urban vegetation in the city.

The need to implement more stringent measures for the permitting and approval process for new buildings is therefore vital to achieve successful results. Regarding the need to increase urban vegetation around existing buildings, these can potentially be enforced upon homeowner’s payment of annual fees for water supply at the Beirut and Mount Lebanon Water Authority, which is part of the Ministry of Energy and Water (MOEW). As for enforcement of the proposed cool roofing strategy for existing buildings, this can potentially be achieved upon payment of electricity bills for example and further, by raising awareness for lower electricity bills by cool roofs, similar to the approach for the successful solar water heating campaign implemented a few years ago. This campaign, however, should be conducted through the joint efforts of MOEW and MOE. This research can therefore help bring together all relevant stakeholders, including researchers and policy makers and concerned authorities, to recognize the significance of the findings of this research, the various associated health risks and the future well-being or urban residents, the necessary steps that need to be taken to improve the transfer of urban climatic knowledge, the need to modify existing policies and to accordingly implement mitigative actions for cool roofing and urban greening of the city.

These aforementioned recommendations were based on TEB simulation results conducted in this research, which stressed that “cool roof strategies” and “urban greening strategies” have the most significant impact on reducing the unpleasant impacts of the urban heat island in Beirut. This research also proposed that the relevant urban planning and decision-making authorities in Lebanon can make sustainable urban planning
decisions for city scale by referring to TEB simulation results. This could successfully be achieved through implementation of the evidence-based planning approach which could be advantageous for the Beirut context where TEB acts as the scientific tool to provide the scientific evidence required for future sustainable decision-making in urban planning and design of the city.

Therefore, the aim of this research is to potentially provide the incentive and detailed guidance to concerned policy makers to modify the two legal documents of relevance, namely the Urban Planning Law #69 under which Lebanon currently functions today, and the Building Code #646, which is the centerpiece of all construction activities in Lebanon, with the aim to protect the urban climate in Lebanon. By making these modifications as detailed above, by establishing an agency or council that deals solely with urban climatic issues, by ensuring the systematic implementation of the proposed modifications to existing urban planning and building code through the joint efforts of all involved stakeholders, and by strengthening the existing institutional framework through employment of skilled and trained staff with frequent documentation and reporting and continuous follow-up, the first vital steps toward combatting the urban heat island of Beirut could essentially be achieved.

Regarding the limitations of this research, the potential impact of street orientations was not assessed since TEB does not provide this option. Consideration of this urban geometric parameter could be important in assessing the feasibility of this future mitigation scenario since it can affect exposure to solar radiation and accordingly impact heating and cooling energy demands. Architectural data entry for each x, y grid cell was also somewhat simplified in TEB, thus raising the possibility of inaccurate data
representation. Having said this, TEB has been validated in numerous studies and is therefore considered to be a reliable and accurate modeling scheme for analysis of the UHI.

Moreover, this research considered patterns of existing urban form of Beirut as opposed to real values, as these data were either limited or unavailable; as such the required data were obtained by extrapolations from the most recent aerial image of Beirut dated 2008. Furthermore, it was not possible to access weather records from operating weather stations within the administrative boundary of Beirut due to either data inconsistencies or operational problems of weather stations or because they were not provided by the relevant authorities. The distance of over 3 km of the selected weather station from the study area can be considered to be another limitation of this research although simulation results were found to be acceptable and consistent with similar studies in Paris, Marseille, and Athens.

As for future research works, it would be interesting to investigate the actual possibility of intervention and implementation of strategic mitigating actions for Beirut given its architecture, its urban form, and so on. It would also be interesting to identify additional economic or social constraints which may hinder the effective implementation of a new policy pertaining to the protection of the urban climate. Conversely, these different strategies could result in extra economic gain as seen for the case of the recent implementation of solar water heating for an impressive number of home owners across Beirut. Moreover, it would be interesting to investigate the effects of the existing transportation and infrastructure sectors as well as anthropogenic heat emissions on the UHI of Beirut as this research focused primarily on the existing urban geometric
characteristics of the city. Indeed the implementation of the proposed mitigating scenarios in this research coupled with the need to reduce traffic emissions by improving non-motorised mobility could also be considered in future urban planning scenarios that could potentially reduce UHI impacts in Beirut. Furthermore, the impacts of the existing urban morphology and anthropogenic heat emissions on urban heat stress could also be investigated.

In addition to the need to examine and revise areas of the existing Urban Planning Law #69 and Building Code #646, the question of the possibility to integrate protection of the urban climate has to be consciously considered and investigated in the practice of urban planning and design parameters. The need to understand why such modifications are important to certain parties but of less interest to other parties needs likewise to be examined.

The economy may similarly help as it has for the reduction of greenhouse gas emissions in other cities worldwide, for example, which reflects the need to create tools to facilitate the implementation of proposed strategies to reduce impacts on the urban climate. As such, implementation of cool roof strategies and urban greening strategies can be advocated by relevant authorities like the Higher Council for Urban Planning (HCUP), the Order of Engineers and Architects, MOEW and the Ministry of Environment (MOE). These strategies can be economically beneficial since they can generate additional business opportunities and accordingly boost the economy for markets specialized in cool roofing and urban soft landscaping.

The need to examine various other urban planning and design approaches could additionally be interesting for the Beirut context, such as the investigation of the impacts
of cooling by increasing evaporation, cooling by implementation of water-film surfaces, implementation of infrastructure that utilize water, implementation of green infrastructure, active and passive cooling, thermal efficiency of buildings, and urban heat stress. These aforementioned actions could also be considered in future urban planning investigations for Beirut within the context of future urban heat island mitigation scenarios. Having said this, undoubtedly the question of the feasibility of implementation of the aforementioned water scenarios arises. Although Lebanon has a favourable share of water resources relative to other countries in the region (Bou-Zeid and El-Fadel, 2002), temporally inconsistent rainfall patterns combined with seasonal water shortages and saline intrusion increase the danger of water resource scarcity in Beirut. Water resources in Lebanon are particularly vulnerable to higher temperatures and changes in patterns of precipitation (Hatzaki, et al., 2010). Water shortages can constrain economic growth and present a complex challenge for future development, which is why it is imperative to properly manage the collection and distribution of water resources in the country. Indeed, one such example to achieve this goal can be found in the current works being carried out between the Council for Development and Reconstruction (CDR) and MOEW with design and funding plans being carried out in affiliation with the World Bank almost finalized to build the Bisri Dam (www.cdr.gov.lb) situated toward the south of Lebanon with the aim to boost water supply to the residents of Beirut. This would potentially significantly improve the water shortage problem in Beirut not to mention the potential to more successfully implement the aforementioned urban cooling scenarios. Up until such time however, it is recommended to allocate select pilot study areas for application and testing of the success of this proposed water cooling scenario. Other
research areas of interest that could be examined include for example a comparison of approaches and decision-making tools used to combat the UHI with other cities that are similar to Beirut or are in the region like Athens, Amman, Barcelona or Paris; this could be especially useful in identifying strengths and weaknesses in the existing system in Beirut and a means for improvement of the approaches used to mitigate UHI (Kaloustian, Diab, Bechtel, & Oseenbrügge).

Finally, it would be interesting to obtain and conduct simulations based on real values of data as opposed to extrapolated data and this could potentially be achieved by collaborative works between the relevant authorities like MOEW and the MOE, urban planning authorities and policy makers, and reputable academic institutions like the American University of Beirut or Université Saint Joseph. Indeed these latter academic institutions have recently been showing more interest in this topic and could possibly more easily arrange for funding required to conduct such a large scale campaign. The evidence-based planning approach which has been recommended in this research could help facilitate this collaboration between the relevant parties. In addition, weather records from their operational stations could be accessed and simulations could essentially be compared and used for validation of results in this research. Therefore in this latter case, the need to improve the transfer of urban climatic knowledge can be achieved through collaborative efforts between policy makers and academic research institutions.

To conclude, this thesis contributed to a better understanding of the urban environment of the city of Beirut and the respective urban parameters that have the most significant impact on reducing some of the effects of the urban heat island phenomenon. In doing so, this research has paved the way for further work on reducing the UHI effect
in Beirut, with the ultimate aim of creating a comfortable and safe environment for its residents, and future generations.
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Appendix I: Climatic records for Beirut City
a. History of TMIN and TMAX trends; b. Precipitation levels; c. Wind rose diagram; d. Sun path diagrams of Beirut city
Appendix II: Zoning Specifications for Beirut
<table>
<thead>
<tr>
<th>Zones</th>
<th>Hauteur des bâtiments</th>
<th>Recul des façades par rapport à</th>
<th>Coefficient d'exploitation au sol</th>
<th>Coefficient d'exploitation total</th>
<th>Parcelles Constructibles</th>
<th>Parcelles de lotissement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>L'alignement</td>
<td>Limites</td>
<td></td>
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<td>61 LE et Modificatif</td>
<td>4.50m axe voies alignées à 4.50m</td>
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<td>100%</td>
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<td>100 9 7</td>
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<td>R.D.C. 100%</td>
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<td>2</td>
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<td>4.50m axe voies alignées à 4.50m</td>
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<td>tuage 70%</td>
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<td>Voir majoration</td>
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<tr>
<td>3</td>
<td>H=2.5(R1+L+R2)</td>
<td>4.50m axe voies 4.50m</td>
<td>-------</td>
<td>50%</td>
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<td>120 10 8</td>
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<td>6.00m axe voie &lt;10m</td>
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<td>Voir majoration</td>
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<td>5</td>
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<td>Comiche 4.00m</td>
<td>2.50</td>
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<td>Voir majoration</td>
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<td>7</td>
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<td></td>
<td></td>
<td>50%</td>
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</tr>
</tbody>
</table>

Note: Les coefficients et les parcelles sont des exemples hypothétiques pour illustration.
<table>
<thead>
<tr>
<th>ZONES</th>
<th>Surface min. des lois (m²)</th>
<th>Longueur min. de façade (m)</th>
<th>Profondeur min. des lois (m)</th>
<th>Reuel sur l'alligement (m)</th>
<th>Reuel latéral (m)</th>
<th>Reuel postérieur (m)</th>
<th>Projection min. sur la façade du bâtiment</th>
<th>Surface construitible min.</th>
<th>Nombre max. d'étages</th>
<th>Coefficient max. d'exploitation</th>
<th>Hauteur max. (m)</th>
<th>Surface max. R.D.C.</th>
<th>Surface max. des autres étages</th>
<th>Surface max. du roth</th>
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</thead>
<tbody>
<tr>
<td>ZONE A. 1</td>
<td>(1) 1200</td>
<td>30</td>
<td>35</td>
<td>cf plan</td>
<td>6</td>
<td>6</td>
<td>20%</td>
<td>4</td>
<td>0.90</td>
<td>17</td>
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<tr>
<td>ZONE A. 4</td>
<td>(1) 900</td>
<td>25</td>
<td>30</td>
<td>cf plan</td>
<td>4.5</td>
<td>6</td>
<td>40%</td>
<td>4</td>
<td>1.40</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZONE Spéciale</td>
<td>(1) 1300</td>
<td>20</td>
<td>05</td>
<td>cf plan</td>
<td>5</td>
<td>8</td>
<td>00%</td>
<td>30%</td>
<td>2.00</td>
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<tr>
<td>ZONE II A</td>
<td>(1) 1200</td>
<td>30</td>
<td>40</td>
<td>cf plan</td>
<td>5</td>
<td>8</td>
<td>60%</td>
<td>20%</td>
<td>1.25</td>
<td>0.10</td>
<td>1.00</td>
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<tr>
<td>ZONE II B</td>
<td>(1) 1200</td>
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<td>40</td>
<td>cf plan</td>
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<td>8</td>
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<td>25%</td>
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<td>0.10</td>
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<tr>
<td>ZONE II C</td>
<td>(1) 1200</td>
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<td>40</td>
<td>cf plan</td>
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<td>8</td>
<td>60%</td>
<td>25%</td>
<td>1.75</td>
<td>0.10</td>
<td>1.50</td>
<td>0.15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legende:
(1) Parcelles de Lotissement
(2) Parcelles constructibles

