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Architectural design solutions for combating dust storms in residential buildings (case study: Abadan City, Iran)

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Abstract

The practice of developing urban areas without considering climate factors has contributed to global warming, increased drought, changed the pattern of rainfalls, magnified the effects of storms and in cases, paired them with dust and particle pollutants. Considering the large share of residential spaces in the urban fabric, it can be argued that revising the design methods used in residential buildings may contribute to the quality of life for the residents, improve environmental conditions, reduce energy consumption and control pollution levels. One of the main environmental issues in the dry and humid cities of South-western Iran is the winds carrying particles and dust. Therefore, in designing residential buildings, priority must be given to the factors that help combat the unpleasant effects of dust storms and particle pollution. By studying the prevailing desirable and undesirable winds blowing into Abadan city, collecting and analyzing the structural and design data from a sample group of residential buildings located in the historic fabric of the city, and by considering the latest technological advances which help to improve the quality of life for the residents in dust-prone areas, this study suggests several solutions that offer the best combination of form and direction in planning residential spaces to preserve the natural structure of the city and minimize the unwanted effects of dust storms. Recommended design solutions include methods of optimizing ventilation in the building's open spaces and corridors, paying attention to the orientation of the building's site and optimization of the building orientation relative to the desirable and undesirable winds, careful planning of the location of windows and openings, the use of wind deflectors and re-designed wind towers.

Keywords: Abadan, Climate, Residential architecture, Environmental quality, Particle pollution

1. Introduction

Dust storms and particle pollution are among the most destructive environmental issues that today, due to the close and direct relationship between their occurrence with climate change and global warming, call for promoting the practice of designing climate-friendly habitats. Given Iran's geographical latitude range which stretches from 25° 3' to 39° 47', and considering the overall dry and semi-arid climate of over 2/3 of its area, it is of utmost importance to provide the people with favourable environmental conditions, especially in residential developments. To further zoom in, given the proximity of the southern and southwestern parts of the country to the sources of dust storms in the Persian Gulf region primarily located to the west and south-west of Iran's borders, and considering the low average annual rainfall of $342^{mm}/_{year}$ in Khuzestan province (IWRM website, 2020)which is not enough to help settle the dust, improvements in designing residential buildings can be an effective step in reducing the problem of particle pollution which disrupts people's everyday lives. The city of Abadan is one of these southwestern cities in which improvements in the design of residential buildings can effectively reduce the effects of undesirable dust-carrying wind and at the same time, utilize desirable wind for natural ventilation. In line with the goals of this paper, which is to identify and recreate climate-compatible design methods for residential developments to combat the unwanted effects of dust storms and particle pollution, this study takes an investigative look into the environmental performance of the design methods and models used in the old residential fabric of the city, the prevailing desirable and undesirable winds blowing into the city throughout the year, and combined with the theoretical foundations for climatic design strategies, proposes design solutions that can help with optimization of residential developments in terms of environmental efficiency.

2. Theoretical Foundation

2.1 Quality of the Environment in Residential Spaces

Space that is designed as residential should be in direct contact with its surroundings and provide residents with a desirable environment. Housing design methods can add value to their surroundings, or reduce it if they are undesirable (Prinz, 2016). Adding quality to spaces designed for residential use encompasses a wide range of factors. Considering the damages caused to human health by dust storms and the consequent disruption of the lives of ordinary citizens, the environmental quality of residential spaces and design methods, along with other spatial, physical and social attributes, must be addressed thoroughly and design models should be determined according to the climate factors of cities to reduce the effect of dust particles.

In areas with dust storms, people's social activities outside their homes are inevitably limited to urgent and essential matters, which means that the interiors of homes

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and complexes may become the only spaces in which they can rest and relax, carry out social interactions and enjoy leisure activities. By relying on climate-friendly design principles and certain architectural solutions to mitigate and control the effects of dust storms, architects and designers can be largely successful in increasing the scope of people's activities over a wide range of hours within residential spaces (Bahraini and Khosrawi, 2015).

2.2 The Role of Climate Change in Designing Residential Spaces

Studies on climatic models have shown a temperature increase of 0.3 to 0.6 degrees Celsius in the nineteenth century and predict that by 2100, a temperature increase of 1 to 3.5 degrees Celsius should be expected as a prominent feature of climate change (Varesi and Khosrawi, 2007). Climate change in the last few decades has had significant effects on human life and has lowered the environmental quality of human settlements by reducing rainfall, increasing droughts, weakening vegetation and bringing dust storms and particle pollution (Talebzadeh, 2015).

In designing residential spaces, human response to global warming and climate change can be effective either by adapting to the new conditions or by reducing their adverse effects on the quality of life (BMZ, 2012). As shown in Figure 1, "Climate-friendly design" as a sub-category of "environmental sustainability" is at the core of sustainable development and its methods of preserving and improving environmental quality through the use of environmental technologies can play a role in reducing the impact of particles in residential spaces (Hirmandi Niasar, 2016).

