CLIMATIC CONSIDERATIONS IN TRADITIONAL BUILT ENVIRONMENTS: THE EFFECT OF NATURAL VENTILATION ON THERMAL COMFORT IN ALAÇATI, İZMİR, TURKEY

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ABSTRACT

CLIMATIC CONSIDERATIONS IN TRADITIONAL BUILT ENVIRONMENTS: THE EFFECT OF NATURAL VENTILATION ON THERMAL COMFORT IN ALAÇATI, İZMİR, TURKEY

The traditional settlements in Turkey are under a growing danger of either destruction and despair or tourism. The urban tissue of historical settlement areas is attractive for touristic activities and vacation programs, but in many of these settlements the tissue is mostly ruined. The main reason of this deformation is the lately defined conservation regulations. The buildings of the old settlements are ruined or fixed with unhealthy methods and the infill or new settlement areas cannot integrate morphologically with the old heritage. The conservation of the buildings in the historical settlements is expensive, so especially in historical settlements close to tourist attraction centers such as Şirince and Alaçatı in the Aegean Region, the construction of new buildings to answer the need for new residential building stock increases. The problem in the design of these new dwellings constructed in the empty parcels within the settlement or in the boarders of the settlement is that they do not follow the design principles of the traditional settlements and when they seem to follow the design principles they do that only at the level of image.

The objective of this thesis is to evaluate the physical conditions of the old traditional settlement examples, and to compare these data to find out new design criteria for the design of climatically responsive new buildings in these specific areas.

To invent a method to evaluate the air pressure change between the open, semi-open, and closed spaces of traditional Turkish houses will be the main goal of this study. The point where this study outstands from the other similar studies is the observation of different housing typology, which needs to be studied with the airflow factor under temperate-hot climate conditions. The houses of Anatolian settlements are mainly not mid-courtyard houses and the semi-open spaces are the most important part of these houses, so the observation of natural ventilation behavior is different from other studies working with different climate areas. Alaçatı, Izmir, TURKEY is chosen as the case study area for this study, because it is one of the fastest growing urban sites in the Aegean Region of Anatolia.

ÖZET

GELENEKSEL YAPILI ÇEVREDE İKLİM ETKİSİ: ALAÇATI, İZMİR, TÜRKİYE'DE DOĞAL HAVALANDIRMANIN ISIL KONFORA ETKİSİ

Türkiye'de bulunan tarihi yerleşkeler tahrip olma veya yok olma tehlikesi altındadır. Özellikle turistik bölgelerde geç geliştirilmiş koruma kararları nedeni ile tarihi yapılar yıpranmış, yanlış şekillerde tamir edilmiş veya yıkılmışlardır. Kentsel doku içinde oluşan boşluklar ve doku dışında yapılan yeni yapılar tarihi yapılara genelde sadece şekil olarak benzetilmiş ve belli parsel koşullarına uyum sağlamaları zorunlu kılınmıştır. Yeni tasarımların tarihi dokunun mekansal organizasyonu ile morfolojik yapıları ile benzerlik göstermediği durumlar çoğunluktadır.

Bu ışıkta önerilen tez çalışma konusu, iklim etkilerinin tarihi yerleşkelerin tasarımında rol oynayan önemli etmelerden biri olduğunu hipotez etmemektedir; sadece böyle bir ilişkinin varlığını teknik olarak ölçebilmek için metot (yöntem) veya metotlar dizisi oluşturmak hedeflenmiştir. Eğer iklim ve tasarım kararları arasında bir ilişki olduğu anlaşılır ise mekansal anlamda iklimle kurulan tasarım ilişkisi kritelerini kullanarak yeni tasarımlar yapılması yönünde öneriler sunma imkanı doğacaktır.

Açık, yarı açık ve kapalı alanlarda farklılaşarak hareket eden havanın hareketi ve basınç değişimlerinin kentsel ve tek yapı bazında incelenerek ısıl konfor koşulları açısından değerlendirilmesi bu tezin temel hedefi olacaktır.

Çalışmada, iklim koşullarının ılıman olduğu Ege Bölgesi yaz koşulları üzerinden değerlendirilme yapılmaktadır. Hava hareketinin yaz aylarında olumlu etki gösterebileceği hipotez edilen tarihi bir yerleşkede çeşitli ölçüm ve simülasyon yöntemleri ile konutlarda ısıl konfor koşulları değerlendirilecektir. Farklı konut tiplerinin karşılaşırmalı biçimde incelenerek değerlendirilmesi ve daha etkin olan konut tipinin ampirik olarak sunulması çalışmanın ilk aşaması olarak değerlendirilebilir. Belli bir bölgedeki tarihsel yapı örnekleri ile yeni örnekleri karşılaştırmak ve bu verileri yeni tasarım karalarında değerlendirmek için alan çalışması, Alaçatı tarihi yerleşkesinde yapılmıştır. Yerleşke son dönemde Ege Bölgesinin en hızlı gelişmekte olan yerleşkelerinden biridir ve çalışmaya uygundur.

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CHAPTER 1

INTRODUCTION

Climatic aspects have greatly influenced the design of the ancient and traditional architecture (Tablada, 2006, Olgyay 1963, Evans, 1980, Oktay, 2002). Although most researchers (Asatekin, 2005, Orhun, 2000, Hall, 1988, Taylor, 2004, Mumford, 1989) in the fields of urbanism and history claim that the formation of historical urban settlements is not primarily shaped by climatic conditions of a location, the importance of thermal comfort conditions in the buildings of such settlements cannot be disclaimed.

There are different factors ranging from social to climatic that affects the settlement and architecture of traditional urban areas. Some have claimed that the physical environment is shaped solely by cultural and social factors, while others (Givoni, 1976;1994;1998, Olgyay, 1973, Alamdari, 2007) have claimed that it is shaped mostly by climate. Without ignoring the impact of social, cultural, economic, and technological factors in the formation of the physical environment, this study looks into the role of climate in shaping the urban physical environment. It proposes an empirical investigation based on numeric data collection and simulation of real situations to inquire the relation between some climatic factors, specifically airflow, and thermal comfort condition relations.

1.1. Review of Climate Considerations in Built Environment

Repeated building practices, which are tried and have evolved over time, have dominated the building production within traditional architecture until the industrial revolution when larger metropolitan areas started to appear. Inevitable growth of capitals and fast industrialization in the nineteenth century dramatically changed the building production and well-known construction methods. Since then, traditional building practices have had limited impact on the formation of physical environment, they were largely abandoned, and finally the body of technical knowledge associated with these practices have ceased to be relevant.

“Urbanism” emerged as a new field of discipline in response to negative effects of the industrial revolution. Cities’ growth, which had been so far shaped by physical and social factors such as climate, topography, nature, culture, and social conflicts, became primarily shaped by the needs of the newly emerging working class, which required cheap and quickly built housing. Cities started to be shaped by the revolutionary economic dynamics rather than the needs of the people living in the cities.

Fast urbanization after the industrial revolution brought new and serious environmental problems for the industrialized capitals in the European countries. Human factor and comfort had ceased to be one of the primary factors in the growth of the industrial city. The unplanned growth left the cities with no infrastructure. There was no concern of environmental and climatic conditions. In the beginning of the twentieth century, urbanism became an important discipline and planning the industrialized cities had been the main goal of urban developers (Taylor, 1999, Hall, 1988, Mumford, 1961). Climatic considerations at both urban and architectural scale gained importance again with the rise of negative effects of industrialization on cities.

With the expectation of better, thermally more comfortable environments, emerging new techniques (use of high-technology equipments) started to be used in the field of architecture with increasing speed. Use of passive techniques (such as passive ventilation, passive heating and cooling systems) has been excluded from the architectural scene till after 1950s, more specifically until the energy crisis of early 1970s when energy consumption of buildings became a major problem. In response, passive techniques in architecture regained popularity. The studies of Olgyay (1963; 1973), Givoni (1976; 1976; 1998; 1998), Brown and Dekay (2001) are some of the important studies in literature related to the passive techniques previously used in traditional architectural practices and alternative passive technique options for future design alternatives.

The technical knowledge in traditional design approaches, which takes its roots from previous heritage and experience, is scarcely externalized. Traditional built environment is unique with its intuitive repetitive character and often considered by users as adaptive to climate. However, in most of the design suggestions of today, the sensitivity towards climate is missing or replaced by a technological interest with more and more high-tech solution for issues related to thermal comfort. Passive cooling and heating alternatives are widely abandoned in temperate climates.

There is, however, a growing interest in passive alternatives of cooling and heating especially in relation to debates on sustainability. Emerging contemporary passive systems, which are regenerated after energy crisis in 1980s, are increasingly more sought after. These systems mostly get their primary inspiration from climatically responsive historical buildings. Stack ventilation, courtyard usage, wind-catcher elements, preventing solar radiation and street ratio relations are only few examples from the past which are used in contemporary design strategies as well[1].

When we examine traditional settlement examples in Anatolia we see that climate considerations have striking effects in their formation. Anatolia, with its diverse vernacular architectural traditions and climatic zones, has not been a primary object of research in studies about climate and architecture. There have been studies on climate and architecture in traditional Anatolian architecture only for the last 10 years, but almost none of the studies (Oktay, 2001; 2002, Eriç, 1979; Engin, et al., 2005, Şerefhanoğlu, et al., 2007) have worked with numeric data collected in traditional settings. Temperate climate behavior and the variety of different housing typologies shaped in Anatolia could be an interesting research subject for analytical studies.

Some specialists of traditional settlements in Anatolia claim that the effect of climate on the formation of these settlements is questionable. Some have claimed that specific conditions of the particular time the buildings were built and availability and economy of materials have shaped the environment of living rather than climatic considerations (Ergül, 2002).

This study employs specific numerical methods to evaluate the relationship between the general design features of traditional settlements and climatic conditions, specifically the effect of natural ventilation on thermal comfort, in Alaçatı, İzmir, Turkey. This study suggests that if a significant relation between built environment and climate is found, this could be used in the design of the new settlements in contemporary cities. It is believed that the effect of climate over Anatolian traditional settlements needs to be studied in detail through experimental studies and requires better scientific explanations.

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[1] For more information: Sun, Wind, and Light book by Brown and Dekay (2001)

1.2. Aim of the Study

The climatic considerations affecting the architecture of a traditional settlement is considered implicitly by local builders. Researchers who study these settlements in Anatolia have not fully explained these implicit approaches previously, given that their studies are confined to surveys rather than numerical analysis. Analytical studies and mainly field work studies should be conducted to show the effects of climate on architecture if there is any.

Natural ventilation by openings is one of the most primitive methods of passive cooling (Givoni, 1974; 1998, Allard, 1998, Brown and Dekay, 2001, Santamouris, 2000;2001;2004; 2007). It has been used all around the world in different architectures by various cultures. The effectiveness of openings for ventilation is known, yet has not been discussed analytically before 1950s. Its effect on thermal comfort has been a more recent issue of discussion. In the last 10 years, it is shown that the effect of natural ventilation on comfort level under hot conditions is positive for people of hot climatic zones. Airflow up to certain levels can cause toleration of extra 3-4 ˚C temperature above limits.

Thermal comfort status of the occupants of a settlement can be one of the most credible issues to determine the effect of climate. This study takes thermal comfort as a tool to investigate the effect of natural ventilation on the design decisions.

Thermal comfort is the state of comfort defined with the given parameters according to the defined standards. Effect of ventilation on thermal comfort is a complex issue, where the standards are mainly limited with the 0.2 m/sec velocity upper level. However, indoor thermal comfort in naturally ventilated building tradition in warm zones faces turbulence over 2m/sec in certain cases, where the cooling effects over the human skin by evaporation is considerable. Evaporation is directly related with airflow around the body. Increase in airflow increases evaporation over skin and causes extra tolerance for hot weather conditions under ventilation.

Ventilation of indoor spaces is directly related with outdoor ventilation potential and its orientation in relation to the placement of and size openings. Natural ventilation depends on the pressure distribution around the building, which is generated by the interaction of the wind with the building itself and the neighboring buildings and obstacles. As Tablada (2006, p.19) describes “the geometry of the building is therefore an essential element that affects many aspects of building climate like the airflow around the building, the potential for natural ventilation and the interior thermal comfort."

In geometric organization of traditional housing examples in Anatolia, one element that is common in nearly all different examples is Sofa or Hayat space. This communal space, where the main activities of the day takes place is first defined by Eldem (1950), who offered a classification of Turkish houses according to Sofa and then followed by many other researchers. Kuban (1995) classifies the traditional houses in Anatolia (Turkish House) under the following headings:

- Turkish House without a sofa
- Turkish House with an open sofa
- Turkish House with a central sofa
- Turkish House with complex plan types

There are other classifications of traditional dwellings such as classification according to room locations (Küçükerman 1973, 1975, 1978), classification according to construction techniques and materials (Eriç, 1979; Tanyeli, 1979; Kuban, 1975, 1995), classification according to regional characteristics (Bektaş, 2001, Asatekin, 2005). The morphology of houses in Anatolia has been the subject of many researchers. The historical development of these houses, their classification, and typologies is a rich research area. Yet, this study will not dwell on the definitions and classifications of Turkish houses. Here, I will look into the impact of sofa space on thermal comfort, as an open living space. Classifications made according to spatial organization of open, semi-open and closed spaces (Kuban, 2005) are more suitable for this study because the morphology of the traditional dwellings is the main differentiating factor affecting the indoor thermal comfort among other housing examples of the world.

This study will investigate specifically the effect of the wind in the coasts of Turkey and its potential impact on the orientation of traditional settlement and housing. The occupants of these regions often underline the cooling potential of natural ventilation in the common living spaces (Sofas) of the residential units. However, to distinguish a general settlement pattern out of the coastal settlements and to come up with physical precise data are not easy. When the case study area was determined, the natural ventilation pattern in a traditional settlement area was the main criterion of choice to examine natural ventilation effect on thermal comfort.

The specific area studied in this research is the west-coast settlements of Anatolia named as the Aegean Region, because the moderate/temperate hot climate offers the possibility of living outdoor for long times during the year. Organization of the houses, which provides semi-open and open living spaces, makes it possible to study the impact of ventilation. Cooling potential of natural ventilation in hot summer period can be well-examined by just studying the common living spaces of the traditional houses in Aegean Region.

The point where this study differs from other similar studies is the observation and comparison of different housing types from the same area, which is studied with the airflow factor under temperate-hot climate conditions. The houses of Anatolian settlements are mainly not mid-courtyard houses and the semi-open spaces are the most important part of these houses, therefore, the observation of natural ventilation behaviour is different from other studies working with different climate areas.

This thesis aims to investigate changes in thermal comfort status of occupants according to different ventilation regimes in houses with different spatial organizations with regards to the variations in common living spaces (evaluate the air pressure change between the open and closed spaces). The results from the study could potentially make it possible to propose thermally more effective house layouts, i.e. with appropriate sofa and staircase organization schemes, for this region that will improve the summer living conditions with natural ventilation.

There are two major phases of this study:

- Conducting a comparative analysis of traditional houses with different plan organizations in the case area, which are hypothesized to be planned according to wind conditions; and
- To propose the most effective sofa/staircase design scheme in order to maximize thermal comfort for future housing studies in the case area.

1.3. Choice of Case Study Area

The traditional settlements in Turkey are under a growing danger of either destruction and despair or uncontrolled alterations because of tourism. Historical settlements are attractive for touristic activities and vacation programs, but in many of these settlements traditional character is disappearing with an increasing speed. When a traditional town becomes popular, construction in the field happens before the conservation regulations are defined as a result of bureaucratic deficiency of growing economies. The buildings of the old settlements are ruined or repaired with inappropriate methods and the infill or new settlement areas cannot integrate morphologically with the old heritage. The conservation of the buildings in the historical settlements is expensive, yet, there is ever growing interest in the market to offer new houses that look traditional and in close vicinity to these settlements. Especially in historical settlements close to tourist attraction centers such as Şirince and Alaçatı in the Aegean Region, we see a proliferation of seemingly old looking constructions. Main problem in the design of these new dwellings constructed in the empty parcels within a traditional settlement or in the boarders of the settlement is that they do not follow the design principles of the traditional settlements and when they seem to follow the design principles they do that only at the level of image.

