EFFECT OF URBAN GEOMETRY ON PEDESTRIAN LEVEL WIND VELOCITY

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To Zeynep Su...

ABSTRACT

EFFECT OF URBAN GEOMETRY ON PEDESTRIAN LEVEL WIND VELOCITY

In the recent years there are many studies on the detection of the Urban Heat Island (UHI) Effect which shows itself mostly by the temperature difference between rural and urban areas. The heat generation in the city, the radiant energy balance, the air flow direction and intensity are the main factors affecting the UHI. Height and shape of the buildings, the street width and orientation, the space between the buildings and the urban topography and vegetation are the main elements of the urban geometry. The air velocity is either increased or decreased by building blocks and the solar energy is trapped in the urban canyons formed by buildings on both sides of the streets. Pedestrian comfort level is greatly affected by the temperature, the relative humidity and the wind speed in urban canyons.

The city of Izmir has been experiencing very hot summers especially in the recent years due to the UHI effect and the global warming. The compact organization of the streets in the mild climate of Izmir during the winter protects pedestrians and building façades from cold winds. However the prevailing wind and the local breeze in the summer season on the coastal region in Izmir are blocked by the buildings as well, causing discomfort during the hot summer days. Although this is a well known problem in Izmir, there are very few scientific studies on the subject to bring it above a speculative level. The aim of this study is to fill this gap as much as possible and find a way to create guidelines for planners and architects for future plans or physical organisation of the city and making strategies for better urban environment and comfort conditions for the citizens of Izmir.

ÖZET

YAYA SEVİYESİNDEKİ RÜZGAR HIZINA KENT GEOMETRİSİNİN ETKİSİ

Son yıllarda ‘Kentsel Isı Adası Etkisi’ (Urban Heat Island Effect) üzerindeki çalışmalar evrensel literatürde önem kazanmıştır. Kentsel Isı Adası Etkisi basitçe kentsel ve kırsal alanlarda gözlemlenen yaklaşık olarak 5-10 ºC’lere varabilen ortalama sıcaklık farkıdır ve ağırlıklı olarak akşam saatlerinde meydana gelir. Kentsel alan içinde pek çok faktöre bağlı olarak belli noktalarda veya ‘ada’ larda sıcaklık artışları tespit edilmiştir ve buralarda özellikle sıcak iklim bölgelerinde, yaz aylarında soğutma giderlerinin arttığı ve dış konforun düştüğü saptanmıştır. Malzeme özellikleri, güneş kaynaklı ışınım, insan etkinliklerinden kaynaklanan ısınmanın yanı sıra kentsel geometrinin, binaların tekil geometrileriyle beraber hakim ve yerel rüzgarları yönlendirmeleri veya engellemelerinin de Kentsel Isı Adası’na etkileri büyüktür. Bitişik nizamdaki yüksek binaların çeşitli genişlikteki sokak ve ana caddelerde sağlı sollu konumlanması rüzgarı yönlendiren ‘kentsel vadiler’in oluşmasına neden olur. Sıcak iklimlerde binaların hava akışını engellediği durumlarda hem kent içinde hareket etmekte olan veya dış mekanlarda bulunan insanların konfor koşulları etkilenir hem de iç mekanlarda bulunan insanlar/binalar pasif soğutma olanaklarından faydalanmakta güçlük çekerler. Bunun yanında sokak yönlenmelerinin hakim rüzgarı alamayacak şekilde olması ve bina yüksekliğinin sokak genişliğine oranının (H/W Aspect Ratio) yüksek olması insan etkinliklerinden kaynaklanan zararlı gazların kentsel vadilerin içerisinden tahliye edilmesini güçleştirir.

Yapılacak çalışmanın amacı, ileride tamamlanabilecek, henüz kent şekillenmeden plancılara, tasarımcılara ve yöneticilere kentsel politikaların geliştirilmesinde yardımcı olabilecek, kentsel ölçekte pasif iklimlendirmeden yararlanmayı sağlayacak pek çok etkenin göz önüne alınmasıyla oluşturulmuş rehber niteliğindeki bir çalışmanın küçük bir parçasını oluşturmaktır.

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CHAPTER 1

INRODUCTION

During the satellite image processing studies, while working for different reasons on the images obtained from satellites with thermal bands, researchers found a concentration of heat on some locations in urban areas similar to the islands in the sea (Voogt and Oke, 2003; Pongracz et al., 2006; Lin et al., 2008; Weng and Yang , 2004; Rosenzweig et al., 2005 etc.). These islands called 'Heat Islands'. In the recent years there are many studies on the detection of the Urban Heat Island (UHI) Effect showing itself mostly by the temperature difference between rural and urban areas. The heat generation in the city, the radiant energy balance, the air flow direction and intensity are the main factors affecting the UHI. Height and shape of the buildings, street width and orientation, space between the buildings and urban topography and vegetation are the main elements of the urban geometry. The air velocity is either increased or decreased by the building blocks generally in rectangular shapes and the solar energy is trapped in the urban canyons formed by buildings on both sides of the streets similar to natural canyons. In urban canyons the pedestrian comfort level is greatly affected by the temperature, the relative humidity and the wind speed. Controlling the city's wind environment with passive cooling techniques is one of the mitigation methods of the UHI effect. The enhancement of the wind speed also serves to mitigate the excess heat during the night period as a result of the transfer of heat gained during the daytime by buildings, roads etc. to the surrounding air. Appropriate wind levels for the pedestrians increase the comfort in the cities situated in hot areas. Furthermore vehicular traffic causes concentration of gas emissions which heats up urban areas. Therefore convenient design of the streets allows flushing the traffic induced gases out with the help of the natural wind flow. On the other hand the high wind levels may also cause discomfort for the pedestrians in the cases where the wind speed is over the comfort and danger levels. Especially in the urban areas the wind flows is not always laminar or parallel to the surface due to the urban morphology (buildings and topography) where the friction forces causes the wind flow in a turbulent way. The duration and the intensity of the turbulence may also cause discomfort. Another reason of the wind flow is the temperature difference between the canyon surfaces and the surrounding air causing air movement induced by this difference especially under low governing wind flow speed.

As a city influenced by the climatic changes on the Aegean and Mediterranean Regions, Izmir has been experiencing long and dry summers in the recent years. The main causes of this situation are the global warming and the urban heat island effect. During hot summers the thermal comfort of the citizens of Izmir drops dramatically and every year the number of the air conditioned buildings increase. Consequently, the energy use of mechanical cooling equipment for the indoor spaces increases. However the heated air which is released to the outdoor environment by the air conditioners causes increase of the temperature on the street level.

In the history of urban planning studies for the city of Izmir the climatic conditions have never been taken into consideration. As a result, the buildings are situated on the areas between the vehicular roads, streets and highways, the Izmir Bay (the sea) and topography as natural borders.

1.1. The Aim of the Study

Izmir is the third largest city of Turkey, situated in the Aegean Region. The climate of the Metropolitan Municipality of Izmir area may be described as hot and dry-humid during the summer, and mild and humid during the winter. According to Izmir Meteorology Station in the Güzelyalı district the prevailing wind throughout the summer season (June, July, and August including September for Izmir) flows from West North West and West directions. However in dense urban areas in Izmir, buildings form a roughness surface as sharp-angled rectangular bodies channelling the wind by decreasing or increasing its velocity. The long streets with narrow crossing roads create geometrical forms similar to natural canyons affecting the wind speed and direction.

As an example, on the coastal region, the wind regime is largely affected by the land-sea breeze locally known as ‘imbat’, however in Izmir, the extensive urban concentration along the coastal belt cuts off this very important inflow of cool air into the inner-city areas. In other words the buildings along the seaside create a ‘wind shadow area’ for parallel streets blocking the necessary wind especially for pedestrian comfort. The airflow speed and direction change once the flow crosses the building barrier. Consequently, besides the pedestrian comfort natural ventilation potential of the buildings by means of the windows, voids or passages on the façades decrease.

Therefore the aim of the study is to investigate the natural cooling potential during the summer season especially on the sites on the coastal region and to investigate the effect of the dense structure of the city (building orientation and forms, street orientations…). The study includes collecting weather data from different districts in the city of Izmir, from the pedestrian level and the roof level on each site. The aim is to answer the questions on the relation of the prevailing wind and the wind behaviour in the built-up area by using the data set obtained by the field study during the summer 2009 in Izmir. Furthermore the aim is to create a qualitative geometric guideline is also aimed by interpreting the wind conditions in the selected sites.

1.2. The Importance of the Study

Apart from the simulation studies, in the literature, field studies are very rare (because they are expensive, difficult, risky etc.). It is difficult to understand which the governing forces on the wind flow are. However they are appropriate for collecting valuable data since urban structures are very complex in terms of wind environment and thermal effects. Simulation studies such as CFD (Computational Fluid Dynamics) and wind tunnel studies are still insufficient to understand the real wind behavior due to the ignored effects on the wind (solar effect, material effect, the effect of air conditioners, the effect of vehicular traffic etc.).

1.3. The Method of the Study

This is a multidisciplinary study between the urban architecture and urban physics. The data collection analysis and its interpretation is the numerical part of the study. In the evaluation part of the third chapter and in the conclusion chapter final analyses are done by using graphical tools in order to create a qualitative guideline for the urban wind environment.

As the first step the main canyons in the sites are evaluated according to their aspect ratios H/W where H is the average height of the buildings and W is the average width. The H/W classification is made less than or equal to 1 and over 1. The scatter diagrams concerning the V_{ped} the pedestrian wind velocity on the x axis and V_{met} the meteorology office upstream wind velocity data on the y axis in m/s. As the second step the parallel canyons on each site are evaluated and compared by the diagrams on the same character. In addition R-WSPD ratio and R-TEMP ratio which are respectively V_{ped} V_{met} and T_{ped} T_{ws} (where T_{ped} is the temperature on the pedestrian level and T_{ws} is the simultaneous temperature on the roof level measured by the mobile weather station on the roof level for each site) are evaluated in line diagrams representing the pedestrian movement from one end to the other. On the third step, the wind comfort on the pedestrian level for each site is investigated. On the last step according to the data evaluated the natural ventilation potential of each site is explored by maps and section diagrams.

1.3.1. The Selection of the Sites for the Field Study

Data collection is done in three locations on the South Cost of the Izmir Bay; Alsancak, Konak and Güzelyalı. All sites are waterfront sites at or near the city centre (Figures 1.1, 1.2, 1.3 and 1.4). The sites are formed by approximately eight storied buildings with a density of 50% as the land coverage ratio as an approximate value. Alsancak, Konak and Güzelyalı have dense vehicular and pedestrian traffic as a result of commercial and residential activities: Commercial on the pedestrian level and residential on the upper floors especially in Alsancak and Güzelyalı, heavy office type usage in Konak in public and private buildings. Therefore the pedestrian comfort on the street level is very important.

The roof level measurements in Alsancak were held on top of the ‘Punta Residence’ building, in Konak from the Konak Municipality Building situated on the seaside (one of the SSK buildings) and in Güzelyalı from the top of a residential building on the first row on the seaside. The roof level wind speed direction and temperature measurements are the first references for the pedestrian level measurements. The wind speed and direction data taken from the National Meteorology Office situated in the Güzelyalı district are the secondary references and the third ones are the wind speed and temperature data measured on the seaside pedestrian level for each site.

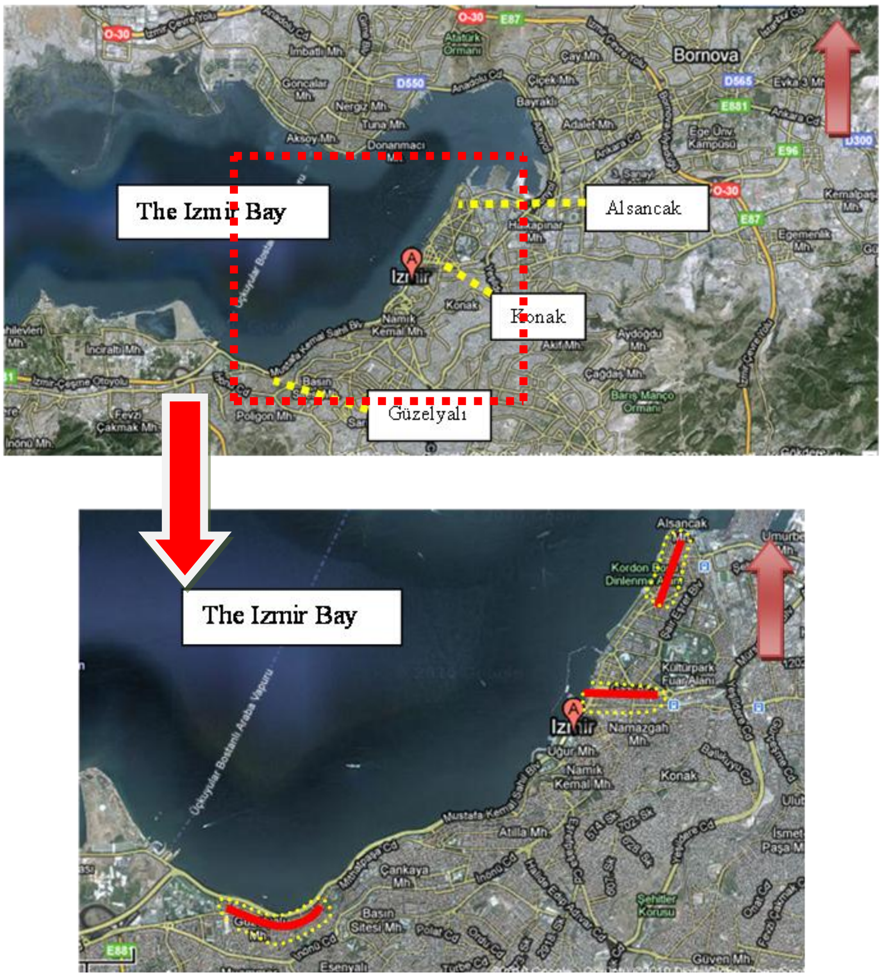


Figure 1.1. The Locations of three sites around the Izmir Bay and the orientation of the main canyons (Source: Google Earth).

The main streets in Alsancak which are ‘Kıbrıs Şehitleri’ and ‘2.Kordon’ are selected due to their proximity and orientation to the waterfront. In addition, the intersecting secondary streets have the potential of channelling the wind flowing over the Bay into these streets. Both of the streets are in NE-SW direction (Figure 1.2).

The 2.Kordon Street is nearer to the seaside than the Kıbrıs Şehitleri Street and open to vehicular traffic. However the Kıbrıs Şehitleri was open only to pedestrian traffic during the measurement time periods which were midday and afternoon.

Similar to the literature the pedestrian level data taken from 2 meters high were also held on the seaside in this site. There are 7 perpendicular secondary streets which relate the three parallel measurement paths (Figure 1.2).

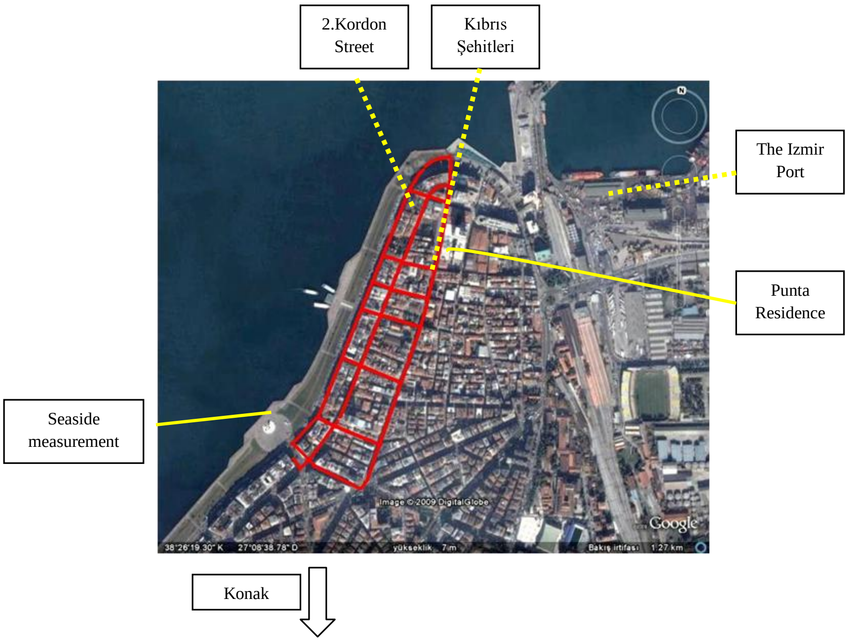


Figure 1.2. Alsancak:Kıbrıs Şehitleri and İkinci Kordon Main Canyons are in NE-SW direction in the Punta District. The measurement path is shown with the red line (Source: Google Earth).

Figure 1.3. The Punta District from the sea and the measurement point.

In Konak, the two main streets Gazi Street and Fevzi Paşa Street are approximately parallel to each other and perpendicular to the waterfront. The Gazi Street is on the North and the Fevzi Paşa Street is on the South. At the sea-end of the Fevzi Paşa Street there is the Konak Pier Shopping Mall (approx 6-7m. high). There are 4 intersecting secondary streets between two main streets and a parallel narrower street Mimar Kemalettin Street which is open to pedestrian traffic during the measurement periods (Figure 1.4 and Figure 1.5).

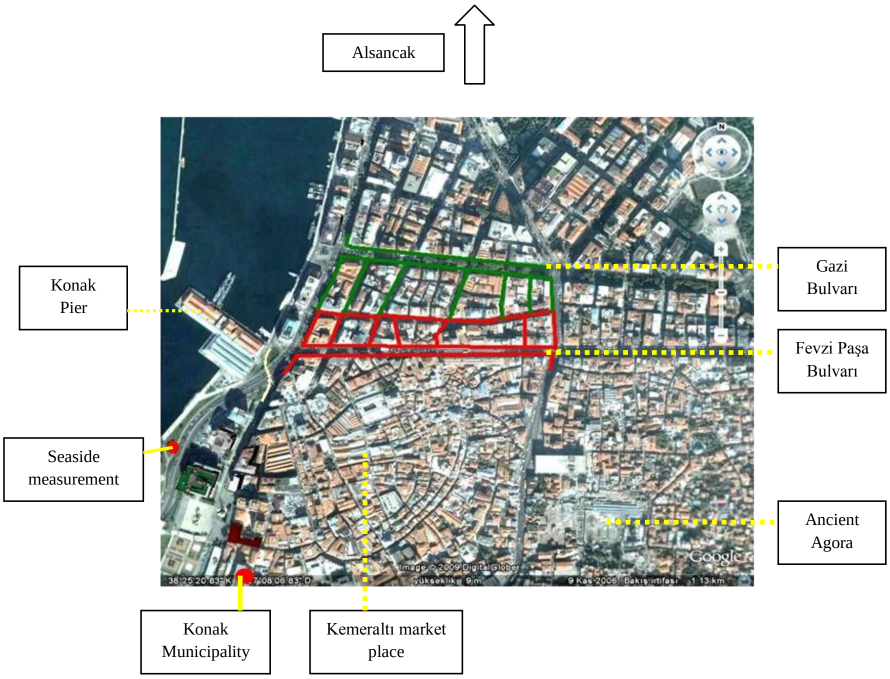


Figure 1.4. Konak: Gazi Bulvarı (the main street in green lines) and Fevzi Paşa Bulvarı (the main street in red lines) are parallel and in W-E direction approximately (Source: Google Earth).

Figure 1.5. The Gazi Bulvarı (on the left) and the Fevzi Paşa Bulvarı (on the right) from the sea.

In the Güzelyalı Site the main vehicular and pedestrian street is the Mithat Paşa Street. Along the Mithat Paşa Street the ground floor level of the buildings is generally used for commercial functions and the upper floors are residential apart from several office buildings. The parking areas of the buildings on the front row are on the sea façades as a result on several buildings there are passages through the buildings for the parking reasons only on the ground level. For the buildings along the South of the street a severe parking and vehicular traffic problem exist. Compared with the other sites secondary streets are more disorganized and oriented in various angles (Figure 1.6 and Figure 1.7).

Figure 1.6. Güzelyalı: The Göztepe District (Source: Google Earth).

The Göztepe District which has the longest street canyon parallel to the seaside (the Mithat Paşa Street) is roughly in W-E direction however in the selected part the canyon has a large V shape with two parts: in NW-SE (the measurement path is in red line) and NE-SW (the measurement path is in green line) directions.

Figure 1.7. The Güzelyalı View from the Susuz Dede Park situated on a small hill.

1.3.2. The Measurement Devices

For the measurements two types of measurement devices were used: 1.) 2 TESTO 400 with 2 hot wire probes with measurement range 0m/s-10m/s for time limited measurements. 2.) A Weather Station: Data logger (Comet), Wind velocity and direction measurement probe (R.M. Young 05305L), Temperature and RH measurement probe (R.M. Young 41382L) (Figures 1.8 and Figure 1.9).

Figure 1.8. TESTO 400 *2 with 2 hot wire probes with measurement range 0m/s-10m/s wind speed for time limited measurements.

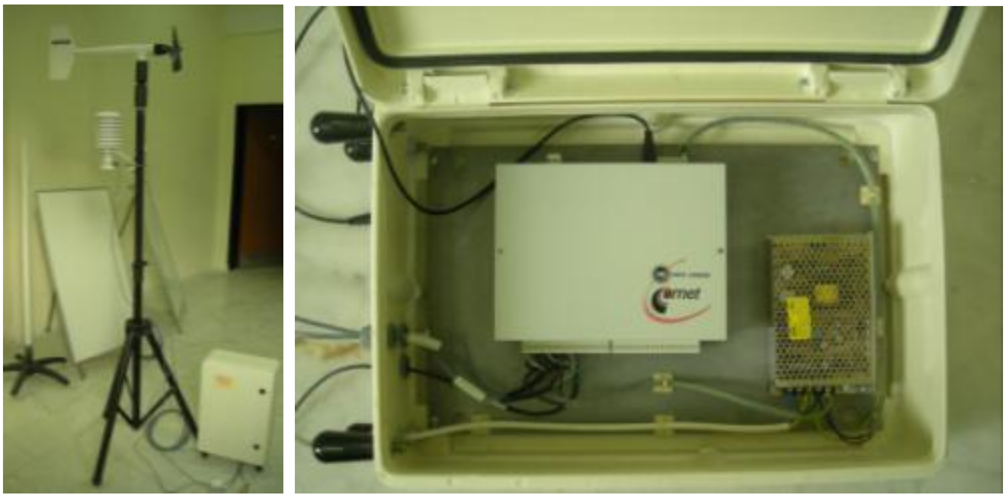


Figure 1.9. Weather station and data logger *1: Data logger (Comet), Wind velocity and direction measurement probe (R.M. Young 05305L), Temperature and RH measurement probe (R.M. Young 41382L).

In each site multiple points were selected according to their two dimensional geometrical characteristics on the pedestrian level from 2meters high. For three of the sites three buildings were selected in order to collect wind speed wind direction and temperature data by means of a weather station. During the measurements the weather station was moved from site to site. In Alsancak the height of the weather station was approximately 60 meters high from one of the highest buildings on Punta (The Punta Residence). In Konak the weather station was positioned on a building roof approximately 30 meters high (A building of the Konak Municipality in SSK Blocks) (Figure 1.10). In Güzelyalı the weather station was on one of the residential buildings on the first row of buildings from the seaside approximately from 29 meters high (Figure 1.11 and Figure 1.12).

Figure 1.10. Measurements from the roof level in Konak from the 10th floor (approx. 30m.height) on the left. Measurements in Konak in the Mimar Kemalettin Street (MKEM) on the right.

Figure 1.11. Measurements from the roof level by the Meteorology Office in Güzelyalı.

Figure 1.12. The Meteorology Office building in Güzelyalı.

1.4. The Research Questions

The data gathered from the field study will be used in the following chapters in order to answer to the questions below:

1) Is there any significant difference with the wind speed and direction data obtained from the portable weather station and from the local stations?

2) On which locations the pedestrian wind level is significantly over the wind speed measured from the roof and from the local weather station due to the urban morphological conditions?

3) What is the effect of the aspect ratios (H/W and L/W) and the orientation of the selected canyons on the heat trapped measured as temperature on the pedestrian level?

4) On which locations the corner effect, the front vortex, the wake effect, the bar effect, the passage effect, the double-corner effect, the Venturi effect, the mesh effect, the urban mask effect, the high-rise building effect can be seen?

5) On which locations the pedestrian wind speed is over or below the comfort limits?

6) Which street canyon can be considered as more comfortable for pedestrians in terms of wind speed and temperature during the measurement months?

7) What should be the urban design solutions for the future planning studies deduced from this thesis?

CHAPTER 2

WIND ENVIRONMENT IN URBAN CONTEXT

2.1. The Urban Heat Island Effect (UHI)

Rapid population growth and industrial activity in the cities throughout the world resulted in dense urbanization. As a consequence of heat balance, air temperature in dense cities became higher than the temperatures of the surrounding rural country. This phenomenon is known as urban heat island effect (Georgakis and Santamouris, 2007).

The urban heat island effect affects the energy balance of the buildings as well as comfort level of pedestrians and residents especially in hot regions. The largest elevations of the urban temperatures occur during clear and still-air nights and elevations between 3-5ºC are common and elevations about 8-10ºC may be observed (nocturnal urban heat island). In hot countries during summer this aspect may aggravate the negative aspects of interference with sleep and its effect on fatigue and health (Givoni, 1998). In winter, most urban microclimates are more moderate than those found in suburban or rural areas. They are characterized by slightly higher temperatures and, away from tall buildings, weaker winds. During the day, wide streets, squares and non-planted areas are the warmest parts of a town however at night; the narrow streets have higher temperatures than the rest of the city. In summer, during the hot months the heat island creates considerable discomfort and stress, with waves of blistering heat emanating from roads and dark buildings. During night fall, the streets are still radiating heat while surrounding rural areas are rapidly cooling (Karatasou et al., 2006). Enhancing air movement through natural ventilation is one of the dissipation techniques of heat generated in urban areas. Airflow around buildings gives the ability to control environmental factors related to temperature, humidity, air motion and contaminants (Santamouris et al., 1998). The urban wind conditions, especially near street level, have direct effect on human health and comfort as well as on energy consumption for heating and air conditioning, and on the concentration of the urban pollutants. The wind conditions in the general urban area also determine the potential for ventilation of the buildings as well as the wind exposure of pedestrians outside the buildings. In hot regions the tendency of the urban temperature to be above the regional level diminishes as the urban wind speed increases, however at specific points the local wind speed may be very high to a degree that it becomes troublesome, even in summer and this should be controlled by appropriate design. Furthermore, the ventilation conditions in the urban space as a whole in particular in major streets with high vehicular traffic, have significant impact on the concentration of pollutants at the street level. The higher the velocity and turbulence of the wind at street level, the greater is the mixing of the highly polluted low-level air with cleaner air flowing above country (Givoni, 1998).

The architecture of the buildings gives city a character while the street layout determines its structure. In modern town planning, streets are generally planned in response to the requirements of the transport systems however the orientation of streets with respect to the path of the sun or to prevailing winds is now rarely considered during the design process, although its effect on microclimate was recognized during the history of the cities (Erell, 2008).

The physical structure of the city in other words the location of the city within a region, the size, the density of the built-up area, the land coverage, the height of the buildings, the orientation and the width of the streets, the subdivision of the building lots, the special design details of the buildings which affect the outdoor conditions and the green areas affect the urban climate (Givoni, 1998). As stated by Givoni, the width of the streets determines the distance between the buildings on both sides of the street with impacts both on the ventilation and solar utilization potential and the layout of the streets also greatly determines the ventilation potential of the buildings as well as the outdoor ventilation conditions.

The space bounded by the urban buildings up to their roofs is often referred as the ‘urban canopy’ and the volume of air affected by the city is the urban boundary layer, also referred as the ‘urban air dome’ (Givoni, 1998). The wind speed in the canopy layer is seriously decreased compared to the ‘undisturbed’ wind speed. As the air flows from the rural to the urban environment, it must adjust to the new boundary conditions defined by the cities, and this results to the development of the so called ‘obstructed sub-layer’, or urban canopy sub-layer which is extended from the ground surface up to the buildings height, while the so called ‘free surface layer’ or urban boundary layer, is extended above roof tops (Georgakis and Santamouris, 2007). The main climatologic factor affecting the urban ventilation is the regional wind which is commonly called the gradient 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 variations over the globe. The undisturbed winds flow at a height of several hundred meters above the ground. The speed of the undisturbed winds increases slightly with height, but at a much lower rate than near the ground. This undisturbed flow is called the gradient wind and its velocity is called the gradient velocity (Givoni, 1998).

A speed of flow which increases from zero at the surface to the full streaming speed away from the body is a summation of a very large number of small impulses on the surface per unit time. In other words while a steady force is acting on the body in the direction of flow, the region of reduced speed is called *the boundary layer* (Figure 2.1).

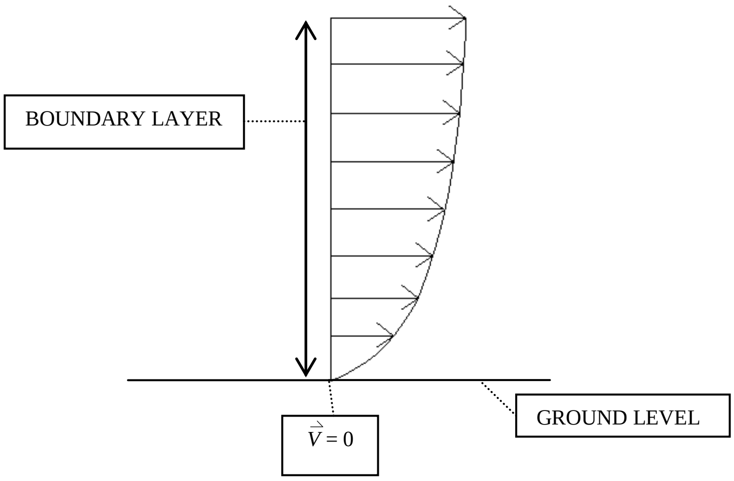


Figure 2.1. The Boundary Layer (BL).

The boundary layer over a city centre is made of an external layer (EL) and an urban boundary layer (UBL). The lower portion of the UBL is termed Internal Layer or Surface Layer (SL), which extends up to an elevation of approximately 10% the total depth of the boundary layer. In the SL the flow is strongly affected by the local geometry. The SL can be separated into Internal Sublayer (IS) and a Roughness Layer (RS) (Ricciardelli and Polimeno, 2006). When the wind flowing over an open area approaches the boundaries of the built-up open area it encounters a higher ‘roughness’ of the surface created by the buildings. The increased resistance resulting from the higher roughness reduces the wind flow at the level of urban canopy. In the city the roughness elements are mainly buildings, they are rigid, sharp-angled (bluff) bodies (Givoni, 1998).

There are two types of flow under the urban boundary level (UBL): The smooth namely *the laminar flow* and the turbulent namely *the eddying flow*. The laminar flow is the flow which layers of fluid move smoothly over or alongside adjacent layers. It is unsteady if the velocity (v) increases or decreases in time. However the fluid motion does not stay in the smooth laminar state for long time. The turbulent flow is the preferred ultimate state of flow motion in nature.

According to Houghton and Carruthers, *turbulence* is a three dimensional time dependent motion in which vortex stretching causes velocity fluctuations to spread to all wavelengths between a minimum determined by viscous forces and a maximum determined by the boundary conditions of the flow. Although there is no generally accepted definition of turbulence there are several common characteristics in these definitions: 1. Turbulent flows are highly unsteady, 2. They are three dimensional, 3. Large amount of vortices present, 4. Conserved quantities are stirred, mixed: turbulent diffusion (exchanging parcels of fluid) (Houghton and Carruthers, 1976).

For the laminar flow on the ground level as a result of the friction forces the wind speed is considered as 0 m/s. In an urban area the height in a section area where the wind speed is lower than the free flow, is higher than in the country where there are lower buildings and trees. The area where the wind speed reduced due to the friction forces is named as the boundary layer (BL). The boundary layer effect is a direct result of kinematic viscosity. The wind flow in the boundary layer can be laminar or turbulent. The intensity or the amount of the turbulence is represented by the Reynolds number (Re). The Reynolds number is the ratio of inertia forces to viscous forces (Equation 2.1.):

$$\mathrm{Re}=\frac{UL}{v}=\frac{\text{inertia forces of the air}}{\text{viscous forces of the air}} \tag{2.1}$$

The U is a characteristic velocity of the flow; L is the characteristic length scale; v is the kinematic viscosity of the fluid. The higher Re represents the higher intensity of turbulence (Houghton and Carruthers, 1976).

2.2. The Definition of Urban Canyon

In "Street Design and Urban Canopy Layer Climate" by Oke, the urban street canyon is defined as the basic geometric unit which can be approximated reasonably by a two dimensional cross-section neglecting street junctions and assuming the buildings flanking the canyon are semi-infinite in length. Oke limited the geometric descriptors to two simple measures which are the ratios H/W where H is the average height of the canyon walls and W is the canyon width and the building density which is A_r/A_l where A_l is the plan or roof area of the average building and A_l is the lot area or unit ground area occupied by each building. These measures can be used to define a roughness density $\lambda = A_s/A_l$ and a building density $\zeta = A_r/A_l$ (Oke, 1988) (Figure 2.2).

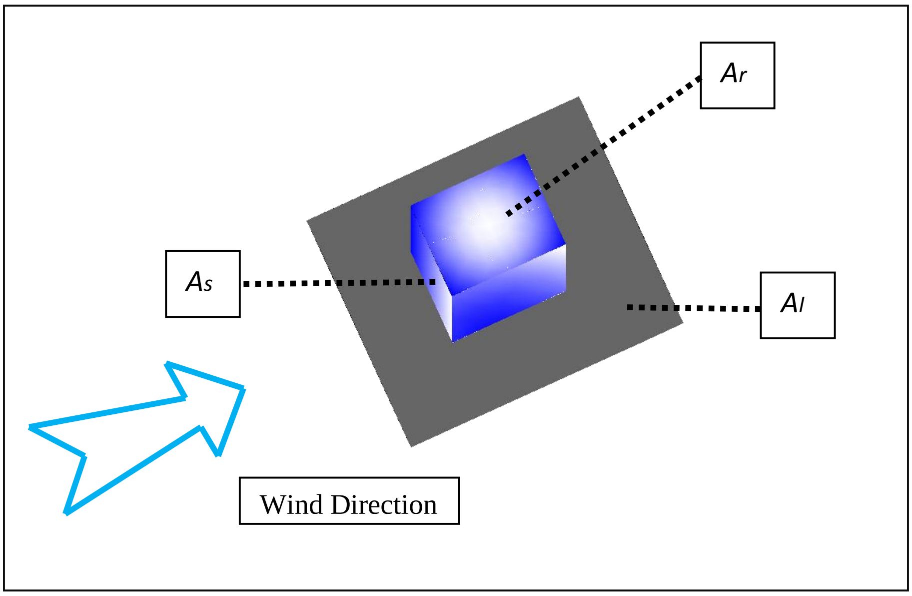


Figure 2.2. Dimensions of an average urban roughness element and its lot, where h is its height, A_s is its 'silhouette' area (the vertical area of the element 'seen' by the approaching wind), A_l is its lot area (unit ground area occupied by each element), and A_r is the element of roof area (Source: Oke, p. 106, 1988).

Street canyons refer to streets with buildings lined up continuously along both sides (Ahmad et al., 2005). Urban canyons are characterized by three main geometrical parameters H, the mean height of the buildings in the canyon, W, the canyon width; and L, the canyon length (Figure 2.3). Given these parameters, the geometrical descriptors are limited to these three measures; the aspect ratio H/W and the ratio L/H (Georgakis and Santamouris, 2007). According to Ahmad et al. the canyon is uniform if it has an aspect ratio of approximately equal to 1 with no major openings on the walls. A shallow canyon has an aspect ratio below 0.5; and the aspect ratio of 2 represents a deep canyon. If L is the length of a canyon, L/H=3 is short, L/H=5 is medium and L/H=7 is long (Ahmad et al., 2005). The characteristics of the flow in the RS are strongly dependant on the building arrangement and H/W ratio (Ricciardelli and Polimeno, 2006).