Le recueil sur l'alignement est de 3m pour les lots situés sur une route de 30m de 6m pour les lots situés sur une route de 20m à 30m de 4m pour les lots situés sur une route de 12m à 15m de 4m pour les lots situés sur une route particulière

### SERVITUDE NON AEDIFICANDI TOTALES

<table>
<thead>
<tr>
<th>ZONE</th>
<th>Destination</th>
<th>Porcentage de construction</th>
<th>Coefficient d'exploitation</th>
<th>Nombre max. d'étages</th>
<th>Hauteur Max.</th>
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</thead>
<tbody>
<tr>
<td>ZONE I</td>
<td>Habitations-Bureaux-Hotels-etc...</td>
<td>10%</td>
<td>1</td>
<td>7</td>
<td>9 m</td>
</tr>
<tr>
<td>ZONE II</td>
<td>Centres sportifs-Balnéaires et de plaisance collectives</td>
<td>15%</td>
<td>20%</td>
<td>9 m</td>
<td></td>
</tr>
<tr>
<td>ZONE III</td>
<td>NON AEDIFICANDI TOTALES</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>ZONE IV</td>
<td>Centres sportifs-Balnéaires et de plaisance collectives</td>
<td>15%</td>
<td>20%</td>
<td>9 m</td>
<td></td>
</tr>
<tr>
<td>ZONE V</td>
<td>NON AEDIFICANDI TOTALES</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZONE VI</td>
<td>Habitations-Centres touristiques</td>
<td></td>
<td></td>
<td>VOIR DECRET No 4011 ET No 4018</td>
<td></td>
</tr>
</tbody>
</table>

Table showing “Urban plan zoning specifications”
قانون التنظيم المدني ومراسيمه التطبيقية

مرسوم انتخابي رقم 99

صدر في 9 أيلول سنة 1983

معدل بالقانون رقم 89/1/15 تاريخ 1989

إن رئيس الجمهورية،
بناء على المندور،
بناء على القانون رقم 82/36 تاريخ 1982 (منح الحكومة حق إصدار مراييم انتخابية)
بناء على القانون رقم 83/10 تاريخ 1983 (تعديل العمل بأحكام القانون رقم 82/17 تاريخ 1982)

وبعد استطلاع رأي المجلس الأعلى للتنظيم المدني،
وبعد استشارة مجلس شورى الدولة،
بناء على اقتراح وزير الأشغال العامة وبعد موافقة مجلس الوزراء، بتاريخ 24/8/1983،

يرخص ما يأتي:

الباب الأول

المجلس الأعلى للتنظيم المدني

المادة الأولى - ينشأ مجلسًا يتألف من:

- المدير العام لوزارة العدل أو من يترتب عليه من
- المديرو العام للإدارة الداخلية أو من يترتب عليه من موظفي الإدارة الداخلية
- المدير العام للطرق والمواصلات في وزارة الأشغال العامة أو من يترتب عليه من موظفي الإدارة الداخلية
- المدير العام للإسكان في وزارة الأشغال العامة أو من يترتب عليه من موظفي الإدارة الداخلية
- رئيس إدارة البرامج في مجلس الائتمان والاعتماد أو من يترتب عليه
- نقيب المهندسين في بيروت أو من يترتب عليه
- مجاز انتخابي في علم الاجتماع
- مجاز انتخابي في هندسة تنظيم المدن
- وعلم بحماية البيئة
- مجاز انتخابي في الهندسة المعمارية
- وعلى الأعضاء الثلاثة المجازون بمرسوم يتألف

ينشأ مجلسًا يتألف من:

- المدير العام للتنظيم المدني
- المديرو العام للإدارة الداخلية أو من يترتب عليه من موظفي الإدارة الداخلية
- المدير العام للإسكان في وزارة الأشغال العامة أو من يترتب عليه من موظفي الإدارة الداخلية
- المدير العام للإسكان في وزارة الأشغال العامة أو من يترتب عليه من موظفي الإدارة الداخلية
قانون التنظيم المدني

1983/9/29

تحكماً بموافقة على القضية المعرضة عليه.

المادة 1 - للمجلس الأعلى للتنظيم المدني

الوافد في شأن تنظيم إدارة مدنية أو بعثة إدارية، أن يرفع للاجتماع ملخص عن الإدارات والبلديات ذات العلاقة بالمواضيع المدرجة على جدول الأعمال.

الباب الثاني

نصائح وأنظمة تنظيم المدن والقرى

النطاق التطبيقية - غابتها - إعدادها ومفاعيلها.

المادة 2 - إن وضع التصاميم وأنظمة المدن والقرى ضمن الخطة الشاملة لمناقشة الأراضي (Aménagement du territoire) هو الزامي:

أ - لمراكز المحافظات والأقضية.

ب - للأماكن المصنفة أو التي تصنف مراكز اصطياف أو إنشاء وللأماكن الأثرية.

ج - للأماكن التي تحدد بمسوح بناء على اقراح بوزير الأشغال العامة والنقل بعد استطلاع رأي المجلس الأعلى للتنظيم المدني.

يمكن وضع تصاميم وأنظمة المدن والقرى لأية منطقة أو حلة أو مجموعة آمال.

وجوز جميع أماكن في منطقة تنظيم مدنية على أن تكون هذه الآماكن موضوع تصميم ونظام واحد.

المادة 3 - التصميم هو المستند المخطط، أما النظام فهو النص.

المادة 4 - إن تصاميم وأنظمة المدن والقرى يمكن أن تقسم إلى تصاميم وأنظمة توجيهية وتصاميم وأنظمة تنفيذية.

المادة 5 - يرسم التصميم والتنظيم التوجيهي النطاق العام للتربية وحدود التقوى والانشطة الأساسية لتنظيم المنطقة وعلى الأخص احتساب

بالنسبة لوزارات الداخلية والأسكان والتعاونيات ومن بين المهندسين المسجلين في نقابة بورون دو فنس، ومن بين موظفي مجلس الإعمار والناشرة للريس إدارت البرامج.

تعتبر اجتماعات المجلس المعنيَّة إذا حضرها أكثر من نصف أعضائه. وتتخذ القرارات بأكثرية أصوات الحاضرين، وتبين النصيَّة عند النصيَّة يُعتبر صوت الرئيس مرجعاً.

لتحلق بجلس الأمين سر دائرة تونس المديري لل우اد لتكوين المندوب.

القانون:

تعد تعريضات الرئيس، وأعضاء، وأمانة سر المجلس يصدر عن وزير الأشغال العامة والنقل.

المادة 6 - المجلس الأعلى للتنظيم المدني هو الجهاز المختص في شأن التنظيم المدني والقرى ويكون، بصورة خاصة، إدارته لأيَّة في المواضع:

- تصاميم وأنظمة المدن والقرى وتصاميم تفسيرية.

- المحافظ:

- مشروع المراعي الرامية إلى إنشاء الشركات المتوازنة واستمالة المناطق وإجراء الضر والفرز.

- المراجعات ضد القرارات المتعلقة بخصوص البيئة والبيئة.

- مشاريع تدبيش التشريع العام للتنظيم المدني والقرى وفقًا:

- مواريخ النشأة.

- يدي المجلس الأعلى للتنظيم المدني رأياً في قضية المعرضة عليه خلال شهر من تاريخ تلتها، وإذا دعت الحاجة إلى طلب معلومات مالية، يعطى المختص مهلة عشرة أيام إضافية، لمره حدة، تجري اعتباراً من تاريخ الحصول على البيانات المطلوبة.

- لا تدخل أيام العطل الرسمية ضمن المهل.

- إذا لم يمد المجلس رأياً ضمن المهل المعينة اعتباراً
قانون التنظيم المدني

1. الأسباب جمالية أو تاريخية أو بيثية.
2. الأراضي التي يجب المحافظة عليها للإستغلال الزراعي.
3. حدود وتنظيم الساحات والحدائق العامة والطبيعية والصناعات الزراعية والتحصينات الصحية.
4. المواسم التي يجب البقاء على ما هو موجود.
5. المناطق، وفي داخل هذه المناطق الأجزاء.
6. الواجب إعدادها لتنوع ماهي الاستعمال أو للكم خاص من السكن.
7. الزيادة في البيئة، والبيئة المتاحة للإستخدمات والتصاميم العامة والأنشطة التي تقتضيها الحياة الاجتماعية.
8. المناطق التي يمكن أو يسمح فيها، ضمن شروط معينة، بإنشاء مؤسسات صناعية وتجارية وسواها وتوسيع مؤسسات موجودة.
9. المناطق الواجب تبنيها بطريقة الهيكلية، وفقا لقانون الأراضي وفرز في الأماكن الأصلية أو بواسطة الشركات العقارية أو بطريقة استملاك المناطق.
10. شروط البنية التحتية لمساحة وقباسات العقارات الموصى بها للبناء وشروط الافراح في كل منطقة.
11. يحدد التصميم والتنظيم التفصيلي الارتفاعات لصالح السلاسة العامة والصحة والضوابط والبيئة، ويمكنها على الاختيار تحديد القواعد المتعلقة بتشييد وتوحيد الأبنية أو مجموعات الأبنية والمصالح بينها واستخدام المصلحة المعمارية والمحافظة عليها، وأعمال الأبنية وارتفاعاتها التصوير والدنيا وعدد طوابقيها وترجعها ووجهة استعمالها وتنظيم محيطها.
12. يمكن أن يتضمن التصميم والتنظيم التفصيلي جزءاً من البنود المذكورة أعلاه.
13. المناطق السكنية، وهو يأخذ بعين الاعتبار العلاقة بين الجماعات السكنية والمناطق المجاورة ثم التوازن الذي يوجب المحافظة على بين تطور منطقين امتداد العمران من جهة والمحافظة على المواقع الطبيعية والrailsات الزراعية والمناطق الحيوية من جهة ثانية. كما يحدد هذا التصميم وجة استعمال الأرض بصورة إجمالية على ضوء المصلحة العامة، ومواقع الخدمات العامة والبيئية الأساسية والتنظيم العام للنقل داخل المنطقة وبين المنطقة وخارجاها، ومواقع النشاطات الإنتاجية وكذلك مناطق امتداد السكن المناسب والأحياء القديمة التي يوجب تصبح مقيما.
14. إن التصميم التجريبي يوجه ويساهم في الأدوات والمؤسسات العامة والبلديات.

