

Chapter Two

Climatic Aspects and Wind Flow

2.1. Introduction

This chapter defines and introduces the concepts of wind, air movement, and natural ventilation within and around a group of urban residential areas. It also aims at introducing the climatic elements and characteristics in different climatic regions worldwide. The chapter also explains wind pattern within and around a group of buildings in urban areas to explore wind directions and patterns through the houses.

2.2. Climatology and Elements of Climate

Climatology is one of the branches of natural geography. It deals with environmental phenomena free of human intervention in their formation and emergence [Ibn Aouf, 1977]. Solar radiations are among the basic elements of the formation of climate. A great variation in the air temperature touches different parts of the earth because of the solar radiations on water surface and land through the atmosphere. Then there will be a great variation in the amount of air (pressure, direction and speed of wind and its temperature and in the amount of rains fall in different parts on the earth. [Ibn Aouf, 1977]. Climate varies from place to another because of the various elements of climate and its variation [Ibn Aouf, 1977]. Climate also affects the life of people and their daily activities directly; therefore, the bigger challenge for the people to cope with natural climate. [Ibn Aouf, 1977].

People have made shelters or refuge to protect them from prig animals and help them overcome the various climatic changes in an attempt to create good environment. [Ibn Aouf, 1977].

Over time, man has been able to understand the natural and environmental phenomena and its geographical and climatic characteristics with scientific and technological advance. He has also been able to develop his shelter in a way that provides him with suitable internal climate. [Ibn Aouf, 1977].

In order to draw positive solutions in architectural design and urban planning in a way that suits these elements, the elements of climate, which interact with man and affect his thermal feelings must be studied.

Elements of climate also interact with built forms and affect their thermal performance. The most important elements of climate that affect human beings and interact with built forms are:

- 1- Solar radiation.
- 2- Air temperature.
- 3- Relative humidity.

2.3. Characteristics of Regional Climate

Architects and urban planners should be aware of the general information about the locations. They must be familiar with the various climatic divisions, which can have a clear reflection on the architectural design and urban planning. [Ibn Aouf, 1977]. Boundaries between the various climate areas can be identified properly, because such divisions intersect each other. [Ibn Aouf, 1977]. Based on variations in the rates of the main climatic elements, climatic regions can be divided in to four (Equatorial, Tropical, Moderate, and Polar). Each has subdivisions. [Ibn Aouf, 1977]. Sudan is affected by the tropical climate.

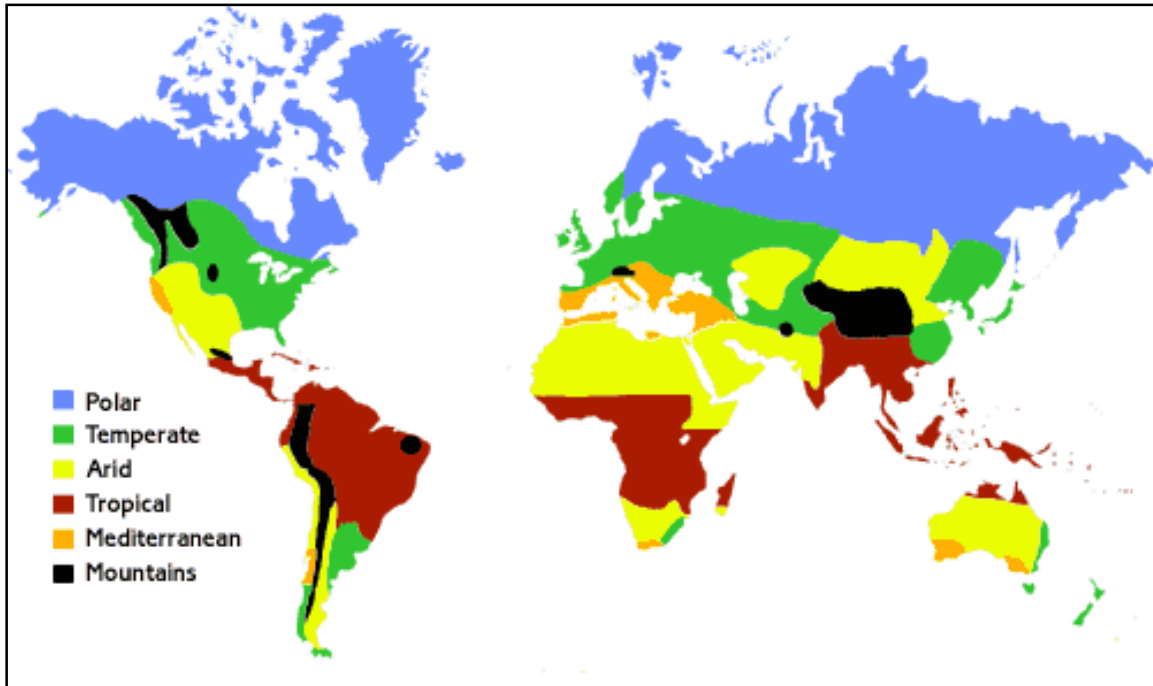


Figure (2.1) Map of regional climates [Source: google, wiki, 2015].

2.3.1. Tropical Climate

Tropical climate is divided into four main sections: hot dry and desert, hot and humid, composite climate, and high lands [Ibn Aouf, 1977]. For the purpose of this research, the hot dry and desert and the hot dry and humid which affect Sudan is discussed below.

a. Hot, Dry and Desert Climate

It's found at two belts: north and south of the equator line, between the latitudes 15 and 30. [Ibn Aouf, 1977]. The hot, dry and desert climate has two main seasons: hot season and moderate season. [Ibn Aouf, 1977]. However, the mean relative humidity ranges between 100 % and 55%. Sky is often clear with scattered clouds due to reduction of the relative humidity. The intensity of solar radiation is direct during the day. [Ibn Aouf, 1977]. Wind often becomes hot and carries impurities of dust and particles of fine sand. [Ibn Aouf, 1977]. Green areas and trees decrease due to reduction of humidity and scarcity of rains.

b. Hot and Humid Climate

Hot and humid climate is found between the same latitude as hot and dry climate, with wide water surfaces. [Ibn Aouf, 1977]. There are two seasons: hot season and the relatively moderate season. [Ibn Aouf, 1977]. The mean relative humidity often increases and ranges between 50% and 90%.

The sky becomes clear as in desert climate with the appearance of light clouds, which might cause glare that result from light intensity due to the reflections of solar radiations. [Ibn Aouf, 1977]. The solar radiations often become strong and direct and reflected by the clouds and water atoms in the atmosphere. [Ibn Aouf, 1977]. Wind is often local and is generated as a result of the variations between the air temperature in land and water surfaces. It varies during the day and night. [Ibn Aouf, 1977]. The wind direction comes from the sea towards the land during the day and from the land towards the sea during the night. [Ibn Aouf, 1977].

2.4. Atmospheric Boundary Layer (ABL)

When we talk about wind studies, it is important, to have a thorough understanding of the region of the earth's atmosphere under consideration.

It is necessary to develop methods that are capable of quantifying wind velocities and characteristics of the wind with respect to mean quantities, turbulent fluctuations, velocities and the directions. [Straw, 2000].

