Elements Affecting Windflaw in Urban Residential Areas

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Abstract - *Providing air is an important factor that will lead to achieve thermal comfort for humans, especially in residential areas in the Sudan as a developing country. Therefore, the study of wind pattern around a group of buildings in urban areas is one of important factors that ensure the penetration of air and ventilation to each building in particular, the residential areas. Knowing the behavior of air movement around a group of residential buildings will be one of the factors, which should be taken into consideration by both planners and architects during the planning process for any residential area, and during the architectural design process of residential units.*

This paper discusses elements, which effects on airflow and wind movement in residential areas in Khartoum, these elements are working as wind brake and prevent the ventilation access to houses, these elements represented in vegetation, the terrain, the water surfaces, and the big and tall buildings.

The wind movement (the speed and the direction) is affected by many elements, some are natural elements, and other are manmade elements, the wind can be directed to the houses by the specific arrangement of these elements.

The main objective of this paper is to study the behavior of wind around residential areas in Khartoum, exactly the third class neighborhoods, and the elements affecting wind flow. The paper concluded that, there are important requirements should be examine during planning process, which are, height of buildings, distance between them, Angle of the skewed building, the shape of building roofs, the width of the streets, the height and shape of plants, and the location of the residential area.

Key Words: **Airflow, Natural ventilation, air movement, residential areas, urban planning, architectural design**

1. INTRODUCTION:

1.1. Climates and humankind

The most important elements of climate effect humankind and interact with built forms are Radiation, Air temperature, Humidity, Air movement. Sunrays are among the basic elements of the formation of climate. According to variation in elements of climate, the climate varies from place to another.

Climate also affects life of humankind and his daily activities directly; therefore, the bigger challenge to humankind has been his effort to cope with natural climate.

Through time and with scientific and technological advance, the environmental phenomena has been understood, the shelters has been developed to provide a suitable internal climate.

Elements of climate interact with built forms and affect their thermal performance.

1.2. Characteristics of climate regions:

Climatic regions have been studied in this section, in order to know the general behaviour of wind and air movement. The interaction of the direct sunrays with the surrounding atmosphere, relief variation and the distribution of land water surfaces lead to many climatic variations in different regions. Based on variations in the rates of the main climatic elements, climatic regions can divided in to four, each has subdivisions:

1.2.1. Equatorial climate.

The wind here often found in one direction or mostly tow direction, its speed increases and may reach up to 30 m/s.

1.2.2 Tropical climate:

Tropical climate divided into four main sections: the first is a Hot, dry and desert climate, the second is, Hot and humid climate, the third is, Composite climate, Fourth one is, Tropical climate of high lands.

1.2.3. Moderate climate:

Moderate climate divided into four, first one is, Climate of the Mediterranean Sea.

The second one is, Marine and moderate climate. The third one is the continental and moderate. The fourth one is, Climate of moderate grass, Climate of moderate grass situated far from the marine effects and are beyond the reach of wind.

1.2.4. Polar Climate:

Polar climate divided into three main groups, the first one, Cold or Semi Polar Climate. The second one is, Polar Climate. The third one is, Climate of ice cover.

This type of climate existing in different regions in world, Khartoum town characterized by desert climate and composite climate. The predominant wind in the Khartoum is the dry north east in the period between November and June in the year

2. WIND CHARACTERESTICS:

2.1. Atmospheric boundary layer (ABL):

When we talking about wind studies, it is important, to have a thorough Understanding of the region of the Earth's atmosphere under consideration.

The Atmospheric Boundary Layer (ABL) can be divided into two distinct regions, the first one is the Interfacial layer that is the lowest region of the ABL and Ekman layer, which is above the interfacial layer, the Ekman layer begins and makes up the remainder of the ABL, which are shown in figure 1.

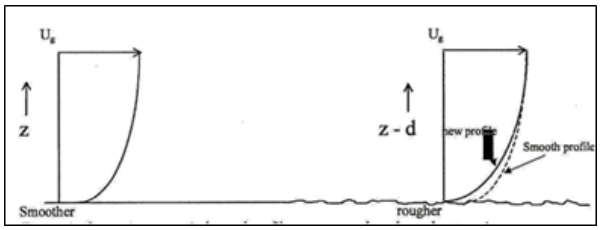


Fig -1: shows the interfacial layer and Ekman layer [1]

2.2. Mean Wind speed Profile in the ABL:

In the Ekman layer, the mean wind speed is negligible; it has not significant effects in the low-rise buildings.