المادة 8 - إن التصميم والتنظيم التفصيلي يحدد، ضمن إطار التصميم والتنظيم التجريبي في حال وجوده، القواعد والشروط لاستعمال الأرض ضمن المنطقة بما في إمكانية مع البناء، ويعيد على الأصل:
1. جهد المنطقة الأولية بعد الأخد بعين الاعتبار القوة الزراعية للأرض وإمكانية وجود تجهيزات هامة للموازنة المكلفة أو المر.
2. وجهة الاستعمال الأساسي للأراضي أو النشاطات الإنتاجية في كل منطقة.
3. عوامل الاستمار المسوحة للبناء في ضوء التجهيزات العامة المتفرقة أو الممزوجة إنها في المنطقة.
4. المناطق المبنية التي يجب المحافظة على طابعها الخاص عند ترميم الأبنية أو عند الترميم بناء جديد في ترجمة شروط النشاط المتضمنة لذلك.
5. حدد ووجهة استعمال شبكة الطرق التي يجب البقاء عليها أو تديلها أو إنشاؤها.
6. حدد الأجزاء أو الشواط أو الأبنية الأخرى أو المواقع الطبيعية المطلوب حمايتها أو إزالتها.
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تمكن وضع تصميم ونظام تنفيذي لمجموعة أهلة أو منطقة دون أن يكون لها تصميم ونظام تنفيذي، ويقوم المصمم والنظام التنفيذي في هذه الحالة مقام المصمم والنظام التنفيذي.

المادة 9 - يمكن أن توضع تحت الدرس المناطق التي يراد وضع التصميم والأنظمة التنظيمية والمحلية لها بمرسوم بناء على اقتراح وزير الأشغال العامة بعد استلام أي من البلديات المجاورة والمجلس الأعلى للتنظيم المدني. ويتبع هذا المرسوم لجنة تنفيذية.

لا يمكن اعتبارا من تاريخ نشر المرسوم الوضع تحت الدرس وقبل مدة سنة قابله للتجديد مرة واحدة بالصيغة ذاتها لمدة سنة أخرى، إن نماز في المنطقة المنظمة رخصة بناء ولا إجازة افراد أو ضم وفرز، كما أنه يتمح إيقاف الاقتراحات والانتفاعات، وتغير الأوضاع الطبيعية للمنطقة غير أن يمكّن الادارة وضع مدة تحت الدرس، وبالصيغة ذاتها المتبعة أعلاه بعد انتهاء عشر سنوات من إنشاؤها أو بعد إنشاؤها تحت الدرس، وعند حصول كوارث أو أحداث استثنائية.

يمكن بصورة استثنائية من غير الرخص والاجازات من السلطات المختصة بعد موافقة المجلس الأعلى للتنظيم المدني، كما يمكن الترخيص لأشكال الصيانتة والترخيص بعد موافقة المدير العام للتنظيم المدني.

المادة 10 - تعد المديرية العامة للتنظيم المدني تصميم ونظام تنظيم المدني والقرر.

تحصل الدولة تحت الدرس وضع تصميم ونظام تنظيم المدني، غير أن بعض البلديات إذا تتوفر لديها الأموال إجراء هذه الأعمال على نفقاتها بالتنسيق مع المديرية العامة للتنظيم المدني.

المادة 11 - تعرض التصميم وأنظمة المدني والقرر، على المجالس البلدية المختصة لإبداء رأيها فيها وفقاً لقانون البلدات وعلى هذه المجالس أن
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أما التصاميم السابقة المذكورة قبل تاريخ العمل بهذا المرسوم الإداري دون أن تكون اللائحة مرفقة به فتعتبر مرسوم تصديقها نافذة بعما والمؤرخه بتأليف من عدم إبلاغ لواحق العقارات المصابة بالارتباك أو الامتلاك إلى أمين السجل المقايري وعدم وضع الإشارة على الصحف المعنية للمقارات.

يمكن على أمين السجل المقايري تسجيل أي معاملة تتعلق بالعقارات إذا لم تكن مرفقة بإفاده تخطيتر وارتباك وراء ذمة من البلدية ومن السلطات المحلية المعنية. لا يعود تاريخها لأكثر من ثلاثة أشهر وعلى أن يسجل إشارة التخطيتر في الصحيفة المعنية للمقاير في حال وجودها وفقًا لإفاده التخطيتر إذا لم تكن مسجلة لدى معا.

المادة 16 - يمكن لكل تلاميذ تعدي التصاميم في التواريخ المذكورة في المادة 15 من هذا المرسوم الإداري وتسمح بها لدفع إشارة إرسال إلى المقاير في حال ضعف إشارة الإرهاق لاحقاً لأي مبرر كان.

الباب الثالث
تنفيذ التصاميم وأنظمة المدن والقرى

المادة 18 - يحق للإشراف أن تحمل المساحات المبينة في التصميم والمعدة للمصالح العامة كالمواطن والطرق والمساحات والمباني، والأية العامة التبادل إلى التحقيق ليصبح الإرهاق المعين في حالة رفع إشارة الإرهاق لاحقاً لأي مبرر كان.

المادة 19 - إن الإرهاقات التي تفرض عملاً بهذا المرسوم الإداري لحماية الصحة والسلامة العامة والمحافظة على مصالح الضيافة في البيئة أو التي تتعلق بجهة استعمال الأرض وعرق الأثرية وأشغالها وألوانها وعدد طوابع الوجبة والراجعة عن خدمة المقاير ومد المقاير السطحي والمواد الإيجار العائم والمعدة الحقنة على البناء لأكثر من ثلاث سنوات وغيرها من الإرهاقات باستثناء تلك التي تخص لوحات خاصة، لا تتعلق الحق في أي توقيع.

إن الإرهاقات المشتركة بموجب تصاميم وأنظمة المدن والقرى
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ب، عندما يبلغ مجموع طلبات الاسم والترز المقدمة من المالكين في المنطقة 20٪ على الأقل من مساحة المنطقة المذكورة أو 20٪ من عدد القرو،

المادة 21 - يُمكن إنشاء شركات عقارية برسوم تنظيم مدنية في مجال الموانئ في لجأ ترتيب إجمالي لأعمال أو لجزء من منطقتها وضع أو سويق لها تصميم ونظام تنظيم مدني.

تقوم هذه الشركات بالشكاوى كما تضمن مع مراكز أحكام البلد 7 من هذه المادة، سائر أصول الحقوق التي تدخل في تقرير قيادة الملاك في السجلات والمستندات، وكذلك الإدارات ذات العلاقة.

وهي في حالة الإدارات في هذا النص الدولة أو البلدان ذات العلاقة سواء كانت متفردة أو مجمعة.

1 - يمكن للحكومة أن تقرر بموافقة الملاك الموجب المرسوم عينه أعلاه إدخال الأراضي في نطاق الشركة، إذا يمكننا أن نقرر إدخال المستأجرين والمستثمر على أن يتم التوضع عليهم وفقاً للإصول.

2 - يجري عند تأليف الشركة ضمن الأملاك العقارية وسائر الحقوق، ويقدم المالكون وسائر أصحاب الحقوق الذين تقومهم الشركة جميع حقوقهم إلى الشركة ويرجعون على أصول مقابل هذه الحقوق، مع مراكز أحكام البلد 7 من هذه المادة.

كما تخصص أيضاً أصول الإدارات مقابل مقدارتها العشبهي وسائر الأمور الشخصية التي تكون قد دفعتها لأجل إنشاء الشركة وتغذية صندوقها.

3 - تشمل الإدارة مجاناً إنشاء أو توسيع الشوارع والحدائق والمساحات العامة، وسائر التجهيزات والانتهادات العامة مساحة عامة، وتعزز خصبة وتعزز بالمثة من كامل مساحة المضايا المقدمة إلى الشركة والكائن في المنطقة موضوع الشكاوي والشكاوي.

ولن تدخل في حساب البنى المعروفة الانتهادات، والمضايا وسائر الأملاك العشبية المباني خاصة، والذين تبقي ملكيتها عادية للإدارة.

على الإدارة أو البلدية المدنية أن تمتلك بموجب مرسوم المساحات العقارية من الملاك إذا كانت غير صالحة للبناء وذلك لمساحة الملاك الملاك، كل تجهة واجبة مثابة وبناء لطلبهم كل تجهة واجبة مثابة.

على الملاك بناء لطلب الإدارة، أن يتوفر يدلاً التقديرية لهذه المساحات على كائنة مصرية تؤمن المبلغ الذي قد يجعل بها على الإدارة نتيجة لهذا الاستكشاف. تقوم الإدارة أو البلدية المدنية بمقام المالك الملاك الملاك الذي يمثل من الشراء.

تتطلب أيضاً أحكام الفقرة السابقة على المساحات العقارية، كما هو وارد أعلاه، من الاستيصالات المادلة في وضع هذا المرسوم الإشراعي موضع التنفيذ.

المادة 19 - يمكن للإدارة المستمالة أو لمين يخوله القانون حق طلب الاستمالة أي تقدح حق المالك بينه وبين مثابة أو مشابة في عقار مبني أو غير مبني، وإن تقدح حق المالك بينه وبين مثابة أو مشابة مرجواً مزاياً للمؤجر الذي سئله الإدارة لإ草案 الحقوق وفقاً للإجراءات المعمول بها في تحديد الحقوق على أن يظل صاحب الحق، المالك، كأن أو مستأجرًا أو تلك التدبير.

المادة 20 - يحق للإدارة، وخاصة عندما لا يسمح الوضع التقسيمي للأراضي تنظيم مظلي معقول، أن تقوم بذلك بعمل الاسم والترز لكل المنطقة موضوع الشكاوي أو الانتهادات. يُقر الاسم والترز ويدعو للقواعد المنصوص عنها في قانون الضر الأراضي وفرزها في الأمكان المباني.

عندما يُقَدَّم طلب تنظيم المدن والقرى الاسم والترز في منطقة ما، يحمي على الإدارة القيام.


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لا تخضع المقدمات العينية لتكوين ورخص السواد العقاري إلى معايير التحقق المنصوص عليها في المادة 18 من قانون التجارة.

9 - ترتبط الشركة المتعلقة ب деятельности المبناة فيها، وبناءً على الأحكام السابقة وتعقيد النموذج، بما يتمكن من أن يرتب الأراضي المرتبة كما يمكنها إنشاء أبنية عليها وبيعها أو تأجيرها أو استثمارها.

10 - يحدد برسوم يتخذ في مجلس الوزراء كل ما يتعلق بتنظيم الشركات العقارية المذكورة ولا سيما مبناها وizzato المساحات في وصول تأسيسها ونظامها وإدارتها وسير عملها وتمويلها وتعاونها وتفصيلها.