Alaçatı, Izmir, Turkey is chosen as the case study area, because it is one of the fastest growing urban sites in the Aegean Region of Anatolia. Furthermore, the wind effect in this settlement and the morphology of the settlement are important factors of this choice. Alaçatı is a unique Aegean town on the western coast of Turkey, which is famous for its architecture, vineyards, consistent and steady wind, and windmills dated over 150 years. Now it is popular in the world as a windsurfing and kite surfing centre.

It is believed that strong Alaçatı wind affected the morphology of the settlement and architecture throughout the time. Local people of the site also mentions about the cooling effect of prevailing wind conditions, which will be discussed in detail in Chapter III. Both, the shape of the bay and the thermal water pressures, create steady and consistent winds blowing side-shore from North to South (*poyraz*) in summer and from South to North (*lodos*) in winter months. The dominant wind direction in Alaçatı is North-west and annually 300 days; and wind blows over 5m/sec in the area.

The tourism potential of the town forces the small town to enlarge, especially increasing in the hot summer period. This inevitable enlargement causes a growing demand for new habitation and housing. This fact also supported the choice of the case study area as Alaçatı.

1.4. Method of the Study

The study uses field measurements and simulations (specifically natural ventilation (NV) simulations) respectfully in order to derive and validate a specific method for analyzing traditional housing examples.

Measurements are performed according to the model proposed by Gail S. Brager and Richard J. de Dear (Energy and Buildings 27 (1998) 83-96). Temperature and humidity have been measured[2] according to measurement criteria of Brager and de Dear (see Section 4.1.1), Class I however indoor wind speed measurements are performed with simple hand anemometers instead of omnidirectional anemometry system. Measurements' aim is to examine indoor thermal characteristics of different traditional Alaçatı houses at the sofa spaces in order to understand the planning characteristics of traditional builders. Data taken from indoor and outdoor allows comparative evaluation for thermal comfort analysis. The results of the final measurements are evaluated by thermal comfort criteria of ASHRAE (2005) and bioclimatic charts of Olgyay (1963; 1973) defined for this region. The evaluation is strengthened by further literature studies based on natural ventilation effect on human thermal comfort.

These measurements will be compared with simulation data. The air circulation in the buildings cannot be exactly defined in energy-simulation programs. For this reason, the airflow pattern and air pressure coefficients should better be simulated by a Computational Fluid Dynamics (CFD) program. These air pressure values then can be replaced into Building Energy Simulation Programs (BES) for accurate results in natural ventilated cases. Thus, simulations need to be performed in two different categories: CFD[3] (Computational Fluid Dynamics) and BES[4] (Building Energy

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[2] Also surface temperatures have been measured for the determination of irradiation effect. They are not used in the study.

[3] Airflow and heat flow system simulation tools: mostly CFD (Computational Fluid Dynamics): CFD software for simulating fluid flow, heat and mass transfer and a host of related phenomena involving turbulence, reactions, and multiphase flow. Some examples of the CFD softwares are; AIRPACK, Microflo, PHONEICS, FLOVENT, Microflo, TAS

Simulation) programs and their coupling is performed for comparative analysis with the field studies.

Validation is a major reason behind running the simulation. The physical processes of natural ventilation, however, are complex, the interpretation of airflow in ventilation effectiveness is difficult and the accuracy of the simulation tools is still questionable. As Santamouris (2002) states “It is very important to note that use of deterministic methods to predict natural ventilation airflow rates in buildings is based on assumptions that often fail to describe the actual conditions with sufficient accuracy. This affects accuracy of the results compared to measured values” (p.64).

Afterwards the analysis of the thermal comfort conditions of different indoor sofa types is evaluated. Alternative design schemes for sofa/staircase organization configurations are studied with further simulation studies.

The proposed method used for the study is defined as a guiding instrument for other similar studies and further steps of this study. New case study areas can possibly be investigated with the same methodology in future.

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[4] Defined in Section 2.3.2

CHAPTER 2

LITERATURE REVIEW

2.1. Definition and Parameters of Thermal Comfort

Thermal comfort is defined as “condition of mind in which satisfaction is expressed with the thermal environment” (ASHRAE 1993, ASHRAE Standards 55 2004). Fanger defines ‘thermal neutrality’ for a person “as the condition in which the subject would prefer neither warmer nor cooler surroundings.” Thermal neutrality based on the heat balance of the human body depends on several parameters described first by Macpheson (1962): environmental parameters including ambient or air temperature (Ta), mean radiant temperature (MRT), water vapor pressure (pv) or relative humidity (RH), relative velocity (v); and personal parameters including clothing or thermal resistance (Icl) and activity or metabolic rate (M). Gender, age and culture are other physiological and psychological factors that are discussed in more recent studies; however these are not well-defined in detail for all different cases of thermal comfort in ISO or ASHRAE standards. National-geographic location, age, sex, body build, menstrual cycle, ethnic difference, food, circadian rhythm, thermal transients, unilateral heating or cooling of the body, color, crowding, air pressure comfort are other issues to be questioned in further thermal comfort studies.

2.1.1. Environmental Indices and Thermal Prediction Methods

According to ASHRAE a simple way of predicting thermal comfort is using figures and tables from manuals. Another way is using numerical and more accurate predictions by applying the PMV/PPD and two-node models. (ASHRAE 2005)

2.1.1.1. Bioclimatic and Comfort Charts for Different Climatic Contexts

Several psychometric or bioclimatic comfort charts are prepared by many researchers and professionals in order to understand the interaction between these various different climatic conditions and human thermal comfort. This is a simple method to analyze the local climatic conditions at a given place. These charts can help designers to find whether the local climatic conditions fall in the range of what is defined as the thermal comfort zone and to figure what passive and low-energy design strategies best suite these conditions."

The most commonly used two charts by researchers and professionals are Givoni's psychometric chart (Givoni 1976) and Olgyay's bioclimatic chart (Olgyay 1973).

Givoni's psychometric Chart (Figure 2.1) defines the temperature and humidity limits of thermal comfort. Besides highlighting the comfort area, different techniques are proposed for maintaining comfort at the upper and lower critical limits, such as, evaporative cooling for higher temperature limits and humidification for lower temperature limits.

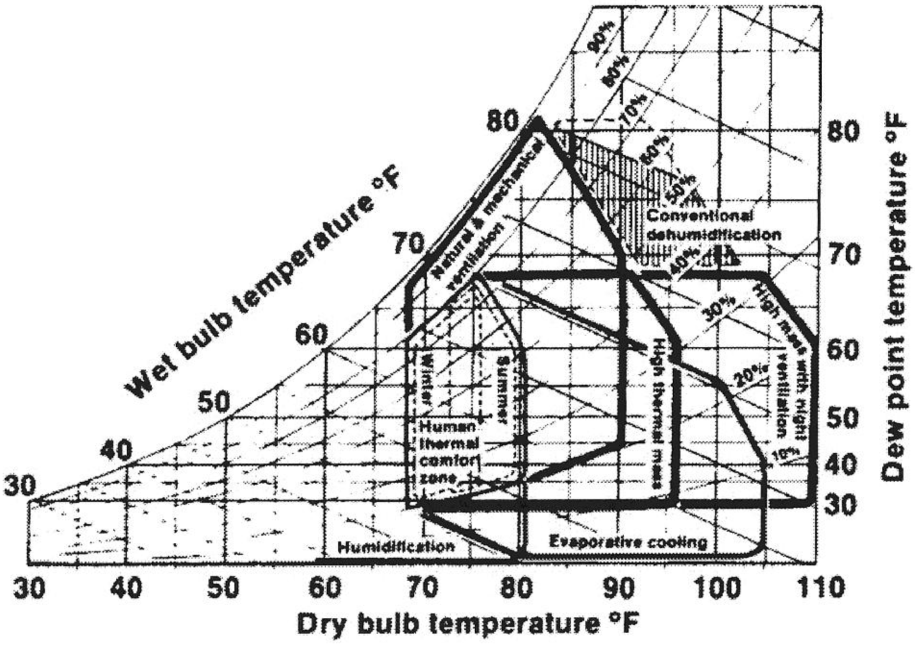


Figure 2.1. Givoni's Psychometric Chart
(Source: Givoni, 1998)

Olgyay’s Bioclimatic Chart gives the first relations of humidity (RH), temperature (dry-bulb), mean radiant temperature (MRT) and wind effect over one simple chart for moderate climate zone inhabitants in the US (Figure 2.2).

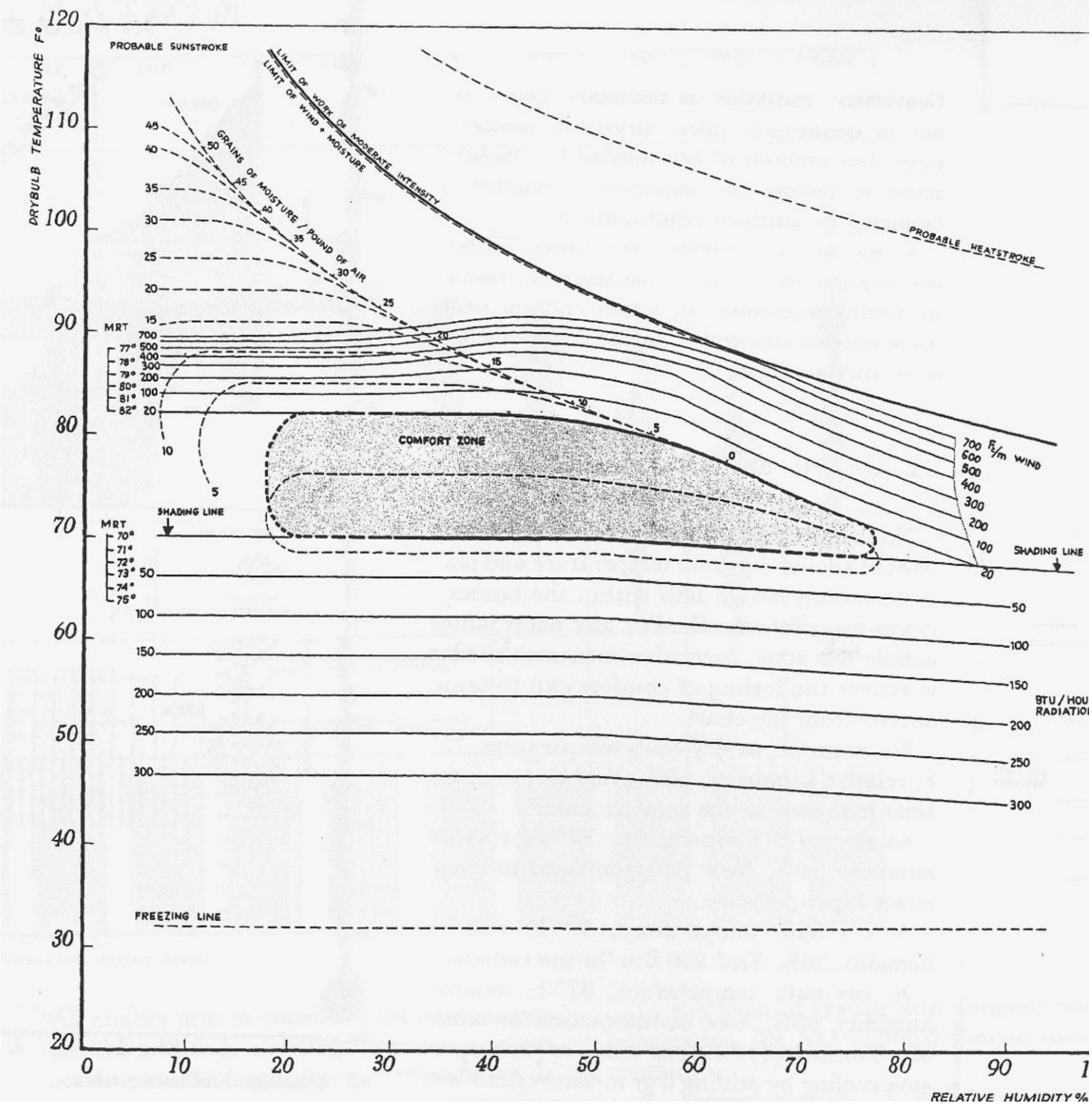


Figure 2.2. Olgyay’s Bioclimatic Chart for U. S. moderate zone inhibitants
(Source: Olgyay, 1973)

2.1.1.2. Numeric Models

Concerning the numeric models, the most commonly used ones are as follows: Fanger (1967, 1970), Gage and Hardy (1967), Hardy (1949), and Rapp and Gagge (1967) which give quantitative information on calculating heat exchange between people and the environment. The most commonly used models Gagge and Hardy (1967) and Fanger model are going to be described in detail. Both models assume that skin temperature and heat transfer over the skin are distributed homogeneously and consider the body as a whole.

Besides these two prevalent models, Stolwijk model (1971) is another model commonly used. This model presumes that the human body is defined in four parts: interior part, muscles, fats, and skin. Heat transfer in between defined parts happen by conduction and blood flow. Metabolic heat production is been distributed respectfully between different defined body parts. It is a more complex model and mostly used for studies concentrating specifically on body cycles and health (Atmaca, 2009).

2.1.1.2.1. Gagge Model

This model takes human body as two cylinders; one placed inside the other. (ASHRAE, 1993; Gagge et al., 1971; Gagge et al., 1986). The inside cylinder symbolizes the inner part of human body (core-skeleton, muscles, and inner organs), while the other cylinder symbolizes the skin layer. In this model, there is heat and mass transfer from outer cylinder to environment. According to Gagge Model:

a. The (core and skin) temperature of each section is uniform/ homogeneous.
b. Metabolic heat production, the heat loss caused by level of activity and respiration is related to interior cylinder (core part).
c. Heat transfer by conduction from the skin can be neglected.
d. Between two cylinders there's energy exchange by conduction and blood flow. Thermal energy stocked in unit time is equal to difference between heat gain and heat loss. This is defined by following two equations 2.1 and 2.2.

$$Scr = M - W - (Cres + Eres) - Qcr,sk \tag{2.1}$$

$$Ssk = Qcr,sk - (C + R + Esk) \tag{2.2}$$

$Scr = thermal\ energy\ stored\ inside\ the\ inner\ cylinder\ per\ unit\ time, \frac{W}{m^2}$

$Ssk = thermal\ energy\ stored\ on\ the\ skin\ per\ unit\ time, \frac{W}{m^2}$

$M = metabolic\ thermal\ energy\ production, \frac{W}{m^2}$

$$W = \text{mechanical activity}, \frac{W}{m^2}$$

$$Cres = \text{Convective heat loss by respiration}, \frac{W}{m^2}$$

$$Eres = \text{Evaporative heat loss}, \frac{W}{m^2}$$

$$Qcr, sk = \text{Conductive heat transfer from innercylinder to skin} + \text{Convective heat transferby blood flow}$$

$$C + R = \text{Heat loss from the skin}, \frac{W}{m^2}$$

$$Esk = \text{Total evaporative heat loss from the skin}, \frac{W}{m^2}$$

2.1.1.2.2. Fanger Model

This model considers human body in thermal-balance and presumes that energy stock does not exist. In this model, human body is accepted as a control volume with steady-state temperature, which is bounded by the skin layer. Fanger states that for a given metabolic rate, the skin temperature (Tsk) and sweat secretion (Esw) are seen to be the only physiological variables influencing the heat balance. The limiting values in which Tsk and Esw ensure thermal comfort vary with the activity level and from person to person. “It is considered as man’s thermal regulatory system is, to a certain extent, effective enough to create a heat balance within wide limits of the environmental variables, even if comfort does not exist” (Tablada, 2006, p.22).

