

The new central business district in Abu Dhabi; high-rise buildings and sandstorms

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Abstract. The new Central Business District (CBD) of Abu Dhabi to be constructed in its desert hinterland is planned as part of the 2030 vision to reflect the image of a global city, and to attract investors through creating a district similar in its skyline to Manhattan, London, Paris, Singapore and Hong Kong. The location and site context that is surrounded by desert warranted that we conduct experiments in an environmental wind tunnel with sand in to predict the patterns of movement of sand around these high-rise buildings in order to simulate sand movement patterns and how they may affect the urban context of the CBD. Wooden blocks replicating high-rise buildings were arranged in different layouts to quantify and minimize the environmental impacts of sandstorms around CBD high-rise buildings. This study evaluates the amounts and distribution of sand on the ground around the buildings. Initial findings highlighted that combining low and high buildings arrangement improved the environment around buildings and reduced the amount of accumulated sand, in addition the experiments offers solutions to reduce the amount of accumulated sand around the buildings, simply by adding a fence/wall in front of the buildings.

1. Introduction

Urban planners, designers and engineers are challenged when it comes to constructing high-rise buildings in desert environment. Oil rich states such as the United Arab Emirates and its capital cities like Abu Dhabi and Dubai compete to attract investors, diversify their gross domestic product and in the process are expanding beyond the boundaries of the coastline inwards in the desert as part of their plan to emerge on the global city's network map; New York, London, Paris, Singapore, and Hong Kong etc. Urban sprawl and the emergence of new satellite cities in the desert such as Khalifa City, Mohammed Bin Zayed City and the new Central Business District (CBD) are planned on western schemes to foster multi-cultural expatriate communities. These new satellite cities include wide avenues and high-rise buildings which are different from typical densely planned Arab medina(s) with low rise courtyard houses, thick windowless walls and narrow shaded pathways. Little of Abu Dhabi's historical built heritage remains which facilitated planning according to western modules, even in the downtown area that was planned in the 1970's by Abdulrahman Makhlof, the grid street pattern, superblocks and concrete towers reflect many ideas of the 'International Style' and are considered to be Abu Dhabi's modern heritage [1]. In the downtown area building heights relate to environmental considerations, through locating the highest buildings adjacent to civic and open spaces, this is similar in principle to Frederick Law Olmsted's location of New York's Central Park in the middle of city surrounded by high-rise buildings to allow the cool breeze to flow across landscaped areas and to



reduce the heat island effect [2].

Sandstorms are one of the major problems that have significant environmental and economic impacts in many countries. Sandstorms impacts are more pronounced in urbanized areas [3-8], as they can cause high levels of pollution and damage to the main facilities and infrastructure (e.g. roads, railway, and power lines). They can cause also tremendous road hazards and accidents due to the formation of thick blankets of sand on the roads, disturbance of transportation systems including diversion and cancellation of flights, and closure of schools, universities, business and public services [9,10]. It is necessary to distinguish between sandstorms and dust storms. In deserts, where there is very little dust, the initial dust cloud is blown away and dust particles may rise to a height of 1000 m [11,12]. Soon after the dust is blown away, one can observe a thick low-lying sand cloud driving across the town with a clearly marked upper surface about 0.9-1.2 m above the ground. Hence, wind transports sand by saltation and surface creep, and dust particles by suspension [13-15]. The main objective of this study is to propose methods for better planning of urban areas subjected to sandstorms to minimize their environmental impacts. An experimental study was conducted in a wind tunnel using physical models consisting of array of buildings to investigate the effects of key factors such as buildings height, configuration, spacing and fences in controlling sand pollution in urban areas. The study evaluated the amounts and distribution of sand on the ground around the buildings. The study aims at finding the optimal buildings configuration that minimizes sandstorms pollution effects, and focuses on sandstorms or more specifically on movement of sand particles by wind and their impacts on high-rise buildings in the desert hinterland of Abu Dhabi.