The Atmospheric Boundary Layer (ABL) can be defined as the region of the earth's atmosphere where the effects of the surface (friction, heating and cooling) are felt directly on a time scale of less than a day. [Straw, 2000]. And in which significant fluxes of momentum, heat or matter are carried by turbulent motions on a scale of the order of the depth of the boundary layer or less. [Straw, 2000]. The ABL can be divided into two regions:

- Interfacial layer
- Ekman layer

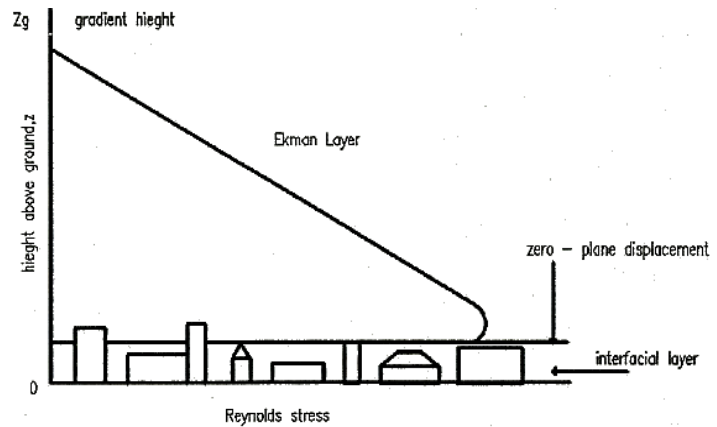


Figure (2.2) Interfacial layer and Ekman layer [Straw, 2000].

2.4.1. Interfacial Layer

The interfacial layer is the lowest region of the ABL and is usually occupied by surface features. The predominant Reynolds stress reduces from a maximum value to zero at the surface as momentum is given up as pressure forces on individual roughness elements. The interfacial layer thickness is defined as the zero-plane displacement. [Straw, 2000].

The size of the zero-plane displacement is a function of the nature of the surface in the region concerned. In urban area, where surface roughness is large, the zero-plane displacement corresponds to about four fifths of the average building height. In rural regions, roughness is very small, hence, the zero-plane displacement is very shallow (e.g. depth of vegetation) and can often be considered negligible. [Straw, 2000].

2.4.2. Ekman Layer

Above the interfacial layer, the Ekman layer begins and makes up the remainder of the ABL. Within the Ekman layer momentum is obtained from the gradient wind (constant free stream wind unaffected by the earth's surface) to form the Reynolds stress. Reynolds stress increases from zero at the top of the ABL (gradient height) to the maximum at the boundary with the zero-plane displacement. With respect to this research, where blocks (buildings in the residential areas) are low, the Ekman

layer is important in terms of wind speed profiles, turbulence and directions. [Straw, 2000].

2.4.3. Mean Wind Speed Profile in the ABL

In the Ekman layer, the mean wind speed is negligible. It has no significant effects on the low-rise buildings. [Straw, 2000]. In the interfacial layer, wind is more significant especially in the urban areas (the areas that have greater surface roughness). Therefore, the interfacial layer would have significant depth. [Straw, 2000].

The mean wind speed profile through the Ekman layer is sensitive to surface roughness, which controls the surface shear stress, for equilibrium conditions to be present in the ABL (i.e. the mean vertical speed profile remains constant with stream wise distance); the free wind must travel a significant distance over a constant surface roughness. When equilibrium is reached, the momentum required to overcome the surface shear stress exactly balances the supplied momentum. [Straw, 2000]. 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, so the nature of the earth's surface defines the supply of momentum requirement for equilibrium. The different surface roughness causes different mean wind speed profiles as shown in figure (2-3).

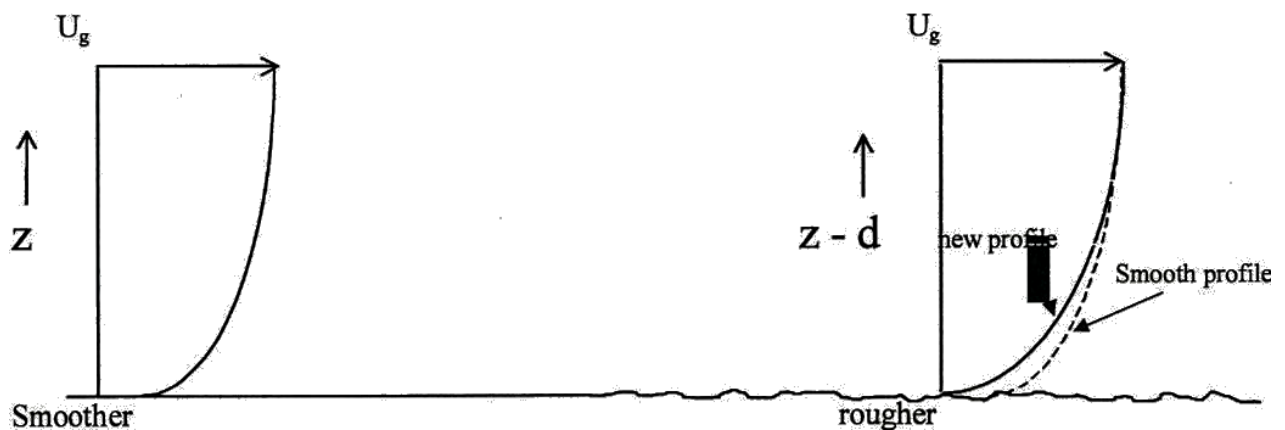


Figure (2.3) Change in mean wind speed profiles over smooth and rougher terrain. [Straw, 2000].

Figure (2.3) 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). [Straw, 2000].

Wind passing from an area of lower roughness to one with greater roughness undergoes changes in the mean wind speed profile (as shown in figure 2.3). This transition is not instantaneous and requires a significant distance before the state of equilibrium is regained. As air reaches the surface of altered roughness surface shear stress is increased, slowing the wind near ground level. This change requires time to work up through the ABL by the action of Reynolds stresses. Further, downstream, when the changes in the profile reach the gradient height, equilibrium is again reached in the altered profile. [Straw, 2000].

2.5. Global Wind Patterns

Winds are named by the direction they blow from. There are six main types of wind that surround the globe. Three types are located in each hemisphere from the pole to equator. They are the polar easterlies, the westerlies, and the trade wind. All of them move north in the northern hemisphere summer and south in the northern hemisphere winter. [www.google. wiki, 2015].

The global wind pattern is also known as the "general circulation" and the surface winds of each hemisphere are divided into three wind belts: [www.google. wiki, 2015].

- Polar Easterlies: From 60°-90° latitude.
- Prevailing Westerlies: From 30°-60° degrees latitude.
- Trade wind: From 0°-30° degrees latitude, (tropical easterlies).

The easterly trade winds of both hemispheres converge at an area near the equator called the "Intertropical Convergence Zone (ITCZ)", producing a narrow band of clouds and thunderstorms that encircle portions of the globe.

The following paragraphs explain some of them which are related to this research. [www.google. wiki, 2015].

2.5.1. Trade Wind

Trade wind blow mostly from the north east toward the equator, its located south of about 30° the northern or north east. [www.google. wiki, 2015].

There are other subtypes of global wind between the main types, which have variable direction and characteristics, which are mentioned as follows: [www.google. wiki, 2015].

Polar front

This type of wind is found between the polar easterlies and the westerlies.

Horse latitude

Where the Westerlies meet the trade winds at about 30° is the horse latitudes, also Variables of Cancer, Subtropical High or Subtropical ridge. This is a region of high pressure, dry air and variable winds and is associated with deserts over land. [www.google. wiki, 2015].

