Urban Studies and Public Administration
Vol. 6, No. 2, 2023
www.scholink.org/ojs/index.php/uspa
ISSN 2576-1986 (Print) ISSN 2576-1994 (Online)

Original Paper

Applying Passive Cooling at an Urban Level: Case Study of Dubai, UAE

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Received: April 9, 2023 Accepted: April 25, 2023 Online Published: Accepted: May 4, 2023

doi:10.22158/uspa.v6n2p14 URL: http://dx.doi.org/10.22158/uspa.v6n2p14

Abstract

This research employs the integrative process of sustainable urbanism by applying passive design strategies to promote a sustainable neighbourhood lifestyle. A selected neighbourhood in Dubai is analysed and assessed in terms of its existing achievements regarding sustainability. It does so by simulating a site's potential, its limitations, characteristics, existing buildings, transportation status, climate, and the Dubai culture in order to optimize and develop design criteria that meet all the requirements at different levels for a sustainable neighbourhood. To permit this, five passive cooling strategies are applied. The methodology adopted for this study is the assessment of the implications of proposed designs through the use of Envi-met software simulation. As per LEED a variety of facilities are included, and land use is differentiated to enhance social interaction and to meet all the daily needs of community users in such a way as to maximize the potential of a sustainable urban design process compared with the conventional way. The sustainable corridor was also oriented toward the northwest which helped generate many wind loops towards in the direction of the central plaza and the community hall and which increased wind speed by 6m/s. Additionally, in the proposed design, open spaces and green areas were increased by 30% through the creation of a major central plaza, a walkable environment, and water features to enhance livability and comfort in the community. Additional daily facilities and entertainment destinations are provided to capitalize on the proposed open spaces. The study yielded several significant findings; most notable was the reduction of surface temperature by approximately 2.5 degrees centigrade as a result of increasing the green areas by 30% and introducing a large water body and water features on-site.

Keywords

passive cooling, Envi-met software, triple bottom line, Dubai neighbourhood, connectivity & liveability

1. Introduction

The term "Urban design" refers to the collaboration and interface between all the elements and multiple layers that form the fabric of our cities. Many urban designers have argued that we need to understand the history of cities and their current design to meet the requirements of future generations and new technologies as well as environmental changes. This has led to a holistic vision of urban design known as "Sustainable urban design" (Farr, 2018). The United Arab Emirates (UAE) has come a long way in meeting the challenges of climate change and energy requirements under the framework of Vision 2021 and the strategic plans of each emirate. There has therefore been a strong call to plan for sustainability on many levels including the urban level (Galli, Vallati, Recchiuti, de Lieto Vollaro, & Botta, 2013). Many authors have noted that, in hot climatic zones like Dubai, there is no outdoor life, an abundance of solar radiation, and local materials and resources are rare or limited (Mike, Elizabeth, & Katie, 1996). It is therefore vitally important to devise new urban design guidelines that align with the climate and enhance both connectivity and social sustainability. While, The key to passive design is enhancing the thermal comfort and consequent health of people by reducing the heat island effect and temperature. It also improves wind flow to encourage walkability in a neighbourhood, provides a liveable community, and increases open spaces.

2. Literature Review

2.1 Sustainable Urban Design

Sustainable development is no longer a new topic. It has been addressed in many earlier research studies by various analysts and urban designers who have explored the various aspects, parameters, and frameworks that affect our built environments and consequently affect the lives of subsequent generations. Achieving a sustainable lifestyle relies on the principles of smart growth, new urbanism, and green buildings. The approach to sustainable urbanism introduced by LEED Neighbourhood Development primarily aims to save our planet and encourage a healthier lifestyle. Sustainable urbanism is a process that integrates high-performance buildings and infrastructure to create a walkable and transit-served form of urbanism (Musco, 2018). It also focuses on the benefits of neighbourhood living, which are considered a basic unit of human settlements, by integrating five elements: definition, compactness, completeness, connectedness, and biophilia. The definition refers to a neighbourhood with defined edges and centre in a walkable environment that is diverse in terms of buildings, people, and functions. Compactness (Ponzini, 2011) is a high-density neighbourhood that improves diversity and enhances public transit services through a dramatic shift from car trips to walking trips. An increased market area can improve the sustainability of businesses in the neighbourhoods where we live, work and play, and improve water quality. It also reduces carbon emissions by 30% and energy consumption by 50%. Completeness refers to creating places where all daily needs can be met on foot by increasing the number and diversity of mixed uses in the centre to enhance the walking environment. It also utilizes a variety of house types to meet the requirements of all families. Connectedness involves achieving internal and external connectivity by creating a safe walkable pathway, biking path, and decreasing the distance between intersections to around 300-400 feet. It also involves creating a narrow street to minimize the speed of vehicles and enhance the safety of pedestrian pathways. Finally, biophilia refers to facilitating a re-connect between humans and nature and integration with other living systems through the creation of sustainable corridors.