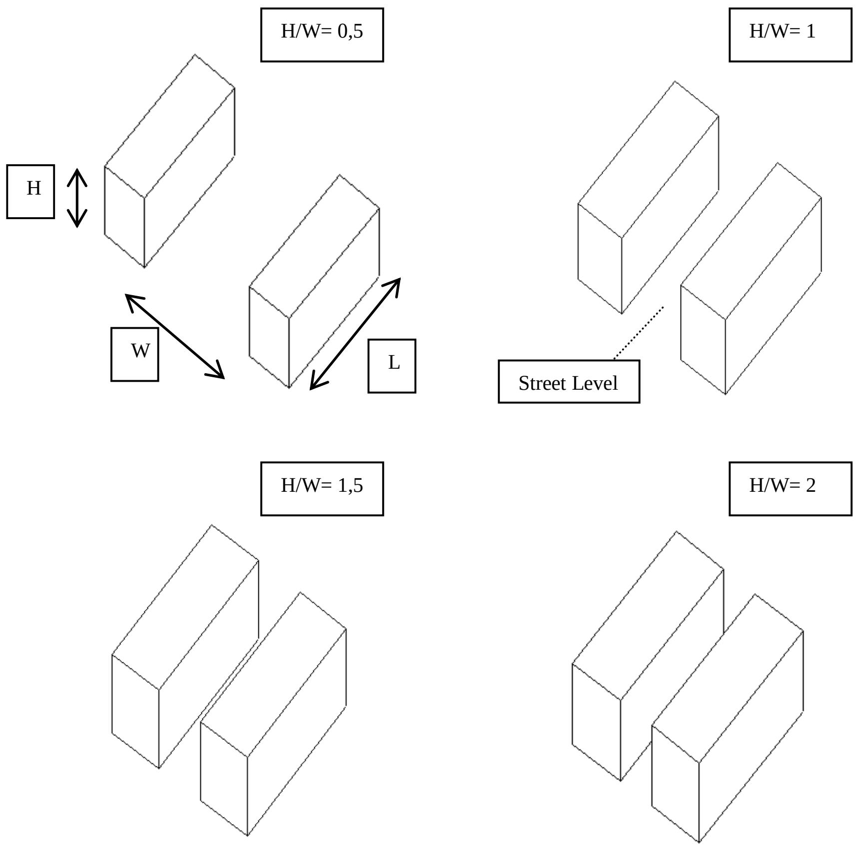


Figure 2.3. Shallow canyon (H/W=0,5), deep canyon (H/W=2) and H/W=1, H/W= 1,5 canyons. H is the building height, W is the street width and L is the canyon length.

According to Santamouris, air circulation and temperature distribution within urban canyons are significant for the energy consumption of buildings, pollutant dispersion studies, and heat and mass exchange between the buildings and the canyon air and are therefore of interest in studies on the energy potential of natural ventilation techniques for buildings, pedestrian comfort etc. (Santamouris, 2001).

In the literature, knowledge of the air flow patterns in urban canyons results either from numerical studies or from field experiments in real urban canyons or with scaled physical models in wind tunnels. The determination of the pollution characteristics within the canyon is the subject of many studies which put their emphasis on situations where the ambient flow is *perpendicular* to the canyon long axis, when the highest pollutant concentration occurs in the canyon (Santamouris, 2001).

When the city streets are *parallel* to the direction of the wind, they create obstacle-free passageways, through which the prevailing winds can penetrate into the heart of the urban area. When the streets are angled in an *oblique* direction of the wind, the wind is distributed between two components. One component is in the direction of the street but is concentrated mainly on the downwind of the street and the other component causes pressure on the upwind side of the buildings. On the upwind side of the street, the air flow is gentler and a low pressure zone surrounds the building. In this case, the widening of the streets improves the ventilation conditions both within the buildings and in the streets.

When the buildings from long rows of the same height are perpendicular to the direction of the wind, the distances between the buildings have little effect on the speed of the wind currents between the buildings. This is due to the fact that the first row of buildings diverts the approaching wind current upwards, and the rest of the buildings behind are left in the wind ‘shadow’ of the buildings standing in front of them. In this case the urban density has a relatively small effect on urban heat island effect because even under low urban density conditions with low buildings with large spaces between them, the free wind flow is blocked by the buildings (Givoni, 1998).

The local wind speed is influenced by the parameters which are the speed of the undisturbed (surface) wind, the orientation, the width W, the height H and the length L of the canyon. In other cases for example when the site of interest is located outside a canyon, a simple rule (Equation 2.2 below):

$$v_{local} = TCF \cdot v_{undisturbed} \quad (2.2)$$

TCF is the correction factor for wind speed (rural or suburban TCF=0.85, urban TCF=0.67, city centre TCF=0.47) (Germano, 2006).

According to Ghiaus et al. when the wind flows perpendicularly with values larger than 2-4 m/s, a correlation exists between the undisturbed and the wind in the canyon. However when 2 m/s or stronger wind flows perpendicular to a street canyon a vortex develops in the canyon axis, and the vertical velocity in the canyon is very low (Ghiaus et al., 2006). If the wind speed out of the canyon is below some threshold value the coupling between the upper and secondary flow is lost. This type of regime is known as '*skimming flow regime*' (Ahmad et al., 2005). In this case, according to Santamouris et al. thermal and mechanical phenomena play an important role. In some studies this threshold value is between 1.5 and 2 m/s or close to 2 m/s. However for the perpendicular wind flow over the canyon the threshold value in the study of Santamouris et al. was found between 4 and 5 m/s and that the wind speed in deep urban canyons under low ambient wind speeds is highly influenced by thermal and mechanical phenomena. Nakamura and Oke also states that for values up to $u_{roof} =$ 5m/s the general relation between the two wind speeds appears to be approximately linear (Nakamura and Oke, 1988) (Equation 2.3):

$$u_{canyon} = p \cdot u_{roof} \quad (2.3)$$

$u_{in=}p.u_{out}$ where for wind speeds normal to the canyon axis, and for a symmetric canyon *H/W*=1, *p* varies between 0.66 and 0.75 under the condition that winds in and out were measured 0.06*H* and 1.2*H* respectively, p= 2/3. At smaller H/W, p approaches unity and there is no longer any shelter (Santamouris, 2001).

In more detail it may be expected that the slope p to show some dependence upon θ roof (angle with the canyon main axis) (Nakamura and Oke, 1988). Important temperature differences between the canyon walls and the air is the source of upward and downward flows that may be much more important than the flow induced by the wind above canyon (Santamouris et al., 2007). In that case scaled models should be used in order to simulate the real situation.

According to Santamouris et al. important temperature differences between the canyon walls and the air is the source of upward or downward flows that may be much more important than the flow induced by the wind above the canyon thus even for a constant value of the ambient wind speed, the flow in the canyon may present a very high fluctuation.

In the mentioned study above if the flow is perpendicular to the street canyon, for the windward façades, it has been found that three zones of the more probable wind speed occur: For the lower parts of the canyon, H/W ratios below 1.5, the more probable wind speed is low and around 0.5 m/s. For medium heights, 1.5<H/W<2, the corresponding mean value is around 1 m/s, while for the higher parts of the canyon, the wind speed increases considerably and may reach values close to 2.5 m/s.

2.3. Wind Flow Patterns in Street Canyons

Wind flow patterns are important to understand the natural ventilation potential in the streets or urban canyons. The prevailing wind angle θ to the canyon axis has important effects on the pedestrian level wind speed. In the literature the orientation of the prevailing wind is categorized in three parts: Perpendicular or normal, oblique and parallel.

2.3.1. Perpendicular Wind Flow

If the spacing between two buildings is too large and the height is comparatively low, then their flow fields do not interact (H/W>0.05). At closer spacing the wakes are disturbed and on the contrary, the smaller spacing between buildings disrupts the 'wakes' resulting in an *'isolated roughness flow regime'*. If the height and spacing of the building blocks are such that they disturb the bolster and cavity eddies, the flow regime changes and is known as *'wake interference flow'*. At a greater H/W, the circulatory vortex is established inside the street canyon. This may be due to the transfer of momentum across the shear layer at the roof height. In this situation, the bulk of the flow does not enter inside the street canyon and forms single vortex within the canyon. This type of regime is known as *'skimming flow regime'* (Figure 2.4). According to Ahmad et al., De Paul and Sheih report that this threshold value ranges between 1.5 m/s and 2.0 m/s for *symmetrical* street canyon having H/W ratio as 1.4 m/s (Ahmad et al., 2005). The skimming air flow regime has attracted considerable attraction, because high H/W ratios are very common in cities. In many of the studies higher wind speeds were found to produce a stable vortex circulation within the canyon. For lower wind speeds, thermal as well as mechanical influences may play an important role in the canyon circulation (Santamouris, 2001).

According to Ricciardelli and Polimeno three different types of behaviour are isolated roughness flow (H/W < 0.3), wake interference flow (0.3 < H/W < 0.65) and skimming flow (H/W > 0.65) (Ricciardelli F. and Polimeno S., 2006) (Figure 2.5).

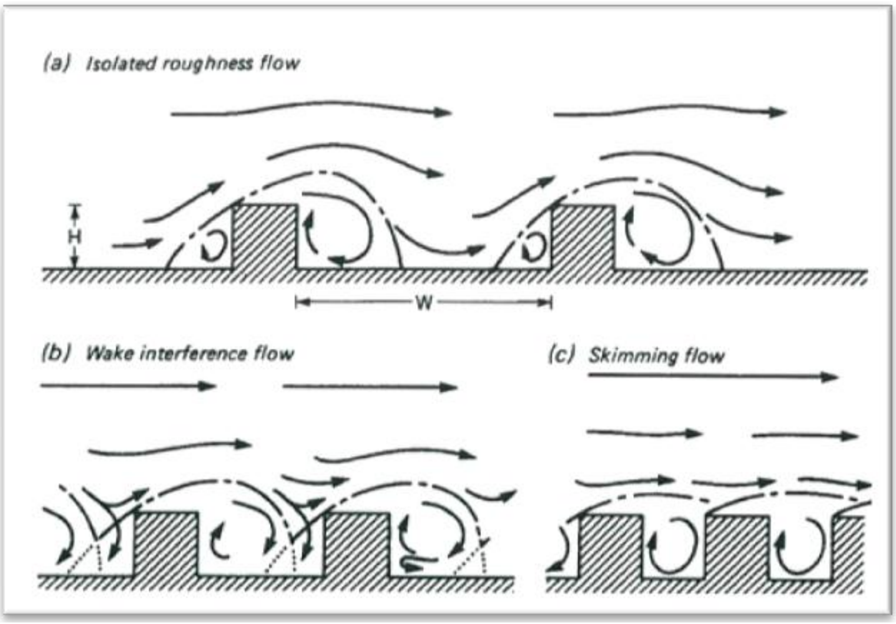


Figure 2.4. The flow regimes associated with air flow over building arrays of increasing H/W. (Source: Oke, p. 105, 1988).

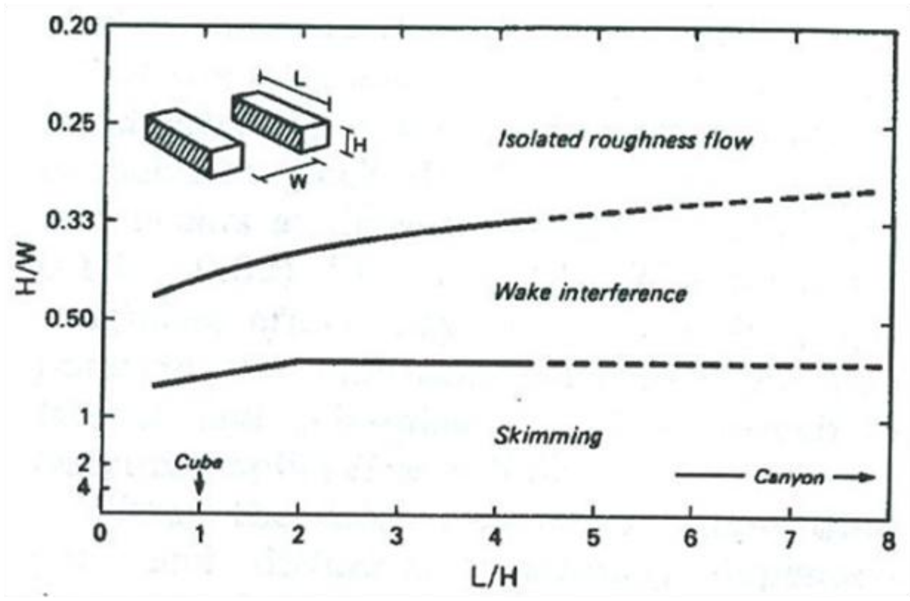


Figure 2.5. Threshold lines dividing flow into three regimes as functions of the buildings (L/H) and canyon (H/W) geometry (Source: Oke, p. 105, 1988).

2.3.2. Oblique Wind Flow

Unfortunately there and not sufficient works on the oblique wind flow in the literature. According to Givoni (1998), when the oblique wind direction to the canyon occur one component is in the direction of the street but is concentrated mainly on the downwind of the street and the other component causes pressure on the upwind side of the buildings.

A spiral vortex is developed along the canyon length (i.e. a cork screw type of action). The flow is not perfectly reflected by the building walls and because of the along wind entrainment inside the canyon, the angle of incidence is greater than the angle of reflection (Niachou et al., 2007).

2.3.3. Parallel Wind Flow

Parallel wind flow generates mean wind along the canyon axis with possible uplift along its walls. The friction of street canyon walls and the surface retard the approaching wind flow (Ahmad et al., 2005). Yamartino and Wiegand propose a relationship $v = u \cos\theta$. Where v is the velocity component along the canyon, u is the freestream velocity. Nakamura and Oke report the linear relationship between two wind velocities, (v and u) for wind speeds up to 5m/s which is given by v = p u, where p varies between 0.37 and 0.68 for the symmetric street canyon, having H/B equal to 1 where B is the width of the street canyon (Ahmad et al., 2005).

According to Ghiaus et al. , when the wind incidence angle is perpendicular or oblique to the main axis of the canyon (+15º), the air models of Hotchkiss and Harlow and Yamartino and Wiegand can be used.

A flow chart algorithm is developed by Georgakis and Santamouris (2007) for estimating wind speed inside street canyons. Which numeric model will be used depends on whether there is a wind flow along the canyon or not (Figure 2.6).

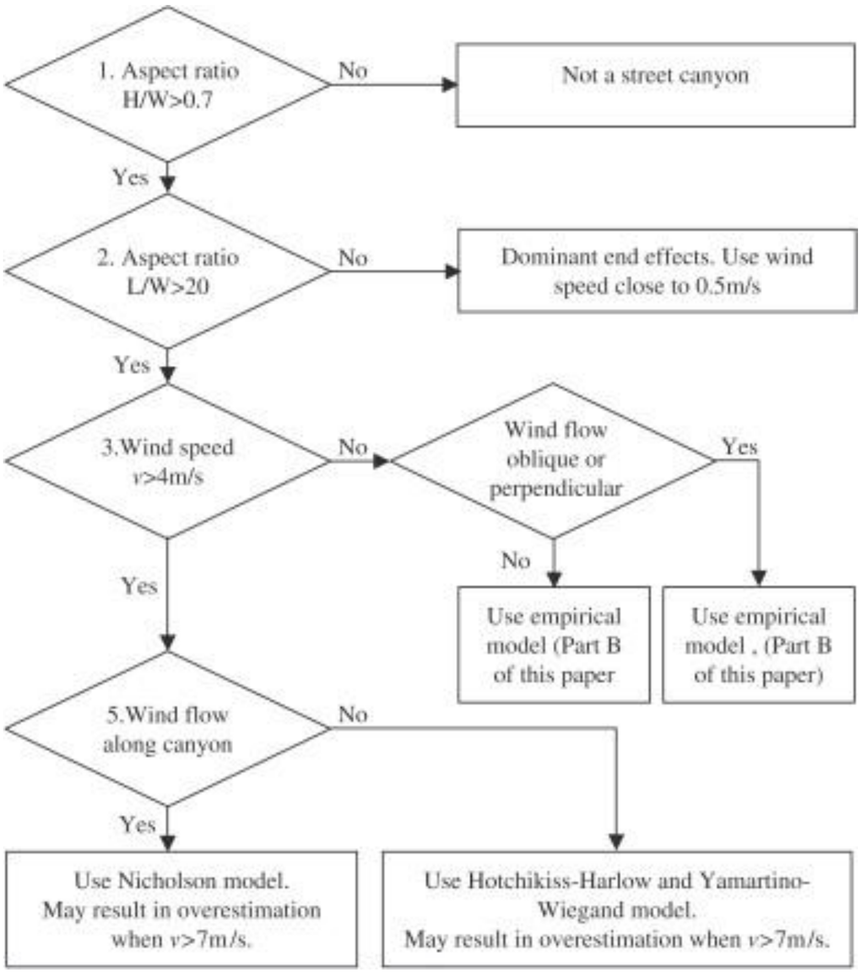


Figure 2.6. Flow-chart of the algorithm for estimating wind speed inside street canyons. (Source: Georgakis and Santamouris, 2007).

The work of Hotchikiss-Harlow and Yamartino-Wiegand can be found in the bibliography part of this study. The part B of the paper written by Georgakis and Santamouris is ‘On the estimation of wind speeds in urban canyons for ventilation purposes. Part two: Using of data driven techniques to calculate the more probable wind’ can also be found in the references of this study (Yamartino and Wiegand, 1986; Ghiaus et al., 2006; Georgakis and Santamouris, 2007, Part II.).

2.4. Solar Radiation and Vegetation Effect in Urban Canyons

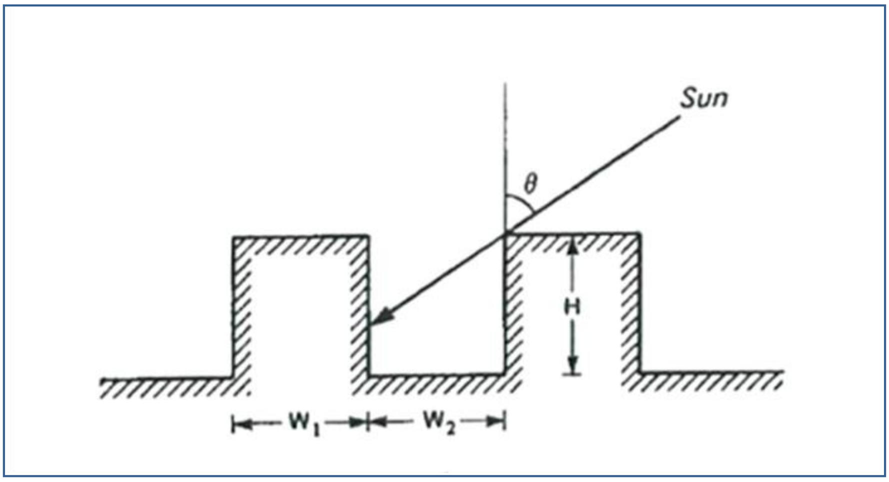
The urban radiation balance has a great effect on the temperature distribution in the urban canopy layer. Solar radiation incident on urban surfaces is absorbed and then transformed to sensible heat. Most of the solar radiation impinges on roofs and on the vertical walls of buildings; only a relatively small part reaches the ground level. However there is a weak connection between geometry and air temperature because the air temperature is dependent upon the flux divergence per unit volume of air including the effects of the horizontal transport (Santamouris, 2001).

The temperature of the external materials in a canyon is governed by its thermal balance. Surfaces absorb short-wave radiation as a function of their absorptivity and their exposure to solar radiation. They absorb and emit long-wave radiation as a function of their temperature, emissivity and view factor. And they transfer heat to or from the surrounding air and exchange heat via conduction procedures with the lower material layers (Figure 2.6).

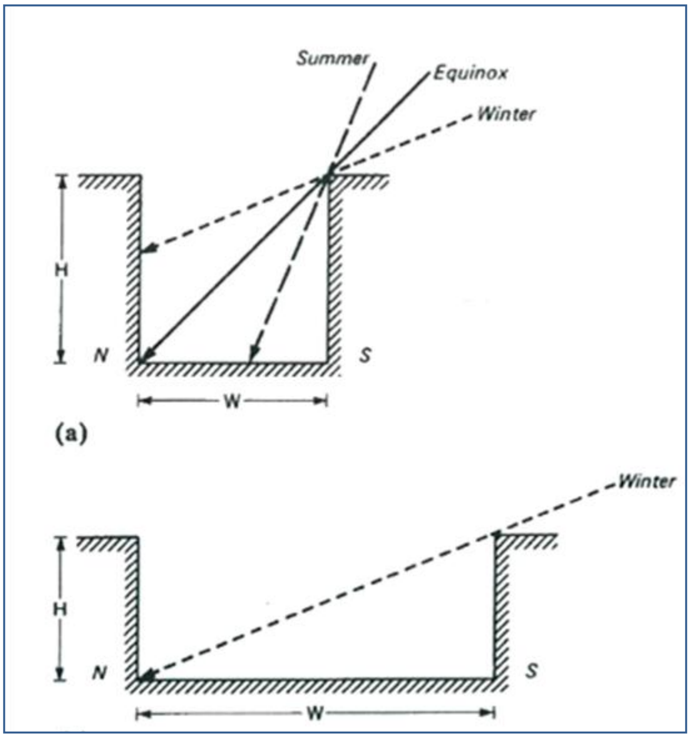
The thermal balance of a surface in a canyon can be expressed as follows (Equation2.4):

$$Q^{*} = Q_H + Q_G \qquad (2.4)$$

Where Q^{*} is the net radiation, Q_H are the convective heat exchanges and Q_G the conductive heat exchanges with the substrate” (Santamouris, 2001).



(a)



(b)

Figure 2.7. (a) The solar zenith angle θ (H/W_2 = 1.0), (b) Angles of incidence of direct-beam solar radiation at noon in an E-W canyon, in a city at 45°N. In a canyon H/W = 1.0 and H/W = 0.40 respectively (Source: Oke, 1988).

Similar to the heat islands in cities there can be cool islands. In the literature cool islands are defined by air temperature, where the effects of surface temperature variation are diluted by near-surface turbulent mixing and advection by wind. Whereas the park cool islands (PCI) are defined by surface temperature which may be quite large during daytime. At night the thermal properties of surfaces and the radiative geometry are the major controls on cooling. According to Spronken-Smith and Oke (1999), urban parks may also be classified as grass, grass with the border, savannah (grass with isolated trees), garden, forest and multi-use. These researchers have also found that daytime PCIs formed as a result of the combined effects of soil moisture and shading: trees shade the surface, while grass is typically cooler than most solid surfaces during the daytime if it is well irrigated. Therefore the relative coolness of irrigated parks peaks in the afternoon for forest type, or early evening in garden, savannah, multi-use types. On the other hand, trees also inhibit nocturnal long-wave radiative cooling by blocking off part of the sky, while excess moisture increases the thermal capacity of the soil and slows down the surface cooling. In other words night time PCIs typically form in relatively dry urban parks with a sparse tree cover. Since the sky view factor is close to unity these pars are driven by the long-wave radiative cooling. In addition since evaporative fluxes are generally weak at night, evaporation does not play a significant role in formation of this type PCI. Furthermore in such parks daytime temperatures may sometimes be higher than in neighbouring urban areas (Erell, 2008).

According to Erell (2008), the mechanisms by which the energy exchange between buildings and the environment may be summarized as:

1) Vegetation can reduce energy consumption in buildings in hot climates if air temperature is reduced near the planted area.
2) Plants may shade building surfaces.
3) Plants may reduce wind speed near buildings: by limiting unwanted infiltration but also restricting ventilation and reducing convective exchange at building surfaces. The last one may be unwanted in cooler climates.
4) Plants in warm climates may reduce temperatures of ground surfaces through evapotranspiration with two effects: cooler surfaces emit less infrared radiation, thus reducing the radiant load on building surfaces; and they release less sensible heat to the adjacent air so that buildings are exposed to cooler ambient air.
5) Roof gardens.

2.5. The Examination of the Urban Geometrical Principles

The architect and the city planner may have overall responsibility for producing the plan and for coordinating the project, crucial inputs are provided by consultants from other disciplines. The role of the urban climatologist is also in the process of optimization that takes place in urban planning (Erell, 2008).

For this reason in the same study ‘The application of urban climates research in the design of cities’ in the book ‘Advances in Building Energy Research, volume 2’ Erell also summarized the effect of various features of the urban form on microclimate from the perspective of an urban planner as *urban density, street orientation, street aspect ratio, neighbourhood and building typology, size type and location of urban parks, building and paving materials*:

Erell points out the different definitions of the *urban density* in the literature of architects and planners versus urban climatologists. The urban density for architects and planners is the density of a city generally determined by economic considerations, reflected in the price and availability of land. They typically measure urban density by means of the number of dwellings per unit area of the site. Whereas for urban climatologists, the urban density is the plan area density which is the ratio of the building’s footprint to the total area of the site; or the frontal area density (from the façades) which is the ratio of its (windward) elevation to the site area. Density has a direct effect on the exposure of urban surfaces to direct solar radiation (Erell, 2008). Buildings block the solar radiation according to the orientation of the streets and cast shadow over the street.

The *street layout and orientation* determines the structure of a city. In modern town planning, streets are generally planned in response to the requirements of transport systems however in ancient cities whether their effect on the urban microclimate was considered is discussable (Erell, 2008). In his work ‘Wind as an influential factor in the orientation of the orthogonal street grid’ in 1985, Kenworthy based on the regular street pattern of some ancient cities such as Miletus finds out that promoting exposure to regional winds on an urban scale has been an aim of city planners from ancient times (Kenworthy, 1985). Other effects are discussed in different parts of the present study.

Oke stated that urban planning is always involved in making choices between alternatives and in the case of designing for street climate the objectives may be contradictory for example, whilst open geometry is conductive to air pollution dispersion and solar access, a more densely clustered arrangement is favourable for shelter and energy conservation (Oke, 1988). Therefore an optimization all the effects during the summer and in winter conditions should be made. However due to the multiplicity of these effects it is very difficult to come up with an equation including all variables. In the literature one can find combinations of mathematical equations of energy balance derived from or compared with computer simulations and wind tunnel experiments with a few field studies in addition various geometrical guidelines especially created by architects and urban planners.

Architects in densest cities in the world searched for creation of guidelines. As an example in the study “Policies and technical guidelines for urban planning of high-density cities-air ventilation assessment (AVA) of Hong Kong”, since the waterfront city Hong Kong has a hot and humid climate, Ng (2008) suggested for city’s dense urban area that it would be better to increase the permeability of the district near the sea at the ground level by opening major roads to air ventilation and by proper linking open spaces, creation of open plazas at road junctions, maintaining low-rise structures along prevailing wind direction routes and widening of the minor roads connecting to major roads and also avoid obstructing the sea breeze (Ng, 2008).

In the study mentioned above it was also suggested that in the case of a new town in order to avoid obstruction of the sea breeze, the axis of the buildings should be parallel to the prevailing wind and in order to maximize wind availability to pedestrians, towers should preferably about the podium edge that faces the main pedestrian area/street so as to downwash wind to reach street level. Another suggestion is varying the heights of the buildings towards the direction where the prevailing wind comes from.

Building permeability is another important aspect for future plans because the provision of permeability/gaps nearer to the pedestrian level is far more important than at high levels. Permeability improves not only the air movement on the ground level and improving pedestrian comfort but also help to remove pollutants and heat generated at the ground level. The channelling effects created by voids also help to improve ventilation performance for the residential units at the lower floors and creation of openings in the building blocks to increase their permeability may be combined with appropriate *wing walls* that will contribute to pressure differences across the building façades and thus will permit the air flow through the openings of the buildings. A qualitative guideline for planners and architects is listed as; Breezeways and air paths, Orientation of street grids, Linkage of open spaces, waterfront sites, non-building area, building heights, scale of podium (i.e. for high-rise buildings a terraced podium design should be adopted to direct downward air flow which can enhance air movement at the pedestrian level), building orientation, shading greenery and cool materials, projecting obstructions such as elevated walkways in Figure 2.8 and Figure 2.9 below (Ng, 2008):

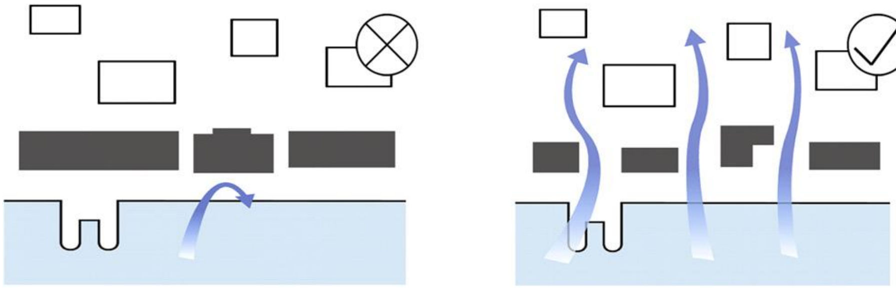


Figure 2.8. Waterfront sites in Hong Kong
(Source: Ng, 2008).

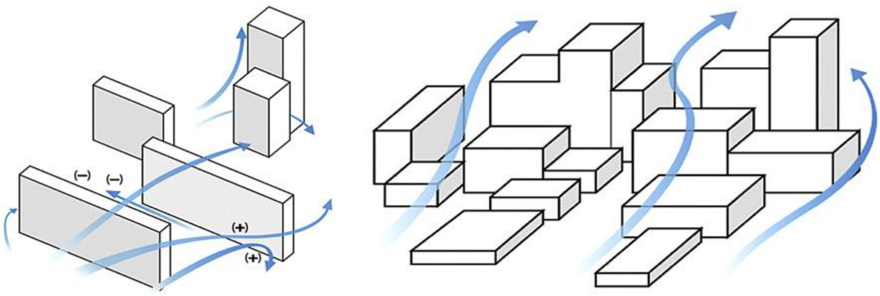


Figure 2.9. The relation of the variety of building heights and airflow coming from the waterfront is shown on the graphic (Source: Ng, 2008).

The urban environment consists of rectangular bodies (buildings) and voids between them (roads, parks, non-built areas, etc.). The construction of the buildings inevitably changes the outdoor climate at the building site in other words the microclimate. Wind speed, wind direction, air pollution, driving rain, radiation and daylight are all examples of physical aspects that constitute the outdoor climate and that are changed by the presence of the building (Blocken and Carmeliet, 2003).

In most of the large cities the presences of the dense urban structure cause several unfavourable microclimatic changes: 1. *Increased wind speeds* around the building leading to uncomfortable or even dangerous conditions for pedestrians. 2.

Decreased wind speeds leading to insufficient removal and accumulation of traffic or industrial exhaust gases. 3. *Shadowing* or reflection of sunlight by the building. 4. *Visual pollution*. 5. *Acoustical changes*, etc. (Blocken and Carmeliet, 2003).

Reiter lists the simple graphical tools which were developed for quantifying the following wind effects around buildings (Reiter, 2010):

- the corner effect:

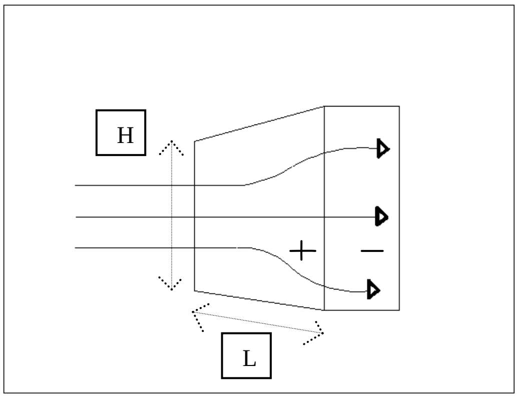


Figure 2.10. The corner effect.

In the case of an unsheltered building, when passing the corner, pedestrians often have to stoop to resist the wind effect (Figure 2.10).

The corner effect was found to be nearly independent of building length (L).

On the other hand the building height (H) is the key parameter influencing the corner effect around a single building: The higher the building the more critical the wind discomfort zones (Reiter, 2010).

To limit the corner effect it is advisable to reduce the height of the buildings along public spaces, using setbacks or bases around corners (Reiter, 2010).

- the front vortex:

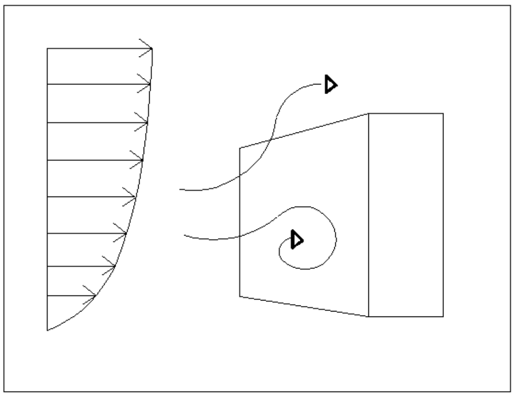


Figure 2.11. The front vortex.

This wind effect is uncomfortable when the building height is greater than 60m. However when the height is less than 50m there is a protection zone upwind of the building (Reiter, 2010) (Figure 2.11).

- the effect of shielding:

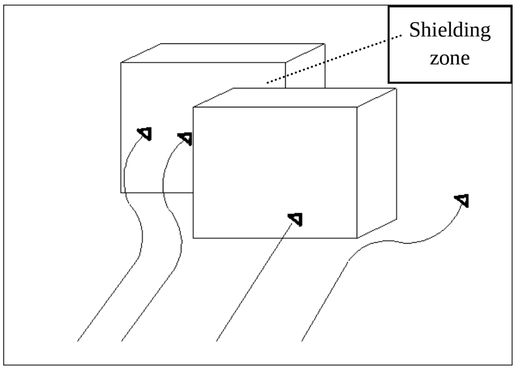


Figure 2.12.The effect of shielding.

Between two shifted buildings a shielding zone is created (Blocken and Carmeliet, 2003) (Figure 2.12).

- the passage effect:

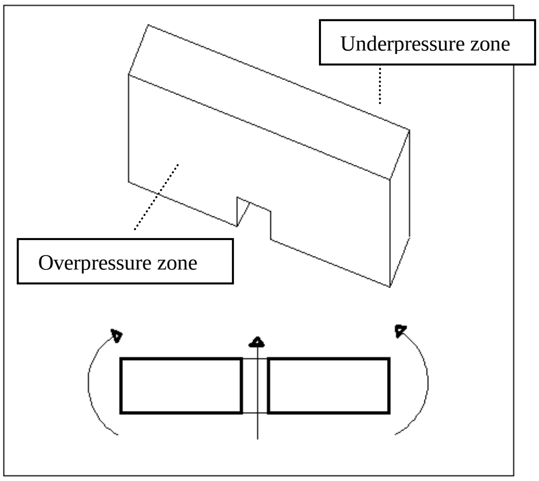


Figure 2.13. The passage effect.

The pressure distribution around a building can be modified by the ‘permeability’ of the building (Blocken and Carmeliet, 2003) (Figure 2.13).

- the double-corner effect:

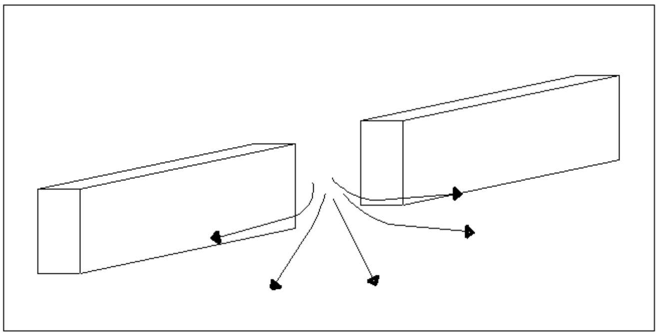


Figure 2.14. The double-corner effect.

The double-corner effect does not exist if the width between the buildings is less than 6m since the wind speeds measured in the passage in this case are lower than those generated by a conventional corner effect (Reiter, 2010) (Figure 2.14).

