# 491: Microclimate and Urban Form in Dubai

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## Abstract

This paper presents the results of measurements taken in Dubai in July 2007, during the hottest period of the year. The measurements help explain how the built forms of the 'Old' Dubai (the Deira and Bastakia areas) and of the 'New' Dubai (the Dubai Marina area) respectively modulate the urban microclimate. Observations and measurements from this fieldwork also helped calibrate a microclimatic model that was then run simulating a number of variants. Results are reported in the paper. The preliminary findings from this work provide the basis for preliminary recommendations for urban design in this city.

Keywords: Hot-climate, Urban Microclimate, Built Form, Water and Vegetation

## 1. Introduction

Started as a small fisherman's village some 200 years ago, Dubai is currently one of the two largest construction sites in the world. Up to 1956, when the city's first concrete building was built, a large proportion of its population was nomadic and lived in temporary houses made of palm leaves or coral dug from the Arabian Sea [1]. Since 1971 Dubai had developed as an important port for the oil industry, and more recently as a centre of service industry and tourism. There are plans for rapid increase in population by attracting foreign nationals and developing into a world class city. Today most of the building work in Dubai is being undertaken by overseas firms and has a global character that ignores local climate and tradition. These characteristics have a profound effect on the use of energy in buildings, on outdoor thermal comfort and urban air quality.

Urban microclimates are characterised by environmental conditions that are distinct from those of the surrounding rural and suburban areas. Although urban areas can be warmer than their surroundings owing to the concentration of anthropogenic heat sources and the high absorption of solar radiation, they may equally be cooler at times owing to the geometry and material properties of the built form [2]. A conceptual model of microclimatic modification processes is shown in Fig.1. The main tools by which designers and city planners can influence these processes are: the geometry and materiality of the built form, vegetation and water, as well as strategies for limiting the generation and impact of anthropogenic heat.

As part of a collaborative research project, two study trips were undertaken in the area providing opportunities for short-term observations and measurements that were then followed by analytic work and design studies [3] [4]. This paper summarises the findings of fieldwork undertaken in the course of the second trip in outdoor and semi-outdoor spaces in the Bastakia and Deira areas of the old town of Dubai and in the city's new Marina area along the coast. The measurements were undertaken in the month of July in order to study conditions in the hottest period of the year. The conclusions from the measurements formed the starting point for modelling using the ENVI-met microclimate simulation model [5]. A series of simulations were performed to investigate the respective microclimatic effects of built form, vegetation and water in the urban environment.

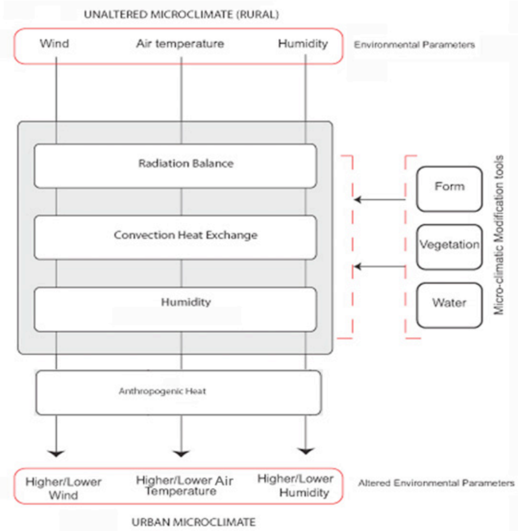


*Fig.1 Climate Modification Process*

## 2 Context

### 2.1 Climate

Dubai (25.14°N, 55.17°E) is built on a stretch of land close to the Southern end of the Gulf. Based on weather data obtained from the Meteonorm database [6] the annual cycle can be divided into three distinct periods: a four-month period of mild weather (December to March inclusive) characterised by daily mean outdoor air temperatures of 20-23°C; a warm period (November and April) with average temperatures of 25-26°C, and a hot period of six months (May to October inclusive) with mean daily temperatures of 29-34°C [3]. The first two periods lend themselves well to passive techniques and outdoor spaces can be pleasantly comfortable if well shaded and exposed to the breeze coming from the Gulf. The hot period is more of a challenge. The high temperatures are exacerbated by high incidence of solar radiation as well as high levels of absolute humidity at certain times of the day. The potential for evaporative cooling is good for parts of the year but is quite limited at the peak of the hot period. However, there is good potential for nocturnal radiative cooling throughout the year and the mean wind velocities exceeding 4.0m/s can help provide relief in outdoor spaces.