2. Literature review

Abu Dhabi's strategic plan to emerge on the map of global cities is heavily dependent on the construction industry [16]. This is evident from the rapid urbanization of Abu Dhabi's islands such as Al-Reem, Al-Maryah, Al-Saadiyat and Yas Island in addition to new satellite cities such as Khalifa and Mohammed bin Zayed (figure 1). Many projects integrate in their design the environmental context such as Masdar City while neighborhoods such as the new Central Business District (CBD) are planned to have towers with high density office and residential spaces constituting around 3 million square meters of mixed use spaces beyond the Abu Dhabi Island. The CBD plan exhibits high-rise buildings arranged in a radial formation around a central space emulating Haussmann's plan of Paris especially the Champs-Élysées. Haussmann's plan is revisited in the CBD within a modern context as new technologies allow higher buildings and reflect the vision to create high concentrations of office use with the intention of rapid development (figure 2). High-rise buildings in the CBD reflect the notion to construct a city image of Abu Dhabi as the forthcoming national center of finance and in the process has perhaps become more visually connected to outside world than to its peripheries and desert hinterland [17]. As Kevin Lynch highlighted the city is perceived as a built image, here Lynch's 'landmarks' are implemented as singular objects that serve as general public as reference points and



Figure 1. High-rise buildings and sandstorms Mohammed Bin Zayed City - Abu Dhabi.

also serve as new spaces to be enjoyed by a certain social group [18]. In reality, these elements in the built environment are interdependent and overlapping. In combination, they provide a city's overall image. These new landmarks that are looked upon as signs of modernity have become distinctive signs of a new Abu Dhabi emerging as competitor with high-rise buildings arranged according to a specific hierarchy [19].



Figure 2. Abu Dhabi new Central Business District.



Figure 3. Landscape elements and diversifying building heights used as protection from sandstorms.

In desert environment the main issue for high-rise buildings is to shelter from sandstorms especially in towers that use extensive glass surfaces on their facades. Offer different scenarios for the layout of high-rise buildings and protecting them through provisions such as small gardens, trees and walls when designed correctly can create shelter and reduce the force of sandstorms (figure 3). This also can prove effective in reducing the negative impact of sand abrasiveness on glass facades. Therefore, studying the wind dynamics and wind rose in Abu Dhabi can determine wind patterns, direction and utilize wind cooling effect and reduce dependency on mechanical systems. Regional building traditions have used wind for ventilation for centuries, today such traditions are revisited by Foster and Partners in Masdar City which manifests one of the examples in which wind tunnel tests can be used to simulate the wind movement and simulate wind resistance along facades of buildings. Masdar also represents a medium of educating the community as a living experience that links theory to practice. This is manifested by the facades of many of its buildings such as the Siemens Headquarters, the Incubator Building and Masdar Institute that revisit presidents of desert architecture [20-22]. The design of the new CBD can benefit from such new interpretations of traditional building forms in desert environments, as fundamentals for sustainable design coupled with the warranted image of modernity. The CBD is planned to predominantly reflect a certain image of Abu Dhabi as global city as manifested by the planning of extensive numbers of office building towers located around concentric circles. Therefore, studying the sand movement patterns in wind tunnels is essential to provide recommendations for the reduction of the negative effect of sand accumulation and to counter the harsh climatic conditions of the site of the CDB.

3. Methodology

The methodology involves sand experiments to evaluate the sand pollution around array of buildings made from wood using an environmental wind tunnel 8.4 m long with a test section of 1.2 by 1.2 m (figure 4). The sides of the test section 2.4 m in length are made from acrylic panels for ease of monitoring. While the floor is lined with wooden platforms to place and secure the building models, level the floor, and feed and trap the sand. Velocity around the buildings was obtained using a telescoping hotwire anemometer inserted in holes distributed uniformly on the top acrylic sheet of the test section. Four industrial pedestal fans at the entrance of the tunnel each has a diameter of 0.76 m and a maximum speed of 1400 rpm are used to generate wind in the tunnel. The procedure was same for different experimental runs, where the proposed physical buildings were placed in the model section and the sediment feeder was filled with the experimental sand. The fans were switched on at full speed of 1400 rpm and kept running until the sand patches around the buildings reach a quasi-equilibrium condition, when their shapes do change considerably with time. The operation duration of the runs varied from 7-9 hrs, depending on the time required for each run to reach equilibrium. Pictures were taken periodically during the run to record the sand patches patterns around the buildings and the fences. After completing each run, the fans were stopped and the sand around the buildings and in the sediment trap downstream of the buildings were collected via a vacuum cleaner and weighted. The wind tunnel was cleaned from the sand before the starting of the next run [23].