According to Fanger Model, the human body is considered as one whole part, so control of body temperature by shivering and blood flow is neglected. Temperature is accepted as constant through time. There’s no heat storage according to Fanger model, thus the heat produced by body is equal to heat loss, as seen in equation 2.3.

$$M - W = Qsk + Qres = (C + R + Esk) + (Cres + Eres) \tag{2.3}$$

$$Qsk = \text{Total heat loss from skin}, \frac{W}{m^2}$$

$$Qres = \text{Total heat loss by respiration}, \frac{W}{m^2}$$

Fanger model also involves practical assessment of thermal environments. In between empirical-numerical models the most widely used thermal model is the

Predicted Mean Vote (PMV) first presented in 1970. PMV predicts the mean value of the votes of a large group of persons on a thermal sensation scale that has seven points (Butera, 1998). Thermal sensation of subjects is found in surveys, where people are asked to reply to the questions on: how do you feel? They can choose as a reply one of the descriptors on the ASHRAE or the BEDFORD scale. These surveys can be conducted in real buildings (known as field studies) or in controlled room in a laboratory (climate chamber) where the conditions are closely controlled and people are subject often in stationary thermal conditions for up to three hours. This ‘comfort vote’ of subjects is used to determine what temperature or combination of conditions they find most comfortable (the comfort temperature). There are two main scales that use the same number of points but with different semantic, the ASHRAE thermal scale and the Bedford’s scale. ASHRAE scale is as follows: -3: cold, -2: cool, -1: slightly cool, 0: neutral, 1: slightly warm, 2: warm, 3: hot. The Bedford’s scale is as follows: -3: much too cool, -2: too cool, -1: comfortably cool, 0: comfortable, 1: comfortably warm, 2: too warm, 3: much too warm. The PMV index has been accepted as international standard since 1980’s (ISO standard 7730) and in ASHRAE 55-1992. The PMV index was developed for steady-state conditions, but according to several researchers it can be applied with good approximation during minor fluctuations of one or more of the variables, provided that time-weighted averages of the variables are applied (Butera, 1998).

The relation of PMV to the imbalance between the actual heat flows required for thermal comfort at the specified activity is expressed in Fanger’s equation (Fanger, 1970, ASHRAE 2005).

$$PMV = [0.303\, exp\, (-0.036M + 0.028\, L)] \quad \textbf{(2.4)}$$

M: is the metabolic heat produced by the body (W/m), L: the thermal load on the body (W/m) defined as the difference between internal heat production and the heat loss to the actual environment for a person hypothetically kept at comfort values of Ta and Esw.

From the equation of PMV the percentage of dissatisfied people can be calculated using the Predicted Percent Dissatisfied (PPD) index that account for the people not voting in between -1 and +1. A PPD of 10% corresponds with PMV range of

±0.5 and even with PMV=0, around 5% of the people feel dissatisfaction. The formula is:

$$PPD = 100 - 95\, exp[-(0.03353PMV^4 + 0.2179PMV^2)] \quad \textbf{(2.5)}$$

2.1.2. Summary of Thermal Comfort Defined by ASHRAE 55-2004 and ISO 7730

ASHRAE Standard 55-thermal environmental conditions for human occupancy tries to specify combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% (Class B Comfort Criteria) or more of the occupants within a space(ASHRAE, 2005)

Thermal Comfort interval given by ASHRAE Standard 55-2005 can be read from the graphic if the metabolic rate and clothing state is defined as: 1.0 met<M< 1.3 met, 0.5clo<Icl<1.0 clo. Office staff mainly resembles this occupancy group. The graphic in Figure 2.3, the operative temperature interval resembles the acceptable temperature for 80% humans. The comfort interval is also valid if the air velocity is under 0.2 m/s.

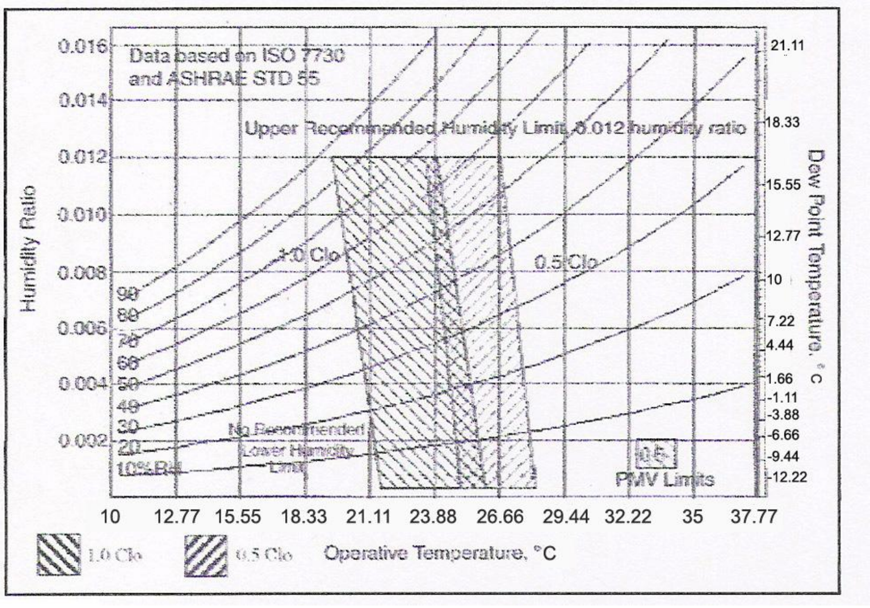


Figure 2.3. ASHRAE Standard 55 Thermal Comfort Chart
(Source: ASHRAE, 2005)

According to ASHRAE Standards and ISO standards, for summer (cooling) period, operative temperature is 24.5 ˚C±1.5 ˚C, relative humidity interval is between 30% and 70%, and horizontal temperature difference between 0.1 m and 1.1 m level from ground must be less than 3 ˚C. Mean air velocity level given in the stated operative temperature interval is 0.2m/sec at 10%-20% turbulence density. For winter (heating) period, operative temperature is 22 ˚C±2 ˚C, relative humidity interval is between 30% and 70%, and horizontal temperature difference between 0.1 m and 1.1 m level from ground must be less than 3 ˚C. Surface temperature of the ground level should be in between 19 ˚C and 26 ˚C (if the heating system is from the floor, this can exceed to 29 ˚C). The irradiation temperature asymmetry caused by window surfaces or other cold surfaces should not exceed 10 ˚C. Irradiation asymmetry caused by heating from the ceiling should be less than 5 ˚C. Mean air velocity level given in the stated operative temperature interval is 0.2 m/sec at 10%-20% turbulence density.

In ISO 7730, thermal comfort standards are also defined for sedentary conditions (M=70, W/m2=1.2 met) separately for cooling and heating periods. For these standards summer clothing defined by 0.5 clo and winter clothing by 1 clo. In this standard, variable combinations of PMV index for different clothing values, metabolic activity levels and air velocity values are defined in various tables. PMV index tables are available in following intervals:

- $0 \text{ clo} \leq I_{cl} \leq 2 \text{ clo}$
- $58 \text{ W/m}^2 = 1 \text{ met} \leq M \leq 232 \text{ W/m}^2 = 4 \text{ met}$
- $0.1 \text{ m/s} \leq v \leq 1 \text{ m/s}$

When warmer conditions are faced or with increased activity levels, the thermoregulatory control processes (vasomotor regulation and sweating) occur in order to dissipate the metabolic heat generated and maintain the heat balance of the body and its surrounding. In such conditions, the most important thermoregulatory control process is active perspiration. If the relative humidity is high, the latent heat dissipation ability of the body reduces depending on the increase in vapor pressure and the sweat rate increases over the body. Therefore, human feels discomfort due to increase in skin temperature and residual skin wettedness (Berglung 1998, Atmaca and Yigit, 2005).

As a last note, at high humidity, too much skin moisture tends to increase discomfort (Berlung and Cunningham 1986, Gagge 1937), particularly skin moisture of physiological origin (water diffusion and perspiration). At high humidity, thermal sensation alone is not a reliable predictor of thermal comfort (Tanabe et al. 1987). The discomfort appears to be due to the feeling of the moisture itself, increased friction between skin and clothing with skin moisture (Gwosdow et al., 1986), and other factors. To prevent warm discomfort, Nevins et al. (1975) recommended that on the warm side of the comfort zone the relative humidity not exceed 60% (ASHRAE 2005).

2.1.3. Thermal Comfort Expectations Changing According to Context (AC and NV buildings)

The thermal comfort zone is delimited by a lower, Tcl, and an upper comfort limit, Tcu. These limits vary with the season or, more precisely, mean monthly outdoor temperature. It is argued that the thermal comfort in naturally ventilated buildings has larger seasonal ranges than assumed by International Organization for Standardization (ISO)7730 and by American Society of Heating; Refrigerating and Air-conditioning Engineers (ASHRAE)55 standards (de Dear et al, 1997; Brager and de Dear, 1998; Nichol and Humpherys, 2002). On the contrary, field studies have shown that indoor temperatures in fully HVAC-controlled buildings have a mean temperature of 23^{o}C, with a standard deviation of 1^{o}-1.5^{o}C and a seasonal shift of 0.5^{o}-1^{o}C, which is narrower than the range of 3^{o}C and the seasonal shift of 3^{o}C required by ASHRAE Standard 55 (Fountain et al, 1996 in Santamouris, 2006) (See Figure 1.15).

First step must be to recognize that comfort depends on context. As explained in the ASHRAE standards:

People living year-round in air-conditioned spaces are quite likely to develop high expectations for homogeneity and cool temperatures, and may become quite critical if thermal conditions in their buildings deviate from the centre of the comfort zone they have come to expect. In contrast people who live and work in naturally ventilated buildings where they are able to open windows, become used to thermal diversity that reflects local patterns of daily and seasonal climate variability. Their thermal perceptions–both preferences as well as tolerances–are likely to extend over a wider range of temperatures than are currently reflected in old ASHRAE standard 55 comfort zone. (R. J. de Dear, Gail S. Brager, Energy and Buildings 34, Thermal Comfort in naturally ventilated buildings: revisions to ASHRAE Standard 55, p. 550).

Ventilation plays a major role in maintaining acceptable thermal comfort and improving energy performance. The thermal behavior of a building is strongly coupled with ventilation and air infiltration. Airflow depends on different thermal levels of the building zones. In the absence of wind, these differences are the only driving forces for ventilation (Givoni, 1976).

Air conditioning systems can be accepted as the mandatory innovation for thermal comfort standards of large constructions, yet the effect of natural ventilation can decrease the energy consumption needs, especially for summer conditions. Natural ventilation and the effect of air flow on thermal comfort are applications to be used for adaptive studies even in AC buildings.

2.1.4. Adaptive Approaches for Thermal Comfort

With the support of the field studies performed all around the world simultaneously, effect of minor facts, which was previously observed by Fanger, are opened to discussion. Other researchers questioned these facts and some adaptive approaches are driven with these changing adaptations of human beings.

2.1.4.1. Humpherys and Nicol's Approach

The Adaptive Approach to thermal comfort (Humpherys and Nicol, 1998) has been developed from field studies of people in daily life. While lacking the rigour of laboratory experiments, field studies have a more immediate relevance to ordinary living and working conditions (de Dear, 1998, Humpherys 1975, Auliciems, 1981). The adaptive method is a behavioral approach and is based on the observation that people in daily life are not passive in relation to their environment, but tend to make themselves comfortable by adjusting (adaptations) their clothing, activity and posture, as well as to their thermal environment. Humpherys plotted indoor outdoor monthly mean temperatures as shown in Figure 2.4 based on data from surveys performed worldwide.

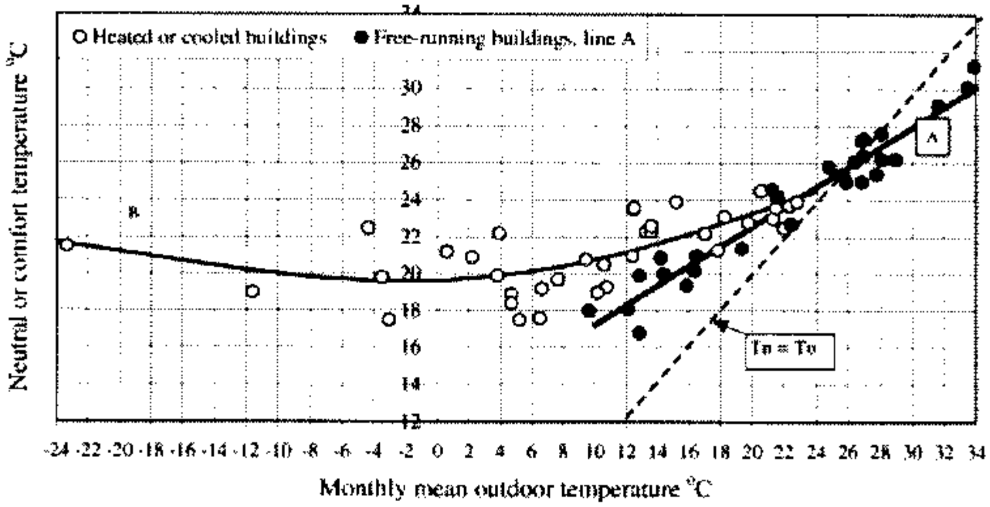


Figure 2.4. Nicol and Humpherys Adaptation Chart
(Source: Nicol and Humpherys, 1998)

Over time people tend to become well-adapted to thermal environments they are used to, and to find them comfortable. Adaptation is assisted by the provision of control over the thermal environment to give people the opportunity to adapt. A control band of ±2 K should be sufficient to accommodate the great majority of people (Nicol and Humpherys, 2007). Humpherys derived the following formula out of the plotted graphic in Figure 2.4.

$$Tcomf = 13.5 + 0.54\,Tmmo \qquad \textbf{(2.6)}$$

$$Tmmo = the\ monthly\ mean\ outdoor\ air\ temperature,\ {}^{\circ}C$$

Equation 2.6 pretend to offer a standard of ‘good practice’ rather than a standard or a methodology of rational indices that according to the authors are difficult to use in real situations and are poor indicators of comfortable conditions in buildings in order to help designers make decisions about successful strategies in terms of the design of the building (Nicol, Humphreys, 2002, p. 556).

2.1.4.2. Prianto and Depecker's Approach

Prianto and Depecker suggest using a new PMV based on the original PMV equation (Equation 2.4 in Section2.1.1.2.2) but replacing the operative temperature (To) of PMV equation with standard effective temperature (SET).

2.1.4.3. Adaptation of Fanger's Model, ASHRAE and ISO Approaches

ASHRAE and ISO standards derived by Fanger's, Humphery's, and Storwijk's thermal comfort models are being questioned regarding their avoidance of different behaviours of people in various climatic regions.

ASHRAE Standard 55 is currently based on the heat balance model of the human body, which assumes that thermal sensation is exclusively influenced by four environmental factors, namely temperature, thermal radiation, humidity and air speed; and two personal factors, namely activity and clothing. An alternative (and complementary) theory of thermal perception is the adaptive model, which states that factors beyond fundamental physics and physiology play an important role in building occupants' expectations and thermal preferences. Thermal sensations, satisfaction, and acceptability are all influenced by the match between one's expectations about the indoor climate in a particular context, and what actually exists (Fountain, 1997, Brager, de Dear, 1998).