2.2 Urban Cooling Strategies

Improving thermal conditions for pedestrians in summer is a top priority and a challenge for urban planners, especially in hot regions or in the summer. For instance, research conducted in Athens by Shashua-Bar (Shashua-Bar, Tsiros, & Hoffman, 2012) found that the thermal effect of trees is the dominant factor as they provide shade to decrease the air temperature. Another study conducted in Rome by Galli et al. (Shoba, 2014) found that the physical and geometrical properties of the buildings in any urban area, as well as the presence of green areas, have a large impact on the urban climate and on the thermal conditions of the people who are the end-users of these open spaces. Thus, the role of an urban planner is to reduce thermal stress and design comfortable outdoor spaces for people. Urban heat islands are a new type of microclimatic phenomenon that show a significant increase in the temperature of cities compared to surrounding areas (Ponzini, 2011). In the context of Dubai, a study (Taleb & Abu-Hijleh, 2013) confirmed that changing the configuration of the urban layout has a substantial effect on temperature variations throughout the year. Other scholars such as (Taleb & Musleh, 2015) have highlighted the absence of clear urban regulations and policies: they argue that attention should not only be given to regenerating urban areas, but also to defining a positive and communicative image in the context of global economic competition among cities.

2.3 The Climate of Dubai

Dubai is located on the Arab Gulf Coast, approximately 8m above sea level. It has an arid desert climate characterized by hot humid weather in the summer and pleasant weather in the winter. The following chart explains the weather in Dubai using climatic analysis software and the Dubai international website. This will be incorporated into the design strategies and the effects these have on the urban environment, energy consumption, and the comfort level of users. The hottest temperatures in Dubai are experienced in July and August with an average high of 45°C and an average low of 35°C. The coldest months are January and February, with an average high of 20°C and an average low of 15°C, as shown in Figure 1. The highest yearly average wind speed is around 6.1m/s and occurs mostly in May. The lowest average wind speed is just under 4m/s.

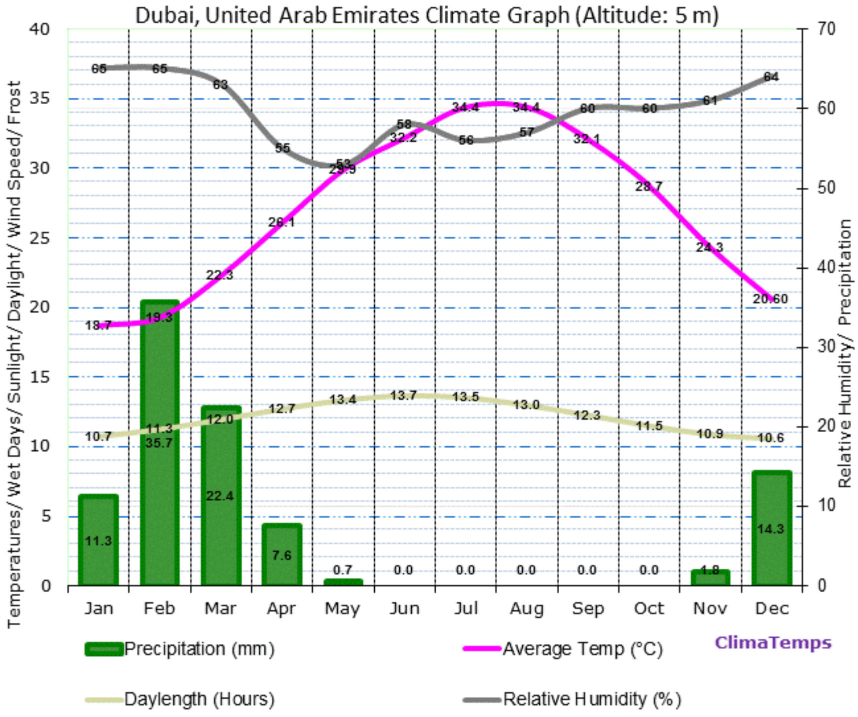


Figure 1. Dubai Climate (Source: Climatemps, 2019)

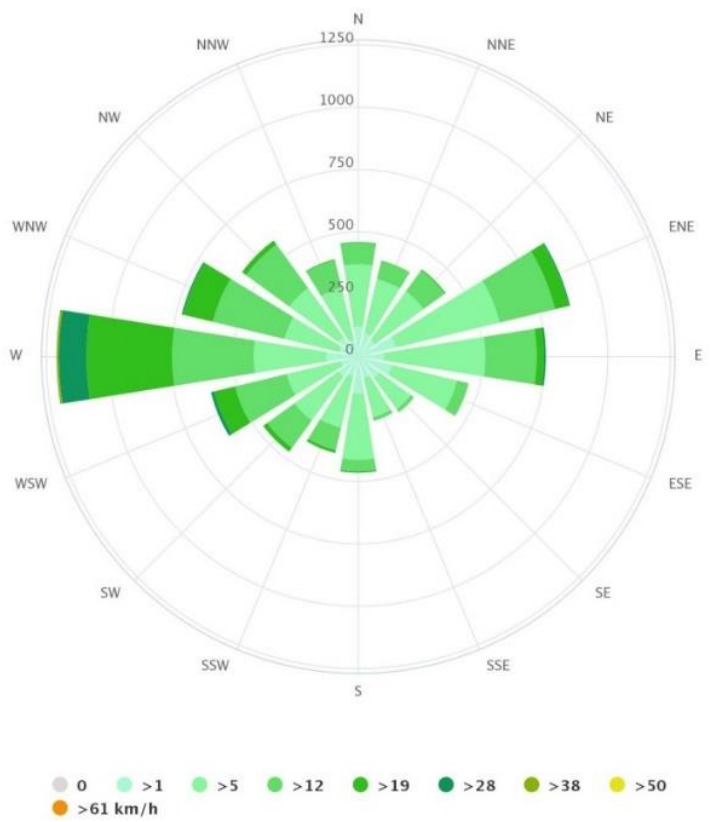


Figure 2. Wind Rose Pattern and Flow Rate Distribution Chart for the City of Dubai