In the interfacial layer, wind is more significant exactly in the urban areas .Therefore; the interfacial layer would have significant depth. [1]

There is a different in the mean wind speed profiles in the area of high-rise buildings and the area of the low-rise buildings. [1]

The different surface roughness causes the different mean wind speed profiles which being produced as demonstrated in figure2. [1]

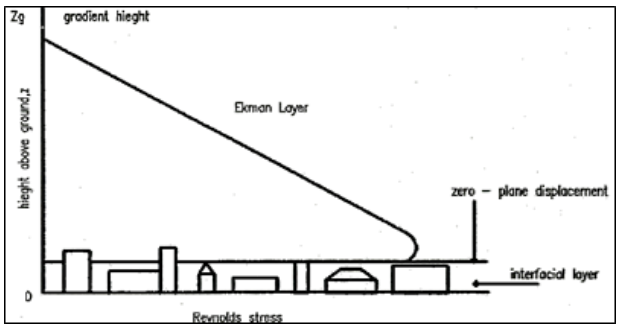


Fig -2: shows how wind speeds close to ground level are faster for smoother surfaces than at the same height for rougher surfaces (however, the depth of the ABL remains constant). [1]

2.3. Global wind pattern:

Winds are named according to the direction, which they blow from, and there are six main wind types, which the globe is surrounded by. Three of them located in each hemisphere from pole to equator they are the polar easterlies, the westerlies, and the trade winds. All of them move north in the northern summer and south in the northern winter. The following paragraphs explain them.

The global wind pattern is also known as the "general circulation" and the surface winds of each hemisphere are divided into three wind belts:

1- Polar easterlies.
2- Prevailing Westerlies.
3- Trade wind.

Trade wind blow mostly from the north east toward the equator, its located south of about 30º the northern or northeast.

There are other subtypes of global wind between the main types, which is have variable direction and characteristics, which mentioned in the following figures:

Sudan affected by the trade winds on most days of the year.

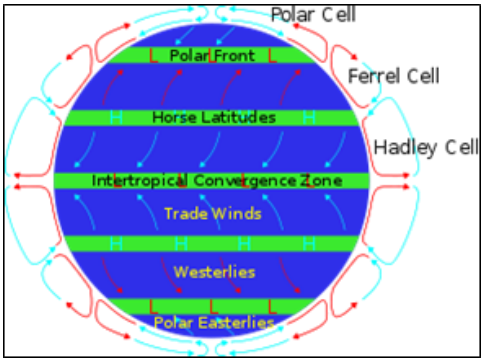


Fig -3: shows types of winds surrounded globe

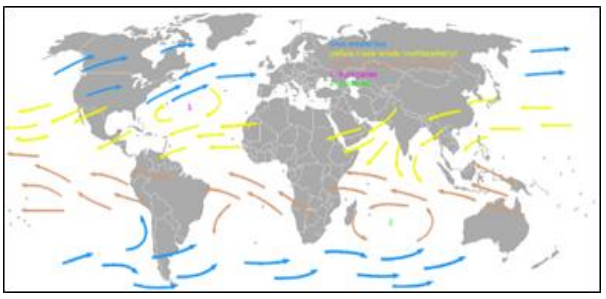


Fig -4: shows types of winds surrounded globe
Blue = westerlies. Yellow = trade wind (northeasterly).
Broun =trade wind (south easterly)
1 = hurricanes. 2 = cyclones

2.4. AIR MOVEMENT:

Wind is the moving air, it is known by the direction where it comes from. Its direction changes from a moment to another and from season to season.

Wind moving along the earth's surface is of different types - the permanent and the semi-permanent blowing in a planetary form such as the local wind (monsoon) that does not exceed specific areas.

There is also the daily wind that blows in regular times and directions.

There is also the wind that is not restricted by specific times or routes, known as tropical storms.

Table -1: wind speed and its effects on land. [2]

No	Chrematistics according to Beaufurt scale	Wind speed	Effects of wind on land
0	Quiet weather	Zero -0.2	Vertical and higher rise of smoke
1	Light wind	0.3 – 1.5	Wind direction is identified by movement of smoke
2	Light breeze	1.6- 3.3	Hiss of leaves and the feeling of the face
3	Quite breeze	3.4- 5.4	Movement thin branches and leaves
4	Moderate breeze	5.5-7.9	Rise of dust- movement of tree branches
5	Zephyr	8.0- 10.7	Swing of mellow bushes
6	Strong wind	10.8- 13.8	Whiz of electrical wires
7	Gale	13.9 – 17.1	Movement in the street becomes difficult
8	Stormy wind	17.2- 20.7	Branches get broken and movement becomes difficult
9	Storm	20.8- 24.4	Occurrence of some glitches on the ceilings
10	Strong storm	25.5- 28.4	Roots of trees get pulled
11	Cyclonic storm	28.5- 32.6	Serious destruction
12	Tomado	32.7and above	destruction