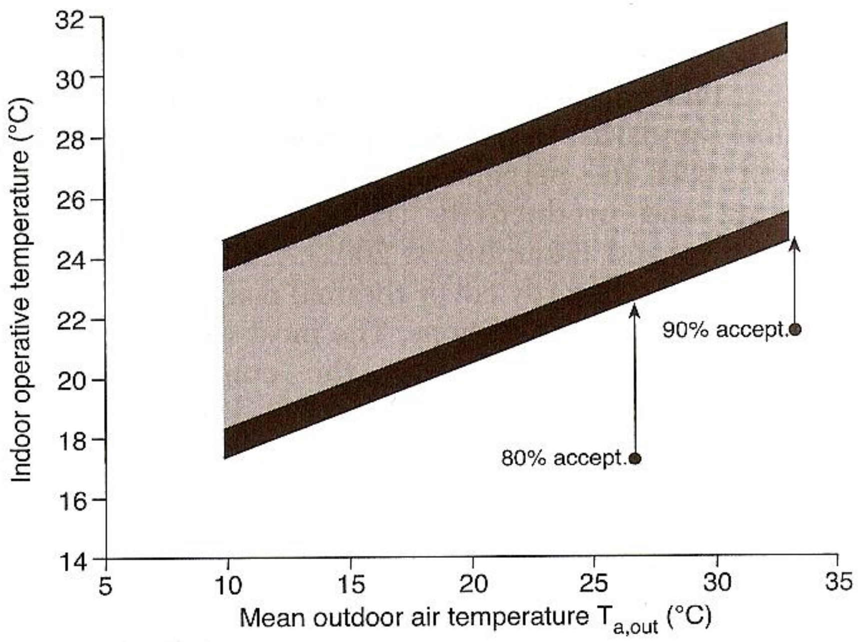
While the heat balance model is able to account for some degrees of adaptation such as changing one's clothing or adjusting local air velocity, it ignores the psychological dimension of adaptation, which may be particularly important in contexts where people's interactions with the environment (i.e. personal thermal control), or diverse thermal experiences, may alter their expectations, and thus, their thermal sensation and satisfaction (de Dear, Brager, 2005, p. 549).

Adaptive comfort standard proposed by de Dear and Brager in 2002 for ASHRAE is still used. It is a regression equation that relates the neutral temperature indoors to the monthly average temperature outdoors.

$$T_{comf} = 0.31\, T_{a,out} + 17.8 \tag{2.7}$$

$$T_{a,out} = \text{the mean outdoor dry bulb temperature}$$

After averaging the comfort zone widths across all the NV buildings used for the study, the reported mean comfort zone band can be followed from Figure 2.5. According to these charts there’s a range of 5 ˚C differences for 90% acceptability level and 7 ˚C for 80% acceptability level in operative temperature ranges in naturally ventilated spaces (ASHRAE, 2003). This standard is accepted in the revision of ASHRAE 55 Standards in 2005.



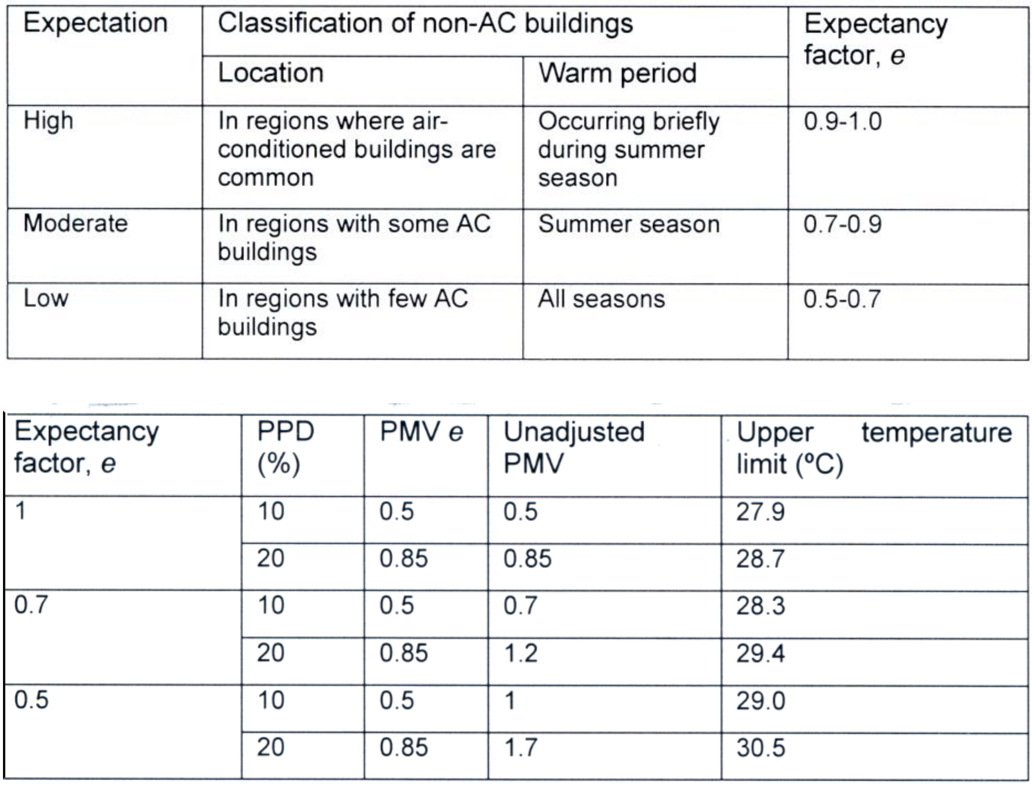
Source: De Dear and Brager (2002)

Figure 2.5. Adaptation Graph of Standard, ASHRAE 55
(Source: ASHRAE, 2003)

2.1.4.4. Fanger’s Approach and Critique

Fanger criticizes the ASHRAE 55 model because it uses one single variable of average monthly outdoor temperature, which at its highest may have an indirect impact on the human heat balance. After the criticism of the previous model derived by Fanger (1970), he also worked on the model and proposed an alternative solution for different expectations. Extension of the PMV model to non-air-conditioned buildings in warm climates includes an expectancy factor *e* estimated to vary between 1 and 0.5. This expectancy factor is multiplied by the PMV to reach the mean thermal sensation vote of the occupants and it is 1 in air-conditioned buildings, which the Fanger model founded successful at prediction by various different authors. According to Fanger, occupants of non-air-conditioned buildings in warm climates may perceive the warmth as being less severe than the PMV predicts and this is mainly caused by low expectations (P. Ole Fanger, and J. Toftum, 2002). The adaptation of human body to context they live in is an issue to be studied further, especially with regards to the winter indoor thermal expectations of people of warmer climates and colder climates, which are considerably different.

Table 2.1. Expectancy factors for non-air-conditioned buildings in warm climates (Source: Tablada, 2006, pp. 40-41)



Expectation	Classification of non-AC buildings		Expectancy factor, *e*
	Location	Warm period	
High	In regions where air-conditioned buildings are common	Occurring briefly during summer season	0.9-1.0
Moderate	In regions with some AC buildings	Summer season	0.7-0.9
Low	In regions with few AC buildings	All seasons	0.5-0.7

Expectancy factor, *e*	PPD (%)	PMV *e*	Unadjusted PMV	Upper temperature limit (ºC)
1	10	0.5	0.5	27.9
	20	0.85	0.85	28.7
0.7	10	0.5	0.7	28.3
	20	0.85	1.2	29.4
0.5	10	0.5	1	29.0
	20	0.85	1.7	30.5

2.1.5. Discussions on the Effect of Air Flow over Human Thermal Comfort

Indoor air movement is related to air movement around the building or building groups. Morphology and building geometry have effect on natural air accessing indoors and this subject is studied more and more by various researchers. Briefly, use of natural ventilation during the daytime has three objectives:

- Cooling of the indoor air as long as outdoor temperatures are lower than the indoor temperatures;
- Cooling of the structure of the building;
- A direct cooling effect over the human body (through convection and evaporation).

As suggested by Allard and Santamouris:

> If the natural ventilation takes place during the night-time, the objective is to use the thermal mass of the building as an intermediate storage medium, which enables us to use during the day the coolness stored during the previous night (This is only applicable to office buildings where the building is not occupied during the night.) (Allard and Santamouris, 1998, p.41).

However, in hot and humid regions day and night time temperature differences are not so big and night time cooling is not effective. Natural ventilation is preferred during the day hours. Air speed caused by the ventilated air may have a major effect on the thermal feeling of the occupants. Higher air velocities increase the evaporation rate over the skin surface and give a cooler sensation. This is produced because the air movement determines the convective heat and water mass exchange of the human body with the surrounding air (Allard and Santamouris, 1998).

The air temperature and humidity combined in the enthalpy have a strong impact on the perceived air quality, and perceived air quality determines the required ventilation in ventilation standard. In tropical humid and temperate humid climates obtaining the comfort conditions in the buildings is possible with sufficient interior air velocity. Air movements inside a building depend not only on external wind velocity, but also a number of architectural design element (Prianto and Depecker, 2003).

2.1.5.1. Approaches of Thermal Comfort Range of the Researchers Working in the Area

There is not a definite agreement on the effect range of air flow on human thermal comfort as explained in thermal comfort standards, however the effect is accepted. Air velocity factor cannot be directly related with the increase of thermal comfort level, yet there are many studies which subject the positive effect of controlled air velocity on the acceptability of higher operative temperatures in hot climate conditions. These studies all work with summer conditions and Free-Running FR (NV and NV/AC combination) buildings.

According to Givoni, natural ventilation can reduce the heat sensation under temperatures about 33 ˚C. Between 33 ˚C and 37˚C, air speed does not affect significantly the thermal sensation, although it might produce discomfort if the humidity value is low. With higher air speed control of those air speed values people admit higher temperatures and can achieve the same level of acceptability as with lower airspeed and lower temperature combinations (Tablada, 2006).

ASHRAE Standard 55-thermal environmental conditions for human occupancy include a new adaptive comfort standard (ACS) that allows warmer indoor temperatures for naturally ventilated buildings during summer and in warmer climate zones (De Dear, Brager, 2002). One context where these factors play a particularly important role is naturally ventilated buildings.

Air speed required offsetting increased temperature according to ASHRAE 55 is given in the chart in Figure 2.6.

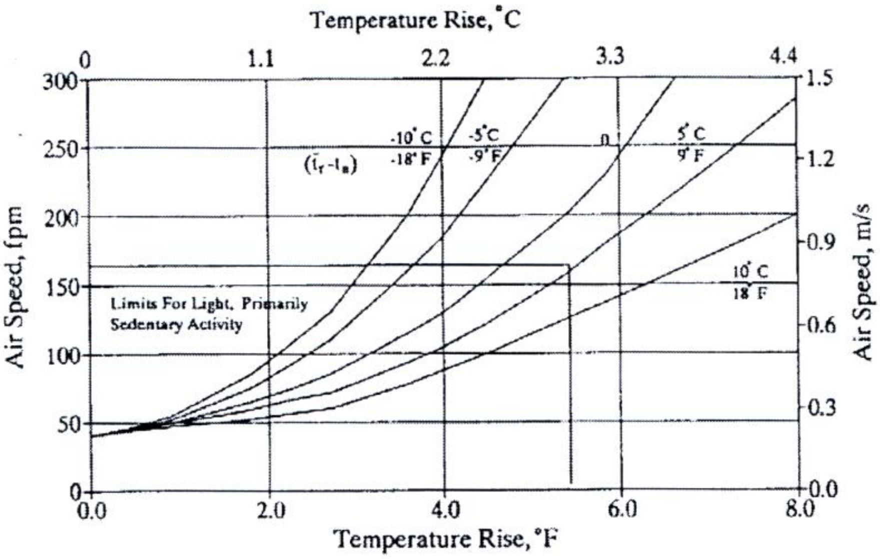


Figure 2.6. ASHRAE Temperatures Offset Chart
(Source, ASHRAE, 2003)

There are limits for the increase of airspeed according to the function and requirements of the room. ASHRAE 55 Standard recommends a limit for indoor airspeed of 0.8 m/s as higher speed values can produce paper loss. Such air velocities permit one to maintain a room about 2 ˚C warmer, at for example 60% relative humidity, and still maintain optimum comfort.

Tanabe's study (Tanabe et al., 1987, pp.546-577) about comfort reactions of subjects to various air velocities revealed that preferred air velocities at 50% of RH were from 1 m/sec at 27 ˚C to 1.6 m/sec at 31 ˚C. According to the PMV-model, that would be felt equally warm by a subject wearing 0.6 clo; both above the upper limit proposed by ASHRAE.

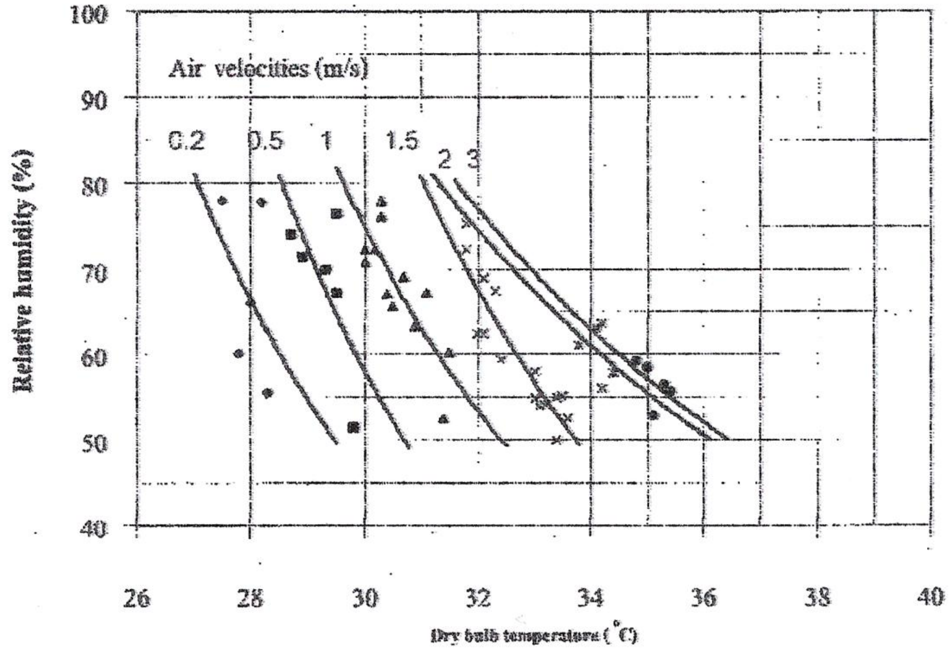


Figure 2.7. Adaptation in Humid Climates (Thailand Ventilation Comfort Chart)
(Source: Tanabe, 2000)

Tanabe also cites the study of McIntyre (1978), where the test subjects are allowed to control the speed of overhead ceilings fans. It is analyzed that subjects increased airspeed up to 2 m/sec at 30˚C temperature level. In a comprehensive physiological research of the McIntyre, the effect of airspeeds on comfort and general feeling of pleasantness was monitored, up to a speed of 4 m/sec. Also, airspeed of 2 m/sec was comfortable for subjects without noticing excessive wind (Givoni, 1998).

In another study of Kimura and Tanabe (Recommended air velocity against combinations of temperature and humidity for sedentary occupants in summer clothing, 2004) it is shown that higher air velocities are required in order to maintain the thermal comfort sensation when the evaporative cooling is suppressed by the increasing of relative humidity at high temperatures (Figure 2.7).

In Wu’s study relation of temperature and absolute humidity with air flow effect on comfort is being questioned. At 31˚C and humidity ratio of 14.5 gr/kg, the subjects felt less comfortable than at higher temperatures 32 and 33˚C but with lower humidity. At very still air (0.1 m/sec) humidity had more of an effect than temperature, however at airspeeds higher than 0.25m/sec lower discomfort was experienced at 32˚C and 12 gr/kg than at 33˚C and 11 gr/kg. At all combinations of temperature and humidity increasing the air speed reduced systematically the thermal sensation (Givoni, 1998).

A study conducted in Thailand by Khedari (2000) suggests using natural ventilation and fans all the time if outdoor-indoor temperatures are below 34 ˚C. When outdoor temperature is above 34 ˚C, air speed values higher than 3 m/sec are needed. This limit is argued with its cause of disturbance by the noise of the fans.

Rohles et al. (1983) and Scheatzle et al. (1989) demonstrated that if the air movement was created by a ceiling fan, the acceptable air velocities could be extended to an effective temperature of 29 ˚C at 1 m/s with comfort remaining the same as at lower temperatures and still air. These studies focused mostly on overall thermal sensation and comfort.