11 - توزع صفائف الأموال الناتجة عن هذه البيع أو التأجير أو الاستثمار على المساهمين بنسبته إلى الأسس التي بحوزتها.

المادة 22 - يمكن للحكومة برسوم يتخذ في مجلس الوزراء أن تنوي مؤسسة أو مؤسسات عامة ذات طابع تجاري لأجل ترتيب كل أو جزء من منطقة وضع أو موضع لها تصميم ونظام تنظيم مدني.

تعتمد هذه المؤسسات بالشخصية المعنوية والاستقلال المالي والإداري وتخضع لرقابة ديران المحاسبة المؤخرة دون أي رقابة أخرى.

تحدد برسوم إنشاء هذه المؤسسات، جميع الأحكام المتعلقة بنظامها وسير عملها ولا سيما أهدافها وصلاحياتها وإدارتها وتعاونها وتفصيلها وعلاقاتها مع مال站着 المؤسسات العامة والبلدية أو البلدات ذات العلاقة.

أولاً: تناول المساهمات العامة كل أو بعض الأئمدة الآتية:
1- التملك المؤقت ب بواسطة الاستئصال، لجميع العقارات الواعية ضمن نطاق عملها بما فيها جميع الحقوق على هذه العقارات.

(1) راجع القانون رقم 1991 لائحه 13/7/8911 المشتركة فيما بعد.

إذا نسب من التصميم الموضوع للمنطقة موضوع الشركة العقارية أن مساحة الأراضي العقارية التي تتعلق بها هي أقل من المجموع المكون من مساحة الأراضي العقارية الكائنة ضمن إطار المنطقة قبل وضع التصميم مضافًا إليها مساحة الخمسة والثلاثين بالمائة المقطعة وفقًا للائحة الأولى من هذه المادة.

تعتبر المساحة الإضافية المبدعة من المجموع المتبقي إلى ما زالت خاصًا بالادارة ويعود لهذه الأخيرة حق الخيار بين تقديم هذه المساحة إلى الشركة مقابل إعفاءها منها بقيمة هذه المقدمات أو الحصول عليها على قطع من الأرض تعادل المساحة المذكورة لدى ترتيب المنطقة وقامت الأرض.

4 - ترتبط على كامل المنطقة موضوع الشركة، فور نشر مرسوم التحقيق بتأسيس الشركة، الأحكام الناتجة عن التخطيط المتعلق بالمنطقة أو إعلان المنتج.

العامة لجهة إعطاء رخص البناء أو الترميم.

5 - يتم الاحوال المركزي وصاحب الحقوق في التصرف بأراضي بقرارية انعقاد الجمعية التأسيسية التي تعلن تأسيس الشركة على رواق القانوني، ويقل هذا الحق إلى الشركة اعتباراً من هذا التاريخ.

6 - يمكن للإدارة برسوم يتخذ في مجلس الوزراء أن تنوي مساحة الحقوق التي لا تتجاوز قيمتها حقوق مبناها معينًا يحدد الرسوم المذكور في الخيار بين تقديم حقوقهم إلى الشركة لقاء أسهم أو قرض حقوقهم بقرارية على دفعة واحدة أو دفعات.

وتحت الإدارة في هذه الحالة محل أصحاب الحقوق في كل حقوقهم وتحصل على أسهم في الشركة مقابل تقديمها لهذه الحقوق.

7 - تقرر حقوق الرهن والأعمال الطريق، وحجز على العقار أو المؤسسة التجارية الكائنة في المنطقة موضوع الشركة العقارية لدى إجراء المؤسسات العينية إلى الشركة وتحت هذه الحقوق نفس الرتبة السابقة التي كانت لكل منها، على الأسهم العائدة لصاحب هذا العقار أو المؤسسة مقابل مقدمات.
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1 - إعداد برامج التجهيزات العامة وتنفيذها مباشرة أو بواسطة الإدارات والهيئات العامة المخصصة والبلديات.

2 - ضم وفرز العقارات الواقعة ضمن نطاقها وفقاً لمقتضيات المخطط التنظيمي الموضوع وإعادة توزيع العقارات، بعد ترتيبها، على المالكين بنسب حقوقهن كل منهم.

3 - إعداد برنامج البناء وتأمین إعادة البناء مباشرة أو بواسطة المالكين أو بواسطة أية اتفاقيات أخرى تراها مناسبة.

4 - يتألف عودة المستأجرين والمستثمرين إلى أماكن جديدته في الأبنية المشيدة أو التعريض عليها.

5 - تقوم المؤسسة بعملها على الشكل التالي:

أ - تلتقي الإدارة مجانًا لإنشاء أو توسيع الشوارع والحدائق والروّاد العامة وسائر التجهيزات والأساليب العامة أو غير ذلك مساحة خمسة وعشرين بالمئة من كل مساحة العقارات الواقعة ضمن نطاق المخطط الموضوع.

ب - تدخل في مجلس الوزراء عن المؤسسة العامة فما فوق تقلد الحقوق العامة لفائدة المستأجرين والمستثمرين الآتية:

1 - المستأجرين والمستثمرين الذين لا تفقط عليهم العمل التجاري مع وجهة الاستعمال المقرر في المخطط التنظيمي الموضوع للمنطقة الكائن فيها ماجورهم.

2 - المستأجرين والمستثمرين الذين لاتجاوز حقوقهم مبلغاً ميناً يعددها المسود المذكور.

وفي جميع هذه الحالات تحل المؤسسة محل أصحاب الحقوق في كامل حقوقهم.

3 - تسد المؤسسة العامة حقوق المالكين بعد ترتيب المنطقة، بمثل كل مالك عقاراً أو أشماً في

(1) ان المرسوم الإقليمي رقم 11 تاريخ 19/7/1/1987 يطبق بالميزة التجارية.
قانون التنظيم المدني

الباب الرابع

رخص البناء

المادة 25 - يخضع تشريع الأمنية على

المادة 17 - لا يجوز تشريع الأمنية على

المادة 16 - لا يجوز تشريع الأمنية على

المادة 15 - لا يجوز تشريع الأمنية على

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المادة 11 - لا يجوز تشريع الأمنية على

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قانون التنظيم المدنى

مرسوم انتهاجي رقم 29 تاريخ 1983

الصيغة النهائية المدنية.

1 - يحدد المرسوم التنفيذي أيضاً الإعفاءات من بناء الاجتماع السنوي موضوع اليد (2) أنداء والورق والإفكازات والمخاطر، التي يتعرض لها المستشار الآمن من الالتزامات المدنية، للاستفادة والقواعد المقررة، كما يحدد أيضاً على سبيل المثال لا الحصر الإدارات التي تتولى الموافقة الفنية وإعطاء الرخص وإجراء المراقبة ومعايرة المدن.

2 - يحدد وزير المالية دفاتر الالتزام المدنى للمشتريات، مدة من طلب الترخيص عند إعطائه الرخصة إلى مشترى المباني المخصصة أو إلى مصروفات الحجزية خارج نطاق البند، وذلك عن كل متر مربع من مساحة أرض المقلع أو الكارثة وفقاً للخريطة المرتبطة المدفوعة في الموافقان، وفقاً للمجلس الأعلى للتنظيم المدني.

3 - يحق للإدارة بموجب تصريح توجيه أو تفصيل تحديد مناطق مخصصة لإنشاء واستثمار المقلع والكسارات يكون لها طابع مؤقت يؤدي بحيث يكون الأعمال المشار إليه للرصيد وليست للمقاطعات التحتية التي تضمها الإدارة لهذه الغاية.

4 - يتألف صدور المرسوم التنفيذي المذكور في البند (1) أعلاه هي سارية المفعول أحكام القرار رقم 253/1981 (تنظيم المقاطع) بامتثال أحكام المادة 12 منه التي تلقى وتطبيق بعض البند (2) أعلاه، في هذه الحالة الحصول على موافقة مباشرة من المجلس الأعلى للتنظيم المدني.

يجب أن يقدم مع طلب الترخيص ومع المستندات المرفقة به الخريطة الفضائية للموقع قبل المباشرة باستمار المقلع أو الكارثة والخريطة التحتية للموقع بعد انتهاء الأشغال، ينتج على المستمر أو على المالك إعادة ترتيب أرض الموقع على نفسه بعد انتهاء الأشغال وفقاً لخريطة التحتية الموافق عليها بما فيها إمكانية فرض ترتيب وإعادة تشير الموقع.

الباب الخامس

نظام القفاح والكسارات

المادة 6 - 1 - إن إنشاء واستئجار القفال والكسارات في المشاريع وفي الأملاك الخصوصية وفي الأملاك العمومية والخصوصية لدولة المؤسسات والإدارات العامة والبلد، يخضع لخريطة والشروط والقواعد المذكورة في الإدارة المدنية بالاشتراك مع الدوائر المختصة في وزارات الاقتراضوالإصلة والهندسة والنقل والداخلية والصحية العامة والنقل، تصدر بمرسوم تنفيذي يتخذ في مجلس الوزراء، بناءً على توجيه وزير الأشغال العامة والأعمال، بعد استطلاع رأي المجلس الأعلى للتنظيم المدني.
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المادة 27 - يشكل إقراراً بفقدان هذا المرسوم الإشراعي كل عملية يكون موضوعها تقسيم عقار أو عقدة عقارات إلى قطع.

أما إذا كانت النائية من الإفرار إزالة شيوغ ناتج عن أثر أو حادث قبل تاريخ 30/6/1977 فيطبق الحد الأدنى لمساحة وقياسات القطع الموجودة الصالحة للبناء العاملة للمنطقة وذلك في الإفرار موضوع الإفرار مع البند التأديب الشروط التنظيمية للفرز في المنطقة، وامرأة عقار المساكن على الدوائر الفنية المختصة لإعداد الرؤية للإGLISH أو التأكد من توفر هذه الشروط. لا يمكن أن تكون عن عدد القطع عدد الوحد في الحالة الأولى أو عدد الشراك في الحالة الثانية.

المادة 28 - يخص الإفرار لإجازة مسبقة. تطوع بوجبة قرار يصدر عن المرجع المختص.

المادة 29 - يرفض طلب الإفرار المسبقة المنصوص عليها في المادة 28 من هذا المرسوم الإشراعي إذا لم يكن مشرع الإفرار مطلقاً للتصور التأديب المتعلق بالنظم المدني والبناء الواجب تحقيقه في المنطقة المختصة وعلى الأخص للأحكام المتعلقة بالمساحات والقياسات النية للفرز، في الأماكن وجماعات الأماكن المماثلة والمناطق حيث لا تحدد الأحكام التأديب هذه المساحة، تحدد المساحة والقياسات الدنيا بقرار من المجلس الاعلى للتنظيم المدني.