Southern Hemisphere

In the southern hemisphere the belts are reversed. The southeast trade winds blow from the southeast toward the equator. The southern equivalent of the horse latitudes (or Variables of Cancer) is called the Variables of Capricorn. The southern westerlies start somewhat south of South Africa. They tend to be stronger than the northern westerlies because they are mostly over water. The southern polar easterlies are mostly over Antarctica. [www.google. wiki, 2015].

Doldrums

At about the equator is Interropical Convergence Zone or doldrums, a region of light and irregular wind broken by occasional thunderstorms and squalls. The width and exact location of the doldrums is hard to predict. Sailing ships are

sometimes becalmed here for many days waiting for a proper wind. [www.google.wiki, 2015].

Seasonal Shift

The entire belts in the northern hemisphere move north in summer and south in winter. Because of global heating and cooling lags behind the position of the sun they reach their northernmost latitude at or after the end of the northern summer. This brought the trade winds to Spain and Portugal. The northernmost position of the wind belts corresponds to the Atlantic hurricane season. [www.google.wiki, 2015].

Monsoon

The annual equivalent of the daily land and sea breezes is the yearly monsoon. During summer, the land heat becomes more rapidly than the oceans. Air over the land becomes lighter than ocean air landward, producing a wet season. During winter the process reverses and cold, dry heavy air flows outward from the continents, producing a dry season. The monsoon is most striking in south Asia because of the size of the Eurasian landmass and because the Himalayas tend to bottle up the air above the continent. Approximations of the Indian monsoon exist in other places but they are poorly developed. [www.google.wiki, 2015].

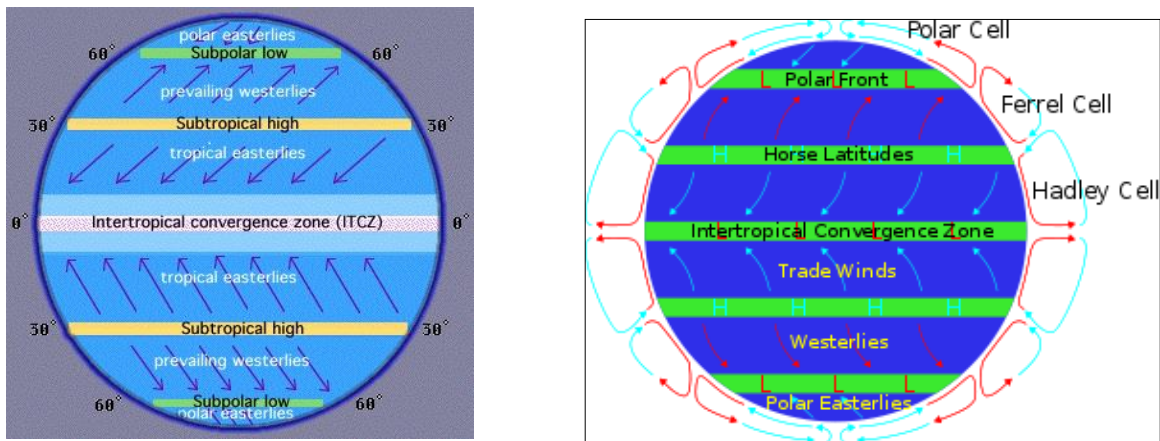


Figure (2.4) Types of winds surrounding the globe [www.google.wiki, 2015].

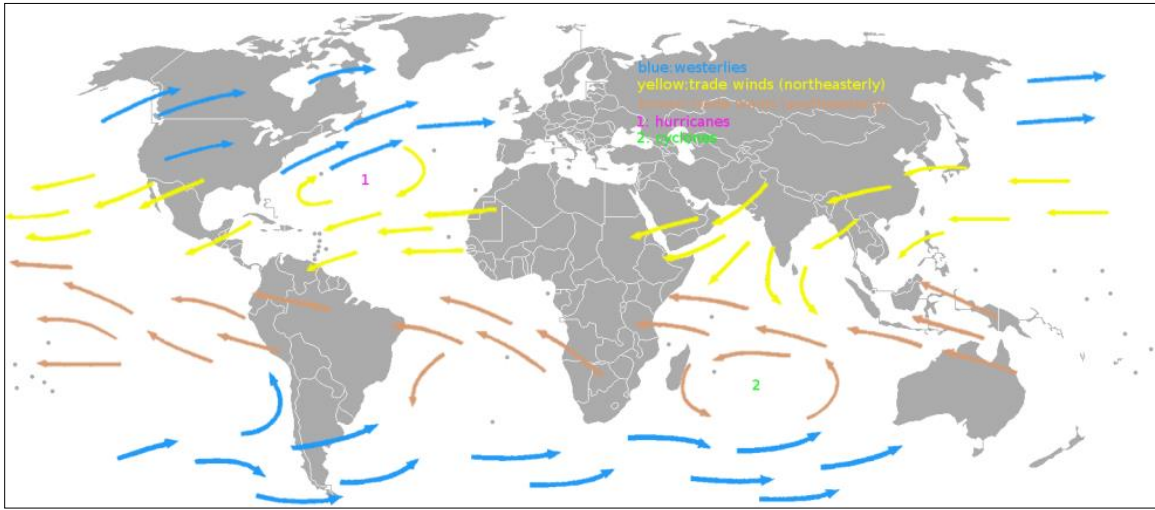


Figure (2.5) Types of winds surrounding the globe [www.google. wiki, 2015].
 Blue = westerlies. Yellow = trade wind (northeasterly). Brown =trade wind (south easterly)
 1 = hurricanes. 2 = cyclones

2.6. Regional Wind

The regional undisturbed winds are generated by differences in the atmospheric pressure, caused by the uneven distribution of solar radiation and the resulting temperature and air density variation over the globe. [Gevoni, 1998].

The flow from the high to low pressure regions is modified by the Coriolis force, as a result of the rotation of the earth, as well as by the land topography and the global distribution of land and ocean areas. [Gevoni, 1998]. These undisturbed winds flow at a height of several hundred meters above the ground. The speed of this winds increases slightly with height, but at a much lower rate than near the ground. [Gevoni, 1998]. This "undisturbed" flow is called the "gradient wind" and its velocity is called the "gradient velocity." (Gevoni, 1998), however, the wind experience friction its speed is retarded more steeply and its turbulence increases. [Gevoni, 1998]. Even more flat open areas, the wind encounters friction by the land surface and the vegetation cover, shrubs and trees further increase the friction and the retardation of the wind speed near the ground. [Gevoni, 1998].

The regional gradient wind speed and the urban design features, has significant role on the street level, air velocity and turbulence conditions. [Gevoni, 1998]. In both cold and warm regions, the comfort of people is affected by the wind conditions within the urban area. Also the wind conditions in the general urban area determine the potential for ventilation of buildings and the wind exposure of pedestrians outside the buildings. [Gevoni, 1998]. The wind field is characterized by two parameters: The vertical profile of the mean wind speed and the turbulence spectrum. Both are affected and modified by the profile of the terrain and in an urban setup, by the urban structure. [Gevoni, 1998]. There are many mathematical models of the wind speed vertical profile which should be presented later. [Gevoni, 1998].