In conclusion, even for the same individual, sensitivity to air movement may change from day to day as a result of, e.g., different levels of tiredness. At temperatures up to 22-23 ˚C, at sedentary activity and with occupants feeling neutral or cooler there is a risk of air movement being perceived as unacceptable, even at low velocities. In particular, a cool overall thermal sensation negatively influences the subjective perception of air movement. With occupants feeling warmer than neutral, at temperatures above 23 ˚C or at raised activity levels, humans generally do not feel draught at air velocities typical for indoor environments (up to around 0.4 m/s). In the higher temperature range, very high air velocities up to around 1.6 m/s have been found to be acceptable at air temperatures around 30 ˚C. However, at such high air velocities, the pressure on the skin and the general disturbance induced by the air movement may cause the air movement to be undesirable. At high heat loads, air movement can increase the cooling effect and maintain thermal comfort at elevates temperatures. (Toftum, 2004, p.40)

With air velocities fluctuating according to different fluctuation patterns (sine wave, constant, random, pulse), Kimura et al. (1993) showed that fluctuating air movement of a sine wave nature made the subjects feel cooler than did other fluctuation patterns. Kimura and Tanabe (1993) presented a relationship between air velocity and operative temperature that takes into account the effect of air movement on clothing insulation and skin wettedness (Toftum, J., 2004, p.42).

2.1.5.2. Indoor Air Quality Needs for AC and NV Buildings

Ventilation may also have harmful effects on indoor air quality and climate if not properly designed, installed, maintained and operated. Ventilation may bring indoors harmful substances or deteriorate indoor environment. Ventilation interacts also with the building envelope and may deteriorate the structures of the building and may cause or prevent infiltration of pollutants from structures or adjacent spaces (Toftum, 2004).

Minimum ventilation rate[5] is required to dilute odors and the concentration of CO_2 to an acceptable level, and to provide oxygen for occupant needs. Amount of fresh air needed to satisfy these requirements can vary greatly as a function of occupation and occupant activity; these determine the rate of production of occupant-related pollutants (cigarette smoke, body odours, carbon dioxide and water vapor). A typical range is from a minimum of 5 litre/s (90 m^3/h) per person for heavy smokers. Minimum ventilation rates for hygiene requirements are usually set by national building codes and environmental standards; recommended ventilation rates are also indicated in the European Prestandard P762:1994 (Allard, 1998, p. 203)

The IAQ varies over time as a function of the ventilation rate and the rate of pollutant production. Hence, the ventilation effectiveness is not only a function of the average ventilation rate over a given period, but also a function of the ratio of air change to the pollutant concentration. This is particularly important in spaces, such as in classrooms, with a concentration of occupants for some period of the day.

Quantitative air change requirements are currently set for spaces supplied with mechanical ventilation systems, whereby a fixed air change rate can be provided over a given period of time. When natural ventilation is the only air change system applied in a building, a fixed air change rate cannot be achieved. A variable daily profile for air change requirements would fit better with the characteristics of natural ventilation.

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[5] The ventilation rate in buildings can be expressed in terms of air changes per hour (arch), i.e. the number of times in an hour that a volume of air equal to the volume of a room or building is renewed with fresh outdoor air; this can also be given in litres per second (litre/s), or cubic meters per hour (m^3/h). (Allard, 1998)

Standard air change requirements should then be considered in terms of average values, obtainable for the whole day (or for a considered period), when natural ventilation is applied.

Rajapaksha (2003) discusses another subject in his study of Sri Lanka; it was found that higher air rates improved thermal conditions inside a courtyard house, but until certain limits. One of the conclusions in this study is that optimum comfort is achieved with ventilation rates of 1.5 to 2 air changes per hour, which is very low air change rate for naturally ventilated buildings.

2.1.6. The Comfort Chart Defined for This Specific Study

The experimental results of the measurements conducted in Alaçatı will be evaluated according to spread sheets prepared with different bioclimatic and thermal comfort zone charts blended for climate of the city; and will be discussed with further information about the air flow effect on thermal comfort.

ASHRAE Thermal comfort chart revised in 2005 will be the main model explained for thermal comfort conditions of humans in detail. The thermal comfort indices of Izmir, Turkey will then be reinterpreted with the syntax of Bioclimatic chart of Olgyay and ASHRAE thermal comfort chart defined with Test Reference Year Values of Izmir (Figure 2.8 & Figure 2.9). Detail limitations given in the chart can be found in Section 4.6.4.

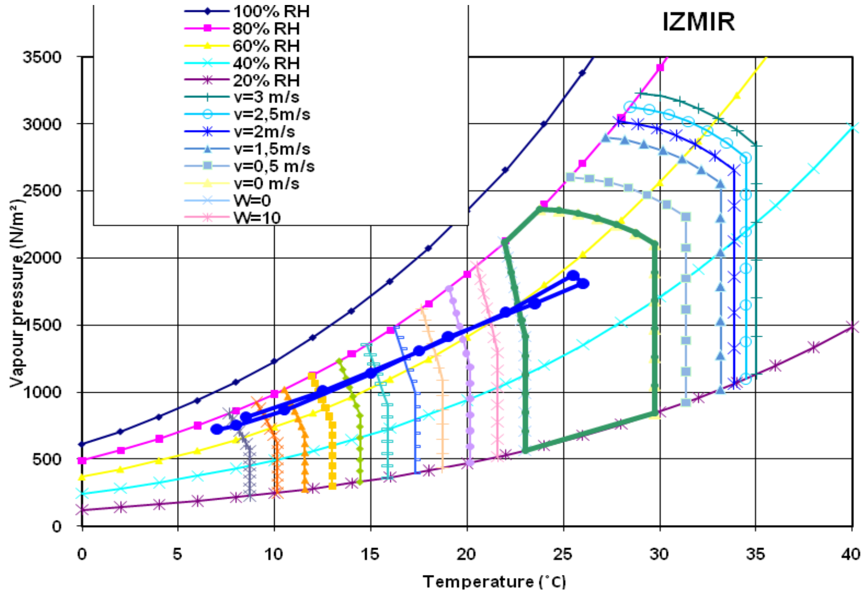

Figure 2.8. ASHRAE Comfort Chart with Mean Monthly Values for Izmir 38.5˚
(Source: Spreadsheet of Prof. Frank De Troyer, KUL)

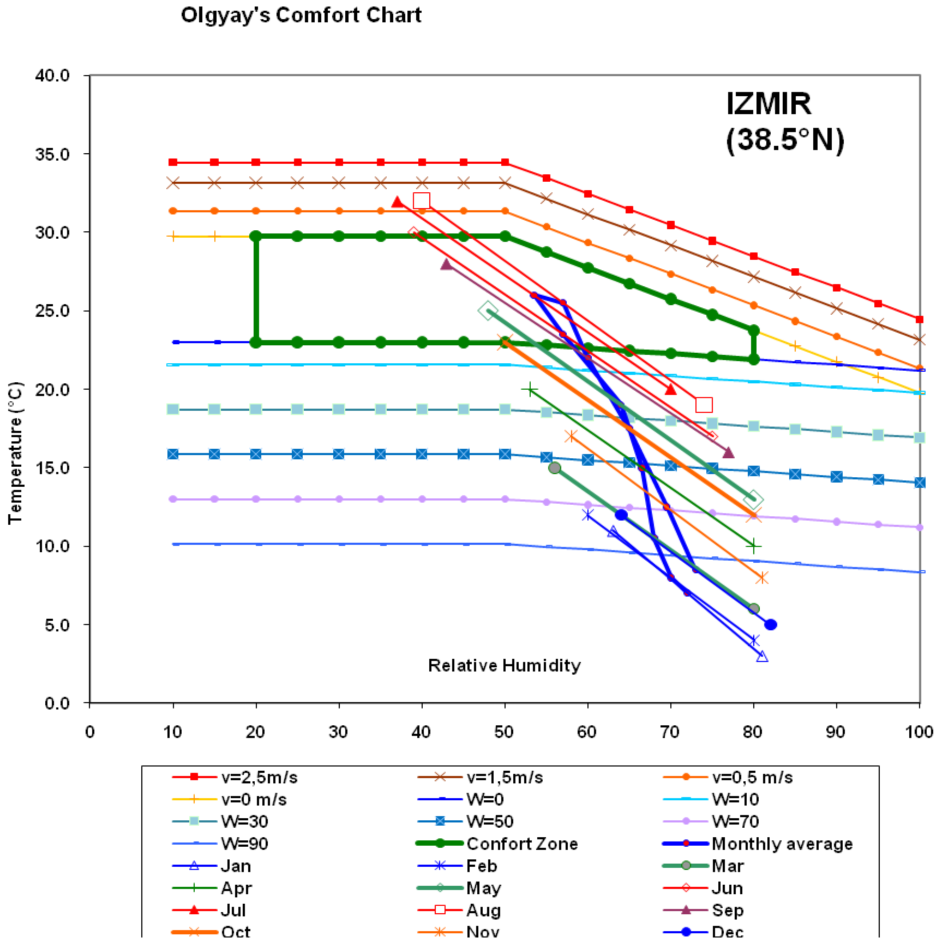

Figure 2.9. Olgyay’s Comfort Chart with Mean Monthly Values for Izmir 38.5˚
(Source: Spreadsheet of Prof. Frank De Troyer, KUL)

The above chart is an adaptation of bioclimatic chart adapted by Olgyay for U.S moderate climate in Figure 2.2. According to Test Reference Year (TRY) climatic values of Izmir the two of the above charts could be developed. Further explications about the limits in the chart and their usage can be found in Chapter 4.

2.2. Wind Flow and Natural Ventilation Effect on Thermal Comfort

According to Peguy (1970), there are eight types of air mass over the total surface of the globe: arctic air; continental (dry) or maritime (humid) polar air, warming or not; continental (dry) or maritime (humid) tropical air; and equatorial air. Beyond the limits of the regions where these air masses are formed, the climate is influenced by the more or less rapid passages of the air masses through each region. This occurs particularly in temperate regions, such as Western Europe, where there is a conflict between various air masses (Peguy, Ch.P., 1970, Precis de Climatologie,Masson& Cie, Paris). The context of his study is Mediterranean temperate hot climate (see Section 3.1 for details).

2.2.1. General Characterization of Wind Flow in Urban Environment

Temperature differences create pressure differences that drive the movement of air defined as winds (Stull, 2000). The strength of the pressure differences determines the wind speeds. Wind is a transient flow with high variability of speed and direction (Tablada, 2006). There are both turbulent and laminar (free-stream) flows. The dimensionless Reynolds number characterizes whether flow conditions are laminar or turbulent[6].

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[6] Turbulent flow is distorted in patterns of great complexity containing both coarse and fine features. The flow is said to contain eddies, regions of swirling flow that, for a time, retain their identities as they drift with the flow, but which ultimately break up into smaller eddies. ..Mathematical analyses of steady laminar viscous flows show that infinitesimal disturbances to the flow can grow exponentially with time whenever the Reynolds number is sufficiently large. Under these conditions, the flow is unstable and cannot remain steady under practical circumstances because there are always some disturbances that may grow spontaneously. The most rapidly growing disturbances are those whose size is comparable to the transverse dimension of the flow. These disturbances grow to form the largest eddies, with a velocity amplitude of generally 10 percent of the average flow speed. These large eddies are themselves unstable, breaking down into smaller eddies and being replaced by new large eddies that are continually being generated. (Santamouris & Wouters, 2006)

Terrain roughness and thermal instabilities mainly affect the wind velocity and turbulence. When the roughness of the ground surface is high, the wind speed is lower and the turbulence near the ground is greater. Therefore, the size and geometry of buildings, also the pattern and spacing of the objects in the urban area greatly affect the wind characteristics and the aerodynamic roughness length (y_o) (Jia, and Sill, 1998). The aerodynamic roughness length "…indicates the extent of influence of terrain roughness on wind speed and longitudinal turbulence: the more uneven the terrain (building height and density), the longer the extent of roughness, increasing the effect of friction on wind speed retardation" (http://www.disaster-info.net/viento/english/Structural.htm). However, for higher densities than PAD[7] =0.25, the relative roughness length y_o/h (where h is the average height of the elements) decreases because the interference of individual wakes weakens their role in producing turbulence (Oke, 1988 in Tablada 2006).

The mean wind velocity over uniform level surface can be described by a logarithmic function of the height above the ground as seen in Equation 2.8.

$$U(y) = \frac{u*}{K}\ ln\left(\frac{y}{y^0}\right)$$

(2.8)

The mean velocity is zero (U=0) at the reference height $y = y_o$ where y_o is the aerodynamic roughness length; u* is the friction velocity which represents the magnitude of the velocity fluctuations in the turbulent boundary layer; and κ is the Von Karman constant ≈ 0.42. This profile is generally used as an inlet boundary condition for wind-tunnel studies and computer simulations to take into account the roughness conditions upstream of the model (Blocken, 2004).

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[7] PAD: Plan Area Density

Table 2.2. Roughness length and class
(Source: Wieringa, 1991 in Allard, 1998, p. 14)

Type of surface	Roughness length(y0)	Roughness class
Sea, snow, sand	0.0005	I
Sea with very strong wind	0.005	II
Short grass	0.01	III
Cultivated open fields	0.05	IV
High plants, open country	0.1	V
Countryside and spread habitat	0.25	VI
Peripheral urban zone	0.5	VII
Mean city centre, forest	1.0	VIII
Metropolitan centre, tropical forest	4.0	IX

Table 2.2 shows the values of the roughness length for different types of terrain. When the density of buildings is high (PAD>0.25), the apparent level of the ground alongside the flow is raised. Therefore, the concept of displacement height (d_o) is introduced in the formulation of the vertical velocity profile in Equation 2.9:

$$U(y) = \frac{u_*}{K} \ln \left[\frac{y - d^0}{y^0} \right] \tag{2.9}$$

Where d_o is around (0.7 to 0.8) h_o (Allard, F., 1998) and y_o is the average height of the environment. In cases where homogeneous obstacles occupy more than 60% of the ground area, i.e. old city centers, the value of d_o can be considered equal to y_o. This is the case of the simulations in this thesis in which we consider the roof of the buildings as a ‘ground’ level and the street canyon as an ‘underground’ cavity or space. Then, roughness length takes into account the variability of the roof levels instead of the depth of the urban canyon.

Mean wind speed is ideally measured at a meteorological station in flat, open terrain at 10m above the ground. In this study, portable meteorology station placed on flat/terrace roof level that enables the measurement of wind profile exactly in the roof level with all the side effects of obstacles in the area. Also there are wind measurements obtained from another station facing the measured area up at 60m level. These actual wind speeds (U) measured of the studied site must be adjusted for a specific height. This can be calculated using several different wind profiles, however ASHRAE power-law formula[8] is preferred.

ASHRAE power-law formula calculates the hourly average wind speed Uz at wall height z in the undisturbed wind approaching a building in its local terrain from Uref: (Tablada, 2006, p.51)

$$Uz = Uref\left(\frac{href}{zref}\right)^{\alpha ref}\left(\frac{z}{h}\right)^{\alpha} \tag{2.10}$$

Values of the wind boundary layer thickness h and exponent α is shown in Table 2.3, Uref is the wind speed at the meteorological station and generally correspond with values of αref=0.14 and href=270m for the case of this specific study.

Table 2.3. Atmospheric Boundary Layer Parameters
(Source: Tablada, 2006, p. 51)

Terrain characteristics	**Exponent α**	**Layer thickness h**
Flat, unobstructed areas exposed to wind flowing over water for at least 1.6 km, over a distance of 500m or 10 times the height of the structure inland, whichever is greater	0.1	210
Open terrain with scattered obstructions having heights generally less than 10m. including flat open country typical of meteorological station surroundings	0.14	270
Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of a single-family dwellings or larger, over a distance of at least 2000m or 10 times the height of the structure upwind whichever is greater	0.22	370
Large city centres, in which at least 50% of building are higher than 21m, over a distance of at least 2000m or 10 times the height of the structure upwind whichever is greater	0.33	460

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[8] See Section 5.2.1.4 for information on how it is calculated for this study case.