3. Methodology

3.1 Research Approach

The research involves visiting and thoroughly investigating a "Heartland" urban community in Dubai. Based on an extensive literature review, a proposal is developed to enhance connectivity and social sustainability. A set of passive cooling strategies are proposed, including urban community orientation, the use of particular materials, and greenery. Using Envi-MET software, the proposed design is assessed against the base case in relation to air temperature, wind flow, and relative humidity. Envi-MET is a state-of-the-art simulation tool used to assess climatological conditions to help urban planners create sustainable living conditions by minimizing heat stress, air pollution, and wind effects. The simulation was of a particular area on 15 August 2019 represents a period of peak heat in the UAE with measurements being taken at 10:00 am, 11:00 am, 12:00 pm and 1:00 pm, for both the base case and the revised case. A comprehensive comparison was performed to assess the revised case strategies associated with changing materials.

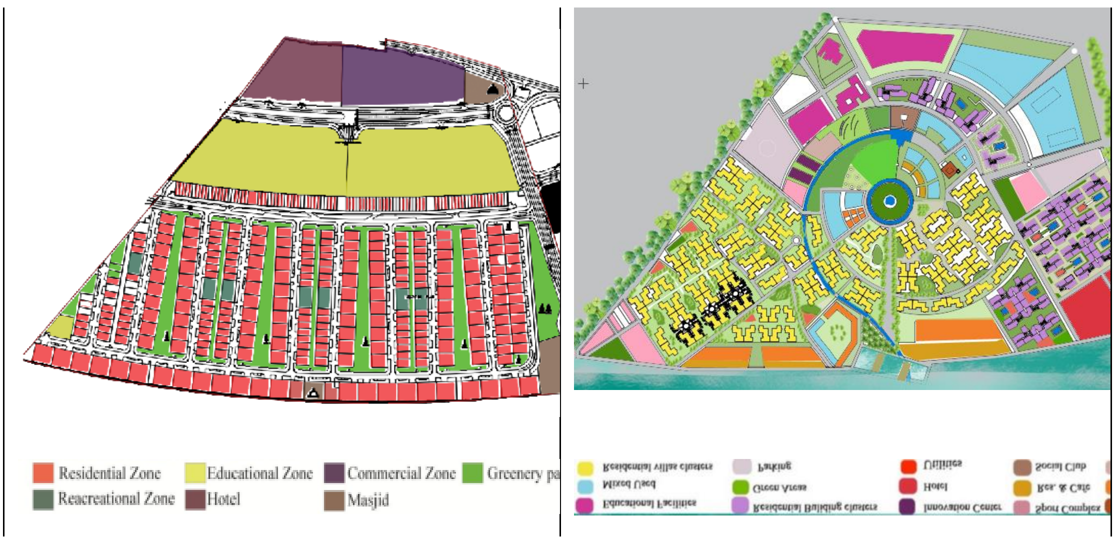
3.2 The Case Study

The "Heartland" urban community in Dubai (Shoba Developer, 2014) (UAE Government, 2019) is located in Mohammad Bin Rashid Al Maktoum City. It is considered to be one of the most unique and iconic neighbourhoods in the city, encompassing 8 million square feet of spacious homes and world-class amenities combined with 12% greenery and stimulating views. The layout in Figure 3 depicts the orientation of units in different zones. Furthermore, the existing land use in the current master plan shows a high density of residential areas comprising around 40% of the total land area. In contrast, the open spaces form only 12% of the total land area. One of the main within the community. The developer envisages the target number of residents to be from 8,000 to 10,000 persons.

Figure 3. Base Case Land Use Layout (Author)

3.3 Redesigning the Base Case

The authors adopted several urban design techniques developed by Dr. Jon Cooper that involve using layers of thinking and mapping to enhance connectivity. Six main aspects are proposed as discussed hereafter. First, responding to the use of the Dubai water canal which utilizes the power of water in shaping the urban fabric and enhancing the Urban Heat Island (UHI) of the project. A large water body was also introduced in the centre which reduced the temperature on-site and included water features, cascades, and fountains. Second, the entire urban area is oriented towards the North using wind channels to improve the incidence of fresh breezes on-site and reduce solar gain. Third, land use is incorporating joining and segregating to optimize the sustainable features of the project by increasing the diversity of land use and site potential. This will enhance the profitability of the master development and its liveability, by taking into consideration the residents' safety, security, and privacy. It also provides non-residents with an ideal opportunity to explore and experience the facilities provided on-site. Third, making the Southern edge, which is the Dubai water canal, form the historical and environmental boundary and enhance the connectivity between all the main attractions, landmarks, and districts, as mentioned previously in the existing site analysis. These features of the design helped improve walkability by creating a promenade which would enhance healthy lifestyles, adding a jogging and cycling track with convenient facilities such as parking spaces for bicycles and scooters near the main stations such as those of the water taxi and the metro stations. A mixed-use environment will also be created by adding shops, restaurant, cafes, an outdoor seating area, and supermarkets. Fourth, incorporating educational facilities such as schools, nurseries, a library, and a research centre to enhance the value of education and increase awareness of sustainability among students and their parents through various activities and forms of entertainment. These will also help to enhance the social value of the design. Fifth, altering urban materials to include more greenery compared with pavement and asphalt to enhance microclimatic performance. Figures 4 and 5 present the suggested revised plan, taking into consideration the introduced five aspects. As a result of the implementation of all previous strategies in terms of the urban fabric, it has managed to save area and introduce a variety of facilities such as shops, retail outlets, supermarkets, masjid, educational facilities, increased residential units and more greenery and open spaces as shown in Figure 4.