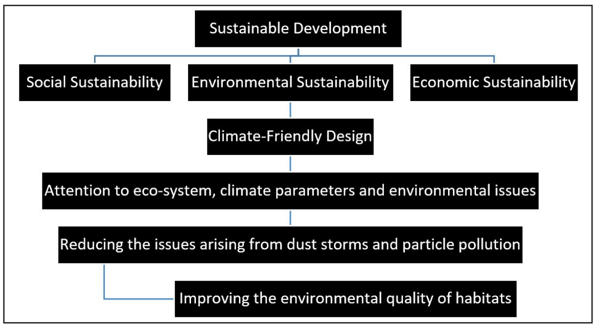

Figure 1. The Position of Climate-Friendly Design among Sustainable Development Issues (Hirmandi Niasar, 2016).

2.3 Materials

In the first stage of this case study, the current climatic features of the area have been studied and analyzed particularly concerning the issue of dust storms. Secondly, the historical climatic conditions were studied to trace back and understand the traditional methods used in the region's vernacular architecture to combat the dust problem. It was concluded then, that based on the currently available evidence and considering the aggravated problem of the dust storms both in their intensity and in frequency paired with the increasing temperature in the urban fabric, the traditional methods, despite their usefulness, cannot address the contemporary issues single handedly. They cannot also respond to the modern expectations from residential buildings nor in aesthetics neither functionality. Consequently, by studying and understanding the available technological advancements and modern solutions and fusing them with the features of vernacular architectural models used in the old fabric of the area, this study has tried to offer a solution compatible with the requirements of the modern urban fabric of the city.

3. Discussion: Site Analysis

According to the Iranian Meteorological Organization's website, Abadan is located at 30° 19' 57" N,48° 18' 8" E, and is elevated by 6.6 meters above sea level. Abadan Peninsula with its geographical location map shown in Figure 2 extends approximately 84 km from north to south along the two rivers of Bahmanshir and Arvandrood. The peninsula varies in width from 6 to 30 km (Zameni, 2015). Being part of the Khuzestan Plain, this peninsula features warm and humid climates of the southern coast of Iran and in part, shares the warm and dry central plateau climate, meaning that in general, it has a warm and semi-humid climate (Pourvahidi, 2010). Figure 3 offers a brief overview on the climatic conditions of Abadan from 1980 to 2016.

Figure 2. Location of Abadan city (Google maps).

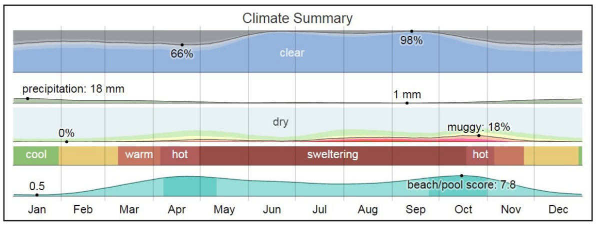

Figure 3. Climate Conditions of Abadan in Brief 1980-2016 (weatherspark.com, 2020).

Along with the severe heat and sunshine, high humidity, very low rainfall, and relatively low vegetation, winds carrying dust and particles are also considered to be among the unfavourable climatic phenomena in Abadan city. Studies have shown that with the arrival of the dust wind stream into Abadan, the density of the particles reaches 9360 micrograms/m^3 which is almost 40 times greater than the pollution standards and makes it a serious environmental threat. As such, adverse environmental effects such as general air pollution as well as the prevalence of respiratory, gastrointestinal, heart disease and other illnesses paired with lack of sunshine cannot be ignored (Tarkashvand and Kiani, 2017).

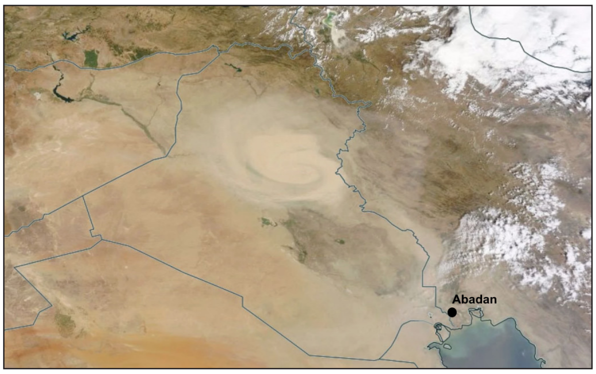

Figure 4. The dust storm, captured by NASA satellites. (NASA).