2.6.1. Effects on Urbanization on Wind Flow Change

Urban wind flows change to the greatest extent by urbanization. It can be controlled and changed by urban design. [Gevoni, 1998]. Wind encounters a higher roughness of the surface created by the buildings when it flows over an open area. So the wind flow at the level of the urban canopy can be reduced, due to the increased resistance resulting from higher roughness (buildings). [Gevoni, 1998].

The reduced wind speeds in built up areas are well documented by researches, for the example:

- Research done by Landberg (1981) is mentioned several cases where such reductions were measured.
- Munn (1970), points out that the buildings are organized into city blocks with streets forming corridors for the wind flow.

The air flow above and a round building have a lower overall air speed and a higher turbulence, due to the friction by the buildings. [Gevoni, 1998]. Thus the urban wind field is characterized by a lower average speed, but higher speed variations and turbulence, as compared with the wind flow over open country. [Gevoni, 1998]. In this way a transitional zone is created between the ground and the undisturbed wind

flow above the urban air dome, the so called urban boundary layer. [Gevoni, 1998]. Boundary layer is subdivided into two subzones, especially when the buildings are of the same approximate height. [Gevoni, 1998] Wind speed in the urban canopy is lower than in the open country at the same height, with relatively small speed variation with height. [Gevoni, 1998]. There is a sharp increase in the wind speed above the roof level at the top of the city's air dome. The wind retains to its speed in the open country at the same height. [Gevoni, 1998]. The urban wind speed and turbulence at the street level is affected by the specific design details of the buildings and the streets, especially the height of the buildings relative to one another, and the orientation of the individual buildings with respect to the wind. [Gevoni, 1998]. In the rural areas, the trees are the roughness elements which encounter the wind, but the resistance encountered by the wind near ground level is soft, so it causes less retardation and turbulence than in a densely built up urban area. [Gevoni, 1998]. A research conducted by Munn, has concluded that the height of the buildings across the urban area is not constant. It rises to maximum at the town's center. He has pointed to the effects of the turbulence generated by vehicles. [Gevoni, 1998]. He noted that in Detroit at the WJBK television tower, located near an expressway, the nocturnal inversion does not usually form until traffic diminishes about midnight, while at another comparable locations the inversion develops several hours earlier. [Gevoni, 1998].

2.6.2. Orientation of the Buildings

Wind direction in streets and between buildings changes due to their orientation relative to the regional wind direction. [Gevoni, 1998]. Under certain metrological conditions the average urban wind speed can actually be higher than in the surrounding open country. [Gevoni, 1998]. Heat island of the city generates its own airflow pattern during the periods of calm and clear nights, so the warm air rises over the city's center and flows out ward, and cooler air from the surrounding country

converges near the ground level and flows towards the center. [Gevoni, 1998]. Another research done by Jauregui (1984), has introduced a table which shows urban – rural wind speed differences for Mexico City, during January and July, for several periods of the day. [Gevoni, 1998]. He showed that in the cool season and during daytime urban wind was weaker than over the sub urban of the city. Greatest difference was observed in the afternoons (1-7 pm) as a result of the prevailing regional turbulence and greater surface roughness of the city.

Table no (2-1): urban rural wind speed differences for several periods of the day In Mexico City. 1980. [Gevoni, 1998].

hours	January					July				
	City wind more	Mean Diff m\s	City wind less	Mean Diff m\s	calm	City wind more	Mean Diff m\s	City wind less	Mean Diff m\s	calm
0-12	18	0.7	9	1.2	73	49	0.7	5	0.4	45
13-19	19	0.8	74	1.8	6	61	1.0	35	0.8	1
20-23	36	1.1	30	1.4	32	58	0.7	23	0.9	11

During the night hours, mainly in July, the urban wind in Mexico City was stronger. [Gevoni, 1998].

Chow (1984) in Shanghai observed that the wind speeds in urban areas during periods of light regional winds is higher than the inversion is formed over rural areas.

Lee (1979) also observed this phenomenon. [Gevoni, 1998].

Eventually, it should be pointed out that the increase or decrease of the urban wind conditions, caused by the specific urban and building details, either intentionally or by design, according to different human comfort objectives in different climatic regions. [Gevoni, 1998]. Wind conditions can be changed by the following urban design elements which mentioned bellow: [Gevoni, 1998].

- The overall density of the urban area

- The size and height of the individual buildings, and existence of high rise buildings
- Orientation of the streets
- Availability, size distribution, and design details of open space and green shelter belts

2.6.3. Vertical Profile of the Mean Wind Speed

The mean wind speed increases with height above the ground and decreases downwards as a result of friction with the earth's surface. [Gevoni, 1998]. Several empirical formulae of different forms have been developed to describe the variation of the mean wind speed with height .[Gevoni, 1998]. The urban effect on the wind speed is presented in models describing the vertical profile of the wind, from the gradient wind level down to the ground. [8].

The urban effect is expressed by modifications of the parameters of the models. A parameter used by some models, which is greatly affected by the urban structure, is the aerodynamic roughness. [Gevoni, 1998]. The vertical wind profile presented in the following logarithmic formula:

$$U(z) = ((t/p1/2/k) \ln(z/z(0)))$$

Where: $u(z)$ = air speed at height z .

t = wind shear stress.

P = air density

K = von karmans constant, about 0.4

Z = height

$Z(0)$ = roughness parameter

Values of the roughness parameters for urban settings with three types of buildings are shown in the following table:

Table No (2-2) Urban Roughness Parameter Values, X [Gevoni, 1998].

Parameter	Building type (urban density)		
	low	medium	high
Height (m)	4	20	100

Silhouette area (m ²)	50	560	4000
Built up area (m ²)	2000	8000	20000
Roughness parameter	0.5	0.7	10

The model explains that at a height equal to the roughness parameter above the ground level, the wind speed is always zero, regardless of the gradient wind speed above the city. [Gevoni, 1998]. There is a simple formula developed by Davenport (1960) which indicates the limitations of the logarithmic mathematical wind models for estimating the urban wind conditions near the ground. The formula is:

$$V_z/V_g = (Z/Z_G)^\alpha$$

Where: V_z = wind speed at height Z

V_g = height where the gradient wind starts

Z = the height for which the wind speed V_z is computed

Z_G = the height at which the gradient velocity V_b is first observed

α = an empirical exponent which depends on the surface roughness,

Many researchers have suggested different values for Z_G and α , for example, values introduced by Davenport (1960) and used by Gevoni in Table (5) below:

Table No (2-3): Values of Z_G and α for various terrain conditions. [Gevoni, 1998].

Terrain condition	Z_G (m)	α
Open country, flat coastal belts, prairie grass land...etc.	270	0.16
Wooded countryside, parkland, small towns, outskirts of large cities, rough coastal belts....etc.	390	0.28
Centers of large cities	510	0.4
Centers of very large cities	600	0.5

Poreh and Paciuk (1980) have determined the values of Z_G shown in this table 2-5 below:

Table No (2-4): Values of Z_G and α for various terrain conditions. [Gevoni, 1998]

Terrain conditions	Z_G (m)	α
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Open flat country, prairie, grassland	300	0.16
Low wooded land, sparse trees, rural areas, airports	400	0.2
Woodedland with high trees, small towns, suburbs, urban meteorological stations	400	0.25
Medium size towns, building of height up to five stories, medium density centers, large cities	400	0.30
Centers of cities, buildings of more than 10 stories	500	0.40
Centers of large cities, buildings of more than 30 stories	600	0.50

Gevoni suggested synthetic table for these parameters to make them more consistent with terrain conditions, as shown in Table (2-6) below:

Table No (2-5): Values of ZG and α given by Poreh and Paciuk, [Gevoni, 1998].

