THE BIOCLIMATIC-ZONES CONCEPT: LANDSCAPE DESIGN STRATEGY FOR SITE PLANNING IN HOT ARID CLIMATES

Shady Attia.[1*]

Keywords: *bioclimatic landscape design, bioclimatic zones concept, site planning, hot arid*

Abstract

One of the primary objectives of landscape architecture in hot areas is to improve the micro-climate passively by modifying the extremes of particular environmental conditions through increasing or decreasing the effect of prevailing conditions. In hot arid climates, we wish to make the outdoor environment cooler, breezier and more humid. This happens through planting vegetation as different design elements, e.g. shelterbelts, wind barriers, wind filter or water elements.

This paper attempts to endorse the Bioclimatic-Zones Concept, as a passive landscape design strategy for site planning, in hot arid climates. In essence, we are attempting to create bioclimatic zones. Each zone should specifically fulfill certain desired climatic improvements through a group of design decisions. This happens through the intensive or extensive use of plants materials and water elements. Helwan University Campus was employed as a case study to assess and verify this design strategy. Some methodologies such as field measurements and computer simulations (ENVI-MET) were employed. This paper presents the more interesting result and explains why this concept was successful and how the Bioclimatic-Zones Concept improved the micro-climate.

1. Introduction

1.1 Background

Many people's activities take place in bordered outdoor spaces. The duration and intensity of the use of an outdoor space is greatly affected by the comfort or discomfort conditions already existing in the area. Therefore, minimizing the duration and level of uncomfortable conditions can greatly increase the benefits derived from the outdoor space. Therefore landscape designers and planners should be prepared with a tangible design strategy for site planning based on design guidelines that can improve the micro-climate and also conserve energy (O'Reilly, 1996).

1.2 Introduction to the Concept

The Bioclimatic-Zones Concept is a primary part of designing and site planning in hot arid climates. The objective of this concept is to classify bioclimatic zones through landscape elements, such as vegetation, water bodies and light structures. In order to achieve an improvement in the micro-climate of the outdoor spaces, a strategy needs to be applied. The Bioclimatic-Zones Concept is based on creating a set of zones; each zone is linked to a group of landscape- design decisions that should specifically fulfill a desired climatic improvement. The Bioclimatic-Zones Concept is a landscape-design strategy that forms a backbone for the site planning. The effects of vegetation and water elements in each zone should be expected in advance. For landscape zones, the author's attitude aims to create relative magnitudes of differences between plant associations and their climatic impact. In the Bioclimatic-Zone Concept, the vegetation types and water bodies are looked at in terms of actual climatic variables.

The bioclimatic zones are mainly classified and characterized by different types and percentages of vegetation. Water bodies are also considered. Each zone is defined by detailed climatic conditions for each zone. This information is especially valuable for the present study, in which one wants to evaluate the effects of vegetation zones on the thermal environment.

[1] Université Catholique de Louvain, Architecture et Climat, [*] shady.attia@uclouvain.be
On sabbatical leave from the Faculty of Fine Arts in Cairo, Helwan University, Egypt

1.3 Objective

The aim of the present study is a conceptualization of bioclimatic zones that functions as a passive design strategy. For site planning, climate, soil and hydrology and many similar aspects have to be taken into account that should be balanced in terms of efficient landscape-design. Issues of climatic protection, thermal comfort and energy conservation stand as vital requirements in hot arid climates. This Bioclimatic-Zones Concept is based on the need for an integral concept to design outdoor places placing the human being in the center of attention.

The expected climatic impact of each design decision can be quantified through field measurements after the implementation. Computer simulation software can help in predicting some scenarios of different conditions. The parameter are wind speed, amount of heat absorbed and dry bulb temperature, in addition to a shading-pattern study, deciduous trees and sheds, reducing of buildings cooling loads screens and landscape elements.

2. ESTABLISHING THE BIOCLIMATIC-ZONES

The Bioclimatic-Zone for hot arid areas identifies broad climatic zones defined primarily on solar radiation, wind airflows and evaporation. These zones correspond with potential, but not necessarily existing, vegetation boundaries. Both the type and location of plant material can have a substantial effect on micro-climate (Jusuf, 2006). The use of arid plants has been emphasized for its ability to withstand extended periods of drought. The location of plant material in relation to structures and other site elements can have an equally important influence on plant-climate relations. Plants in an exposed, windy location will require many times more water than plants located in protected areas, such as under overhangs or behind walls. It is important therefore, to identify the micro-climate or “Bioclimatic-Zones” for various plant types that might be chosen for any site. In this concept, seven climatic zones are determined. Each zone is linked to a landscape-design strategy. Figure 1 is an abstract representation for the Bioclimatic-Zones Concept.