Microscopic dust particles that are lifted from drought-prone areas can travel more than a thousand kilometres through the wind to other areas. Figure 4 shows an example of dust storm formed in Northern Iraq and captured by NASA satellites. The northwest winds, as well as the wind coming from the western region of Baghdad and Hoor al-Azim, have been identified as major forces of dust storms in southwestern Iran, especially during the summer months (Mofidi and Jafari, 2011). Studies have shown that the most frequent occurrence of dust storms in the southwestern part of Iran, including Abadan, takes place during summer and decreases in spring, winter and autumn respectively. The highest rate is in mid-July and August and then in June (on average about 15 days) and the lowest in mid-December to mid-February. The highest intensity of dust and particles have been recorded between 9 am and 6 pm, usually followed by a gradual decrease in the amount of dust, and the lowest rate is recorded late at nights and early in the mornings (Azizi et al., 2012).

It should also be noted that the reduced field of view caused by high dust levels shortens the hours of outdoor activities as well as the presence of people outside their homes. This means that the leisure time for families gets almost eliminated, which in turn may have detrimental effects on people's mental health.

To achieve a proper design model that can address the issues caused by the dust phenomenon, the condition of the winds blowing into the city, especially the prevailing wind, must be examined.

The Wind Rose of Abadan city illustrated in Figure 5 shows that the winds are mostly blown in from the northwest, west and southeast of the city, classified into three general groups as per the following:

1. The Northwest wind is the Prevailing wind in the city, which is referred to as the North wind by the locals and blows during almost all months of the year. The constant dry wind that drives the Mediterranean flows into the city generally lasts for 9 months, and peaks from mid-June to mid-September. During some summer months, especially from mid-June till late July, the north wind lowers the intensity of mid-day humidity and makes the heat more tolerable compared to August and September which are characterized by high winds and humidity. The persistence of the wind is higher in late March to mid-June and its speed reaches its peak in summer. Another important point is that for most of the year since the wind passes through arid and hot regions, it is often associated with dust and particles, which greatly reduces the quality of the city's air.
2. The winds coming from the West of the city called "Samoum" or "Sam" are the second most frequent winds and blow in from the Saudi Arabian deserts with a high concentration of soil and sand and every once in a while, pollute Abadan's air in the early hours of the morning. Due to the intense heat that it carries, this wind may cause dehydration for a lot of residents, particularly when it is paired with severe sunlight. In recent years, these winds carrying dust and particles have been reducing the environmental quality of the city and disrupting living conditions.
3. The South-east wind is one of the most significant winds. Since it passes over the Persian Gulf, it brings in high humidity levels and is referred to as the "temperate wind".This wind is desirable from late winter to mid-spring as it blows into the city like a cool breeze and due to its humidity, it is often combined with clouds, fog, and even rain. The highest intensity of this wind is between mid-March and mid-May. But the same wind, with the advent of the hot summer months, especially in August and September, becomes an undesirable one which in combination with the high temperature, causes dramatic changes in the city's air. This may cause breathing difficulties and respiratory problems for the people.

Paying attention to the angular range and direction of the prevailing winds into the city as per the Figure 6 can help in choosing the optimal direction of the passages and buildings to improve the environmental quality of the residential fabric and increase the comfort level of the residents.

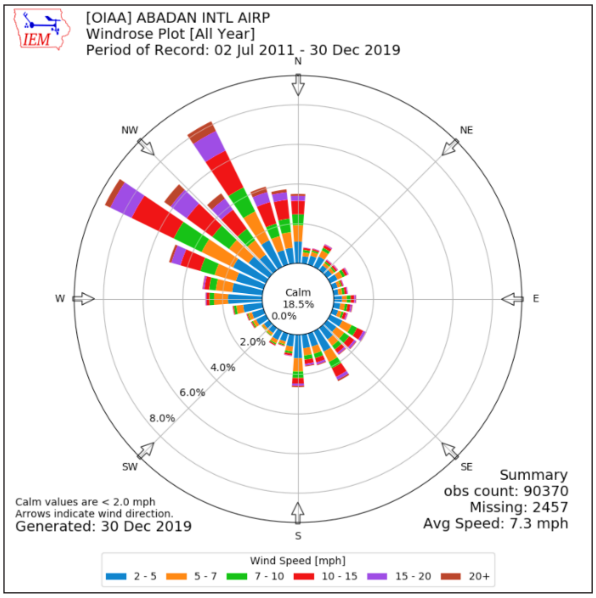

Figure 5. Speed and Direction of Wind in Abadan, 2011-2019 (Iowa Environmental Mesonet Website, 2020).

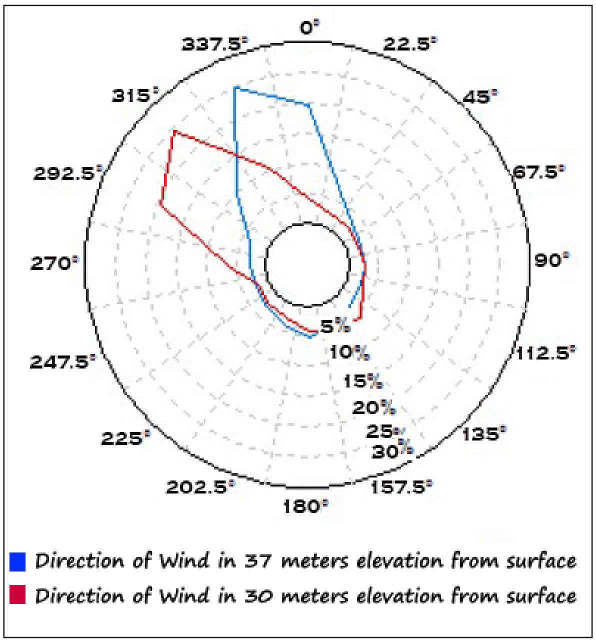

Figure 6. Direction of prevailing winds blowing into the city (Nedaei, 2012).