Terrain conditions	ZG(m)	α
Open field, desert	300	0.15
Cultivated fields, low vegetation, and scattered trees, low density rural area	400	0.20
Wooded land, urban areas with medium to high density, typical building of 10 meters height (three stories)	400	0.20
City center, buildings of medium to high density, typical building of 30 meters height (10 stories)	400	0.28

There is a graphical illustration of the changes in the vertical wind velocity profile over urban /suburban and open rural areas according to this model. The figure presented by Chandler (1976) was mentioned previously in this research. Here below it will be explained in details.

From this diagram, it can be concluded that, the wind profile described by this power law does not represent realistic wind conditions near the urban ground level, for example: up to about 5-10 m, because of the high turbulent nature of the urban wind

at that layer. [Gevoni, 1998]. It should be noted that the temperature profile have a significant role in the vertical profile of the wind. Figure 2.6.

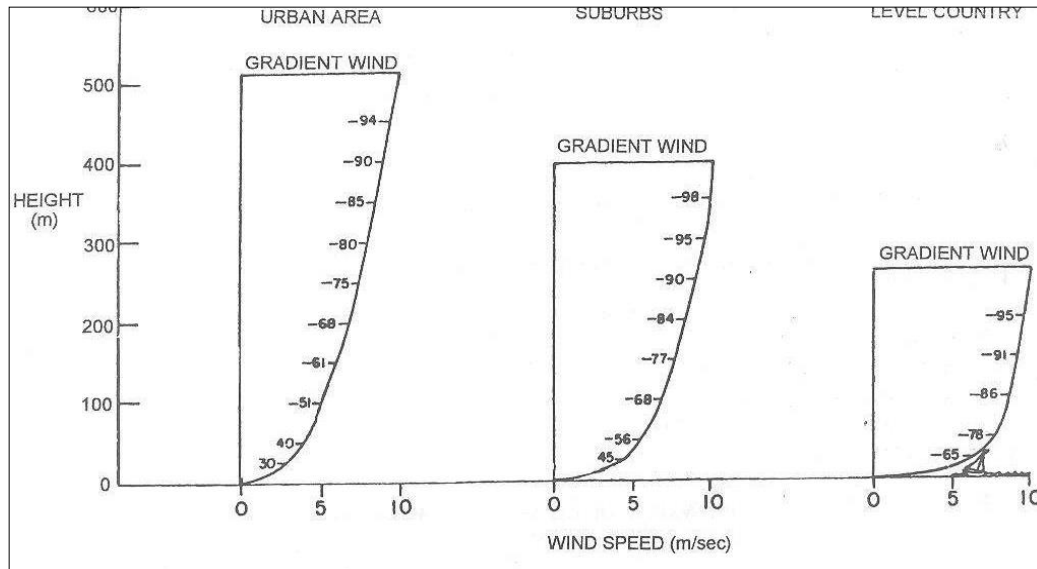


Figure (2.6) Diagrammatic wind speed profiles above urban, rural, and sea surface, percentage of the gradient wind speed. [Gevoni, 1998].

2.7. General Characteristics of the urban climate

This section discusses the differences between the urban climate and the climatic conditions prevailing in the surrounding urban areas. [Gevoni, 1998]. These differences are affected by firstly, by wind speed, and secondly, by the structure of the city, such as buildings density and width of streets. [Gevoni, 1998].

According to Baruch Gevoni in his book "Climate Consideration in Building and Urban design", the main differences between the urban and the rural climates which affect human comfort are in the air temperatures and wind speeds near street level. [Gevoni, 1998]. These differences are caused by changes in the radiant balance of the urban space, the convective heat exchange between the ground and the air flowing, and by the heat generation within the city. [Gevoni, 1998]. The following

topic discusses one of the general characteristics of the urban climate and its relation to air movement:

2.7.1. Urban Temperature and Wind Movement

The urban heat Island means the difference between urban temperature and that of the surrounding rural areas, when the urban temperature is above than rural area temperature. The maximum urban – rural difference is defined as the heat island intensity. [Gevoni, 1998]. In the common conditions, the differences in temperature between city centers and surrounding country are usually smaller during daytime, it's about 1 -2°c, but, during windy periods the urban – rural temperature difference may be insignificant. [Gevoni, 1998]. Some urban structures features, such as the width of streets and the materials of the buildings (their heat capacity) affect the relationship between the urban and the rural temperatures in opposite way (this will be discussed later in this section).

The differences between the urban and the "rural" temperatures are affected by two types of factors. One, they are correlated with meteorological factors such as the cloud cover, humidity, and wind speed. Two, various features of the urban structure, such as the size of cities, the density of the built-up areas, and the ratio of buildings heights to the distances between them can have strange effect on the magnitude of the urban heat island. [Gevoni, 1998].

The comparison studies between urban centers and the surrounding areas (rural) were done in cities surrounded by cultivated land (rural areas) in temperate climates, but the situation may be different in desert cities which are surrounded by dry land. [Gevoni, 1998].

2.7.2. Spatial Pattern of the Urban Heat Island

The boundary of the heat island follows the urban air dome. During the nights, the rise of the horizontal temperature gradients from the periphery to the center, is largest at the outer boundaries of the urban area and flattens towards the center of a

built-up area. [Gevoni, 1998]. The heat island expanded with the direction of the wind to reach the area behind the built-up area. [Gevoni, 1998]. The height of the heat island is more than three or five times higher than the average height of the buildings. [8]. There is small difference between urban temperature and rural temperature above this height. [Gevoni, 1998]. The urban temperature is affected by different and independent factors:

- a- Differences in the overall net radiation balance between the urban area and the surrounding open country side. The major factor contributing to the higher urban temperature is the lower rate of radiant cooling during the nights.
- b- The solar energy which stored in the mass of the buildings during day time hours is released during the night hours.
- c- Concentrated heat generation by the activities taking place in the urban area around the year (transportation, industry etc.), the so called anthropogenic heat island.
- d- Lower evaporation from soil and vegetation in the urban built-up area, as compared with an open rural area.
- e- Seasonal heat sources, heating of the buildings in winter and air conditioning in summer. All the heating and air conditioning energy is ultimately released to the urban air.

Urban temperature has a positive effect on urban areas with cold climate, where utilized in thermal comfort and reduce the energy consumed in heating. But in hot urban areas, it has negative effects - thermal discomfort and the need to use air conditioning. [Gevoni, 1998]. There are some meteorological factors that affect urban heat island and not human intervention, such as the cloudiness and the regional wind speed. [8].

There are some factors that can be controlled by man to reduce urban temperature, such as colors that help buildings reflect solar radiation away, the amount and

distribution of urban vegetation, energy used for heating and cooking, density of the built-up areas, types of buildings, and orientation of the streets with respect to wind direction. [Gevoni, 1998].

The relative role of the factors mentioned above generating the heat is land effect depends upon the climate seasons (dry or humid), and type of activities in the city. [Gevoni, 1998].

Energy consumed by conditioning equipment is converted into heat, discharged to the outdoors, and ultimately raises the temperature of the urban wind. [Gevoni, 1998]. Commercial buildings are air-conditioned year round, especially during hot summer days. Residential buildings are less conditioned. Consequently, the consumption of energy for air conditioning is concentrated mainly in urban commercial areas. [Gevoni, 1998]. All the heating energy, including cooking, washing, and so forth, and energy consumed by air conditioning is eventually released to environment, elevating the urban temperature. [Gevoni, 1998].

