

Chapter Three
Wind Movement and Natural Ventilation

3.1. Introduction

This chapter discusses natural ventilation important for health and thermal comfort. To do so, the chapter explores wind pattern and elements that affect wind movement and natural ventilation in residential areas. Natural ventilation is caused by the movement of air to achieve the thermal comfort for human. The chapter also deals with urban design elements that affect wind movement. Urban treatments which help create natural ventilation in residential buildings are also discussed.

3.2. Wind Movement

Wind is the moving air. Wind is known by the direction where it blows from and its direction changes from a moment to another and from season to season. Wind Vane is a simple device used to measure its direction. Another device called anemometer supported with a speed gauge is used to measure its speed. [Elmusheir, 1977]

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). Local wind does not exceed specific areas. [Elmusheir, 1977]. Daily wind blows in regular times and directions. Another wind known as tropical storms is not restricted by specific times or routes. [Elmusheir, 1977].

Table (3.1). Characteristics of Wind Movement: [Elmusheir, 1977].

No	Characteristics according to Beaufort 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 identified by movement of smoke
2	Quite breeze	1.6- 3.3	Hiss of leaves and the feeling of the

			face
3	Light 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	Mild breeze	8.0- 10.7	Swing of mellow bushes
6	Strong wind	10.8- 13.8	Whiz of electrical wires
7	Very strong wind	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	Tornado / hurricane	32.7 and above	destruction

Wind, regardless of its types, is one of the elements that affect formation of the climate in the various regions. Wind results basically from the difference between high air pressure and low air pressure. It travels from areas of high air pressure to area of low air flow. The rotation of the earth around its axis and the sun and the exposure of the northern and southern parts of the earth to the direct solar radiation would respectively change wind direction. [Straw, 2000].

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

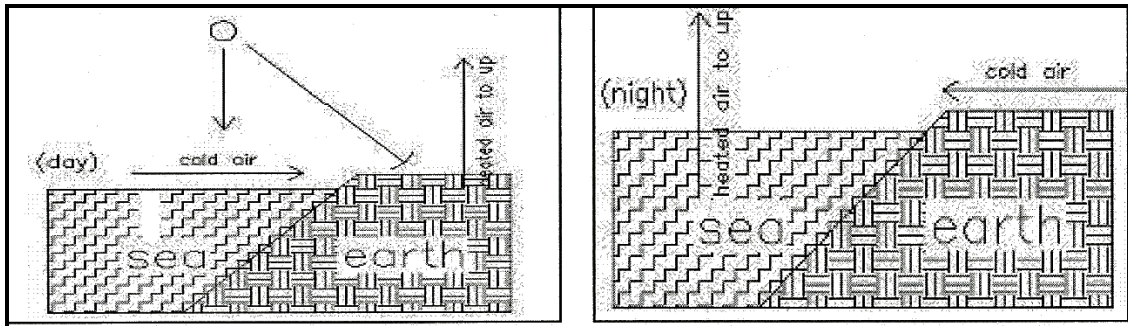


Figure (3.1) shows contrast in wind movement as a result of variation in temperatures [Elmusheir, 1977].

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

3.3. Importance of Wind Movement

Thermal comfort of human body is related to movement of wind and air speed in urban areas. Therefore, it is important to study the chrematistics and ways of wind pattern for ideal distribution that can allow for the transmission of air through all buildings and allow for the provision of the needs of thermal and health comfort of the residents. [Gevoni, 1998].

Building laws in Khartoum State stipulate some terms relating to natural ventilation in the residential buildings. The law specifies a distance of 1/3 of height between the residential multi story building and the neighbor on both the northern and southern sides; that is, in the direction of the prevailing wind in Sudan during summer and winter. However, officials and legislators of the Ministry of Physical Planning (Khartoum State) have assured that such a distance has not been based on any scientific reference.

Sudan as the one of the third world countries has negatively influenced the standard of services, especially electricity. The daily power outages for an hour, two hours or more than three hours would make it difficult to perform the various activities, especially in the deep office buildings. Therefore, it is important to have natural ventilation flowing through these built forms.

Nevertheless, it is necessary to define natural ventilation and the like to recognize its importance for thermal and health purposes.

3.4. Wind Pattern in Urban Areas

Urban areas have a significant impact on metropolitan regional wind patterns in two ways: [Gevoni, 1998].

Firstly: 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. [Gevoni, 1998].

These winds can be significantly stronger than those of the surrounding countryside. [Gevoni, 1998].

Secondly: 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. Warmer polluted city air then tends to rise, creating a negative pressure that sucks cooler air from the city perimeter toward the center. [Gevoni, 1998]. 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. [Gevoni, 1998].

Two main urban design elements are required:

Firstly: a band of undeveloped, preferably vegetated land at the perimeter that can serve as a cool air source. [Gevoni, 1998].

Secondly: wide corridors to provide a pathway for the air to move from less dense to more dense areas. [Gevoni, 1998].

This implies a system of linear greenways or boulevards in a converging organization, with one or more centers. [Gevoni, 1998]. Accordingly, the followings can be treated as a rule:

a: Vegetated avenues and open linear parks of 100 m (320ft) or more in width could be used to enhance urban cooling on calm nights. [Gevoni, 1998].

b: Orient some of these wind corridors parallel to the prevailing breezes to bring width deep in to dense, built - up areas. [Gevoni, 1998].

c: Locate the corridors to connect perimeter greenbelts with centers of built-up density. [Gevoni, 1998].

d: Area of greenbelt should be 40 - 60 % of the size of the urban area to be cooled. [Gevoni, 1998].

f: Maximize wind velocity reduction in urban environments, organize streets and blocks into neighborhoods spaced perpendicular to summer and winter winds, and interspersed with open spaces of 400 x400 m (1300x1300) minimum size, which allow wind to reach its unobstructed velocity. [Gevoni, 1998].

3.5. Wind Movement and Planning

Wind movement is one of the important climatic elements in urban areas especially in crowded residential areas. This is a substantial challenge in the planning, urban design, and architectural design of buildings; therefore, it is necessary to preserve the wind tracks in order to provide adequate, fresh, and clean air to buildings.

3.6. Principles of Wind Movement

The main principle of wind movement is the pressure differences. The air moves from high-pressure areas to low-pressure areas where temperature difference leads to pressure difference. illustrates that the wind direction changes when the wind collides with a barrier, whereas wind has a mass and inertia and when the wind collide with a barrier a high pressure area (+) formed in front of the barrier as a result of the compression of the wind. Figure (3.2) below

Moreover, a low pressure area (-) is formed behind the barrier which extends to the point at which the wind recover its original direction, and it's so called the static or the shadow area. This is the low pressure area. So the question is how

long is the shadow area? In order to, insure the availability of natural ventilation for each building.

In the shadow area, the air is static and doesn't move, so we have to know the length of the wind shadow in order not to put up buildings.

The path that the wind mass follows when collides with the barrier called the air current graph.

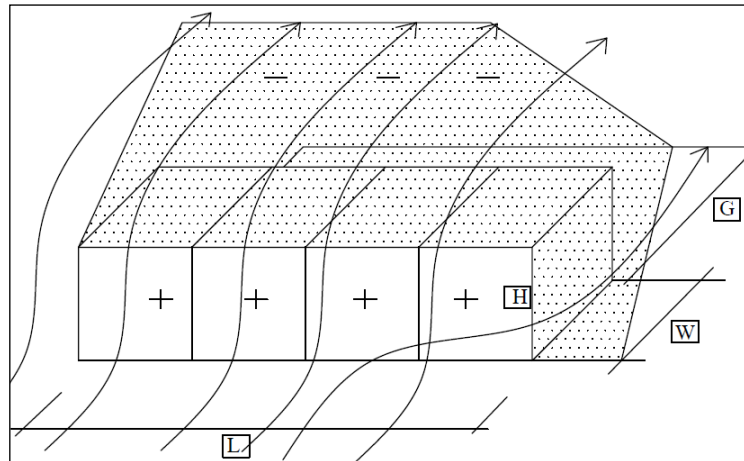


Figure (3.2): wind movement and shadow area. [Elmusheir, 1977].
H= the height, L= the length, W= the width, G= the depth of the wind shadow.

3.7. Buildings Arrangement and their effect on Wind Flow

A research carried out by Rimsha has concluded that good wind movement provides reasonable ventilation to buildings exposed to wind compared with other ones. [Elmusheir, 1977].

If buildings are arranged in the form of chess pieces as shown in figure (3.3-c), buildings will allow wind flow to return to its original path before it reaches the other ones. [Elmusheir, 1977]. However, the distance between buildings which can be adopted as a measurement or standard during planning process was left untouched by Rimsha.

High buildings obstruct wind flow creating a static area (wind shadow) from less high ones. In this area, ventilation will be insufficient because of wind movement. Figure (3.4-a). [Hassan, 2008].