المادة 31 - يصح قرار الإفرار بدون مفعول إذا لم يباشر بالعمالات العقارية في خلال سنة من تاريخ تسليم الإجازة وذلك إذا لم تتم الأشيال خلال المادة المحددة في قرار الإجازة التي لا يجوز

المادة 32 - يمكن أن يرفض طلب الإفرار المسبقة أو أن تطوع الإجازة إلا بشرط التقيد بأحكام خاصة إذا كان الإفرار من شأنه أن يؤثر بالسلامة والصحة العامة أو بالمنشآت الطبيعية أو إذا كان يرفض على الجماعات العامة تحقيق
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المادة 35 - عندما يرفض طلب إلغاء الإفراز أو تعليل الإجازة بشرط التنفيذ في رأي الحكم يعتبر صاحب الإفراز غير قانوني أو غير منطلق، فيمكنه أن يعرض القضية في مدة ثلاثة أشهر إبتداء من تاريخ تلبية القرار على وزير الأسنان العامة والنقل، ولا يجوز ذلك دون المراجعة القضائية التي يمكنها اللجوء إليها. يقبل الوزير بالأمر بعد استطلاع رأي المجلس الأعلى للتنظيم المدني.

الباب السابع
أحكام مختلفة وتطبيعية

المادة 36 - إن جميع الأشغال المنفعة خلافًا لأحكام التصاميم والأنظمة النافذة يجب أن تقدم أو أن يجعلاها المخالف مطعقة على أحكام القانون بعد إصدار تحدد مملكة التنفيذ يوجه إلى المخالف رئيس السلطة التنفيذية في البلدية أو المحافظ أو القائم بأعمالها، حيث لا يوجد بلدية، إذا لم يرضخ المخالف في نهاية المهلة التنفيذية على نقشه ومسؤوليته الأشغال اللازمة لإزالته المخالفة. يحدد الجُلِّ الموجب من قبل السلطة التي وجهت الإذن ويدخل من قبل دوائر الضرائب في وزارة المالية وفقًا لقواعد المبتعثة في جلية الضرائب والرسوم. يحاكم المخالف عدا ذلك بغرامة تراوح من 900 إلى 6000 ليرة لبنانية (1) وبالغ ببوي من يوم إلى 15 يومًا أو إحدى هاتين العقوبتين.

المادة 37 - يعاقب كل من قام بإلغاء دون الحصول على الإجازة التي يفرضها هذا المرسوم الأشغال أو كل من ينقذ إلغاء دون التنفيذ بالأحكام الخاصة التي تفرض الإجازة بالإفراز، بغرامة من 5000 إلى 6000 ليرة لبنانية (1) وبالغ ببوي من يوم واحد إلى 15 يومًا أو إحدى هاتين العقوبتين. (1)

(1) راجع: الفضاء المدني - وزارة العدل - رفع مقتضى الغرامات التي تفرضها المحاكم.
قانون التنظيم المدني

المادة 36 - تضبيط المخالفات المذكورة في المادتين 37 و 38 من هذا المرسوم الإشراعي من قبل الموظفين والأشخاص المخولين ضبط المخالفات ضمن البلديات المعنية أو من قبل عامل تابع للأمن الداخلي المخول بذلك.

المادة 37 - كل شخص يقوم، بناءً على الطلب الإداري ولحسابه برداً من تنظيم مدني، يعتبر ملزم بالرقم المدني، ويعرض في حال خلافته لهذه الأحكام للملاحقة وفقاً لقانون العقوبات.

المادة 40 - إذا تضمنت التصريحات التي تنظم الشؤون المدنية شرطًا خاصًا باستعمال الأرض كالضم والفرز والبناء والاستثمار، أحد من الشروط المحددة في قانون البناء، وفي نظام المنطقة، يعمل بالشروط المبينة في التصريحات التي تنظم الشؤون المدنية.

المادة 41 - يمكن لحالك عقار أو مجموعة عقارات أن يفرض شروطًا لاستعمال الأرض والضم والفرز والبناء والاستثمار أشد مما هو محدد في قانون البناء، وفي نظام المنطقة، فالمجسم ينصح فائلاً لاستخدام أفضل للمجموعة البناء، وتحديثيًا لتنوعها، وأشكالها الهندسية. تسجل هذه الشروط بناءً علىطلب المالك في السجل العقاري بعد موافقة المدير العام للتنظيم المدني عليها، وللمطالبة بها بحالة أهلية.

المادة 42 - بغية تسهيل الترتيب المدني، يمكن أن تمنح البلديات من موازنة الدولة قروضاً...


المادة 42 - بغية تسهيل الترتيب المدني، يمكن أن تمنح البلديات من موازنة الدولة قروضاً...
Appendix IV: Extract on calculation of building heights from Construction Law or Building Code #646 of Lebanon (in Arabic)
- إن عملية ضم الفضيلة إلى العقار ليست الزامية للإدارة إلا إذا أعلنت تخصصها للإستعمال العام.

المادة السابعة - الغلاف

مع عدم إمكانية تجاوز الارتفاع الأقصى المحدد في نظام المنطقة التي يقع فيها العقار، وفي حال عدم وجود أحكام خاصة تتعلق بالغلاف، يخضع إنشاء البناء للشروط التالية:

أولاً- غلاف الأبنية على الطرق

تشاد الأبنية داخل خط غلاف من أقصى محدد كما يلي:

أ-1- بخط عامودي مقام على حدود الطريق العام أو على حدود الارتفاع، ارتفاعه يساوي مرتين ونصف عرض الطريق أو الارتفاع المقرر لارتفاعه المصدق مع حد أدنى قدره 15 متراً.

وعند وجود ارتفاع تراجع مفروض على جانب أو على جانب الطريق أو التخطيط بقام الخط العامودي عند حد التراجع لجهة العقار. وتعتبر المسافة بين خط التراجع المفروض بمثابة سعة الطريق لتحديد الارتفاع.

( راجع الرسم رقم 21 )

- إن شراء فضيلة أملاك عمومية أو خصوصية عائدة للدولة أو للبلديات ناتجة عن تنفيذ تخطيط ( عادي أو ضمن مخطط توجيهي عام ) أو استمراراً، لا يتم إلا بعد موافقة الجهة مالكة الفضيلة بناءً على إنهاء الإدارة الفنية المختصة التي أعدت دراسة الإجراء الفنى تطبيقه. أما شراء فضائل الأماكن الخصوصية فيتم وفقاً لأحكام قانون التنظيم المدني، وليس إزامية لإعطاء الترخيص.

- إذا رأت الإدارة الفنية المختصة والجهة مالكة الفضيلة وجوب ضم هذه الفضيلة إلى العقار موضوع طلب الترخيص بالبنية، على الدوائر الفنية المعنية بدراسة ملف الترخيص بالبناء تضمين التكنولوجيا الفنية، ثم الفضيلة لصالح الجهة مالكة العقار والمقدرة على أساس التخمين الم.Entity للعقار لفرض رسم البيع.

ويتوقف إعطاء رخصة البناء على دفع التأمين المذكور من قبل المالك أو من يحل محله قانوناً، على أن تجري فيما بعد معاملات الرسوم البيع والضم على نفسه طالب الشراء.

تغطي الفضيلة في هذه الحالة مضمومة إلى العقار موضوع طلب الترخيص بالبناء إذا توافرت فيه شروط الضم المنصوص عليها في القوانين العقارية وإلا إعتبرت الفضيلة وحدة عقارية مع العقار المذكور.

- يحدد ثمن الفضيلة نهائياً من قبل اللجنة المحددة في المادة 80 من القرار رقم 26/275 وفقاً للسعر الرأي بتاريخ دفع التأمين وفي حال الخلاف على الثمن فصل بذلك لجان الاستملاك الإستثنائي المختصة على نفس الأسس وذلك خلال سنة من تاريخ دفع التأمين. وبعد مرور هذه الفترة، يعتبر التأمين المدفع ثمناً لهذه الفضيلة ويتوجب على الدوائر العقارية ضم هذه الفضيلة إلى العقار الأساسي بناءً على طلب الشاري.
يؤخذ مستوى الرصيف أو الطريق في حال عدم وجود رصيف، أو مستوى المقطع الطولى للخطين، أو وسط الواجهة كنقطة إبداء على الخط العامودي المذكور.

وفي الطرق المنحدرة، إذا كان الارتفاع بين طرفي الواجهة يزيد عن ثلاثة أمتار ونصف تجوهر الواجهة إلى أقسام لا يتعدى الارتفاع بين طرفيها ثلاثة أمتار ونصف ويؤخذ خط عامودي على وسط كل قسم على حدة.

أ - 2 - بخت مائل يمد من الطرفي العلوي للخط العامودي لجهة داخل العقار، ويوفر مانعاً على الخط الأفقي بنسبة 2/5 (أثنين قاعدة خمسة ارتفاع).

ب - الغلاف على ساحة:

إذا كان العقار واجهة على ساحة، يعتمد لتحديد علو الخطوط العمودية على هذه الساحة وعلى الطرق المنفرعة عنها بعمق 30م من حدود التراجع عن الساحة، عرض الطريق الأكثر سعة المنفرعة عن الساحة مع تراجعاتها المختلفة.
د - الغلاف على زاوية طريقين أو أكثر:

عندما يقع العقار على زاوية طريقين أو أكثر، يطبق على كل تفاصيل، وطول لا يتجاوز الثلاثين متراً (30م) لجزء من واجهة البناء (بما فيه التوسعات) الواقعة على الطريق الأقل سعة، (يرتك الخير بتركيزه للالمصمم) يطبق الغلاف التالي: 

1 - خط عامودي مقيم على تخطيط الطريق العام معادل لخمس مرات الامبر المقرر للطريق.

وعند وجود ارتفاع تراجع مفروض على جانب أو جانبي الطريق، يقام الخط العامودي على حدود التراجع لجهة العقار وتعتبر المسافة بين خط الارتفاع المفروض بمثابة سمة الطريق ارتفاع. تؤخذ نقطة إبتداء علو هذا الخط العامودي كما هي محددة لخط العقار العائد للقفرة "أ" من البنّ "أولا" من هذه المادة.

2 - خط مائل ينتمي من الطرف العلوي للخط العامودي ويكون مالاً على الخط الأفقي بنسبة 1/5 (واحد قاعدة لخمسة ارتفاع) لجهة داخل العقار. يجب أن لا يتجاوز العلو الأقصى للبناء الارتفاع الذي ينتج عن تطبيق غلاف الطريق الأقل سعة، وتطبيق على باقي أجزاء الواجهة المطلة على الطريق الأقل سعة الخط الغلافى العائد لهذه الطريق.

(راجع الرسم رقم 26)

(راجع الرسم رقم 27)

(راجع الرسم رقم 25 ورقم 26)
هـ - يتم البت في حالات الغلاف الإستثنائية غير المذكورة أعلاه من قبل المجلس الأعلى للتنظيم المدني.

