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EVALUATING THE TRANSFORMATION OF LAND USE AND MORPHOLOGY ON THE MICROCLIMATE: THE CASE OF GEMMAYZEH NEIGHBOURHOOD – BEIRUT

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Abstract

This paper investigates the effect of urban areas on local climate by examining the correlation between urban morphology, land use and urban thermal climates. It focuses on Gemmayzeh area in Beirut. Urban parameters were evaluated by developing an energy balance model with the aim of understanding how heterogeneous geometry, height, and finishing material can change the mechanical and thermal structure of the urban atmosphere. It simulates the current urban condition in order to compare it with other scenarios using ENVI-met 4.The results from the numerical simulation reveal that a network of green infrastructure connecting the existing green patches can ameliorate heat extraction and improve the outdoor thermal comfort level. The PMV value at the pedestrian level is reduced from extreme heat stress to moderate heat stress near the green areas. The study concludes that Beirut city center can mitigate the urban heat island by using vegetation and especially green roofs and densification of high trees in the left over spaces.

Keywords

Beirut, ENVI-met, Urban canyon, Hot Humid Climate, PMV

1. INTRODUCTION

With the spread of urbanization, natural land cover is replaced with an artificially-built surface. Hence, the modified physical characteristics of the city associated with anthropogenic heat promote the interaction between the urban surface and the atmosphere through heat flow exchanges, altering the thermodynamic structure of the urban boundary layer. One of the most studied city-based phenomenon is known as the Urban Heat Island, where inner areas of the city become warmer than its surroundings (Oke, 1988). It deteriorates the urban environment, intensifies the building energy demand for cooling, and worsens the pedestrian comfort level (Santamouris, 2014). Moreover, health-related problems may be exacerbated by these heat waves. Thus, it is crucial for planners and urban designers to be provided with guidelines that correlate between the urban parameters and microclimate affecting the outdoor thermal comfort (Stathopoulos, 2006).

1.1 Effect of Urban Heat Island on Outdoor Thermal Comfort

Urban energy balance is defined as the quantifiable assessment of heat and momentum fluxes that are related to solar radiation, relative humidity and wind speed (Grimmond, 2010 the international urban energy balance models). It is affected by the urban morphology resulting in radiation balance variation and depends on building configuration, street aspect ratio, materials, anthropogenic factors and land use (Santamouris et al., 1999 Arnfield, 2000). Calculating urban energy balance is complicated due to the non-homogenous urban geometry that modifies the heat fluxes through a series of processes, and the vertical reflections of radiation (Arnfield, 2003). Human-biometeorological The International Society of Biometeorology (ISB) (2013) defines biometeorology as “An interdisciplinary science that considers the interactions between atmospheric processes and living organisms (plants, animals and humans).” assessments indicate that outdoor thermal comfort is closely related to the short and long-wave radiation fluxes received by human beings.

The majority of these studies have explored how urban design variables affect the urban microclimate concentrating on symmetric geometrical street layouts, and how wind speed and temperature are affected; however, it is crucial to investigate the thermal and mechanical turbulences contributed to asymmetrical urban canyon, which has not been often studied (Ali-Toudert and Mayer, 2007). Moreover, deep canyons defined by the height, length and width of streets avoid radiation release and ventilation. Wind flow is related to street orientation, whether it is parallel or perpendicular to the prevailing wind (Santamouris et al., 1999).

The number of studies related to outdoor environment is still limited in comparison with the indoor thermal comfort studies. Nikolopoulou and Lykoudis (2006) conducted outdoor thermal comfort surveys in five different European cities. They correlated the comfort temperature and climatic air temperature through a linear equation. Nicola et al. (2006) suggested an equation that thermal sensation vote will decrease with increasing wind velocity. (Givoni et al., 2003) investigated the outdoor comfort level in Japan. They proposed a simplified equation to predict the thermal sensation considering the relative effects of air temperature, solar radiation and wind velocity, and neglecting less significant parameters. (Spagnolo and De Dear, 2003) proposed a broader scale for outdoor comfort zone relatively to the indoor environment. (Ali-Toudert and Mayer, 2006; Pearlmutter et al., 1999) correlated the outdoor thermal comfort to street geometry depending on shallow and deep canyons. (Nikolopoulou et al., 2001) also investigated the effect of urban geometry on outdoor comfort.

Many indices have been developed to calculate the energy balance of human body, these are mainly based on the influence of climatic parameters including air temperature, humidity, mean radiation temperature and wind speed (Mayer and Höppe, 1987) and human factors (clothing and metabolism). One of the most useful indexes to calculate comfort conditions is PMV (Predicted Mean Vote), which was first developed by Fanger (1973) to predict thermally-comfortable indoor climates depending on clothing and physical activity. It can also be applied for outdoor thermal conditions by adding outdoor radiation, which is the most significant heat gain of the pedestrian.

