

Urbanizing the deserts of Dubai: an outdoor thermal comfort case study of Dubai International Academic City, UAE

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Abstract

The urbanization of deserts in Dubai is one way in which this city can expand and explore its full potential. In this piece of research, a case study of the Dubai International Academic City was used as a basis from which to study the impact and importance of planning and orientation of projects in open unpopulated land. It demonstrates the various alternatives for project orientation relative to the sun and wind, its effects on temperature and wind readings and consequently on outdoor thermal comfort levels. ENVI-met was used to simulate various scenarios generated from the existing base case in both summer and winter. The orientation which best promoted and allowed for higher wind flow through the project was found to record the best outdoor Predicted Mean Vote levels, approaching the neutral state. The findings of this research may be used for setting up regulations regarding the planning of desert areas in Dubai on the basis of early assessment of designs.

Keywords: thermal comfort, PMV, urban planning, orientation, ENVI-met, Dubai.

1 Introduction

Urban outdoor spaces have implications on the people using them. Architects today strive to design outdoor corridors and urban spaces rather than having them either emerge accidentally, or as a by-product of design. Outdoor spaces must be utilised to their full potential, or else the need for such spaces may be completely eliminated and they could become disregarded as a favourable space for people to use. Outdoor spaces, or “urban in-between spaces”, need just as much attention and thought in their design as indoor spaces. In urbanizing empty



deserts and land, planners and designers have the advantage of a clean slate onto which theories of optimum outdoor thermal comfort conditions can be applied. Considering the physical characteristics of the site should be done at the onset of such planning. Research is lacking within the UAE, which combines thermal comfort studies with urban planning. This work will therefore help to shed light on that aspect of research in the UAE.

This paper presents a case study of the Dubai International Academic City (DIAC) as an example of the urbanization of a desert area in Dubai. Desert areas here refer to uninhabited land surrounding the edges of the city of Dubai. As the city expands, it ventures into the open desert to utilise that land's potential for new mega projects. DIAC is a complex of university buildings and educational institutions including facilities to support the student body. The project is surrounded by open land and is about 15km away from the edge of Dubai. This study intends to test the project from several orientations and consider the impact of such activities on outdoor thermal comfort levels. The results of the research will indicate the impact of planning decisions such as orientation and layout on the comfort of users within a "thought-out" design. Urban design decisions, especially when urbanizing deserts, should utilise a more conscious process of design. Even though urbanization may alter the microclimate, it may be altered in a way in which users of the outdoor spaces benefit the most. Although an open empty land is a good justification for uninhibited design, it is also a challenge for urban planners and architects to design it as best as possible with the best sustainability practices in mind.

2 Literature review

Although research on thermal comfort in indoor spaces is abundant, that related to outdoor spaces is much less prevalent due to the complexities it entails. One of the most important factors is that people tend to use indoor spaces 90% of their time as opposed to spending 10% of their time outdoors during the summer and 2-4% during winter. With very minimal time spent outdoors, it is difficult to reach a thermal steady state to get proper thermal comfort results [1]. Furthermore, outdoor spaces are exposed to uncontrollable climatic variations, which makes it increasingly difficult to measure and assess comfort levels. The interaction between the different climatic variables is a complex one and thus has hindered research in the area of outdoor spaces and urban areas, in comparison to indoor studies, where conditions are more controllable.

Thermal comfort, in its basic definition, is the human reaction to the surrounding indoor or outdoor environments. More specific definitions of this term are summarised under three different categories. The psychological definition relates to the mind's expression of satisfaction with the thermal surrounding (ASHRAE). Thermophysiological definition is related to the biological reaction of the body and nervous system to external influences on thermal receptors on the skin. The third definition, which is more of an "energetic" definition, relates directly to the balance between heat flow to and from the human body [1].