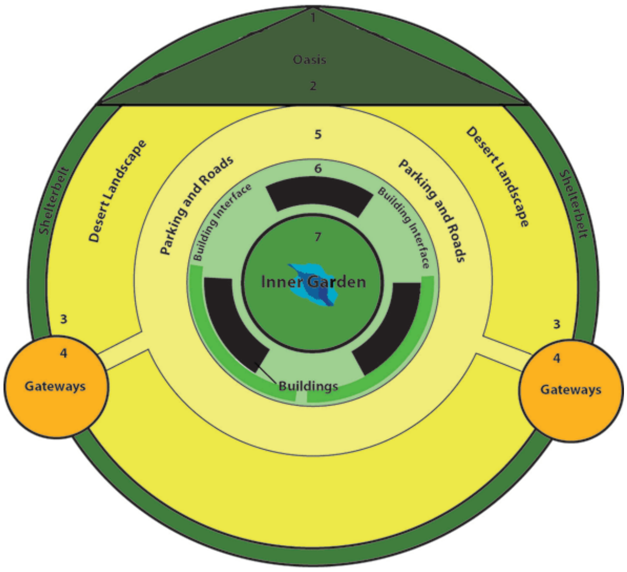


Fig 1 Bioclimatic-Zones Concept illustration for the Northern hemisphere assuming N-S prevailing wind

Based on the cause-and-effect relations of climate and landscape-design elements, a thorough analysis have been made to define and locate vegetation, water bodies and other landscape design elements for each bioclimatic zone (Olgyay, 1963). The success of each zone should be verified through measuring the climatic impact for every design decision. Table 1 was developed based on Givoni’s classification for the climatic parameters that influence thermal comfort in outdoor areas in hot arid areas as listed below (Givoni, 1992, Givoni, 1991).

1. Solar radiation (radiation control, heat control, albedo control and glare control)

2. Wind airflows (dust control, soil erosion control and natural ventilative cooling)

3. Evaporation (evaporative cooling and diurnal cooling)

Therefore, the Bioclimatic-Zone concept is vital in site planning during the conceptual phase. The landscape-design decisions for the site planning are interrelated between the expected climatic impact and landscape design elements including vegetation. Each of the listed zones was first examined extensively and intensively on the site scale. The Bioclimatic-Zones Concept is based on the design inventory and analysis phase, followed by the generation of alternatives based on the potential bioclimatic zoning in the site. The listed climatic impacts for each zone, in table 1, help designers to identify areas most suitable for the establishment of each bioclimatic zone. During the process of site planning, designers have to find areas of suitability. The areas of suitability are used in the final determination of the bioclimatic composite. Next, we will find seven zones that correspond to this concept.

Therefore, the Bioclimatic-Zone concept is vital in site planning during the conceptual phase. The landscape-design decisions for the site planning are interrelated between the expected climatic impact and landscape design elements including vegetation. Each of the listed zones was first examined extensively and

intensively on the site scale. The Bioclimatic-Zones Concept is based on the design inventory and analysis phase, followed by the generation of alternatives based on the potential bioclimatic zoning in the site. The listed climatic impacts for each zone in table 1 help designers to identify areas most suitable for the establishment of each bioclimatic zone. During the process of site planning, designers have to find areas of suitability. The areas of suitability are used in the final determination of the bioclimatic composite. Next, we will find seven zones that correspond to this concept.