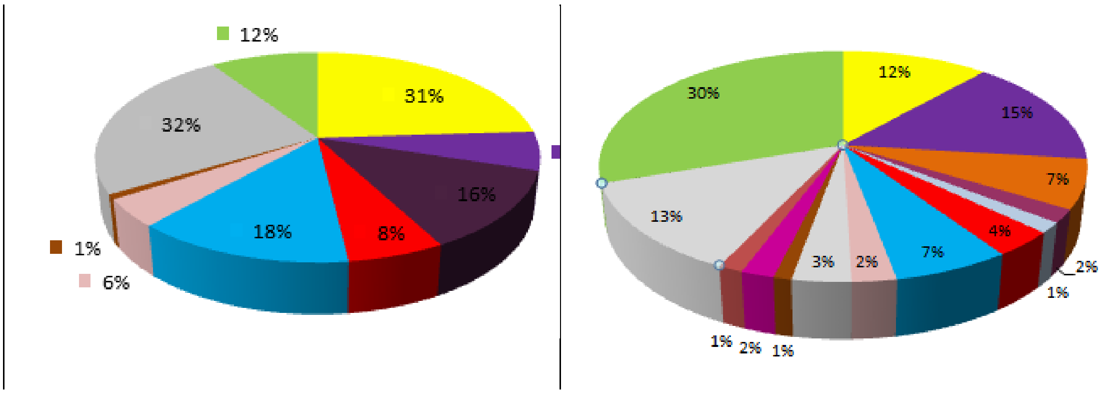


Figure 4. Base case land use and proposed land use (Author)

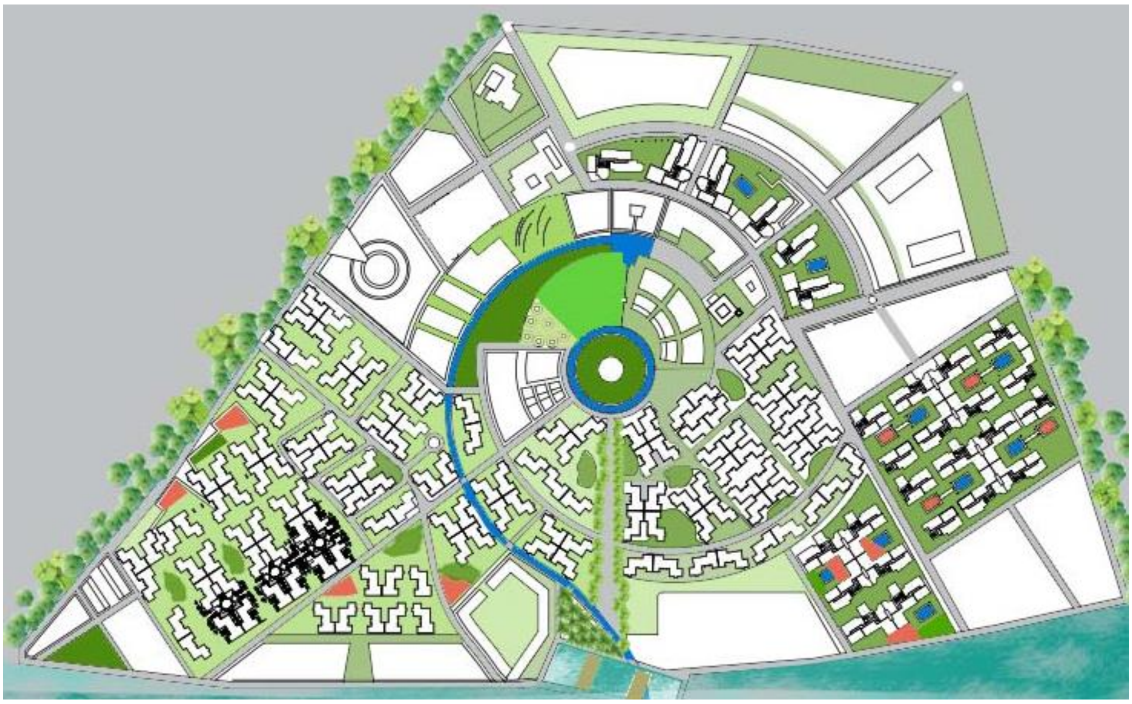


Figure 5. Proposed (revised) Master Plan (Author)

4. Results and Analysis

4.1 Base Case Simulations

The simulation was conducted for the base case over six hours, taking into consideration the climatic parameters measured on site on 29/09/2018. As shown in Figure 6, the highest temperature was 38.6 ℃. Furthermore, the wind flow, as shown in Figure 7, shows how the buildings on the base condition interrupt the wind flow and block ventilation in the corridors at open spaces. Figure 8 presents the relative humidity in the base case.