Types of city have impact on the growth of the urban heat island phenomenon resulting from the temperature generated from industrial areas. [Gevoni, 1998]. For example, we find that heavy industries like steel mills may be the main factor of the increase in the temperature of the city, while it does not pose a problem in some cities. [Gevoni, 1998]. All the energy consumed by light industries transformed to heat and contributes to this phenomenon. The contribution of the energy used by transportation in the emergence of the urban heat island has relation to the size of the city and the type of public transportation in it. [Gevoni, 1998]. Larger cities have more overall traffic, but the trips and the energy they consumed are distributed over a larger area. However more people and trips are concentrated in the center of larger cities, as compared with smaller cities. [Gevoni, 1998]. The energy input by transportation at the town center may be related to the size of the city. This effect may be changed by the type of the urban transformation system, the heat generated

from private cars is more than which from buses and electrical subways. [Gevoni, 1998]. According to the complexity of these factors, the difficulties face the researchers are to find a realistic mathematical predictive model to estimate the heat island phenomenon. [Gevoni, 1998]. Each one of the individual factors affecting the urban – rural temperature differences has a specific effect and any observed temperature differences reflects the combined effect of all these factors. [Gevoni, 1998].

Understanding the impact of each one of these factors on the urban rural temperature differences is useful for the analysis of the factors which can be treated by urban design features. [Gevoni, 1998].

2.7.3. Localized Distribution of the Urban Heat Island Sources

Temperature in the period of the day in any area in the city, depends on the local situation of the city, the density of the buildings that cover of the earth, buildings heights, the nature of the earth's surface (vegetation, gardens, shades), the exposure of the site to the regional wind etc. any local area can be warmer or cooler than the surrounding areas. [Gevoni, 1998].

The density of the urban heat island during the night is related to density of buildings more than the size of the city. [Gevoni, 1998].

In fact, some studies have demonstrated that heat islands can be developed even on relatively small scale urban areas. [Gevoni, 1998].

So, the warmer air above such small- scale, heat island mixes eventually with the bulk of the urban air and this slowly elevates the ambient air flowing across the city downwind. Therefore, although the origins of the urban heat island may be small pockets, their effect accumulates to produce the peak of the temperature elevation near the town's center. [Gevoni, 1998].

2.7.4. Solar Radiation and Urban Geometry Impact on Urban Temperature

The ratio of the height (H) of the buildings to the spacing (width) between them, which namely the H/W ratio of the spaces between the buildings, indicates the impact of the solar impinging radiation on the climate near the ground. [Gevoni, 1998]. Figure (2.7) illustrates the analysis done by Ludwig (1970). It explains the effect of this ratio on the radiation and air temperature near ground. [Gevoni, 1998]. His analysis shows a schematic distribution of the impinging solar radiation in three different types of areas: an open flat country, a built-up area with H/W ratio of about 1, and high density urban area with H/W ratio of about 4. Most of the impinging solar radiation is reflected away or emitted, after absorption, as long-wave radiation to the sky in the flat area. It strikes other buildings or the ground and is eventually absorbed at near the ground level in the medium density area (H/W ratio about 1). [Gevoni, 1998]. In the high area (H/W) Ratio of about 4 or more, most of the absorption takes place high above the ground level. [Gevoni, 1998].

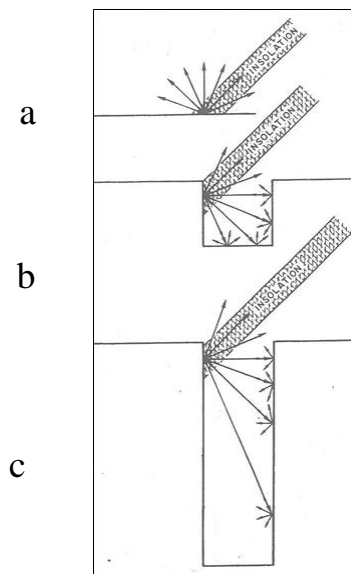


Figure (2.7): Distribution of impinging solar radiation in an open flat country, (b) built up area with H/W ratio of about 1, and (c) high density urban area with H/W ratio of about 4. [Gevoni, 1998].

The amount of radiation reaching the ground, and heating the air near the ground is smaller in the high density than in the case of medium density (Figure 2.8 above).

[Gevoni, 1998]. The term urban canyon introduced and applied by Oke (1981), in developing a predictive formula for heat island intensity. And there is study done by Oke (1981), when he took a H/W Ratio approximately 0.9, he found that about 60 percent of the midday solar gain was transferred as sensible heat to the air contained in the volume of the canyon, about 30 percent was stored in the canyon materials to be released during the night, and about 10 percent was consumed by evaporation from the canyon surfaces. [Gevoni, 1998].

2.8. The Urban Wind Field

From the standpoint of providing suitable wind speed for effective natural ventilation and human comfort by urban design, enhancing the urban wind conditions offers the great potential.

There are various urban design elements that help increase of the wind velocities at street level according to the different comfort needs in different climatic region.

[Gevoni, 1998]. In detail, such urban design elements as the

1. Orientation of streets with respect to the wind direction.
2. Size, height and density of buildings.
3. Distribution of high rise buildings among low rise ones.

These elements have great impact on the urban wind conditions. [Gevoni, 1998].

The regional wind (the gradient wind) is the main factor that affects the cross natural ventilation in the city. [Gevoni, 1998]. Add to this temperature differences between the densely built up urban cores and surrounding open country can generate centripetal (toward the center) airflow near ground level, in particular during calm clear nights. [Gevoni, 1998]. Human health and comfort are affected directly by the urban wind conditions, in particular near street level. [Gevoni, 1998]. The effect is due to energy consumption for the purpose of heating, air conditioning, and air pollution concentration. [Gevoni, 1998]. The wind conditions in the urban areas

identify opportunities to provide air for buildings, and the urban heat island decrease with the increase of wind velocity. [Gevoni, 1998]. Sometimes, the local wind speed is high near the high rise buildings. This troublesome phenomenon can be controlled by appropriate design of high rise building. [Gevoni, 1998].

2.8.1. Wind Effect on Urban Areas

It is more difficult to provide natural ventilation to urban areas than to provide it to rural areas. Especially in street canyons due to reduced wind velocity, urban heat island, noise and pollution, which are considered to be important barriers to the application of natural ventilation. [Gevoni, 1998].

2.8.2. Urban Wind Turbulence

Wind speed and direction is changed constantly in time and between nearby points. The intensity of the winds turbulence (I_g) is defined by the quadratic value of the wind speed fluctuations around the mean speed (V_{av}). [Gevoni, 1998].

Wind turbulence may reach about 30 percent in urban areas, while in open rural areas is about 10 percent. [Gould, 1972]. The wind speed can be defined by two scales, due to its changes at a given point with time, and at the same time it changes between different points.

The first one is a length scale, which means a measure of the fluctuations of measurement taken at the time at different points. [Gevoni, 1998].

The second one is the time scale, which means a measure of the fluctuations of measurements at the same point at different times. [Gevoni, 1998].

In urban areas, the length scale is the more relevant one because it is greatly affected by design details of the buildings, the orientation of the streets, and the existence of a high rise buildings etc. [Gevoni, 1998].