- The Venturi effect:

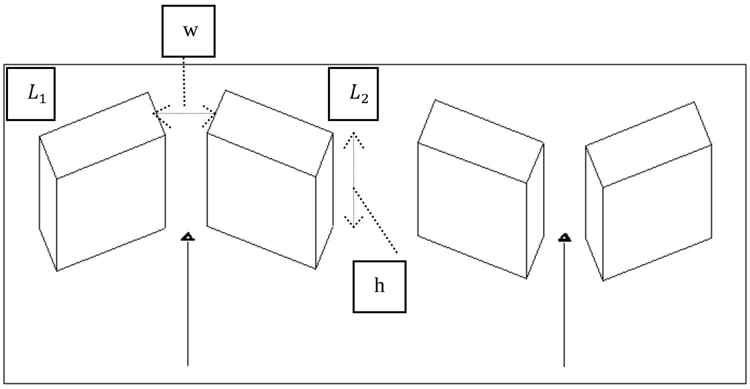


Figure 2.15. The Venturi effect.

The condition for the occurrence of the Venturi effect (Gandemer, 1975):

1) H>15m
2) $L_1 + L_2$>100m
3) Exposed Site
4) For maximum flow: w/h = 2 or 3

(Figure 2.15).

- the mesh effect:

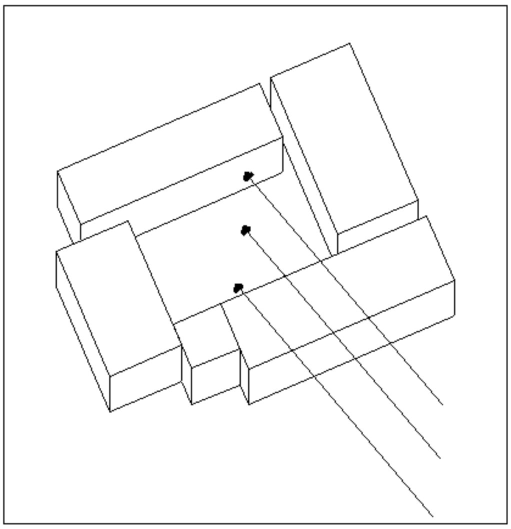


Figure 2.16. The mesh effect.

A built mesh generates a closed area protected from the wind (Reiter, 2010) (Figure 2.16).

- the high-rise building effect:

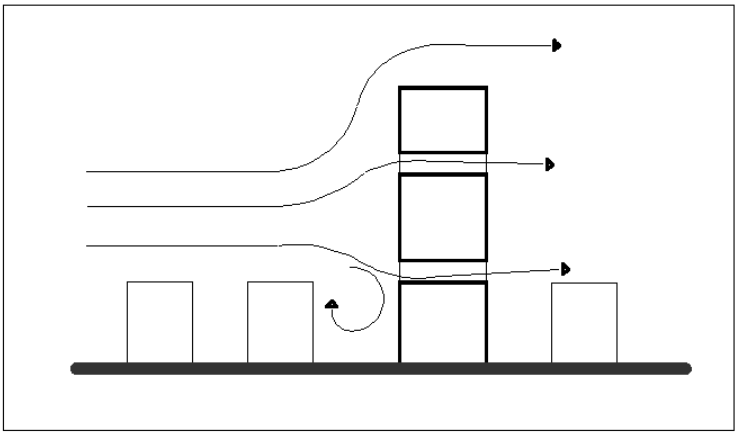


Figure 2.17. The high-rise building effect.

Tall buildings are those whose height is at least double the average height of the surrounding buildings. In the case of a tall building surrounded by smaller buildings the average wind speed at pedestrian level depends essentially on the ratio between the height of the tall building and the average height of the surrounding buildings (Reiter, 2010) (Figure 2.17).

Investigations of the conditions downstream of the screen have shown that if the porosity –i.e. the ratio of hole to screen area-is greater than 38% there will be no appreciable eddying. Eddying flow causes for more discomfort than does steady one. If the porosity is 38% the degree of shelter is decreased. Recommended is 35-40% porosity for sheltering (Blocken and Carmeliet, 2003).

- The shielding effect provided by screens:

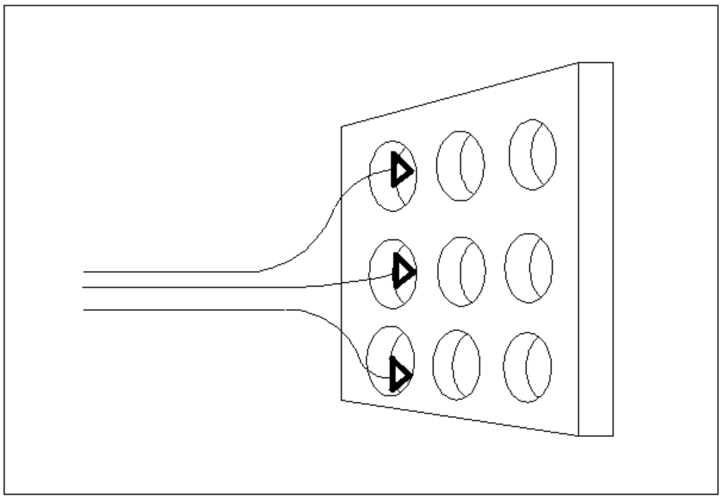


Figure 2.18. Porosity of the shielding screen.

Similar to the porosity of a shielding element in an urban area the windward façades facing the prevailing wind can be at a ratio of porosity in order to let the air flow pass through between buildings. In addition shading elements can be in a way that the sun light is partially blocked on the other hand the air is channelled into the building (Figure 2.18).

2.6. Wind Discomfort due to the Increased Wind Speed in Urban Environment

Although in the literature the emphasis is put generally on the increased wind speed in the urban environment. In order to examine low-speed wind flow conditions the wind acceleration conditions should be understood. The atmospheric environment around the building must be tolerable for pedestrians and others in normal conditions.

As mentioned before in the urban boundary layer (UBL) there are two types of wind flow: Laminar flow and Turbulent flow. Laminar flow represents the wind flow which layers of fluid move smoothly over or alongside adjacent layers. However, the fluid motion does not stay in the smooth laminar state for long time. The general flow type is the turbulent flow. The intensity or the amount of the turbulence is represented by the Reynolds number (Re). The Reynolds number is the ratio of inertia forces to viscous forces.

For high Re numbers in other words when the wind flow is turbulent the wind may cause disturbance for the pedestrians. According to Houghton and Carruthers (1976), tests show that the expenditure of energy while walking against the wind is highly affected by wind speeds up to 5 m/s. Wind speeds above 5 m/s which represents the Beaufort scale 3, considerable cooling of the body occur, and unpleasant disturbance of hair and clothing is experienced while at the same time eyes may be irritated. At Beaufort scale 4 (5-8 m/s) dust is raised from the ground by the wind, the greater vertical velocities in a highly turbulent wind aggravating the problem of eye irritation. On the other hand 5 m/s wind speed is considered too high for recreational areas, parks or similar places. Acceptable wind speed depends not only to the activity of the person subjected to the wind but also his age: younger or elderly people are less resistant against high wind speeds.

The wind effects on a site can be divided in two as: 1. Mechanical wind effects and 2. Thermal wind effects. The mechanical wind effects can be formulised as below:

$$U_e=U+k\sigma \tag{2.5}$$

U is the mean wind speed, k is the peak factor and σ is the standard deviation:

$$\sigma=\sqrt{\frac{\sum (x-x')^2}{N}} \tag{2.6}$$

An overview of published thresholds in the literature had been done by Bottema (2000) and the reasonable choice of the scientist is:

- For comfort threshold: $U+\sigma_u>6\ m/s$ (only for walking)
- For danger threshold: $U+3\sigma_u>20\ m/s$

Discomfort probability and danger probability are defined as the percentage of hours (during a year) in which thresholds are exceeded. The maximum allowed percentage depends on the type of human activity:

$$P_{max} = 15\ \%\ \text{(for strolling and walking)}$$

In addition to the wind speed the duration of the exceeding speed is important. Based on the Bottema's work Blocken and Carmeliet (2003) states;

1. A gust of 4 m/s during 5 s causes hair to be disturbed.
2. A gust of 7 m/s during 5 s can cause hair to be disarranged.
3. A gust of 15 m/s during 2 s can bring people out of balance and is dangerous for the elderly and the infirm.
4. A gust of 20 m/s can be dangerous, even for young people.
5. A gust of 23 m/s will flow people over.

In "A Method for optimisation of Wind Discomfort Criteria" (2000) Marcel Bottema defines a wind comfort criteria as a combination of: 1. A discomfort threshold, 2. A maximum allowable exceedance probability. In the mentioned study the wind discomfort criteria are compared and optimised using a $U\ U_{pot}$ framework which represents the allowable wind amplification factor (U is the local hourly mean of wind speed and U_{pot} is the hourly mean at an ideal meteorological site. For the case of Amsterdam, the maximum recommended value of $U\ U_{pot}$ is between 0,3-0,7 (0,3 for sitting and 0,7 for safety only) (Bottema, 2000).

The wind statistics measured at the meteorological site are transformed to the building site by the wind amplification factor:

$$\gamma = \frac{U}{U_{pot}} = \frac{U}{U_0}\ \frac{U_0}{U_{pot}} \tag{2.7}$$

U is the local wind speed at the building site (approximately 1,75-2 m.),

U_0 is the reference wind speed that is taken at a certain distance upstream of the building site,

U_{pot} is the mean potential wind speed;

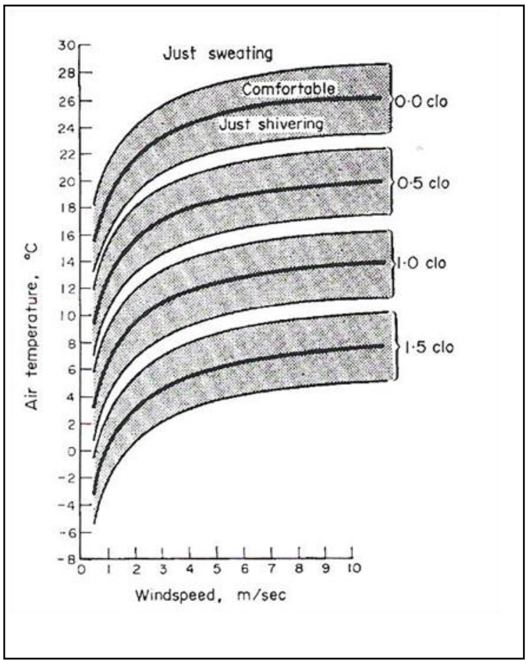
$$\frac{U}{U_0}$$

is the 'design related contribution' in other words the effect of the building geometry, orientation, the interaction between the buildings etc. where the role of architecture and urban design starts.

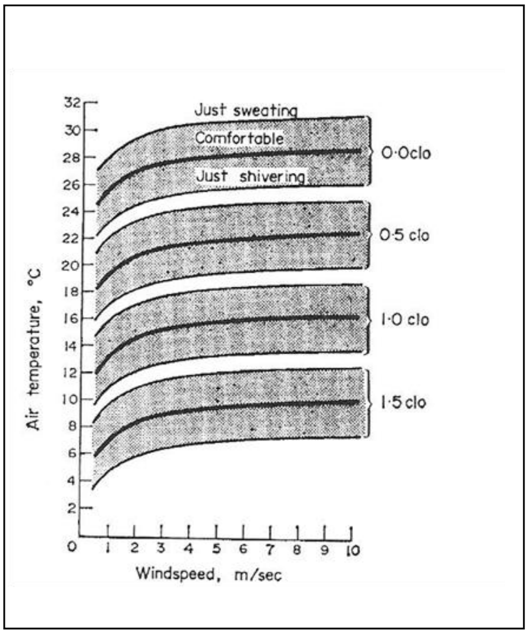
$$\frac{U_0}{U_{pot}}$$

is the terrain related contribution such as differences in terrain roughness between the meteorological site and the terrain surrounding the building site.

In 'Acceptable Wind Speeds in Towns', Penwarden (1973) summarizes the comfort regions for shade and for full sunshine in outdoor conditions by two diagrams:



Figures 2.19. Comfort conditions for strolling in full sun.
(Source: Penwarden, 1973)



Figures 2.20. Comfort conditions for strolling in shade
(Source: Penwarden, 1973).

The ‘clo’ unit represent the thermal insulation of various types of clothing where 0.0clo and 0.5clo are for light summer cloths, 1.0 is for the typical British business suit and 1.5 is for typical winter clothing with overcoat (Penwarden, 1973). The grey coloured areas in both figures represent the wind comfort zones in different clothing values. Over and under each grey zone according to the temperature variable sweating and shivering starts as a biological response to uncomfortable conditions (Figures 2.19 and 2.20).

In this study the decreased wind speed level in the city of Izmir is the focal point. However the increased wind speed conditions should also be considered since excess wind speed at the pedestrian level is one of the problems that are considered most important by city planners, architects, scientist etc. throughout the world. In addition Penwarden’s work on the wind comfort levels with the air temperature (°C) and wind speed (m/s) variables (with the clothing units) is useful for this study since the temperature and the air speed on the pedestrian level are the main variables.

CHAPTER 3

THE WIND ENVIRONMENT ON THE PEDESTRIAN LEVEL IN THE IZMIR CASE: THE FIELD STUDY

After the declaration of the republic in 1923, many planning studies have been made for the city of Izmir. Kemal Aru's plan approved in 1955 is considered as the origin of the actual situation which is a dense urban structure with few green areas. According to the mentioned plan, the estimated population for the year 2000 was 400,000 whereas Izmir's population in 1955 had already reached 300,000. In 1955 the Bodmer plan proposed 900,000 people for the year 2000. However in 2000 the population number was 2,250,149. In addition according to the projection of population in the municipality boundaries, for the year 2005 the estimated number is 3,400,000. This unexpected population growth required a heavy construction work for new buildings and a massive construction era had started. After 1960 a rapid outward movement took place towards the surroundings of the city core. This resulted in the extensive linear expansion of urban development along the major transportation axes. As a result today all settlements around the Izmir Bay are interconnected forming an urban ring which extends outwards approximately 50 kilometres from the city core of Konak. After 1980's neo-liberal policies, social, institutional and spatial structures in urban areas in Izmir have been influenced by the changes. In 1984 according to the '*Law of Greater Metropolitan Municipalities (No. 3030)*' the metropolitan status was given to Izmir. After that time many large scale projects changed the urban landscape in Izmir and the city experienced an intensive urban sprawl (Arkon, 2006).

High land values on the coastal area around the Izmir Bay, resulted in continuous multi-storeyed building line with few openings to the parallel streets (Figure 3.1). In the actual physical urban structure, only the buildings on the first row benefit from the prevailing wind and from land-sea breeze during hot summer season. The building heights are uniform especially near the seaside which is not favourable for the wind environment in the city. There is a scarcity in vegetation and urban parks. There are no intentionally planned linkages of wind paths or voids in the city. Wherever there is an appropriate void for wind passage another building across the street blocks the flow creating multiple wind shielding zones between the buildings (Figure 3.1).

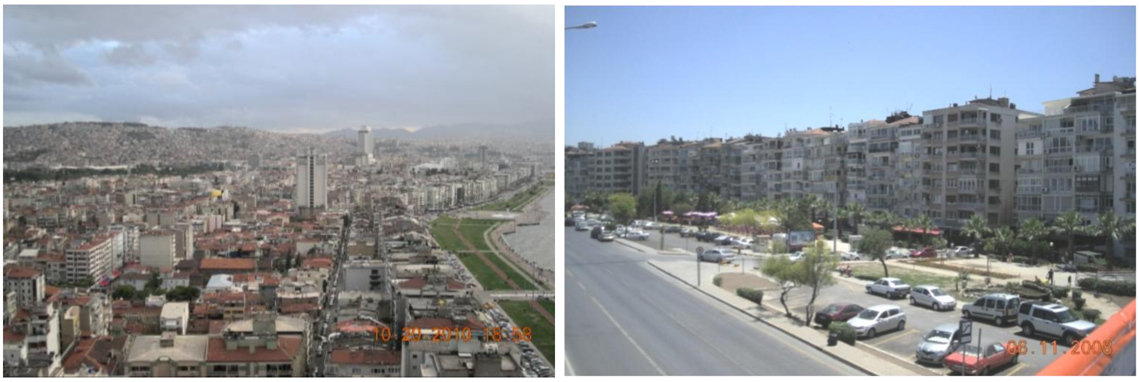


Figure 3.1. The urban sprawl in the year 2010. View from the Punta district towards Alsancak and Konak (Left), Figure 2.20. Continuous multistoried buildings along the coastal line in Güzelyalı, Izmir (2008) (Right).

Therefore the measurements on three sites were held during the summer season in the year 2009. The sites are Alsancak, Konak and Güzelyalı in Izmir, Turkey. The sites situate on the Southern banks of the Izmir Bay. In addition the sites have heavy pedestrian and vehicular traffic.

The collected wind speed and direction data from the mobile weather station is compared with the wind speed and direction data obtained from the National Meteorology Office on the average values per minute basis.

The National Meteorology Office in Izmir situates in the Güzelyalı District in proximity to one of the studied sites. The wind speed and direction differences between the official data and the site data can be considered as the effect of the roughness surfaces around each measurement sites.

3.1. The Data Collection Phases

Measurements were held in the following months:

- During July 2009 (6 days two tours of measurements)
- During August 2009 (3 days one tour of measurements)

- During September 2009 (3 days one tour of measurements)

  12 days of measurements in total in three different sites (Figure 1.10).

- For each path and point different ID numbers were given:
  - i.e. **G1, G2, G3…or P1, P2…P60**
  - measurement points were chosen according to their two dimensional physical conditions
- For each site there are approximately 70-80 points (Figure 3.3, Figure 3.4 and Figure 3.5).
- For one day and for one site there are **two periods of time**

  (Mid-day and evening including the sunset were temperature variations and wind speed fluctuations occur)

- For each point representing **1 min.** Measurement of wind speed and temperature is and will be compared **with the simultaneous weather station data.**
- **The character of the points** is defined by openness, half openness or being closed to the prevailing wind etc.
- **The character of the street** is defined by the orientation, solid-voids of the street boundaries, prevailing wind conditions, height of the buildings and width of the street-aspect ratios-(H/W and H/L), and the density of the urban structure etc.
- **The climatic data** is measured by the Weather Station and Field Data by measurement devices for wind speed direction and temperature.

For the evaluation phase:

- A database is produced by using the EXCEL program
- Combinations sets were made in order to compare the pedestrian wind velocity $\boldsymbol{V_{ped}}$ and the roof –level wind velocity $\boldsymbol{V_{ws}}$

Figure 3.2. Measurement paths on three sites: Alsancak, Konak, Güzelyalı. Different colors represent different measurement groups of two persons.

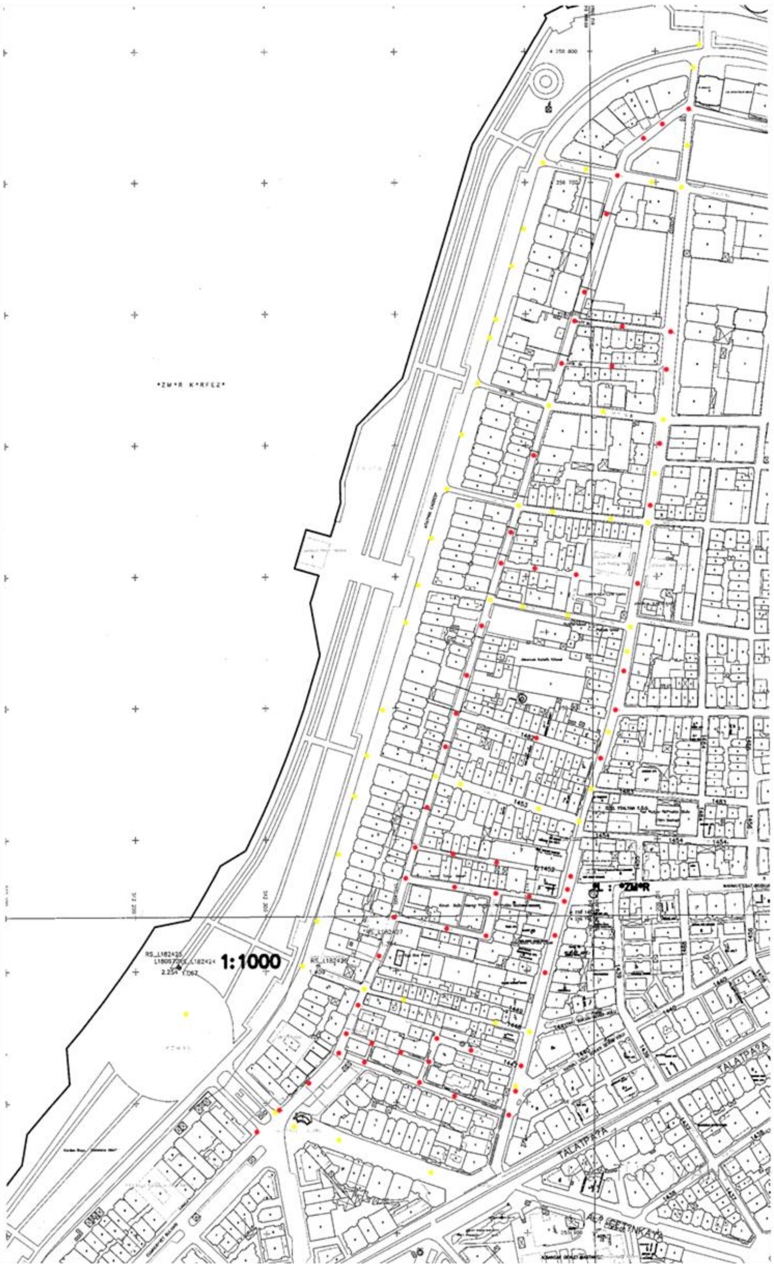


Figure 3.3. Measurement points in the Alsancak Site: Red points represent the K path (group), Yellow points represent the B path (group).

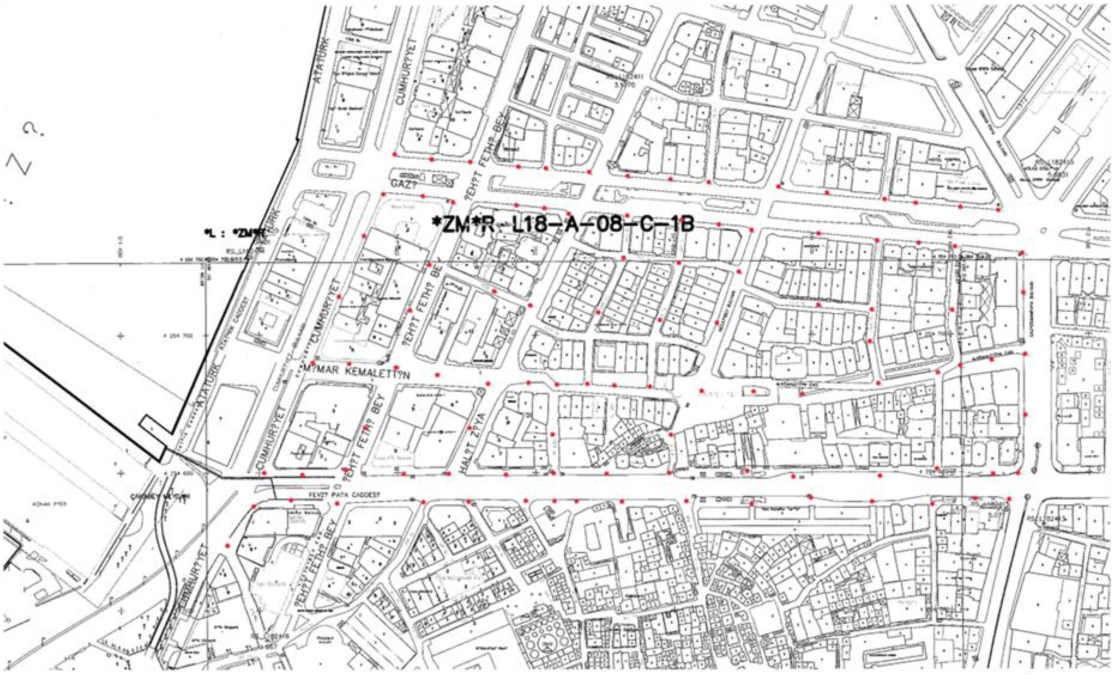


Figure 3.4. Measurements in the Konak Site.

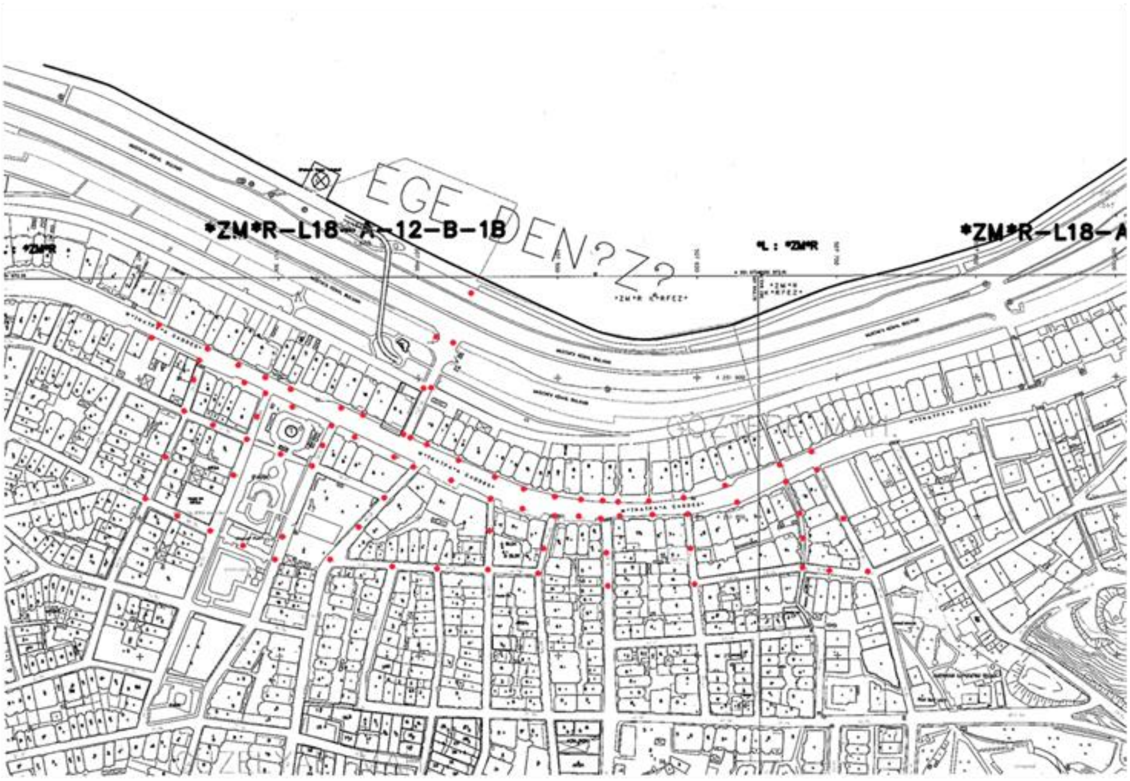


Figure 3.5. Measurement points in the Güzelyalı Site.

3.2. The Database

The database consists of these variables below:

1) Location **(LOC):** Alsancak **(ALS)**, Güzelyalı **(GZYL)**, Konak **(KNK)**

2) **ID**: P1,P2,P3,...,Pn or G1,G2,G3,...,Gn for each measurement point: Pn and Sn are for GZYL site (Güzelyalı Parkı and Susuz Dede Parkı respectively), Gn and Fn are for Konak KNK (Gazi Bulvarı and Fevzipaşa Bulvarı respectively) and Bn and Kn are for Alsancak ALS (Büyük tur and Küçük tur respectively)

3) Date of the measurement

4) Measurement period: Midday **(MID)** and Afternoon including the sunset **(AFT)**

5) Exact time of the measurement (in minutes)

6) The name of the main cayons: Kıbrıs Şehitleri Sokağı **(KBSS)**, Ikinci Kordon **(2KRD)** in Alsancak, Gazi Bulvarı **(GZBL)** and Fevzi Paşa Bulvarı **(FVZPS)** in Konak, Mithatpaşa Caddesi **(MTPS)** in Güzelyalı

7) Main Canyon **(MC)**

8) Secondary Canyon **(SC)**: which are generally perpendicular to the main canyons

9) Width of the canyon as an average number in the canyon **(W)**

10) Length of the canyon **(L)**

11) Average height of the buildings flanking on the both sides of the canyon (3 meters for each building storey) **(H)**

12) The aspect ratios **(H/W)**

13) The canyon length ratio **(L/W)**

14) Urban density ratio (partial) $\boldsymbol{A_d} = (\boldsymbol{A_r}\ \boldsymbol{A_l})$ ($\boldsymbol{A_r}$: The total area of the building roofs, $\boldsymbol{A_l}$**:** The total area of the land)

15) **(L/H)**

16) First canyon angle **(FCA θ°)** : The angle of the main canyon axis from the North

17) Second canyon anle **(SCA β°): (FCA θ°) + 180°**

18) Secondary canyon's first canyon angle **(SFCA θ°)**

19) Secondary canyon's second canyon angle **(SSCA β°): (SFCA θ°) + 180°**

20) Point type in 2D **(PNTTYP):** Closed **(CLSD),** Cross **(CRSS),** Shifted cross **(SFTCRSS),** T-shape **(TSHP),** Seaside **(SSD),** Open **(OPN),** Opening on the pedestrian level **(PDST),** T-cross **(TCRSS=PDST+TSHP),** Park **(PRK) (**Figure 3.6, Figure 3.7 and Figure 3.8).

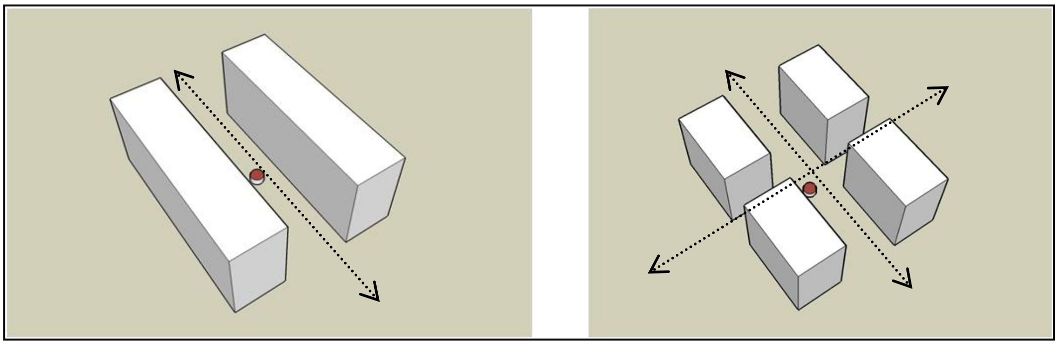


Figure 3.6. CLSD and CRSS type points.

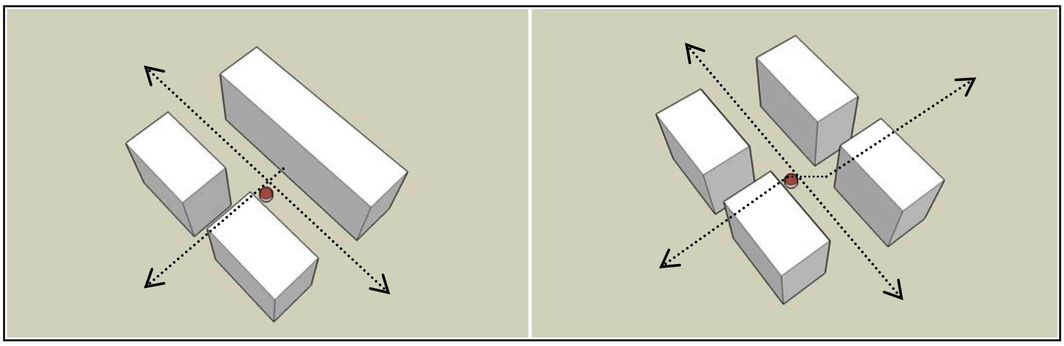


Figure 3.7. TSHP and SFTCRSS type points.

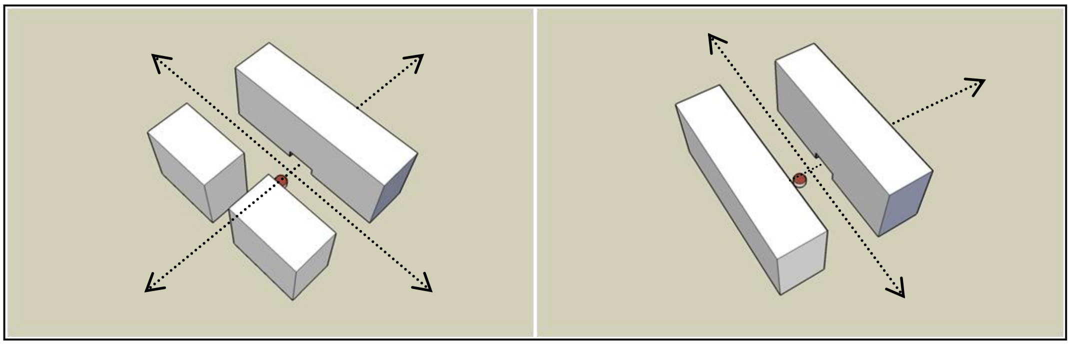


Figure 3.8. TCRSS and PDST type points.

21) Average wind angle **(WA_avg)**

22) Average wind speed from the roof level for measurement periods (MID) and (AFT): **(WSPD_avg)**

23) Prevailing wind direction in the main canyon **(WDC)**: Oblique **(OBLQ)**, Parallel **(PARLL)**, Normal **(NORM)** (Figure 3.9.). Based on the study of Niachou et al. (Part II, 2007) classification of ambient wind incidence angles in parallel, perpendicular (normal) and oblique relative to the long canyon axis can be made as:

Normal if $|WA\_avg-\theta| = 90° \pm 10°$ (80-100°)

$|WA\_avg-\theta| = 270° \pm 10°$ (260-280°)

Parallel if $|WA\_avg-\theta| = 180 \pm 10°$ (170-190°)

$|WA\_avg-\theta| = 360 \pm 10°$ (350-10°)

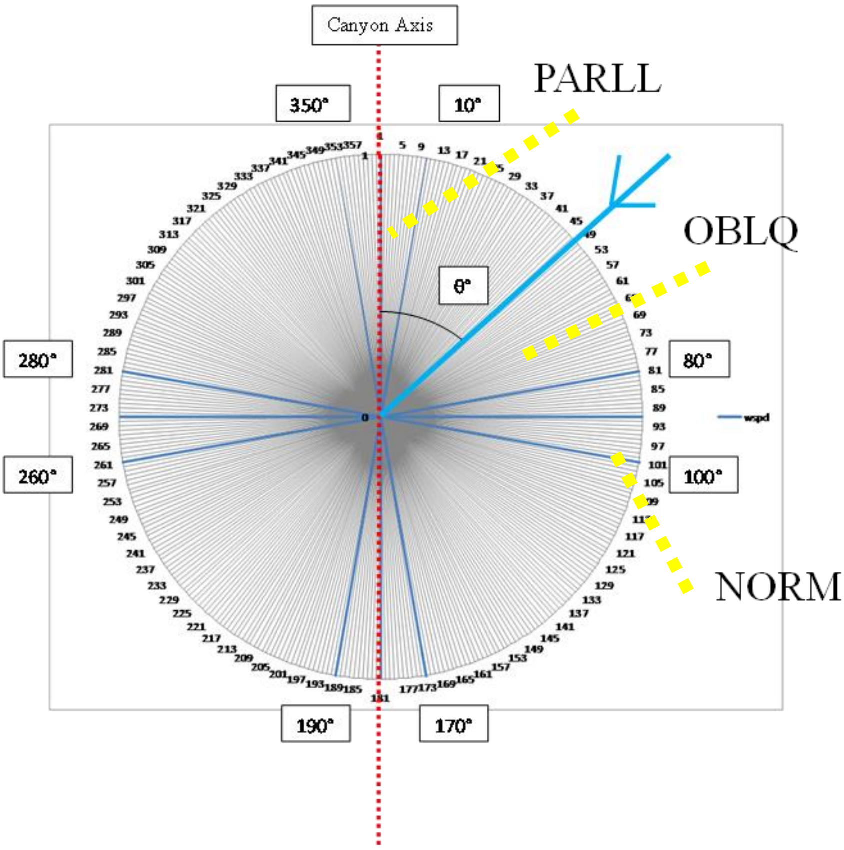


Figure 3.9. Different wind directions to the canyon axis.