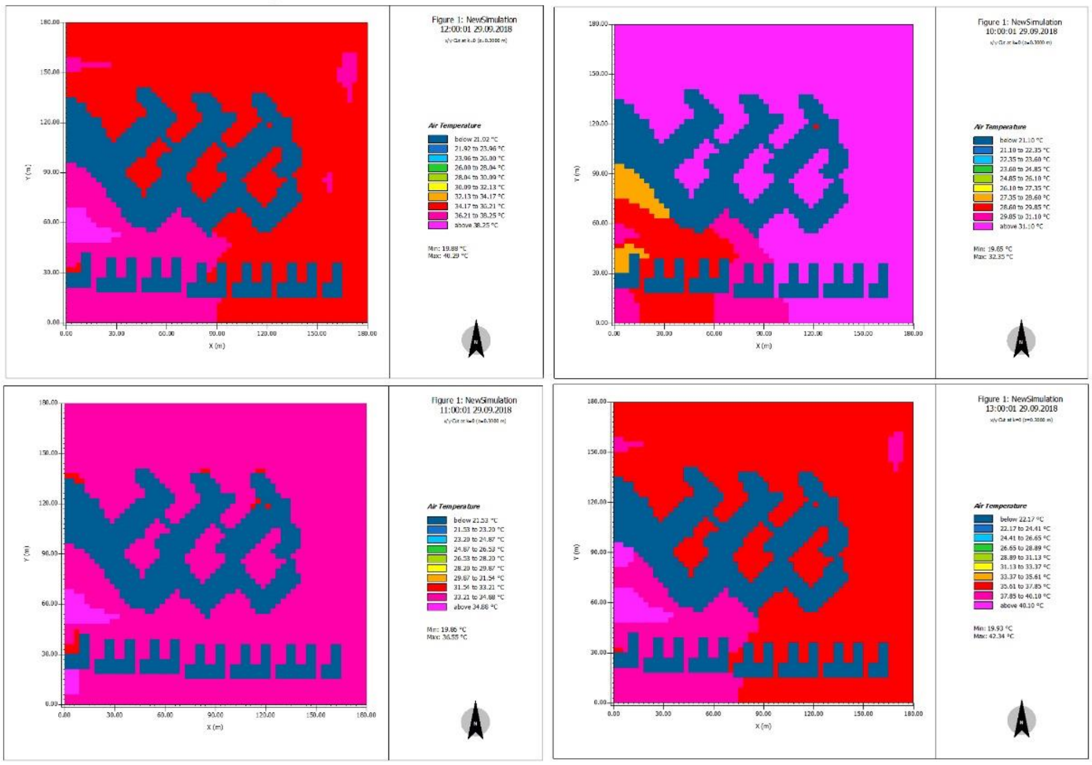


Figure 6. Base Case Air Temperature (Envi-MET Software)

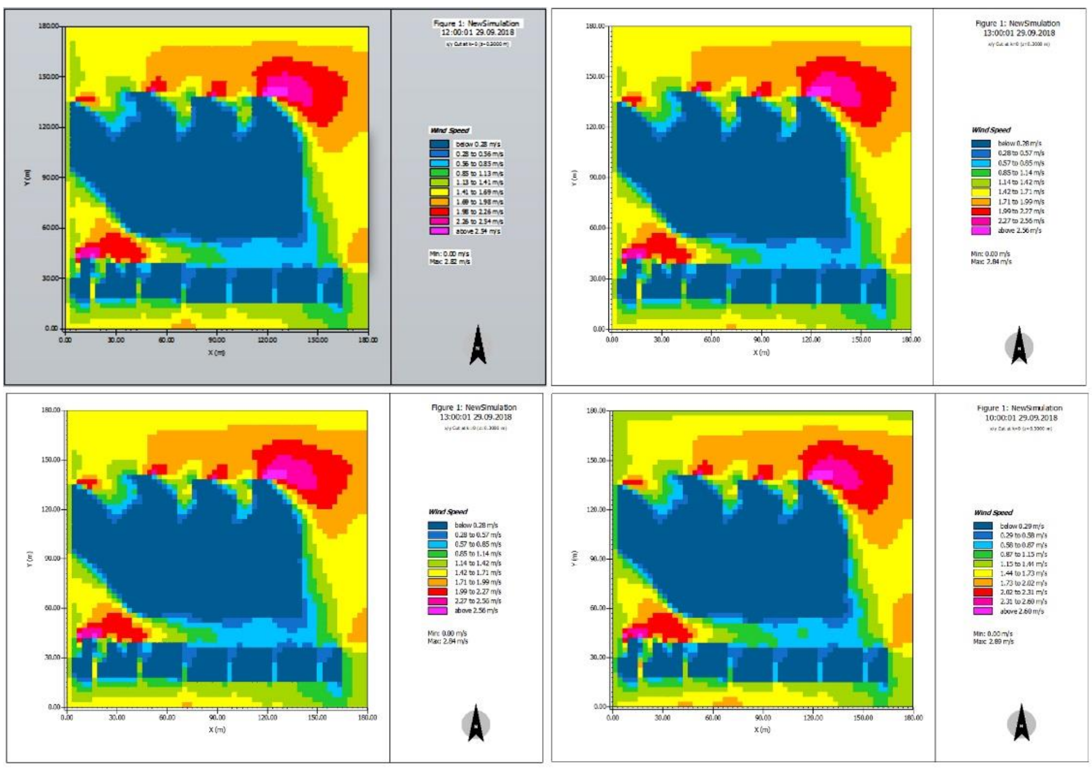


Figure 7. Base Case Wind Flow (Envi- MET software)