Wind, regardless of its types, is one of the elements that affect the formation of climate in the various regions. The movement of wind basically results from the difference between high air pressure and low air pressure, as wind travels from areas of high air pressure to area of low air pressure. The rotation of the earth a round its axis and around the sun, and the exposure of the northern part and southern part of the earth respectively to the direct rays of the sun would result in change of wind route. [2]

Some changes in the direction and speed of wind may happen due to the geographical variations in the structure of the earth's surface, land and in water surfaces and relief. [2]

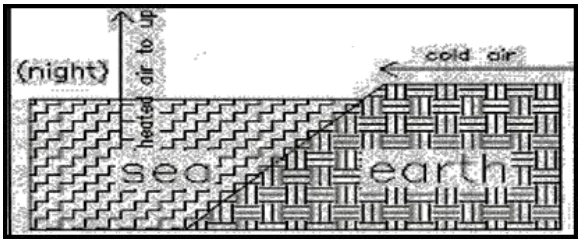


Fig - 5: shows contrast in wind movement because of variation in temperatures. [3]

During the day, air temperature function either surfaces increase, resulting in the rise of water surfaces, which are replaced by relatively cold wind blowing from the sea.

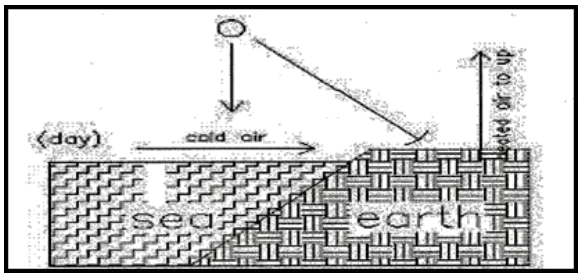


Fig -6: shows contrast in wind movement because of variation in temperatures. [3]

During the night air temperature function water surfaces increase, resulting in the rise of water surfaces which are replaced by relatively cold wind blowing from the earth. [3]

2.5. Importance of air Movement:

The thermal comfort of humankind related to the movement of wind and air speed in urban areas. Therefore, it was important to study the chrematistics and ways of wind movement for ideal distribution that can allow for the transmission of air through all building and allow for the provision of the needs of thermal and health comfort of humanity. [3]

2.6. The air movement in urban areas:

Urban areas have a significant impact on metropolitan regional wind patterns in two ways:

First: when regional wind currents are calm, the urban heat island effect, active mostly at night, causes centripetal wind patterns moving from areas of low density to areas of high density. These winds can be significantly stronger than those of the surrounding countryside can. [4]

Second: because areas of higher development density produce and store more heat during the day than low density areas, and retain it longer, the temperature differential between high density areas and the surrounding countryside increases as the surrounding areas cool at night. Wormer polluted city air then tends

to rise, creating a negative pressure that sucks cooler air from the city perimeter toward the center.
Both of these effects, which are particularly pronounced on calm summer nights, can potentially be utilized to help flush dense areas of heat and pollutants. [4]
Two main urban design elements are required:
First: a band of undeveloped, preferably vegetated land at the perimeter that can serve as a cool air source.
Second: wide corridors to provide a pathway for the air to move from less dense to more dense areas.
This or boulevards a system of linear greenways or boulevards in a converging organization, with one or more centers. [4]
According to that, and as a rule:
A: the vegetated avenues caught be used and open linear parks of 100 m (320ft) or more in width to enhance urban cooling on calm nights.
B: orient some of these wind corridors parallel to the prevailing breezes to bring width deep in to dense, built - up areas.
C: locate the corridors to connect perimeter greenbelts with centers of built - up density.
D: the area of greenbelt should be 40 - 60 % of the size of the urban area to be cooled.
F: to minimize wind velocity reduction in urban environments, organize streets and blocks in to neighborhoods spaced perpendicular to summer, winter winds, and interspersed with open spaces of 400 x400 m (1300x1300) minimum size, which allow wind to reach its unobstructed velocity. [4]

3. EFFECT OF PHYSICAL ELEMENTS ON THE AIRFLOW:

To provide efficient natural ventilation for thermal and health comfort in buildings depends on the formation, type, speed and behavior of airflow around the building.
These aspects of airflow are affected by the natural and made environment around the settlement and buildings. [5]
The elements, which effects on the airflow, can be mentioned below:

3.1. Influence of sun on airflow:

The main factor effects on the air flow is the sun, the different heat gains of earth, plants, made environment, seas ….etc from direct sun rays causes differentiations on the air pressure levels. [5]
The air flow is related to these differentiations for this reason the changing angles of the rays according to seasonal and daily positions of the suns and sun exposures of buildings are important for the efficient airflow. [5]

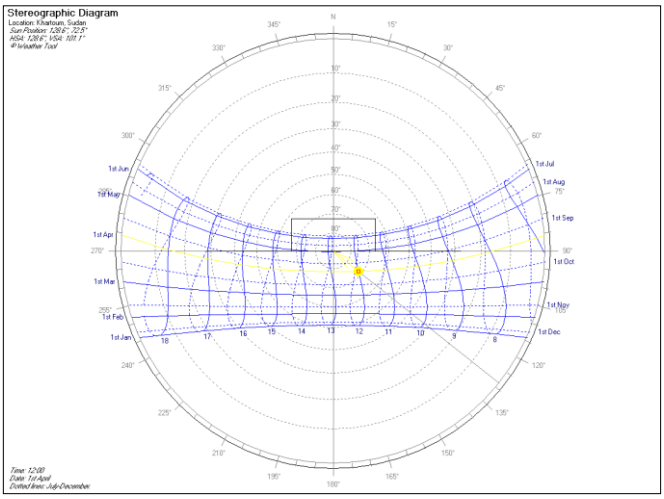


Fig -7: sun path for Khartoum, Sudan

3.2. Influence of the barriers on airflow:

In the normal situation, airflow moves from the high-pressure (positive pressure) zone to the low-pressure (negative pressure) zone. The figure (8)&(9) show that.

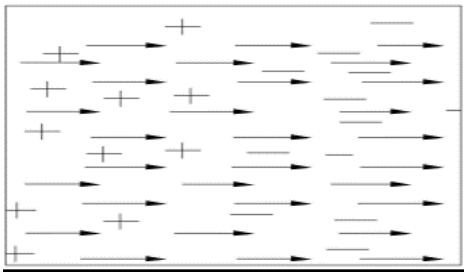


Fig -8: direction of the airflow [5]

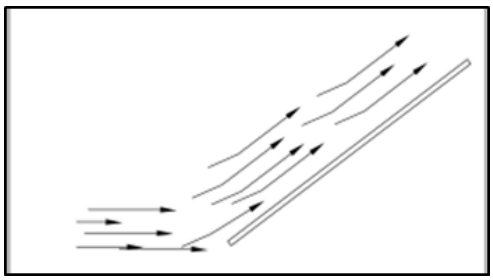


Fig -9: direction of the airflow [5]

In case of appearance of barriers on the path of airflow, its direction cans changes according to the size and the angle of the barrier. [5]
We do not know in which distance the airflow can return to its normal situation after the barrier.
Figure (10) illustrates that, the air returns to its original path and direction after a short and close distance when it collides with a small barrier with a cute angle. [5]

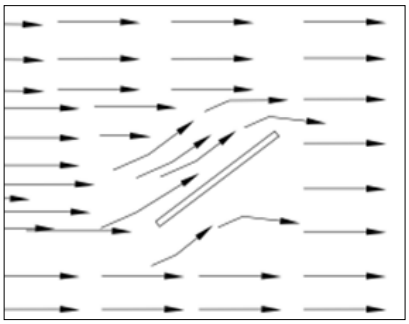


Fig-10: air pattern a round small barrier [5]

Fig -11: pressure zone around barrier [5]

The figure (11) shows that, when the air collides with a barrier at a right angle, the negative pressure zone is formed behind the barrier, resulting in turbulence flow and air dispersion behind the barrier. [5]

Narrow gaps affect airflow, as air loses pressure and gains more speed see figure (12). [5]

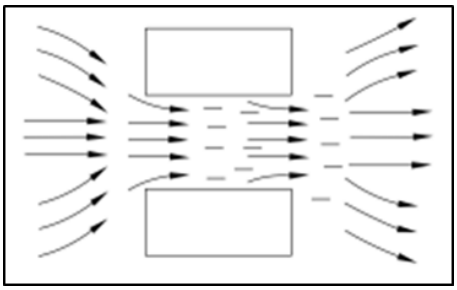


Figure -12: narrow gap effect [5]

The topographic features around urban areas affect the formation, speed, type, air direction and pressure levels. It also affects the dispersion of air around the buildings.