### 2.2 Microclimatic Effects of Built Form

The built forms encountered in Dubai can be broadly divided into three types: high rise towers, mid-rise blocks and low-rise compact courtyard forms. Each of these affects the urban microclimate differently. The high-rise towers, are very popular in recent developments and have the advantages of privacy, exclusivity and views. The mid-rise urban blocks were a previous favourite. They characterise a denser built form. The compact low-rise courtyard blocks are a traditional form that was presumably well suited to an earlier way of life in the region. However, it is now found only in few areas of the city and cannot be regarded as a model for the future growth of Dubai. Each of these forms has a different effect on the resulting environmental conditions at ground level. One of these effects is illustrated in Fig. 2 which compares the different levels of shading achieved on the ground by different built forms for the same built volume. It shows the potential of courtyard blocks and denser developments to provide well shaded streets for pedestrians.

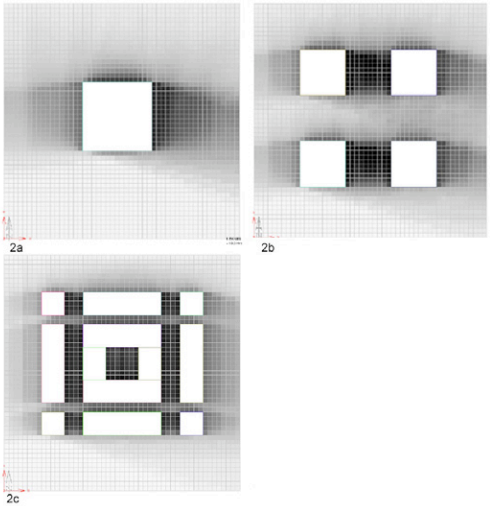
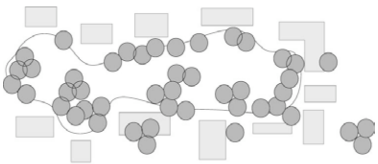


*Fig. 2 The area of shadow cast on the ground increases for a constant built volume (of 57,120 $m^3$) as a function of built form from (a) a 63.5 m high tower, (b) 35.7 m high blocks, (c) 21 m courtyard blocks.*

### 2.3 Vegetation

Greenery is a valued and appreciated commodity in Dubai. Green spaces have a large marketing value for developers. However, large areas of greenery are expensive to maintain due to the harsh climate and cost of desalinated water. While older parts of Dubai are mostly devoid of greenery, new developments are provided with large green spaces, Fig. 3. There is growing evidence that shading of buildings by trees can help reduce use of energy for air conditioning, and that at the urban scale trees and vegetation will improve urban air quality and lower the ambient temperature as well as providing shade for pedestrians [7].


Mass Plantation in contemporary Urban Design

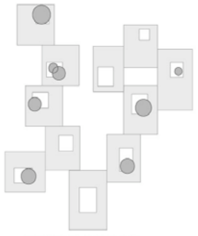

Scattered Plantation in Traditional settlements

*Fig 3 Current and Traditional Use of Vegetation in Dubai*

*Fig.4 Satellite View of Deira(left) north of the creek and Bastakia(right)south of the creek. Source: Google Earth*

### 2.4 Water

Evaporative cooling by fountains and ponds is a traditional feature of hot climates. However, in old Dubai such use was not extensive, possibly due to the high humidity that characterises some periods of the year here, as well as because of water scarcity. At present, however, large water bodies are being planned in most urban developments and many new areas are being developed next to the water.

## 3 Field Studies

### 3.1 Methodology

Measurements taken in the urban environment are fraught with difficulty. Given that results can vary greatly, both between and within different parts of a city, it is rarely easy to draw meaningful comparisons. Thus comparability was a key criterion in the selection of sites for the measurements taken in Dubai in July 2007. Two representative areas were selected for measurements and thermal comfort surveys. Area 1 was selected to include sites in the Bastakia and Deira quarters of the oldest part of Dubai near the creek, Fig. 4. Area 2 is a new residential development some 25km south along the coast. A number of spots were then chosen in each area for the measurements. A third location was also selected a little more inland and data loggers were installed on the roof of a building there for readings considered to be unaffected by the influence of built form, vegetation or water and therefore providing a reference met station for comparisons.