Table 1: Bioclimatic-Zones Concept: Decisions and impacts matrix

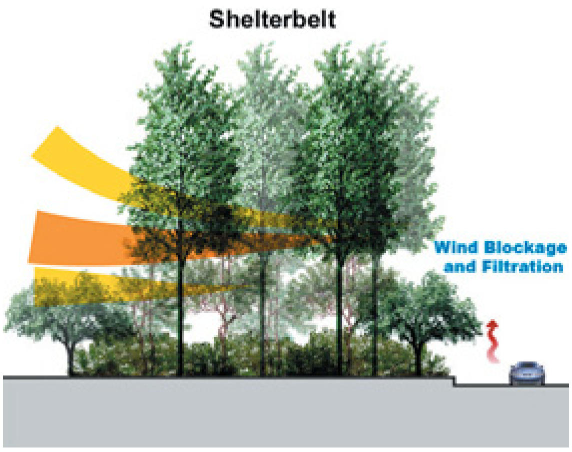
Zone Name		Climatic Impact	Landscape Design	Verification
1.Shelterbelt		Wind, Sand Storm Protection	High Barrier Trees Mulching & Soil Stabilization	Less Wind Speed Cleaner Air (Dust)
2. Oasis		Air Filtering Lower Temp. Better Comfort	Palm Groves Shading Ground Cover	Higher Air Speed Lower Ambient Temp. Lower Dry Bulb Temp.
3. Desert landscape		Drought Tolerant Vegetation Soft Barrier	Boundary Layer Xeriscape Desert Conditions	Less Wind Speed Cleaner Air (Dust)
4. Gateways & Entries		Reduce Solar Radiation Better Comfort	Water Surfaces Vegetation	Lower Temp. Lower Relative Humidity
5.Parking and Roads		Minimize Solar Intensity	Shading	Less Direct Solar Radiation
6. Building / Landscape Interface		Reduce Direct Radiation Reduce Indirect Radiation	Deciduous Columnar trees Green Roof Green Ground Cover	Less Direct Solar Radiation Lower Ambient Temp. Lower Dry Bulb Temp.
7. Inner Garden		Cool Reservoir Promote North Wind Lower Temp. Reduce Solar Radiation Better Comfort	Green Ground Cover Shading, Canopy of trees Water Surfaces	Less Direct Solar Radiation Lower Ambient Temp. Lower Dry Bulb Temp. Higher Air Speed Cleaner Air

Zone 1: Shelterbelt

The edge of the property, often the most exposed, typically represent the most arid zone on the site. Because this zone is usually a low use area, it should be planned accordingly as a low maintenance area. Climatically, the Shelterbelt Zone lends itself well to large-scale trees and shrubs that serve either as a buffer to activities on adjacent sites or to reduce wind velocity. One of the primary functions of the shelterbelt is to create protected leeward side areas and protect the site from encroaching dunes. This Zone should be planted with the most drought tolerant plants forming narrow shelterbelt that allows the wind to reduce its speed but still flows over (Miller, 1980). See figure 2a.

Zone 2: Oasis

In ancient times, people survived desert storms by hiding in oasis. The dense grid of palm trees provided a kind of protection by influencing the micro-climate. Palm oases are most probably famous for standing the extremes of temperature, tolerating alkaline soils and salt, resist drought and lifting up the wind. The climatic definition of the desert 'oasis effect' refers to the cooling effect cause by vegetation and water (Givoni, 1991, Kai, 1997). In this study the Oasis Zone is aiming to create a lee that funnels the wind up and faces sand storms as shown in figure 2b. Growing an oasis will prevent desertification and fight sandstorms besides reducing temperature, direct radiation and moderation of wind velocity (Potcher, 2008). Another major significant role of the Oasis Zone is dust control. In general, plants prevent sand and dust from being carried away by the wind because of the difference of the land-surface characteristics such as particle size distribution, plant vegetation and surface soil moisture content and so on (Rizvi, 2006).



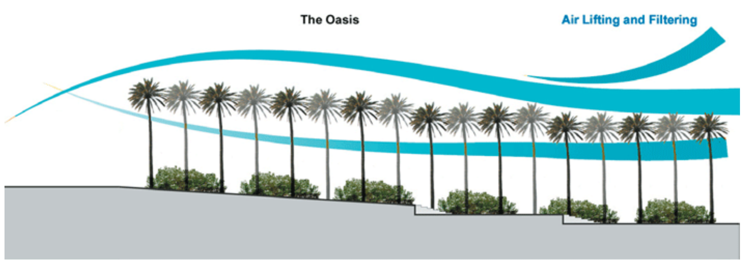


Figure 2.a. Section in the Shelterbelt Zone, *b. Section in the Oasis Zone*

Zone 3: Desert Landscape

The desert landscape is also part of the Bioclimatic-Zones Concept. Designing this zone aims to stabilize the soil and offers a soft barrier. Succulent and drought tolerant are planted to create a boundary layer. Less sand movement creates more favorable environment for plants such as salt bush and indigenous grasses that can germinate in the created zone (Abohassan, 1978).