The buildings positioned in a bowlike area cannot benefit from airflow due to the topography. Figure (13). [5]

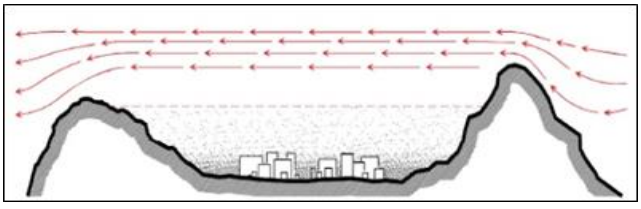


Figure-13: airflow and a settlement in a bowlike area [5]

The efficient of natural ventilation in areas like this affected by height and distance between the hills.

In mountainous areas and terrain areas, the temperature of the lower parts, which are not exposed to direct sunlight, is less than the temperature of the upper parts. So air moves from the bottom to the top during the day.

At night, the upper parts lose heat faster than the bottom parts, and the air moves from top to bottom at night [5] , this illustrated in figure (14, 15).

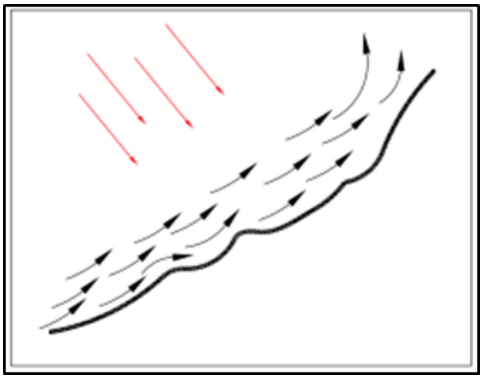


Fig -14: airflow during daytime. [5]

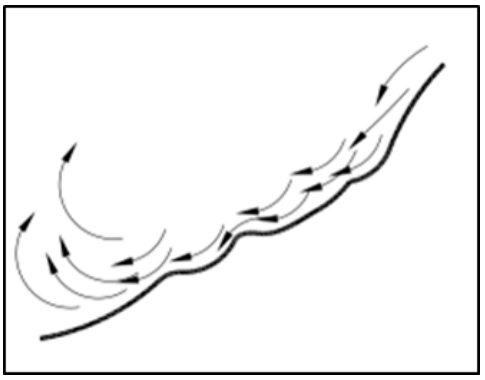


Fig -15: airflow during nighttime [5]

The form of airflow required in urban areas surrounded by terrain and mountains is related to the slope, direction of the mountain and the sun exposure. [5]

Airflow happens between the water and the land in the urban areas, which located near by a lake or sea.

The sunrays absorbed faster, by the surface of the land than the surface of the water. [5]

Therefore, the air above the land gains heat and then rise, and the colder air above the water replaces it.

The land looses heat faster than the water in the night, so the hot air above the water rises to be replaced by the air flowing from the land. See figure (16, 17). [5]

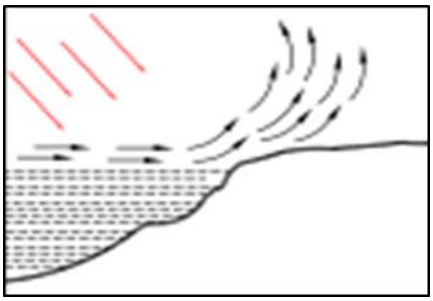


Fig -16: airflow during daytime [5]

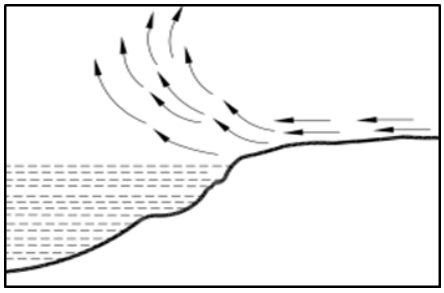


Fig -17: airflow during nighttime [5]

3.4. Influences of green space on the airflow:

The airflow is affected by the green space and plants ribbon with different aspects.

The build environment (building and roads) absorb the heat faster than the green space or plant, and therefore the temperature of the air is approximately 5 degree higher around the buildings [5]. Shown in figure (18).

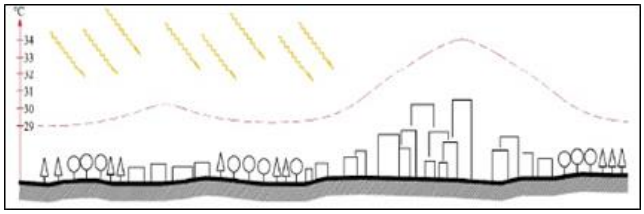


Figure-18: changes of air temperature around buildings and green space. [5]

Hot air rises above buildings, due to differences in temperature between buildings and green areas to be replaced by cold air coming from green areas; it is possible that green areas play an important role in the form of airflow around buildings [5]. figure (19).