Figure 4. The environmental wind tunnel.

4. Results

Four experimental runs were conducted in the wind tunnel using uniform sand of mean diameter of 0.17 mm and physical models consisting of array of buildings to evaluate the amount of sand around the buildings. The first run (SE1) was conducted with staggered array of buildings of the same height (figure 5A). The second run (SE2) and third run (SE3) were conducted with the same array of buildings used in run SE1. However, a V-shape fence with an angle of 90° , side length of 70 cm and height of 5 cm was placed in front of the buildings in run SE2 (figure 6A) and the last row of building was removed in run SE3 (figure 5C). The fourth run SE4 was conducted with staggered array of low and high-rise buildings (figure 5D). In figure 5, the dimension of the base area of the short buildings and tall buildings was $10 \times 10 \text{ cm}^2$, while the height of the short and tall buildings was 25 and 60 cm, respectively. The spacing between the buildings in the transverse and the longitudinal directions was 14.5 and 12.5 cm, respectively. The different runs were conducted with a constant air flow rate of $7.462 \text{ m}^3/\text{s}$ and mean velocity of 5.86 m/s. The duration of the runs varied from 7-9 hours depending on the time required for the sand patches around the buildings to reach a quasi-equilibrium condition, when their shapes do change considerably with time. Figure 3A shows the sand patched developed around the buildings for run SE1. It can be seen from the figure that the sand was concentrated more between the last two rows of the buildings. It can be seen also that the sand patches were formed in

front and behind the first row of buildings and only behind the buildings in the middle rows. Similar sand patches were observed on run SE4 as shown in figure 5D. However, less amount of sand was accumulated around the buildings. Adding the fence in run SE2 reduced the amount of sand formed in front of the first row, while removing the last row of buildings in run SE3 reduced the amount of sand formed in the last two rows of the buildings as shown in figures 5B and 3C, respectively. Although, the fence reduced the amount of sand formed in front of the first row, it can be seen in figure 6B that a lot of sand was accumulated in front of the fence.