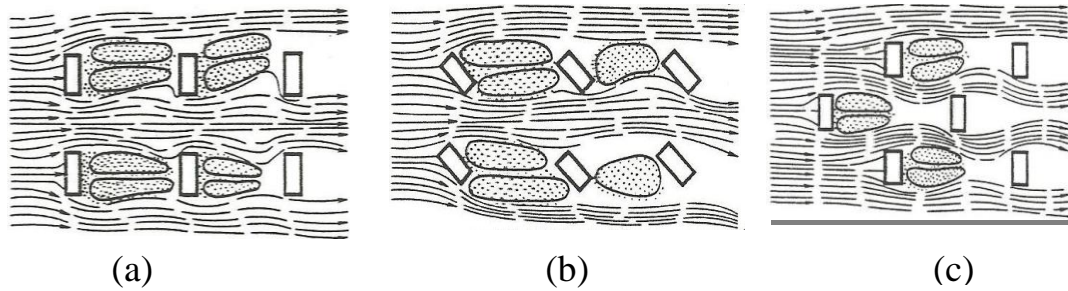


Figure (3.3) Wind tracks through built forms in a plan. a- in shape of grid iron b- in diagonal shape. c- in shape of chess [Elmusheir, 1977].

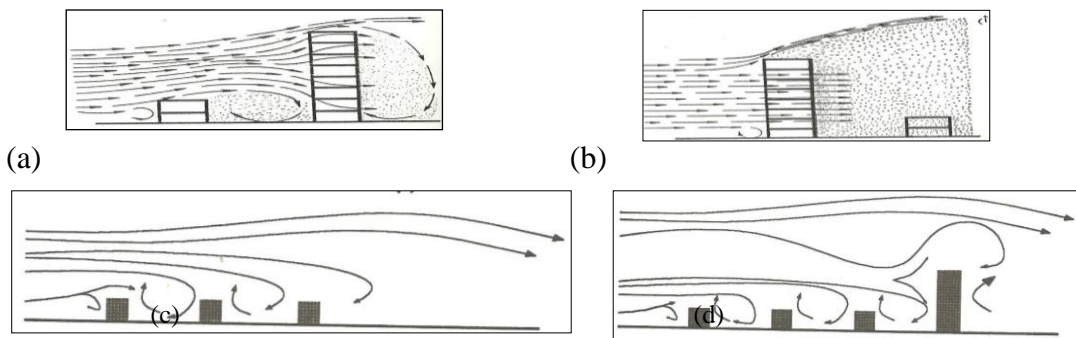


Figure (3.4). Wind tracks through built forms in elevation. [Hassan, 2008].

For well-arranged buildings, equal natural ventilation is to be provided for each building. The researcher therefore is concerned with the distance between the buildings, their heights and orientation to avoid static area for some of them. Figure (3.4-a, b, c and d). Orientation of the built forms is important to provide natural ventilation. Figure (3.5)

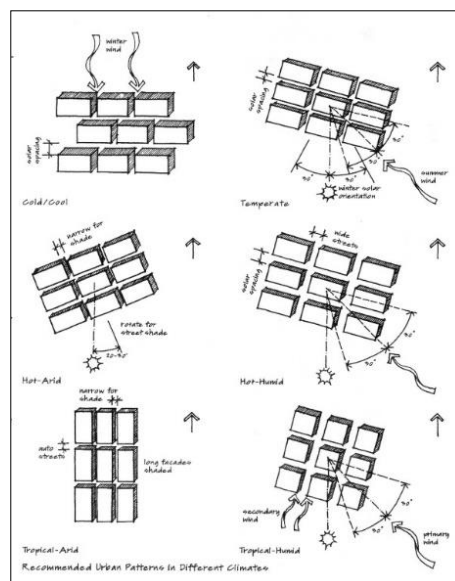


Figure (3.5) Configuration and orientation in plan (different shapes) [Brown,2001].

Geometrical characteristics of the buildings, their proportions, heights, distance between each other, distance between buildings and streets and distance between them and open spaces affect wind flow through buildings. Figure 3.6.[Brown,2001].

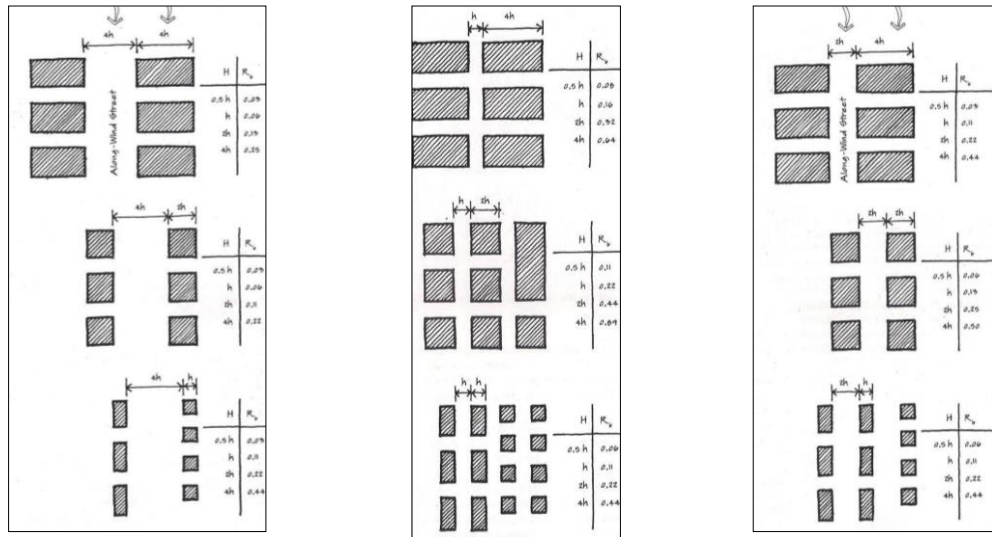


Figure (3.6) shows different organizations of built-up forms in urban area [Brown,2001].

3.8. Effects of Physical Elements on Wind Flow

Providing buildings with efficient natural ventilation, thermal and health comfort depends on the formation, type, speed and behavior of wind flow. [Darcin, 2010]. Wind flow is affected by natural and manmade environment around the settlement and buildings. [Darcin, 2010]. Below are the elements that affect the wind flow:

3.8.1. The Sun

The sun is the main factor that affects wind flow, the different heat gains of earth, plants, made environment, and seas etc. Direct solar radiation causes differentiations on the air pressure levels. [Darcin, 2010].

Wind flow is related to these differentiations, for this reason the angles of radiation change according to seasonal and daily positions and exposures of buildings to sun. All these factors are important for the efficient wind flow. [Darcin, 2010].

Figure (3.7) shows the altitude and azimuth of the sun for Khartoum on a sun path diagram for 21st December and 21st June.

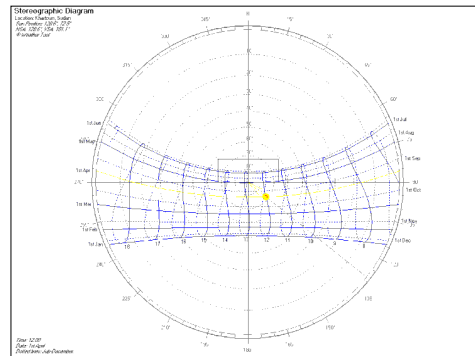


Figure (3.7): sun path for Khartoum (latitude 15.9° N – longitude 32.8° E)

3.8.2. Barriers

Normally, wind flow moves from high pressure (positive pressure) zone to the low-pressure (negative pressure) zone. See figure 3.8 and figure 3.9.

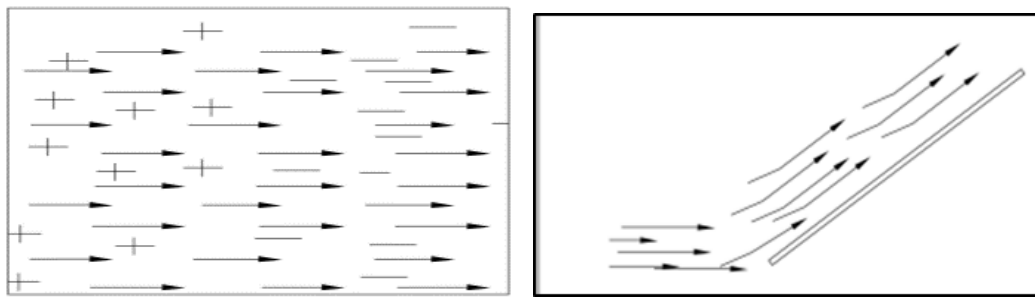


Figure (3.8) Wind movement

figure (3.9) Direction of the wind flow

Figure (3.8&3.9): Influence of barriers on wind flow. [Darcin, 2010].