Measurements in each location included records of air and globe temperatures, relative humidity, wind speed, and illuminance levels. Surface temperatures were also recorded. A thermal comfort survey was undertaken involving passers by as well as subjects found sitting in the selected locations. Measurements were carried out with temperature and humidity data loggers installed at selected points. Where it was not possible to install data loggers, the measurements were taken at regular intervals by hand-held equipment. Comfort survey, wind measurements and surface temperatures were recorded by hand held equipment. The results discussed below show considerable but systematic differences between the "dry" inland reference location and the wetter locations of the old town and the waterside new developments. These provide some useful insights on ways for improving microclimatic conditions in this city.

### 3.2 Weather Conditions

In the period of the measurements (9-15 July 2007) air temperatures recorded at the reference met station set for this fieldwork peaked above 40°C throughout the week, Fig. 5. The mean air temperature for the week was of 36.4°C and the maximum 46.5°C (at 13.30 on the 10th July). After sunset air temperatures dropped slowly to minima around 30°C. The relative humidity was in the range 15-60% for the first four days, rising to 30-80% on the last two days of the measurements. Owing to the high air temperatures, the peak values of relative humidity represent fairly high levels of absolute humidity. The maxima of 80% (at 01.00 am on the 14th July) registered on the last two days of measurements correspond to a moisture content of 23.5 g/kg dry air. The lowest RH value of 11.5% (at 11.00 hours on 13th July) corresponds to a moisture content of 6.5 g/kg dry air. Throughout the week relative humidity levels were lowest around mid-morning at which time conditions felt quite dry, whereas later in the day the high humidity values caused discomfort. This variation indicates there may be scope for evaporative cooling during the morning hours to cool the air for later use.

Wind velocities of up to 2.5 m/s were measured in open areas throughout the fieldwork period. These were welcome by pedestrians throughout the day even when air temperatures were as high as 40°C. Bright but dusty skies of up to 92,500 lux were recorded during the week. The brightness of the sky caused glare and was consistently commented by subjects as a cause of urban discomfort.

### 3.3 Bastakia

Dating from the 1890's the Bastakia quarters in Dubai comprise buildings that form a dense urban tissue around narrow winding streets. Measurements were taken in the courtyard of a restored house and in a nearby street and compared with readings taken at the reference station. The courtyard, which had a height-to-width ratio of 1.8 : 1 recorded the lowest temperatures, Fig. 6a-d. These were 1-3K lower than those recorded in the street canyon which had a 2 : 1 height-to-width ratio, and by as much as 4-6K lower than temperatures recorded at the reference station. This advantage was partially eroded on the day of the measurements by higher humidity levels in Bastakia owing to Northerly winds from the creek.

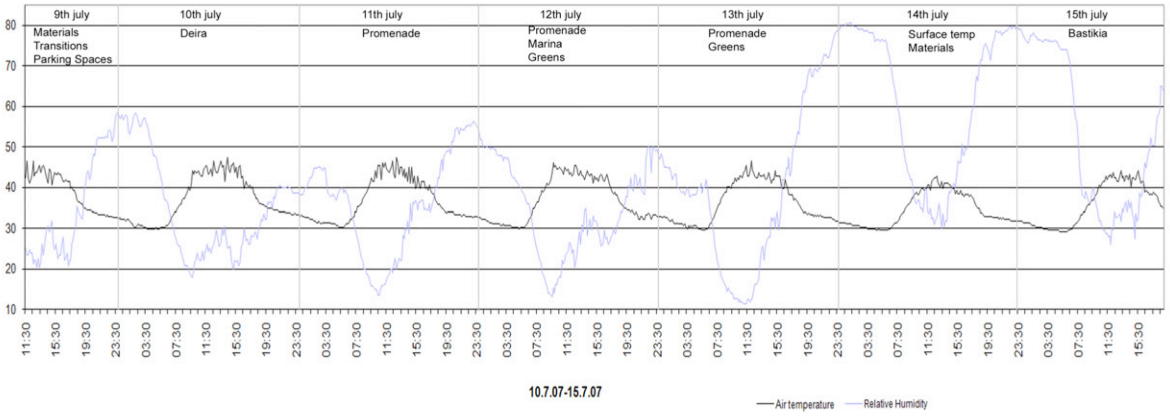
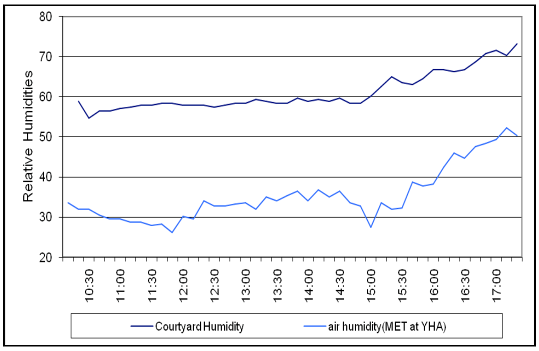