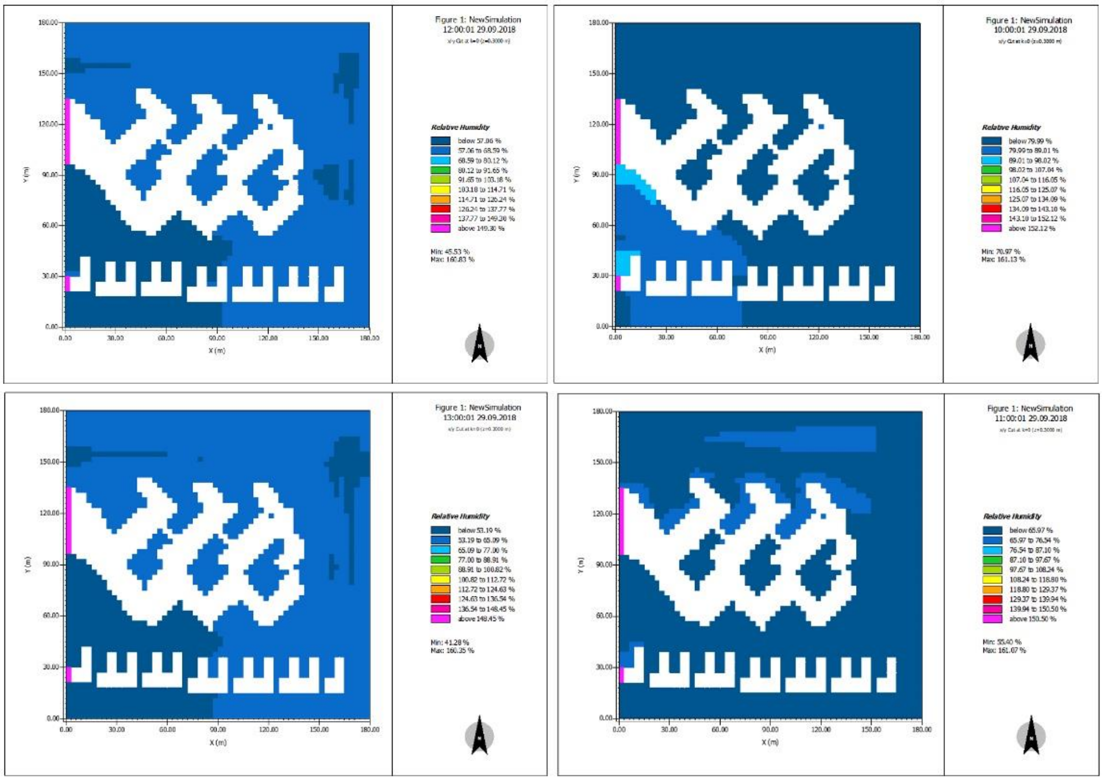


Figure 8. Base Case Relative Humidity (Envi-MET Software)

4.2 Revised Case Simulations

The simulation was conducted to improve the revised plan by orienting the buildings toward the north and vistas towards the northwest. The simulation was based on climatic analysis, incorporation details such as the sun path and the wind direction which is mainly from the north-west in Dubai. This will play a key role in enhancing the impact of the wind flow on-site, as orienting the sustainable corridor toward the northwest to maximize the generation of wind loops towards the central plaza and the community hall. Also besides, big trees will serve as a buffer to the penetration of sand-laden winds, protect the site from obstacles, and provide an acoustic barrier. Figure 9 presents the air temperature. The impact of the wind flow enhances the comfort zone between the villas which were also improved by the courtyard design. The orientation of vistas increases the wind speed to 6m/s. This will have a substantial influence on residents as it will relatively reduce temperature and humidity, encouraging them to walk and enjoy the fresh breeze between the buildings. Furthermore, adding trees and water features will reduce temperature and UHI. Open spaces and green areas are increased by 30% in the proposed design where the creation of a major central plaza, a walkable environment, and water features enhance livability and comfort in the community, as well as providing extra facilities and entertainment.