If barriers appear on the path of wind flow, the wind direction will change in proportion to the size and angle of the barrier. [Darcin, 2010]. We do not know the distance the wind flow can turn back to its normal situation after the barrier. One of the objectives of this research is to determine this distance.

If the size of the barrier is small and is positioned in acute angle to the direction of the wind flow, wind flow can turn back to its original direction. We need to determine the specific distance. See figure (3.10) [Darcin, 2010].

Positive and negative pressure zones are created on the wind ward and leeward of the barrier respectively as a result of the drive and vacuum effects which are in turn caused by the wind flow. [Darcin, 2010].

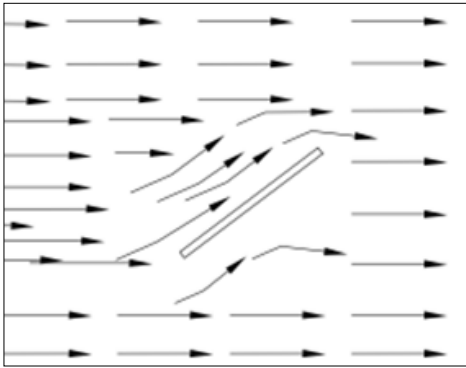


Figure (3.10) Permanency of the wind flow Figure (3.11) Pressure zone around barrier
 Figure (3.10& 3.11): Wind pattern around barriers. [Darcin, 2010].

Turbulent flow appears due to the wind molecules. It is induced by the negative pressure zone behind the barrier and the current direction of the wind, when the wind flow obstructed by a barrier positioned in a right angle. The increase of the wind flow speed results in a decrease of the pressure. Similarly, the narrow gap forces the wind to get through and loses its pressure by gaining speed. See figure (3.12). [Darcin, 2010]

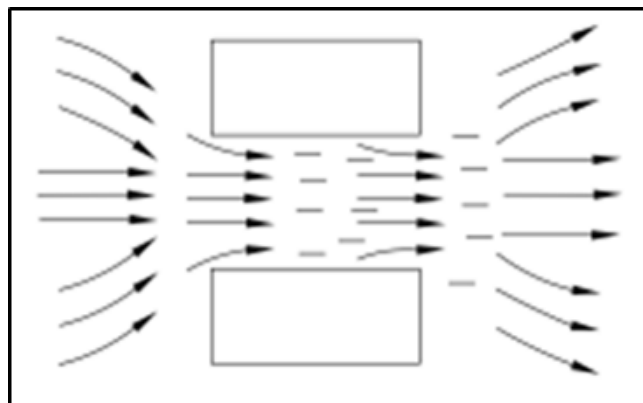


Figure (3.12): a narrow gap effect. [Darcin, 2010].

3.8.3. Topography

Topographic features around a settlement and buildings affect the formation, speed, type, and direction of the wind and air pressure levels. They also affect the zone dispersion created around buildings, which are necessary for effective natural ventilation, see figure (3.13). [Darcin, 2010].

Settlements and building groups, positioned in a valley area, figure (3.13) cannot benefit sufficiently from wind flow because of the topography. As a

result, the removal of constantly polluted air around the buildings and provision of clean air become more difficult. [Darcin, 2010].

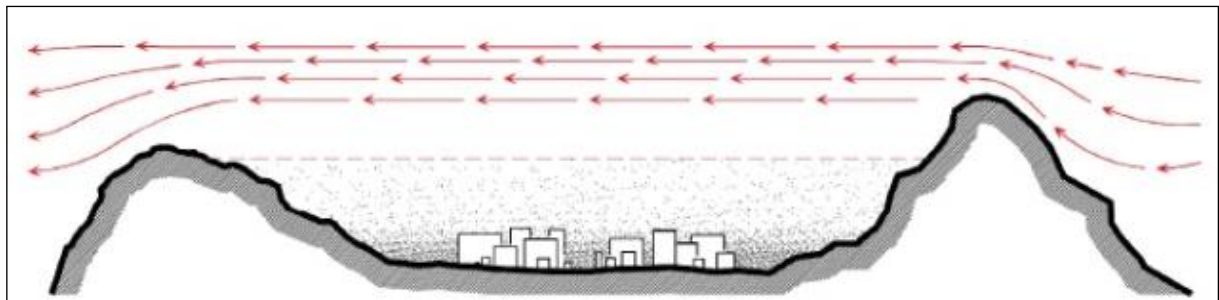


Figure (3.13): Wind flow and a settlement in a valley area. [Darcin, 2010]. Efficiency of natural ventilation in areas like this is affected by height and distance between the two hills. [Darcin, 2010].

During the day temperature of the upper parts exposed to direct sun radiation exceeds the temperature of the lower parts or the surface of the water, which is not exposed to sun radiation. Therefore, the wind blows from bottom to top and from sea to land during the day period. [Darcin, 2010]. However, during the night, the higher levels of the terrain lose heat rapidly forcing the wind to move in the opposite direction. This phenomenon is illustrated in figure (3.14&3.15). [Darcin, 2010].

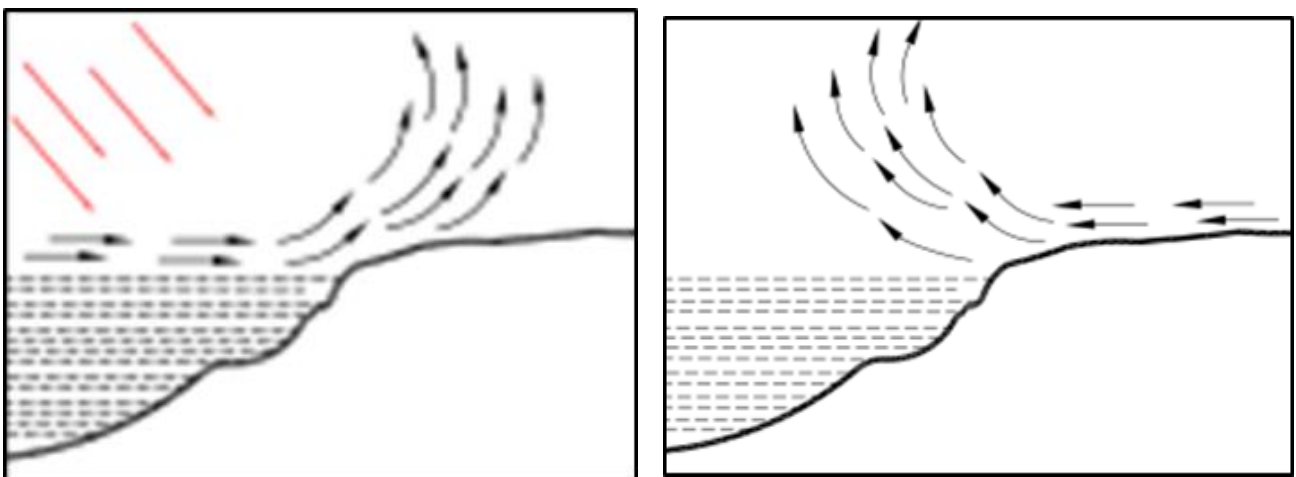


Figure (3.14) shows wind flow during day time Figure (3.15) shows wind flow during night time
Figure (3.14& 3.15): wind flow created by the topography. [Darcin, 2010].

3.8.4. The Green Space

Wind flow is affected by the green space and plants ribbon with different aspects. [Darcin, 2010]. Built environment (buildings and roads) absorb heat faster than the green space or plant, and therefore the temperature of the air is approximately 5°C higher around buildings as shown in figure (3.16). [Darcin, 2010].

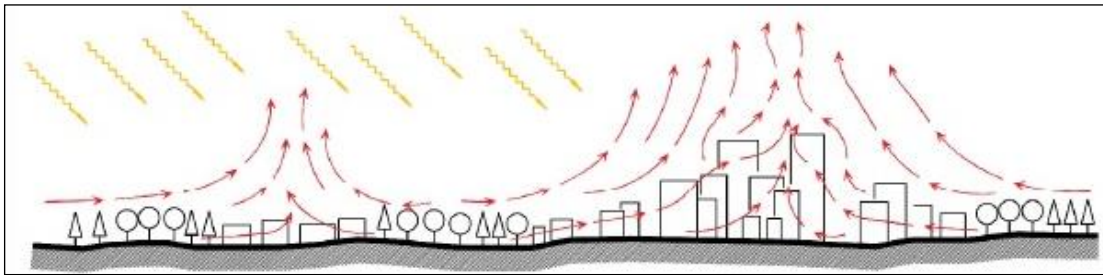


Figure (3.16): Changes of temperature around buildings and green space. [Darcin, 2010].

Different air temperature around buildings and green space is behind the rise of hot wind above the settlement, so it should be replaced by cold wind moving from planted area. This creates windflow between these two areas as shown in figure (3.17). [Darcin, 2010].