24) Prevailing wind direction in the secondary canyon **(SWDC)**

25) Standard deviation of the temperature measurement on one point **(temp_stdv) C°**

26) Average of the temperature measurement on one point **(temp_avg) C°**

27) Percentage of the standard deviation in the average temperature measurement : fluctuation **(temp_fluc) C°**

28) The standard deviation of the wind speed measured on the pedestrian level on one point **(wspd_stdv) m/s**

29) The average wind speed on the pedestrian level measured on one point **(wspd_avg) m/s**

30) Percentage of the standard deviation in the average temperature measurement: fluctuation **(wspd_fluc) m/s**

31) Temperature measured on the roof level by the weather station **(WS_temp) C°**

32) Wind direction measured on the roof level by the weather station **(WS_wdir) (0°-359°)**

33) Wind speed measured on the roof level by the weather station **(WS_wspd) m/s**

34) Canyon starting point distance **(CSPD) m:** the distance of the measurement point from the starting point of a main canyon

35) Canyon end point distance **(CEPD) m:** the distance of the measurement point from the end point of a main canyon.

If CSPD = x_1 and CEPD = x_2, then $x_{1+}x_2$ = x_{canyon} , x_{canyon} is the total canyon length L.

36) The specific H/W for each point different fron the average H/W in the canyon when the measurement point is situated if CSPD and CEPD are given

37) Vped/Vws The ratio of the wind velocity on the pedestrian level to the wind velocity on the roof level.

The data analysis is done by using the EXCEL program for the scatter diagrams and for other charts. In this study, the transfer of knowledge on the wind patterns in the urban environment from the engineering literature to the architectural literature is aimed.

For Alsancak (ALS), Konak (KNK) and Güzelyalı (GZYL) sites 3+3 days are selected as typical days for August (AGST) and September (SEPT), 6 days are selected for July (JULY), therefore 12 days in total (Table 3.1, Table 3.2 and Table 3.3).

Table 3.1. The wind speed and direction measurements from the official meteorological station (blue) and from the roof level (red) in Alsancak (ALS) during the MID and AFT periods.

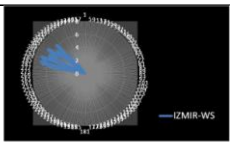
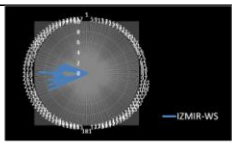
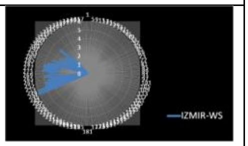
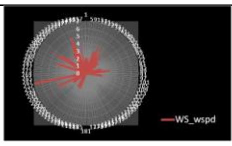
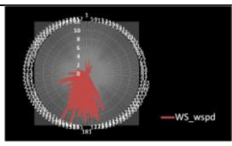
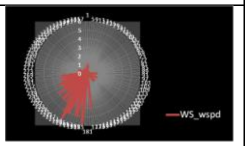
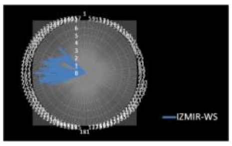
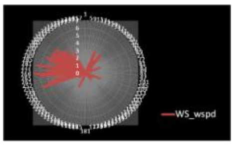
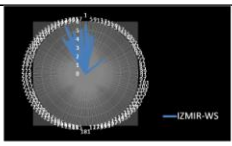
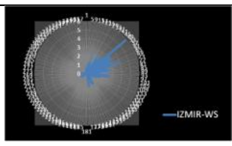
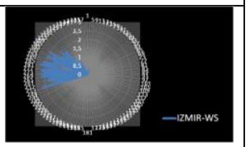
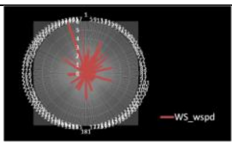
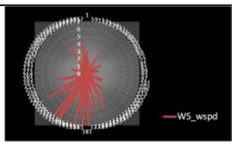
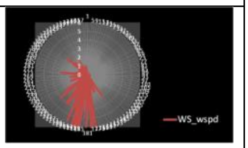
Site	ALS	ALS	ALS	ALS
Date	2 JULY	13 JULY	25 AGST	15 SEPT
MID				
		7m/s	9m/s	6m/s
				
Max.	 	7m/s	12m/s	6m/s
AFT				
		6m/s	6m/s	3m/s
				
Max.	6m/s	6m/s	7m/s	6m/s

Table 3.2. The wind speed and direction measurements from the official meteorological station (blue) and from the roof level (red) in Konak (KNK) during the MID and AFT periods.

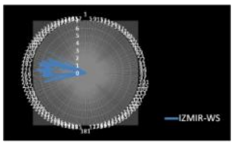
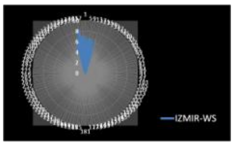
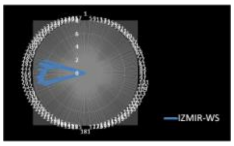
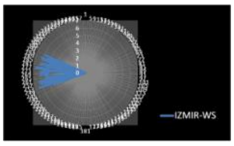
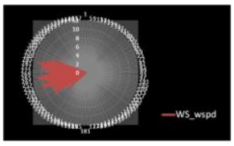
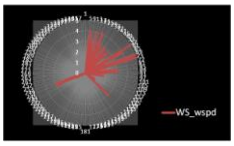
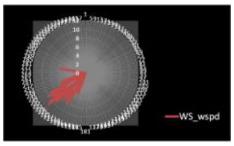
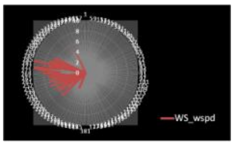
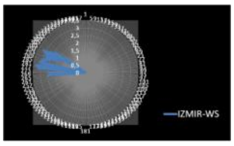
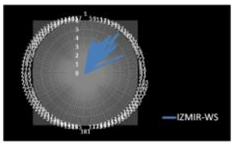
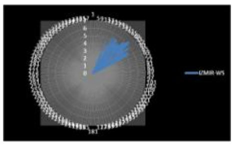
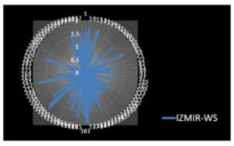
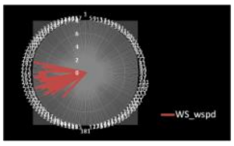
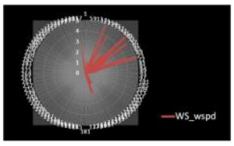
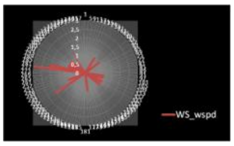
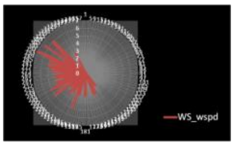
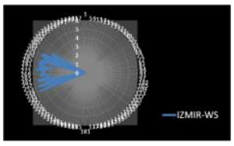
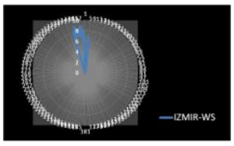
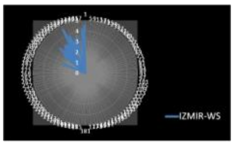
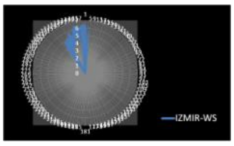
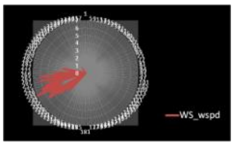
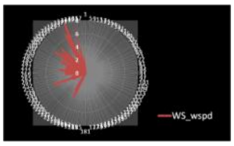
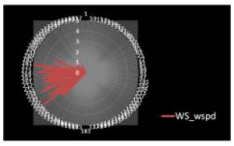
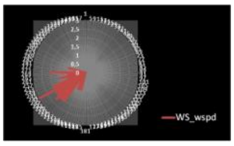
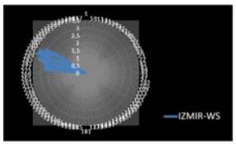
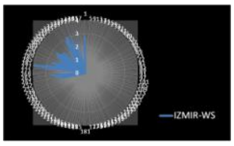
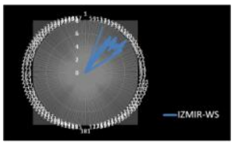
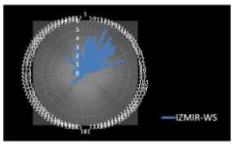
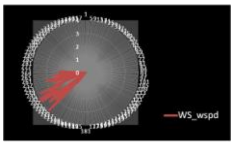
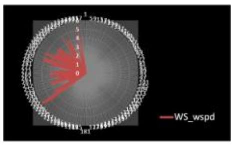
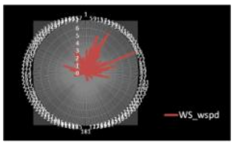
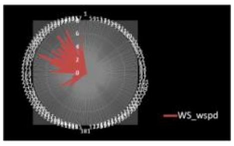
Site	KNK	KNK	KNK	KNK
Date	3 JULY	14 JULY	26 AGST	16 SEPT
MID				
	6,5m/s	8m/s	8m/s	7m/s
				
Max.	11m/s	5m/s	11m/s	10m/s
AFT				
	3,5m/s	6m/s	6m/s	2m/s
				
Max.	8m/s	5m/s	3m/s	7m/s

Table 3.3. The wind speed and direction measurements from the official meteorological station (blue) and from the roof level (red) in Güzelyalı (GZYL) during the MID and AFT periods.

Site	GZYL	GZYL	GZYL	GZYL
Date	6 JULY	16 JULY	21 AGST	19 SEPT
MID				
	6m/s	10m/s	5m/s	7m/s
				
	7m/s	8m/s	5m/s	3m/s
AFT				
	3,5m/s	4m/s	8m/s	6m/s
				
	4m/s	6m/s	7m/s	7m/s

In addition to the weather station data, the wind speed and direction from the seaside in each site were measured. The aim is to understand wether the wind speed on the seaside level can be used for the natural ventilation of the streets and buildings behind the first row of buildings by channeling the wind.

The comparisons of the starting point measurements from the seaside (2m. approximately) and the average pedestrian wind speed along the main canyons in the three sites (KNK, ALS, GZYL) for three months (JULY, AGST and SEPT) are below (Figure 3.10).

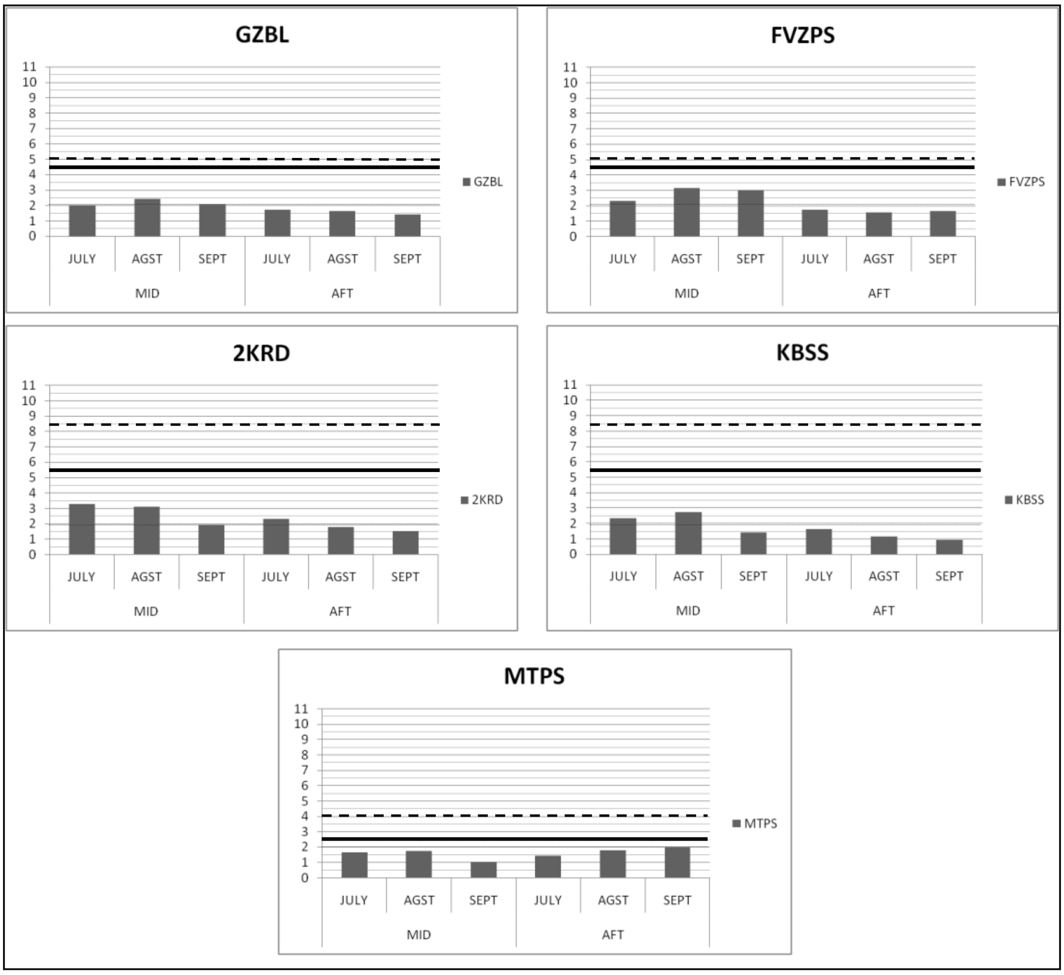


Figure 3.10. The average measurement in three months (m/s) for MID and AFT periods in the main canyons GZBL, FVZPS, 2KRD, KBSS and MTPS where (____) is the average pedestrian wind speed on the seaside in the MID period. (_ _ _) is the average pedestrian wind speed on the seaside in the AFT period.

According to the data in the Figure 3.1, during the MID periods in three months the average wind speed in the main canyons on the pedestrian level are higher than in the AFT period except for the MTPS canyon. Especially for 2KRD and KBSS canyons in the AFT periods when the wind speed is lower than 2m/s the wind speed on the seaside (2m.) can be used for natural ventilation purposes. Channeling the wind into the canyons may enhance the night ventilation of the streets. Therefore a special design solution should be thought according to the wind wind direction on the seaside.

3.3. The Relation between the Wind Speed Measured by the Meteorology Office and the Wind Speed on the Pedestrian Level in the Main Canyons.

In this study it is assumed that the depth of the street canyons and the openness of the streets to the prevailing wind have an important effect on the wind speed on the pedestrian level. This hypothesis is tested in many articles in the literature mostly with simulation studies.

During the measurements the reference wind speed from the roof level changed the speed and direction as expected. However the orientations of the canyons remain the same. Therefore different angles of the reference wind to the canyon axis should be categorized as oblique (OBLQ), parallel (PARLL) and normal (NORM) (Figure 3.11).

First 0<H/W≤1 canyons and second H/W<1 canyons were analyzed by scatter diagrams. In the scatter diagrams throughout this study the x axis represents the pedestrian wind velocity in m/s (V_{ped}) the y axis represents the reference wind velocity taken by one of the highest building's roof which is situated in the main canyon (V_{ws}). The f(x) =x line represents the correlation between (V_{ped}) and (V_{ws}).

If the aspect ratio H/W =1 the average width of the street is equal to the average height of the buildings flanking on both sides of the street. H/W =1 is the reference aspect ratio for the following scatter diagrams.

Up to V_{ped}= 3m/s the wind speed is considered as influenced by the thermal and mechanical effects.

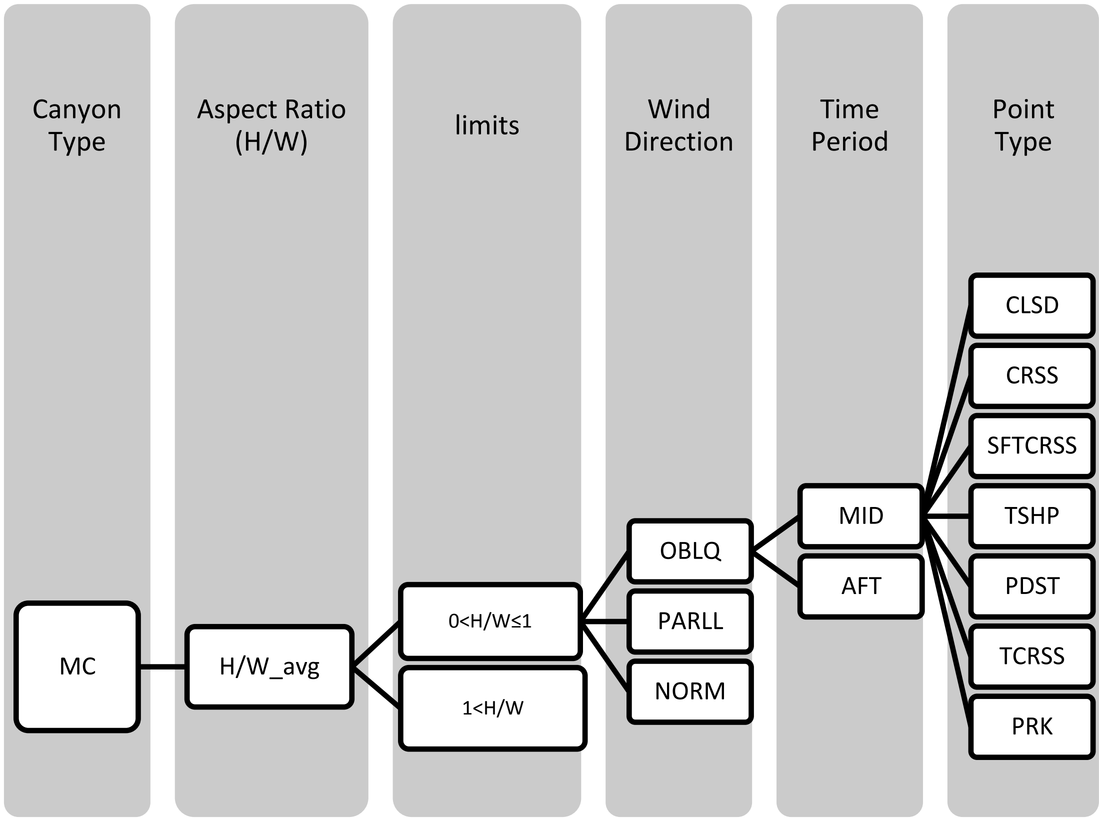


Figure 3.11. Combination diagram of the wind speed measured from roof level and from pedestrian level.

In the analysis of the scatter diagrams (V_{ped} on the x axis, V_{ws} on the y axis) weighted average (WA) is calculated for MID and AFT periods:

$$x = \frac{1}{N}\sum_{i=1}^{N} x.dm \qquad y = \frac{1}{N}\sum_{i=1}^{N} y.dm \tag{3.1}$$

In the previous equations N is the total number of the measurement points, dm is considered equal to 1 (dm = 1) (Equation 3.1).

3.4. All Point Types in 0 < H/W ≤ 1 Canyons

In this study the main canyons where the aspect ratio is between 0 and 1 (0<H/W≤1) are GZBL, FVZPS and MTPS. When the wind direction over the roof level is normal (NORM) to the main canyon axes the scatter diagrams of V_{met} V_{ped} in the MID and AFT periods are below (Figure 3.12).

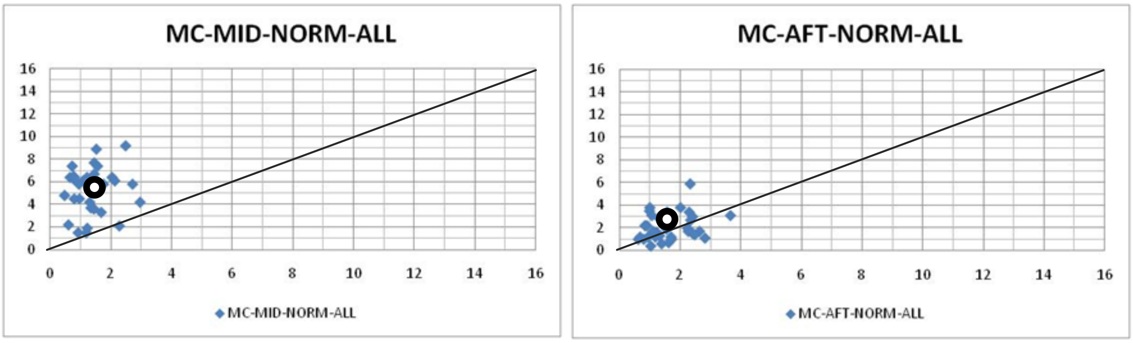


Figure 3.12. MID&AFT-MC-NORM-ALL combination for 0<H/W≤1.
WA_mid: $(X_{avg,}Y_{avg})$ = (1,54; 5,73), WA_aft: $(X_{avg,}Y_{avg})$ = (1,63; 3,32).

When the wind direction over the roof level is parallel (PARLL) to the main canyon axes the scatter diagrams of V_{met} V_{ped} in the MID and AFT periods are below (Figure 3.13).

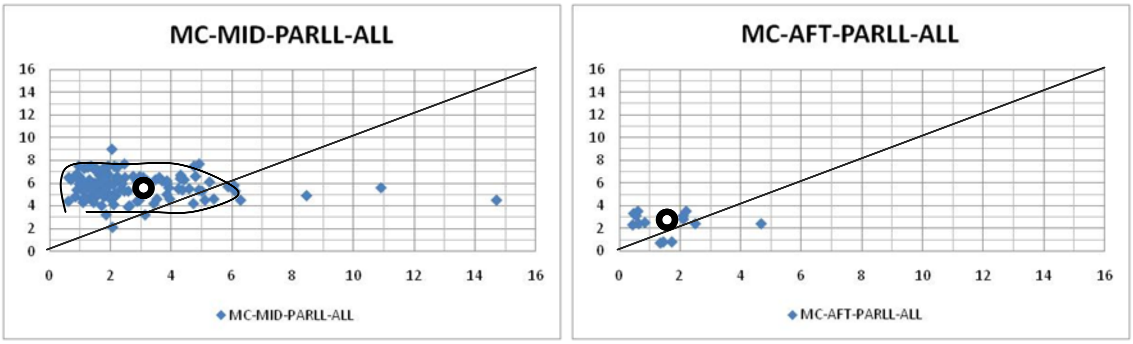


Figure 3.13. MID&AFT-MC-PARLL-ALL combination for 0<H/W≤1.
WA_mid: $(X_{avg,}Y_{avg})$ = (2,65; 5,66), WA_aft: $(X_{avg,}Y_{avg})$ = (1,63; 2,57).

During the MID period the measurements where 3m/s < V_{ped} consist of 42% CRSS and SFTCRSS type points, 30% CLSD points, 28% TSHP points (Figure 3.13).

When the wind direction over the roof level is oblique (OBLQ) to the main canyon axes the scatter diagram of V_{met} V_{ped} in the MID period is below (Figure 3.14).

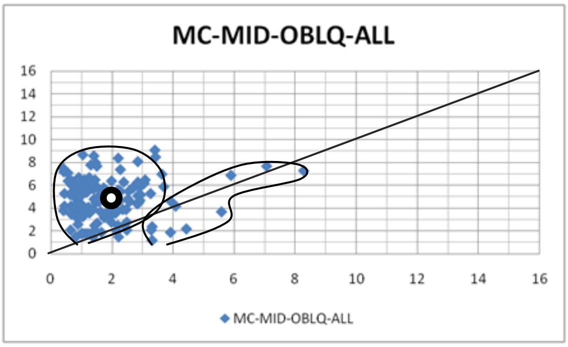


Figure 3.14. MID&AFT-MC-OBLQ-ALL combination for 0<H/W≤1.
WA-mid: $(X_{avg,}Y_{avg}) =$ (2,06; 5,06).

During the MID period the measurements where 3m/s < V_{ped} consist of 35,48% CRSS, SFTCRSS and TCRSS points, 45,16% CLSD points, 16,13% TSHP points and 3,23% PDST points.

3.5. All Point Types in 1 < H/W Canyons

In this study the main canyons where the aspect ratio is over 1 (1<H/W) are 2KRD and KBSS. When the wind direction over the roof level is normal (NORM) to the main canyon axes the scatter diagrams of V_{met} V_{ped} in the MID period are below (Figure 3.15).

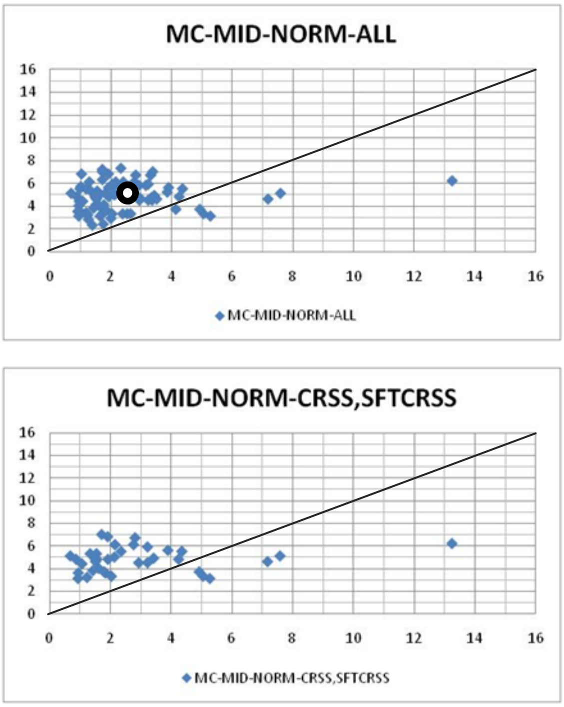


Figure 3.15. MID&AFT-MC-NORM-ALL combination for 1<H/W.
WA-mid: $(X_{avg,}Y_{avg})$ = (2,49; 4,82).

During the MID period, the measurements where the 3m/s < V_{ped} 57,14% are CRSS and SFTCRSS points, 28,57% CLSD points, 14,29% TSHP points.

When the wind direction over the roof level is oblique (OBLQ) to the main canyon axes the scatter diagram of V_{met} V_{ped} in the MID and AFT periods are below (Figure 3.16).

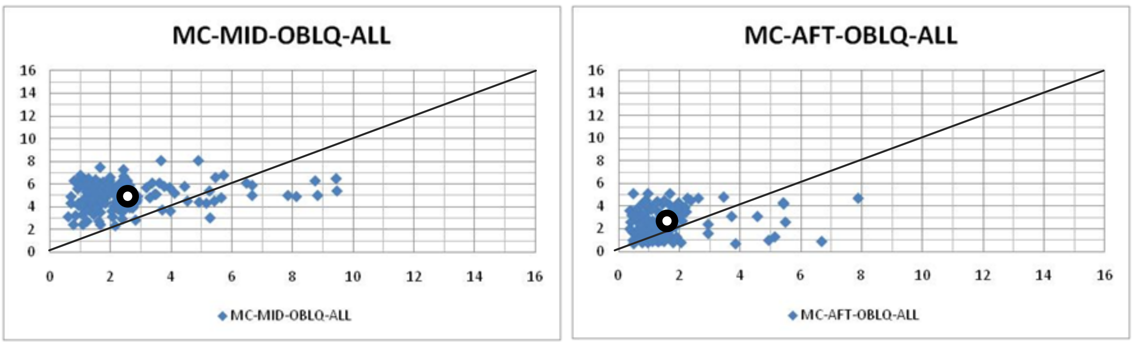


Figure 3.16. MID&AFT-MC-OBLQ-ALL combination for 1<H/W.
WA-mid: $(X_{avg,}Y_{avg})$ = (2,55; 4,92), WA-aft: $(X_{avg,}Y_{avg})$ = (1,57; 2,63).

During the MID period the measurements where 3m/s < V_{ped} consist of 60% CRSS and SFTCRSS type points, 23,34% CLSD points, 16,67% TSHP points. While during the AFT period the measurements where 3m/s < V_{ped} consist of 54,55% CRSS type points, 36,36% CLSD points, 9,09% TSHP points (Figure 3.17).

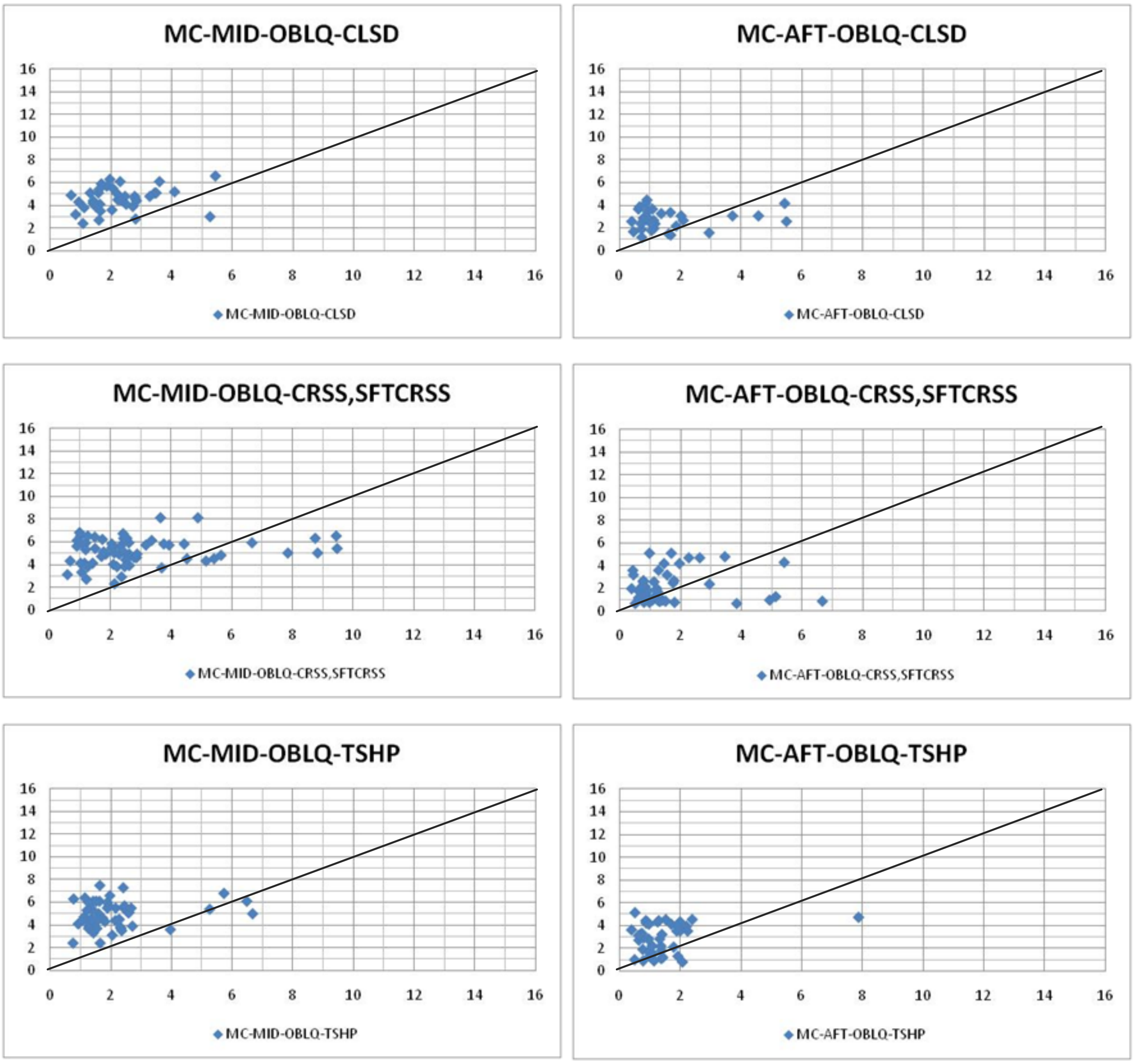
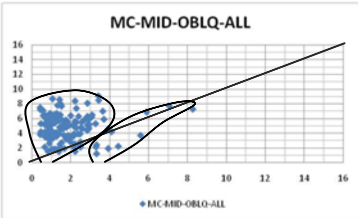
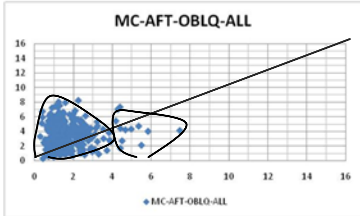
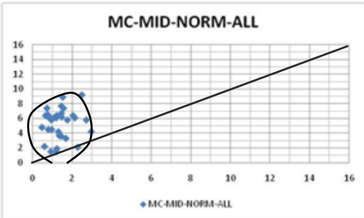
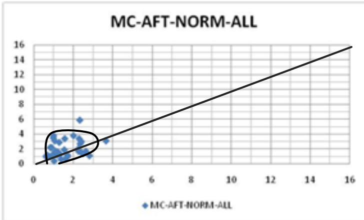
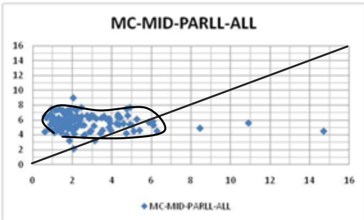
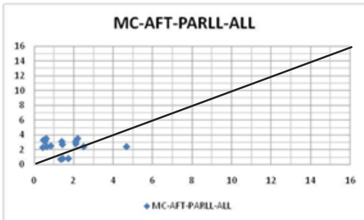
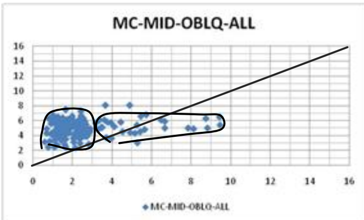
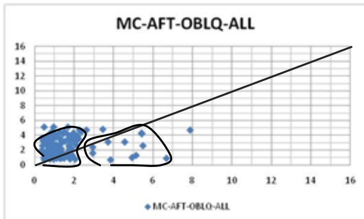
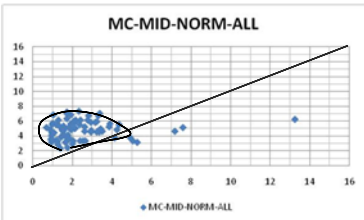


Figure 3.17. MID&AFT-MC-OBLQ-for CLSD, CRSS, SFTCRSS, TCRSS, TSHP points 1<H/W.

Under the oblique wind direction over the roof level the majority of the V_{ped} over 3m/s are originated from the data gathered from cross type points (Figure3.17).

A summary of three different wind directions for different aspect ratios are listed in the following table.

Table 3.4. The comparison of all types of points in different H/W in OBLQ and PARLL directions is represented in the table.

Aspect Ratio	Reference Wind	MEASUREMENT PERIOD	
H/W	DIR.	MID	AFT
0<H/W≤1	OBLQ		
	NORM		
	PARLL		
1<H/W	OBLQ		
	NORM		No Data

When the main wind direction over the canyon level is OBLQ to the canyon axes the scatter diagram where the y coordinate represents V_{met} and the x coordinate represents V_{ped} and 0<H/W≤1, is divided in two data clusters: one around the $V_{ped} =$ 2m/s and one along the f(x) = x line which is clearer in the MID period (Table 3.4).

When the wind direction is NORM to the canyon axes, the wind shadow effect of the buildings along the both sides of the canyons can be seen as a cluster of data in the MID period where 0< V_{ped}≤3m/s while the V_{met}reaches to 10m/s approximately. The pedestrian level wind speed may be considered as the result of thermal effects caused by the temperature differences between the surfaces and the surrounding air in the canyon (Table 3.4).

On the other hand when the wind is parallel (PARLL) the distribution of the scatters is relatively homogeneous apart from some irregular scatters. However due to the friction forces on the surfaces of the canyons, obstacles on the wind path or vehicle traffic etc. more points are gathered around V_{ped}= 2m/s (Table 3.4).