Zone 4: Gateways and Entries

Entries and gateways create critical gaps in site planning. They require to be especially treated as separate bioclimatic zones. Since gaps within a shelterbelt reduce its effectiveness. Gaps can result in an increase in wind speed due to the wind accelerating as it funnels through the gap within the shelterbelt. This effect is often called wind tunneling. Therefore, the location of entries and gateways needs to be determined based on climatic background. A solution for such gaps could be a design for small strips of shelter in front of the gap or creating an angled gap that can overcome this problem (Robinette, 1983).

Zone 5: Parking and Roads

The level of use of the Parking and Roads Zone, a transitional zone, is moderate. Here we find roads for pedestrians and vehicles in addition to parking areas. Zone 5 is in charge of creating a safe and comfortable environment for pedestrians and vehicles. Landscape-design should provide comfortable and shaded pedestrian and bicycle paths. Trees should be planted in regimen for ease and efficiency of water use, canopy production and shade delivery. Also the earth should be shaped to block undesirable solar radiation and winds. Effects are most useful within five times the height of berm away from windbreak (Robinette, 1983).

Significant areas of sites are typically devoted to the parking of automobiles. The current provision of large areas of impervious asphalt or concrete leads to elevated surface temperatures during the summer and heat island effect. Preferably, parking should be located under planted roofs. Otherwise, parking lots should be broken into many small bays, small bays, parking pockets and planted with canopy trees and/or shade structures. Perimeter berming and planting enhance human comfort and thermal performance in these areas. Also soil-bioflitration should be considered through permeable pavement. Generally, low-maintenance deciduous trees in parking lots require little water, they can take the heat, and they do not lose their leaves. See figure 3a.

Zone 6: Building Interface

The Building Interface Zone is very important because it has a direct impact on thermal comfort and energy conservation in and around buildings. This zone includes elements such as screens, light structures, rooftop greening, grass and canopy trees. Robinette and many others pointed to locating vertical shade screens on the most solar exposed facades of the buildings to impede solar heat gain (Robinette, 1983). Also shades and isolative dead air areas can reduce the delivered energy to cool the spaces behind these facades. Vegetation can satisfy the need of glare reduction as long as reduced thermal gains on buildings. Akbari proofed that urban vegetation reduces the energy needed for indoor climate control (Akbari, 1997). Cool air reservoirs around buildings, such as fountains and pools of water, have a great cooling effect and can reduce the harshness of the micro-climate. Trellis, pergolas, ramadas, tents, canopies, car ports and other elements are also an essential design element for the Building Interface Zone. In general, large paved areas should be broken up with shaded areas or with zones of vegetation and ground cover (Reynolds, 2002). Excessive large areas of paving should be located on the leeward side of structure so that any heat build-up will be blown away from buildings. Planting roof gardens will minimize solar impacts on buildings and improve the surrounding micro-climate. Habitable roofs can also be used in conjunction with vegetated ones (Attia, 2006). See figure 3b.