ثانياً - ارتفاع الأبنية على الفسحات

في حال تأمين وقوع نظر على الفسحات، تشاد الأبنية أو أقسام الأبنية المنارة على هذه الفسحات داخل خط غلاف أقصى كما يأتي:

1- بخط عامودي مقام على واجهة البناء بدون النتوءات على الخط الغلاف لجهاز الفسحة يعادل خمس مرات المسافة الدنيا لوقوع النظر العالمي المؤمن في البناء من الغرف المجهزة والمضادة على الفسحة التابعة للعقار أو على الفسحات المشتركة مع العقارات المجاورة. تكامل هذه المسافة بين الخط العامودي المنصوب في النقاو مواجهة عند محور الفتحة التي تصل بين الواب وللمحاور وبين الخط العامودي المنصوب على حدود العقار أو خط عامودي آخر(مع مراعاة نص المادة التاسعة)، داخل حقل وقوع النظر وعلى محور الفتحة (دافئة أو باب زجاجي أو واجهة زجاجية) وذلك من ابرز نقطة من هيكل البناء مقابل الفتحة.

( راجع الرسم رقم 30 )

عندما يكون وقوع النظر مؤمن على فسحة مشتركة مع العقارات المجاورة، يجب أن تكون واجهة الغرف، أو طرف الفرندا أو اللوجيا أو شرفة المسندة البناء، المؤمن لها مدى وقوع النظر على مسافة أربعة أمتار ونصف على الأقل من الحدود المقابلة للفسحة المشتركة.

( راجع الرسم رقم 28 و 29 )


إجمالاً: الدرجات الحرة غير المقفلة:

أ - 1 - على الطريق التي تقل سعتها عن تسعة أمتار بمنع أي نشاط.

أ - 2 - على الطرق التي تساوي أو تزيد سعتها عن تسعة أمتار، يسمح بنزوح أقصى قدره 1,05م. (متر وخمسة سنتيمترات).

لا يمكن وضع رأس البناء أو سُقفه في الجزء العلوي من العرض أو في الطابق البالي. إذا كانت العمق مساحة، يسمح بنزوح بناء أو سقفه في المنطقة، وذلك مع التقيد بانحلال البند 2 - من المادة التاسعة من هذا المرسوم.

يُسمح تحت الفسحات المشتركة المرتفعة بعدم البناء أو بالنور والهواء بانتشار الطواف السفلي المرمودة إذا لم يكن ذلك يتعارض مع الشروط الخاصة التي قضيت بإنشائها ومع أنظمة البناء في المنطقة، وذلك مع التنقيح بأحكام البند 2 - من المادة التاسعة من هذا المرسوم.

لا يمكن وضع رأس البناء أو سُقفه في الجزء العلوي من العرض أو في الطابق البالي. إذا كانت العمق مساحة، يسمح بنزوح بناء أو سقفه في المنطقة، وذلك مع التقيد بانحلال البند 2 - من المادة التاسعة من هذا المرسوم.

تؤثر الفسحة قانونية لأخذ مدى وقوع النظر عليها عندما لا تقل مساحتها عن 30 م² (ثلاثين مترا مربعا) و تستوعب مستقبل قياسياته الدنيا 4.50 x 5.50م. (أربعة أمتار ونصف وخمسة أمتار ونصف).

تؤثر الفسحة مستقلة طالما لا تتصل بإمكاني الفسحات أو إذا كانت تتصل بفسيحات أخرى بعرض يقل عن 4,50م.

(ارتفاع أمتار ونصف).

(راجع الرسومتين رقم 28 ورقم 29).
Appendix V: Forcing data for the months of February and July on excel
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Appendix VI: Environmental Law 444/2002 (in Arabic)
قانون حماية البيئة

المادة الأولى: يحدد هذا القانون الاطار القانوني العام لتنفيذ سياسة حماية البيئة الوطنية بهدف الوقاية من كل أشكال التدهور والتلوث والذين يهددان بيئتنا. يهدف القانون لتشجيع واستراتيجيات البيئة المستدامة للاستدامة المستدامة للموارد الطبيعية وتعميم اطار حماية البيئة سليمة ومستقرة.

المادة الثانية: لكل أنسان الحق ببيئة سليمة ومستقرة، ومن واجب كل مواطن السهر على حماية البيئة وتأمين حاجات الاجيال الحالية من دون المساس بحقوق الاجيال المستقبلية.

المادة الرابعة: في إطار حماية البيئة وادارة الموارد الطبيعية، على كل شخص من أفراد المجتمع، معاية أو خاص، أن يتزعم وراءه الامور، أو يقيس قدرته على استخدام أفضل تقنيات التحكم في التلوث والتشدید في الاصطلاحات المستخدمة. يهدف القانون إلى تحقيق التوازن بين التنمية الاقتصادية والبيئية.

المادة الثالثة: لغايتي هذا القانون، يقصد بعبارات:

- بيئة: المحيط الطبيعي، والمادي والبيولوجي، والاجتماعي الذي تعني فيه الكائنات الحية ككل ونظم التفاعلات داخل البيئة، ومكافحة التنوع البيولوجي واهتداء البيئة.

- تنوع البيولوجي: تباين الكائنات العضوية الحية المستدمة من المصادر كافة بما فيها، الفيزيائي والكيميائي والبيولوجي، والأحياء المائية والمركبات الكيميائية التي تتعارض بها، وذلك لتضمن البيئولوجي داخل الأنواع وبين الأنماط والنظم الإيكولوجية، التفاعلات بين البيئة في الحياة باعتبار أنها تمثل وحدة إيكولوجية.

المادة الرابعة: في إطار حماية البيئة وادارة الموارد الطبيعية، على كل شخص من أفراد المجتمع، معاية أو خاص، أن يتزعم وراءه الامور، أو يقيس قدرته على استخدام أفضل تقنيات التحكم في التلوث والتشدید في الاصطلاحات المستخدمة. يهدف القانون إلى تحقيق التوازن بين التنمية الاقتصادية والبيئية.

المادة الخامسة: لغايتي هذا القانون، يقصد بعبارات:

- الموارد الطبيعية: عناصر البيئة الآتية: الهواء، المياه، الأرض والكائنات الحية.

- الحداثة الإيكولوجية: مجموعة الكائنات الطبيعية التي تتفاعل مع البيئة في الحياة باعتبار أنها تمثل وحدة إيكولوجية.

المادة السادسة: لكل أنسان الحق ببيئة سليمة ومستقرة، ومن واجب كل مواطن السهر على حماية البيئة وتأمين حاجات الاجيال الحالية من دون المساس بحقوق الاجيال المستقبلية.

المادة السابعة: بحماية البيئة، يهدف القانون إلى تحقيق التوازن بين التنمية الاقتصادية والبيئية، وضمان الاستدامة المستدامة للموارد الطبيعية وتعميم اطار حماية البيئة سليمة ومستقرة.
قد تكون الموارد الطبيعية كالماء والهواء والتربة والغابات والبحر والأنهر وغيرها.
وهمدًا المشاركة القاضي بأن:
1- يكون لكل موطن من الحصول على المعلومات المتعلقة بالبيئة، وفقًا للقوانين والأنظمة المراعية الإجراء.
2- يسره كل شخص طبيعي أو معنوي، عام أو خاص، على سلامة البيئة، ويساهم في حمايتها وأن يبلغ عن أي خطر قد يهددها.
3- يسري مبدأ التعاون، الذي يقضي بأن تتعاون السلطات العامة والمحلية والمواطنون على حماية البيئة على كل المستويات.
4- يُحبّب مبدأ أهمية المعيار العرفي في الوسط الريفي، الذي يقضي بوجود الأخ الأخر في حالتنا النزاعات.
5- يسري مبدأ مرافق التلوث الذي يهدف إلى الوقاية من التلوث والتحكم به في الأنظمة البيئية كافة من ماء وهواء وتراب ونتوء وتفاوت، حيث لا تؤدى معالجة التلوث في الوسط البيئي إلى انقلاب التلوث إلى وسط آخر أو التأثير عليه.
6- يسري مبدأ الإعداد على المفاهيم الاقتصادية كأداة مراقبة وتخطيط من أجل التخلص من كل مصادر التلوث ورقابة الإجراءات البيئية، وتعزيز سياسة التنمية المستدامة.
7- يسري مبدأ تقديم الاتر البيئي كوسيلة للتخطيط والإدارة من أجل مكافحة التلوث وتدوير الموارد الطبيعية أو تقليلها أو تصور حجمها إلى أدنى حد.

الفصل الثاني
تنظيم حماية البيئة

الفصل الأول
التخطيط البيئي

المادة الخامسة: تنشأ مجلس Nacional للبيئة من أربعة عشر عضوًا. يتم تأليف المجلس الوطني للبيئة وطريقة عمله بموجب مرسوم يتخذ في مجلس الوزراء بناءً على اقتراح وزير البيئة، على أن يكون الممثل مناصفًا بين الوزارات المعنية بالبيئة وذوي العلاقة من القطاع الخاص (الجمعيات البيئية والخبراء البيئيين وأعضاء نقابات المهندسين).
1- بغية الوصول إلى مراقبة متكاملة للتلوث ، يتعين بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح وزير البيئة ، معايير التصاريح المتصلة بالمدن والمناطق المصنفة والمصانع والمؤسسات الأخرى التي تقوم بإصدار مصادر تلوث ، وبرامج رقابة ذاتية أو تدقيق بيئي ، بهدف تطبيق معايير ودوام قاعدة التدابير المتخذة في مجال مكافحة التلوث أو تقليله واعتماد الرأي العام بنتائج هذه التدابير.

المادة الثالثة عشرة: يشمل تقييم وضع البيئة وحمايتها تنفيذ برامج ادارية بيئية تقوم بها الهيئات والمؤسسات والمؤسسات المصنفة والمؤسسات العاملة في مجال البيئة، وبرامج رقابة ذاتية أو تدقيق بيئي، بهدف تطبيق معايير ودوام قاعدة التدابير المتخذة في مجال مكافحة التلوث أو تقليله واعتماد الرأي العام بنتائج هذه التدابير.

المادة الرابعة عشرة: يوضع نظام لادارة المعلومات المتصلة بالبيئة وطرق حمايتها ، يطبق بشراف وزارة البيئة ، يتعين أن تحدد طرق تنظيم إدارة المعلومات البيئية بمرسوم يخض في مجلس الوزراء بناء على اقتراح وزير البيئة واستشارة المجلس الوطني للبيئة.

المادة الخامسة عشرة: يجب أن يتعين على هذه المعلومات ضمان مهلة شهر ، وكل رفض لإعطاء المعلومات المطلوبة يجب أن يكون معلما.

المادة السادسة عشرة: تقوم وزارة البيئة على تنفيذ نظام المعلومات والاستشارات والإدار.

المادة السابعة عشرة: وضمن تطوير الابحاث والانجازات والتطور البيئي، وضمن تطوير الابحاث والتقدم البيئي، وضمن تطوير الابحاث والتقدم البيئي.
المادة التاسعة عشرة: تحدد بمراسم تتخذ في مجلس الوزراء بناءً على اقتراح وزير البيئة، بعد استطلاع رأي الوزارات المختصة، أصول تطبيق نظام مشاركة المواطنين المذكور في المادة الثامنة عشرة من هذا القانون.