3.1 Role of the Wind in Designing Residential Spaces

How winds blow is influenced by the velocity, direction, intensity and quality of the airflow, and pollutants they carry. Their impact on the environmental quality of residential spaces has long been in direct contact with the urban built environment formed by the combination of mass and open spaces. The more the structure and composition of the built environment are in line with the information obtained from the city's Wind rose, the better the productivity of desirable winds and the less the impact of adverse winds. If buildings are of non-similar position and altitude in residential areas, they interrupt the direction and velocity of the airflow that will disturb residents in corridors -and even indoors-, while they inadvertently concentrate or release pollutants, reduce the thermal comfort of people and increase the costs of heating and cooling systems in buildings (Khodakarami and Asgari, 2014).

Figure 7 shows the effective range of winds on the ventilation relative to the two fronts of a given rectangular building. The maximum impact of wind on indoor airflow is when the wind angle relative to the building is between 45 and 90 degrees. If the wind blows at less than 25 degrees to the building, it will not affect the flow and the wind cannot penetrate the building (Afshari, 2012). In such a case, the building is said to be "in the shadow" of the wind, which is the best position in order to shield the building from the undesirable wind.

Wind Towers(or windcatchers) are among the most prominent examples of integration of wind in the design of traditional Iranian residential spaces and have been designed and implemented for centuries in different shapes and structures for ventilation and cooling in hot and dry or humid areas. The first examples of these Wind Towers date back to about 1,200 years ago in hot and dry regions of Iran, and later on, they spread to other countries in the Middle East and Egypt.

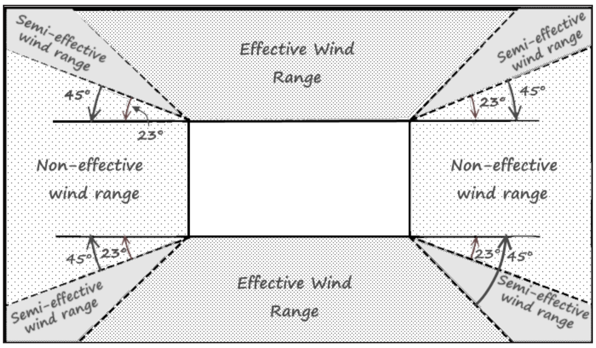

Figure 7. The effective range of winds on the ventilation relative to the two fronts of a rectangular building (Afshari, 2012).

Wind Towers come in 4 main categories:

1) One-sided Wind Towers, 2) Double-sided Wind Towers, 3) 4/6/8-sided Wind Towers, and 4) Cylindrical Wind Towers. As urban spaces in Abadan began to develop mimicking the western styles, the use of wind towers like the ones in the cities with similar warm and humid climates, such as Bushehr and Band Abbas, became less frequent. As we will discuss the matter further, it can be claimed that applying wind towers and modifying their mechanism to suit the climate of the city of Abadan will significantly improve the volume of natural ventilation in buildings. At the same time, it should be noted that the traditional wind towers, while effective to some extent, we're not flawless. If used in contemporary design, they need to be re-calibrated to meet the current climate conditions of each region. Possible flaws which need rethinking include:

1. Possibility of small birds and insects entering into the wind tower and subsequently, the building,
2. The uncontrolled entry of dust and particles into interior spaces,
3. Static nature of the crater structures and the lack of the possibility to turn the structure toward the Prevailing wind in different months,
4. Spatial limits; Limited number of Wind Towers can be used in a building,
5. Inefficiency; Some of the air may flow in and out of the Towers without getting into the building,
6. Low performance in areas with very low wind speed, and
7. Severe erosion against rain, wind and sun.

3.2 The role of wind in the design of the historical fabric of the city

Our field study on the design models and architectural methods used in the historical fabric of the city indicates that in the old days, since the winds carrying dust and particles did not constitute a major issue, climate-friendly features used in the buildings were aimed at boosting ventilation, maximizing the natural airflow, and reducing the heat and humidity inside the buildings. However, no measures were taken to combat dust and particles as the levels of dust were much lower.

3.2.1 General spatial structure and design features of the historical fabric of the city

Table 1. General spatial structure and design features of the historical fabric of the city.