(Thorsson et al., 2004) concluded after examining behavior and calculating PMV in an urban park, that thermal comfort is linked to the thermal physiological and behavioral aspects. Other thermal indices such as PET (Physiological Equivalent Temperature) (Höppe, 1999; Matzarakis et al., 1999), SET* (Standard Effective Temperature) (Gagge et al., 1986) or Outdoor Standard Effective Temperature (Out_SET*) (Spagnolo and De Dear, 2003) were studied and documented, including important meteorological and thermo-physiological parameters. The advantage of these thermal indices is that they require the same meteorological input parameters: air temperature, air humidity, wind speed, short and long wave radiation fluxes. The sky view factor (SVF) indicates the ratio between radiation received by a planar surface and that from the entire hemispheric radiating environment (Watson & Johnson 1987). According to Oke (1988), SVFs represents the ratio at a point in space between the visible sky and a hemisphere centered over the analysed location. Consequently, when the SVF is equal to zero, it indicates that the entire sky is blocked from view by obstacles.

1.2 Role of Vegetation in Mitigating Urban Heat Island

Many urban interventions and strategies have been developed to modify city energy balance by improving the microclimate and mitigating the outdoor comfort conditions in urban areas taking into consideration the role of the urban form design, shading and green infrastructure. Urban trees reduce solar heat gain into the buildings, decrease air pollution, provide shading, cool air despite evapotranspiration effect during the hot summer days, and shield buildings from cool winter and hot summer winds. Recently the role of vegetation to mitigate UHI (Urban Heat Island) impacts has been intensely studied (Akbari, 2002; Dimoudi, A., & Nikolopoulou, M., 2003; Rosheidat, 2014; Taha, 1996).

(Fahmy et al., 2010) studied the leaf area index related to tree selection for the thermal pedestrian enhancement in identifying trees for Cairo's urban developments and discussed improvements for outdoor comfort of the building by using Ficus Elastica tree. Pedestrian thermal stress is reduced by cooler surfaces in urban areas (Ali-Toudert and Mayer, 2006; Pearlmutter et al., 1999). (Shashua-Bar et al., 2012) studied that the efficiency of moderating the microclimate by vegetation is relative to the percentage of green in relation to the built area and to the characteristics of the plant such as type, size, shape, age and location.

2. AREA OF STUDY

The city of Beirut (33°53′ N, 35°29′ E), Lebanon's capital, is a coastal city lying on a peninsula on the east shore of the Mediterranean Sea and extending over 9 km into the sea. The north and west sides are opened to the sea while the east side is surrounded by Mount Lebanon. There are two hills within Beirut (Ashrafieh and Ras Beirut); the highest at 95m above sea level. The city has a Mediterranean climate characterized by hot humid summer and experiencing four distinct seasons. August is the hottest month of the year with a monthly average temperature of 30◦C. It is cooled during the hot season by the sea breeze, which enables the prevailing southwest wind to infiltrate its urban form. However, this wind flow is dependent on the building layout, height and orientation.

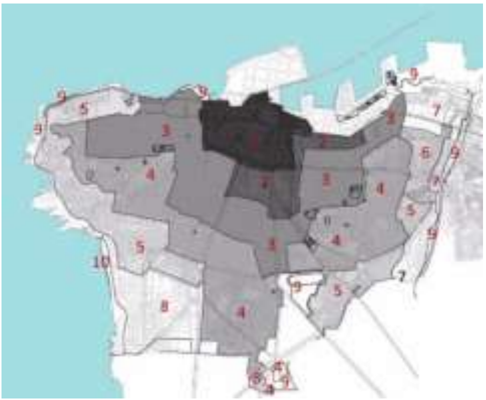


Fig.1: Beirut Zoning

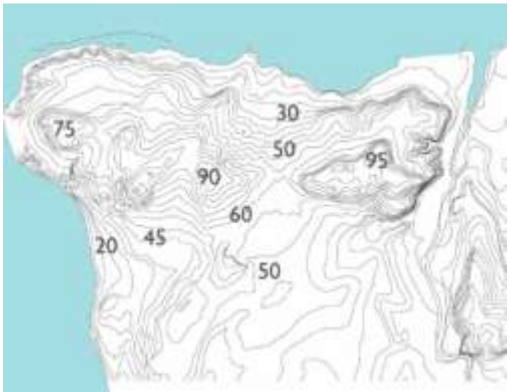


Fig.2: Beirut Topography

Beirut's building regulations subdivide the city into several concentric zones that specify the allowed construction on a parcel. Each zone is subject to floor area ratio and building coverage ratio. The central zone of BCD has the highest exploitation ratio; the ratio decreases as the zones get further away from the centre. The zoning regulations allow low exploitation ratio along seashore in addition of setbacks from all lots' sides which increase the permeability of the wind in zone 5 (figure 1). On the contrary, in other central zones buildings in adjacent lots can be attached with no setbacks, which create a wall effect building reducing airflow. Historically, from Ecochard's plans to Beirut in 1943 and 1964 until the "Plan Horizon 2000" proposed by council for reconstruction and development and lately the physical master plan of Lebanese territory in 2005, urban planning policies in Beirut do not take into account green spaces. (Faour, 2015) looked into the evolution of urbanization in the Greater Beirut Area by analysing topographic maps and satellite images.