الفصل الثالث
التدابير التحفيزية
المادة العشرون:
1) كل من يستعمل تجهيزات وتكنولوجيات تسمح بتقليص أو ابتعاد عن أي أنواع تتلوث بيئة و옜ها أو التلوث كمواد ضارة أو تلوثها، سيساعد خلال رفعه إلى الأسواق، ويقدم تفاصيله واعادة تصنيفه وعملياته، تسبب في تغييرات على العلوم المدارية المتوفرة على هذه التجهيزات وتكنولوجيات، بنسبة 50% (خمسين بالمئة) كحد أقصى وفقاً للشروط واللوائح التي تحدد برسوم يتخذ في مجلس الوزراء بناءً على اقتراح وزير البيئة والمالية.
2) كل شخص طبيعي أو معنوي يقوم بنشاط يقلب تنظيمه على البيئة يستفيد من تخفيضات على الضرائب التي تتناول هذه النشاطات، بنسبة 50% (خمسين بالمئة) كحد أقصى وفقاً للشروط واللوائح التي تحدد برسوم يتخذ في مجلس الوزراء بناءً على اقتراح وزير البيئة والمالية.
3) مجلس الوزراء بناءً على اقتراح وزير البيئة والمالية والوزير المختص، يتم إنشاء كل تدابير تحفيزية واقتصادية أو مالية أخرى.

الباب الرابع
تقييم الأثر البيئي
المادة الواحدة والعشرون:
1) على الجهات المعنية في القطاعين العام والخاص اجراء دراسات الفحص البيئي المبدئي أو تقييم الأثر البيئي للمشاريع التي تهدد البيئة، بسبب جمعها أو طبيعتها أو تلوثها أو تأثيرها أو شموعها. تراجع وزارة البيئة، هذه الدراسات وتوافق عليها بعد التأكد من كفاءتها لنشر سلامة البيئة واستدامة الموارد الطبيعية.

المادة الثانية والعشرون:
1) إن كلمة "مشروع " تعني: أجعل المنشأ أو وماواها من الإنشاءات. بيئة داخلية أو المحافظة على الطبيعة بما في ذلك تلك التي تتضمن أعمال استخراج أو إضافة الموارد الطبيعية.

المادة السادسة عشرة:
1) على كل مؤسسة تربوية، إعدادية، دبلومية، جامعة، خاصة أو خاصة، وعلى كل مؤسسة أكاديمية أخرى، أن تدخل ضمن مناهجها أحدهما تحرير تثبيت لبنانية وفقاً للشروط تحدد برسوم يتخذ في مجلس الوزراء بناءً على اقتراح وزير البيئة والوزراء المختصين.

المادة السابعة عشرة:
1) على الجهات المعنية في القطاعين العام والخاص، إعداد تفاصيل النقل والبيئة، وأن تكون مع وزارة البيئة والوزارات المختصة، على تطبيق حلقات تامين وحملات توعية حول حماية الأطراف البيئية والممارسات البيئية، وتطبيق التكنولوجيا وتطبيق تقنيات الوقاية.

الفصل الثاني
نظام المشاركة في إدارة البيئة
المادة الثامنة عشرة:
1) تؤمن مشاركة المواطنين في إدارة البيئة وحمايتها عبر:
2) تونس حر إلى المعلومات البيئية وفقاً للقوانين والأنظمة المرعية للإجراءات.
3) وضع آليات الاستشارة على المستويين الوطني والمحلي، تضمن مواطنين وجماعات يتناسبون مشروعاً البيئة.
4) تطوير التربية البيئية في النظام التربوي الوطني.
5) إلزام جميع المواقع المخصصة بأداء التقنيات، وстроية والمواد المناسبة وقلاوي من النشاطات، لا سيما على المستوى المحلي.
6) تطوير التكنولوجيات الخاصة بأعمال التصنيع ومراكز التجميع والفرز والتخلص من النفايات، لا سيما على المستوى المحلي.
7) تخصيص توجيهات باستخدام التكنولوجيات الخاصة والطاقات والموارد البديلة، وضمان الاستثمار في المواد الطبيعية، ووضع مشاريع متاحة تتمدح الوقاية من التلوث والتقليل من وقته.
الباب الخامس
حماية الاوساط البيئية
الفصل الأول
حماية الهواء ومكافحة الروائح المزعجة
المادة الرابعة والعشرون: 1) على كل شخص طبيعي أو معنوي، عام أو خاص، وخاصة عند استعمال الآلات أو المحركات أو المعدات أو المركبات أو عند استخدام ألات التربة ومركبات الصوئ، ان يلتزم بعدم انبعاث أو تسرب ملوثات للهواء، بما في ذلك الروائح المزعجة أو الضارة محظورة بمقتضى هذا القانون ونصوصه التطبيقية، أو بما يتجاوز الحدود القصوى المسموح بها والتي تحددها المعايير الوطنية لنوعية البيئة، مع الأخذ بالاعتبار نص الفقرة (د) من المادة الثانية من هذا القانون.

المادة التاسعة والعشرون: تهدف حماية البيئة البحرية من التلوث إلى تحقيق الأغراض التالية:
أ- حماية شواطئ الجمهورية اللبنانية ومواردها الطبيعية ومرافقها من مخاطر التلوث بجميع صوره.
ب- حماية المياه الإقليمية اللبنانية الطبيعية الحية وغيرها من مخاطر التلوث بجميع صوره وتشكلها.

المادة الثالثة والعشرون: 1) يجب عند حرق أي نوع من أنواع الوقود أو المحروقات أو غيرها، سواء في اغراض الصناعة أو توليد الطاقة أو أي غرض آخر، أن تبقى
المادة الثالثة والثلاثون:

(1) تؤدي انضمام لبنان إلى معاهدات الدولية والإقليمية التي تتعلق بالبيئة، يمنع منعاً باتاً كل تصريف أو غمر أو حرق في المياه الاقليمية للبنان كل مادة من شأنها بصورة مباشرة أو غير مباشرة، أن:
أ- تضر بصحة الإنسان أو الموارد البحرية.
ب- تؤذي الأنشطة والكائنات البحرية، بما فيها النماذج والاست העشية والنباتات والطحالب.
ج- تفسد نوعية المياه البحرية.
د- تقلص من القيم الترفيهية ومن الإمكانيات السياحية للبحر والشواطئ اللبناني.

(2) تحدد المرسوم المذكور في البند 1 من المادة الثلاثين، شروط وإجراءات منح التصريحات المنصوص عليها في البند 1 من هذه المادة، واجراءات القطاعات المختلفة لضمان توزيعها بشكل منطقي وتحسين توزيعها.

الفصل الثالث

حماية البيئة المائية من التلوث

المادة الخامسة والثلاثون:

(1) مع مراعاة الالتزامات المتعلقة بالعوامل المؤثرة، وتحقيق الأغراض المذكورة في البند 1 من هذه المادة، بما فيها حماية مياه البحار والشواطئ والمواقع الرطبة، ينظم تطبيق هذه المادة
(2) يحدد المرسوم المذكور في البند 1 من المادة الثالثة والثلاثين، جميع التدابير اللازمة للوقاية من كل تلوث بحري ناتج عن سفن أو مراكب أو مشاريع أو مشاريع في المياه الاقليمية للبنان.
الارض وجوف الأرض ومواردها الطبيعية، والخسائر في الأرضي والزراعية بـ "التدابير التي تهدف إلى تشجيع الاستعمال الشديد للأرض أو جوف الأرض ومواردها الطبيعية. باستثناء البيانات التي تستخدمها أو ب <<= التهابها، قد تتم تدفق الأرض وجوف الأرض ومواردها الطبيعية، وممارسات الإصلاحات وحالات تكوين مياه ورشفية والري.

المادة الثمانين والثلاثون: تحدد بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح وزير البيئة والوزير المختص في مهل يحددها هذا المرسوم: 
أ-الأصول وضع جريدة عامة قياس مستوى تلوث المياه والأنهار والأزهر ومعاييرها وضارتها، وشراكات وسياسات توزيع مياه الشفاء وفقًا للري على ان يعاد النظر بهذه الجريدة العامة كلما دعت الحاجة إلى ذلك.
ب-المعايير الوطنية والكيميائية والبيولوجية والبيولوجية التي يجب أن توفر في المياه والأنهار والأنهار ومعاييرها وضارتها، وشراكات وسياسات توزيع مياه الشفاء وفقًا للري.
ج-المعايير الوطنية ل النوعية التي يجب أن تتوفر في المياه المخصصة للاستهلاك البشري ولسائر الاستخدامات.

المادة الخمسون: تحدد بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح وزيرة البيئة ووزير الزراعة السابقين: 
أ-شروط الحماية الخاصة التي تهدف إلى الحد من تدهور التربة وتآكلها وتلوث الأرض وجوف الأرض ومواردها الطبيعية، وموارد الأراضي القابلة للزراعة، ضمن مهل يحددها هذا المرسوم:...

المادة الستون: تحدد بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح وزير البيئة والوزراء المختصين:
أ-الأصول وضع جريدة عامة قياس مستوى تلوث المياه والأنهار والأزهر ومعاييرها وضارتها، وشراكات وسياسات توزيع مياه الشفاء وفقًا للري...

المادة السبعون: مع مراعاة أحكام القانون رقم 36/88 تاريخ 12/8/1888 لحماية البيئة، ونفايات أو مواد خطرة على الصحة والسلامة العامة التي تحتوي على مواد خطرة أو تلوث البيئة أو تلوثها.

المادة الثمانون والثلاثون: تحدد بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح وزير البيئة والوزراء المختصين:
أ-الأصول وضع جريدة عامة قياس مستوى تلوث المياه والأنهار والأزهر ومعاييرها وضارتها، وشراكات وسياسات توزيع مياه الشفاء وفقًا للري...

المادة تسعون: مع مراعاة أحكام القانون رقم 36/88 تاريخ 12/8/1888 لحماية البيئة، ونفايات أو مواد خطرة على الصحة والسلامة العامة التي تحتوي على مواد خطرة أو تلوث البيئة أو تلوثها.

المادة اعتبرت: تحدد بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح وزير البيئة ووزير الزراعة السابقين:
أ-الأصول وضع جريدة عامة قياس مستوى تلوث المياه والأنهار والأزهر ومعاييرها وضارتها، وشراكات وسياسات توزيع مياه الشفاء وفقًا للري...

المادة تسعونا: مع مراعاة أحكام القانون رقم 36/88 تاريخ 12/8/1888 لحماية البيئة، ونفايات أو مواد خطرة على الصحة والسلامة العامة التي تحتوي على مواد خطرة أو تلوث البيئة أو تلوثها.
المادة الواحدة والاربعون

مع مراعاة احكام الباب السادس من هذا القانون ، تخضع الأماكن المتضررة نتيجة لأعمال يتم القيام بها من دون التقيد بالأحكام القانونية والتنظيمية النافذة ، والأماكن الملوثة بسبب المكبات البرية أو الطمر غير المسموح ، لتدابير تهدف إلى القضاء على التلوث وتصحيح البيئة ، وذلك على نفقة المسؤول عن هذه الأماكن بغية إعادتها قدر القدوم الى حالها الأصلية .