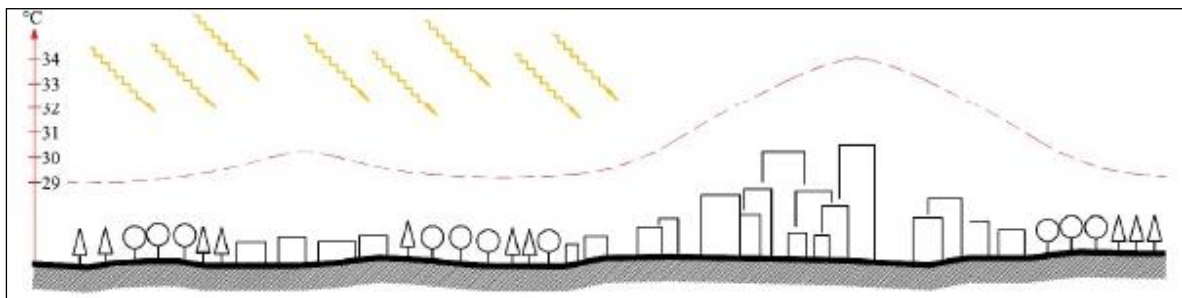


Figure (3.17): Wind flow between the green space and settlements. [Darcin, 2010].

For providing natural ventilation in settlements, we need to determine the effective distance between the building and the green area. In this connection, is it possible to manipulate and direct the wind flow by making use of the plants to the buildings?

Arrangement of plants helps buildings have access wind flow. Moreover the plants can control speed, type, and direction of the wind, pressure levels and

dispersion created around the building. This will result in better natural ventilation for the buildings. See Figures (3.18). [Darcin, 2010].

In the case of adjacent buildings, the arrangement is probably unsuitable to direct the wind flow for all buildings, so the general planning of the site is important. [Darcin, 2010].

Plants arranged as shown in figure (3.18, 3.19) can cause negative pressure zones around the buildings with an increase in the speed of the flow. [Darcin, 2010].

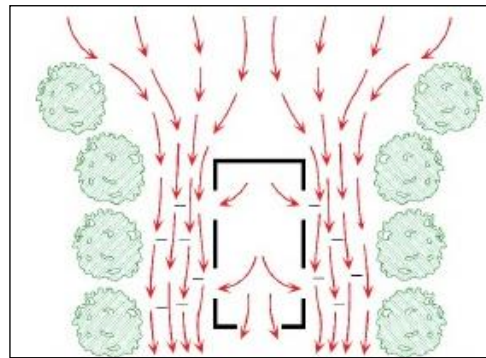
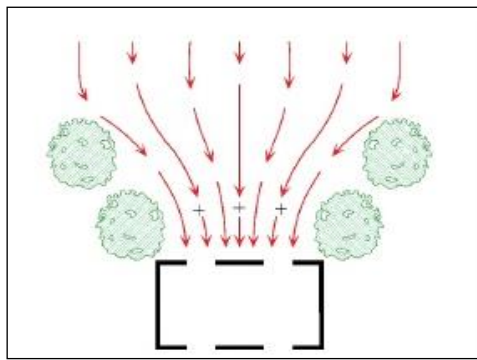


Figure (3.18) Directing more windflow for the buildings with plants Figure (3.19) Accelerating the wind flow with plants

Figures (3.18&3.19): Directing windflow with plants. [Darcin, 2010].

Furthermore, the dense foliage plants, which are arranged as shown in figure 3.20, figure 3.21 create different pressure zones around the buildings or buildings groups.

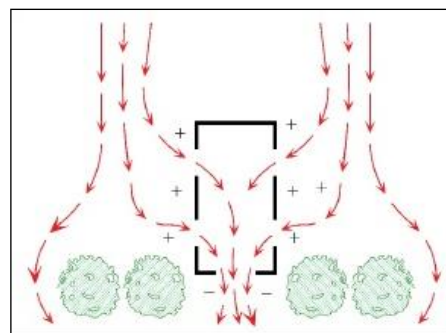
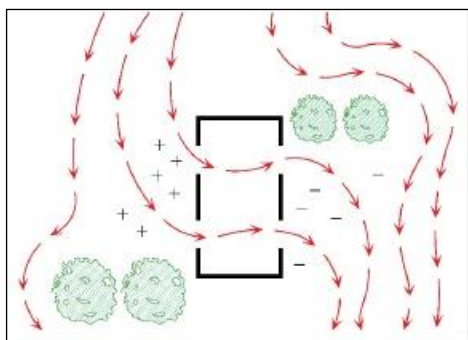


Figure (3.20)

Figure (3.21)

Figures (3.20, 3.21) shows pressure zones around the buildings created by the plants. [Darcin, 2010].

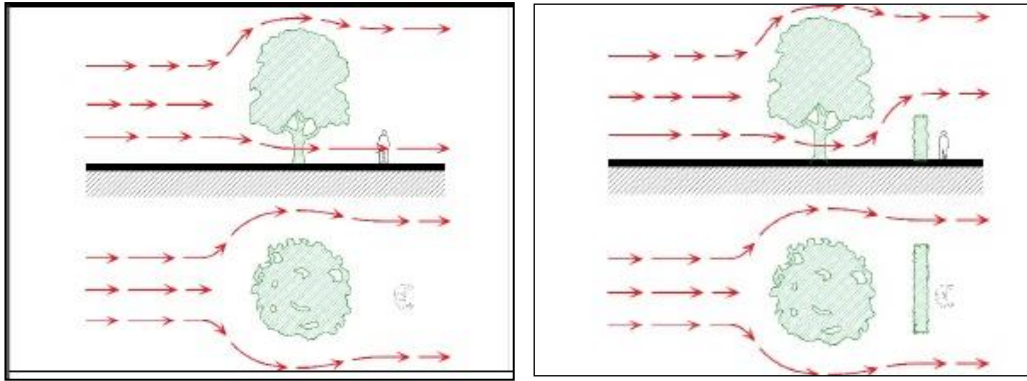
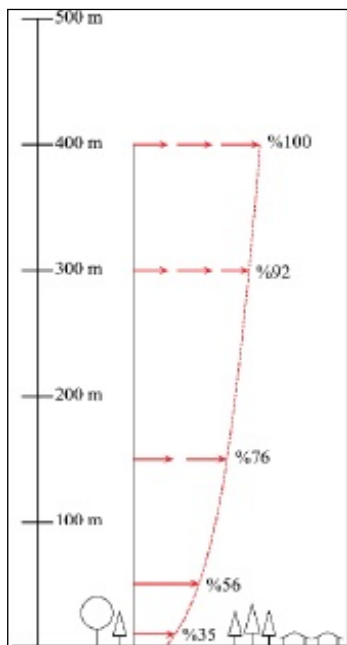


Figure (3.22) Effect of a high tree to the wind flow Figure (3.23) Effect of a bush to the wind flow
 Figures (3.22&3.23): Effects of plant types on the wind flow. [Darcin, 2010].

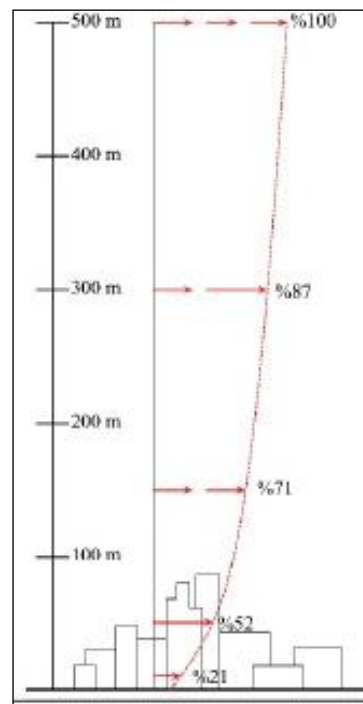
3.8.5. Built forms

Forms and positions of buildings, roads, and squares affect aspects of wind flow necessary for settlements. [Darcin, 2010]. Pattern of the wind flow and speed depend on the features of the land surface. In rural areas, the surface is smoother than the center of the settlements because of fewer barriers. [Darcin, 2010].

The speed of the air flow decreases in the settlements. Air direction changes with turbulent wind flow formation according to the surface coating. See figure (3.24) [Darcin, 2010].



Wind flow speed in rural area



Wind flow speed in urban area

Figure (3.24): Speed of the Wind flow in rural and urban areas. [Darcin, 2010].

3.8.6. Positions of the Buildings

Aspects of airflow and the solar radiation are affected by the positions and distance between buildings. [Darcin, 2010]. The position of buildings determines speed, type and direction of the wind flow and the pressure zones around the buildings. [Darcin, 2010].

Decrease in the sizes of gaps between buildings forces the wind to gain speed. Furthermore, the wind loses pressure and reveals vacuum effect on the facades due to the acceleration of the flow. See figure (3.25). [Darcin, 2010].