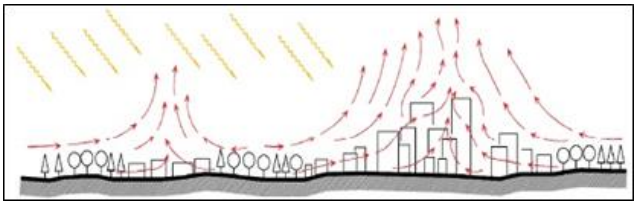


Figure -19: the airflow between the green space and settlements. [5]

Figures (**20**) shows that, Trees and plants can be used to direct the airflow around buildings to provide proper natural ventilation.

In the case of group of adjacent buildings, this arrangement is probable not suitable to direct the airflow for all buildings, so the general planning of the site is important. [5]

Note that placing and arranging trees as in Fig. 21 causes the appearance of the negative pressure zone around the buildings with increased of air velocity.

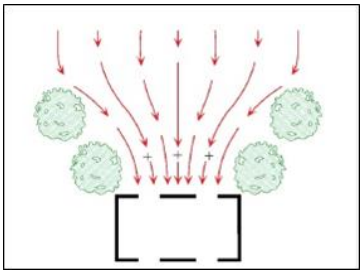


Fig -20: directing more airflow for the buildings with plants [5]

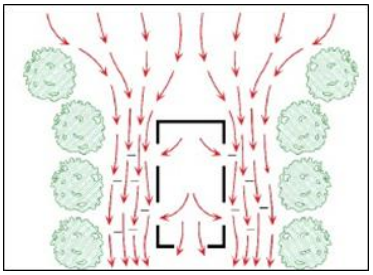
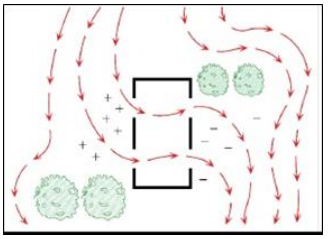


Fig -21: accelerating the airflow with plants [5].

Furthermore, the dense branched and large leaved plants, which arranged as shown in figure 22, figure 23 create different pressure zones around the buildings or buildings groups. [5].



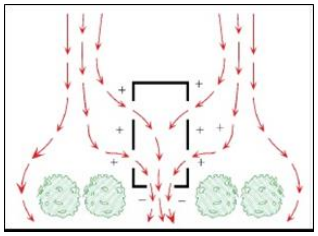


Fig -22, 23: the pressure zones around the buildings created by the plants. [5]

Large, high trees and bushes affect the direction and path of airflow [5]. As shown in Figure (24) & (25).

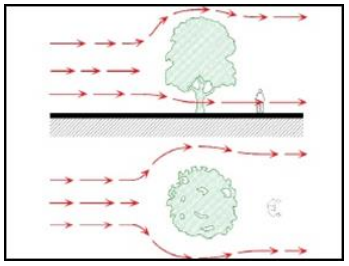


Fig -24: the effect of a high tree to the airflow [5]

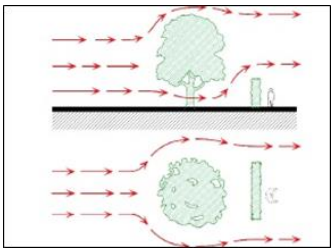


Fig -25: the effect of a bush to the airflow [5]

3.5. Influences of settlement (buildings) on the airflow:

The elements of the settlements such as buildings and it is forms and positions, roads, squares affect the aspects of airflow, which is necessary for the settlements. [5]

The speed pattern of the airflow, depend on the features of the land surface. [5]

In rural areas, the surface is smoother than the center of the settlements due to the less structuring.

Figure (26) & (27) show that, the speed of the airflow decreases in the settlements and it is direction changes with turbulent airflow formation according to the surface coating. [5]

The transportation network and the building groups with various functions affect the air quality in urban areas. [5]

Also the air pollution caused by different elements, such like industrial areas, waste disposal areas, roads with heavy traffic and other building groups.