For the canyons where 1<H/W when the wind is in an oblique (OBLQ) direction to the canyon axes, the distribution of the data in the V_{met} V_{ped}diagram resembles a combination of the scatters under normal and parallel wind directions. The diagrams in the MID and AFT periods are distinctively separated into two parts: one around where $V_{ped}$is equal to 2m/s and one sparsely distributed near f(x) =x line especially in the MID period. On the other hand the second cluster in the AFT period is mostly under the f(x) =x line where the wind speed on the pedestrian level is higher than the wind flowing over the canyon. Approximately the half of these data is the result of the cross type points and one third of it consists from closed type points (Table 3.4).

While when the wind direction is perpendicular or normal to the canyon axes where the aspect ratios (H/W) are over 1, although the data cluster is smaller than under an oblique direction it is more inclined on the f(x) =x line compared with the similar case in the 0<H/W≤1 canyons (Table 3.4).

3.6. The Comparison of the Parallel Canyons in the Sites

After a global evaluation on the main canyons for each site a comparison study should be done for the parallel canyons in KNK and ALS and for the unique main canyon in GZYL. For this reason although the weather data was recorded by the mobile weather station simultaneous data was also obtained from a nearby National Weather Station Office.

A recent average wind speed and direction data was also requested from the National Weather Station Office. The wind speed measured from 29 m. with the number of flow according to the direction between the years 2007 and 2010 during the summer periods are below:

Table 3.5. The wind speed (m/s) and direction data from the National Weather Station Office in the Güzelyalı District which is one of the measurement sites.

SUMMER 2007-2010	PREVAILING WIND DIRECTION			
	W		**WNW**	
MONTH	wspd (m/s)	# flow	wspd (m/s)	# flow
june	3,30	2602	2,80	2565
july	3,50	3306	3,10	2973
agst	3,70	4472	3,00	3846
sept	3,20	2067	2,80	1368
AVERAGE	**3,43**	**3111,75**	**2,93**	**2688**

The table (Table 3.5) shows the wind flows in average 3111 times at 3,43m/s from the West and 2688 times at 2,93m/s from the West-North-West for Izmir. On the other hand the wind speed and direction might be different from the latter data due to the local effects and the anemometer height. Therefore for each site two data sets will be compared in order to understand the local effects.

3.6.1. Comparison of Two Main canyons in Konak KNK (GZBL, FVZPS)

Gazi Bulvarı (GZBL) and Fevzi Paşa Bulvarı (FVZPS) are two main axes in the Konak district which are quite parallel to each other in West-East direction and perpendicular and open to the seaside (Figure 3.18.). GZBL and FVZPS have similar but different aspect ratios; H/W = 0,58 and H/W = 0,64 respectively. During the experiments which were held in July, August and September in the year 2009 the wind directions to the canyon axes were oblique (OBLQ) and parallel (PARLL) to the canyon axes.

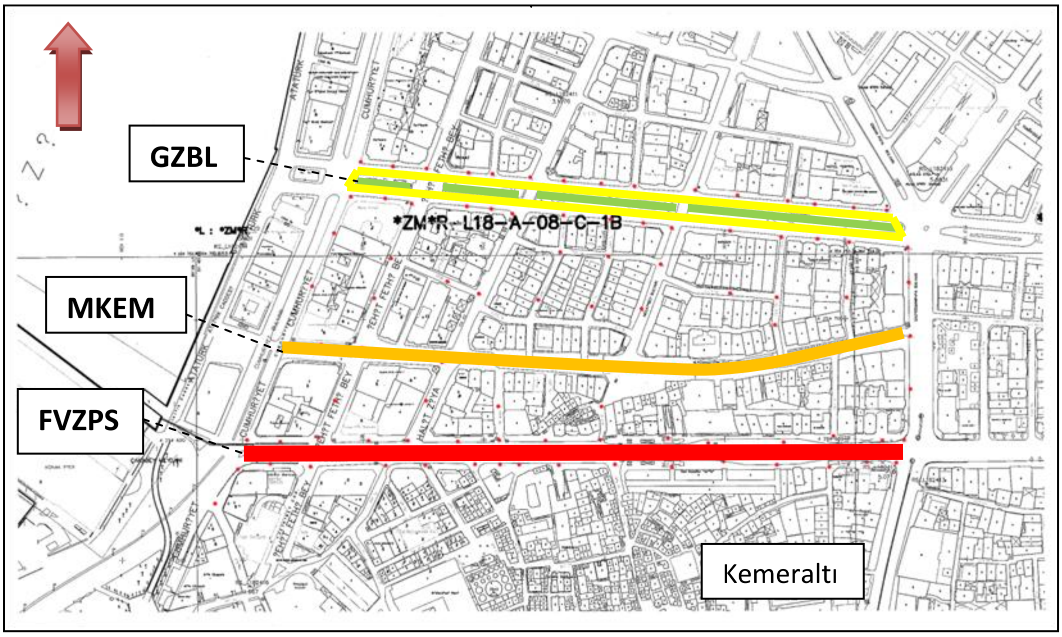


Figure 3.18. Konak Site: GZBL and FVZPS. The yellow line represents GZBL main canyon axis, orange: MTPS, red: FVZPS, green: the double tree row on the main axis of the canyon.

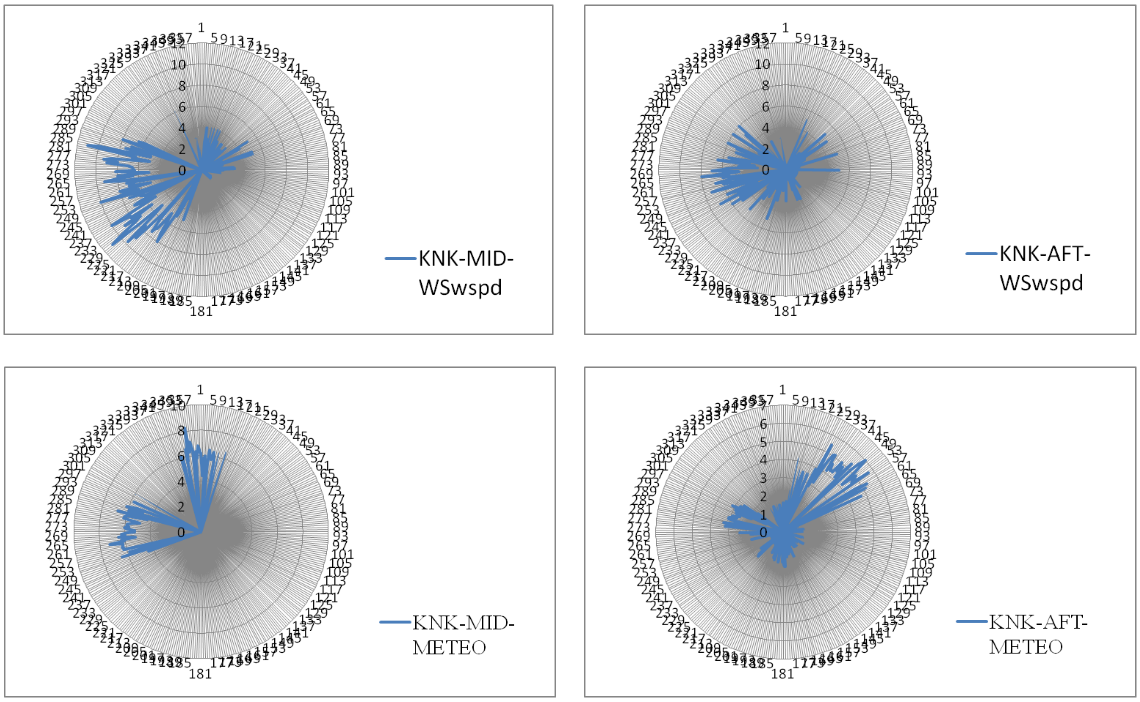


Figure 3.19. The wind speed and direction data in Konak for both time periods from the mobile weather station and from the Meteorology Office respectively.

The average wind speed and direction diagrams measured over the canyons and by the meteorology office for three months in MID and AFT periods are in the Figure 3.19.

Since the data gathered from the mobile weather station used by the researcher has quite scattered results the wind speed and direction data from the local (Güzelyalı) meteorology office on the minute basis was also requested. In the Figure 3.19 above the first two diagrams are from the mobile station and the two below represent the data of the meteorology office. According to the latter, the wind direction during the MID period in the summer months in 2009 is mainly from the North and West directions. The wind diagrams represent the data corresponding with the pedestrian level measurements on the minute basis. In the AFT period according to the meteorology data the wind direction during the measurements is in the North-East direction in a lower average wind speed compared with the MID period wind speed.

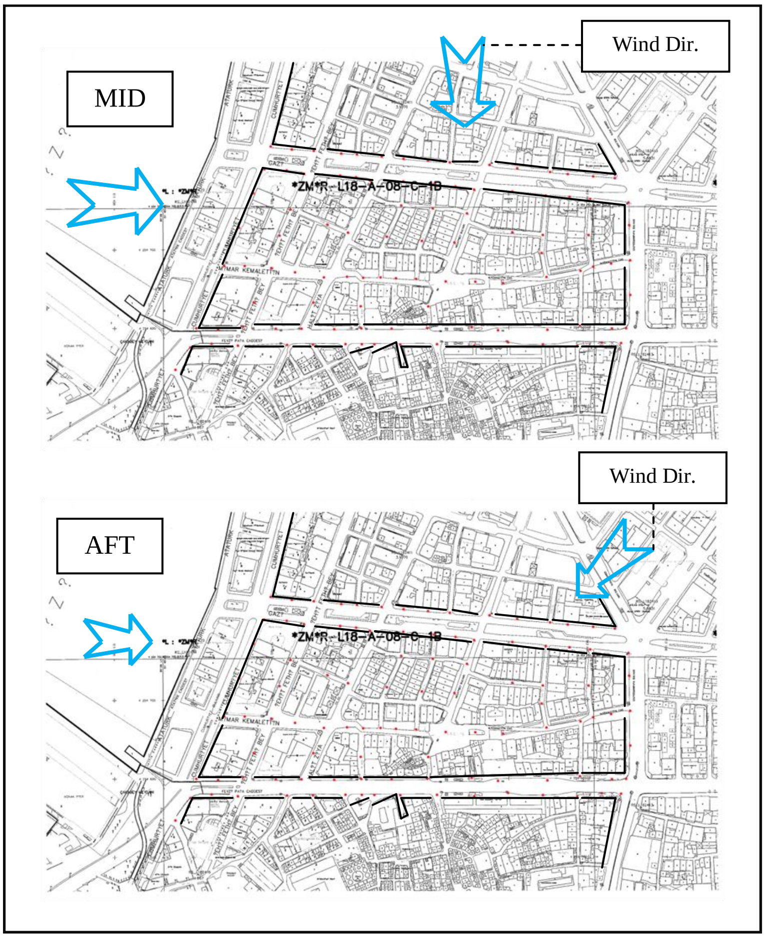


Figure 3.20. During the MID period the average wind direction is from the North and West directions. In the AFT period the wind direction is from the West and from the North-East at a lower velocity.

3.6.1.1. Gazi Bulvarı (GZBL)

The Gazi Bulvarı situated on the North side of the site has a heavy vehicular and pedestrian traffic along the axis. The canyon is on the WNW-ESE direction. Due to the vegetation shadow and a more pleasant view is provided for the vehicles and pedestrians. GZBL is in the central business district and also has commercial functions (Figure 3.21).

Figure 3.21. View from the GZBL showing the heavy vehicular and pedestrian traffic.

When the wind direction is oblique (OBLQ) and parallel (PARLL) to the main canyon axis of the GZBL (Figure 3.22):

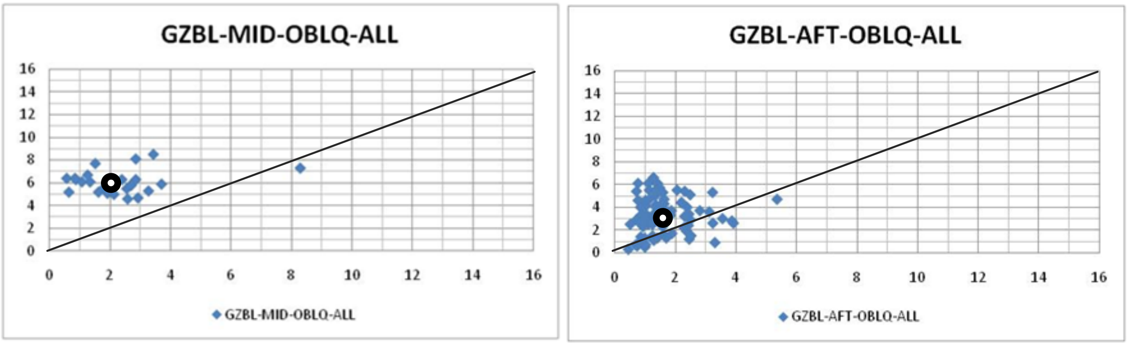


Figure 3.22. GZBL-MID-OBLQ-ALL points combination.
WA-mid: $(X_{avg,} Y_{avg})$ = (2,32; 6,08), WA-aft: $(X_{avg,} Y_{avg})$ = (1,63; 3,35).

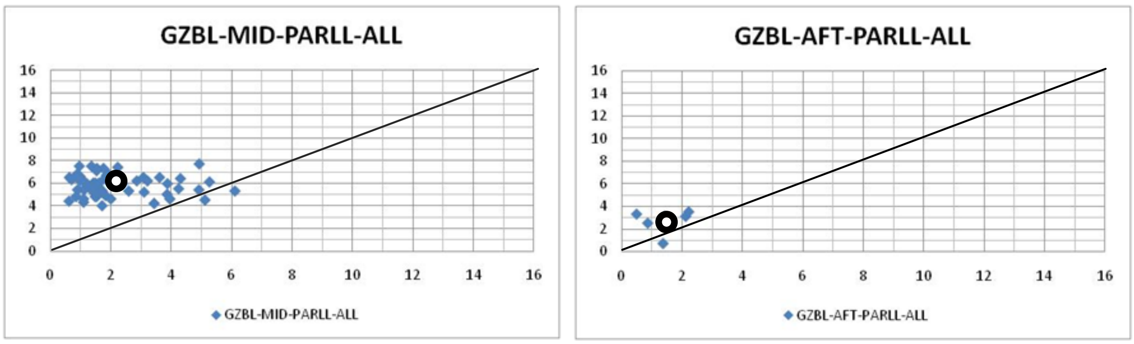


Figure 3.23. GZBL-MID-PARLL-ALL points combination.
WA-mid: $(X_{avg,} Y_{avg})$ = (2,18; 5,81), WA-aft: $(X_{avg,} Y_{avg})$ = (1,4; 2,7).

When the upwind is parallel to the canyon during the MID period with the parallel wind direction, the measurements where the 3m/s < V_{ped} 40% are CRSS and SFTCRSS points, 20% CLSD points, 40% TSHP points (Figure 3.23).

3.6.1.2. Fevzi Paşa Bulvarı (FVZPS)

FVZPS is on the South of the site with a West-East direction. On the West end which is open to the seaside there are few palm trees. Similar to GZBL there is a heavy vehicular and pedestrian traffic. Along the Bay from Konak centre the boulevard is the main connection with the Basmane Square which is also an important nodal point in terms of the vehicular traffic (Figure 3.24). On the South bank of FVZPS situates an old bazaar 'Kemeraltı' district. Kemeraltı has commercial, historic and touristic importance mainy pedestrian with narrow and angled streets. On the other hand the area is filled by 2 or 3 storey buildings except for the contemporary ones.

Figure 3.24. FVZPS from the East end of the boulevard.

When the wind direction is oblique (OBLQ), parallel (PARLL) and normal (NORM) to the main canyon axis of the FVZPS (Figure 3.25).

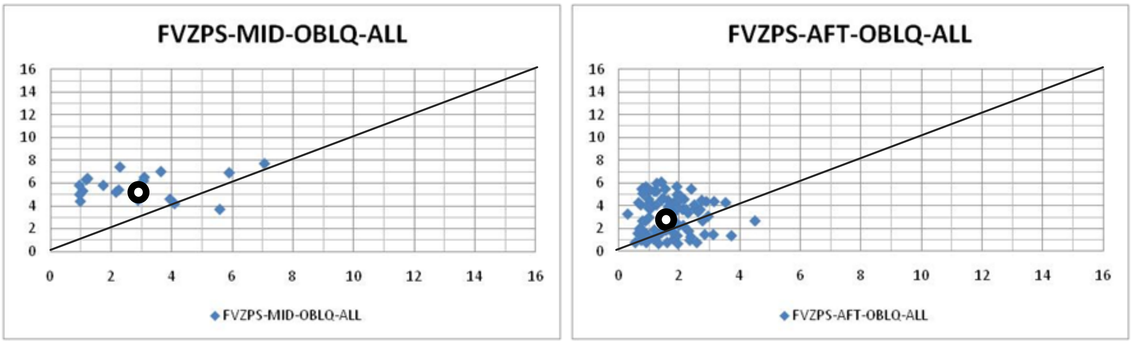


Figure 3.25. FVZPS-MID-OBLQ-ALL and FVZPS-AFT-OBLQ-ALL combinations. WA-mid: $(X_{avg,}Y_{avg})$ = (2,84; 5,65), WA-aft: $(X_{avg,}Y_{avg})$ = (1,69; 3,27).

In the beginning of this study from the field experiments it was expected that the pedestrian level wind speeds in the Gazi Bulvarı (GZBL) in Konak would be higher than the pedestrian level wind speeds in the Fevzi Paşa Bulvarı (FVZPS) because of the double tree row along the canyon axis in GZBL.

On the other hand in FVZPS canyon there are few trees (mostly palm-trees) on one of the sides of the canyon. Furthermore on the South side the average height of the buildings is lower than the opposite row. However the Kemeraltı district has no grid structure. As well as the number of the cross type points the depth of the streets might be effective on the pedestrian wind speed.

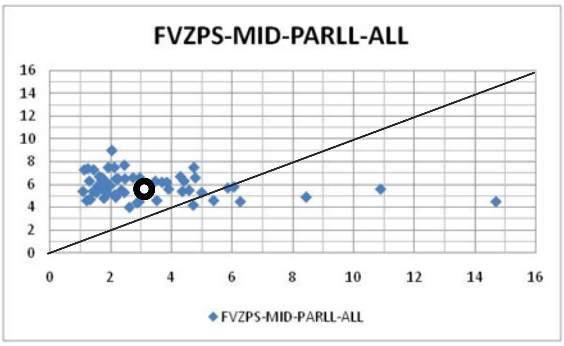


Figure 3.26. FVZPS-MID-PARLL-ALL combination. WA_mid : $(X_{avg,}Y_{avg})$ = (3,12; 5,85).

When the upwind is parallel to the canyon axis during the MID period, the measurements where the 3m/s < V_{ped} 50% are CRSS points, 35% CLSD points, 15% TSHP points (Figure 3.26).

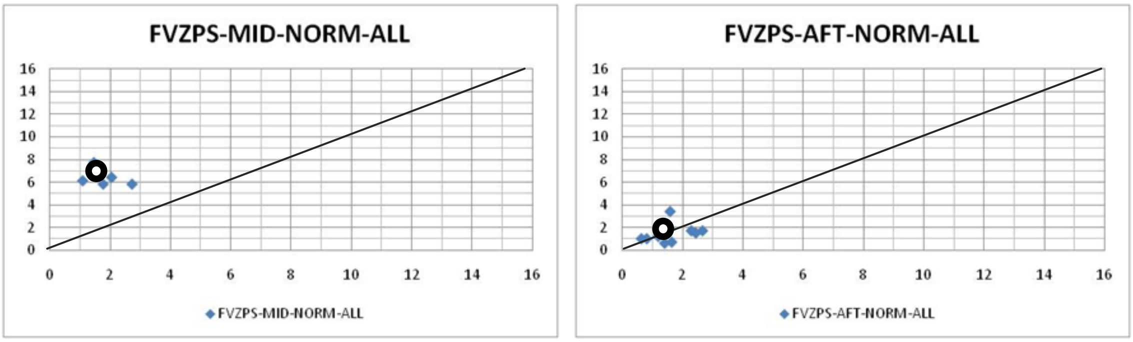
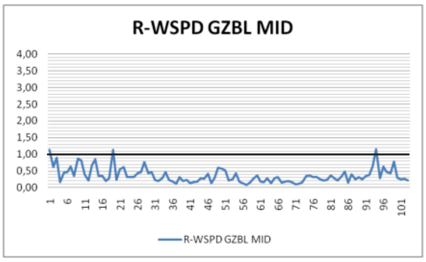
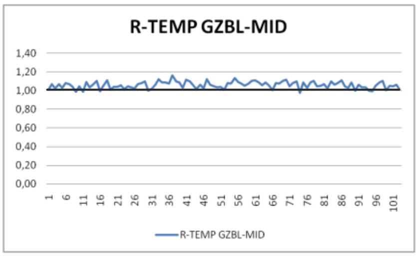
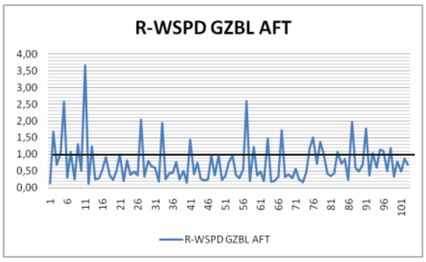
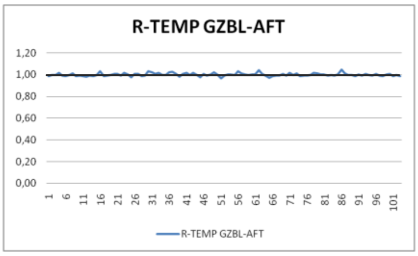
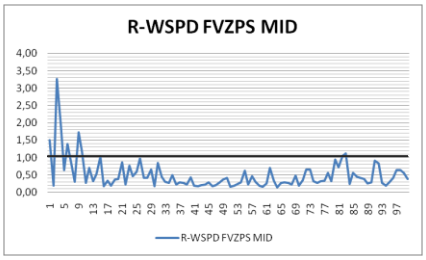
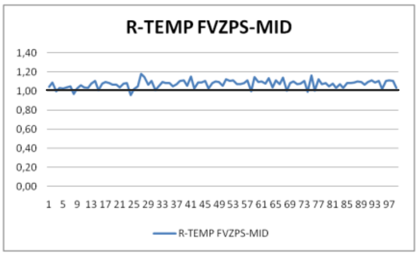
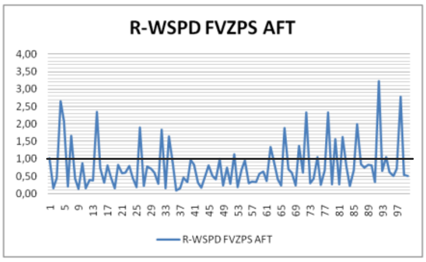
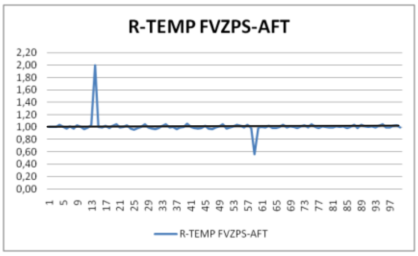


Figure 3.27. FVZPS-MID-NORM-ALL and FVZPS-AFT-NORM-ALL combinations.
WA-mid: ($X_{avg,}Y_{avg}$) = (1,65; 6,4), WA-aft: ($X_{avg,}Y_{avg}$) = (1,55; 1,48).

The R-WSPD and R-TEMP ratios:

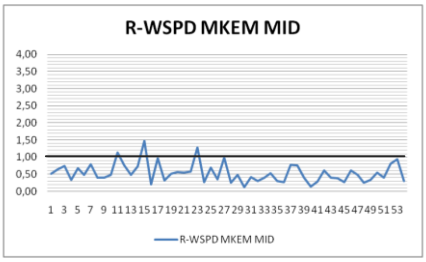
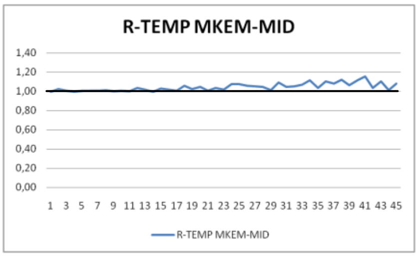
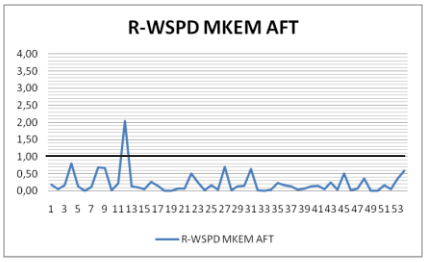
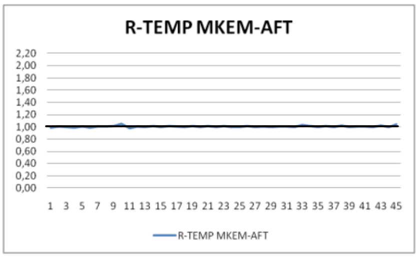
Along the main canyon axes the V_{ped} V_{met} ratio and T_{ped} T_{ws} ratio are analyzed. V_{ped} and T_{ped} represent the average wind speed and the temperature recorded on the measurement points starting from the West ends to the East ends of both canyons (Table 3.6 and Table 3.6 (cont.).).

Table 3.6. The wind speed ratio (R-WSPD) and the temperature ratio (R-TEMP) in the main canyons GZBL and FVZPS, Konak in MID and AFT periods where R-WSPD = $V_{ped}\ \ V_{met}$ while R-TEMP =$T_{ped}\ \ T_{ws}$.

Canyon	Period	R-WSPD = $V_{ped}\ \ V_{met}$	R-TEMP =$T_{ped}\ \ T_{ws}$
GZBL	MID		
	AFT		
FVZPS	MID		
	AFT		

(cont. on the next page)

Table 3.6 (cont.).

Canyon	Period	R-WSPD = V_{ped} V_{met}	R-TEMP =T_{ped} T_{ws}
MKEM	MID		
	AFT		

According to the R-WSPD and R-TEMP ratios GZBL and FVZPS show canyon characteristics with higher R-WSPD during the AFT periods and higher R-TEMP during the MID period. During the afternoon period when the surrounding air in the canyon cools down an air movement occur due to the temperature difference between the air and the canyon surfaces. In this case V_{ped} might be higher than V_{met} over the canyon. In addition during the mid-day period due to the solar heat gain the air temperature in the canyon rises (Table 3.6).

On the other hand, MKEM situated between GZBL and FVZPS does not show the same characteristics apart from a slight R-TEMP rise on the East end of the street (Table 3.6).

3.6.2. The Comparison of Two Main Canyons in Alsancak ALS (2KRD, KBSS)

In the Alsancak Site (ALS) İkinci Kordon (2KRD) and Kıbrıs Şehitleri (KBSS) are two parallel canyons approximately in North-East directions with aspect ratios H/W are equal to respectively 1,68 and 1,6. 2KRD is open to the vehicular traffic and KBSS is partially open to the vehicular traffic and generally open to the pedestrian traffic (Figure 3.17).

The area is partly residential and commercial. A business district 'Punta' is situated on the North of the site with approximately 20 storey mixed use buildings.

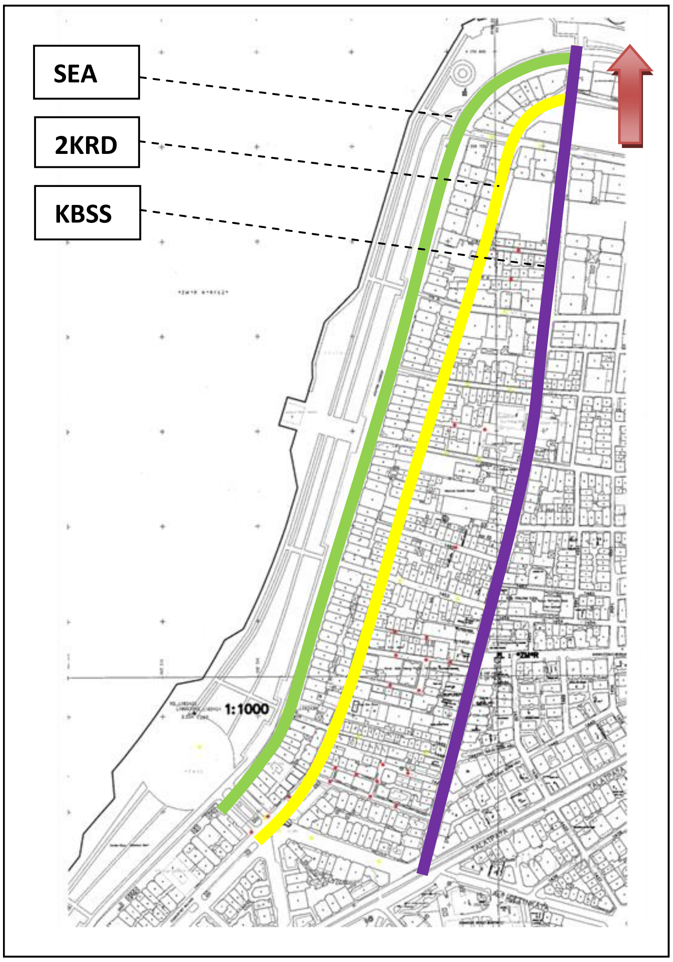


Figure 3.28. SEA, 2KRD and GZBL represented by orange and purple lines respectively.

The average wind speed and direction diagrams measured over the canyons and by the meteorology office for three months in MID and AFT periods are below (Figure 3.29):

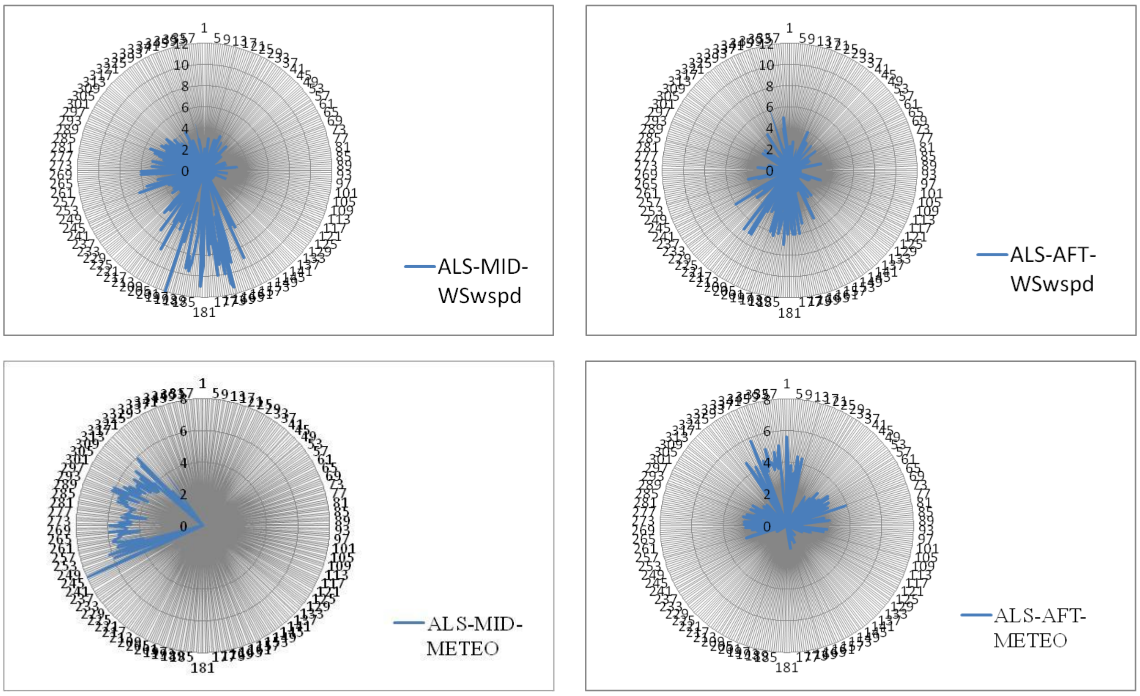


Figure 3.29. The wind speed and direction in Alsancak for both periods from the mobile weather station and from the Meteorology Office respectively.

Since the collected data from the roof level by the researcher was found to be unreliable compared with the meteorology office data the latter one was used for the data evaluation. The ALS-MID-WSwspd and ALS-AFT-WSwspd combinations seem to be affected in the same fashion probably the position of the weather station situated in the wind shadow of the high-rise building on the first row from the sea (Figure 3.30).

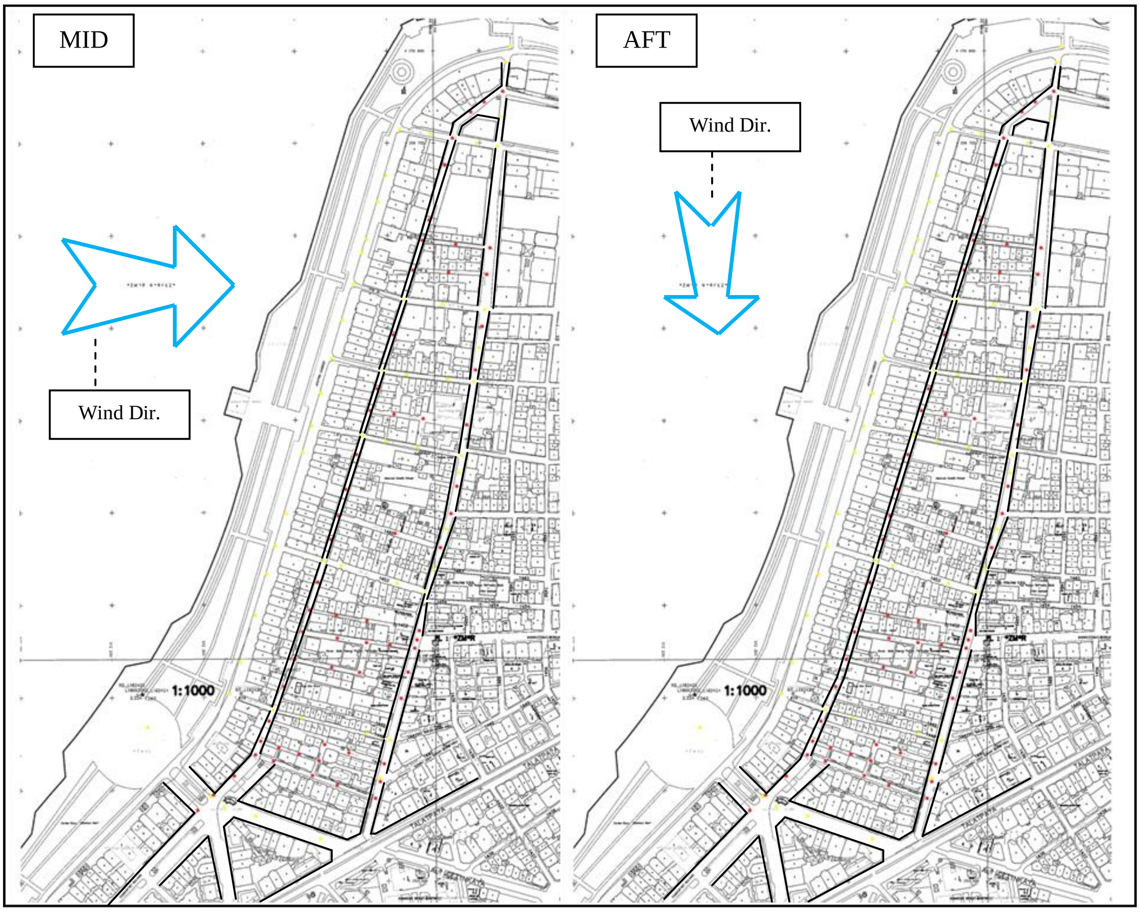


Figure 3.30. During the MID period the average wind is mainly flowing from the South and West directions. In the AFT period the wind flows from the South.

3.6.2.1. İkinci Kordon (2KRD)

2KRD is parallel to the seaside in NNE-SSW direction. The street is used as a passageway for vehicles travelling from Konak to the Punta district. 2KRD is quite narrow and buildings on both sides cast shadow during the daytime. Pedestrian walkways are narrow and uncomfortable to walk on. The ground levels of the buildings are commercial and residential on the upper floors (Figure 3.31).