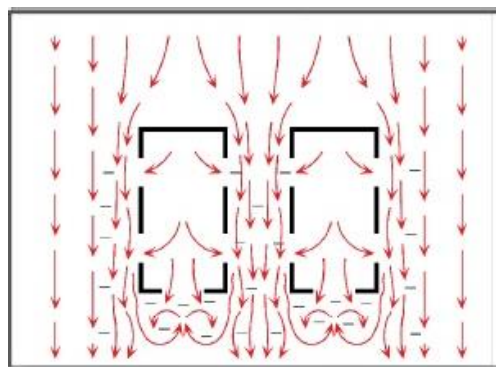


Figure (3.25): Venturi effect between buildings. [Darcin, 2010].

The position of the streets is important according to the angle between the street and wind flow direction. If streets are positioned with an acute angle on the direction of the wind flow, the speed of the flow increases and vacuum effect occurs on the facades of the buildings. Figure (3.26).

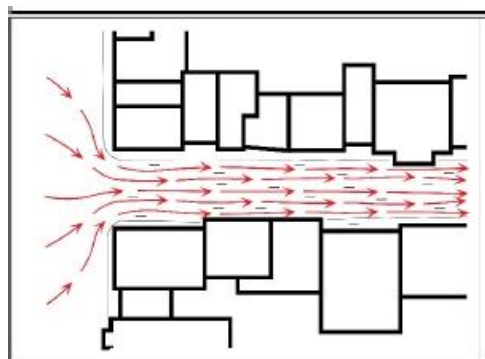


Figure (3.26): Wind flow gaining speed through the street. [Darcin, 2010].

So, if buildings are positioned in a right angle with the wind flow, the wind flow changes according to the distance between buildings. [Darcin, 2010].

Each group of buildings becomes independent barriers to the airflow, if the size of the gap is more than the building heights. The wind rises after encountering the first group, passes through then directs to the lower levels. Figure (3.27).

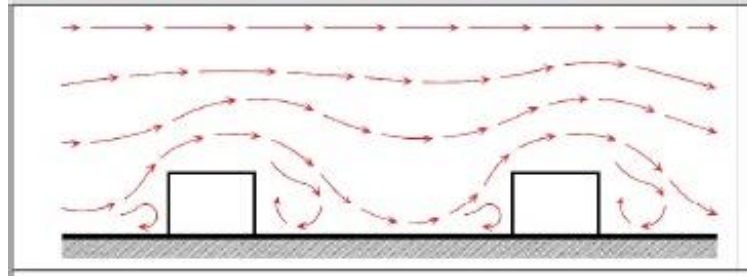


Figure (3.27): Wind flow if the distance between buildings more than the building height [Darcin, 2010].

In this situation, buildings can benefit from the wind flow. [Darcin, 2010].

Regarding distances less than the building height, the wind cannot fill the gap efficiently because of the second building group. [Darcin, 2010]. Only small turbulence occurs around the buildings along the increasing pollution. Figure (3.28). [Darcin, 2010].

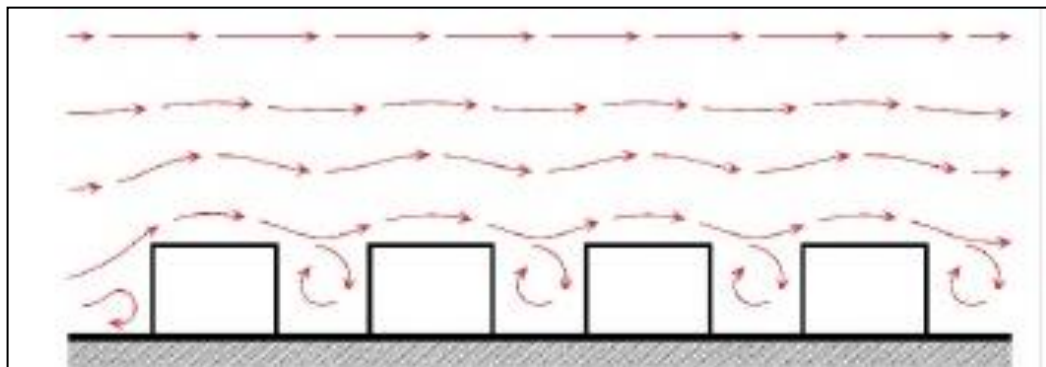


Figure (3.28): Wind flow if the distance between buildings is less than building height [Darcin, 2010].

This research aims to determine building height and width of the streets to ensure natural ventilation. Position of buildings affects the solar radiation. The latter creates the wind flow by causing different heat gains for the building groups. [Darcin, 2010], so the distances between buildings, positions and sizes are important. [Darcin, 2010].

Solar radiation casts shadows in varying sizes around the barrier. This is because of the different positions of the sun throughout the different seasons and days. The buildings therefore can create shadows on each other. [Darcin, 2010].

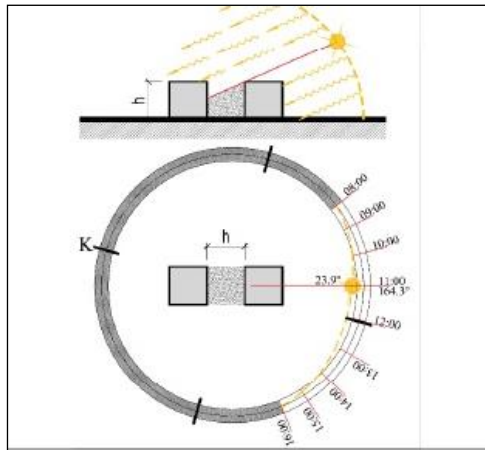


Figure 3.29 Shadow if the distance between buildings is equal to building height [Darcin, 2010].

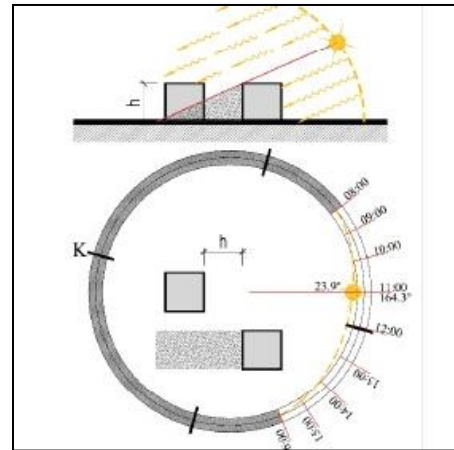


Figure 3.30 Shadow with a different position of buildings [Darcin, 2010].

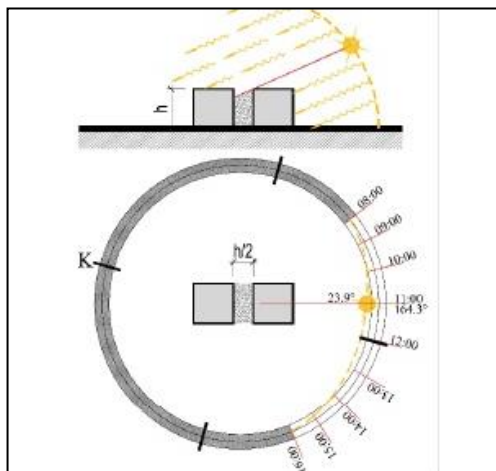


Figure 3.31 Shadow if the distance between buildings is half of the building height [Darcin, 2010].

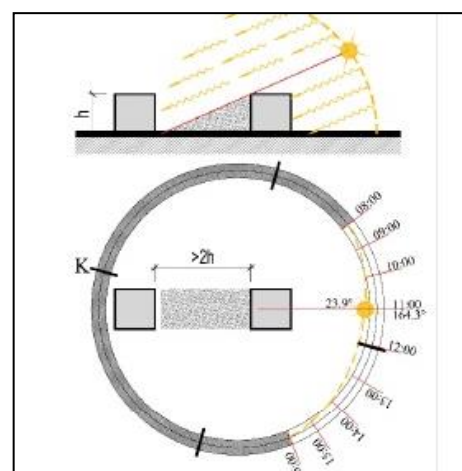


Figure 3.32 Shadow between buildings is more than twice the height [Darcin, 2010].

3.8.7. Size and Form of the Buildings

Wind flow pattern and dispersion around buildings are affected by the size and form of the buildings. Similarly, the building envelope and form of the roofs affect pressure zones around buildings. [Darcin, 2010].

Below are pressure zones around three buildings with different roof forms: building with a flat roof, building with a pitch of 30°, and a building with a pitch more than 30°. See Figure (3.33) [Darcin, 2010].