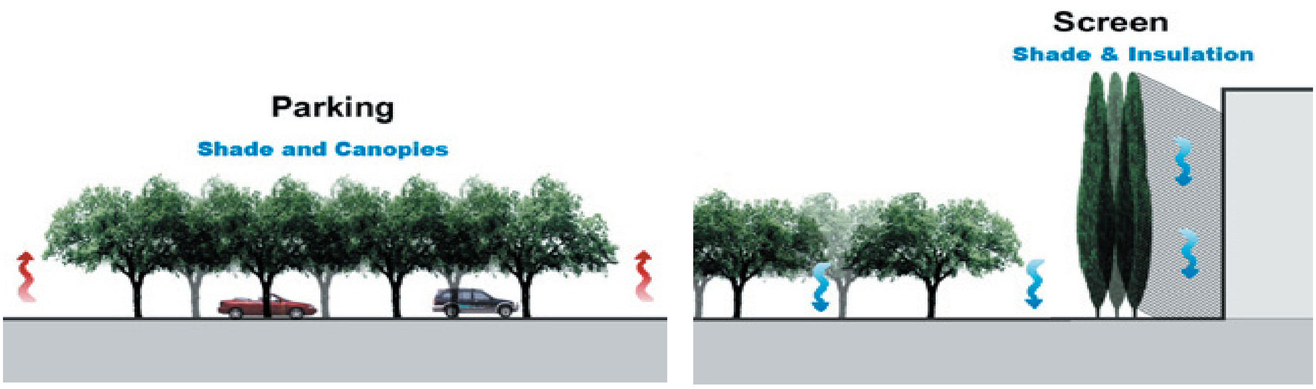


Figure 3.a. Section in the Parking and Roads Zone *b.Section in the Building Interface Zone*

Zone 7: Inner Gardens and Courtyards

Zone 7 affords the most protection from wind and sun. Structural overhangs, walls shade trees, fences, pergolas, and atriums provide an environment more suitable for high-water consumption vegetation than either Zone 1 or 5. If tender exotics are planted, this is the zone where they are most likely to survive. The level of use and the visual interest of zone 7 are high. Accordingly, the exotics, potted plants, and annuals suitable for this zone will capture the attention and provide impetus for the maintenance is generally easier due to the proximity to utilities. Despite the scarcity of water and difficulty of providing large water pools to increase humidity and create air current, elements such as fountains, cascades or spray at least on a seasonal basis.

The last zone of the Bioclimatic-Zones Concept, shown in figure 6, seeks to create relatively cool enclosed air reservoir through intensive landscape (canopy trees and water elements) in contrast to an open hot extensively planted area.

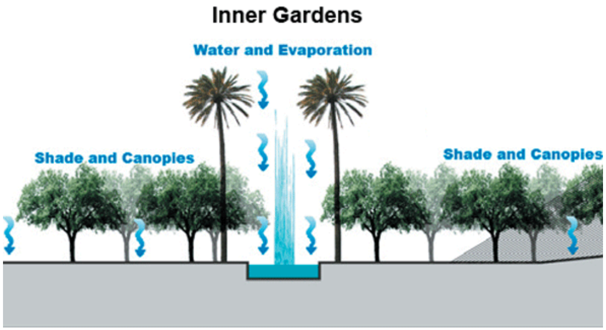


Figure 4. Inner Gardens landscape

3. Case Study: Helwan University

3.1 Introduction

Helwan University Campus is 30 km south of Cairo on a plateau enclosed on the southwest and southeast by steep El Mokattam limestone hills and lying some 50m above the Valley of the Nile, 3km away. Since its establishment in 1975, Helwan University is considered to be under construction. The campus covers an area of 147 hectares and comprises 18 colleges as well as 50 research centers and productive units while many open spaces are left empty. It has a warm, dry desert climate with more than 330 days of sunshine per year. The SOM office was involved in the design of the Master Plan during the seventies; however, many buildings were designed and constructed later by local architects without maintaining a certain Landscape Master Plan. The existing landscape at the campus is a group of scattered patches that were designed by the commissioned architects during the process of designing the different buildings. See figure 5.a.

3.2 Comparing Two Scenarios

The study verifies the Bioclimatic-Zones Concept through two scenarios for the same site. The first scenario will keep the existing site without any change. The second scenario will adapt the Bioclimatic-Zones Concept all over the site. It is important to mention that applying the Bioclimatic-Zones Concept in this case is more difficult because the site already includes several buildings and landscape patches. However, a landscape amalgamation will occur in the site respecting the physical built environment. Finally, the estimated changes in micro-climate, for both scenarios, will be compared through simulations and field measurements.