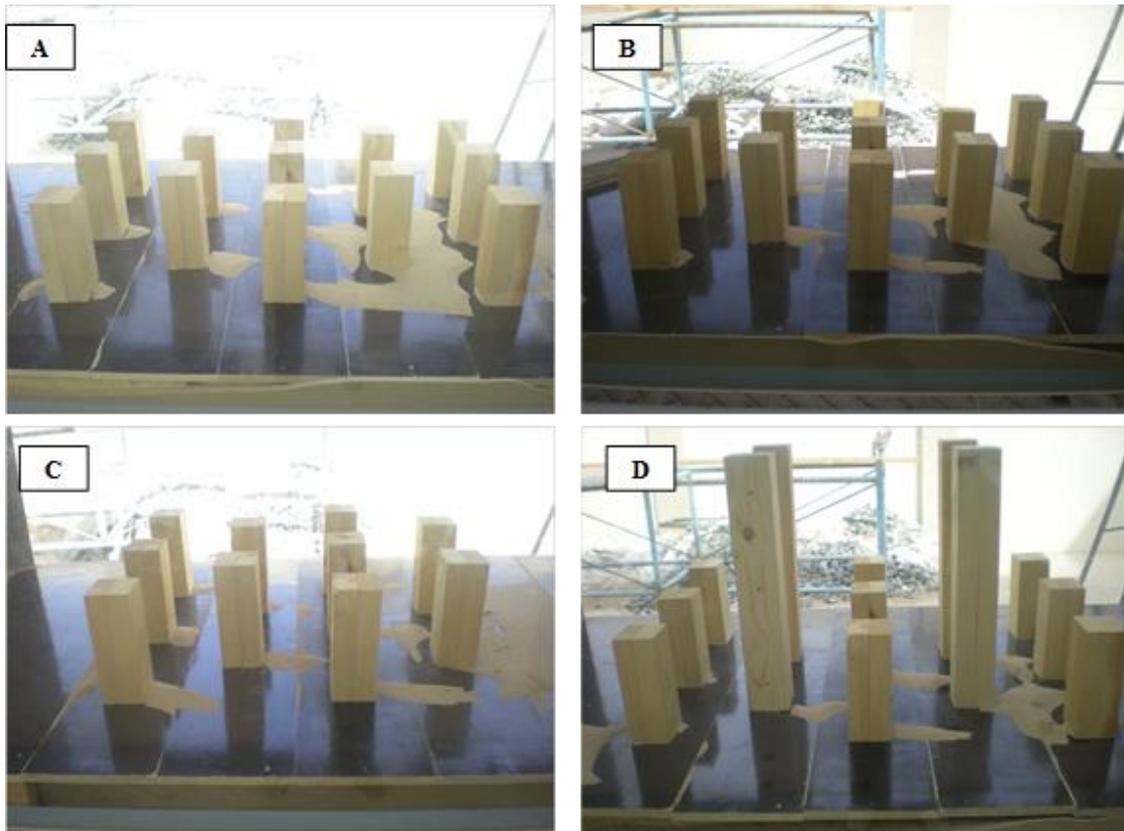


Figure 5. Sand patches developed around the buildings in different runs: A) SE1; B) SE2; C) SE3; D) SE4.



Figure 6. Experimental run SE2 with a fence in front of the building: A) Experiment arrangement; B) Accumulated sand in front of the fence.

Table 1 summarizes the total amount of sand accumulated around the buildings for different runs and the total amount of sand passed the buildings and collected in the sand trap. It can be seen from the table that the amounts of sand accumulated around the building to the total amounts passed the buildings were 31% for run SE2, 6.7 for run SE3, and about 10% for runs SE1 and SE4. For all the runs, the total amount of sand around the buildings was between 0.5 and 1.2 kg. This proves that the arrangement and spacing of the buildings were optimal and effective in minimizing the sand pollution around them. Combining low and high buildings in run SE4 improved the environment around buildings and reduced the amount of accumulated sand by 17% compared to run SE1 with the buildings of the same height. Removing the last row of the buildings in run SE3 reduced the amount of accumulated sand around the buildings by 34% compared to run SE1. Adding the fence in run SE4 provided the best results by reducing the amount of accumulated sand around the buildings by 59% compared to run SE1. However, a lot of sand was accumulated in front of the fence. Thus, although the fence improved the environment around the buildings significantly, most probably it will affect the environment upstream the buildings.

Table 1. Summary of the experimental results.

Run	SE1	SE2*	SE3	SE4
Sand around the buildings (kg)	1.2	0.5	0.8	1.0
Sand passed the buildings (kg)	11.9	1.6	12.1	9.1
Percent of sand around the buildings to passed amount	10.1	31	6.6	11
Percent of sand around the buildings of a run compared to SE1	100	41	66	83

* The amount of sand accumulated in front of the fence and behind it were 5.98 and 0.78 kg, respectively.

5. Conclusion

The urban sprawl of Abu Dhabi into its desert hinterland is expected to provide new job opportunities, diversify the gross domestic product and reshape the image of Abu Dhabi from a desert transit city to a sophisticated urban environment that offers a modern lifestyle with high-end recreation with dining and shopping amenities. The new Central Business District of Abu Dhabi is planned to reflect the image of a modern Arab City, and to attract investors through iconic high-rise buildings that are planned along the lines of Haussmann's Paris. However, planning new urban expansions in desert environment is challenging to designers especially because they need to balance between the need for spectacular architecture warranted as a catalyst for investment, spaces of attraction of investors, expatriate communities, and the limitation caused by the harsh desert environment and limited water resources needed to shape fundamental landscape. This warrants studying of sand patterns for the protection of high-rise buildings and their surrounding amenities. In this study, experiments were conducted with sand in an environmental wind tunnel using physical models consisting of array of low and high-rise buildings to quantify and minimize the environmental impacts of sandstorms around buildings. The study evaluated the amounts and distribution of sand on the ground around the buildings. The proposed buildings arrangement and spacing proved to be optimal and effective in minimizing the sand pollution around the buildings. Combining low and high-rise buildings arrangement improved the environment around buildings and reduced the amount of accumulated sand by 17% compared to the run with the buildings of the same height. Adding a fence in front of the buildings provided the best results by reducing the amount of accumulated sand around the buildings by 59% compared to the run with the buildings of the same height. However, a lot of sand was accumulated in front of the fence. Thus, although the fence improved the environment around the buildings significantly, most probably it will affect the environment upstream the buildings.

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