Although outdoor spaces can be modified using smaller design details such as shading devices, selection of surface materials, vegetation and water bodies on the site, it is of greater importance to start off the design process with the right intentions. Such design details may be used to enhance outdoor environmental quality and therefore individual thermal comfort levels. However, finding the means for predicting the impact of changing a certain climatic parameter and its effect on levels of outdoor thermal comfort [2] is important at the onset of the design process. The manner in which the buildings are located in accordance to each other and solar and wind orientation, their configuration and specific parameters are some of the major considerations when it comes to outdoor thermal comfort [3]. Furthermore, understanding the psychological adaptation process, people's behaviour in outdoor areas, and their impact on design considerations is yet another concern for planners and architects to take into account [4, 5].

There are physical characteristics of a site contributing to thermal comfort: air temperature (T_a), mean radiant temperature (MRT), wind speed (W_v) and direction, and relative humidity (RH). Additionally, other external factors contributing to thermal comfort include: clothing (insulation) and activity level (metabolism) [6]. To calculate thermal comfort using the predicted mean vote (PMV) index, at least three out of the six criteria are those that can be used to orient and plan out the project during the design process. Considering solar orientation, wind direction, wind speed, and surface material selection are a means of predicting thermal comfort levels before even implementing the design.

Although the PMV index was originally intended, and widely used for, indoor thermal comfort measurements, Honjo [7] has indicated that with the lack of outdoor thermal comfort indices, PMV, Physiological Equivalent Temperature (PET), and standard Effective Temperatures (SET) may be applicable "at the current state of the art".

3 Methodology

The methodology for this piece of research was started by setting up a simulation model, using ENVI-met software, which has the capability to simulate microclimatic variations of urban structures. It has the capacity, based on fluids and thermo-dynamics, to simulate flow around buildings and to calculate the complex heat exchange processes of different surfaces.

Three additional scenarios were generated from the base case and the difference was restricted to changing the orientation of the project towards the wind. In all four cases the wind direction is 325 deg (blowing North-West). Due to restrictions in the software in rotating the drawing, the North orientation was rotated 90 deg for the three altered scenarios. In relation to the North, the wind remains blowing from the North-West, however the sides of the project on which the wind blows in each case is different. This allowed for each of the four sides of the project to be simulated as being exposed to the wind direction. The simulations were run for both summer and winter, when the highest and lowest temperatures of the year are recorded. The simulations were run for 24 hrs



starting and ending at 6am. More specific data was analysed during university operating hours, from 8am till 10pm.

The base case study was the current formation and orientation of the DIAC as it is on site, with its current orientation to the wind and sun. Figure 1 shows the location of the project within empty land and the layout of the project itself.



Figure 1: Dubai International Academic City location and orientation.

In this research, fixed variables include building and surface materials, layout of the buildings and the exclusion of vegetation on the site. Wind speed and initial air temperature were fixed variables but season dependant.

Site specific input data in the software included:

Location: Dubai, Lat: 25.25°Long: 55.33

Simulation days: 21st of June and 21st of Dec.

Building specifics included:

Roof Albedo: 0.1 (reflects 10% of incoming radiation),

Wall Albedo: 0.1 (reflects 10% of incoming radiation)

U value of walls: 2 W/m².K

U value of roof: 1 W/m².K.

Climatic data included:

Initial Temperature 305.15K

Wind Speed: 3.6 m/s,

Relative Humidity: 50%

Cloud Cover: clear sky

For more specific thermal comfort readings, PMV was used to pinpoint specific trends. Seven points were selected to represent various locations throughout the site. Figure 2 shows the layout on ENVI-met as well as the location of the seven selected data points. The figure also shows the orientation of the project in all four scenarios.

A PMV calculator (www.lumasenseinc.com) was used to calculate PMV values for each of the selected points on the site using a metabolic rate of 1.0 met and a clothing level of 0.5 clo.