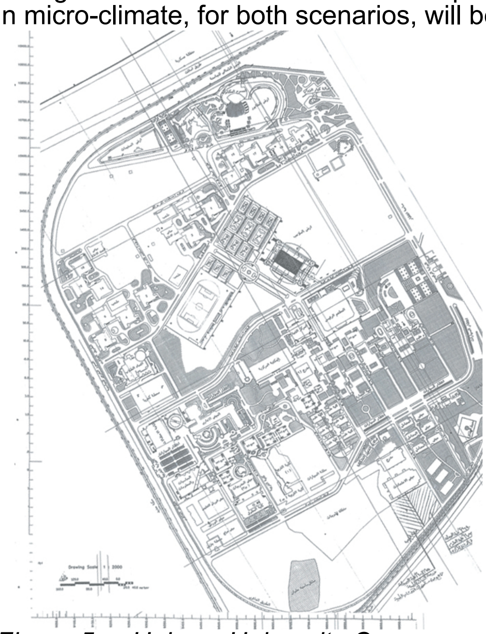


Figure 5.a. Helwan University Campus, b. Measurement locations

3.3 Field Measurements

Two instruments measuring temperature, humidity and air speed (operating range -50o to +700 C, 0.44 to 67 MPH and RH accuracy ±5.4%) were used in this study. Measurements were taken at intervals of every 30 minutes on a height of 1.5 m from the floor. The field measurements were taken on hot days from 16th – 20th July 2007. The measurements were deployed in four areas with respect to their different shading and greenery distribution conditions. The four measurements were selected to represent four bioclimatic zones as shown in figure 5.b.

As shown in figure 6, measurements prove that there are differences in temperature, humidity and air speed among the estimated zones.

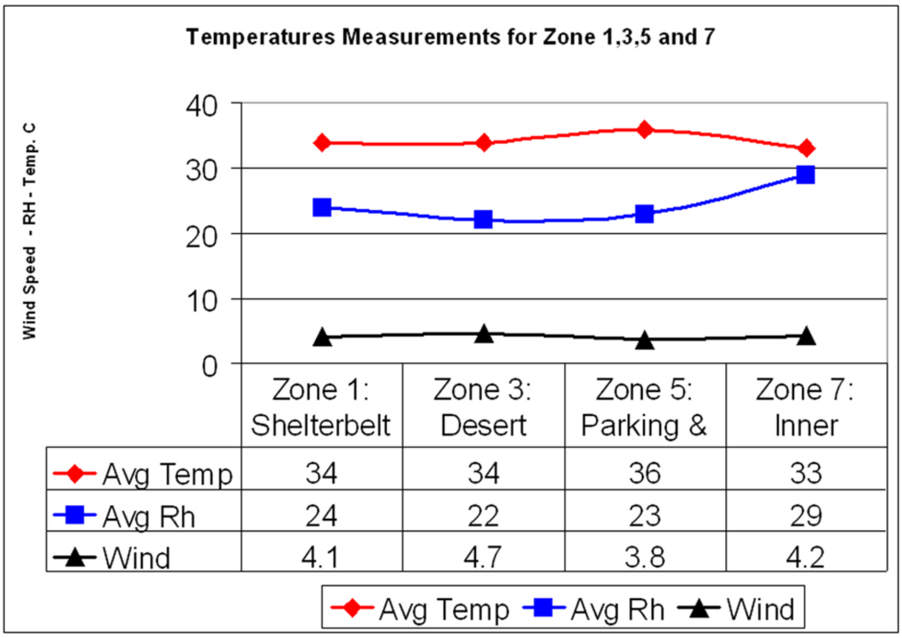


Figure 6: Measurements of four different zones

3.4 ENVI-MET simulation

ENVI-Met is a three-dimensional non-hydrostatic urban climate model. It provides detailed environmental conditions, for instance, air temperature and humidity, for each landscape patch within each square within a grid system (Bruse, 2004). This information is especially valuable for the present study, in which one wants to evaluate the effects of vegetation in each Bioclimatic-Zone on thermal environment of the various locations of the Campus. The model input parameters used are shown in table 2. Several simulations were produced for this case, including different types of vegetation covers and various atmospheric background conditions. Simulations are briefly summarized in the findings and discussion.

Table 2: ENVI-MET models' input

Location	Climatic Impact
Location	N29.51 deg., E31.18 deg.
Date, time of simulation	16-20 July; 1400 hours
Initial wind	3.0 m/s at 10m from 315 deg
Boundary	Temperature= 312K Specific humidity = 4.6g/Kg
Grid size	00x00x00 grid spacing, 2m; Z grid spacing, 2m
Plants	Trees in parking lots: 20m high, dense foliage, deciduous Street trees: 10m high, distinct crown, 9m wide
Surfaces/soil profiles	Asphalt road profile: asphalt to 60 cm, loam to 2m
Soil initial condition	Temperature = 309K

4. Findings and Results

Simulations are reported here, and relevant results obtained from simulations. Figure 7 shows temperature profiles throughout Helwan University Campus environment at 14.00. In condition a-daytime, the areas are hot as indicated by yellow and red color representation. In contrast, case b-daytime has a higher presence of dense green areas. The Bioclimatic-Zones Concept, clearly contribute to low ambient temperatures. The same effect can be illustrated by blue and green color during night.