Therefore, the pollutants must not be transported to other building. [5]

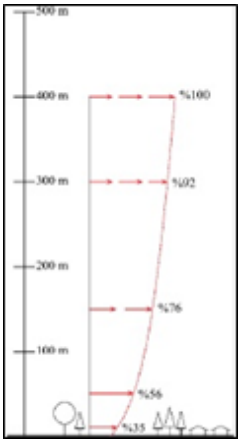


Figure- 26: airflow speed in rural area [5]

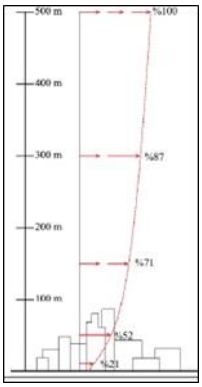


Fig 27: airflow speed in urban area

3.6. Influences of the positions of buildings on airflow:

The aspects of airflow and the sunrays affected by the positions of buildings and the distance between them. The position of buildings plays important role in the speed, type and direction of the airflow and the pressure zones around the buildings. [5]

The decrease in the sizes of gaps between buildings causes the air to gain speed. In addition, due to the acceleration of the flow, the air looses pressure and reveals vacuum effect on the facades. Figure (28) shows the air pattern between buildings. [5]

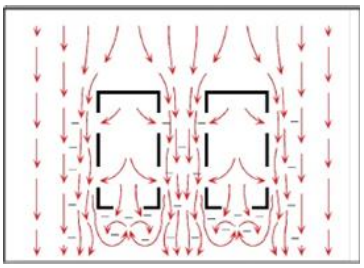


Fig-28: the venturi effect between buildings. [5]

The streets positioned with an acute angle with the direction of the flow cause increasing in the speed of the flow and occur of the vacuum effect on the building facade [5]figure (29).

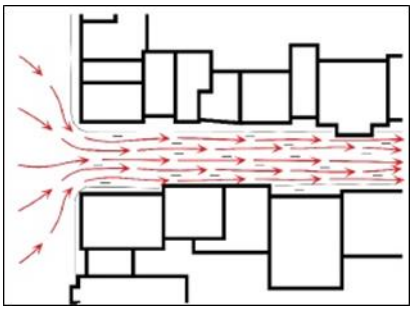


Fig- 29: airflow gaining speed through the street [5]

In case of positioned in a right angle with the airflow, the aspects of the flow change according to the distance between buildings. [5].
Each building group becomes independent barriers to the airflow, if the size of the gap is more than the building heights. The air rises after encountering the first group, passes this group and directs to the lower levels. [5]. figure (30).

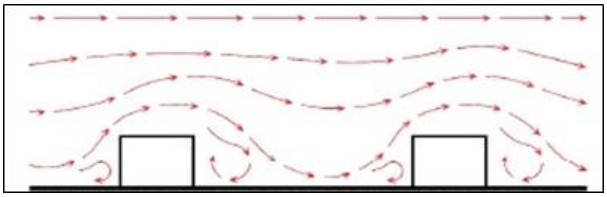


Fig-30: the behavior of airflow if the distance between buildings more than building height [5].
In this situation, buildings can benefit from the airflow. In the distances less than the building height, the air cannot fill the gap efficiently because of the second building group.[5].
Only small turbulence occurs around the buildings along the increasing pollution.[5].. Figure (31).

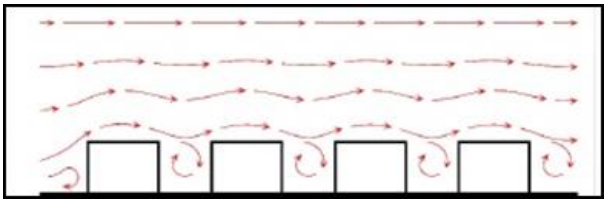


Fig-31: the behavior of airflow if the distance between buildings is less than building height [5].

3.7. The effects of the size and form of the buildings:

Airflow pattern and dispersion around buildings affected by the size and form of the buildings. In addition, the building envelope and the type of roofs affect the pressure zones around buildings. [5]
Figure (32) shows the pressure zones around three buildings with different roof forms, the first building with a terrace roof, the second with slope less than 30°, and the third with slope more than 30°.
There is increasing in speed of airflow with the height, and there is a dispersion in towards the roof, ground, and side facades when the airflow collides high rise building, then the different pressure zones are created around the building especially the vacuum effect. [5]

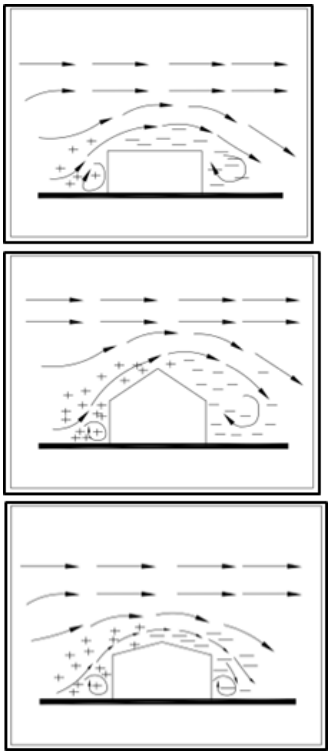


Fig-32: pressure zone dispersion around buildings according to the form of the roof. [5]