Fig.3: Gemmayzeh Location in Beirut

According to his studies, the urbanized area was around 68 km2 in 1963 and has expanded to double the area in 2005, reaching a total of around 143km2. The continuous pressure exerted by population growth on Greater Beirut which area is 2.2% of the Lebanese territory (UN-Habitat, 2011), has caused many changes in the physical characteristics of the city.

With rapid urbanization, Beirut has experienced a significant loss of natural areas and a major hike in constructions, which is leading to an environmental degradation. Green spaces, for example, count for only 0.8m2 per capita of the city, while the World Health Organization recommends a minimum of 12m2 per capita (Stanley D. et al., 2016) .

Recently, the city has been becoming denser and deprived of green spaces. Concentration of urban pollutants has been significantly increasing at the pedestrian level within its street canyon due to its car dependency, urban morphology and land use. Despite the focus on urban climatology in many cities over the decades, there is still a lack of numerical studies on urban design and planning strategies on Beirut, which could have an implication on modifying the city's energy balance.

2.1 Gemmayzeh Neighborhood

This study focuses on Gemmayzeh, one of the rare neighbourhoods that still preserves its significant architectural heritage. A study conducted by APSAD (date to be added) identified many historical buildings in Gemmayzeh to be preserved, dated from mid of the 19th century till the beginning of the 20th century. However, the valuable natural and built environment of this neighbourhood is deteriorating due to the construction of new high-rise buildings (Mneimne, 2010).

These unrestrained developments are the result of the failure of the current zoning and building regulations to limit rapid urbanization, where it can be argued that building regulations have played a negative role in rapidly increasing this phenomenon. The high allowable exploitation factor of lots that lie in this zone allows profit maximization from densification at the expense of the urban quality. In the case of Gemmayzeh, which in zones 2 and 3, the factors of exploitation are respectively six and five, which subjects to an elevated risk of densification. This new urban morphology does not only impact on the urban character of the city, but will also lead to urban perturbations affecting the urban microclimate. It is therefore important to understand the changes in land use and their surface characteristics, including an increase in the impervious surfaces as well as a decrease in vegetation.

Several urban studies concerning Gemmayzeh have been conducted and provided qualitative recommendations on how to preserve the built heritage and cultural identity. In expanding this, the approach used in this study is methodologically quantitative and focuses on the environmental perspective. The understanding of the neighborhood's current microclimate and the assessment of its changes due to high-density developments and loss of green areas, are valuable in re-evaluating the current building and planning regulations that are dated back to many decades. As shown in Figure 4, the map based on field measurements covering Beirut City (Salhab, 2011) identifies the area of Gemmayzeh close to the Beirut port as one of areas with the highest temperature in the city.

Fig.4: Distribution of Temperature in Beirut/ Summer Season/ night time dated on July 23, 2011 (Salhab, 2011)

3. METHODOLOGY AND DATA SOURCES

The various urban parameters affecting the atmosphere and consequently the complexity of exchange processes within the environment make it difficult to study the urban microclimate. Hence, in recent years, numerical modeling methods have been developed to aid this process. As such, this study aims to generate energy balance models through the simulation of microclimate scenarios through ENVI-met software (Bruse, 2004). These will be used to assess how variations in urban geometry and urban densification can affect microclimate and the outdoor thermal comfort, as well as how green infrastructure can enhance the quality of urban space and the street thermal comfort level.

3.1 Creating An Urban Energy Balance Through Envi-Met 4

In this paper, the urban energy model is created using the latest version of 3D model ENVI-met V4.0 which has been recently developed to include new features ("Home | envimet," n.d.). This holistic microclimate modelling system is capable of simulating the surface-plant-air interactions and can assess the thermal and fluid dynamics taking place at different heights above the ground surface. The input parameters including buildings, vegetation, soil and meteorological variables are incorporated and analysed with a typical resolution of 0.5 to 10m and a maximum grid size of 250x250x30 grids. In order to calculate any climatological aspect such as temperature, relative humidity or wind speed, the software considers all these interacting elements of the complex outdoor environment, which can now be visually edited making version 4.0 much more user friendly than the previous versions. The modelling procedure can be implemented in the conceptual or detailed model. In the latter, the walls and roof materials can be specified, and it is also possible to assign materials for each façade. This improved package allows the terrain to be modelled by specifying each grid size altitude above sea level.