Structure and Design Feature	Implementation Quality	Advantages and Disadvantages
Spatial Density	Semi-dense with high spatial extent	Advantage: Increases the chance of ventilation and reduces humidity
The ratio of the width of corridors to the height of walls	Relatively High	Advantage: Higher ventilation, Lower humidity Disadvantage: Uncontrolled natural light, requires shading
Dominant orientation of buildings and corridors	East-West	Advantage: Proper intake of sunlight and desirable wind
The volume of Green and Open Spaces (Private and Public)	High	Advantages: High per capita green space /High density of vegetation / Preservation of biodiversity / Strengthening the morale of the residents / Humidity and Temperature adjustment /Satisfaction of the residents
Number of floors	Few (1 or 2)	Advantages: Appropriate population density in residential areas / Lower Heat Island effect usually caused by activities of refineries and petrochemical complexes
Height of interior spaces	Relatively high	Advantage: Increases the chance of ventilation and reduces the temperature Disadvantage: Heating becomes difficult during winter
The ratio of openings to the surface of buildings	Relatively high	Advantage: Ease of airflow and natural ventilation to reduce humidity and temperature Disadvantage: Unwanted absorption of more heat during the warmer seasons of the year

3.2.2 Traditional small-scale design models in the old fabric of Abadan city

Below are the most significant design features in the old fabric of the city which encourage better ventilation and counter the heat and possibly, humidity:

1. Large windows at the bottom and smaller openings on top of them. As pictured in Figure 8, smaller openings are located underneath the ceiling to vent the warm air out (In recent years, all of these ventilation openings have been blocked due to heavy dust).

Figure 8. Openings for inflow and outflow of the air.

2. Positioning the rooms with high ceilings aligned with the direction of the wind and limiting the height of the buildings to two stories which will not block the wind, for better use of the airflow.
3. Narrow windows and openings designed to facilitate two-way ventilation and lower humidity. These are covered by wood, plaster or brick netting to create shade while allowing the airflow to pass through.
4. Use of aerodynamic surfaces in some parts of houses (especially in the Southern Buvardeh neighbourhood, as shown in figure 9) to direct the wind to the openings as much as possible.

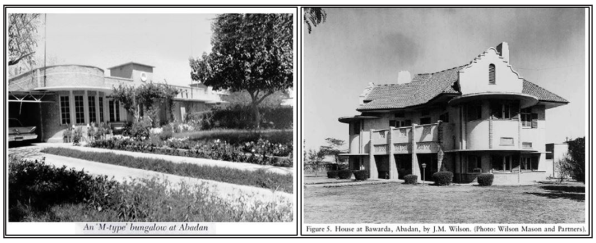

Figure 9. Aerodynamic surface to direct wind (Abadantimes Website, 2019).

5. Combining shades with airflow by expanding the ceilings and porches and lattices of the porch to allow the wind to pass through and reduce the temperature of the air flowing into the interior. Examples of this can be seen in figures 10 to 12..

Figure 10. Lattice of porches (Abadantimes Website, 2019).

Figure 11. Arches of the entrance porch.

Figure 12. Shades over the northern façade at the building's entrance, Fabric of "Bahmanshir"1950´s (PMDC, 2020).

6. Maximum use of green spaces: In designing the old residential fabric of the city, pictured in figures 13 and 14, British designers tried to implement the Garden City model. Making maximum use of vegetation for the comfort (physical and mental) of the residents, along with the low density of buildings and the ability to spend leisure time around the residential fabric, have played an important role in reducing temperature and humidity.

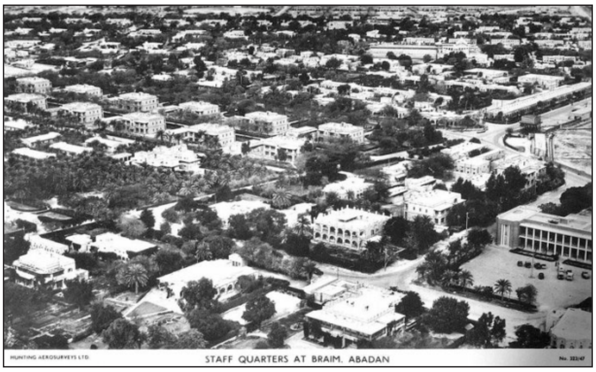

Figure 13. Fabric of "Braim" neighborhood - 1950´s (PMDC, 2020).

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ABADAN—THE FRUIT OF BRITISH INDUSTRY THAT PERSIA COVETS.

ABADAN FROM THE AIR, LOOKING NORTH-WESTWARDS. THE SHATT EL ARAB AND ITS JETTIES LIE TO THE LEFT, THE FOREGROUND BEING DOMINATED BY THE ANGLO-IRANIAN OIL CO.'S BAWARDA HOUSING ESTATE. THE TOWERS AND CHIMNEYS OF THE REFINERY RISE IN THE RIGHT BACKGROUND.