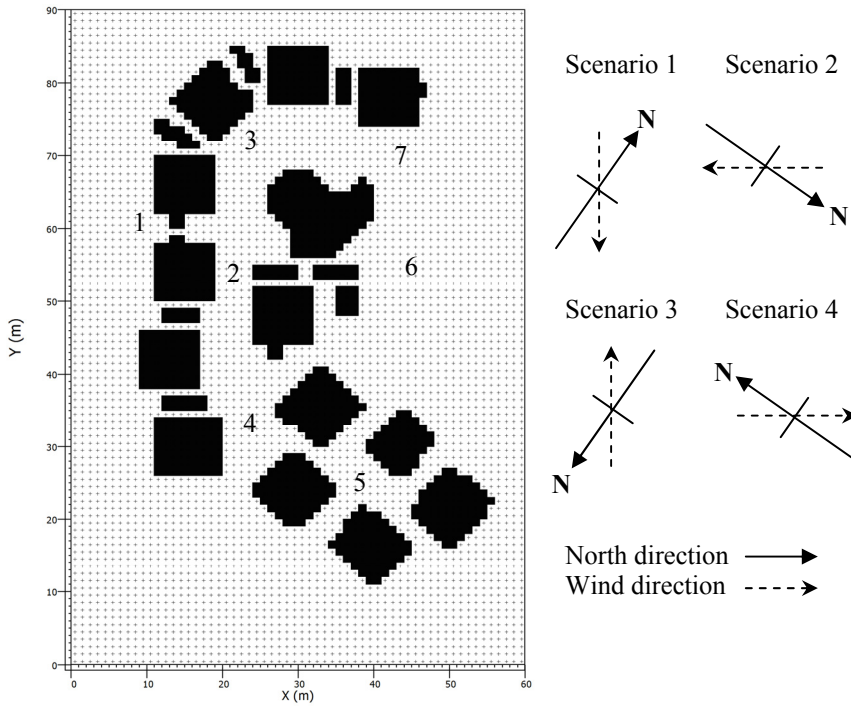


Figure 2: ENVI-met layout of the site showing the seven selected points for specific data extraction and the four scenario orientations.

4 Results and discussion

Analysis of the initial data showed daily trends of average wind speed and average temperatures throughout the entire site. The trends are similar for both summer and winter with a difference of values between the two seasons. Figures 3 and 4 show the average temperature and average wind speed throughout the site for 24 hours on June 21st, representing the summer season. The main finding is that the average temperatures for all 4 scenarios are very similar throughout the day, with the exception of the hours between 1300hrs and 1700hrs when Scenario 1 recorded the lowest value. The wind trends, however, show very different readings for all four scenarios. Scenario 3 recorded the highest wind speed averages, while both Scenario 2 and 4 recorded the lowest. From a performance perspective, the relatively lower wind speeds of both Scenario 2 and 4 accounted for their slightly higher temperature readings. These readings are an indication that the orientation of the buildings did not assist in the faster flow of wind through the project. With wind blowing on the long side of the project, it faced a barrier through which wind was either made stagnant in Scenario 2, or blocked from entering the project as was the case in Scenario 4. In winter, the same trends occurred.

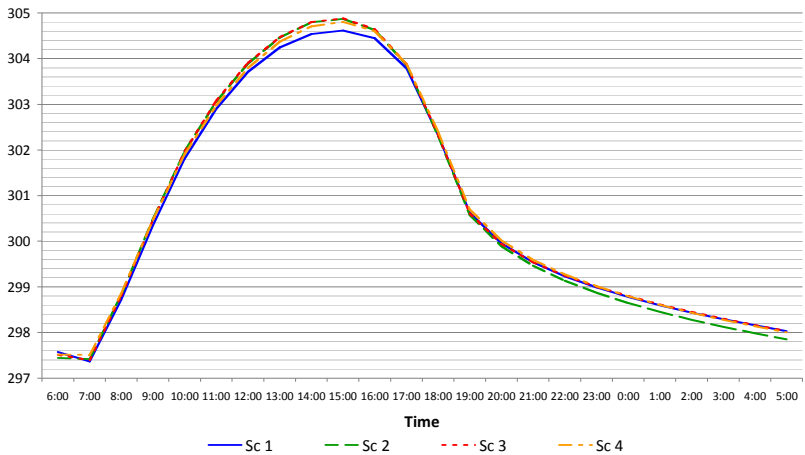


Figure 3: Daily average temperature (K) for the four scenarios in summer.