The model included the selected case study topography which extends from 0 m (Beirut Port Area) above sea level till 90 m above sea level (Achrafieh Hill). Moreover, horizontal cuts can follow the terrain slope and allows the generation of cuts at different heights. In addition, LEONARDO 2014; the visual interface is now part of the ENVI-met V4.0 package.

The model computes all radiation fluxes of direct, diffused and reflected solar radiation from the atmosphere and their incident at the horizontal and vertical surfaces. Hence, the Mean Radiant Temperature (MRT) is calculated considering the spectral radiation fluxes (Ali-Toudert, 2005; Emmanuel and Fernando, 2007). Moreover, ENVI-met has the capability to calculate the thermal comfort index PMV (Predicted Mean Vote) using ENVI-met Biomet, which is a post-processing tool that interrelates with simulation output and calculates the thermal comfort index that depends on the human body balance. As explained in ("apps:biomet [The Hitchhiker's

Guide to ENVI-met],” n.d.), the basic PMV equation indoor and outdoor conditions are given by:

$$PMV= [0.028+0.303.\ \exp(-0.036\ .\ M/A_{Du})]\ .\ (H/A_{Du}-Q_{Ed}-Q_{Esw}-Q_{Ere}-Q_{HA}-Q_{H}-I)$$

Meteorological variables: Air temperature Ta, Mean radiant temperature Tmrt, Vapour pressure e, Local wind speed u Personal settings human body: Clothing insulation Iclo, M: Mechanical energy production of the body, η: Mechanical work factor (0 most of the time).

H/ADu is the internal heat production per unit area is, in Wm–2, where H is the sum of the total metabolic value, and M is the mechanical energy. The energy loss by the diffusion of water vapor through the skin QEd, the evaporation of sweat QEsw, the latent QEa and the sensible heat loss QHa by respiration, the convective heat loss QH, and the longwave radiation loss I.

3.2 Experimental Setup / Input Data

The simulation was conducted first to the current situation of Gemmayzeh neighbourhood (dimensions= 960mx960m) taking the maximum allowable size to model through ENVI-met (resolution of dx=dy=4). The official weather measurements are taken from the closest weather stations to the location of the case study which is located in Achrafieh, Risk (“Achrafieh,Rizk Weather | Personal Weather Station: IBEIRUTB3 by Wunderground.com | Weather Underground,” n.d.). The finishing material of building envelope is represented in ENVI-met by the thermal conductance, U-value, and the albedo. Buildings geometry were obtained from GIS Geo databases and updated from field observation during the summer 2018 for each building including its finishing material as well as landscape materials Figure 5 shows the land use map of the neighbourhood.