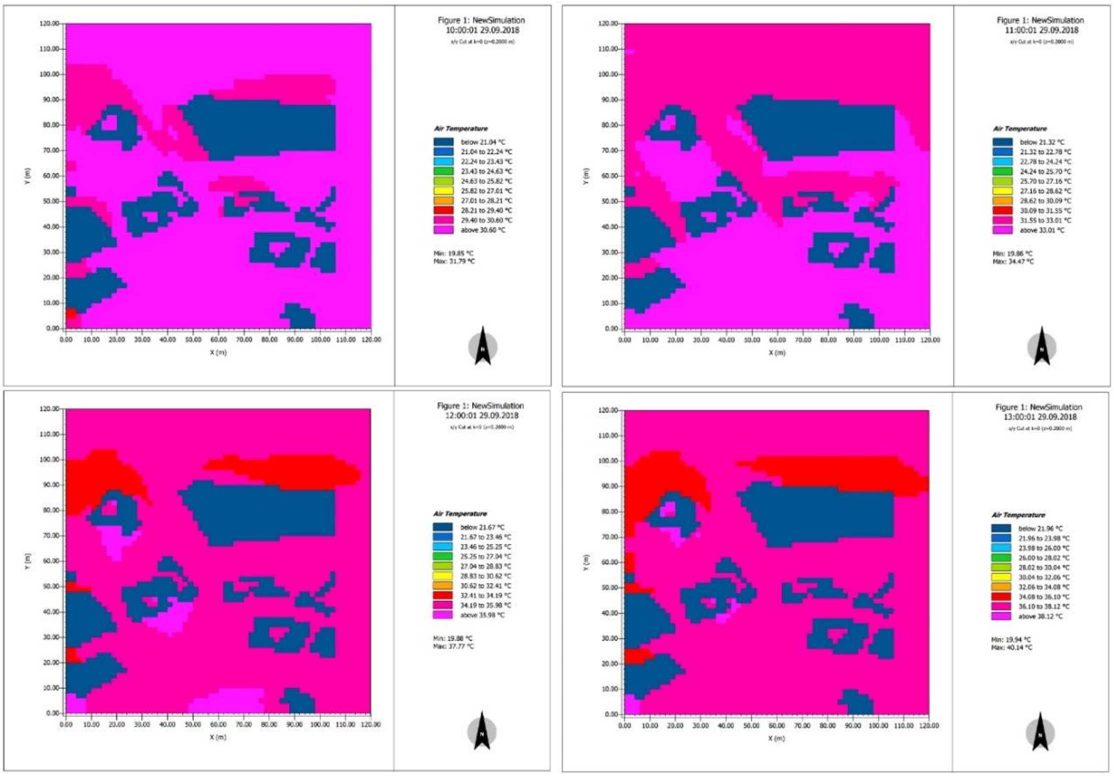


Figure 9. Revised Case Air Temperature (Envi-MET Software)

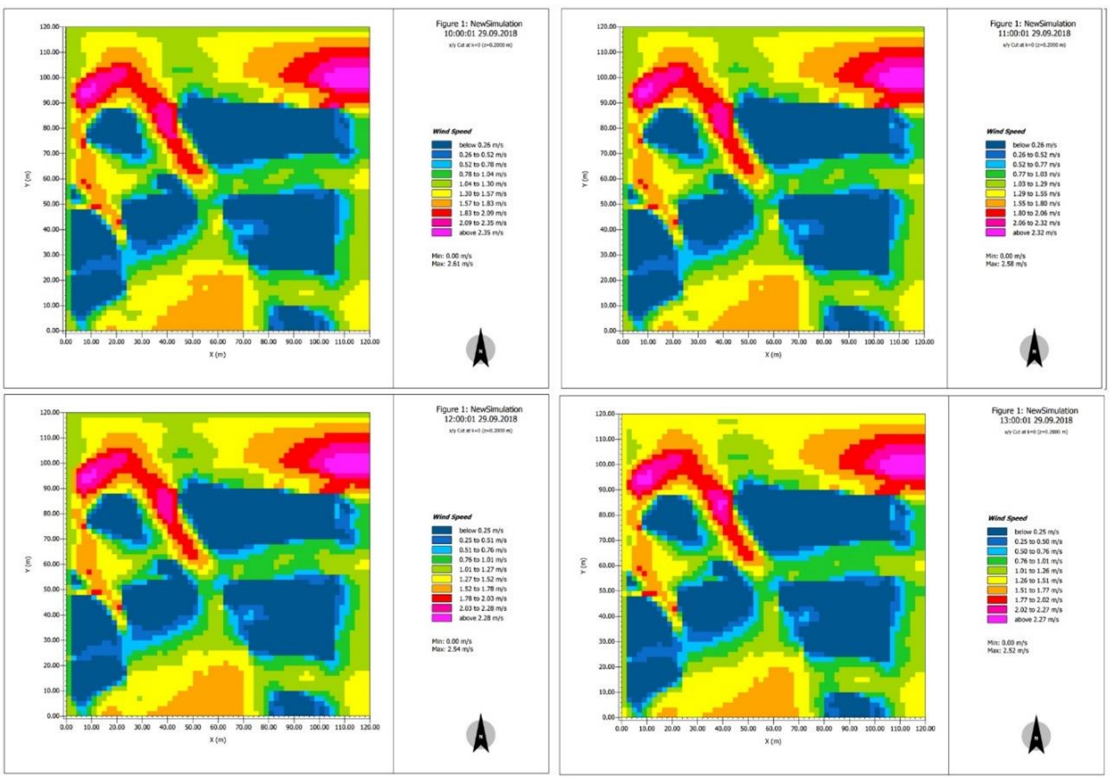


Figure 10. Revised Case Wind Flow (Envi-MET Software)