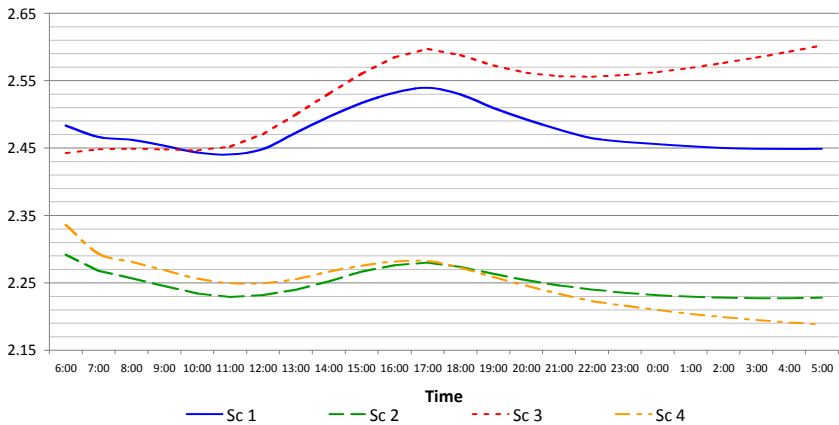


Figure 4: Daily average wind speed (m/s) for the four scenarios in summer.

These readings from the entire site throughout the day record very minimal variances between the four scenarios in terms of temperature and thus are not indications of thermal comfort levels. Therefore, another level of analysis was used to more accurately assess thermal comfort throughout the site. Thermal comfort data was extracted for 7 points across the site during operating hours and tabulated. Although PMV levels most commonly range between -3/-4 and +3/+4, more extreme temperatures allow for the levels to exceed this range to cover a larger scale of between -8 and +8. In this research, the PMV scale was used basically to include, aside from air temperature and wind speed, relative humidity and MRT in calculating thermal readings. Figure 5 shows the PMV

trends with the highest (hottest) value occurring around 1600hrs. Table 1 shows the average values for the seven selected points of all physical parameters as well as the PMV values for each of the four scenarios. A closer look at the PMV values shows that Scenario 1 recorded the second lowest PMV value while Scenario 3 recorded the lowest average PMV of the day, rendering it as the most comfortable of the four scenarios.

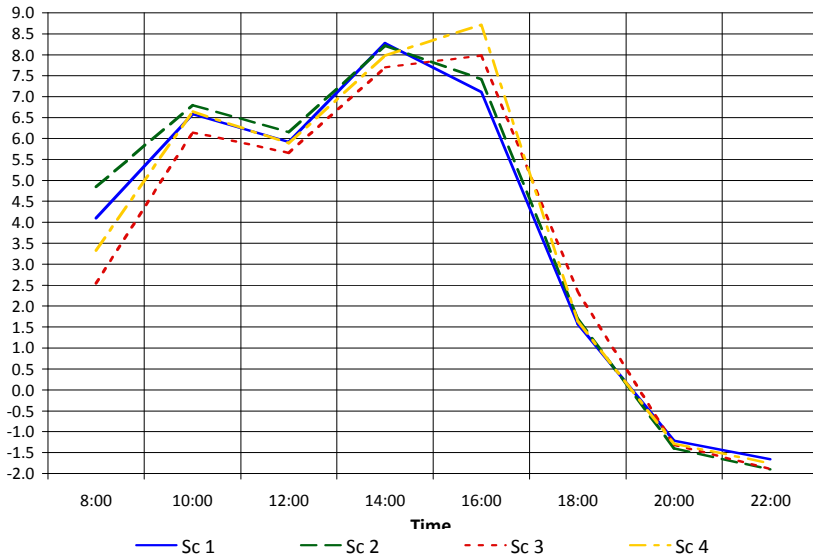


Figure 5: PMV values for four scenarios in summer during operating hours.