وقد ما تحدده وزارة البيئة،

تحدد دقائق تطبيق هذه المادة في المراسيم التي تصدر في مجلس الوزراء تطبيقاً لأحكام هذا القانون.

الفصل الخامس

المنشآت

المادة الثانية والاربعون:

1 - تخضع كل منشأة ، أن تتوفر لديها امكانيات مراجعة بيئية ومراقبة ذاتية بهدف القياس المنظم لصداراتها الملوثة ونتائج أنشطتها على البيئة .

2 - تخضع كل منشأة للتصريح المسبق بالاستثمار الذي يعين الحدود الخاصة لكل أنواع الاصدارات الملوثة ، بما فيها تلك المتعلقة بمعالجة النفايات ، والنتائج الأخرى لأنشطة المنشأة على البيئة ، فضلا عن شروط تنفيذ المراجعة البيئية والمراقبة الذاتية المذكورة في البند (1) من هذه المادة .

3 - تحدد بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح من وزير البيئة والوزراء المختصين ، المعايير الوطنية الخاصة بكل فئة من فئات المنشآت ، ودقائق تطبيق احكامها على المنشآت القائمة بتاريخ نفاذ هذا القانون ، وشروط وقف أو اغلاق أو شطب كل منشأة ، عندما تشكل هذه المنشأة خطرا على البيئة لا يمكن للتدابير الملحوظة في هذا القانون تلافيه .

المادة الثالثة والاربعون:

عندما يكون استثمار أحدى المنشآت مصدر ضرر لأحد عناصر البيئة على السلطة المحلية أن تتحلي وزارة البيئة بالضة لإجراء التحقيق المطلوب، وتنذر السلطة المحلية المستمر بتقديم اتخاذ التدابير الضرورية كافة للوقاية من هذا الخطر واتخاذ التدابير المناسبة من ذلك على نفسه الخاصة .

فم ما تحدده وزارة البيئة،

تحدد دقيقتين تطبيق هذه المادة في المراسيم التي تصدر في مجلس الوزراء تطبيقاً لأحكام هذا القانون .

الفصل السادس

المواد الكيميائية ، الضارة و/أو الخطرة

المادة الرابعة والاربعون:


2 - تطبق هذا القانون ونصوصه التطبيقية على التكتيكات المصنوعة من المواد المذكورة في البند "1" من هذه المادة .

3 - حدد بمرسوم يتخذ في مجلس الوزراء بناء على اقتراح من وزير البيئة والوزراء المختصين ، المعايير الوطنية الخاصة بكل فئة من فئات المنشآت ، وفقاً للشروط واحترام والإجراءات الخاصة بالمادة المذكورة في البند "1" من هذه المادة .

المادة الخامسة

المنشآت
المادة الثانية والاربعون:

- تركز إدارة المواد الطبيعة والحفاظ على التنوع البيولوجي في لبنان على:
  - وضع جردة بالإنسان الحيوي ونباتية الموجد، وخاصة تلك المعرضة لخطر الزوال.
  - إضافة كل شكل من شكل الساس بالبيئة للاعمار والبيئة المحيطة.
  - اقتراح خطط حماية للنساء البيئية والبيئة والبيئة وشروط حياتها وشروط قوانين طبيعية ومناطق حماية واقترح سلطات حماية المواقيع والمناطق الطبيعية.
  - وضع نظام مرافق علم المواد البيولوجية والبيئة والبيئة والبيئة واستعمالاتها.
- استعمالاتها وفقاً للاتفاقيات والمعاهدات الدولية التي أقرها أو برمتها لبنان، وذلك بالإضافة إلى الوزارة المعيشة.

المادة الخامسة والاربعون:

- تحدد مواد الحمض، كالذين يتأثر بأعمال الله، ولا يسمح بهم، ويتأثر بأعمال الله.

الفصل السابع
الأذية الصوتية والضجيج

المادة السادسة والاربعون:

- تحدد مواد الصوت، كالذين يقوم بهم، ولا يسمح بهم، ويتأثر بأعمال الله.

المادة السابعة والاربعون:

- تهدف إدارة المواد المشتركة مع الدول الأخرى للستطيع المستدام على الأسس العامة، ول-choice.

المادة الثامنة والاربعون:

- تحدد مواد الصناعة، كالذين يقوم بهم، ولا يسمح بهم، ويتأثر بأعمال الله.

المادة التاسعة والاربعون:

- تحدد مواد الصناعة، كالذين يقوم بهم، ولا يسمح بهم، ويتأثر بأعمال الله.

المادة العشرون والاربعون:

- تهدف إدارة المواد المشتركة مع الدول الأخرى للمعنى المستدام على الأسس العامة، ول-choice.
الادارات والسلطات المختصة في تنفيذ هذه التدابير
بمراسيم تتخذ في مجلس الوزراء بناءً على اقتراح
وزير البيئة والوزراء المختصين.

الباب السادس
المؤسسات والعقوبات

الفصل الأول
المؤسسات والعقوبات

المادة الواحدة والخمسون:
مع مراعاة احكام قانون الموجبات والعقود وقانون العقوبات، ان كل انتهاك للبيئة يلحق
ضررا بالاشخاص او بالبيئة يسأل فاعله بالتعويض
المتوجب. وللدولة ، ممثلة بوزارة البيئة ، المطالبة
بالتعاون الخاصة الناتجة عن الاضرار اللاحقة
بالبيئة.

المادة الثانية والخمسون:
1- ان المسؤولين عن اي ضرر يطال البيئة بسبب
عمال منزهة من دون تصريح أو بصورة مخالف
للأحكام القانونية والتنظيمية النافذة ، لا سيما تلك
المتعلقة بدراسات الفحص البيئي المبكر أو تقييم
الآثار البيئي ، ملزمون باتخاذ كل التدابير التي تؤدي
الى ازالة الضرر ، على نفقتهم الخاصة.
2- ان النفقات الناتجة عن التدابير التي تتخذها
السلطات المختصة لمنع كل
ضرر يطال البيئة، تكون
على عاتق المسؤول عن هذا الضرر.

المادة الثالثة والخمسون:
على كل من يستثمر مؤسسة او يستعمل مواد كيميائية
، ضارة و/أو خطرة كما يحددها هذا القانون
ونصوصه التطبيقية، ان يوقع عقد ضمان ضد كل
المخاطر التي تهدد البيئة.

الفصل الثاني
ضبط الجنح

المادة السابعة والخمسون:
ان تطبيق العقوبات الجزائية لا يحول دون صلاحية
الإدارات والسلطات المختصة ، بعد اداء حكما
تيبلغه بالطريقة الادارية الى المخالف ، بأن تتخذ بحقه
كل أو بعض التدابير الادارية التالية:
1- توجب محاصر ضبط ، وتصويبه التطبيقية ، بموجب محاصر ضبط
ينظرها افراد الضابطة العدلية وفقا لقوانين المرعية
بالاجراء.
2- من أجل ضبط المخالفات ومراقبة التطبيق ، لأفراد الضابطة العدلية
القانون ونصوصه التطبيقية ، لأفراد الضابطة العدلية
الفصل الرابع
العقوبات

المادة الثامنة والخمسون:
1- يعاقب بالحبس من شهر الى سنة وبالغرامة من خمسة عشر مليون الى مئتي مليون ليرة لبنانية، او باحدى هاتين العقوبتين، كل من:
- ينفذ مشروع يشترط دراسة فحص بيئي مبدئي او تقييم الأثر البيئي من دون اجراء هذه الدراسة مسبقا او تجاهلها او خلاف من موافقة وزارة البيئة والوزارات والادارات المختصة.
- ينفذ مشروع لا يستوجب دراسة فحص بيئي او تقييم الأثر البيئي و
غير متطابق والمعايير الوطنية.
- يعارض او يعرقل اجراءات المراقبة والتفتيش والتحاليل المنصوص عليها في هذا القانون و/أو توصيات التنفيذية.
- في حال تكرار المخالفة تضاعف العقوبة.

المادة التاسعة والخمسون:
1- يعاقب بالحبس من شهر الى سنة وبالغرامة من خمسة ملايين الى عشرة ملايين ليرة لبنانية، او باحدى هاتين العقوبتين، كل من:
- يخالف قانون الغابات الصادر بتاريخ 2 كانون الثاني 1949 لا ما زاده 98، يعود مجموع الغرامات والتعويضات المضقي بها علما بحكم هذا القانون ونصوصه التطبيقية، الى الصندوق الوطني للبيئة.

المادة السادسة والستون:
حق لوزير البيئة اجراء مصالحة على الع葇ات وعلى التعويضات التي يحكم بها بشأن الأضرار التي تصيب البيئة، تطبيقا لأحكام هذا القانون ونصوصه

المادة السابعة

الباب السابع

الحكم نهائي

المادة السادسة والستون:
يدعو القضاء الى النظر في حالة ال لزيدية بناء على صياغة الافعال، وعلى التعويضات التي يحكم بها بشأن الأضرار التي تصيب البيئة، تطبيقاً لأحكام هذا القانون ونصوصه، بالإضافة إلى ما يحكمه أحكام القانون رقم 24/88.

الباب الثامن

الأخيرة

المادة السادسة والستون:
يدعو القضاء إلى النظر في حالة ال لزيدية بناء على صياغة الافعال، وعلى التعويضات التي يحكم بها بشأن الأضرار التي تصيب البيئة، تطبيقاً لأحكام هذا القانون ونصوصه، بالإضافة إلى ما يحكمه أحكام القانون رقم 24/88.

المادة السابعة

الباب السابع

الحكم نهائي

المادة السادسة والستون:
يدعو القضاء الى النظر في حالة ال لزيدية بناء على صياغة الافعال، وعلى التعويضات التي يحكم بها بشأن الأضرار التي تصيب البيئة، تطبيقاً لأحكام هذا القانون ونصوصه، بالإضافة إلى ما يحكمه أحكام القانون رقم 24/88.
الفصل السادس: المواد الكيميائية، الضارة و/أو الخطرة المادة (44-45)
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الفصل الرابع: تمويل حماية البيئة المادة (8-11)
الفصل الخامس: إيات رقابة التلوث البيئي المادة (12-13)
الفصل السادس: نظام المعلومات البيئية والمشاركة في إدارة البيئة وحمايتها المادة (14)
الفصل الأول: نظام المعلومات البيئية المادة (15)
الفصل الثاني: نظام المشاركة في إدارة البيئة المادة (16-17)
الفصل الثالث: التدابير التحفيزية المادة (18)
الفصل الرابع: تقييم الأثر البيئي المادة (19-20)
الفصل الخامس: حماية الأرواس البيئية المادة (21-23)
الفصل الأول: حماية الهواء ومكافحة الروائح المزعجة المادة (24-25)
الفصل الثاني: حماية الساحل والبيئة البحرية المادة (26-27)
الفصل الثالث: حماية البيئة المائية من التلوث المادة (28-29)
الفصل الرابع: حماية البيئة الأرضية وجوف الأرض المادة (30-31)
الفصل الخامس: النشاط المادة (32-33)
Appendix VII: SURFEX data on Excel