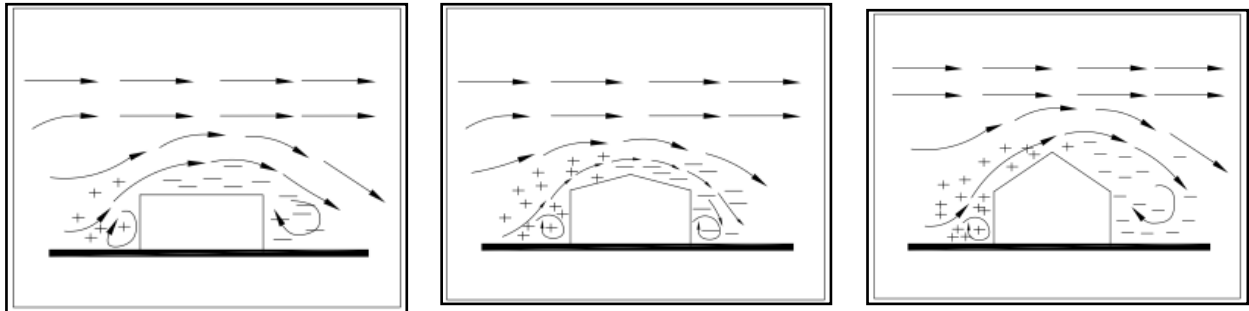


Figure (3.33): pressure zone dispersion around buildings according to the form of the roof. [Darcin, 2010].

There is an increase in wind speed with the height. There is dispersion towards the roof, ground, and side facades when the wind flow collides with high rise building. Then the different pressure zones are created around the building especially the vacuum effect. See figure 3.33. [Darcin, 2010].

3.9 Local Urban Arrangement and Wind Pattern

The gridiron approach is used in planning of residential areas in urban centers of Sudan. Linear streets pass from east to west, where the plots orient to south and north.

Such planning helps provide wind and natural ventilation to the buildings, where the prevailing wind blows from the north in the period between October to June and from the south in the period between Julys to October. The most important factor that affects movement of the wind around the residential buildings is the presence of boundary wall, which separate between plots, act as wind barrier and lead to the formation of vortex in the buffer zone between the boundary wall and the building. In this area, dust and rubbish are accumulated along boundary wall. Figure 3.33.

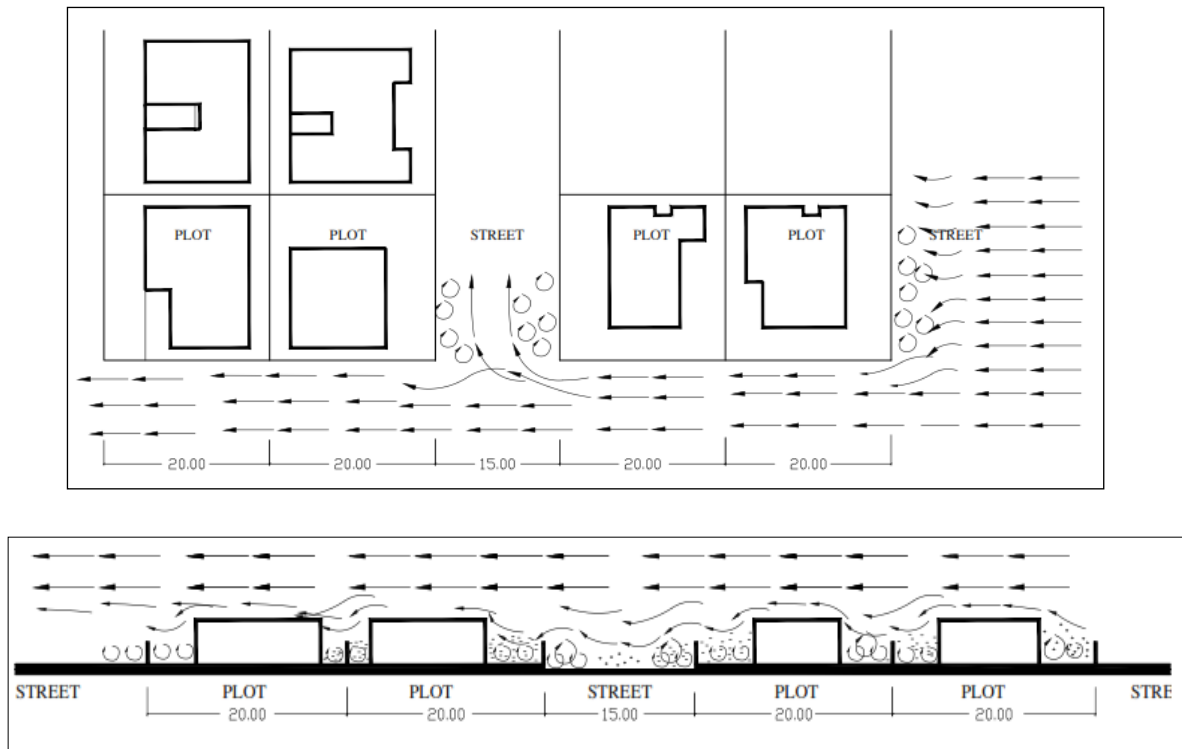


Figure (3.34): residential areas arrangement in Khartoum. [auother, 2016].

3.10. Natural ventilation

The proper cross ventilation is the effective way to ventilate a building and provide oxygen and indoor air quality. Mechanical ventilation system is also affective, but it has many disadvantages:

- a- It uses nonrenewable resources.
- b- It increases energy consumption.
- c- It causes indoor air pollution and consequently leads to some serious health problems.
- d- Increase the total cost i.e. Cost of energy, running, maintenance. In

offices alone about 60% of the energy is consumed by central air conditioning system. In my private house, more than 68% of the energy is consumed by the air conditioners.

For these reasons, natural ventilation is preferred to mechanical system. This system is economical because it saves energy and repairs cost and provides

healthy indoor environment. For effective natural ventilation, the following should be considered:

- a- To achieve quality outdoor air in a neighborhood (the area).
- b- To locate the neighborhood according to the wind flow.
- c- To arrange the buildings according to the wind flow.

3.10.1. Definitions of Natural Ventilation

Natural ventilation is defined as the movement of air through openings in a buildings fabric, due to wind or to static pressures created by the differences in temperature between the interior and exterior of the building (generally known as the stack effect), or to a combination of these acting together. [Straw, 2000].

Natural ventilation is subject to variability of wind speed and direction, air temperature and opening configuration. These factors do not only affect the rate of fresh air supply, but they also determine whether openings will act as an inlet or outlet for the air in any space within a building. Natural ventilation can be defined as the process of exchanging the internal air by a fresh air by natural means only. [Straw, 2000].

The availability of the minimum amount of natural ventilation inside buildings is one of the fundamental elements of human life and his/her comfort and health. [Straw, 2000].

It reduces human thermal strain, helps get rid of carbon dioxide, noxious smells and the impurities harmful to health and reduces the temperatures of walls, ceilings and floors through the convection currents. [Straw, 2000].

3.10.2. Advantages of Natural Ventilation

Advantages of natural ventilation can be outlined as follows:

- Natural ventilation for human comfort
- Natural ventilation for thermal comfort
- Natural ventilation for health comfort

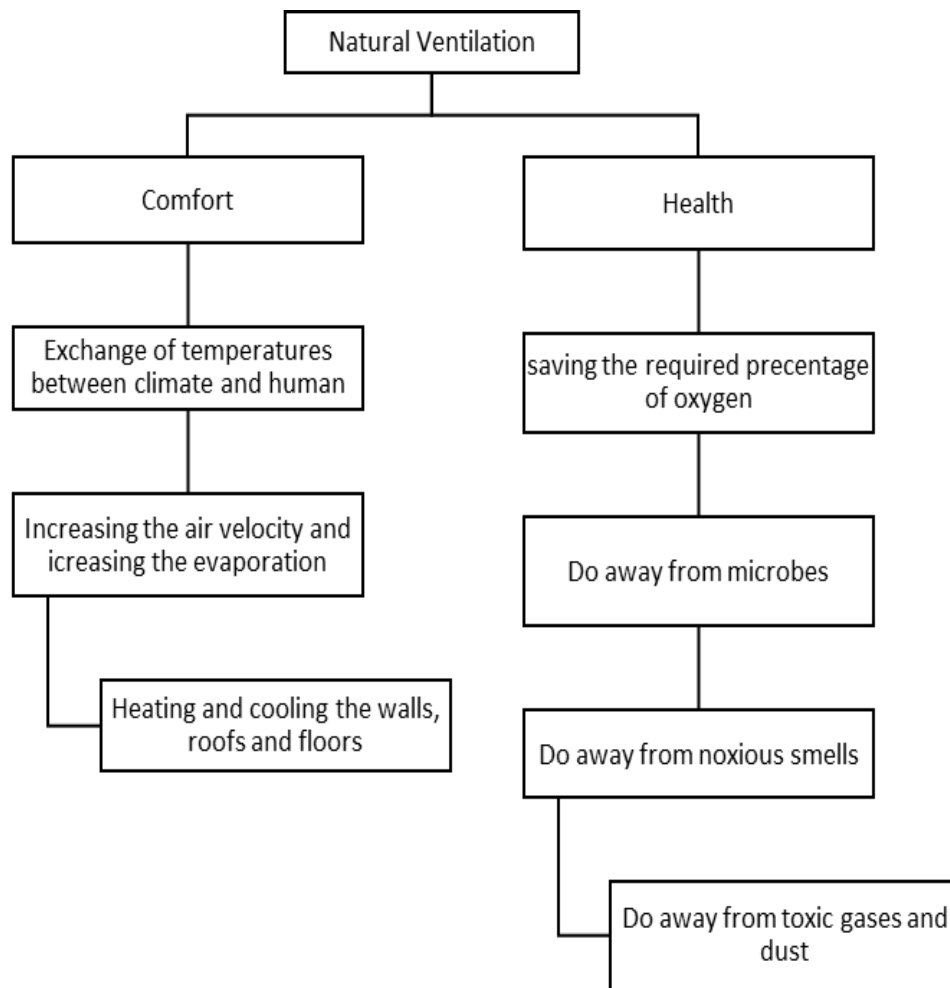


Figure (3.35) Requirements of ventilation in build forms. [Aouther, 2017].