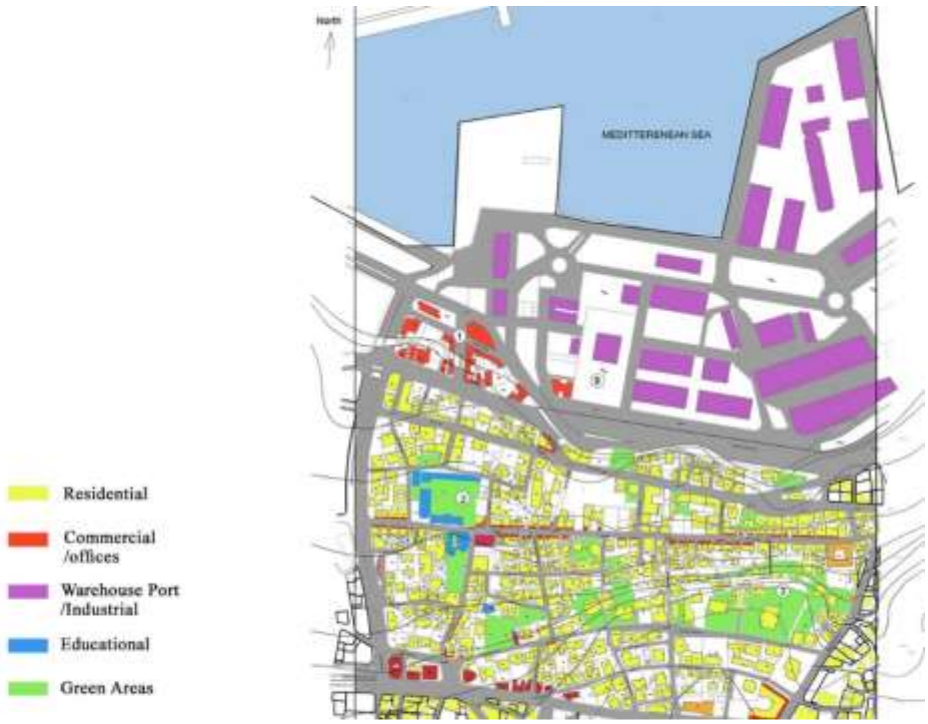


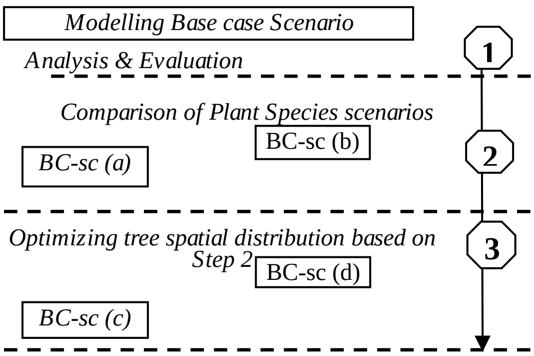
Fig.5: Land use Mapping – Gemmayzeh Neighbourhood

3.3 Simulation Scenarios

Model Parameter	Model Input Value
Location	Beirut, Lebanon, Latitude 33.53 Longitude 35.31
Climate type	Mediterranean climate characterized by a hot, dry summer
Simulation day	Typical summer day, 15 August 2018
Simulation duration	From 6:00 till 24:00 (18 h)
Spatial resolution	Grid size: 240x240x25 (x,y, and z grids) dx=4, dy=4, dz=10
Wind speed at 10 m above ground	3.0 m/s at 10m height
Wind direction	220° from North
Relative Humidity at 2m	68 %
Specific Humidity in 2500m	17g/kg
Ta	306 K 32.85°C
U values walls	For walls hollow block For roof tiles or clay
Roughness Length	0.01
Pedestrian Clo.	0.50 (1Clo=0.155 m2.K/w; i.e. Light summer cloths)

In order to simulate the surface temperature and wind flow for various scenarios in urban geometry in Gemmayzeh, the following scenarios were defined. These are defined to allow for the assessment of how green infrastructure affects the microclimate and outdoor thermal comfort, where environmental modeling is used as a tool to assess different green configurations and built densities, as well as to test mitigation strategies.

Table 2: Methodology Flow Chart



- Base Case Scenario: Current Situation
  The first scenario represents the present situation; this model enables to understand the current atmospheric conditions and to have a base case energy balance in order to compare it with various alternatives.
- Scenario a: Current Situation + Adding grass and shrubs
  In this scenario, all the empty
- Scenario b: Scenario a + optimized tree spatial distribution
  In this scenario, all the empty
- Scenario c: Scenario b + green walls and green roofs

4. RESULTS AND DISCUSSIONS

The SVF value varies between 0 and 1. ENVI-met can generate SVF by building radiation of the entire model. The SVF is approximately 1 near the port area, which indicates that no obstruction surrounding it. On the other contrary, it reaches almost null in certain points of the dense inner zone, which means complete obstruction especially due to dense trees (figure 6).