Figure 3.31. 2KRD view from the South end towards the North.

During the measurements on the site, the wind on the roof level (at 60m. approximately) was in oblique and parallel direction to the canyon axis.

The scatter diagrams of V_{met} V_{ped} under different wind directions to the main canyon axis are below:

The following figure represents the perpendicular flow to the street axis where the data cluster is mostly over the f(x) =x line thus the wind speed over the buildings has higher speeds. During the afternoon period (AFT) the V_{met} and the V_{ped} are quite low (Figure 3.32).

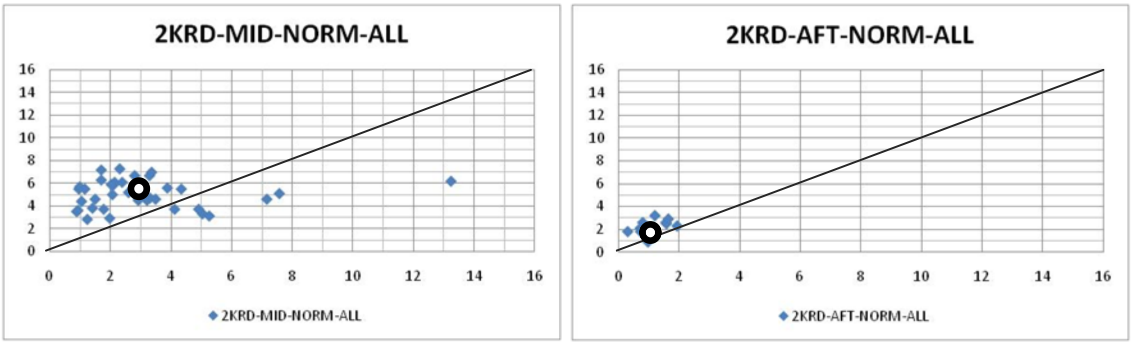


Figure 3.32. 2KRD-MID-NORM-ALL and 2KRD-AFT-NORM-ALL combinations.
WA-mid: $(X_{avg,} Y_{avg})$ = (3,08; 5,01), WA-aft: $(X_{avg,} Y_{avg})$ = (1,13; 2,19).

When the wind direction is oblique to the street axis the 2KRD benefits more from the upwind speed. In the MID period the scatters near the f(x) =x line represent a relationship between V_{met} and V_{ped} (Figure 3.33).

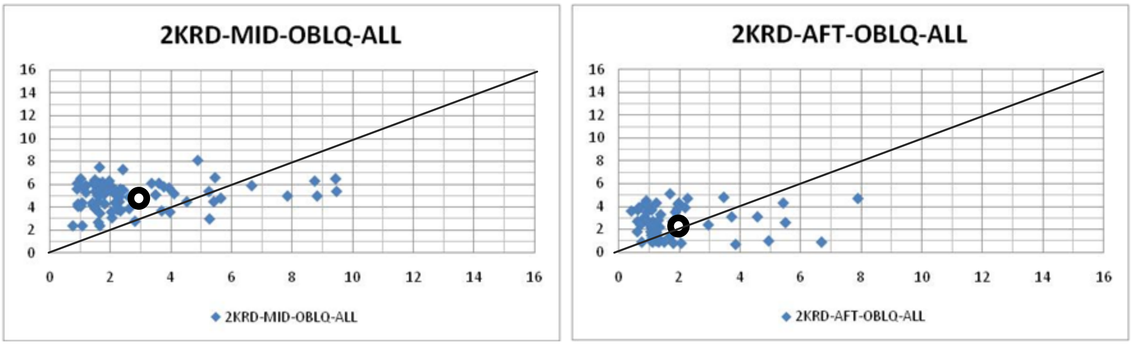
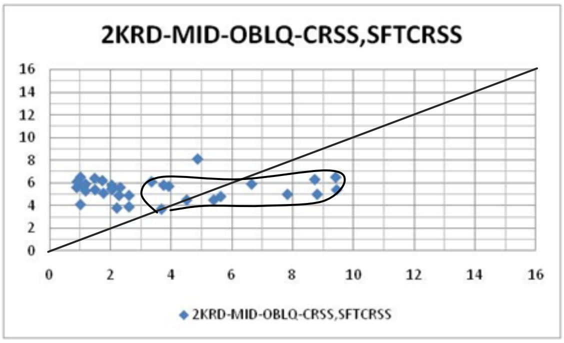


Figure 3.33. 2KRD-MID-OBLQ-ALL and 2KRD-AFT-OBLQ-ALL combinations.
WA-mid: $(X_{avg,} Y_{avg})$ = (2,79; 4,99), WA-aft: $(X_{avg,} Y_{avg})$ = (1,82; 2,7).

In the following figure (Figure 3.34) the contribution of the cross type points (CRSS and SFTCRSS) can be seen with V_{ped} over 3m/s.



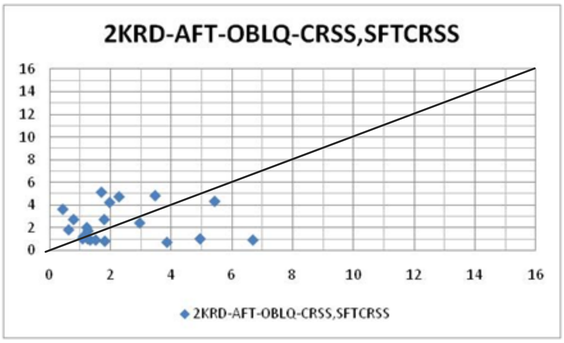


Figure 3.34. 2KRD-MID-OBLQ-CRSS, SFTCRSS and 2KRD-AFT-OBLQ-CRSS, SFTCRSS combinations.

3.6.2.2. Kıbrıs Şehitleri (KBSS)

The Kıbrıs Şehitleri (KBSS) street is approximately parallel to 2KRD in NNE-SSW direction with more distant from the seaside slightly skewed to the North at the end. The street is pedestrian except in a time interval between the midnight until 9-10 o'clock in the morning. On the ground level of the buildings there are commercial usages and residential on the upper floors mixed with office buildings. KBSS is also the main passageway for the tourists arriving by seaway to the Izmir Port near to the Punta district. Since the street has touristic, commercial, residential functions the comfort of the pedestrians walking through the KBSS is important (Figure 3.35).

Figure 3.35. Pedestrian way from the South to the North in KBSS.

Similar to KBSS when the upwind flow is normal to the street under the wind shadow effect of the buildings along the street can be seen as very few measurements where the V_{ped} is over 3m/s (Figure 3.36).

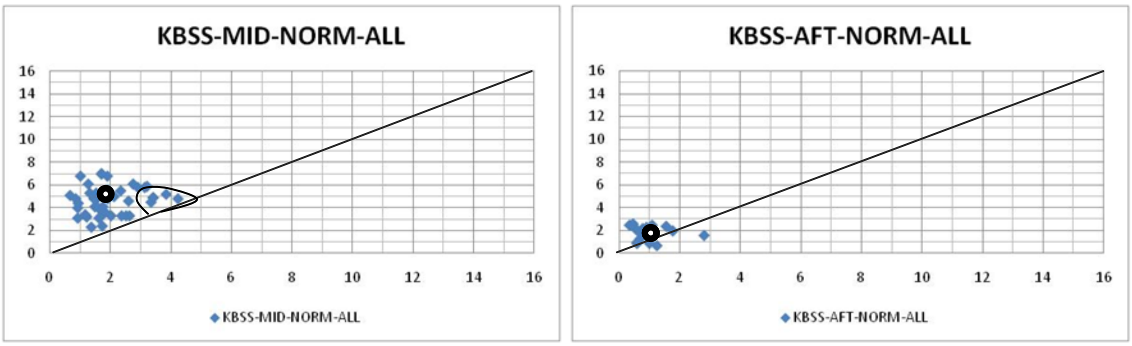


Figure 3.36. KBSS-MID-NORM-ALL and KBSS-AFT-NORM-ALL combinations.
WA-mid: $(X_{avg,}Y_{avg})$ = (1,99; 4,67), WA-aft: $(X_{avg,}Y_{avg})$ = (0,95; 1,83).

When the wind is oblique to the street axis compared to 2KRD more measurements are gathered around V_{ped}=2m/s (Figure 3.37 below).

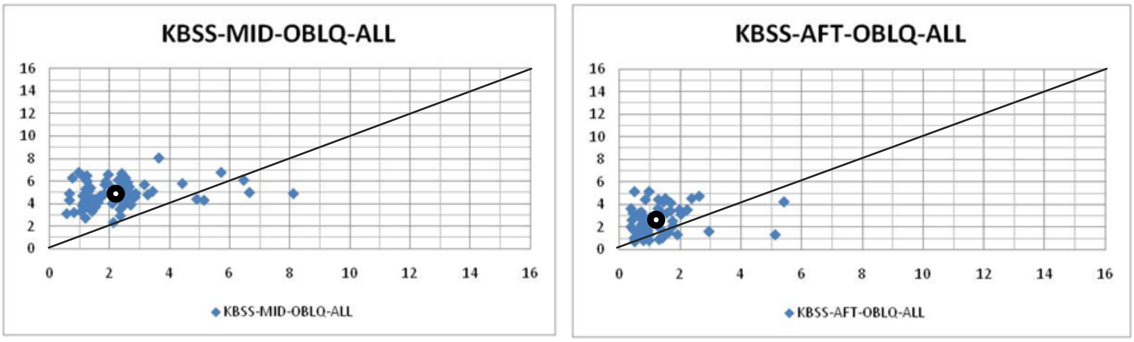


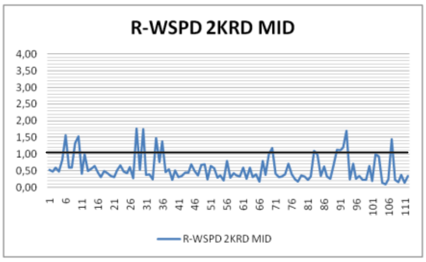
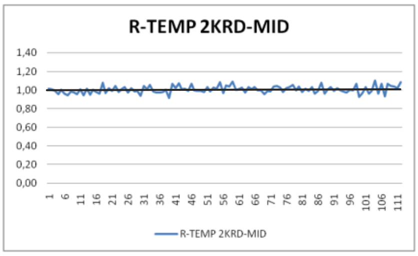
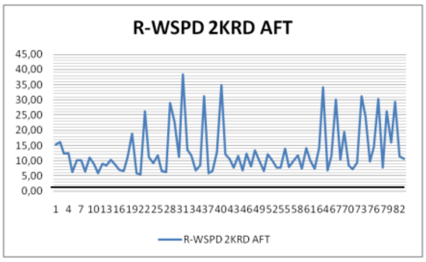
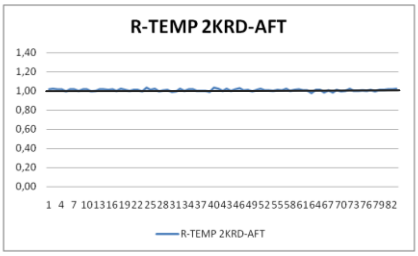
Figure 3.37. KBSS-MID-OBLQ-ALL and KBSS-AFT-OBLQ-ALL combinations.
WA-mid: $(X_{avg,}Y_{avg})$ = (2,31; 4,84), WA-aft: $(X_{avg,}Y_{avg})$ = (1,29; 2,56).

During the MID period, the measurements where the 3m/s < V_{ped} 44,44% are CRSS and SFTCRSS points, 22,22% CLSD points, 33,34% TSHP points.

The R-WSPD and R-TEMP ratios:

Along the main canyon axes the V_{ped} V_{met} ratio and T_{ped} T_{ws} ratio are analyzed. V_{ped} and T_{ped} represent the average wind speed and the temperature recorded on the measurement points starting from the North ends to the South ends of both canyons.

Table 3.7. The wind speed ratio (R-WSPD) and the temperature ratio (R-TEMP) in the main canyons 2KRD and KBSS in addition the seaside, Alsancak in MID and AFT periods where R-WSPD = V_{ped} V_{met} while R_TEMP =T_{ped} T_{ws}.

<table>
<tr><th>Canyon</th><th>Period</th><th>R-WSPD = V_{ped} V_{met}</th><th>R-TEMP =T_{ped} T_{ws}</th></tr>
<tr><td rowspan="2">2KRD</td><td>MID</td><td>
</td><td>
</td></tr>
<tr><td>AFT</td><td>
</td><td>
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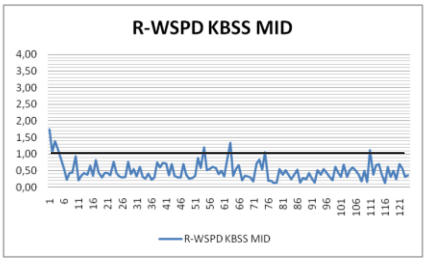
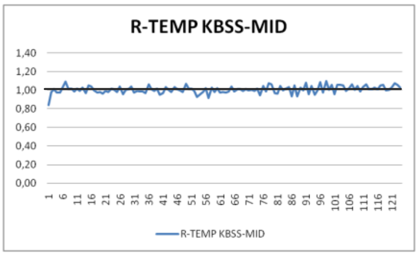
<tr><td rowspan="2">KBSS</td><td>MID</td><td>
</td><td>
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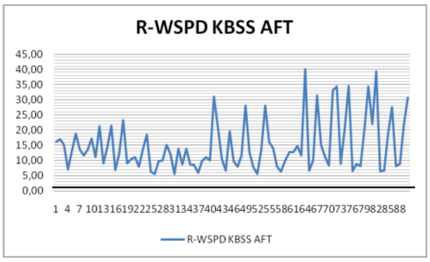
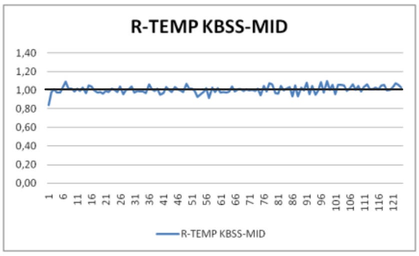
<tr><td>AFT</td><td>
</td><td>
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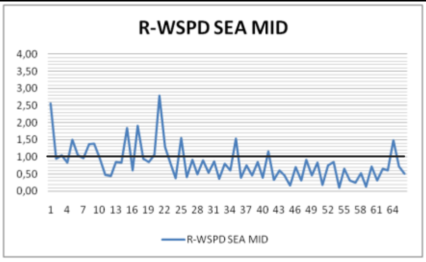
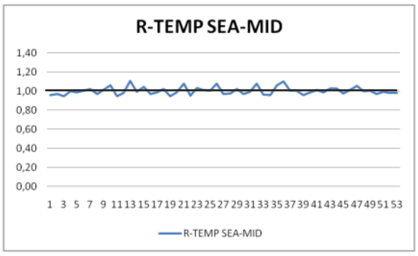
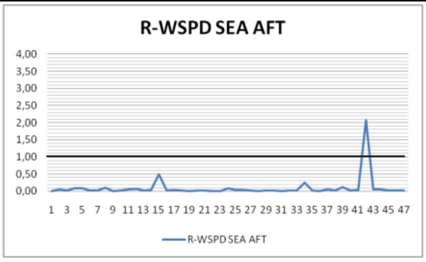
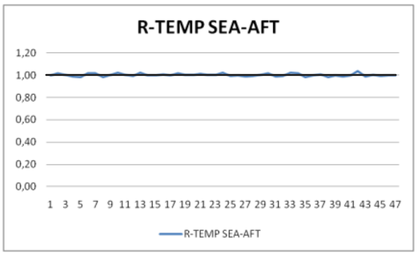
Table 3.7 (cont.).

Canyon	Period	R-WSPD = V_{ped} V_{met}	R-TEMP =T_{ped} T_{ws}
SEASIDE	MID		
	AFT		

According to the Table 3.7 in terms of R-WSPD ratio both for MID and AFT periods 2KRD and KBSS streets show canyon characteristics: the R-WSPD ratios in the AFT periods are dramatically higher than in the MID periods (Table 3.7).

The R-TEMP ratios in the MID periods for 2KRD and KBSS are different from the same ratios in GZBL and FVZPS due to the canyon orientation: 2KRD and KBSS are oriented in North-East and South-West directions where the pedestrians benefit from the shadow. In addition these canyons are deeper (have higher aspect ratios) compared with the Konak canyons. Therefore the surfaces heat up partially during the daytime thus less heat stored in the canyon.

3.6.3. The Güzelyalı Case and the Main Canyon Mithat Paşa Street (MTPS)

The Mithatpaşa Street (MTPS) is situated in the Güzeyalı district in Izmir. MTPS is one of the longest street canyons in Izmir and starts from Konak and ends in Üçkuyular. However for this study MTPS is studied partially due to the limitations such as time, the number of the measurement devices and topographical differences on the NE portion. Therefore, a limited area is chosen which is one of the vivid areas on the street in terms of pedestrian and vehicular traffic, the existence of recreational areas such as the Güzelyalı Park, the accumulation of the gastronomic and commercial usages on the pedestrian level, the approximately flat topography etc. (Figure 3.38). In the partial MTPS canyon the aspect ratios are H/W=1 and L/W=52.

Figure 3.38. The Mithatpaşa Street in the Güzelyalı District.

On the other hand the selected portion of the canyon has 3 parts in terms of the street angle: NW-SE, W-E and WSW-ENE however the rough orientation is in the West-East direction (Figure 3.39).

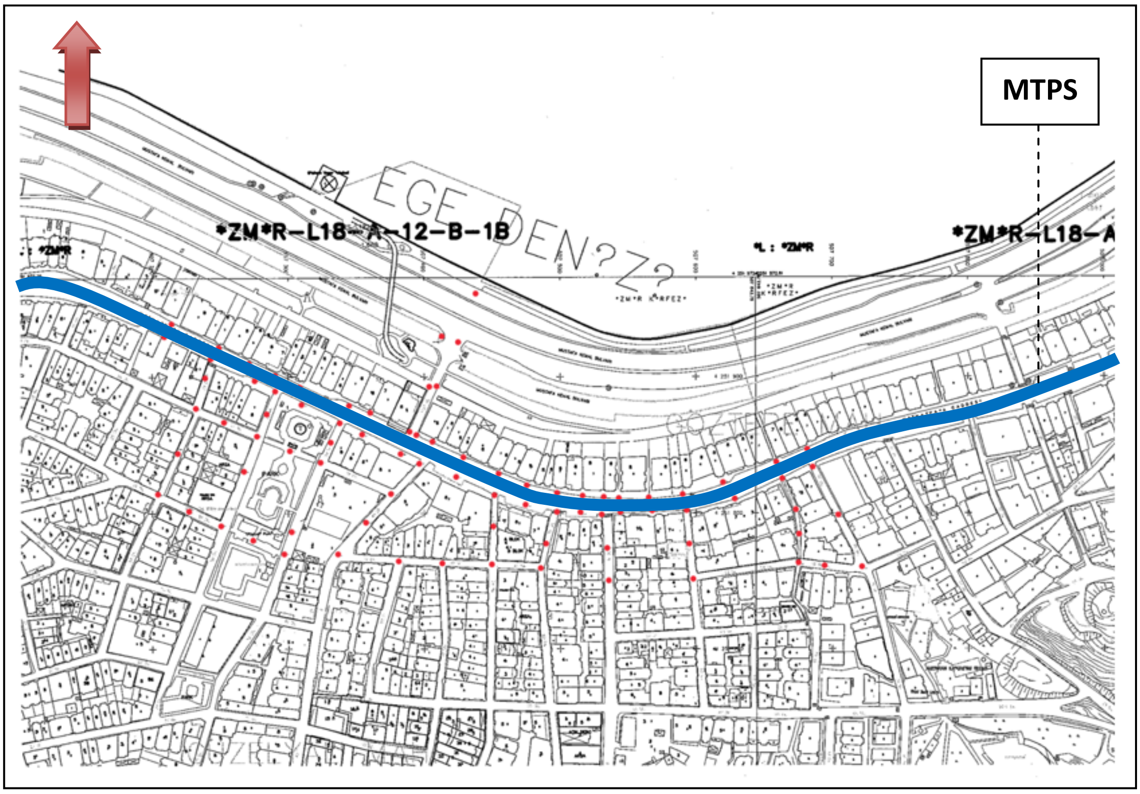


Figure 3.39. The selected portion of the MTPS is represented by the blue line.

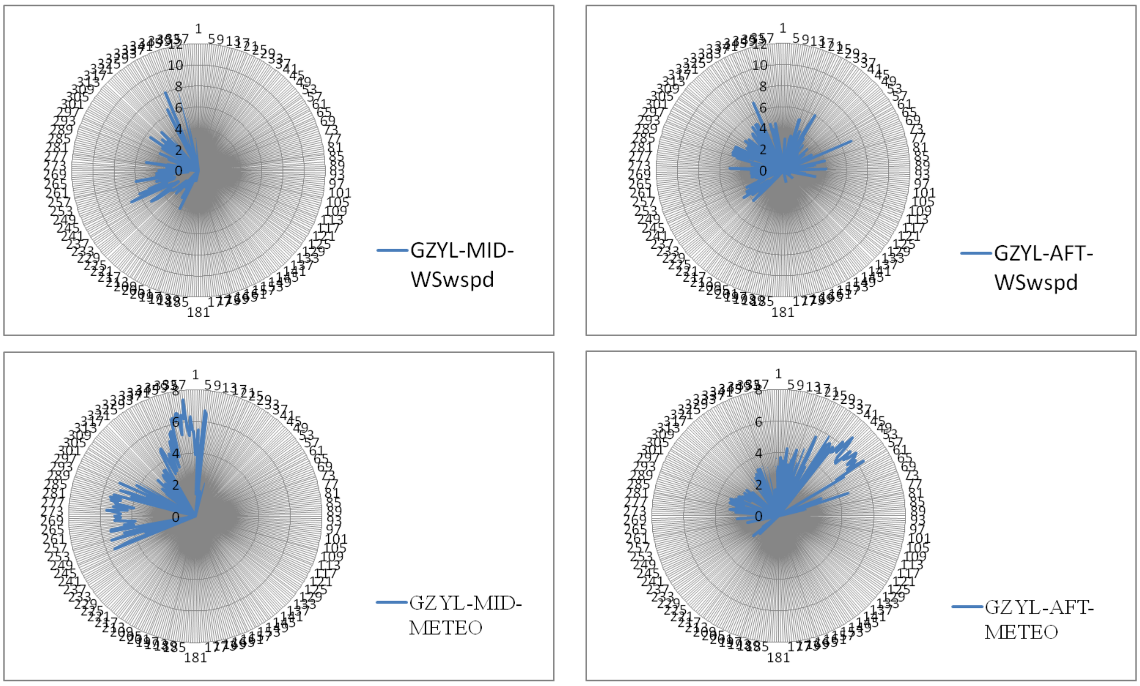


Figure 3.40. The wind speed and direction in Güzelyalı for both periods. from the mobile weather station and from the Meteorology Office respectively.

The average wind speed and direction diagrams measured over the canyons and by the meteorology office for three months in MID and AFT periods are in the Figure 3.40.

According to the Meteorology Office during the MID period in the summer 2009 the wind direction in the Güzalyalı District (GZYL) was mainly North and West. While in the AFT period the wind direction is North-East (Figure 3.40).

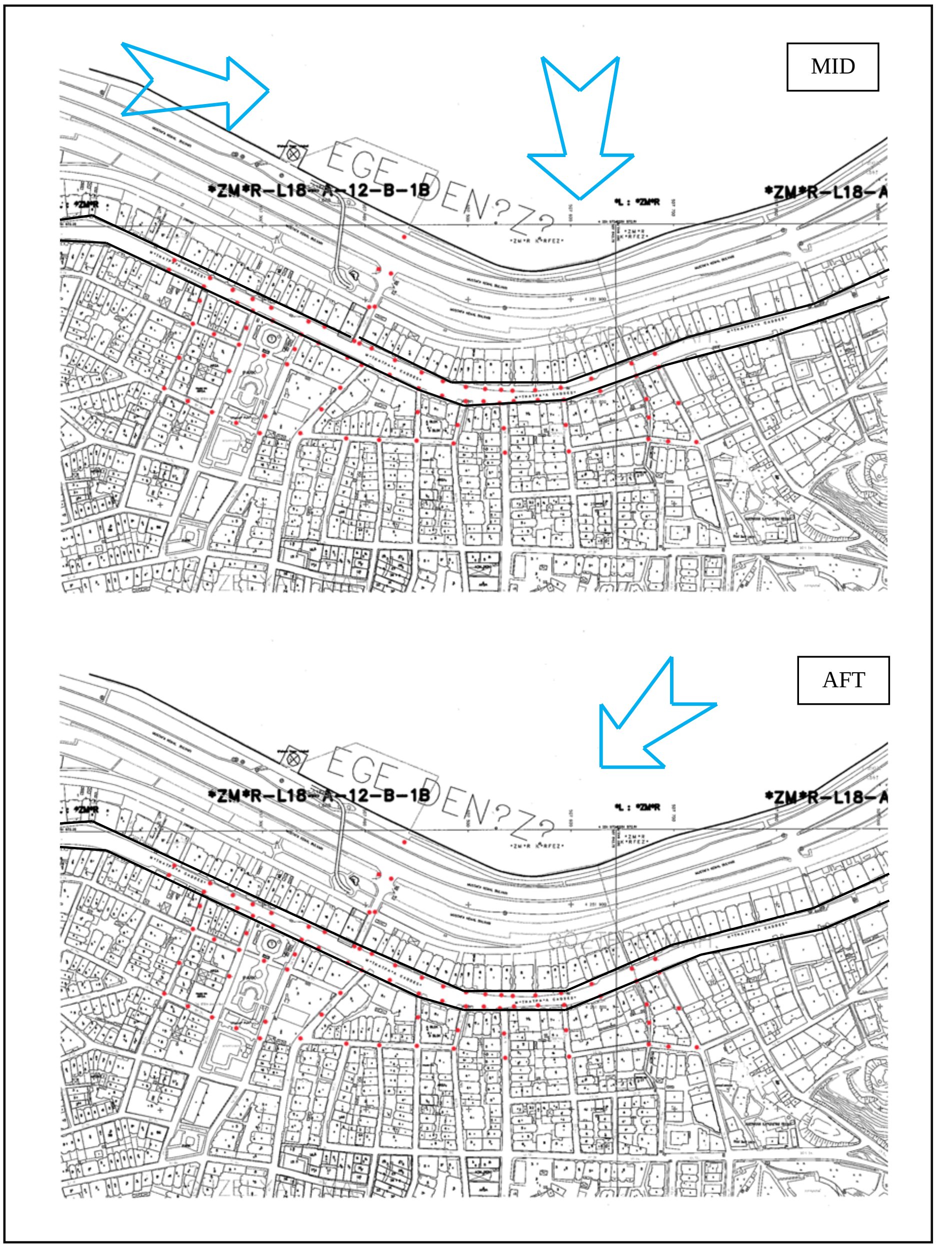


Figure 3.41. During the MID period the average wind is mainly flowing from the West direction. In the AFT period the wind flows from the North-West and North-East at a lower velocity.

When the wind flow is perpendicular or normal to the canyon axis due to the scarcity of the cross points and air paths on the first row of buildings on the seaside, V_{ped} in the MTPS canyon is generally lower than 2 m/s (Figure 3.42).

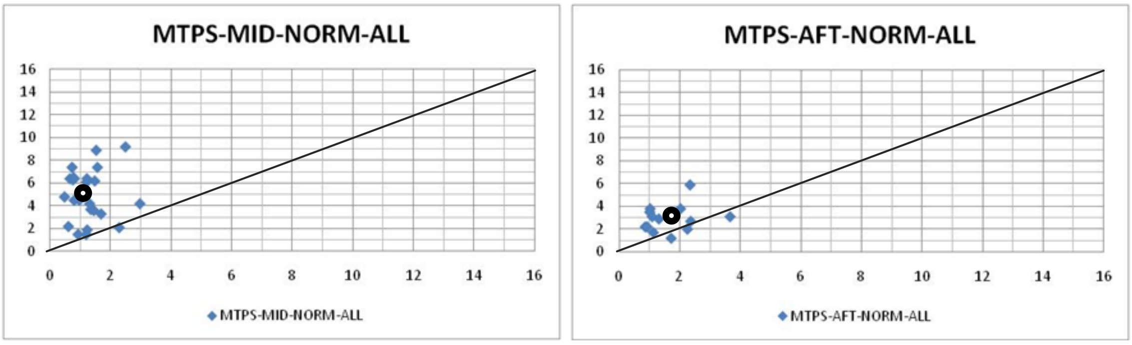


Figure 3.42. MTPS-MID-NORM-ALL and MTPS-AFT-NORM-ALL combinations.
WA-mid: $(X_{avg,}Y_{avg})$ = (1,26; 4,97), WA-aft: $(X_{avg,}Y_{avg})$ = (1,66; 2,93).

There are few data when the wind is parallel to the canyon axis (Figure 3.43).

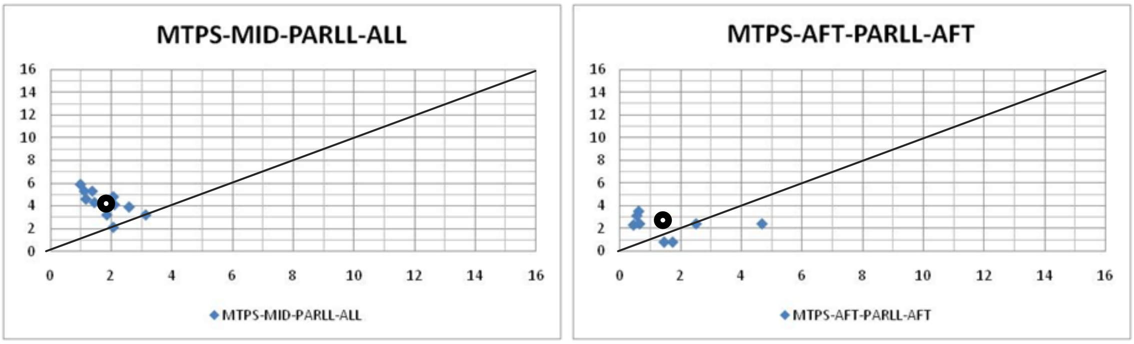


Figure 3.43. MTPS-MID-PARLL-ALL and MTPS-AFT-PARLL-ALL combinations.
WA-mid: $(X_{avg,}Y_{avg})$ = (1,81; 4,25), WA-aft: $(X_{avg,}Y_{avg})$ = (1,57; 2,27).

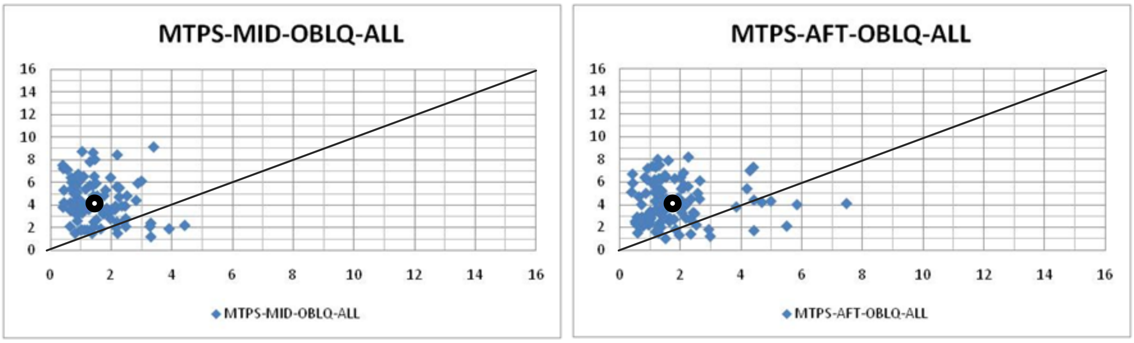


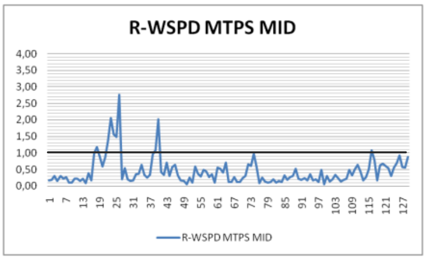
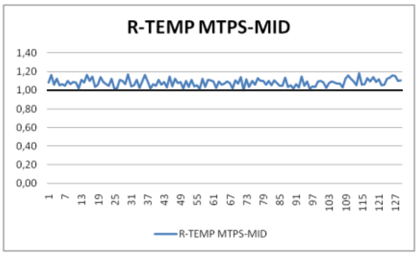
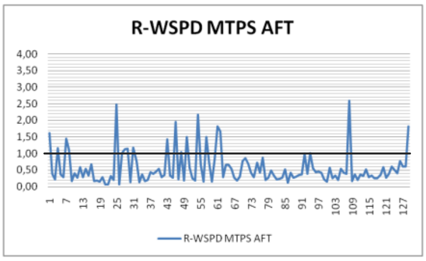
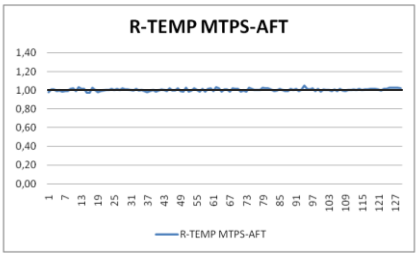
Figure 3.44. MTPS-MID-OBLQ-ALL and MTPS-AFT-OBLQ-ALL combinations.
WA-mid: $(X_{avg,}Y_{avg})$ = (1,52; 4,37), WA-aft: $(X_{avg,}Y_{avg})$ = (1,77; 4,08).

When the wind is in an oblique direction to the main canyon axis in the MID period, the measurements where V_{ped}<3m/s consist of 42,86% CRSS, SFTCRSS and TCRSS points, 14,29% TSHP points, 28,56% CLSD and 14,29% PDST type points. In the AFT period the measurements where V_{ped}<3m/s consist of 45,46% CRSS and SFTCRSS points, 27,27% PDST points and 27,27% TSHP points (Figure 3.44).

The R-WSPD and R-TEMP ratios:

Along the main canyon axes the V_{ped} V_{met} ratio and T_{ped} T_{ws} ratio are analyzed. V_{ped} and T_{ped} represent the average wind speed and the temperature recorded on the measurement points starting from the West end to the South end of the canyon (Table 3.8).

Table 3.8. The wind speed ratio (R-WSPD) and the temperature ratio (R-TEMP) in the main canyon MTPS in addition the seaside, Güzelyalı in MID and AFT periods where R-WSPD = V_{ped} V_{met} while R_TEMP =T_{ped} T_{ws}.

Canyon	Period	R-WSPD = V_{ped} V_{met}	R-TEMP =T_{ped} T_{ws}
MTPS	MID		
	AFT		

Similar to the other canyons in the Konak district the MTPS canyon has higher R-TEMP values. Since GZBL, FVZPS and MTPS are oriented in West-East direction allowing solar heat gain through the daytime.

CHAPTER 4

THE GENERAL EVALUATON OF THE PARAMETERS AND THE WIND COMFORT CONDITIONS IN THE SITES

The evaluation of this study on three sites is focused on the separation of the canyons as the main canyons and the secondary canyons. The latter ones are considered as the connections or potential air paths between the main canyons or with the inner parts of the sites.

Since it is very difficult to consider all the parameters on the wind speed and direction in urban scale several dominant parameters were chosen based on the geometrical conditions and the orientation of the streets in the whole measurement period:

In the following tables the wind comfort percentage is based on the minimum and maximum comfort levels as 2m/s and 5m/s for the outdoor activities. The comfort percentage is the ratio of the pedestrian wind speed in the comfort range stated previously to the total measurements on the pedestrian level (Table 4.1 and Table 4.2 below).

The average wind speed and the temperature in the canyon is calculated based on the two measurement periods MID and AFT for the roof level and the pedestrian level. The average wind speed and temperature taken from the seaside point as the second reference point.