3.10.3. Natural Ventilation and Health

Internal air should be replaced by external fresh air containing necessary amount of oxygen needed for breathing, burning, cooking or disposing of carbon dioxide accumulations. Normal air contains 21% oxygen, between 0.03% to 0.04 % carbon dioxide, about 78% nitrogen, 1% inert gas and between 5 to 25 grams of water evaporation per each cubic meter of water. [Ibn Aouf, 1977].

The components and characteristics of internal air are affected by people and their different activities. The amount of carbon dioxide and water evaporation will increase due to breathing, cooking and other activities as well. Germs that would transmit diseases by means of exhalation, sneezing and slut will spread. [

Ibn Aouf, 1977]. Smell of the internal air is also affected by the organic caused by secretions of human body.

Smoking also affects the components and characteristics of air. [Ibn Aouf, 1977]. Air exhaling from lungs during breathing consists of 16.3% of oxygen, 4% of carbon dioxide, 79.7% of nitrogen and other gases and 45 grams of water evaporation per each cubic meter. [Ibn Aouf, 1977].

The human needs of oxygen depend on the nature of the activity. For residential, commercial, recreational and education buildings, variations take place in respect to the amount of carbon dioxide and oxygen does not leave a big effect on human health. [Ibn Aouf, 1977].

Harmful effects on human health can only occur if the oxygen drops to lower than 16% to 18% and the amount of carbon dioxide increases to more than 1-2% [Ibn Aouf, 1977].

Therefore, the amount of oxygen and carbon dioxide in the internal air will never be taken as the main criterion for identifying the minimum necessary amount of internal natural ventilation. [Ibn Aouf, 1977].

Air quality depends on many factors:

The amount of carbon dioxide which is considered as the easiest to identify, subsequently, the amount of noxious smells can be identified approximately in accordance with the amount of the carbon dioxide in the air. The allowable amount of carbon dioxide has been set in some European countries and in the United States to guarantee the minimum requirements of health ventilation. As for industrial installations, the French officials have set the maximum carbon dioxide at 1.0%. The United States has set an amount of 5%. It has to be confirmed that there is no direct relation between the amount of carbon dioxide and the other elements which affect the components and characteristics of air which depend on the health aspects and the social customs and traditions of the users of the building. [Ibn Aouf, 1977].

This can reflect the clear and big contrast in the maximum of carbon dioxide allowable in the various countries. [Ibn Aouf, 1977].

Noxious smells are formed as a result of the dynamic interaction in the human body and as a result of the smells of cooking and smoking etc. [Ibn Aouf, 1977].

Studies and laboratory and field experiments have proved that disposal of noxious smells in the building require maximum amounts of natural ventilation compared to the amounts that allow for the necessary oxygen. [Ibn Aouf, 1977].

Some countries have set rules and regulations that specify the required amounts of natural ventilation to get rid of noxious smells. Those regulations depend on two criteria: the first is based on the average of air change of cubic meter per hour as shown in table 3.2 below; and the second is based on the number of times of air change of the whole space per hour.

The Table no (3.2): Average of air changes in cubic meter per hour, [Ibn Aouf, 1977].

Average of internal air change Cubic meter per hour				Averages of natural ventilation of the space and number of times of the air change in the whole space per hour				country
Water closet	bathroom	kitche n	Living conditio n	Water closet	bathroom	Kitche n	Living conditio n	
-	-	-	-	-	-	-	1	Belgium
-	25	-	-	5	-	3	1	Hungary
-	-	-	-	-	-	-	0.3-1	Poland
-	-	-	45	-	-	-	-	Swede
25	25	60-90	45	-	-	-	-	Russia
-	-	-	-	2	3	3-4	1-1.5	France

3.10.4. Natural Ventilation for Thermal Comfort

Human beings exchange heat with the surroundings by means of convection currents and radiation, and temperature is lost as a result of the evaporation of sweat from the body. [Ibn Aouf, 1977].

Natural ventilation plays an important role in the thermal balance of human body, because it affects the speed, amount of the internal air and the temperature of the surfaces of the internal spaces, walls and floors. [Ibn Aouf, 1977].

In areas with cold weather and low temperature, there is no need for natural ventilation, because it causes the reduction in temperature of the internal air which leads to the consumption of much energy for heating. Therefore, the main purpose of natural ventilation in such places is to get rid of noxious smells and accumulations of carbon dioxide, to provide the necessary ratio of oxygen. [Ibn Aouf, 1977].

However, in areas with hot weather, natural ventilation requires getting rid of noxious smells and making use of the impetus of the external air current to increase air flow through the internal spaces. [Ibn Aouf, 1977].

Increase of air speed in the internal spaces increases evaporation of sweat from human body. It also helps get rid of high humidity especially in areas characterized by hot and humid climate. Therefore, air speed is more important than air change in such areas. [Ibn Aouf, 1977].

In areas characterized by hot and humid climate, wind speed should not be less than 2 m per second. However, in regions characterized by hot and dry weather, air speed should not be less than 1 m per second. [Ibn Aouf, 1977].

Air movement is important for thermal comfort of human body. It is one of the elements that identifies the average thermal exchange between human body and the surroundings as well the average sweat evaporation from human body. There is a close relationship between the natural ventilation for thermal comfort and air temperature and relative humidity inside the building. [Ibn Aouf, 1977].

When high air speed becomes one of the needs of thermal comfort, this might indicate lack of homogeneity in the distribution of air movement and the big contrast in air speed in the various places of the internal spaces.

Therefore, it is useful to use the air speed as a main criterion of natural ventilation instead of using the average of air change for the whole space or using the average of air change for cubic meter per hour. [Ibn Aouf, 1977].

Certainly air speed is affected by the engineering shape and the internal distribution of the space as well as the sites of openings and their design and reflection towards the current of external air. [Ibn Aouf, 1977].

The average of thermal current between human body and the surroundings depends on number elements, among which is the difference between human body temperature and the air temperature. When human temperature is higher than air temperature, human body loses temperature to the air. And when the air temperature is high, it is necessity to increase the air speed to keep average temperature loss. [Ibn Aouf, 1977].

Human body also exchanges temperature with the internal surfaces such as walls, ceilings and floors through radiation. The average of thermal exchange depends on the difference between human body temperature and the average radiation temperature of the internal surfaces. There is a thermal exchange between the internal surfaces of the air. Subsequently, air can affect the identification of the averages of temperature of the internal surfaces.

The quantity of the temperature lost or gained by the internal air as a result of natural ventilation is multiplied by the average of the natural ventilation and the quality temperature of air volume and the difference between external air temperature and internal air temperature. [Ibn Aouf, 1977].

The quantity of the temperature gained or lost by the internal air as a result of natural ventilation can be fixed by the following equation: [Straw, 2000].

$$Q_v = C_v \times V \times \delta t.$$

$$Q_v = 1300 \times V \times \delta T$$

Q_v = the amount of temperature gained or lost by the internal air (Watt)

C_v = the quality and volume of air temperature equal 1300 gul per cubic meter - centigrade.

δ = difference between temperatures (centigrade)

V = the average of natural ventilation (cubic meter per hour)

Such equations are related to the internal air temperature which might remarkably be different from the temperature of the internal surfaces and the internal air temperature. [Straw, 2000].

In some experiments, a variety of construction materials along with various colors of the external surfaces and three levels of natural ventilation have been used as follows: [Straw, 2000].

1- lack of natural ventilation

2- natural ventilation 24 hour day and night

3- 3- natural ventilation for 12 hours at night

Of the general observations of the results of these experiments is that if grey color has been used for external surface of the western wall, the deviation will be higher compared to usage of white color. [Straw, 2000].