Abadan, the world's greatest oil refinery and the plum which the Persians are expecting to fall into their hands, is a monument of British private enterprise and industry. In 1929 it was not even marked on the latest maps of the Persian Gulf. It is now a city of 40,000 inhabitants, the centre of which is the huge refinery plant of the Anglo-Iranian Oil Co., built to handle the oil from the Persian oilfields. Not only has the company supplied the *raison d'être* for the town, it has also built the majority of it, together with such important amenities as hospitals, schools, technical colleges, clubs, sports grounds and cinema. The two aerial views reproduced on this and the facing page are taken from different angles and are complementary. The town fronts on to the Shatt el Arab River, whose other bank is in Iraq. The refinery area stretches from the jetties on the river frontage, between two creeks, which run beside storage yards; and in this section also lie a native non-company area and, on the other side of the plant, an area of British and Persian bachelor quarters. South of this section lies the Company's Bawarda area, a large estate of British and Persian family houses for staff. In this area can be seen a swimming pool and tennis courts.

Figure 14. Fabric of "Braim" neighborhood - 1950´s (PMDC, 2020).

4. Solutions

Considering the desirable and undesirable prevailing winds, the main design features of the old residential fabric of the city which have been abandoned due to the increase of dust and particle in the wind, and in line with the need of the residents to enjoy residential spaces with desirable environmental quality in the currently unfavourable climatic conditions suffering from the effect of dust and particles, the following solutions are suggested:

1. Improvements in design and organization of open spaces and corridors: It is best to build corridors parallel to desirable winds to attract and direct them to target spaces. At the same time, corridors that cross the wind's path can provide shelter against dusty winds and reduce the rate of intake of pollutants. In Abadan, due to the high humidity in summer and the need for airflow to reduce humidity, it is recommended to use passages with near-perpendicular angles along the winding paths, so that while the distribution of wind is carried out in a controlled manner, entry of particles and dust pollution is also minimized. The location and dimensions of the squares and intersections, which attract the wind and divide it into adjacent corridors, also depend on various factors such as wind speed, direction and angle, shape and dimensions of squares and intersections, and network structure of the crossings which connect to open spaces, that must be designed and structured according to the wind situation in the city.

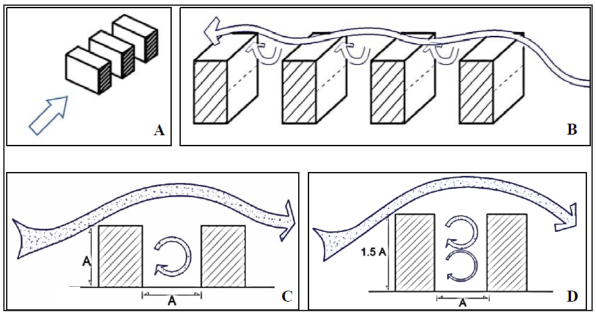

Figure 15. The rotation of the wind in different modes of corridors crossing and blocking the wind's direction (Abbaszadeh et al., 2014).

As per the illustration in Figure 15, the higher the ratio of height to width of a corridor, the better the protection against dust, while increasing the number of rotations at the cross-section and decreasing its intensity at lower rotations also prove beneficial. The optimum width to height ratio for reducing dust is between 1.5 to 1~ 2.5 to 1 (Abbaszadeh et al., 2014). To reduce the speed of the wind which carries dust and decrease the concentration of pollutants, it is advisable to gradually increase the width of the corridors relative to the crater or to change the width of the corridor in different places. Considering the intensity of sunlight in Abadan, the ratio of width to height of 1 to 2 ~ 1 to 4 is suggested (Abbaszadeh et al., 2014).

2. Appropriate orientation and form of building masses on site: Important spaces should be located on the opposite side of the building which is shielded from the dusty wind. Due to the association of wind speed with the deposition of dust particles, and the decrease in air velocity on the opposite side of the building relative to the wind, the suspended particles remain sediment and will not be transferred to other parts of the site. Otherwise, important spaces should have properly filtered openings. Placing buildings in the shade of the undesirable wind will be another way to deal with the negative effects. Proper design and alignment of building blocks relative to each other can, even in the absence of sufficient airflow, create high-pressure and low-pressure areas in different parts of the structure, enabling accelerated airflow and better ventilation.

3. Paying attention to the structure of building blocks relative to the open spaces: Generally, in the warm and semi-humid region of Abadan, the semi-dense, semi-enclosed fabric and the relative interconnectedness of the construction blocks seem to be the most appropriate form of climate-friendly urban design. To control the winds carrying dust, the positioning of the taller building blocks should be carefully planned. Given the effect they have on the absorption and distribution of the winds blowing above the surface of the residential area, they must be placed on the edge of intersections and open spaces.
4. Optimal orientation of buildings relative to the wind: To decide on the optimal orientation of buildings to reduce the unwanted effect of winds carrying dust, attention to the direction of winds alone is insufficient. The climatic condition of the city which makes higher radiation and moisture loss in residential areas inevitable must also be taken into consideration; this means that airflow, especially in the summer, along with the reduction of the effect of the particles, is necessary. The proposed angle of orientation of the building as demonstrated earlier in Figure 7 covers a range of east-west up to 22.5 degrees southeast.