2.8.3. Urban Areas Effects on the Wind Flow and Air Movement

Wind is affected by the different features of the physical structure of the city, so the physical structure can be controlled by urban planning and design and it's possible

to change or enhance the urban climate and wind pattern in particular through urban policies, designs of neighborhoods and completely new cities. [Gevoni, 1998]. With enhancing the city climate and wind pattern in a city, the comfort of the inhabitants outdoors and indoors can be improved, and the demand of the buildings for cooling in summer can be reduced. [Gevoni, 1998].

The urban climate and urban wind are affected by the following physical features, which will be discussed in this section in details: [Gevoni, 1998].

- The location of a town within a region
- Size of towns
- Density of the built- up areas
- Land coverage
- Height of buildings
- Orientation and width of the streets
- Subdivision of the building lots
- Special design details of the buildings which affect the outdoor conditions
- Parks and green areas

2.8.4. Location of a Town within a Region

Urban climate, comfort of the inhabitants, and the expansion of the town are affected by the location of a city. [Gevoni, 1998].

Geographical location of a town is very important to take into consideration, because it may exist for many centuries unlike the buildings which may be demolished and rebuilt; the land use may change with time.

It's very important, therefore, to be careful with location of the town. Any unwise decision for a town may subsequently result in future environmental quality of a very large population. [Gevoni, 1998]. Therefore the climatic analysis of the region is very important because it leads to suitable choice of specific location. [Gevoni, 1998].

Sometimes, the different locations within a given region may vary in wind condition. This variation may be caused by different factors such as the distance from the sea, altitude, direction of slope, and the general topography of the area. [Gevoni, 1998]. Some of these factors are discussed below. Wind is one of the actual criteria for choosing the location of a town within a given region. The protection from the wind is required in cold region, while in a hot region, and especially a hot humid one, the maximum wind exposure is required. [Gevoni, 1998]. The comfort, health, productivity, and demand for cooling or heating can be enhanced by the location of town with a better natural climate exactly wind flow.

2.8.5. Effects of Mountain Ranges and Altitude

When humid air rises over the windward slopes of a mountain, it cools down and its moisture condenses in to clouds, promoting precipitation. However, as the airstream passes over the top of the mountain range, it sinks down and heats up. [Gevoni, 1998]. The water droplets in the clouds evaporate and thus precipitation is prevented. Consequently, there are very sharp differences in the clouds, precipitation, and humidity conditions between the windward and the leeward slopes. [Gevoni, 1998]. These differences are manifested primarily in the wind speed, clouds, and precipitation, with the windward facing slopes being more windy and rainy; where as those of the other sides of the ridge are arid and less windy. [Gevoni, 1998].

Due to different changes in the air pressure, the temperatures over short distances are different. The temperature falls 1°C for every 100 m of height when a body of air ascends and it rises by the same rate, when the temperature descends (adiabatic lapse rates of heating and cooling). [Gevoni, 1998]. The changes in the air temperature near ground level during the daytime are smaller than the adiabatic lapse rate. [Gevoni, 1998]. When an air mass is ascending terrain slope, the adiabatic cooling is compensated, in part, by heat absorption from the warmer ground. [Gevoni, 1998].

In consequence, the actual cooling rate near the ground is often only about 0.8°C for each 100 m of elevation in altitude. The diurnal and annual temperature ranges are smaller than in land areas. Therefore the summer temperature and especially the daytime temperature are lower near a sea. The changes are not linear. Within approximately 20 km of the sea there are great differences in the diurnal range within relatedly short distances. Beyond this range the moderating effect of the sea becomes smaller. This factor, therefore, has special importance for cities located on coastal plains. [Gevoni, 1998].

2.8.6. Effect of Local Topography on Wind Condition and Air Movement

Effect of topography on local wind exposure illustrated in figure (2.9), wind speed at the bottom of the upland areas is much higher than in the highest region, when the wind blows from the bottom to top. [Gevoni, 1998].

Flat valleys surrounded by mountains have poor wind speed which causes poor natural ventilation in buildings and lower temperatures in the night hours. A narrow valley facing the wind concentrates the wind flow, especially in cold regions, may suffer excessive wind speed. On the other hand, the high speed of wind is required for natural ventilation in warm-humid regions, and main criteria for choosing the location is wind exposure in the area. [Gevoni, 1998].

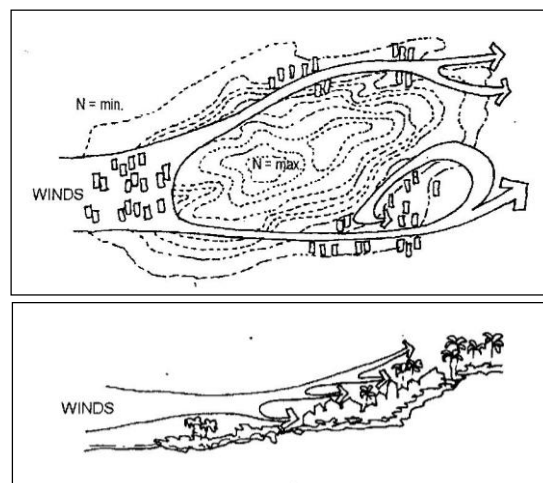


Figure (2.8): Effect of Topography on Local Wind Exposures. [Gevoni, 1998].

2.9. Local Wind

2.9.1. Wind Pattern around Single Building

Airflow around a building causes distributed pressure around it, and this in turn causes pressure differences between the two opposite side of a building. [Straw, 2000].

This section discusses the airflow patterns and pressure distributions around single building in two different manners:

2.9.2. Incident Normal Wind

When the wind of the ABL meets the windward face of the building, the velocity gradient leads to increased wind speeds higher up the face. [Straw, 2000]. In this case, two-thirds of the way up the windward face benefits from the wind termed the 'stagnation point'. Above the stagnation point, air flows up and over the roof of the building. [Straw, 2000].

Under the stagnation point air is forced to move down the face until it reaches the ground. Wind moving towards the ground possesses greater kinetic energy than the slower moving incident wind at the same height. This greater kinetic energy allows the flow to move against the wind when it reaches the ground, in doing so, losing its kinetic energy until it is provided. The wind is then forced to reflect and travel with the incident wind forming a vortex close to the ground in front of the windward face as shown in figure 2.10. [Straw, 2000].

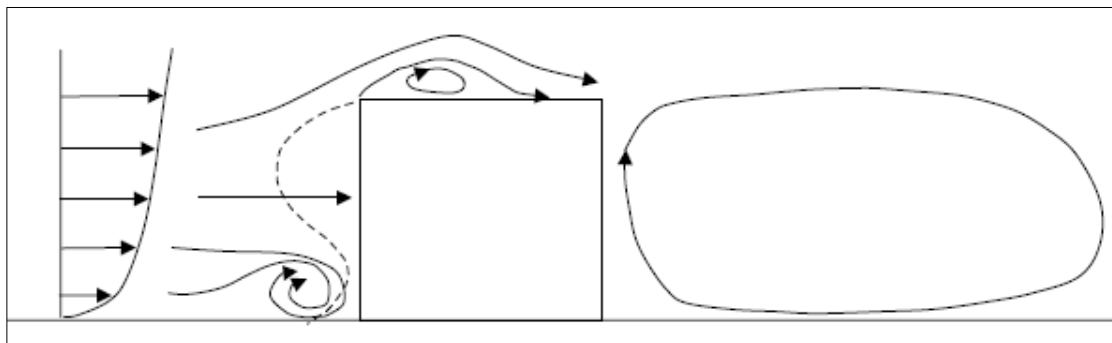


Figure (2.9) Side Elevation of Wind Flow. [Straw, 2000].