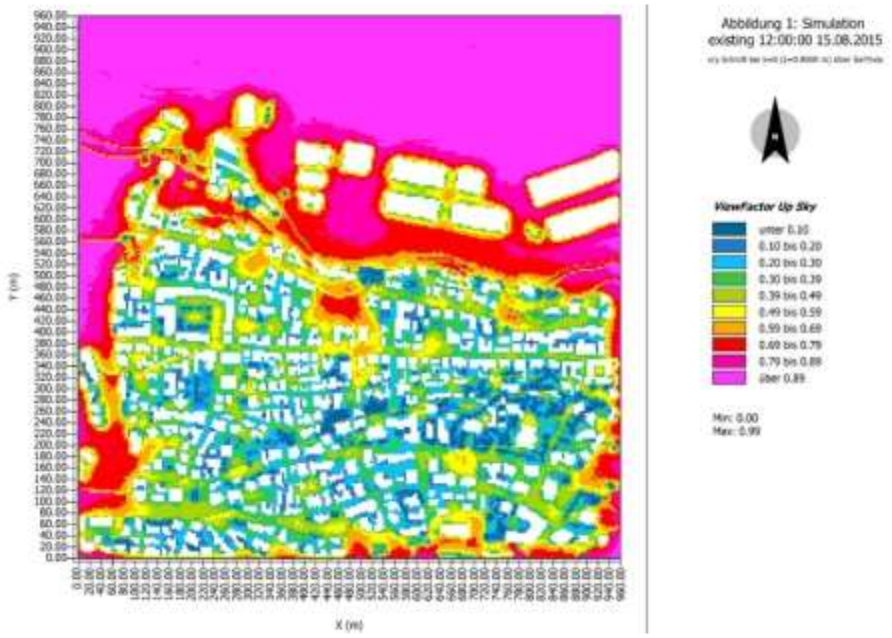


Fig.6: Sky View Factor Current Condition

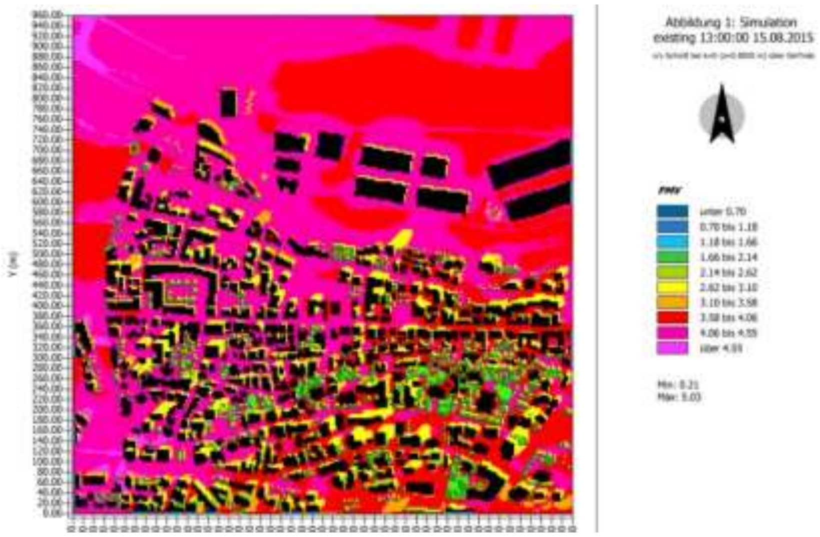


Fig.7: PMV values - Current Situation at 13:00

Figure 7 shows the PMV value of the existing condition. Evaluating a number of defined points highlights the unstable pattern of PMV variation, which depends on the receptor closeness to the urban surfaces and the physical characteristics of the surrounding buildings. The outdoor comfort level is better in the sheltered areas near trees canopies and shaded buildings.

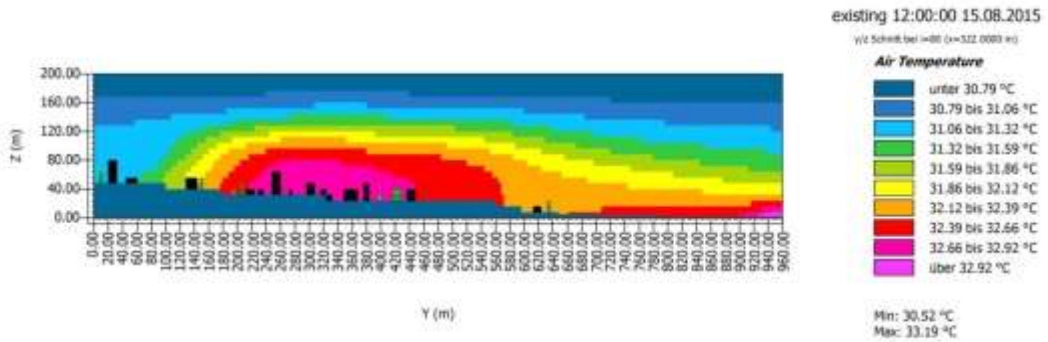


Fig.8: Transversal Section showing the topography

As we can see in the above section (figure 8), the air temperature decreases at the highest levels; it reaches its lowest at Achrafieh hill which is 60 m above sea level. Topography characteristics enhance the cooling effect of the prevailing south-west wind paths, which blows from the sea breeze by ventilating the internal urban fabric and reaches the elevated areas of Beirut's neighbourhoods.

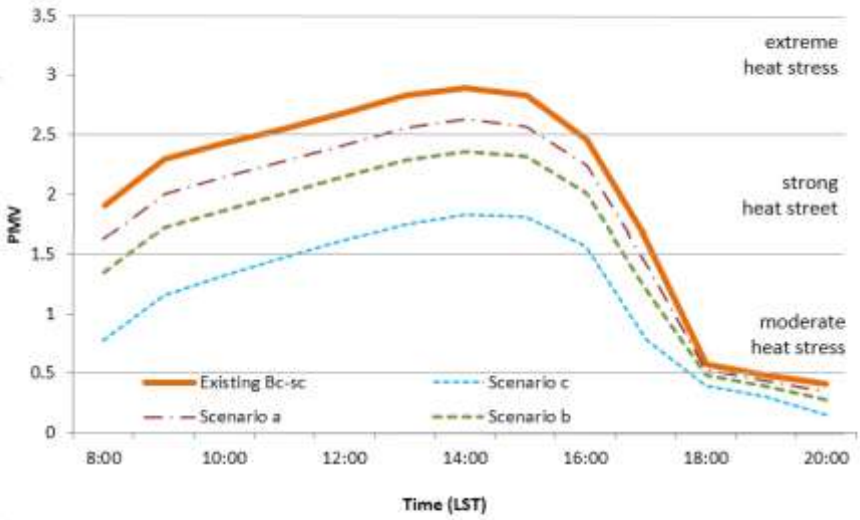


Fig.9: Current Mean Daily course of PMV values of the base case with enhanced scenarios