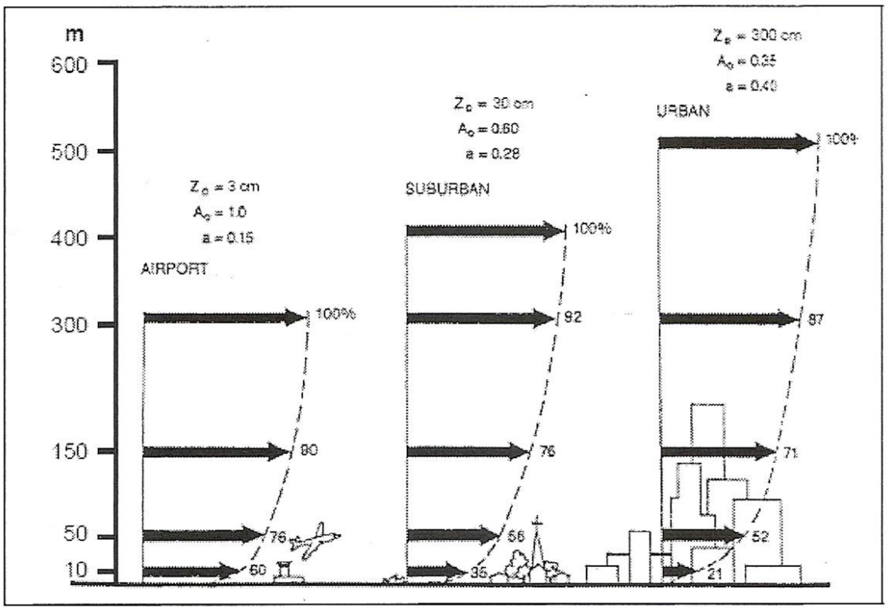

Figure 2.10. Typical wind speed profiles over different terrain roughness according to the ASHRAE model 177 (Source: Yuill in Heimans; Wouters, 1990)

Figure 2.10 illustrate vertical gradients of the wind for three different terrain types. In areas without obstacles maximum speed is obtained at lower height than in the high-density built-up areas. The speed, according to the scheme, increases logarithmically from 0 m/s at ground level (see Equation 2.6 & 2.7).

In dense cities, at ground level close to zero wind speed does not occur because important gusts of winds are frequently produced at one to three meters above the ground level. That is why this scheme is not applicable when analyzing the flow of wind within an urban plot (Dequeker, 1993) or under a minimal height equal to 20 times the terrain roughness, i.e. canyon streets (Wouters, 2002 in Tablada, 2006)

2.2.1.1. Wind Flow in Urban Environment

Daily cycle of irradiative heating causes a daily cycle of sensible heat fluxes between the earth and the air. These fluxes cannot directly reach the whole atmosphere. They are confined by the troposphere to a shallow layer near the ground (Figure 2.11). This layer is called the atmospheric boundary layer (ABL) and it experiences diurnal cycles of temperature, humidity, wind, and pollution variations. Meteorological conditions in an urban environment are different from those in a rural area. Turbulence is also familiar with the effect of these variations in the ABL. Boundary layer (BL) is the closer layer over earth seen in Figure 2.10, where people live and change its nature. (Stull, 2000, p.65; Yoshida, 1991, p. 417).

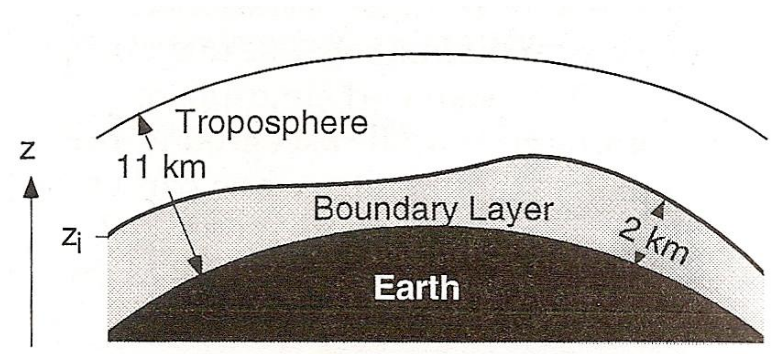

Figure 2.11. Location of the boundary layer, with top at z_i
(Source: Meteorology for scientists and engineers, RolandB.Stull, p65)

According to Oke (1983), the urban atmosphere (boundary layer) is divided into several layers as can be seen in Figure 2.12, PBL is the planetary boundary layer and UBL is the Urban Boundary Layer. The latter is influenced by the layer next to the level of the ground which is UCL Urban Canopy Layer, which has its upper limit at the average level of the buildings' roofline.

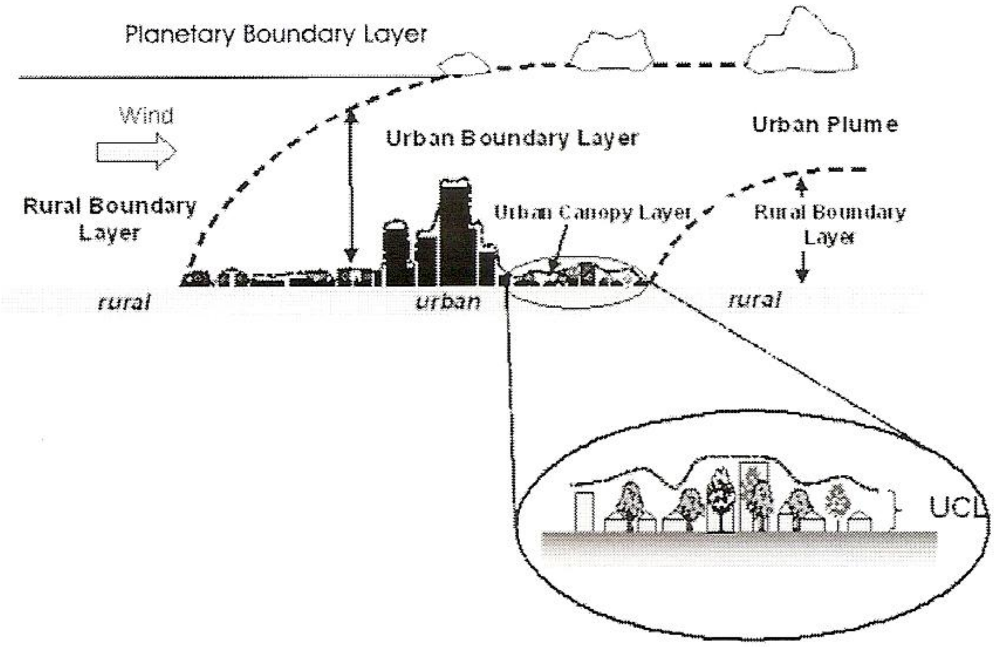

Figure 2.12. Schematic arrangement of the main components of the boundary layer structure over a city (Source: Voogt,J.A., Urban Heat Islands: Hotter Cities, 2004 -httpwww.actionbioscienceorgenviorenmentvoog-)

In an urban environment, buildings, trees and numerous irregular obstacles increases the roughness of the ground compared with the rural environment and the seaside. For moderate to strong winds, and for a height of 20 m above the ground reduction of 20% to 30% in the average wind speed is observed in urban environments compared with nearby rural lands (Allard, 1998, p. 22; Landsberg, 1981, Givoni, 1998). Yet, the roughness produced by the urban geometry can generate an increased turbulence intensity of 50% to 100%. With strong winds, friction due to urban conditions also creates a cyclonic rotation of the flow (up to 10^o). Furthermore, weak winds and calms are 5% to 20% more common in the city than in clear areas. But, since the differences of dynamic pressures in cities become the energizer mechanism of the air (Diaz, 1996), when free-stream wind velocities are less than around 4 m/sec, the wind speed in the city centre is higher than in the periphery of the city due to the increased turbulence (Allard, 1998, p.22).

Givoni (1998) summarizes four urban elements as the most important in the change of the wind's condition in the cities:

- The overall density of the urban area.
- Size and height of the individual buildings; existence of high-rise buildings.
- Orientation of the streets.
- Availability, size, distribution, and design details of open spaces and green shelter belts.

Urban environment has its own airflow nature and the most problematic airflow effect can be stated as the urban heat-island effect[9]. “The heat island phenomenon may occur during the day or during the night. The intensity of the heat island is mainly determined by the thermal balance of the urban region and can result in a temperature difference of up to 10 degrees” (Santamouris, 2001). Urban heat-island effect is related to temperature difference between the urban and the suburban or rural areas, thus additional wind flows occur in the city centres. Factors influencing the heat-island effect include climate, topography, physical layout and short-term weather conditions. This phenomenon is most common during periods of calms during the night and it generates, among other effects, a convective movement of the wind. The hot air (emitted heat by the surfaces of the city as pavements, walls and roofs) rises and the air of lower

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[9] Phenomenon first noticed by meteorologists more than a century ago. According to Landsberg, the heat island is present in every town and city and is the most obvious climatic manifestation of urbanization.The phenomenon of the heat island is characterized by an important spatial and temporal variation related to climate, topography, physical layout and short-term weather conditions. A detailed description of the more important factors influencing heat island is summarized by Oke et al 1976 (in Santamouris, 2001)

temperature found in the city's outskirts and countryside blows to those areas. Breeze from the countryside to the urban area can reach 2 to 3 m/sec (Allard, 1998; Santamouris, 2001) and may be even stronger than the existing breeze in the nearby rural areas.

Regarding urban configuration, higher turbulence can also be produced in non-uniform building and roof geometries such as in pitched roof areas as in the case of this specific study. This higher turbulence provokes, in general, according to Chan (2001) better ventilation for street canyons and therefore, better pollutant dispersion.

In conclusion, each case should better be analyzed separately due to the complexity of the urban geometry. For some cases, irregular urban geometry might cause better ventilation opportunities while for other cases, due to blocking of winds or because the wind direction changes, this irregularity may cause poor ventilation and excessive pollutant concentration (Tablada, 2006).

Urban canyons are one of the most typical configurations in compact and medium dense urban areas. The interaction of the wind above roof level (urban boundary layer) with the buildings and street canyons heavily characterizes the urban airflow and the urban ventilation. Air can flow along the canyon, perpendicular or more commonly, at a certain angle relative to the long axis of the canyon. Depending on several factors like the building geometry, the canyon aspect ratio, the wind speed and direction and solar radiation over the surfaces, the airflow inside the canyon can have different distribution and speed (Tablada, 2006, p. 55).

2.2.1.1.1. Wind Flow in Urban Canyons

Urban canyons are characterized by three main parameters, as shown in Figure 2.13, H, is the mean height of the buildings in the canyon, W, is the canyon width, and L the canyon length. Thus, the geometrical features are described by the following factors:

- The H/W ratio,
- The L/H aspect ratio, and
- The j= Ar/A1 building density

Where Ar is the plan of roof area of the average building and A1 is the ‘lot’ area or unit ground area occupied by each building.

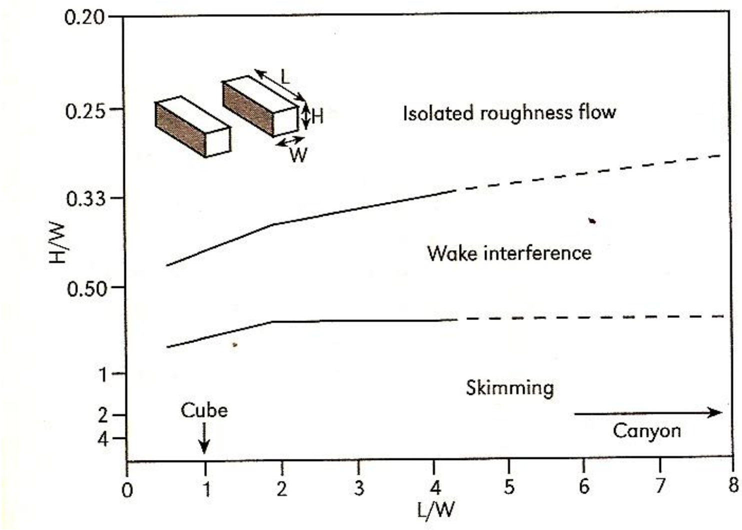
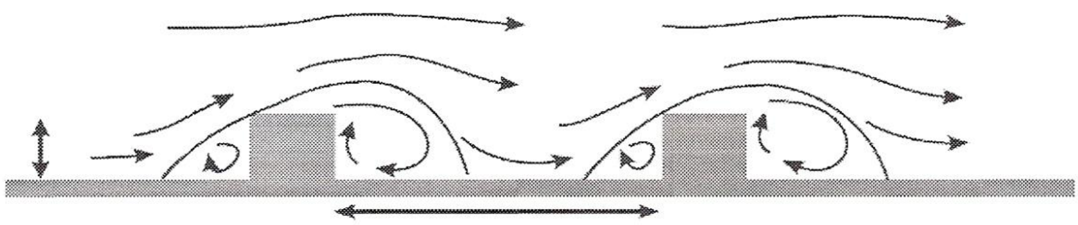


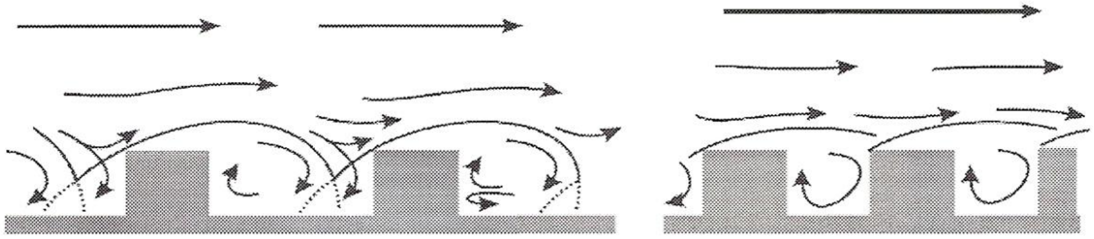
Figure 2.13. Height-to-Width ratio (W/H) and Length-to-Width ratio (L/W) of a canyon are critical to wind flow in the urban canyon (Source: Oke, 1988)

According to studies on urban street canyons, most of the literature focuses on wind-flow perpendicular and along the canyon (Oke, 1988; Johnson, 1998; Chang and Meroney, 2003; Chan, 2001; Chan, 2003; Kim and Baik, 2004; Huang, 2000, Niahou and Santamouris, 2001). Some studies (Sini, 1996; Kastner-Klein, 1999) on canyons with an angled wind have shown that when the buildings and canyon axis are oriented at an angle to the wind, a spiral vortex (cork-screw motion) is induced along the length of the canyon. In studies on parallel flows with the canyon axis (Oke, 1983; Vollebregt, 1998 in Tablada 2006), the sheltering effect disappears to create a wind channeling effect along the canyon axis. This channeling effect creates even higher speeds than in the open (rural) field, yet do not reflect as an effective pressure effect on building surfaces (Oke, 1983, then Santamouris, 2001). The most effective ventilation in urban canyon is perpendicular and angled wind effect.

In perpendicular blowing wind studies certain flow regimes are obtained, when the predominant direction of the airflow is approximately normal (±30^{o}) to the long axis of the street canyon, three types of airflow regimes introduced first by Hussain and Lee (1980) and then (Oke 1988; Tablada, 2006; Santamouris 2001). According to different building organizations, the flows, which are shown in Figure 2.14, which can be described as: (1) isolated roughness flow, (2) wake interference flow and (3) skimming flow.