Hourly relative humidity levels are taken from the official meteorological station situated in the Güzelyalı district. In addition the average wind direction obtained from the weather station on the roof level for each site for MID and AFT periods are stated. Furthermore the difference between the angle of the average wind direction and the canyon or street axis are added in three categories: OBLQ, NORM and PARLL. An approximate street orientation is given according to the main directions N, S, W and E.

As geometrical parameters the aspect ratios H/W and L/W are stated as the average values and the total average values for multiple secondary canyons.

Furthermore the percentages of the point types are given in CRSS&SFTCRSS, TSHP, PDST&TCRSS, CLSD, PRK categories.

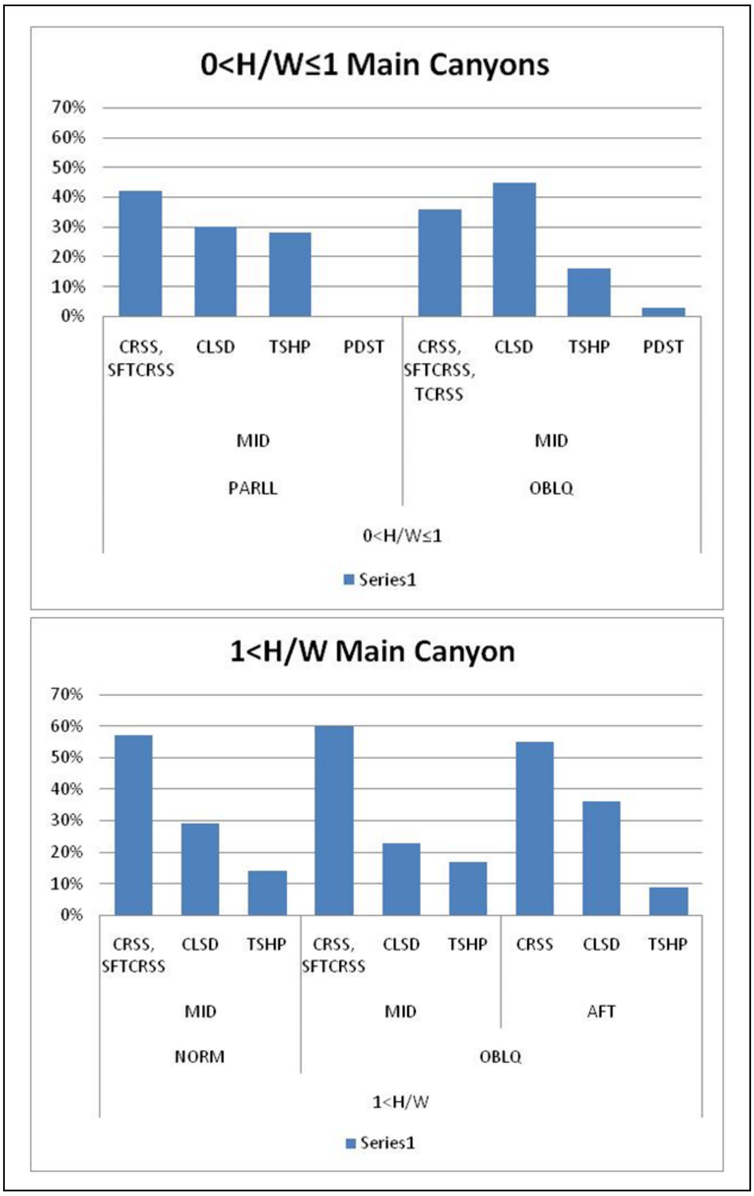


Figure 4.1. The percentage of point types where 3m/s<Vped in 0<H/W≤1 and 1<H/W canyons.

Table 4.1. Main Canyons

SITES and MAIN CANYONS				WIND COMFORT %		AVG WIND SPEED IN THE CANYON (m/s)			AVG WIND SPEED AND TEMPERATURE ON THE SEASIDE POINT		AVERAGE TEMPERATURE IN THE CANYON (°C)			avg RH%	PREVAILING WIND DIRECTION		ASPECT RATIOS	
				% Comfort	% Discomfort	Meteo. and Pedestrian	(m/s)	?m-p (m/s)	(m/s)	T(°C)	Roof and Pedestrian	T (°C)	?P-R (°C)		METEO avg.	METEO avg.	H/W	L/W
SITES	ALS	2 KRD	MID	37,38%	62,62%	m	5	2,19	5,66	26,60	R	29°C	0,02	50,78%	262	NORM	1,68	76
						p	2,81				P	29,02°C						
			AFT	16,70%	83,30%	m	2,69	0,83	8,49	26,92	R	27°C	0,03	55,98%	180	PARLL		
						p	1,86				P	27,03°C						
		KBSS	MID	39,83%	60,17%	m	4,78	2,59	5,66	26,6	R	29°C	0,14	50,78%	270	NORM	1,6	65
						p	2,19				P	29,14°C						
			AFT	9,52%	90,48%	m	2,41	1,21	8,49	26,92	R	27°C	0,11	55,98%	205	OBLQ		
						p	1,20				P	27,11°C						
	KNK	GZBL	MID	36,19%	63,81%	m	5,91	3,77	4,81	28,54	R	28°C	2,01	45,79%	150	OBLQ	0,58	13
						p	2,14				P	30,01°C						
			AFT	26,92%	73,08%	m	3,12	1,50	5,26	27,76	R	28°C	-0,30	50,74%	43	OBLQ		
						p	1,62				P	27,7°C						
		FVZPS	MID	43,14%	58,86%	m	5,91	3,13	4,81	28,54	R	28°C	2,41	45,79%	168	OBLQ	0,64	19
						p	2,78				P	30,41°C						
			AFT	28,43%	71,57%	m	3,05	1,37	5,26	27,76	R	28°C	-0,18	50,74%	50	OBLQ		
						p	1,68				P	27,82°C						
	GZYL	MTPS	MID	24,81%	75,19%	m	4,47	2,97	3,27	30,09	R	30°C	2,24	41,17%	224	OBLQ	1	52
						p	1,50				P	32,24°C						
			AFT	29,46%	70,54%	m	3,85	2,12	3,89	28,75	R	28°C	0,54	48,27%	55	OBLQ		
						p	1,73				P	28,54°C						

Table 4.2. Secondary Canyons

SITES and SECONDARY CANYONS				WIND COMFORT %		AVG WIND SPEED IN THE CANYON (m/s)			AVG WIND SPEED AND TEMPERATURE ON THE SEASIDE POINT		AVERAGE TEMPERATURE IN THE CANYON (°C)			avg RH%	PREVAILING WIND DIRECTION		ASPECT RATIOS	
				% Comfort	% Discomfort	Meteo. and Pedestrian	(m/s)	?m-p (m/s)	(m/s)	T(°C)	Roof and Pedestrian	T (°C)	?P-R (°C)		METEO avg.	METEO avg.	H/W	L/W
SITES	ALS	SC	MID	41,71%	58,29%	m	5,07	2,65	5,66	26,60	R	29	-0,22	50,78%	36	OBLQ	2,09	17,54
						p	2,42				P	28,78						
			AFT	20,34%	79,66%	m	2,32	0,88	8,49	26,92	R	27	-0,06	55,98%	-45	OBLQ		
						p	1,44				P	26,94						
	KNK	SC	MID	30,35%	69,65%	m	5,63	3,71	4,81	28,54	R	28	1,82	45,79%	188	PARLL	1,44	8,8
						p	1,92				P	29,82						
			AFT	11,87%	88,13%	m	3,46	2,16	5,26	27,76	R	28	-0,18	50,74%	74	OBLQ		
						p	1,30				P	27,82						
		MKEM	MID	61,11%	38,89%	m	5,78	2,71	4,81	28,54	R	28	1,5	45,79%	170	PARLL	0,92	26,93
						p	3,07				P	29,5						
			AFT	29,63%	70,37%	m	3,59	1,94	5,26	27,76	R	28	-0,2	50,74%	30	OBLQ		
						p	1,65				P	27,8						
	GZYL	SC	MID	18,52%	81,48%	m	5,08	3,48	3,27	30,09	R	30	2,07	41,17%	144	OBLQ	1,61	17,57
						p	1,60				P	32,07						
			AFT	15,33%	84,67%	m	3,46	2,03	3,89	28,75	R	29	-0,14	48,27%	-16	OBLQ		
						p	1,43				P	28,86						

According to the measurements during the AFT periods in the main canyons the wind discomfort difference compared with the MID periods is in average +13,36%. The same difference is +18,63% for the secondary canyons. Except from the MKEM in the Table B with 61,11% comfort and 38, 89% discomfort during the MID period the wind discomfort is higher in all types of canyons.

The average wind speed difference between the roof and pedestrian levels for the main and secondary canyons in the Konak (KNK) district are higher due to the 6m/s average wind speed on the roof level (which is the roof of the Konak Municipality on the 9th floor completely open to the sea with few buildings around in lower heights).

In the Konak (KNK) district in the MID period the average temperature differences are higher (2,01°C and 2,41°C) in the main canyons. Although the H/W ratios of GZBL and FVZPS are lower their orientation is on the W-E direction which makes them solar-accessible during the daytime. However in the AFT periods the same difference is -0,30°C and -0,18°C respectively due to the low aspect ratios (H/W): 0,58 and 0,64.

In Alsancak (ALS) in the main and secondary canyons the average temperature difference for both MID and AFT periods varies between +0,14°C and -0,22°C which is an insignificant change. The main canyons are in the NE-SW direction with high aspect ratios 1,68 and 1,6. They profit from the shadow of the buildings despite the higher H/W ratios which are available to trap the solar heat. On the other hand the secondary canyons are cooler than the roof level even approximately at the same temperature with the seaside reference measurement during the AFT period with WNW-ESE orientations and H/W=2,09. They are deep enough to block the sun and shorter than the main canyons: L/W 76 and 65 for the main canyons 2KRD and KBSS respectively and 17,54 for the average of secondary canyons.

Except from the Güzelyalı (GZYL) district the temperature difference between the roof and the pedestrian level are lower in the secondary canyons. In GZYL-MTPS this difference is +2,24°C in the MID period and it is +2,07°C in the secondary canyons with three different orientations as NNE-SSW, N-S and W-E with less CRSS type points and high H/W ratio: 1,61.

The average relative humidity level is between 41% and 56% during the whole measurement.

In the main canyons the percentage on CRSS and SFTCRSS type measurements is between 42% and 48% higher than the other point types except from the GZYL district with 21,71%. In this study based on the literature and from the collected data CRSS and SFTCRSS type points enhance the increase in the wind speed on the pedestrian level.

MKEM has the highest number of cross point measurements with 37,04% and GZYL secondary canyons have the lowest percentage: 18,52%.

The average wind speed on the roof level in the MID period is higher than in the AFT period. However during the MID period in each site on some locations and points the average wind speed is measured below 2m/s many times. This refers to a lack of natural ventilation on the location below the wind comfort limits as it is marked in the site maps below (Figure 3.46, Figure 3.47 and Figure 3.48). In addition in the same maps, points where the wind speed is over 5m/s are also showed as dots. On these locations the wind nuisance may occur during the summer season.

In Alsancak, 2KRD is nearer the seaside with a higher aspect ratio (H/W). Approximately in the middle part of the canyon, the wind shadowed zone can be seen in the D cluster. Also in A cluster where the secondary canyons are too deep and disconnected with the seaside there are many measurements where $V_{ped}$is under 2m/s. On two secondary canyons B and E although they are connected with the seaside the wind speed is generally under 2m/s.

In the KBSS canyon in C cluster the canyon become narrower with the buildings and other obstructions. Therefore on this location even the wind direction is parallel the wind speed on the pedestrian level is lower due to the friction.

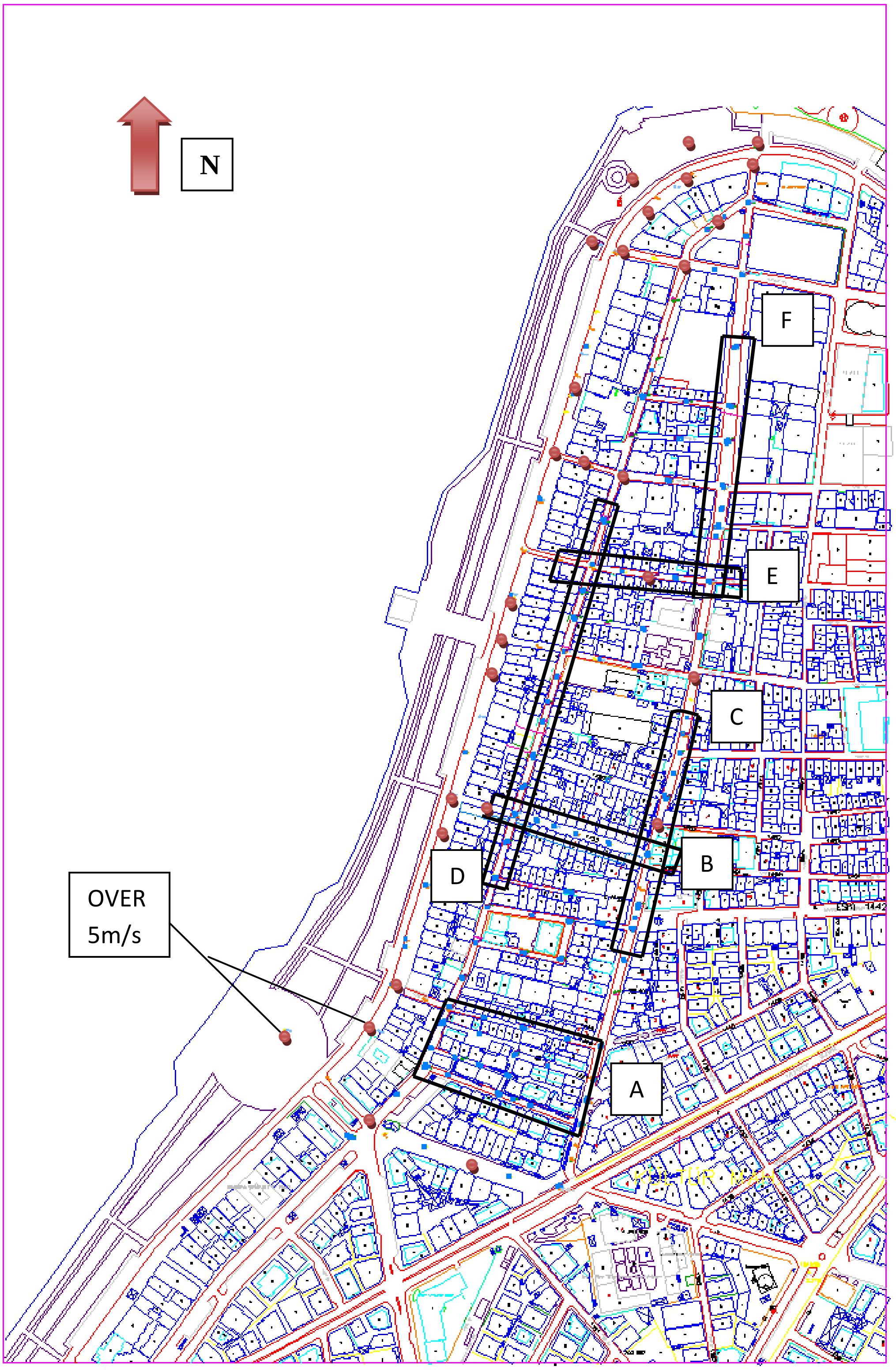


Figure 4.2. The Alsancak site. During the MID period in A, B, C, D, E and F locations most of the wind speed measurements in any direction are below 2m/s.

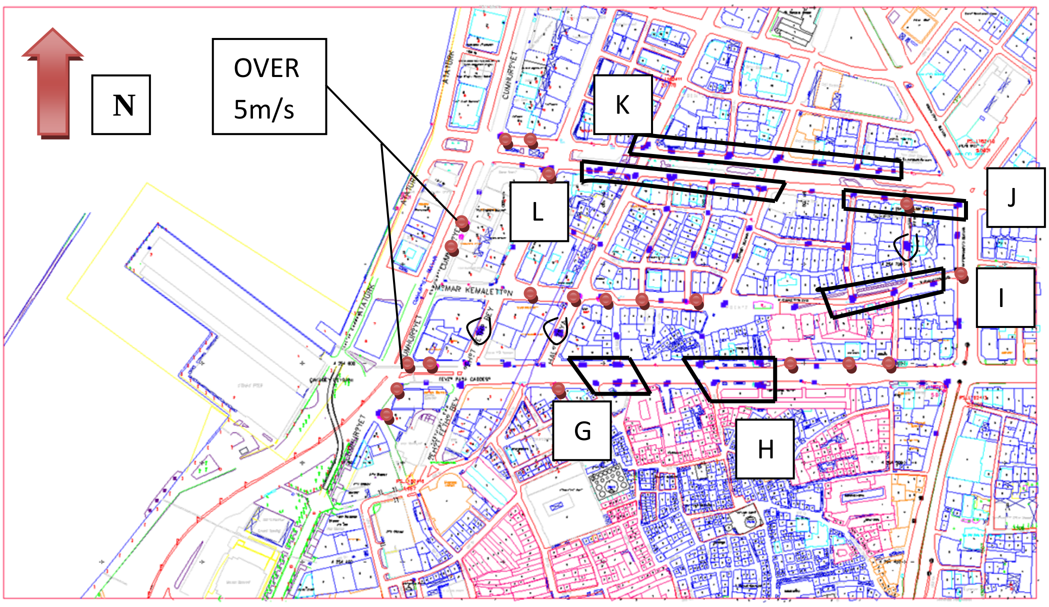


Figure 4.3. The Konak site. During the MID period in G, H, I, J, K and L locations most of the wind speed measurements in any direction are below 2m/s.

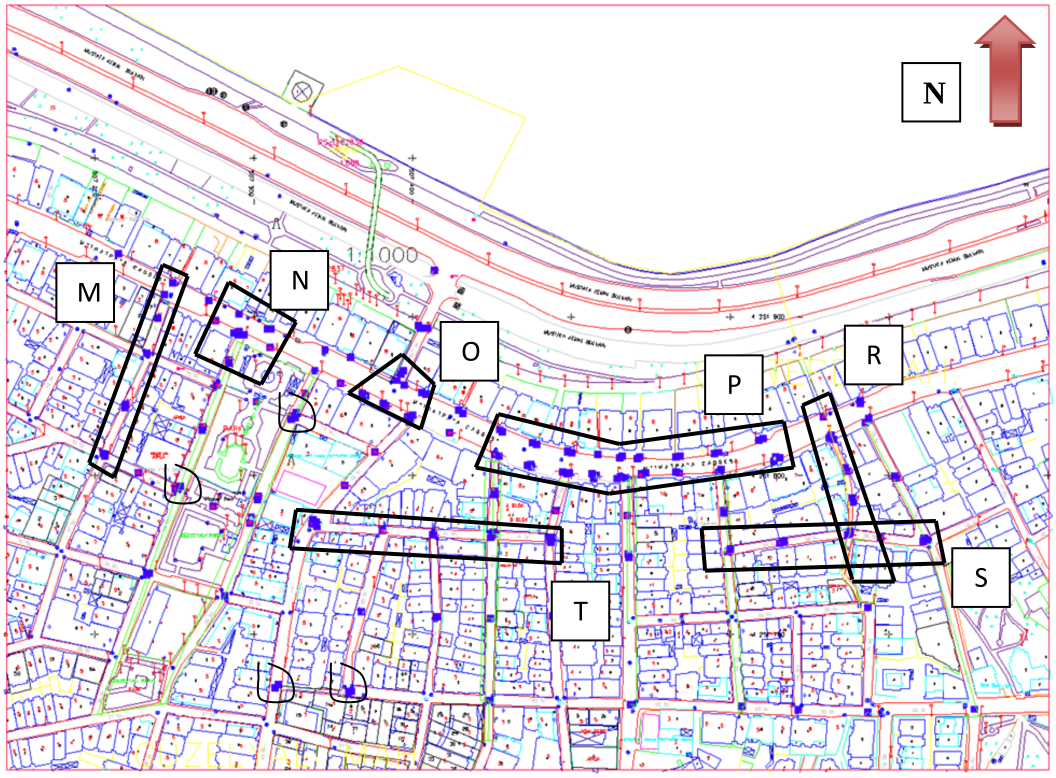


Figure 4.4. The Güzelyalı site. During the MID period in M, N, O, P, R, S and T locations most of the wind speed measurements in any direction are below 2m/s.

When the prevailing wind flows in the South-West direction close to perpendicular to the main canyons Gazi Bulvarı (GZBL) and Fevzi Paşa Bulvarı (FVZPS), the wind shadow effect occur in K, L, G and H. For the parallel wind direction to the canyon axes the pedestrian level wind speed below 2m/s may be the result of the friction forces slowing down the speed generally in the middle part in both canyons (Figure 4.3).

In Güzelyalı when the main canyon changes direction in P measurements less than 2m/s occur on the pedestrian level in parallel and oblique wind direction conditions.

The pedestrian level wind speed in the secondary canyons is generally below 2m/s in T, S, R and M. There are no measurements where the speed is over 5m/s in the main and secondary canyons (Figure 4.4).

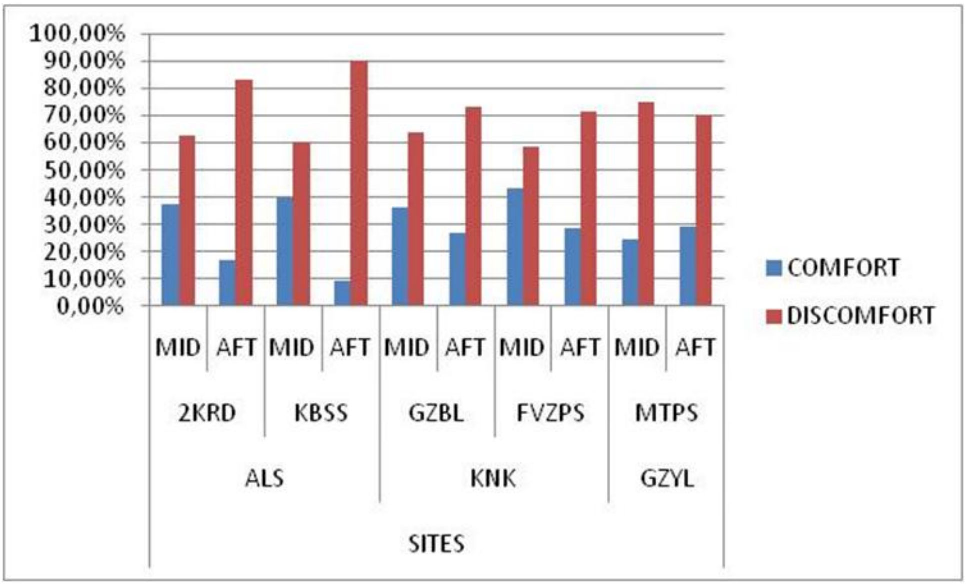


Figure 4.5. The discomfort percentages in the main canyons in both periods.

The major part of the discomfort percentages are presented in the Figure 4.5.

Although the aim of this study is not to calculate the thermal comfort some evaluation can be done according to the Penwarden's work (Figure 4.6):

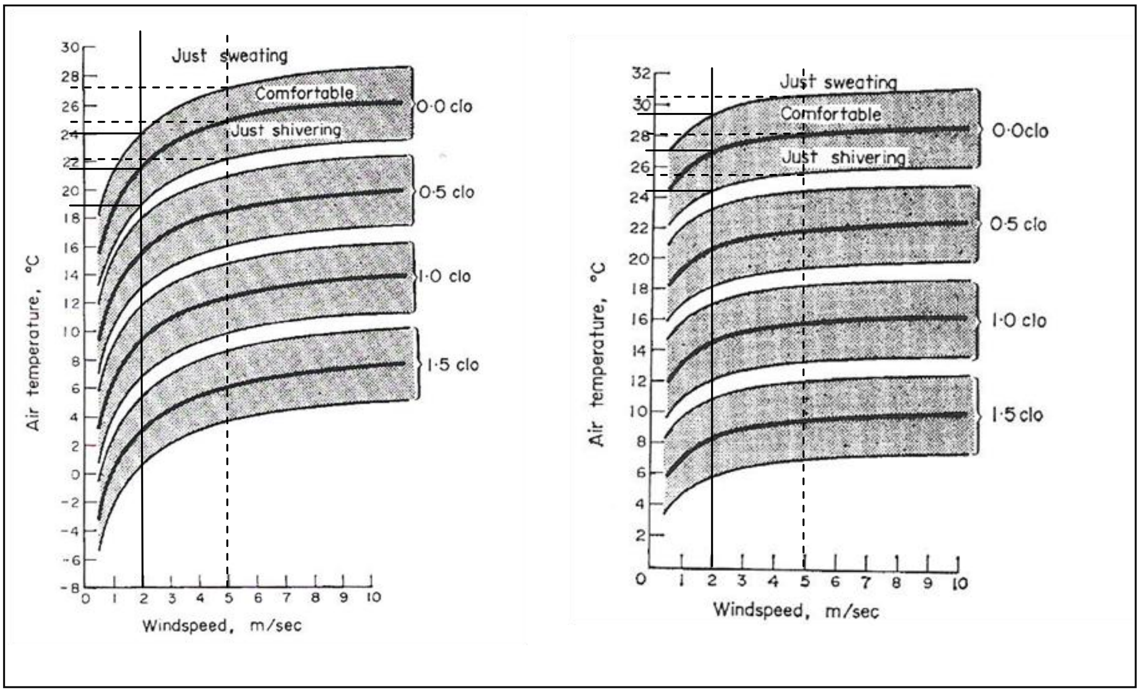


Figure 4.6. Comfort conditions for strolling in full sun and for strolling in shade. 0.0 clo and 0.5 clo represent light summer cloths (Source: Penwarden, 1973).

Based on Penwarden's work during the daytime in full sun for 2 m/s wind speed comfortable temperature for pedestrians is around 21°C and in full sun it is 27°C in full shade. For 5m/s wind speed comfortable temperature for pedestrians is 25°C in full sun and 28°C in full shade (Figure 4.6).

In all sites for MID measurement periods (in full sun or shade) in the main and secondary canyons the comfort conditions based on temperature and wind speed parameters the conditions are above the sweating limit (Table 3.9 and Table 3.10).

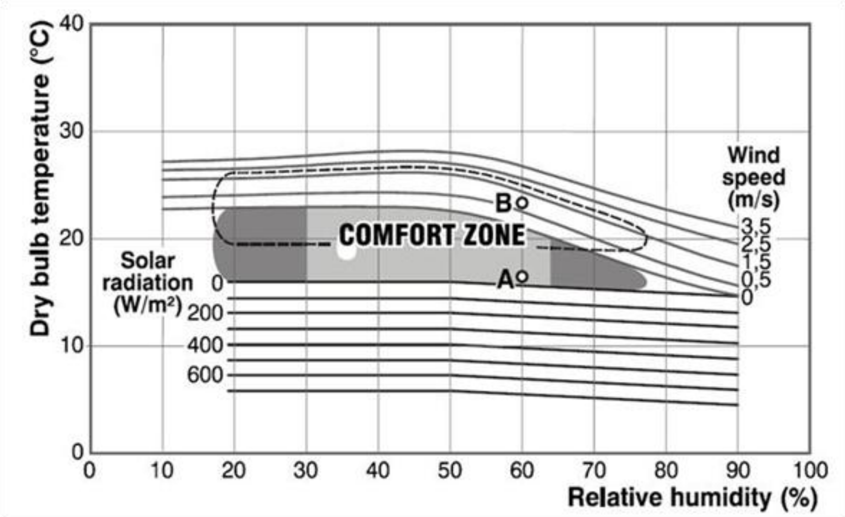


Figure 4.7. The Bio-climatic chart of Victor Olgyay in 1963
(Source: Reiter, 2004).

According to V. Olgyay's bio-climatic chart (1963) approximately 2m/s. is considered as the minimum wind comfort speed on the pedestrian level (Figure 4.7). The minimum temperature measured on the sites is over 27°C and the average relative humidity is between 40% and 60% (Table 3.9 and Table 3.10).

4.1. Characteristics and Natural Ventilation Potentials of the Main Canyons

The variation in the height of the buildings on the South face of the FVZPS boulevard when the wind flows from the West and South-West increases the average wind speed on the pedestrian level (Figure 4.8). However the average building height in GZBL is higher than in FVZPS and the profile is uniform (Figure 4.9).

Figure 4.8. FVZPS with non-uniform buildings mostly on the South side (left).

Figure 4.9. GZBL with uniform buildings along the street.

Although the two main canyons in Alsancak are parallel to each other with a short distance the with a lower H/W aspect ratio KBSS has many wind obstacles for parallel wind direction (Figure 4.10).

Figure 4.10. Wind obstacles on the pedestrian level in KBSS.

As parallel canyons 2KRD and KBSS in Alsancak, MTPS in Güzelyalı the flowing wind over the canyons and on the seaside should be directed inlands by openings and special designs especially during the afternoon periods. In the AFT periods the heat stored during the day should be flushed from the streets.

Long distances between the cross type points create a wind shadow on the leeward side of the buildings when the wind flow is oblique or perpendicular. Especially in Konak the street situated between GZBL and FVZPS the Mimar Kemalettin Street (MKEM) benefits from higher wind speed on the pedestrian level (Figure 4.11). Besides the orientation and the number of cross type points the width of the crossing streets and their longitude are also important. In MKEM the width of the crossing streets (the main and secondary streets) are almost equal. In addition the secondary streets are parallel to the wind flowing on the upper level.

Figure 4.11. The Mimar Kemalettin Street in Konak.

The section in Alsancak site perpendicular direction has a step down character on the seaside (Figure 4.12).

Figure 4.12. 2KRD and the step down section perpendicular to the seaside. View from the Punta District.

A step up section would enhance the natural ventilation of the buildings on the second row.

Although there are secondary canyons open to the seaside most of them are closed. During the afternoon and night period these open spaces are used by citizens frequently for entertainment and gastronomic usages.

In Alsancak while several secondary canyons are directly related to the seaside (Figure 4.13) most of them are interrupted by the first building row from the seaside (Figure 4.14).

In all sites during the MID and AFT periods the wind comfort based on the wind speed and the air temperature parameters is above the sweating limits in full sun and in full shadow conditions according to the Penwarden's work (1973). Natural ventilation is needed especially in the secondary canyons where the aspect ratio H/W is higher than in the main canyons. Except for the Güzelyalı District, the wind speed and the air temperature on the seaside are in the comfort zone.

Figure 4.13. Open streets to the seaside crossing 2KRD and KBSS.

Figure 4.14. Closed streets to the seaside blocked by the buildings on the seaside.

In terms of the relation coefficient between the average wind speed measured by the Meteorology Office (u_{met}) and the average wind speed measured on the pedestrian level (u_{ped}):

$u_{met} = 2{,}09.\, u_{ped}$ for the main canyons

$u_{met} = 2{,}40.\, u_{ped}$ for the secondary canyons therefore:

$\frac{u_{meteo}}{u_{pedestrian}} = 2{,}24$ as an approximate number for this study.

Therefore the street canyon effect on the sites decreases approximately to the half of the upwind speed.

According to the data collected by the National Meteorology Office the prevailing wind direction during the summer season is from the West and West-North-West directions. In addition the sea-breeze flowing over the sea to the land during the afternoon periods can be considered as perpendicular to the buildings along the seaside (around the Bay).

- The Alsancak Site:

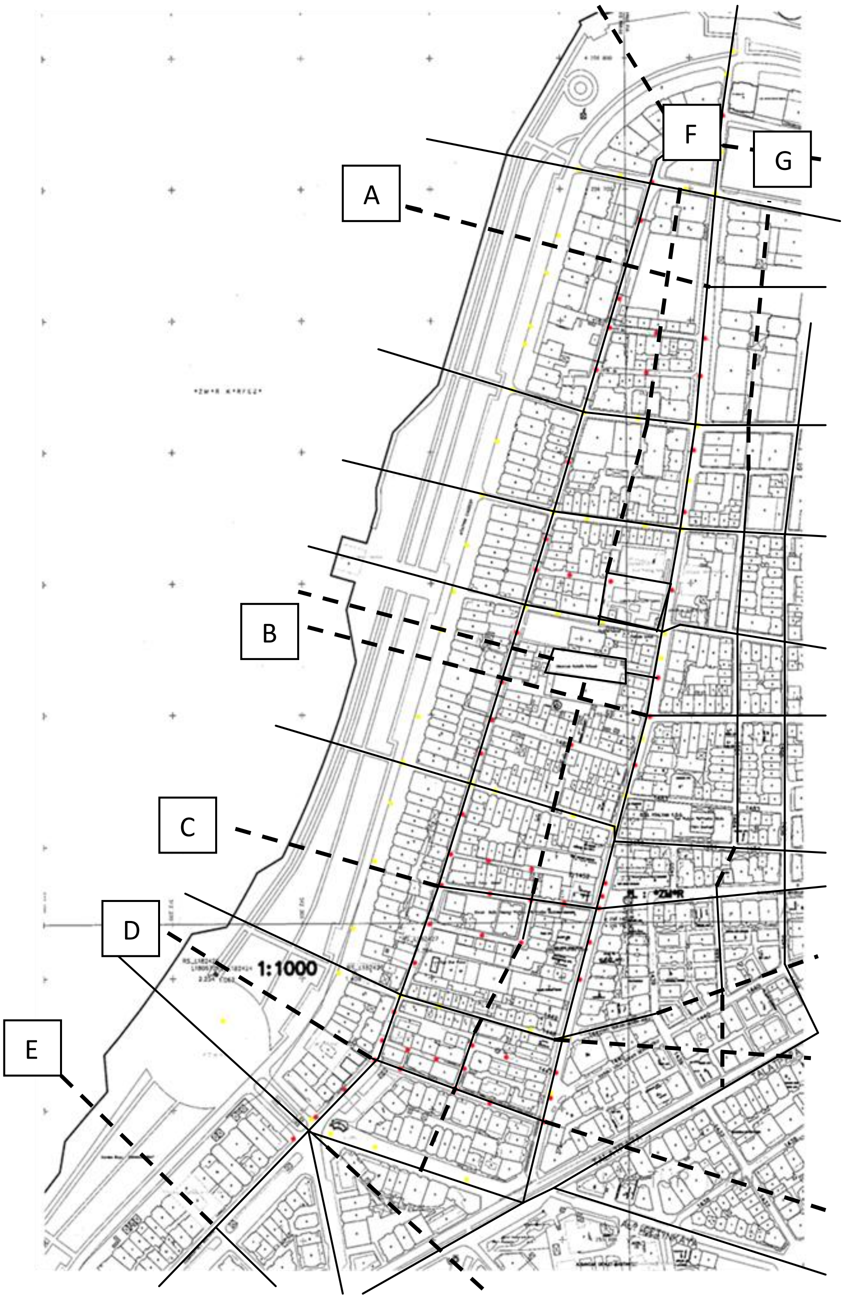


Figure 4.15. The Alsancak Site with the existing (____) and the potential air paths (_ _ _) on the planimetric (2D) level.

The air paths formed by the secondary canyons parallel to the seaside should be continuous.

Based on the Figure 4.15 above, the potential air paths A, B, C, D and E should be open for better natural ventilation by channelling the summer breeze flowing from the sea and the Western prevailing wind. These channels were also be selected according to the existing cross street pattern on the site dividing the building islands in a way that they leave sufficient air gaps around them.

The F and G paths can be opened for the Southern winds which were also measured in the data. The land between the first and the second main canyon parallel to the seaside should be divided in two parts. Therefore with A, B, C, D, E, F and G a gridal pattern with more cross points can be created.

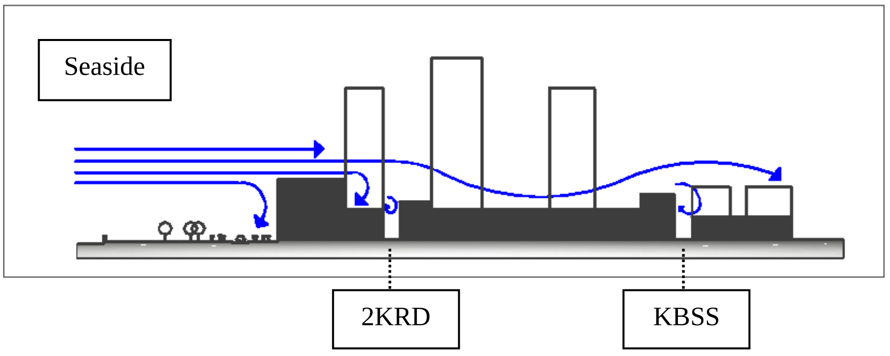


Figure 4.16. The condition in the Konak site when the upwind is perpendicular to the main canyon axes.