To evaluate the outdoor human thermal comfort, the values of the comfort index PMV were extracted from the simulated output data mainly the atmospheric output data, and derived from the defined human energy balance. The hourly values were calculated from the average of all the (240x240) grids that were traced in each domain. PMV values were evaluated according to the human thermal stresses classified by (Matzarakis et al., 1999), which varies between slight heat stress, moderate heat stress, strong heat stress and extreme heat stress in the comfortable and hot conditions.

As indicated in Figure 9, the mean PMV values for the whole domain can be observed from 08:00 until 20:00 (BCsc-Domain Mean PMV) where the warmest time of the day is at 14:00. A correlation can be identified between the existence of trees and the value of PMV. Trees canopies are effective as mitigating the outdoor discomfort between 8:00 am and 4:00 pm.

5. CONCLUSIONS

The findings reveal that incorporating green infrastructural strategy in the urban context plays a role in enhancing the outdoor air temperature and can mitigate the urban heat island. Therefore, these performance measures support the development of healthier and walkable communities. In a general sense, this study can be potentially useful for producing a framework to promote an ecological urbanism approach in the Mediterranean region. Further investigation is needed to integrate pollution dispersion in assessing mitigation measures.

Recommendations for local government and decision makers (CDR, ministry of environment, DGU, municipalities):

- Foster urban renewal initiatives at all levels, including public and private sectors, municipality, non-governmental organizations, and academia to address and define urban scale interventions for green infrastructure.
- Develop urban climatic maps for Beirut city and a database for spatial and climatic information that would be constantly updated with urban changes.
- Oblige large-scale developments to meet sustainable development policies that would be imposed and controlled by the Directorate General of Urbanism in Lebanon by approving on projects to integrate urban design guidelines, such as planting native trees and increasing green cover.

Recommendations for academics, urban designers and planners, and landscape architects:

- Increase interest in urban climate interdisciplinary studies, which are essential considering the complexities in Beirut urban context. Topics related to outdoor comfort level, pollution dispersion and wind flow field can be evaluated through urban numerical modelling simulations.
- Integrate output results of urban effects and energy balance models into numerical weather forecasting models.

Recommendation for locals:

- Actively work as citizens to promote upgrading green space areas within the city based on a bottom up planning approach.
- Contribute to enhancing the quality of the urban environment by increasing walkability.

FUTURE WORK

In the context of this research, future work will include validation of the study by applying this methodology to other case studies in Beirut. Quantifying the effect of green corridors at the city scale and measuring the magnitude of heat mitigation are also essential. Moreover, field measurements will be conducted to further evaluate the simulated output data.

REFERENCES

- Akbari, H. (2002). Shade trees reduce building energy use and CO2 emissions from power plants. *Environmental Pollution*, *116*, S119-S126.
- Ali-Toudert, F. (2005). Dependence of outdoor thermal comfort on street design in hot and dry climate. Universitätsbibliothek Freiburg. Retrieved from www.freidok.uni-freiburg.de
- Ali-Toudert, F., & Mayer, H. (2006). Numerical study on the effects of aspect ratio and orientation of an urban street canyon on outdoor thermal comfort in hot and dry climate. *Building and Environment*, 41(2), 94–108.
- Ali-Toudert, F., & Mayer, H. (2007). Effects of asymmetry, galleries, overhanging facades and vegetation on thermal comfort in urban street canyons. *Solar Energy*, 81(6), 742–754.
- Arnfield, A. J. (2003). Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. *International Journal of Climatology*, 23(1), 1–26.
- Bruse, M. (2004). ENVI-met website.Retrieved from www. Envimet. Com.
- Dimoudi, A., & Nikolopoulou, M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. *Energy and Buildings*, 35(1), 69–76.
- Emmanuel, R., & Fernando, H. J. S. (2007). Urban heat islands in humid and arid climates: role of urban form and thermal properties in Colombo, Sri Lanka and Phoenix, USA. *Climate Research*, 34(3), 241.
- Fahmy, M., Sharples, S., & Yahiya, M. (2010). LAI based trees selection for mid latitude urban developments: A microclimatic study in Cairo, Egypt. *Building and Environment*, 45(2), 345–357.
- Faour, G. (2015). Evaluating Urban Expansion Using Remotely-Sensed Data In Lebanon. *Lebanese Science Journal*, 16(1), 23.