(a) Isolated roughness flow

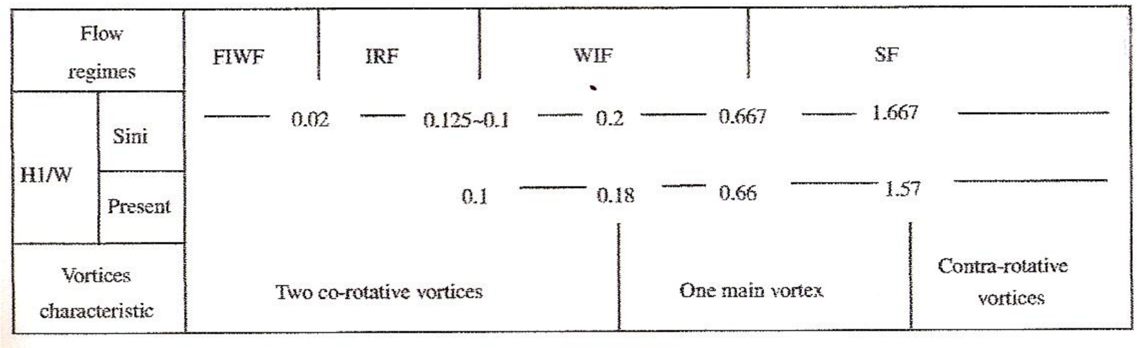


(b) Wake interference flow

(c) Skimming flow

Figure 2.14. The flow regime associated with air flow over building arrays with different spacing (Source: After Oke 1988 in Santamouris, 2001)

Isolated roughness flow occurs when width/height (W/H) are higher than around 8 and lower than around 50, when the buildings are well apart, (H/W> 0.05), their flow fields do not interact. Wake interference flow occurs when W/H is between 8 and around 1.5, when the height and spacing of the array combine, the regime changes to one referred to wake interference flow. This is characterized by secondary flows in the canyon space where the downward flow of the cavity eddy is reinforced by deflection down the windward face of the next building downstream. Aspect ratios lower than 1.5 generates skimming flow according to the wind tunnel experiment performed by Hussain and Lee (1980). However, field observations have indicated a threshold of W/H= 2.5 between wake interference and skimming flows (Johnson and Hunter, 1988 in Tablada, 2006). At even greater H/W and density, a stable circulatory vortex is established in the canyon because of the transfer of momentum across a shear layer of roof height, and transition to a “skimming” flow regime occurs where the bulk of the flow does not enter the canyon. In the study of Xiaomin, Zhen and Jiasong (2006), critical building configurations for decreasing pollutant dispersion has been analyzed and critical H/W limits are defined as two or three vortex regimes is 3.165 and one or two vortex regimes is 1.57. Comparison of results of Xiaomin et al.’s study with previous studies can be followed from Figure 2.15.



Flow regimes		FIWF	IRF	WIF		SF	
H1/W	Sini	0.02	0.125~0.1	0.2	0.667	1.667	
	Present		0.1	0.18	0.66	1.57	
Vortices characteristic		Two co-rotative vortices			One main vortex		Contra-rotative vortices

Figure 2.15. Comparison of flow Regime Limit Values in Symmetrical Canyons (Source: Xiaomin et al., 2006, p.1361)

In isolated roughness regime, there are two or three vortices at the multi-vortex regime, multi-vortex structure results in a high reduction factor of the mean horizontal wind speed and produces an excellent sheltering pedestrian level for pollutant dispersion case (Xiaomin et al., 2005). Wake interference flow is characterized by a distortion of the downward flow due to the closer position of the upstream face which leaves no recovery zone to separate the two vortex structures (Oke, 1988; Sini, 1996). In this regime a main vortex is generated in the canyon, and there are one or two tiny vortices with opposite flow direction to the main vortex, at lower corner of the street canyon (Xiaomin et al., 2005). In geometries close to W/H=1.5 when transition between wake interference flow and skimming flow is produced the relative roughness length (y_o/h) reaches the maximum value (Counihan, 1971, Oke, 1988 in Tablada 2006). In skimming flows, on the other hand, the bulk of the flow does not enter the canyon and stable vortices develop inside the canyon (Oke, 1988, Niachou and Santamouris, 2001, Kovar- Panskus, 2002). Two co-rotating vortices in the street canyon occurs (Xiaomin et al., 2005).

For deeper cavities (W/H<0.6) the centre of the main vortex is displaced close to the top of the cavity while a second or third recirculation flow (contra-rotative vortices) appears bellow with decreasing strength (Kovar-Panskus, 2002, Sini, 1996, Niachou and Santamouris, 2001).

A scheme developed by Sini summarizing the different flow structures on the upper layer and inside the canyons is shown in Figure 2.16. In Figure 2.17 the variation of several parameters according to the aspect ratio of street canyons is illustrated.

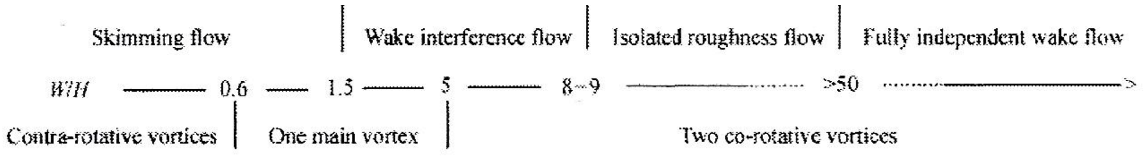


Figure 2.16. Sini's representation of flow limits

Upper subdivisions concern the flow structure in the upper layer and the lower subdivisions concern the in-street flow structure (Santamouris, 2001).

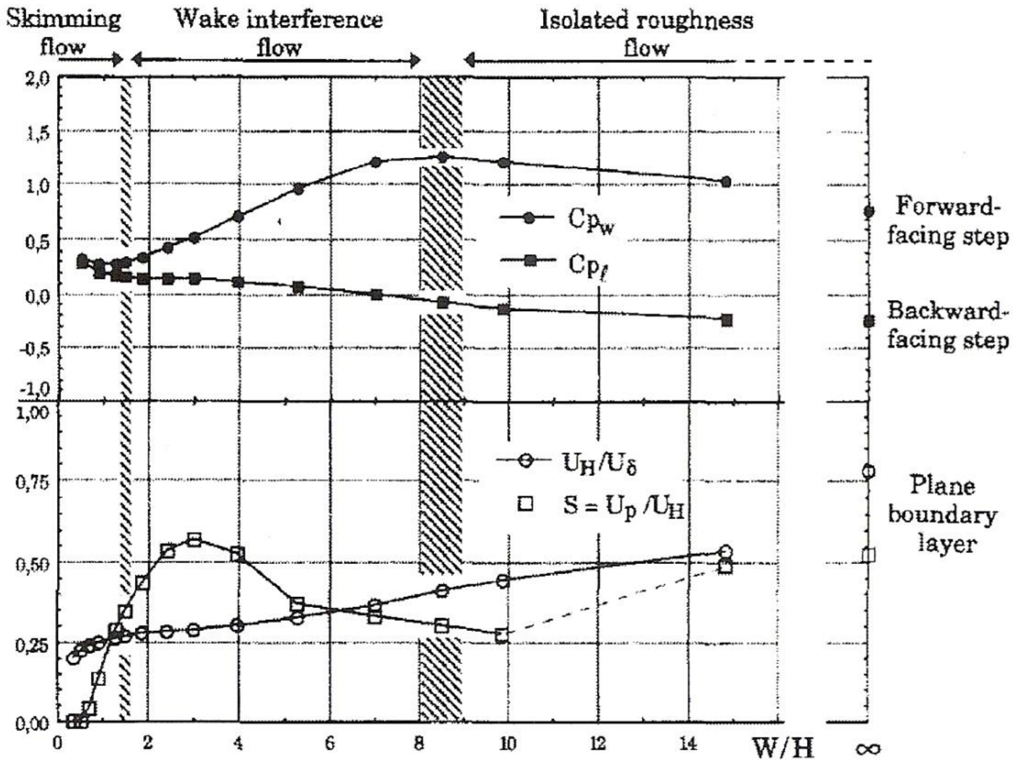


Figure 2.17. Variation of the windward and the leeward wall pressure coefficients Cpw and Cp (Source: Santamouris, 2001, p. 2665)

The mid-canyon wind speed at roof level Un, and the wind speed reduction factor S as a function of the street aspect ratio W/H

Kovar-Panskus et al. (2002) have modeled airflow in 2D cavities (street canyons) with five different aspect ratios (W/H=2.0, 1.0, 0.7, 0.5, 0.3) in a wind tunnel. According to the results: W/H=1.0 a strong full vortex develops in the cavity while in narrower aspect ratio examples, a secondary recirculation flow appears at the bottom of the cavity. For the cavity with wider aspect ratio W/H=2.0 a secondary recirculation flow appears at the bottom of the cavity near the upstream wall. Then, wind-tunnel modeling is compared with CFD simulations with quite good agreement except for the prediction of the horizontal velocity near the wall (Tablada, 2006). This verification study is used for validation in the CFD simulations of the present research. More detailed information of this study is given in Chapter 5.

Huang et al. (2000) compared street canyons with different aspect ratios and described the flow distribution as well as the pollutant concentrations. Similar flow patterns were predicted for cavity ratios W/H=1.0 but for wider aspect ratios the secondary recirculation zone which appear in the wind tunnel experiments reported by Kovar-Panskus et al. at the bottom of the cavity near the upstream wall is not found in Huang et al. simulations. Further experiments were performed by Huang taking into account more realistic geometries and climatic situations with irregular street canyons (upstream building having different height from downstream building) and with vertical variation of wind direction as well as different wind speed (Tablada, 2006).

In the study by Xiaomin et al. (2005) different building geometries (combinations of canyons of pitched roof, flat roofs, and pitched and flat roofs) are analyzed by full-scale field measurements, physical modeling in wind-tunnel and computational fluid dynamics modeling. Since the wind direction is perpendicular to street canyon that the geometry is unchanged along the direction of the canyon, a 2D computational domain is considered for tests performed with B/H=1. According to the obtained results, in general the effect of roofs is rather complicated and in canyon vortex dynamics are strongly dependent on the configuration of roof shape. (See Figure 2.18)

Xiaomin et al. shows the streamlines in street canyon with different configurations. Similar irregularities in cavity geometry are simulated in this thesis (See chapter 5 for details) representing realistic street canyon situations, 4 numbered image in Figure 2.18 will be discussed with 2D similar results of the case study area.

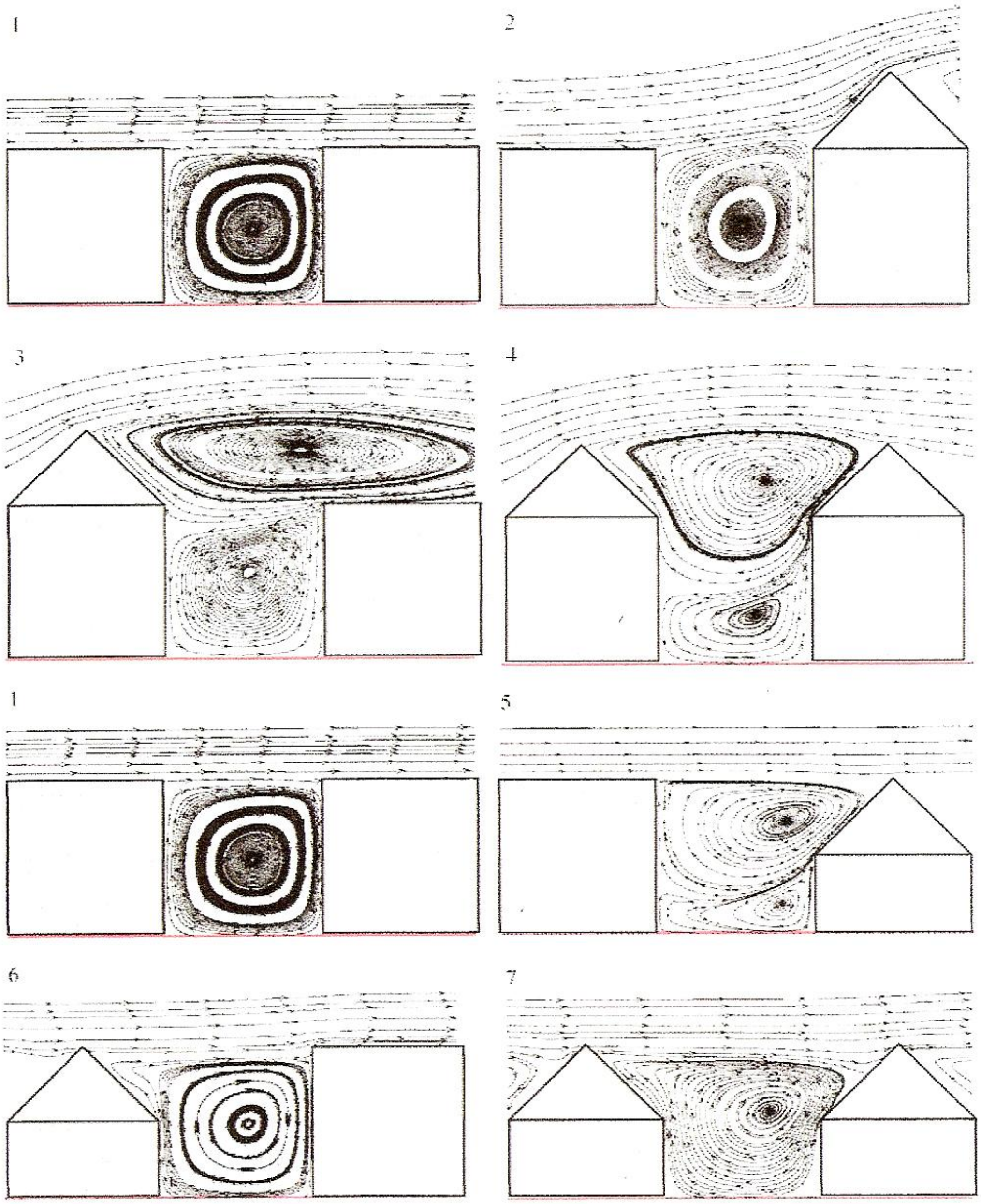


Figure 2.18. Combination of different airflow patterns in a canyon with B/H=1 ratio
(Source: Xiaomin et al., 2005, p. 4523)

Up to this point airflow in street canyons is described with pressure differences changing according to aspect ratio and geometry. However, the actual situation on street canyons is a combination of many factors including buoyancy factor, traffic and the always variable wind conditions.