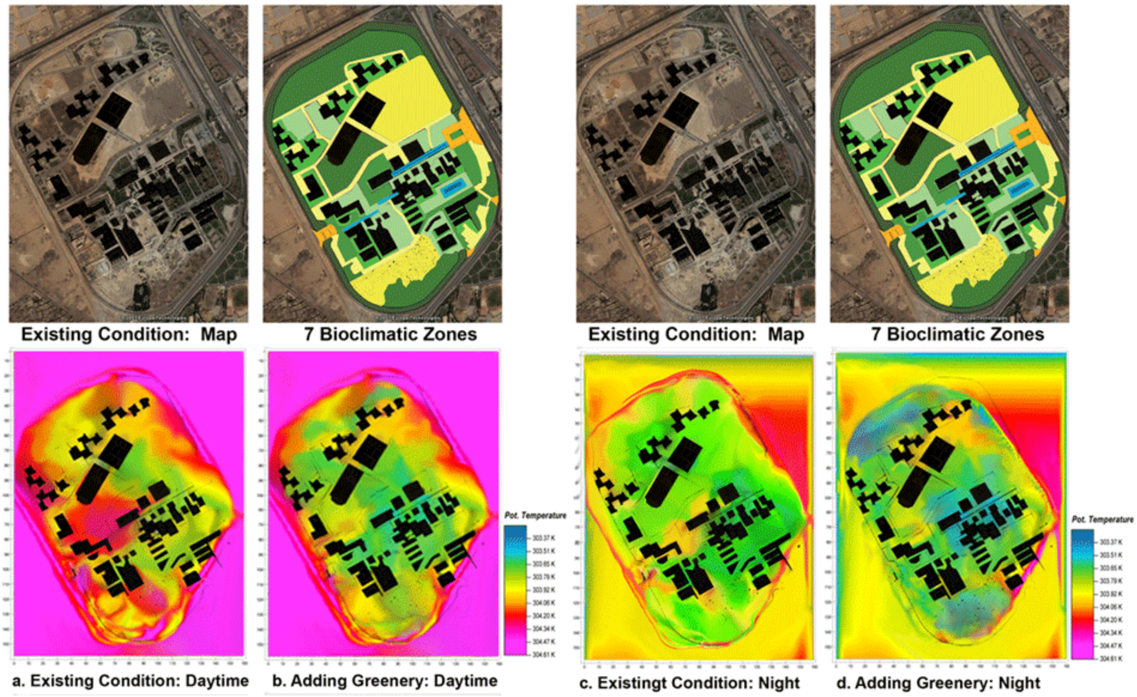


Figure 7: Temperatures comparison (existing condition map – source: Google Earth)

5. Discussion

The Bioclimatic-Zones Concept can help landscape designers to handle several various guidelines. The Bioclimatic-Zones Concept is a passive landscape-design strategy that provides designers with a framework for site planning in hot arid climates. In the field of passive landscape-design, there is much research that is concerned with technical and science based knowledge. However, there is a lack of clear and tangible design strategies that guide the designer in establishing passively planned sites that can improve the micro-climate.

Therefore, the author provides designers with a valid strategy that can lead to micro-climate improvement and energy conservation. The Bioclimatic- Zones Concept presents a road-map for landscape designers to take the guidelines into account creatively and use them on a bioclimatic solid and classified basis. The concept embraces local parameters for outdoor spaces such as wind speed, temperatures, humidity etc.... To achieve the human comfort in outdoor spaces the Bioclimatic Zones Concept was verified through measurements and simulations using ENVI-Met. The simulation showed encouraging results and demonstrated the potential use of such a model to investigate in detail the possible impacts of the Bioclimatic-Zones Concept in hot arid areas, and to help planning the landscape design elements to improve the micro-climate in outdoor areas.