*Fig.5 Temperature and Humidity readings at the reference station, Dubai*



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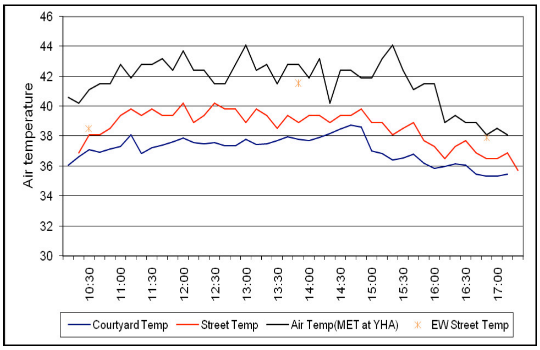

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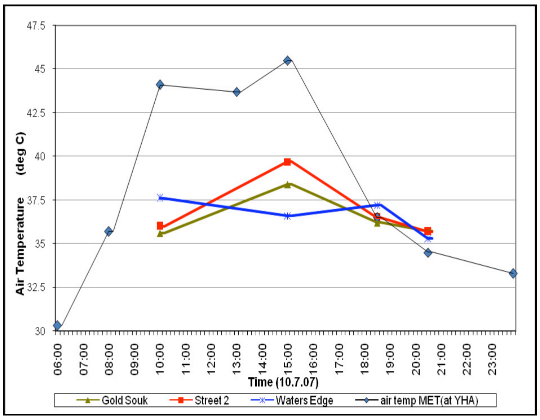
*Fig. 6 Measurements in Bastakia; (a) courtyard ; (b) street;(c)(d) Graph comparing temperature and humidity measurements taken in courtyard, adjoining street and reference urban location at YHA*

## 3.4 Deira

In Deira, a densely built shopping district developed in the 1960's, the measurements were taken in three different locations: the Gold Souk, a street parallel to the souk, and a site near the water along the creek. The graph, Fig. 7e, shows that although not protected from the sun the area near the water, Fig. 7b, registered the lowest and most stable temperatures during the hottest part of the day. Presumably this is due to the stabilizing influence of the water mass and the effect of evaporation. The Gold Souk, Fig. 7c, which is well protected from the sun, achieved a lower temperature than the parallel street, Fig. 7a, which though narrow was exposed to the sun for part of the day. The difference reached some 1.5K during the peak midday sunshine period falling to nil at the end of the day as both spaces cooled toward the ambient air temperature after sunset. Exposure to the sun in the open street led to surface temperatures that were higher than the air temperature thus having a negative effect on pedestrian comfort. On the day of the measurements the mean radiant temperature in the open street was estimated to be higher than the air temperature by more than 5K at 2pm. On the other hand, being protected from the sun throughout the day, the building surfaces surrounding the souk would remain close to air temperature. The importance of this was confirmed by the comfort survey which voted the souk area as comfortable whereas the open street was felt to be uncomfortable. This was a hot day (10th July) with a peak temperature above 45°C at the reference station. This makes the reduction of 7-10K observed in Deira particularly notable.



*7e*

*Fig. 7 Measurements in Deira, (a) street parallel to souk. (b) water's edge (c) Gold souk (d) reference station at YHA rooftop (e) Graph comparing temperature measurements taken in Gold souk, adjoining street and near the water*

### 3.5. Thermal Comfort Studies

The dense organic forms and shaded transitional spaces of Deira and the Bastakia provide clear microclimatic benefits that derive from the resulting solar protection and thermal inertia. Jointly these attributes lead to lower and more stable temperatures than those encountered in less dense areas with higher exposure to solar radiation. However, a densely built form may obstruct air flow which can be problematic. For example, afternoon conditions in the Bastakia courtyard were uncomfortable due to lack of adequate wind movement. The main activity times in the Deira area were in early morning and late afternoon and evenings. Evenings are generally the most popular period for outdoor activities. The thermal comfort surveys conducted during these periods yielded interesting results that confirmed people's adaptive strategies. Key findings were the following:

a) Ambient temperatures close to 40°C were reported as acceptable by subjects in the shade and exposed to wind velocities of some 2.0m/s.
b) Relative humidity levels of up to 40% were found to be tolerable at the peak temperatures as above as long as good wind speeds were available.
c) Use of fans in semi enclosed urban spaces was found useful especially in periods of lower wind velocity and in the late evening when the humidity levels were high.
d) Adaptive strategies employed by subjects included lighter clothing, cold drinks, and frequent resting after a few minutes of walk.
e) Pollution and vehicular traffic were reported as important causes of discomfort in the Deira street; at the Gold Souk their absence contributed to subjects' sensation of better comfort.
f) Two thirds of those interviewed reported glare as a problem. Sources of glare were reported as the sky vault, surrounding buildings, water surfaces, motor vehicles and buses.
g) Illumination levels of 500 lux as measured at the Gold Souk were considered most comfortable. Much higher levels seemed to make subjects feel warmer.

### 3.6 Dubai Marina and Greens

The 'New' Dubai encompasses developments along the coast south of the creek. For this study sites approximately 25km south of the creek were selected for the measurements in the areas known as Dubai Marina and the Greens. The Dubai Marina is a new development still only partly built that incorporates a large body of sea water in the heart of the settlement. This is surrounded by 50-storey residential towers. The 'Greens' is a residential development a little further inland that has been provided with extensive vegetation surrounding low-rise bungalow development. Readings taken in the area of the Dubai Marina and the Greens residential area were lower than the temperatures recorded at the reference station by up to 7K around midday, Fig. 8a-c. The differences diminished after sunset. The Marina area is influenced by the proximity of the water and the winds blowing from the Gulf, while Greens displays the effect of vegetation and shading trees. Measured relative humidity levels were considerably higher near the sea, Fig.8d. This is significant as the comfort survey identified high humidity as a major discomfort factor that undermined the effect of lower air temperatures.

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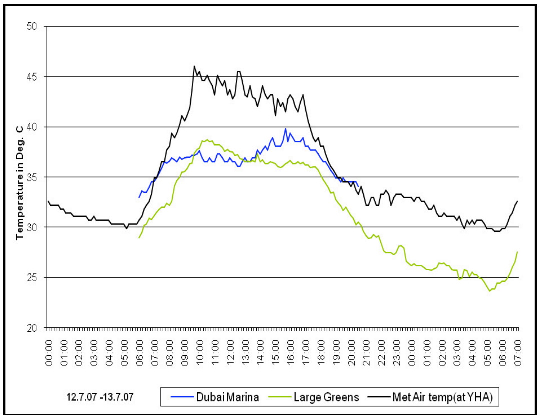

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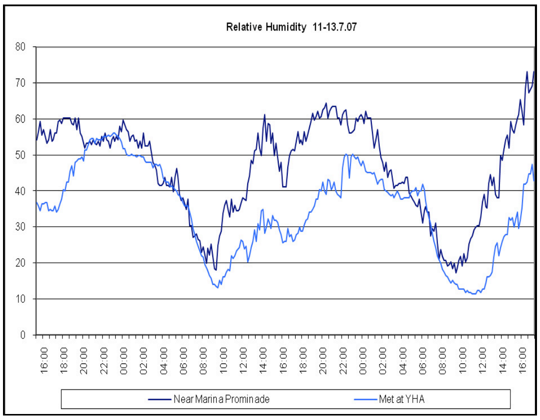

8d

*Fig.8 Measurements in Dubai Marina and Greens (a)Marina (b) Green (c) (d) Graph comparing temperature and humidity measurements taken in Dubai Marina and Greens with reference urban location*

## 4 Microclimate Simulation Studies

Accurate simulation of outdoor urban microclimates is a complex problem. However, credible predictions of likely trends and relative effects can be useful in informing design decisions. A number of simulations were performed using the ENVI-met v3.0 model [5] to see whether its predictions emulated the trends and findings of the measurements taken in Dubai.