Results of the experiments have shown that the overall effect of the natural ventilation divided by the internal surface temperature would also increase owing to the thermal physic chrematistics of the used materials and their thickness. [Straw, 2000].

3.10.5. Elements that Help Control Natural Ventilation

Movement of the air in the internal space depends on the design of the building with respect to the wind, on the design of the openings and their frontage as well as on the coordination of the site around the building especially planning of trees and their distribution.

Building frontage suitable for the wind direction does contradict with the frontage that suits the movement of the sun. Analyses and necessary studies should be made to find out the best solution.

However, elements of design effective to internal air movement can be summarized as follows:-

- Orientation of the openings
- Area of the openings
- Casual ventilation
- Location of the openings
- Way of opening window
- Design of the internal intervals
- Window furniture
- General planning of the site and its relationship with natural ventilation

3-10-6-General Planning of the Site and its Relation with Wind Movement

Wind movement in towns interacts with and is affected by the natural cover (urban planning of the site). There are a number of elements affecting wind speed on earth and its direction which will in turn affect rates of natural ventilation inside a building. [Ibn Aouf, 1977].

Wind speed is affected by the earth topography. Figure (3.36) below illustrates three sites: the first represents semi urban areas which include scattered and less high buildings; and the second site represents urban areas which include densely thick and high buildings. The third one represents rural open area. Despite the rates of wind speed provided by Meteorology Authority in the various countries, no accurate reading can be obtained since some of these anemometers are installed in high levels. As a result, the registered rate of wind speed is higher than the real speed of the air in the urban areas of high density. The real speed of the air in such areas can be assessed by the built curves shown in the figure 3.36. [Ibn Aouf, 1977].

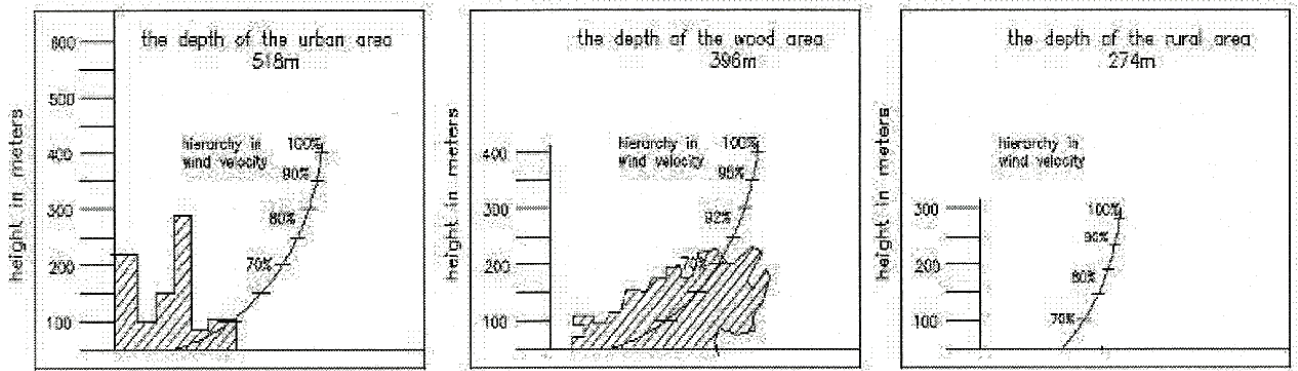


Figure (3.36) shows hierarchy in wind velocity as result of different in earth topography. [Ibn Aouf, 1977].

The general shape of the building also plays an important role in shaping the movement of air around the building. It interacts with its direction to identify the surrounding areas of high pressure and low pressure as shown in figure (3.37).

Identifying areas of high and low pressure helps the architect choose the best site for air flow to get the highest rates of natural ventilation. [Hassan, 2008].

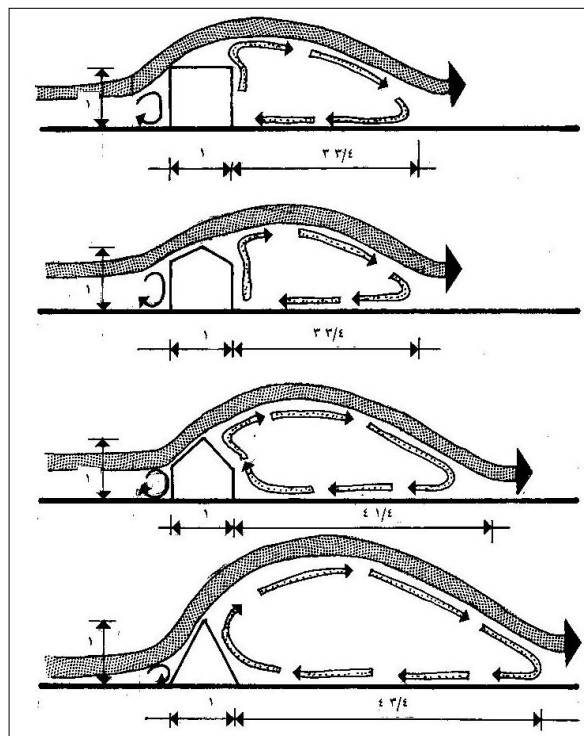


Figure (3.37) shows wind pattern and air movement a round different shape of buildings. [Hassan, 2008].

As for wind, it is desirable to receive a gentle wind and zephyr in summer and avoid the undesirable winds such as monsoon which causes dust. This can be achieved if the following methods are adopted: [Ibn Aouf, 1977].

- Direct streets in areas of complex and hot weather to north and south to increase air speed for effective natural ventilation. [Ibn Aouf, 1977].
- Take into consideration that the window openings are placed and located in a perpendicular position with the direction from which the wind blows. [Ibn Aouf, 1977].
- The location of a building in the direction that allows for flow of summer breeze into the rooms has at the same time resulted in the exposure of the building to undesirable cold winter winds. Such problem can be handled and the internal temperature can be kept during winter by doubling window glasses and increasing the thickness of the walls. [Ibn Aouf, 1977].
- Avoid constructing high-rise buildings in the direction from which wind and moderate breeze blow as low buildings would be behind. [Ibn Aouf, 1977].
- When doing a general planning and planning of residential areas in particular, distance between buildings should be considered in a way that allows for an air cycle in each house and in the space around the building in case of houses. This can be attained by planning the settings with consideration to formation of intervals, spaces and continuous open spaces between these settings that would allow for creation of low pressure areas that draws air from high pressure areas passing between these settings in a greater speed. [Ibn Aouf, 1977].
- Surround the residential areas with green spaces and to trees break winds and purify the weather. Regarding industrial areas from which weather pollutants come, they should isolated from the houses and located in places opposite to the main directions of wind. If wind comes from north, the industrial areas should be planned south of the residential areas and so. [Ibn Aouf, 1977].

We can observe the methods mentioned by Dr. Ahmed Khalid Allam in his book "Planning of Towns" (p 286-287) and by Anatoly Rimsha in his book "Planning of Towns in Hot Areas" (p 51-52). Further details are below.

- Way of distributing and planning streets; we find that chess streets help wind currents pass , continue and increase their speed where it would be difficult to reduce the bad effects such as dust. [Ibn Aouf, 1977].
- When locating high building close to low buildings, dimensions of buildings and distances between them as well as the maximum height should be identified in such a way that the arrangement would facilitate the movement of wind currents through all buildings and none of these air currents will pass through the stillness area and shadow of wind. [Ibn Aouf, 1977].

3.11. Natural Ventilation Mechanism

There are three forms of natural ventilation that must be considered. These are: [Straw, 2000].

3.7.1. Wind induced only

3.7.2. Temperature difference only.

3.7.3. Wind and temperature together

3.12. Conclusions:

1- There are many factors that affect windflow in urban residential areas. These can be represented in solar radiation, barriers, topography, trees and green spaces, buildings, the position of buildings, and the size and form of buildings.

2- In Khartoum, namely in the third class neighborhoods, we find that fence between neighbors, and buildings with attached fence is the most important factor that affects movement of air and ventilation of the adjacent buildings. Fences do not only block the ventilation to adjacent buildings, but they also lead to the accumulation of dust and rubbish in the area between buildings and fence.

3-Solar radiation causes difference in temperature on the earth. This affects air movement, where the air is moving from high pressure area to low pressure area.

4- Barriers also affect air movement, according to their size, their angle, and their heights, where the velocity and wind pattern change accordingly.

5- Topography features and hills affect the air movement and natural ventilation in the residential areas.

6-to overcome these factors, the following requirements should be considered:

- Height of buildings
- Distance between buildings
- Distance between buildings and fences
- Angle of the inclined building
- Shape of building roofs
- Width of the streets
- Height and shape of plants
- Location of the residential area in respect to wind movement and directions