This concept might not always function through the year and most importantly, it functions only in combination with buildings and solid masses. However, the presented study does not deny other design guidelines for site planning in hot arid climates. There are several other guidelines that need to be addressed and considered for site planning such as integrating existing vegetation, topography, waterways and wadis, in addition in integrating the potentials of existing soil. The presented Bioclimatic-Zones Concept should be considered as a landscape-design strategy that crowns the previously mentioned guidelines for site planning.

More importantly, the reclamation of the site under this concept requires a deliberate water efficient irrigation and adequate plant selection. It is fundamental, to think comprehensively and acknowledge the necessity to preserve water resources. Drought-tolerant vegetation must be chosen for landscapes over high water-demanding exotic species.

In summary, proper design and evaluation measures of environmental factors in the planning phase of sites in hot arid climates can achieve considerable environmental and energetic benefits to occupants and operators of outdoor environment.

6. Conclusion

This study presents a theoretical concept that helps landscape designers and site planners to design in hot arid climates based on the classified bioclimatic zones. The concept has a great value, although its utility needs to be empirically tested and verified. The simulations presented in this paper emphasize the important role of landscape-design on micro-climate in site planning, since vegetation can substantially affect the wind, temperature, moisture and precipitation regime in site planning. This concept has very important practical consequences for example heating and cooling requirements of buildings and dispersion. Observation and field measurements were used to compare some of the model results. Even though only approximate atmospheric conditions and land-surface characteristics were used to initialize the model, it appears that the basic structure air temperature and humidity and wind convergence were simulated correctly. These encouraging results demonstrate the potential use of such a concept to investigate in detail the possible impacts of vegetation in campus and to help planning the development of vegetation and water bodies. Then next step will be the commencement of a detailed empirical study.

7. References

Abohassan, A. and Rudolph, V. (1978) "Afforestation for sand dune stabilization in Al Hassa Oasis, Saudi Arabia". In: Proceedings of First international rangeland congress, Vol. 11.

Akbari, H., Kurn, D., Taha, T., Bretz, S. and Handford, J. (1997) "Peak power and cooling energy savings of shade trees", *Energy and Building*, 25, 139-148.

Attia, S. (2006) "The role of landscape design in improving the micro-climate in traditional courtyard buildings in hot arid climates, ". In: Proceedings of PLEA

Bruse, M. (2004) ENVI-met 3.0: Updated Model Overview Vol. 2008.

Givoni, B. (1991) "Impact of planted areas on urban environmental quality: a review", *Atmospheric Environment*, 25B 289–299.

Givoni, B. (1992) "Comfort, climate anlysis and building design guidelines", *Energy and Buildings*, 18, 11-23.

Jusuf, S., Hien, W., Negara, T. and Xucha, W. (2006) "Study in Effect of Greenery in Campus Area". In: Proceedings of PLEA Conference Proceedings, .

Kai, K., Matsuda, M. and Sato, R. (1997) "Oasis effect observed at the Zhangye Oasis in Hexi Corridor, China", *Journal of Meteorological Society of Japan*, 75 1171–1178.

Miller, J. (1980) *Landscape architecture for arid zones, desert housing,* Arizona Arizona University.

O'reilly, W. (1996) Sustainable Landscape Design in Arid Climates, Geneva, Aga Khan Trust for Culture.

Olgyay, V. (1963) *Design With Climate: Bioclimatic Approach to Architectural Regionalism,* New York, John Wiley & Sons Inc.

Potcher, O., Goldman, D., Kadish, D. and Illuz, D. (2008) "The oasis effect in an extremely hot and arid climate: The case of southern Israel", *Journal of Arid Environments*, 72, 1721-1733.

Reynolds, J. (2002) *Courtyards : aesthetic, social, and thermal delight. ,* New York John Wiley.

Rizvi, A. (2006) "Planning Responses to Aeolian Hazards in Arid Regions". In: Proceedings of Architecture and Planning Vol. 1, pp. pp. 59-74.

Robinette, G. (1983) *Landscape Planning for energy conservation,* New York, Van Nostrand Reinhold.

8. Acknowledgements

The author expresses his thanks for Eng. Hesham Youssry for his assistance in conducting the field survey. Also the author extends his gratitude for the valuable advising of Dr. Ingrid Duchart and the Landscape Chairgroup at Wageningen University.