The presence of the vortex on the front face and the position of the stagnation point lead to a very different pressure distribution compared to that exhibited in a uniform incident wind (no shear). In a uniform flow, the point of maximum pressure is located on the centre-line of the face close to ground level. The value of this maximum is equal to the incident dynamic pressure producing a maximum pressure coefficient of unity. However, in a sheared boundary layer, the maximum pressure is located at the stagnation point. The corresponding pressure coefficient at this point would be in the range of 0.7 to 0.9. [Straw, 2000].

In a sheared boundary layer, only flow above the stagnation point is directed over the roof. This flow possesses less kinetic energy than the unconstrained flow (due to the velocity profile). [Straw, 2000].

Together, these factors act to reduce the separation height of flow over the roof of the cube. [Straw, 2000].

The pressure of wind distribution across the roof in a sheared layer shows high negative values as the upwind edge becoming less negative towards the downwind edge. Wind deflected laterally across the windward face separates along the line of the corner with each of the side faces of the cube. Lower down the face, flow moving around the sides originates from the vortex in-front of the windward face as shown in figure 2.11. [Straw, 2000].

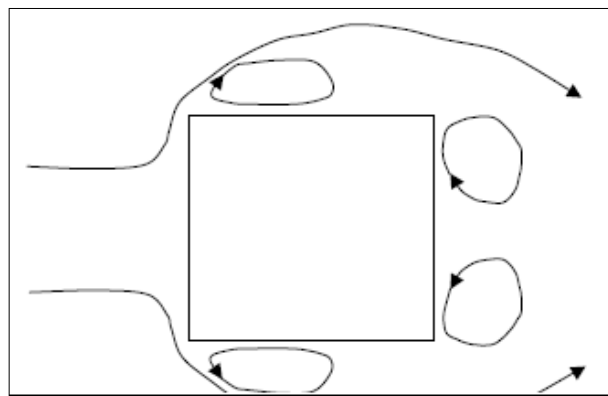


Figure (2.10) Wind flow around a building. [Straw, 2000].

Flow in this region is significantly faster than the incident wind at the same height. Pressure at the upwind edge of the building sides is highly negative due to the separation of flow and becomes less negative with downwind distance.

In the lee of the structure, a large separation of flow occurs and a recirculating weak flow downstream of the leeward face as shown in figure 2.10. Recirculation at each corner of the leeward face is driven by the horseshoe vortex at the front face through shear layers along each side of the building. [Straw, 2000].

A larger recirculation can also be seen in Figure 2.10 that is driven through the shear layer over the roof. This vortex also tends to draw the corner vortices vertically upwards. The flow in the lee of bluff structures is very unsteady with the vortices described behind the building being periodically shed. The weak flow produced in the lee of a structure often affects the flow for large distances downstream. It is a significant distance downstream before the wind profile becomes completely independent of the upwind obstruction. The distance required for flow to return to its undisturbed profile is approximately nine times the height of the obstruction encountered. [Oke, 1892].

2.9.3. Inclined Wind Incident on a Building

When the wind direction skewed to building (i.e.45 degree), flow patterns and pressure distributions are changed according to the wind direction.

In this case, the flow separating from the upwind edge of the roof possesses a component of velocity along the line of separation.

The form of delta wing vortices (A) on each of the leading (windward) edges, are separated near the windward corner of the roof, and they are separating immediately downwind (B), these are shown in figure 2.11.

The vortices of flow A adds to that of B and the vortices continue to form a conical vortex along the edge of the roof as shown in figure 2.11.

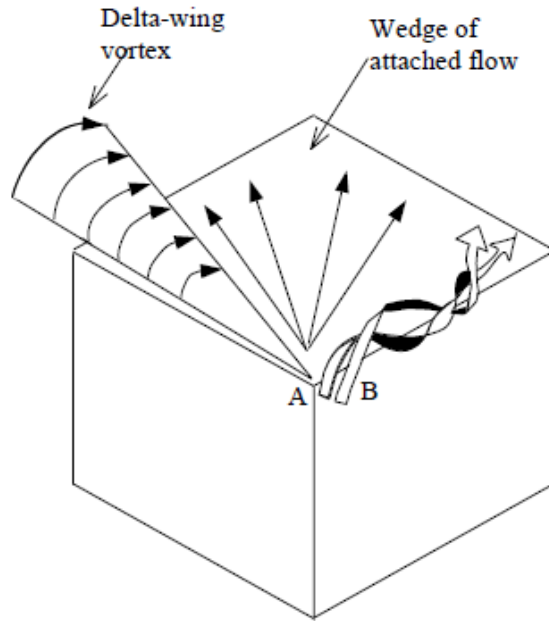


Figure (2.11) Formation of delta-wing vortices over roof with flow skewed to orientation of a building. [Straw, 2000].

The two vortices will usually have different strengths unless the wind angle relative to the recirculation is the same (at an angle of 45 degree to the front corner). [Straw, 2000]. The flow over the region of a roof between the two delta - wing vortices is attached. [Straw, 2000]. Pressure at the centers of the two vortices, are highly negative leading to uplifting forces acting along the peripheral roof edges. [Straw, 2000].

2.9.4. Wind Effect on Buildings Design

Climate elements are very important in building design; it is related to thermal comfort and natural ventilation.

The design of buildings is affected by the following elements:

- Building location and orientation
- Building form and dimensions
- Indoor partitions and layout
- Window typologies, operation, location, and shapes

- Other aperture types (flues)
- Construction methods and detailing (infiltration)
- External elements (walls, screens)
- Urban planning conditions

The following design guidelines are selected from the Whole Building Design Guide, a program of the National Institute of Building Sciences (USA):

Maximize wind-induced ventilation by situating the ridge of a building perpendicular to the summer winds

- Depth of naturally ventilated zone should be narrow (max 13.7 m.)
- Each room should have two separate supplies and exhaust openings.
- Orient windows across the room and offset from each other to maximize within the room while minimizing the obstructions to airflow within the room.
- Window openings should be operable.

2.10. Conclusion

1- Wind movement has been studied at global, regional and urban levels. Climate elements, regions and characteristics are discussed in general in this chapter because they are important for wind movement pattern and urban comfort and interact with built forms and affect their thermal performance.

2- Most important elements of climate effect on humankind and built forms are radiation, air temperature and humidity.

3- Regional wind movement affects urban areas. It was observed that the movement of the wind is due to the difference in atmospheric pressure. This difference in atmospheric pressure results from the distribution of the solar radiation and the rotation of the earth.

4-The wind moves from high to the low pressure zones.

5- This chapter has discussed wind movement pattern in urban areas, the natural and fabricated elements that effects negatively in wind movement, which include solar radiations, landscape elements, buildings, terrain and mountains. These elements block the wind flow to buildings in the urban areas.

6- Characteristics of regional climate have also been reviewed due to their relatedness to architectural design and urban planning.

7- Tropical climate has been studied in detail because it has a link with location of the study area

8- Effects of atmospheric boundary layer (ABL) on wind movement in urban areas.

9- Effect of head island phenomena on urban wind was noted along with air movement and urban wind