- Gagge, A. P., Fobelets, A. P., & Berglund, L. (1986). A standard predictive index of human response to the thermal environment. ASHRAE Trans.;(United States), 92(CONF-8606125-). Retrieved fromwww.osti.gov
- Givoni, B., Noguchi, M., Saaroni, H., Pochter, O., Yaacov, Y., Feller, N., & Becker, S. (2003). Outdoor comfort research issues. *Energy and Buildings*, 35(1), 77–86.
- Grimmond, C. S. B., & Oke, T. R. (1999). Aerodynamic properties of urban areas derived from analysis of surface form. *Journal of Applied Meteorology*, 38, 1262–1292.
- Höppe, P. (1999). The physiological equivalent temperature–a universal index for the biometeorological assessment of the thermal environment. *International Journal of Biometeorology*, 43(2), 71–75.
- Matzarakis, A., Mayer, H., & Iziomon, M. G. (1999). Applications of a universal thermal index: physiological equivalent temperature. *International Journal of Biometeorology*, 43(2), 76–84.
- Mayer, H. (1993). Urban bioclimatology. Experientia, 49(11), 957–963.
- Mayer, H., & Höppe, P. (1987). Thermal comfort of man in different urban environments. *Theoretical and Applied Climatology*, 38(1), 43–49.
- Mohsen, H. (2016). PHD Thesis Optimizing Beirut Urban Neighbourhood through green Infrastructure- A 3 D Urban Modelling Approach - Beirut Arab University
- Mneimne, I. H. (2010). Grounding heritage in locality an urban design intervention for Gemmayzeh’s neighborhood ecological landscapes-by Ibrahim Hassan Mneimne. Retrieved from www.scholarworks.aub.edu.lb
- Nakamura, Y., & Oke, T. R. (1988). Wind, temperature and stability conditions in an east-west oriented urban canyon. *Atmospheric Environment*, 22(12), 2691–2700.
- Nikolopoulou, M., Baker, N., & Steemers, K. (2001). Thermal comfort in outdoor urban spaces: understanding the human parameter. *Solar Energy*, 70(3), 227–235.
- Nikolopoulou, M., & Lykoudis, S. (2006). Thermal comfort in outdoor urban spaces: analysis across different European countries. *Building and Environment*, 41(11), 1455–1470.
- Oke, T. R. (1988). B*oundary Layer Climates* (2 edition). London: Routledge.
- Pearlmutter, D., Bitan, A., & Berliner, P. (1999). Microclimatic analysis of ‘compact’ urban canyons in an arid zone. A*tmospheric Environment*, 33(24), 4143–4150.
- Rosheidat, A. (2014). Optimizing the effect of vegetation for pedestrian thermal comfort and urban heat island mitigation in a hot arid urban environment. Arizona State University. Retrieved from www.repository.asu.edu
- Rizk, A. (2018). Weather | Personal Weather Station: IBEIRUTB3 by Wunderground.com | Weather Underground. (n.d.). Retrieved 4 October 2018, from www.wunderground.com
- Santamouris, M. (2014). Cooling the cities–a review of reflective and green roof mitigation technologies to fight heat island and improve comfort in urban environments. *Solar Energy*, 103, 682–703.
- Santamouris, M., Papanikolaou, N., Koronakis, I., Livada, I., & Asimakopoulos, D. (1999). Thermal and air flow characteristics in a deep pedestrian canyon under hot weather conditions. *Atmospheric Environment*, 33(27), 4503–4521.
- Shashua-Bar, L., Tsiros, I. X., & Hoffman, M. (2012). Passive cooling design options to ameliorate thermal comfort in urban streets of a Mediterranean climate (Athens) under hot summer conditions. *Building and Environment*, 57, 110–119.
- Spagnolo, J., & De Dear, R. (2003). A field study of thermal comfort in outdoor and semi-outdoor environments in subtropical Sydney Australia. *Building and Environment*, 38(5), 721–738.
- Stathopoulos, T. (2006). Pedestrian level winds and outdoor human comfort. *Journal of Wind Engineering and Industrial Aerodynamics*, 94(11), 769–780.
- Taha, H. (1996). Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. *Atmospheric Environment*, 30(20), 3423–3430.
- Thorsson, S., Lindqvist, M., & Lindqvist, S. (2004). Thermal bioclimatic conditions and patterns of behaviour in an urban park in Göteborg, Sweden. I*nternational Journal of Biometeorology*, 48(3), 149–156.

- UN-Habitat, 2011. Lebanon Urban Profile: A Desk Review Report.
- apps:biomet [The Hitchhiker's Guide to ENVI-met]. (n.d.). Retrieved 4 October 2015, from www.model.envi-met.com
- Home | envimet. (n.d.). Retrieved 4 October 2015, from www.envi-met.com/