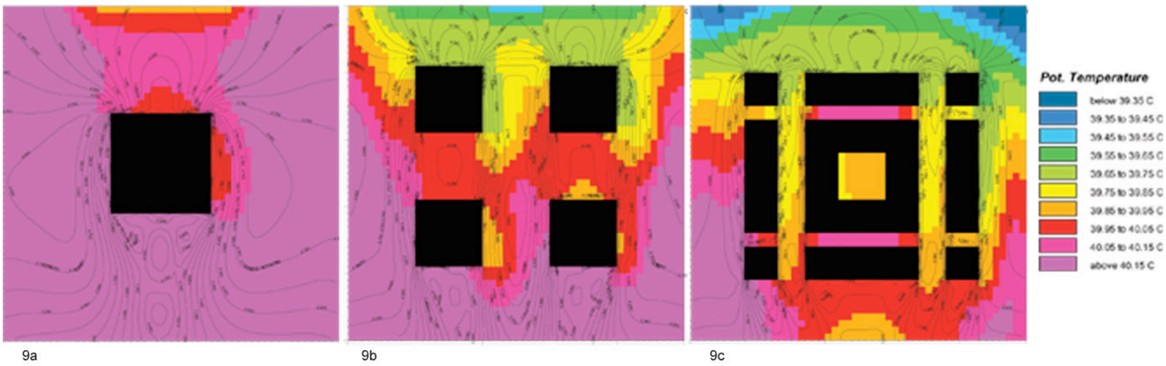

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*Fig .9 Envi-met predictions of air temperatures for 2.00pm on a July day around a constant built volume (of 57,120 m$^3$) on a 100x100m site as (a) a 63.5m high tower, (b) 35.7 m high blocks, (c) 21 m courtyard blocks.*

A first set of simulation runs were performed to assess the relative effect of built form by comparing the impact of different forms on ambient temperature and airflow. A fixed built volume was modelled in the form of a single high-rise tower, four mid-rise blocks, and as a dense courtyard block and simulations runs were performed for a typical summer day. The simulation results show that during daytime the courtyard form has a larger microclimatic footprint due to more of its built mass being closer to the ground, Fig. 9. The courtyard block was the coolest with the open courtyard itself as the coolest spot. As expected wind speeds were lowest around the courtyard block with the narrower east and west streets becoming warmer than those running north-south, possibly due to the lesser air movement. Humidity levels in the courtyard were lower than in the streets. At night the courtyard was warmer than the north-south street due to lesser wind movement.

A second set of simulations tested the effect of vegetation and water on the same three built forms. The ENVI-met simulation showed that vegetation and water would lower the ambient temperature highlighting differences of up to 2K at 2pm for the single tower with mass vegetation planted around it. These preliminary runs suggest that the Envi-met results follow the trends identified by field measurements. However, the simulated values were much lower than those measured.

## 5. Conclusion

The short-term measurements and modelling studies summarised in this paper provide the following preliminary conclusions for improving outdoor microclimatic conditions in Dubai:

- **Built Form** should incorporate well shaded and ventilated urban spaces; transitional spaces mitigating between indoors and outdoors are particularly important and require special attention.
- **Vegetation** has cooling benefits and market value. Surface temperature readings showed grass as being significantly cooler than other surfaces. However, high humidity is an issue and the maintenance of lush gardens may be expensive in Dubai.
- **Water** will also provide lower temperatures, but humidity is again an issue for part of the year. Evaporative cooling may be operational for relief at certain times of the day even during the hot period of the year.
- **Adaptive Activity Zoning** should be exploited creating appropriate microclimates for different activities. Shading, permeability to air flow for convective cooling, and appropriate choice of urban materials are important design strategies.

Microclimate models such as ENVI-met can be applied usefully to get a rough idea of the likely effects of built form, vegetation and water bodies on ambient temperature and airflow.

## 6. References

1. Davis, M. (2006). Fear and Money in Dubai. www.newleftreview.org/?page=article&view =2635 Article accessed on 2nd August 2007.
2. Givoni, B.,( 1998). *Climate Considerations in Building and Urban Design*, John Wiley & Sons, New York.
3. Yannas, S. (2008). Challenging the Supremacy of Air Conditioning. 2A Architecture & Art, Issue No.7, pp20-43.
4. Thapar, H. (2007). Micro-Climate and Urban Form for Dubai. MSc Dissertation. Environment & Energy Studies Programme, Architectural Association School of Architecture, London.
5. ENVI-met v3.0 (2004) by M. Bruse. www.envi-met.com.
6. Meteonorm v6.0 (2007) Global Meteorological Database. Meteotest, Bern. www.meteonorm.com
7. Akbari, H. (2007). Opportunities for Saving Energy and Improving Air Quality in Urban Heat Islands. In Advances in Passive Cooling, pp30-92, Earthscan.