   However, due to the adverse conditions caused by winds carrying dust on the indoor air quality, some spaces can be re-orientated following the pattern of the wind-flow and the openings can get rotated to fit the desired angle of solar radiation relative to the building block.
5. Revising placement of windows and openings: Windows and openings should be moved away as far as possible from the walls facing the dusty winds, or get reduced in number and area on this front and get embedded on the opposite wall or at an angle opposite to the wind. Placing shades around the openings can also help reduce the impact of undesirable winds and improve the air quality inside the buildings.
6. Using external movable awnings: During a dust storm, awnings can allow the daylight in, while they are shut and prevent particles from entering the interior. These awnings can be made of opaque or thin glass material for the light to easily pass through.
7. Using wind deflectors: A wind deflector is most effective when it is 1.5 to 2.5 times the height of the building that it is protecting (Afshari, 2012). Studies have shown that a wall against the wind will reduce the wind speed by 15 per cent, and the maximum reducing effect over the wind by such a barrier equals 2 to 7 times its height. Also, to control the penetration of dust, a barrier of 1.7 meters high with a distance of fewer than 6 meters from the building can work effectively (Afshari, 2012). It should be noted that the windshield should not be completely impenetrable so that a low-pressure void will not be created on the less windy side of the building (Freidman, 2017). The density and structure of vegetation used as a wind deflector are the main factors that can reduce the severity of the devastating effects of dust storms. With proper design and layout, indigenous plants can provide spatial design and define margins for facing the winds, which considering Abadan's winds, can be suggested as per the Figure 16:

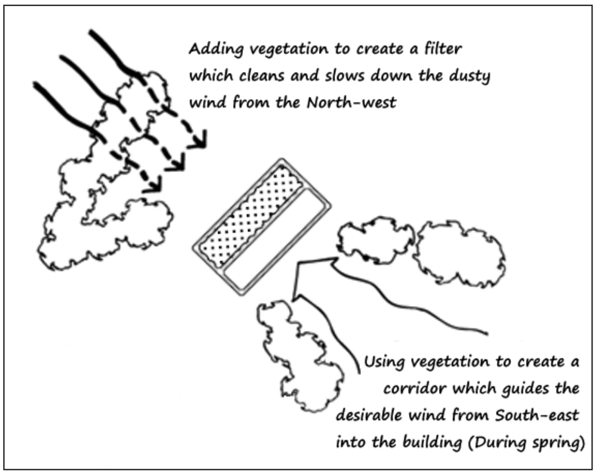

Figure 16. Low and high density of vegetation to control desirable and undesirable winds.

8. Designing an integrated shell in public spaces: This can stop or reduce the penetration of particles and dust. Such a facility could increase residents' willingness to be present in the building's outdoor spaces and promote leisure and social interactions between residents. These overall shells can be designed to incorporate transparent and non-transparent plates depending on the amount of light required in public spaces, and come with fixed and movable parts so that once the weather is fine, airflow from the outside will be possible. Examples of such shells have been well used in the Arab countries of the Persian Gulf to combat dust and particle issues by using the latest technology. These shells, illustrated in Figure 17, allow people to enjoy outdoor activities even in unfavourable climate and during dust storms.

Figure 17. Transparent overall shell in King Abdullah complex, Saudi Arabia (carloratti Website).

9. Using auto-cleaning glass and material: On a large scale, to reduce water consumption needed to clean surfaces from dust.

10. Using re-designed wind towers with filters: By combining the features of traditional wind towers with the world's latest technology, and with the correct orientation of the wind tower's openings, the wind can be trapped at optimum speed and utilized for natural and desirable ventilation. Wind towers can also operate as solar chimneys. Using innovative design methods, such as installing dark-coloured solar panels on the opposite side of the vent or by using a glass or transparent wall in the chimney body to absorb more heat, a warm air mass will be created at the top of the tower and as a result of the chimney effect, hot air gets directed outward from the building with better efficiency. Figure 18 shows the design for such a wind tower with wetted surface and a solar chimney. By improving natural ventilation in the warm months of the year which extend for a long time in the city of Abadan, will reduce the amount of energy used to cool the buildings.