Comparing the four criteria that contributed to the PMV value (with external parameters of clothing and activity level set as constants), Scenario 3 had the lowest relative humidity average as well as the highest wind speed average of all the scenarios. It also recorded the second lowest of MRT values. Despite the fact that Scenario 3 had the highest air temperature value of all the scenarios, it still recorded the lowest PMV value. This indicates the extent of contribution that the other three criteria have on thermal comfort levels. The higher the wind speed within the project, the higher impact it will have on thermal comfort. Similarly, and in addition to wind speed, having lower humidity levels also contributed positively. Lower MRT, which is temperature directly related to the mean temperature of surrounding elements, is also an important contributor. Taking a closer look at Scenario 1, it was found that its relative humidity, MRT, and wind speed were the second lowest. This indicates a very strong correlation between these criteria and the PMV value. Out of the four environmental criteria involved in calculating thermal comfort, two are most definitely criteria that can be controlled, to an extent, one way or another. Wind speed may be controlled, increased or decreased, based on the configuration of the buildings on site, as well as their orientation. It might also be safe to say that the increased wind

speed may have contributed to lowering humidity levels in this situation. From observing the orientation and configuration of the buildings facing the wind in Scenario 3, it is noticed that the staggered layout of the buildings had an impact on increasing wind flow and speed through the project. Scenarios 2 and 4 recorded the lowest wind speeds because of the “blocking” effect the buildings had on the flow of wind. Figures 6–9 show the trend of each of the physical parameters contributing to thermal comfort levels and their behaviour in all four scenarios.

Table 1: Average values of Ta, Tmrt, RH, Wv, and PMV for the seven points in each scenario during summer. Lowest PMV recorded in Scenario 3.

	SC 1	SC 2	SC 3	SC 4
Ta (K)	302.502	302.432	302.814	302.414
Tmrt (K)	325.887	326.709	325.987	326.420
RH (%)	54.140	55.999	53.012	55.110
Wv (m/s)	2.049	1.719	2.414	1.843
PMV	3.84	3.98	3.65	3.89

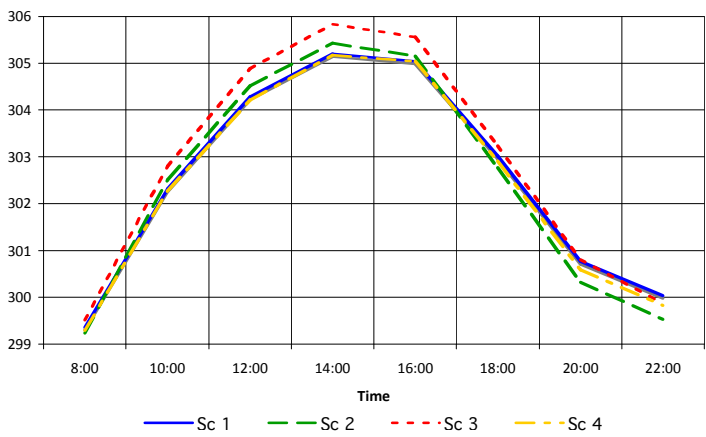


Figure 6: Average air temperature of seven points in the four scenarios in summer.



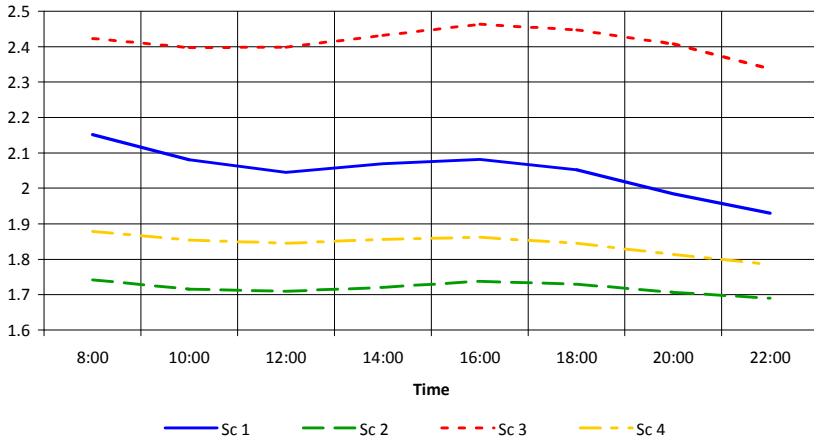


Figure 7: Average wind speed of seven points in the four scenarios in summer.