4. Local urban arrangement and wind pattern:

The gridiron approach is used in planning of residential areas in Sudan, the linear streets passes from east to west, where the plots oriented to south and north.
This type of planning helps in providing air and ventilation to the buildings, where the prevailing wind direction in Khartoum is from the north direction, in the period between Octobers up to July, whereas, the wind direction from the south is in the period between Julys up to October. [6].
The most important elements that affecting the movement of air around the residential buildings is the presence of fences, which separate between plots, and that work as wind barrier and lead to the formation of vortex in the buffer zone between the fence and the building. In addition, it leads to the accumulation of dust and dirt in this region. Figure33.

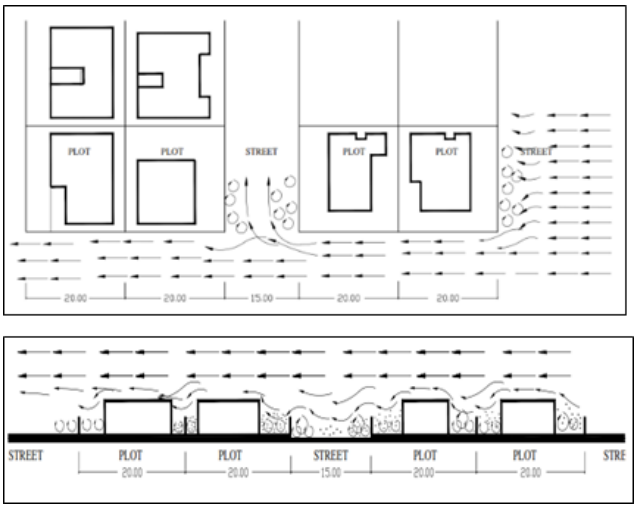


Fig-33: residential areas arrangement in Khartoum

In addition, it can be noted that, in the third class districts, the buffer zone between fence and building may be less than 2 meter, which leads to block arrival of air to neighbors.

Sometimes, the buildings attached to the fence, and it is caused the blocked arrival of air to the neighbor completely.

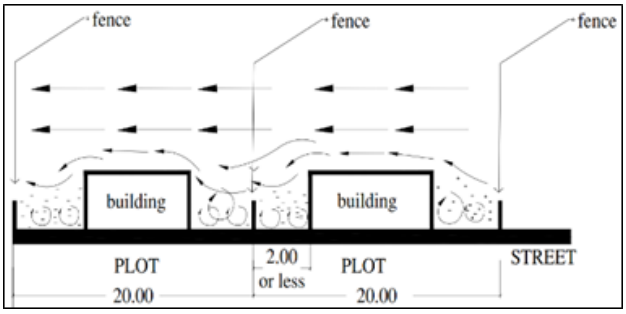


Fig-34: the fences and its effect on air movement in residential areas.

5. CONCLUSIONS:

Eventually, there are many elements affecting windflaw in urban residential areas, these can be represented in sunrays, the barriers, topography, trees and green spaces, buildings, the position of buildings, and the size and form of buildings.

In Khartoum, and exactly in the third class neighborhoods, we find that the most important element affecting the movement of air and works to block the ventilation of the adjacent buildings is a fence between neighbors, and attached buildings with fence.

The fences is not only blocked the arrival of ventilation to adjacent buildings, but also its lead to the accumulation of dust and dirt in the area between building and fence.

sunrays causes the difference in temperature on the earth, this difference affecting air movement, where the air is moving from high pressure area to low pressure area.

The barriers are affecting the air movement, according to their size, their angle, and their heights, where the velocity and wind pattern change accordingly.

In addition. The topography features and hills affecting the air movement and lead to block ventilation from the residential areas.

6. RECOMMENDATIONS:

Through the study of the elements that affect the movement of air in residential areas, it is found that there are factors and requirements, which make these elements affect positively or negatively on the providing ventilation to the buildings. These factors and requirements are defined as follows, and they should be examined during the urban planning process.

- Height of buildings.
- The distance between buildings.
- The distance between buildings and fences.
- Angle of the skewed building.
- The shape of building roofs.
- The width of the streets.
- The height and shape of plants.
- The location of the residential area.

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