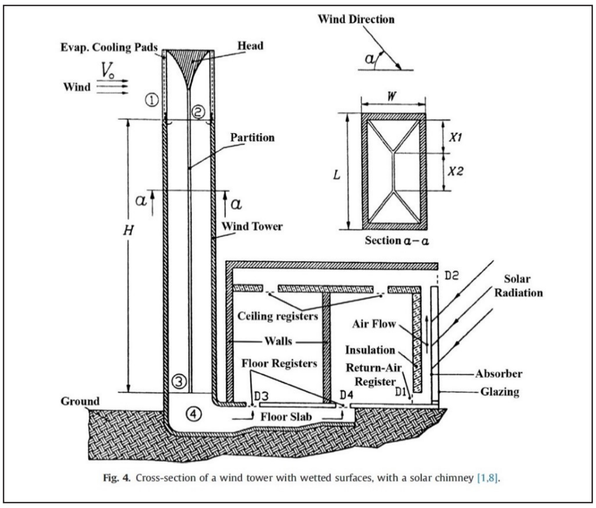

Figure 18. Wind tower with wetted surface and a solar chimney (Dehghani-Sanij et al., 2015).

On the other hand, given the high likelihood of the presence of dust and particles in the winds and the necessity of blocking them from entering the indoor space, the wind tower inlet vents must be versatile and allow opening and closing when necessary. There must also be a multi-stage filtering system mounted both at the inlet and on the walls of the tower so that clean and fresh air can flow indoors. To achieve this, redesigned wind towers updated with new technologies can be utilized which are more efficient in terms of climate-adaptability. Suggested solutions in redesigning different parts of the wind towers include:

Top of the wind tower: By incorporating a movable column or a hinge in the top part of the wind tower, this part, while separated from the body, allows the tower to be opened or closed manually or automatically, or get rotated depending on the climate, allowing it to rotate toward the prevailing wind depending on its direction. A weather vane can be used to correctly rotate the top part of the wind tower toward the desirable wind. It is best to design a pitched roof for the tower to prevent water and dirt from penetrating the structure during rainy days (Dehghani-Sanij et al., 2015).

Body of the wind tower: By using a reel mounted on the inside of the body of the wind tower, it becomes possible to easily rotate the wind tower's top part over its body toward the desired direction. Besides this, the placement of several filter sheets for fine solid particles and dust at different heights of the wind tower's body helps to better refine the quality of the air entering the building.

Openings of the wind tower: It is necessary to be able to open and close the vents using movable plates so that it will be possible to control the inflow of air. It is also advisable to use a fixed lattice plate to prevent the entry of small birds and insects (Dehghani-Sanij et al., 2015).

Samples of such redesigned wind towers are presented by Iranian researchers, two of which can be seen in Figure 19:

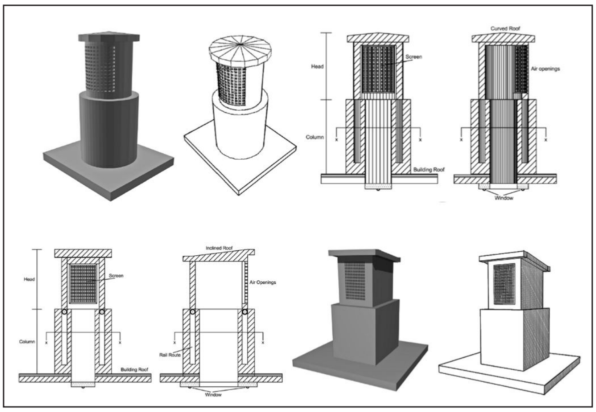

Figure 19. Sample of redesigned adjustable wind towers with filters (Dehghani-Sanij et al., 2015).

Due to the general form of wind towers in warm and humid regions of Iran, low, wide and short forms are recommended for the structure of the towers. However, in a more detailed view, wind towers' dimensions are affected by 4 factors:

1. The amount of airflow required for air conditioning and thermal comfort
2. Dimensions of the building and the building's material
3. Volume and intensity of the wind in each area
4. Security of the building (Dehghani-Sanij et al., 2015).

5. Conclusions

The study carried out on the design features of the historic fabric of the city shows that in the past, a good number of measures had been taken to utilize the wind for natural ventilation. Even though the city enjoys a good amount of natural airflow, the use of the wind towers and traditional design of openings have been abandoned due to their inefficiency against the increasing amount of dust and particles carried by the wind. To create an innovative model in all cities of this region with problems similar to that of Abadan's, integrating the traditional solutions with the latest technological advances can help in re-designing these particular features, such as wind towers, to promote eco-friendly and dust-free ventilation in residential buildings.

Other eco-friendly solutions suggested such as transparent shells and improved shading can help in controlling the intake of sunlight in public spaces of residential buildings and complexes.

Controlling the effects of particles and dust on the outdoor areas of residential buildings also allow people to enjoy being outdoors while the air quality is not within the comfort zone due to pollution. This leads to an increase in the hours of outdoor activity and allows optimum comfort and leisure time in a semi-outdoor environment.

The proposed solutions presented in this study are based on the integration of previous empirical research with the natural conditions of the city and the present problems caused by particle pollution and dust. The efficiency of each solution can be evaluated in future studies and become a foundation for generating innovative design models based on the climate of Abadan and similar cities.

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