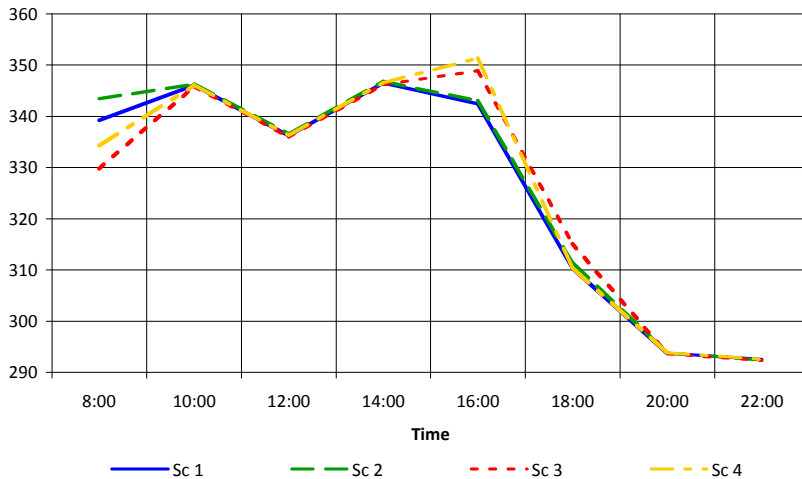


Figure 8: Average mean radiant temperature of seven points in the four scenarios in summer.

For the winter scenario, the average PMV value for all four scenarios approaches closer to zero, the neutral state. Similarly, Scenario 3 recorded the lowest value, followed by Scenario 1.

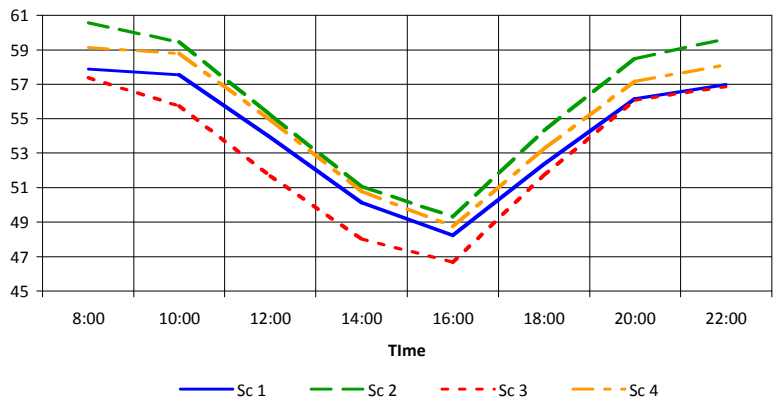


Figure 9: Average relative humidity of seven points in the four scenarios in summer.

Table 2: Average values of Ta, Tmrt, RH, Wv, and PMV for the seven points in each scenario during winter. Lowest PMV recorded in Scenario 3.

	SC 1	SC 2	SC 3	SC 4
Ta (K)	299.41	299.11	299.52	299.29
Tmrt (K)	310.23	310.9	311.87	314.4
RH (%)	58.47	61.06	57.99	59.55
Wv (m/s)	2	1.69	2.38	1.81
PMV	0.4	0.41	0.36	0.92

5 Conclusion

The results of this research give insights into the behaviour and impact of planning on thermal comfort levels. In both Scenario 1 and 3, the smaller edge of the project was oriented towards the wind allowing for better flow through the project. The difference in performance between these two cases is that Scenario 3 allowed for higher wind speeds, most likely due to the staggered formation of the buildings on the wind receiving end of the project, as opposed to a more solid wind receiving edge in Scenario 1.

Urbanizing desert areas and empty land has advantages that designing within the city does not. The limitations are minimal and the potential for designing in an empty environment both efficiently and sustainably is enormous. By identifying the basic criteria that effect thermal comfort, designers and planners can assess the importance of each and integrate those into the design process itself. Some of the criteria are within the control of the designer and can be manipulated through design. Wind speed and flow, MRT and humidity, to name



but a few, can be manipulated through layout and orientation, surface and material selection and placement of vegetation and water bodies respectively. Simulation and CFD software are best utilised for testing several scenarios to achieve the desired results before implementing projects on site.

This research may also be used as a basis for setting up regulations in the UAE which combine urban planning and design with microclimatic evaluation for better urbanized desert areas, for the benefit of the end user.

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