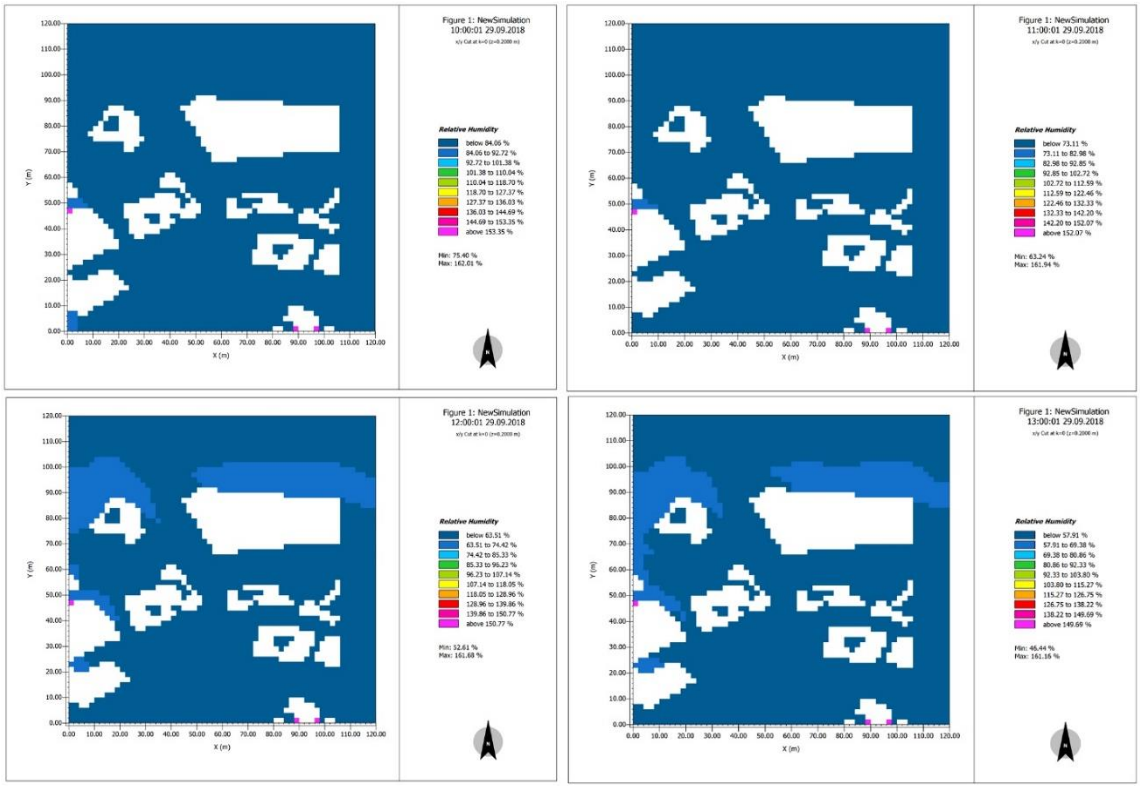


Figure 11. Revised Case Relative Humidity (Envi-MET Software)

4.3 Comparison between the Base Case and the Revised Case

Table 1 presents the maximum and minimum temperature, wind flow, and relative humidity in both the base case and the revised case. The average maximum temperature of the base case and the revised case are (32.35 + 36.55 +40.29 +42.34/4) 37.87 ^{0}C and 36.4 ^{0}C, respectively, which means that the average maximum temperature fell in the revised case by 1.47 ℃, or about 3.9%. The average maximum wind flow of the base case and the revised case are 2.7 m/s and 2.9 m/s, respectively, which means that the average maximum wind flow was enhanced by 0.2 m/s, or by 7.4%, in the revised case. The average maximum relative humidity of the base case and the revised case are 160.8% and 161.7% respectively, showing a 0.6% increase in the relative humidity in the revised case, which is explained by the introduction of water bodies. Unfortunately, the aim was to lower relative humidity. However, all other factors were improved.

Table 1. Comparison between the Base Case and Revised Case

	Time	Maximum Temperature (^{0}C)	Minimum Temperature (^{0}C)	Maximum Wind flow (m/s)	Minimum Wind flow (m/s)	Maximum Relative Humidity (%)	Minimum Relative Humidity (%)
Base Case	10:00 am	32.35	19.65	2.89	0.00	161.13	70.97
	11:00 am	36.55	19.85	2.84	0.00	161.07	53.40
	12:00pm	40.29	19.88	2.82	0.00	160.83	45.53
	13:00 pm	42.34	19.93	2.94	0.00	160.35	41.28
Revised Case	10:00 am	31.79	19.85	2.61	0.00	162.01	75.40
	11:00 am	34.47	19.86	2.58	0.00	161.94	62.24
	12:00 pm	37.77	19.88	2.54	0.00	161.68	52.61
	13:00 pm	40.14	19.94	2.52	0.00	161.16	46.44

5. Conclusion

To conclude, time and scale factors play a key role in the early stages of master planning. They help to ensure compliance of the holistic vision with human requirements and with saving the environment for coming generations by a more considerate rapid growth and the introduction of new technologies, without ignoring the legacy and values that have shaped our communities. Analytical research on the “Heartland” urban community in Dubai involved studying the existing microclimatic performance to provide a baseline that could be incorporated into the proposed design to increase the three pillars of sustainability in the neighbourhood: Environmental, Social and Economic aspects. The research yielded many notable findings. For example, the revised case improved two key aspects: (1) the average maximum temperature fell by 1.47 ℃ (or 3.9%) and (2) the average maximum wind flow was increased by 0.2 m/s (or 7.4%). However, although the average maximum relative humidity increased by 0.6%, such a minor drawback was expected due to the introduction of water bodies.

Finally, it is recommended that different aspects be assessed and researched in future. These include: (1) carrying out similar research in different parts of the UAE; (2) applying passive cooling to urban communities outside the UAE; (3) continuing to develop new passive cooling strategies; (4) studying the effect of the performance of the new microclimate on energy consumption at the building level.

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