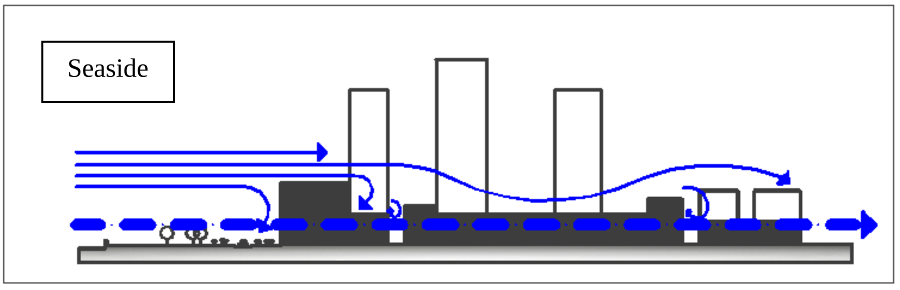


Figure 4.17. The Section from the Alsancak site looking to the North.

The summer breeze can be used for natural ventilation on the pedestrian level with the opening of appropriate passageways (Figure 4.16 and Figure 4.17).

In the future plans the step down canyon can be modified with the new buildings (Figure 4.18).

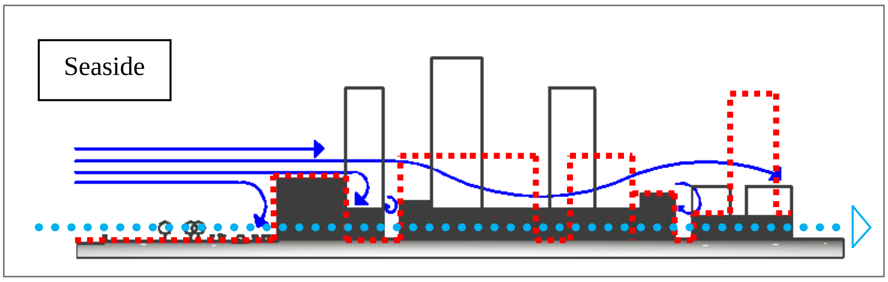


Figure 4.18. Step up section proposition for the Alsancak site.

Furthermore on the proposed air path A, on the land between main canyons situates a high-rise building with an elevated basement which can be used as an air passageway (Figure 4.19).

Figure 4.19. The air passageway on the proposed A part in the Figure 4.15.

However, unfortunately in the Punta district not all of the high-rise buildings provide pedestrian level ventilation over the street (Figure 4.20).

Figure 4.20. The non-porous bases of some of the high-rise buildings in the Punta district.

In addition near the proposed path B situates a void or gap enough wide to redistribute the wind into the streets (Figure 4.21).

Figure 4.21. Potential air gap where can be crossed by the proposed air paths. The buildings are blocking the summer breezes can be seen on the back side of the photograph.

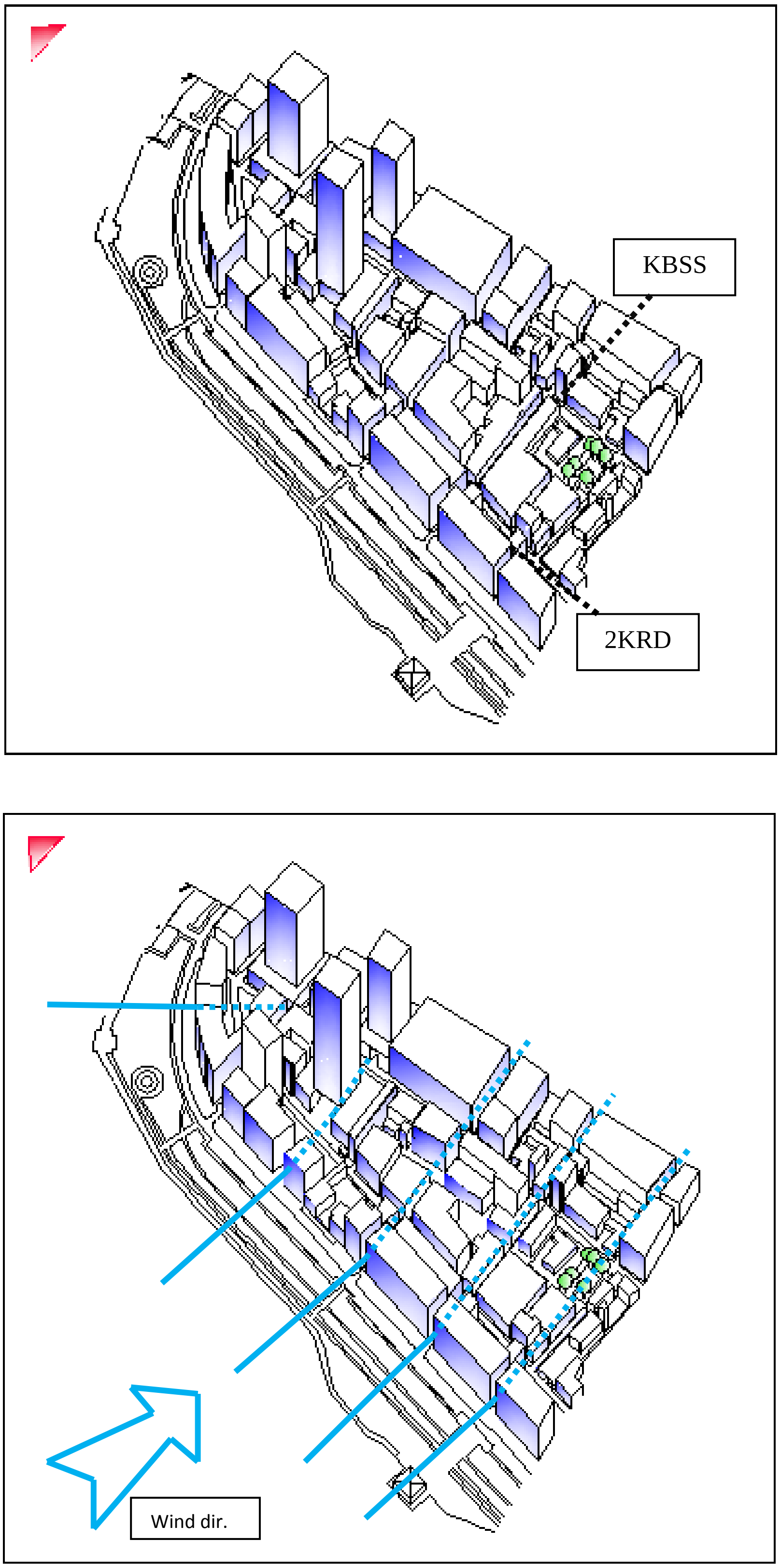


Figure 4.22. The potential air paths can be opened in the direction of the summer wind in Alsancak.

- The Konak Site:

Figure 4.23. The Konak Site with the existing (____) and the potential air paths (_ _ _) on the planimetric (2D) level.

The proposed air paths should be opened without damaging the historical buildings on the South-The Kemeraltı old bazaar area. The proposed air paths in C and D between the GZBL on the North and FVZPS main canyons on the South, should be linear so as to minimize the friction forces which will diminish the wind speed on the pedestrian level. The CRSS type connections enhance the wind speed in the street more compared with the SFTCRSS connections. Therefore the air path in H should be rectified although there is an existing air path (Figure 4.23).

Figure 4.24. The FVZPS view from the seaside.

In the Figure 4.24 on the right (South) when the wind flows from the South-West the variation in the height of the buildings in FVZPS, creates a slightly higher wind environment in this canyon compared with GZBL.

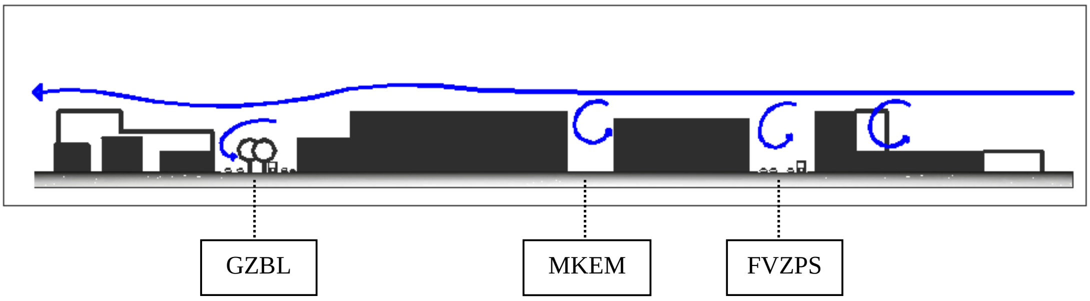


Figure 4.25. The condition in the Konak site when the upwind is perpendicular to the main canyon axes.

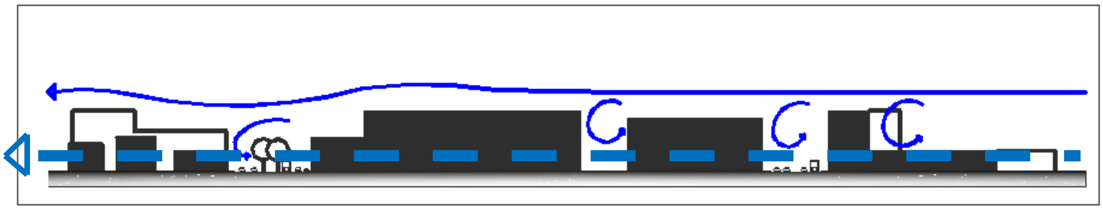
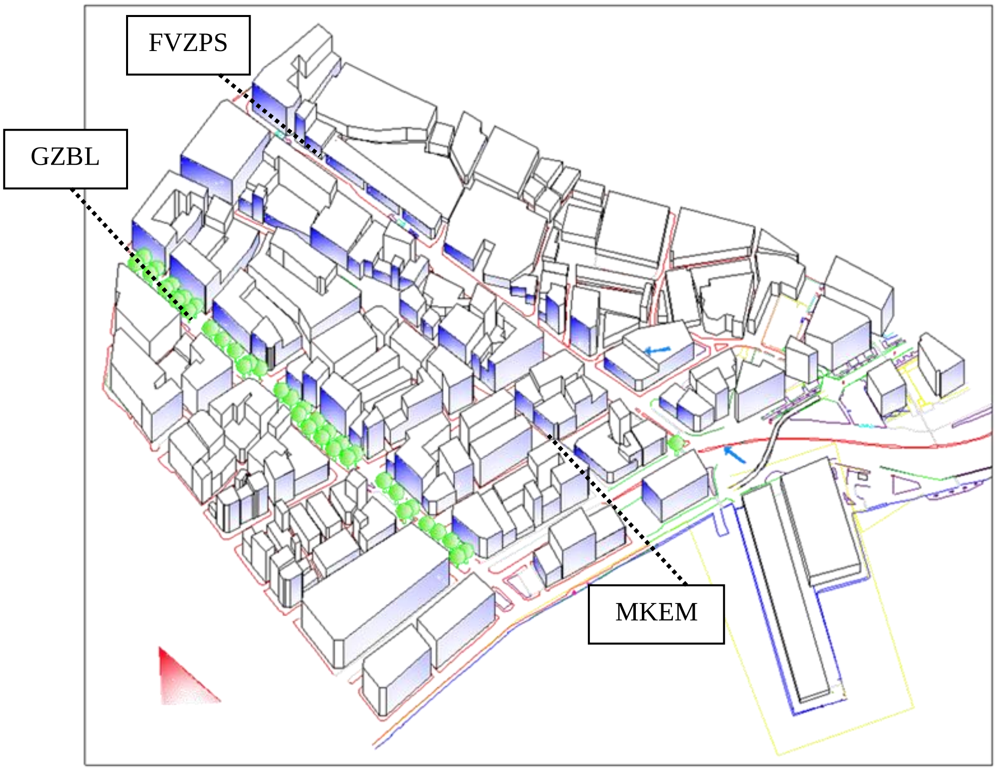


Figure 4.26. Potential air path crossing FVZPS, MKEM and GZBL.

Although the buildings are uniform in GZBL, the double tree row creates a shaded a more pleasant environment on the street level (Figure 4.27).

Figure 4.27. View from GZBL. The double tree row providing shaded outdoor spaces.



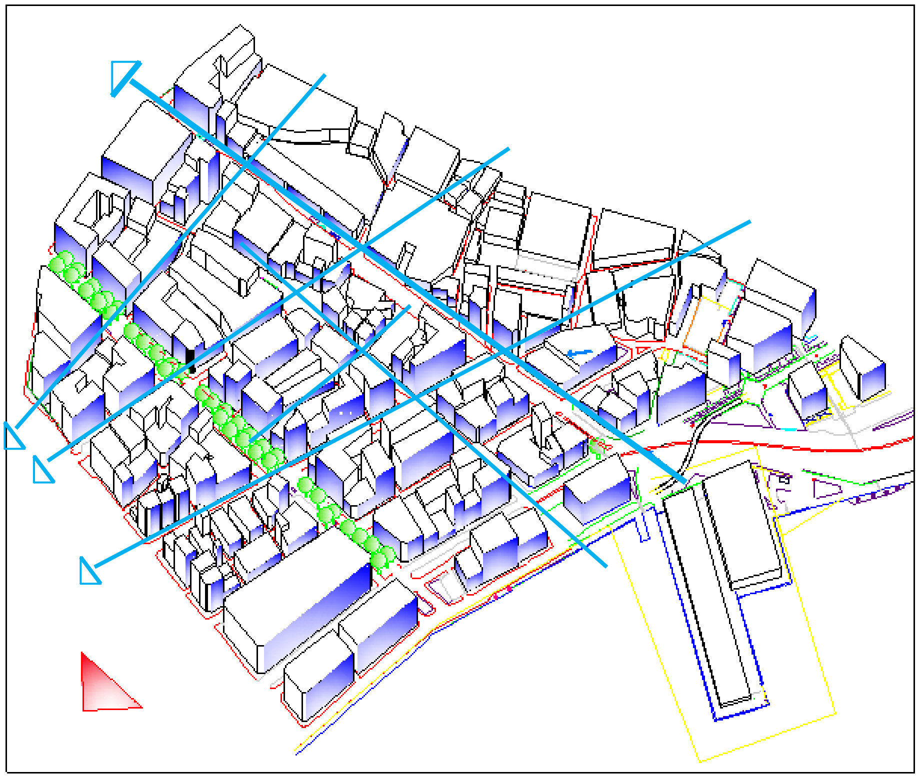


Figure 4.28. The potential air paths can be opened in the direction of the summer wind in Konak.

- The Güzelyalı Site:

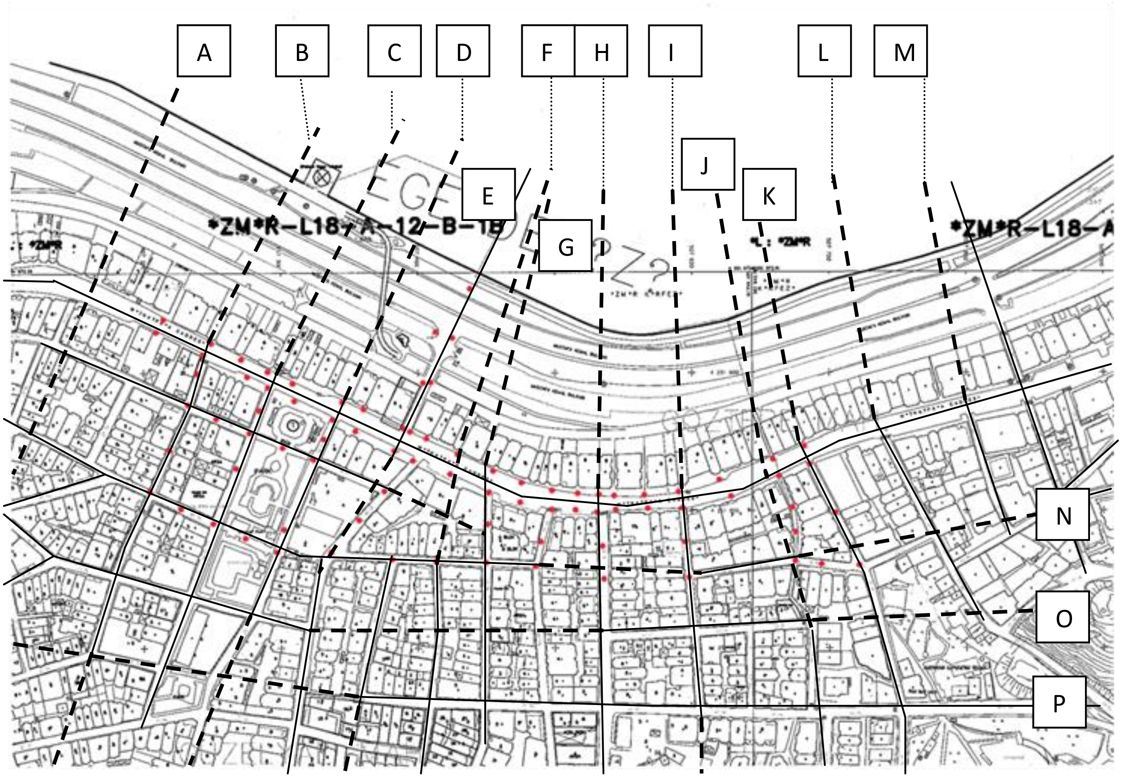


Figure 4.29. The Güzelyalı Site with the existing (____) and the potential air paths (_ _ _) on the planimetric (2D) level.

The continuous line of buildings along the seaside and the irregular character of the secondary streets create blockages for the flowing air on the pedestrian level. By means of the proposed in the Figure 4.29 above air flow between the buildings can be enhanced. The continuous character of the secondary streets in West-East direction may help the Western prevailing wind during the summer enter into the canyons. On the other hand voids positioned in gridal such as parks may help avoiding from the diminishment of the pedestrian wind speed due to the friction.

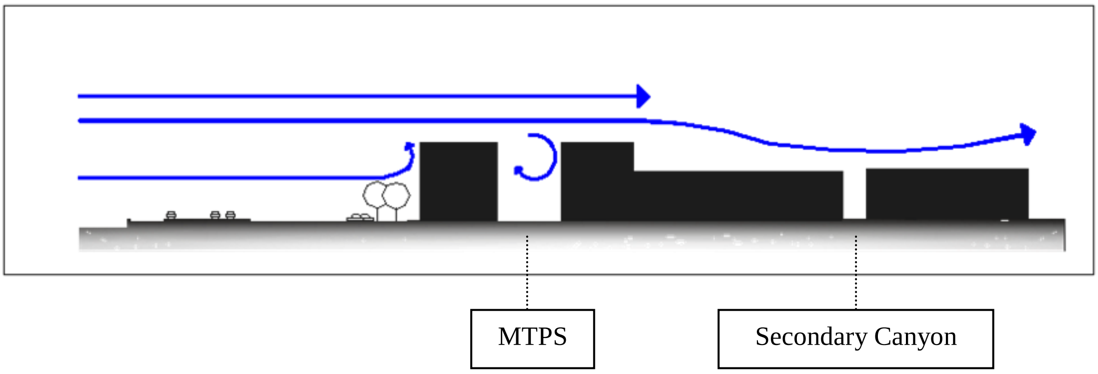


Figure 4.30. The condition in the Güzelyalı site when the upwind is perpendicular to the main canyon axis.

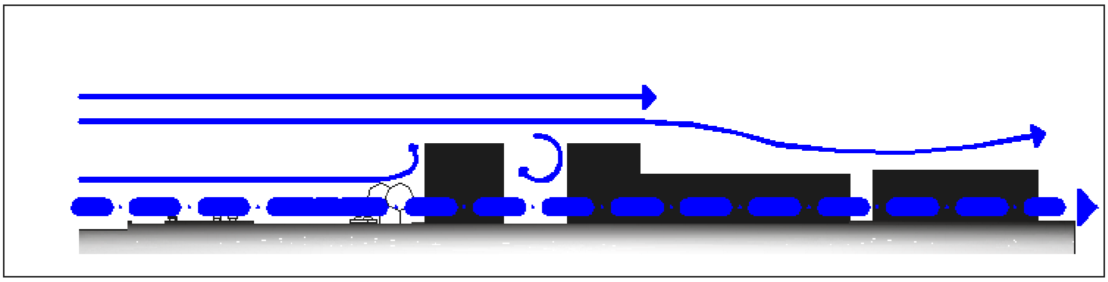


Figure 4.31. Potential air path crossing MTPS and secondary canyons.

Figure 4.32. Two views from the seaside in Güzelyalı. Although there are few air channels to Mithat Paşa Street, pedestrians benefit more if there is also openness on the second row of buildings creating shielding zones.

Similar to the Figure 4.31 air blockages should be opened in order to enhance the pedestrian level wind velocity. The discontinuities of the air paths cause wind shielding areas in MTPS (Figure 4.32). Openings on the first row can be connected with the secondary canyons perpendicular to the main canyon (Figure 4.33).

Figure 4.33. The narrow secondary canyons perpendicular to the main canyon Mithat Paşa Street, Güzelyalı, with high H/W ratios.

Figure. 4.34. An open air cafe space defined by the shadow of the tree benefiting from the air path across the street.

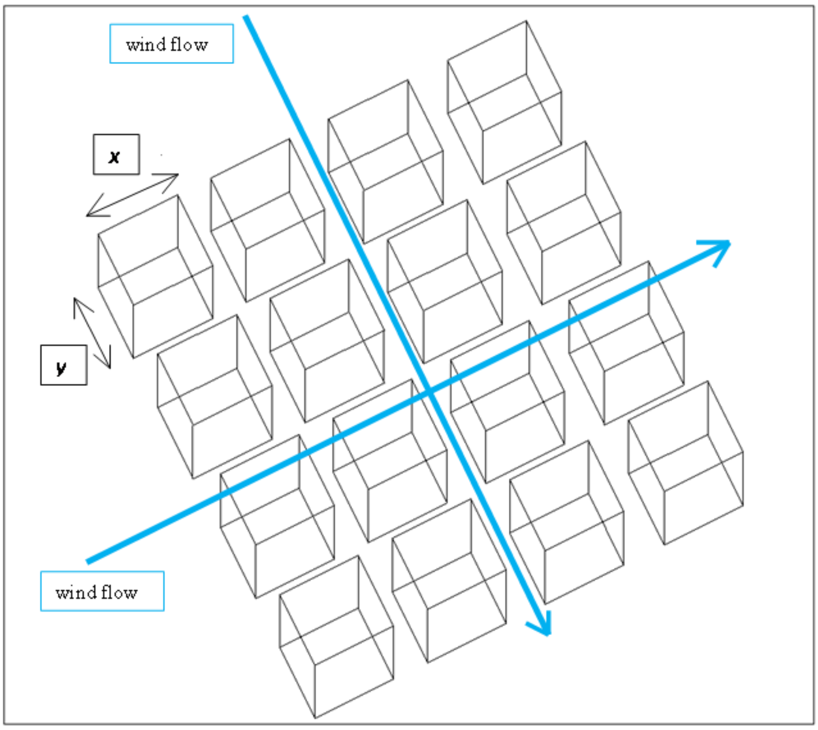


Figure 4.35. The ventilation potential in a dense urban area.

In the future studies cross type junctions on the pedestrian level may help providing the air paths. The *x* and *y* distances should be calculated by simulating the existing conditions in further studies (Figure 4.35).

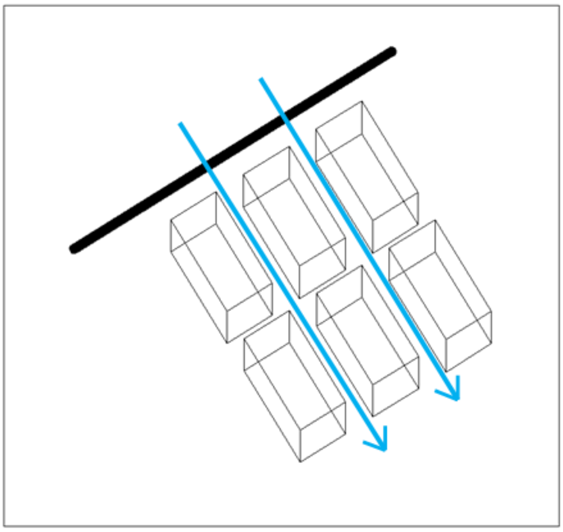


Figure 4.36. The Position of buildings near the sea.

The Buildings on the coastal regions should be either perpendicularly positioned to the seaside or continuous air paths should be created as passageways for breezes (Figure 4.36).

In the locations where there are high rise buildings air paths should be considered three dimensionally in a continuous way with linkages or openings in direction of local and prevailing winds (Figure 4.37).

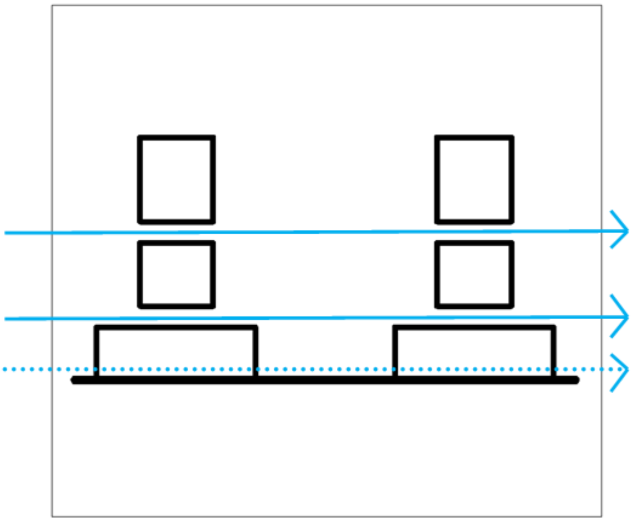


Figure 4.37. Air paths for high-rise buildings.

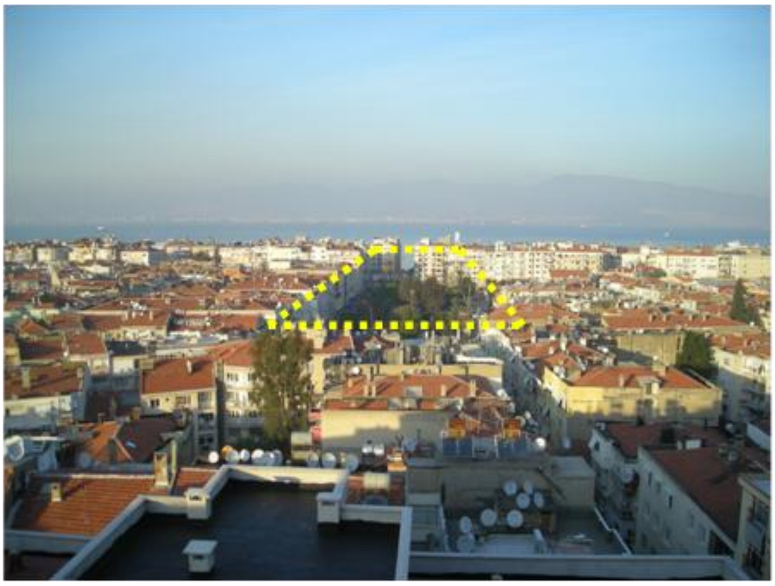


Figure 4.38. The location of the Güzelyalı Park.

Figure 4.39. A potential void for an air path in Alsancak.

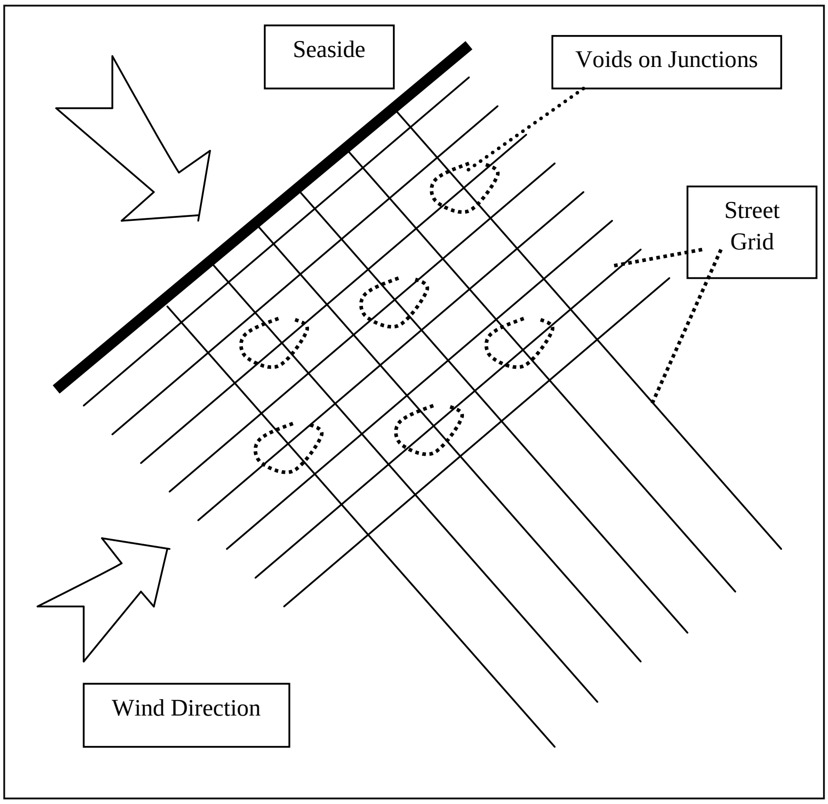


Figure 4.40. The schematic description of potential air paths.

'Voids' in the urban area should be connected with the main air paths. Further studies should be done for their appropriate locations and dimensions Figure 4.40).

CHAPTER 5

CONCLUSION

As the result of the comparative studies between the sites the following points can be listed. In wider canyons where the aspect ratios H/W and L/W are lower, the pedestrians may benefit from the natural wind in terms of the wind comfort. For example in Gazi Bulvarı (GZBL) double tree row exist on the street axis. In summer conditions, the pedestrian comfort can be higher due to the shadow provided by this vegetation. Furthermore they also provide shadow for vehicles (parking or travelling along the street).

The prevailing wind in summer is from the West direction. In Konak it is parallel to the main canyon axes which are perpendicular to the seaside. However the uniformity of the building rows on each side in GZBL blocks the perpendicular local winds which could be helpful for the pedestrian wind comfort. On the other hand in FVZPS the variety in the height of the buildings provide a better wind environment for the pedestrians.

In Konak the canyons are oriented in West-East direction which increases the solar heat gain during the day-time. However in Alsancak due to the NE-SW direction of the main canyons, and higher H/W ratios, less heat is stored during the day-time and the shadow casted on these streets by the buildings on both sides. Besides, the parallel building row blocks the summer breeze and the prevailing wind flowing over the sea. On the other hand the multiple cross points on the secondary canyons which are perpendicularly open to the seaside, provide better local pedestrian wind environment.

During the field study phase, Güzelyalı was chosen as the least comfortable site by the measurement crew. The existence of the cross type points has less contribution to the pedestrian wind speed compared with Alsancak. For an adequate contribution the continuity of the air paths are as important as the number of the cross points for a better wind environment.

Although the present study is only focused on the summer conditions because of the selected measurement period, the wind environment enhancement in open areas such as the Güzelyalı Park should be considered for both seasons: summer and winter. Since based on the observations, during the winter period this space is widely used by elderly people as a gathering area especially in the day-time. The contribution of these spaces to air paths should be examined clearly for example they should not be completely open to winter winds.

The openings on the ground levels of the few buildings have local effects if the air movement is blocked by a second row of building similar in the Güzelyalı case. However if there is a continuity of openings or an air path exist a favourable area for pedestrians is created.

Based on the data from the field experiments held for this study several conclusions can be deduced. The air velocity on the pedestrian level is greatly affected by the presence of the buildings. Even in the streets with lower H/W ratios when $0<H/W\leq 1$ the canyon effect can be seen as lower pedestrian level wind speeds. In addition the uniformity of the building heights has a negative effect on enhancing the pedestrian level wind speed. The angle of the upwind has an important effect when it is perpendicular to the canyon axis resulting in wind speeds lower than 2 m/s on 2 meters high. With an angled upwind direction to the canyon axes, cross type points play a role in enhancing the wind speed on the pedestrian level. When the wind flow is parallel to the canyon the relation with the upwind and pedestrian wind has relatively higher relationship however the friction along the canyon lowers the wind speed.

During the afternoon periods the $V_{ped}\ \ V_{met}$ ratio has higher values on the mid-day period due to the thermal effect: With the sunset the surrounding air become cooler while the surfaces along the canyon are warmer due to the solar heat storage capacity of the materials as a consequence V_{ped} increase is caused by this temperature difference.

The orientation of canyons has a significant effect on the solar heat storage during the daytime. As an example in the field study in Alsancak the canyons are oriented in NE-SW store less heat compared with the canyons in Konak and Güzelyalı oriented in West-East where the R-TEMP ($T_{ped}\ \ T_{ws}$) ratios are higher in the MID period. On the other hand main canyons in the selected site in Alsancak have higher H/W ratios (over 1,6) where the shadow of the building masses cast on a wider area.

The prevailing wind in the summer period in İzmir flows from the West direction. Besides during the field study in summer 2009, wind flow is also from the North and the North-West directions over the İzmir Bay.

In conclusion several solutions for the actual situation are as follows:

The orientation of the streets roughly in N-S direction with higher aspect ratios (1<H/W) provide shadow for pedestrians. However for appropriate natural ventilation for the pedestrians and building façades can be maintained by rhythmic cross connections open to the Western winds.

The Buildings on the coastal regions should be either perpendicularly positioned to the seaside or continuous air paths should be created as passageways for breezes.

In the locations where there are high rise buildings air paths should be considered three dimensionally in a continuous way with linkages or openings in direction of local and prevailing winds. Cross type junctions on the pedestrian level help providing the air paths mentioned above. In addition main street canyons should be linked with secondary canyons connected with cross type points.

In further studies the rhythm of the ideal pattern of cross junctions and the appropriate length of the canyons should be tested. Since when the wind flow is parallel to the canyon axes based on the R-WSPD diagrams V_{ped} relatively lessens compared with V_{met} in the middle of the canyons due to several reasons such as the friction forces on the canyon surfaces (in addition vehicle movement etc.).

The future planning studies should be done considering natural ventilation potentials and testing alternative scenarios by means of simulation in order to find ideal city morphology for appropriate natural ventilation and wind comfort by eliminating also wind nuisance.

In Alsancak and Güzelyalı in the main canyons 2KRD, KBSS and MTPS where the highest aspect ratios H/W and L/W exist, on many points wind speeds less than 2m/s were measured especially in the middle parts of the streets. Therefore the longitude and depth of the canyons has negative effects on the natural ventilation potential in dense urban areas.

4.1. The Limitations of the Study

Due to the limited number of the measurement devices (2 TESTO 400 and 1 Weather Station) the measurement point numbers were also limited so as the duration of the time periods MID and AFT. A complete 24 hour wind environment investigation could be done.

The mobile weather station had to be moved each day to the next site in order to keep the measurements as close as possible in a time schedule.

The mobile weather station on the roof levels was only on 2 meters height from the roof platform. Consequently due to the effect of the buildings on the wind flow the results were not as expected as the researcher. Therefore for obtaining adequate reference data simultaneous with the pedestrian level measurements the wind speed and direction data from the Meteorology Office was used. The sensor of the latter is positioned approximately 10 meters height from the roof level of the Meteorology Office building situated in the Güzelyalı District.

On the other hand the height of the mobile station on each roof (2m.) was adequate for the temperature measurements as reference values.

If there were multiple weather stations in and around the city centre, more useful data could have been collected in order to detect the Urban Heat Island Effect in the city of Izmir and its wind environment.

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