This leads to a more complex situation than the described vortex-flow in many wind-tunnel and numerical simulations as have been reported by Longley (2004) and Louka (2000) has also performed field measurements and concluded that the recirculation within the street is unsteady and thus the mean flow is just a residual of an unsteady turbulent re-circulation and the turbulent fluctuations are dominant. Figure 2.19 show the unsteady re-circulation in the street canyon. The influence of thermal differences between urban surfaces on the flow perturbations have been studied by several authors. Temperature differences over the urban area and the surrounding surface area give rise to flow perturbations of overall urban dimensions (SethuRaman and Cermak, 1996 in Tablada, 2006, pp.62-63)

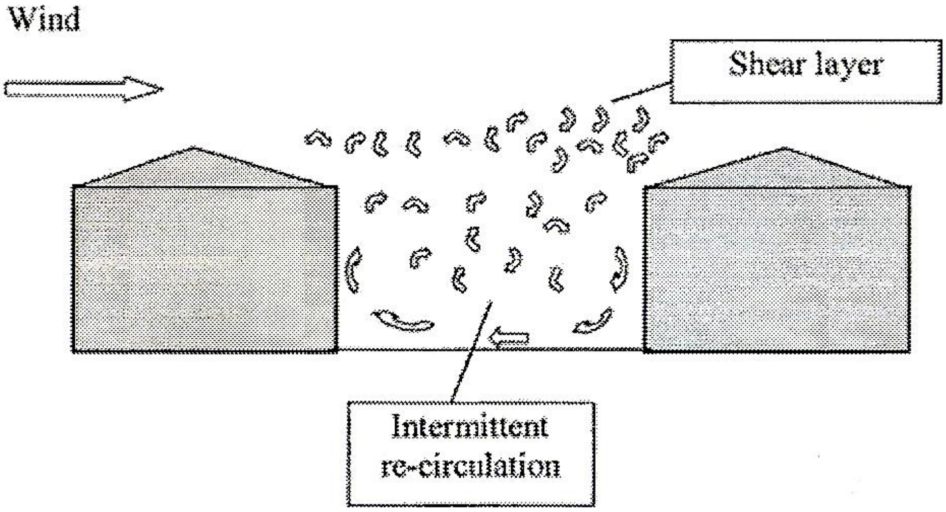


Figure 2.19. Schematic representation of the flow within the street and the roof-level (Source: Nunez and Oke, 1977 in Cermak, 1996, p. 393, in Tablada, 2006, p.63)

Influence of thermal differences between urban surfaces on the flow perturbations have been studied by several authors (SethuRaman et al., 1974, Cermak, 1996 in Tablada 2006). On the other hand, difference in surface temperatures between the street and buildings, due to solar radiation, generates local natural convective flows inside street canyons (Nunez ad Oke, 1996, Kim and Baik, 1998, Kovar- Panskus, 2001, Niachou, 2007). A nominally 2D cavity with an aspect ratio of 1 has been set up in a wind tunnel, permitting uniform heating of the windward facing wall. The experiments indicate that the velocity is driving force for the establishment of the vortex and that the temperature does not greatly affect the overall features. (Kovar-Panskus et al., 2001). Also in studies conducted by Sini (1996) and Xie (2005) with isothermal effect the intensity of the unique vortex strengthens generating a net increase in the vertical exchange and exchange rate. In Xie's study some features of the flow change depending on the wall which is heated by solar radiation is observed in asymmetric canyon configuration examples. (Figure 2.20)

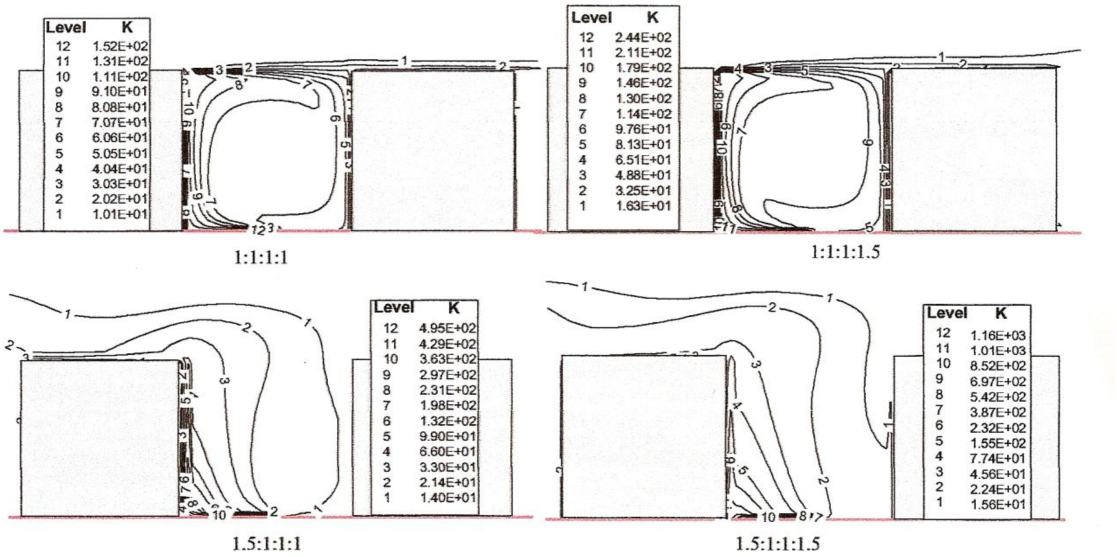


Fig. 8. Concentration profile in street canyon with different height of ambient buildings. Note: the source locate in the center of the canyon, *K* is the dimensionless concentration.

Figure 2.20. Simulated airflow profiles for symmetrical and asymmetrical cases and for isothermal and thermal buoyancy (ΔT= 10 ˚C) (a) symmetrical, U= 2 m/sec; (b) symmetrical U= 1 m/sec; (c) asymmetrical step-up notch, U= 2 m/sec; (d) step-down notch, U= 2 m/sec (Source: Xiaomin, 2005, pp.204)

For the estimation of the effect of thermal radiation on the flow in the street canyon Xie et al. proposes a parameter Gr/Re^2 (2.11), which is the ratio between the Grashof number and the square Reynolds number (Xiaomin, 2005, p.212).

$$\frac{Gr}{Re^2} = \frac{gL(\rho n - \rho)}{\rho n V^2} \tag{2.11}$$

Gr is the Grashof number, Re is the Reynolds number, L is the characteristic scale, ρn the reference density and V the wind speed. If Gr/Re^2 is of the order of magnitude 1, the motion in the canyon is induced by both thermal and mechanical effects. If it is higher than 1, the thermal effect is less pronounced. With low wind conditions and large temperature differences, a large thermal effect is expected. Thermal radiance effect in the canyon is neglected in 2D CFD studies in Chapter 5, because only steady state wind behavior inside the case buildings is tried to be understood at this level of study.

2.2.1.2. Natural Ventilation in Buildings

ASHRAE defines Natural ventilation (NV) as: the flow of outdoor air due to wind and thermal pressures through intentional openings in the building's shell. NV is then, driven by natural/or artificially produced pressure differences. Pressure differences around the buildings generate the potential for natural ventilation (Allard, 1998). These pressure differences created by two forces: temperature difference between indoors and outdoors (thermal force), and wind flow around the building (wind pressure). Regardless of the source of the pressure gradient, the air flow rate generated is proportional to the square root of the pressure difference (Givoni, 1998 in Tablada, 2006).

Natural ventilation plays a major role in maintaining acceptable thermal comfort and improving energy performance of buildings besides providing good indoor air quality and avoiding 'sick building syndrome', which is very common in buildings with poorly designed or maintained mechanical ventilation systems (Jiang 2003). Thermal behavior of a building is strongly coupled to ventilation and air infiltration. At the same time, airflow depends on the different thermal levels of the building zones. In the absence of wind, these differences are the only driving forces for ventilation. (Allard, 1998)

Use of natural ventilation during the daytime has three objectives:

- Cooling of the indoor air as long as outdoor temperatures are lower than the indoor temperatures;
- Cooling of the structure of the building;
- A direct cooling effect over the human body (through convection and evaporation) (Allard, 1998, p.41)

NV is the earliest and previously the only available strategy to achieve thermal comfort or at least to diminish the hot sensation of occupants. The main disadvantage of natural ventilation, in temperate and cold climates, is that heat cannot easily be recovered from exhaust air (Vollebreght and Boonstra, 1998 in Tablada, 2006). According to ASHRAE, NV can effectively control both temperature and contaminants in mild climates, but it is not considered practical in hot and humid climates or in cold climates (ASHRAE, 2001).

In temperate climates such as the study area of this thesis, natural ventilation is the traditional and most sustainable method for thermal comfort in hot summer months. Only disadvantage can be defined as noise pollution and the possible introduction of polluted air indoors. These should be in mind for the design of urban natural ventilation solutions. Otherwise respiratory diseases can easily be caused. It should be mentioned that the traffic and pollution facts can be ignored in the study area of this thesis, because the traditional town centre of the subject is closed to vehicle traffic in summer months.

Natural ventilation can be examined as cross ventilation, single-sided ventilation, and stack ventilation. Cross ventilation occurs between two openings on a room or on multi-rooms. The pressure difference between these openings produces airflow through the internal space. Openings which are not located in different pressure areas (pressure and suction area) do not produce cross ventilation even if air motion is caused by the external wind, which draws air in and out. Single-sided ventilation, on the other hand, is produced in rooms which have contact to the exterior by only one façade. In this case, ventilation flow is dominated by the turbulence of the wind, and as generated by the building itself and its neighbours (Givoni, 1976). Givoni has also proposed several design strategies to create cross ventilation in rooms having a single exterior façade in his studies (1976, 1998), by placing windows on different extreme corners of the façade, and by locating external devices . Sözen also defines single sided ventilation by multiple openings above one another or by a large opening, so that air can enter and be driven out by wind and stack forces by pressure differences on different levelled openings at the same section on the same façade. Therefore again airflow is created through the room in hot Diyarbakır region. (Sözen, 2006)

In this study cross ventilation will be examined by standard corridor cross openings, while single side ventilation will be investigated by one opening placed in main façade of the building, where main wind flow blows in. Thus, examination of different ventilation strategies will be examined by also considering the thermal comfort effect of NV in buildings. According to studies of Jiang, Deru and Burns and Koinakis, Niahou and Santamouris cross-ventilation provides more effective ventilation than single-side ventilation. Cross-ventilation is the most effective passive strategy to ensure enough air speed for thermal comfort, however the upper limit of ventilation rate is described as 1.5 m/sec at most in section 2.1.5.1, and the airflow over this limit may cause discomfort like paper loss (over 0.8 m/sec) or other unhealthy situations. To question the effect of ventilation in the windy environment in Alaçatı within limits of thermal comfort is an interesting study to question the limits of comfort.

Various calculation methods of different NV descriptions are available in Allard's study, 1998; such as British Standards method, ASHRAE method, Aynsley method, and De Gidd and Phaff method. Also simplified methods of Givoni, CSTB and Earnst are available for simple NV empirical calculations. Hence, when NV is through large and multiple openings, the problem of estimation is more complex due to the bidirectional nature of the flow which is different at the upper and the lower part of the opening (Deru, 2003; Koinakis, 2005 in Tablada, 2006). This flow is unsteady most of the time due to air turbulence. Bernoulli's equation (Equation 2-12) for steady and incompressible flows enables to describe this more complex airflow behavior through larger openings (ASHRAE, 2001).

$$Q = CDA\sqrt{\frac{2\Delta p}{\rho}} \qquad \textbf{(2.12)}$$

Where, Q is the air flow rate, (m^3/s), CD is the discharge coefficient for opening, (dimensionless), A is the cross-sectional area of opening (m^2), ρ is the air density (kg/m^3) and Δp is the pressure difference over the height of the opening (Pa). The discharge coefficient CD is a dimensionless number that depends on the geometry of the opening and the Reynolds number of the flow.

2.2.1.2.1. Wind Flow around Buildings

Wind flow around buildings affects working safety, process and building equipment operation, weather and pollution protection at inlets, and the ability to control the environmental factors related to temperature, humidity, air motion and contaminants. Wind causes surface pressures that vary around buildings, changing intake and exhaust system flow rates, natural ventilation, infiltration and exfiltration, and interior pressure. The mean flow patterns and wind turbulence passing over a building can even cause a recirculation of exhaust gases to air intakes.

Air flow in the internal viscous boundary layer is dominated by the effect of viscosity. Depending upon the Reynolds number, the flow in this region is either laminar or turbulent. When a turbulent flow hits a sharp edge, such corner of a rectangular building, layer separation occurs immediately. Nevertheless, the effect of Reynolds number is extremely small for rectangular buildings, because it is no longer the dominating factor in controlling the separation and wake width (Aynsley, 1977, p.163).

2.2.1.2.2. Pressure Distributions on Buildings

Wind flows produce a velocity and pressure field around buildings. When wind blows against a building both pressure and suction zones are created over the building envelope. In this way pressure differences are created and, therefore, airflow through the building is generated. Positive pressure zones are produced on windward or upstream surfaces of the building while suction zones are created on the roof, the rear and the sides of the building due to flow separation from the sharp edges of the building top and sides (Allard, 1998; Vollebregt, 2000) as can be seen in Figure 2.21. On top pressure distribution around a building and inside courtyards or street canyons. On the bottom, flow characteristics around a cuboid building (Source: Tutat and Oğuz, 2002, p. 303). Downstream is the building wake, in which turbulence is increased but horizontal wind speeds are lower than in open field.

Pressure is not uniformly distributed over the upstream surfaces of the building; stagnation pressure is produced at approximately 70% of the wall height diminishing outwards towards the edges of the surface. This variation of pressure is higher when wind flows oblique to the upstream surfaces. In the suction zone, variation of air pressure is less than in the overpressure surfaces (Allard, 1998).

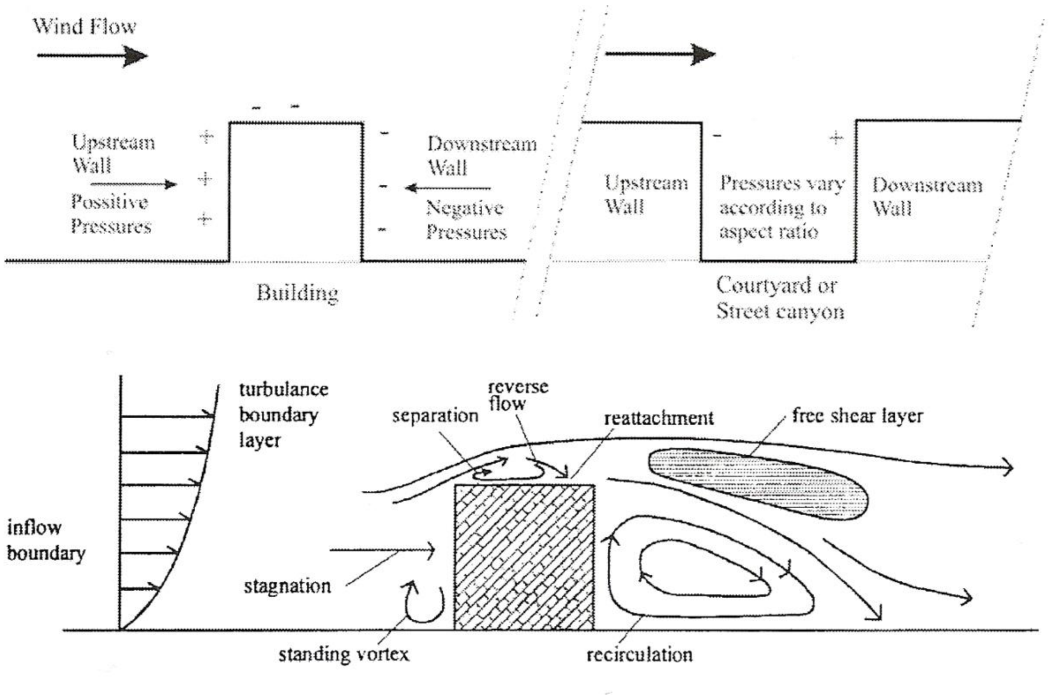


Figure 2.21. On top pressure distribution around a building and inside courtyards or street canyons. On the bottom, flow characteristics around a cuboid building (Source: Tutat and Oğuz, 2002, p. 303)

The pressure difference between two or more points on the building surfaces determines the potential driving force for ventilation if openings are provided at these points. (Givoni, 1976). Dimensionless pressure coefficient Cp is an empirically derived parameter that accounts for the changes in wind-induced pressure caused by the influence of surrounding obstructions on the prevailing local wind characteristics. It can be calculated as the ratio of -the surface dynamic pressure minus the free stream static pressure- to -the dynamic pressure- in the undisturbed flow pattern measured at a reference height. (Swami, 1988, Koinakis, 2005, Allard, 1998).

Cp value changes according to the wind direction, the building surface orientation and the topography and roughness of the terrain in the direction of the wind. Thus, accurate information about local wind characteristics and nearby environment and obstructions are mandatory to correctly predict Cp values (Wouters, 2002). Wind pressure distributions around buildings have been investigated by many authors. The majority of the studies concern orthogonal buildings standing alone. (Ayad, 1999, Richards, 2001, Castro, 1977, Paterson, 1990, Gratia, 2004) However, some researchers have studied groups of buildings (Jiang and Chen, 2002, Hu and Wang, 2005, Bonneaud, 2001, Santamouris and Niachou, 2007) the influence of surrounding buildings (Wiren, 1983, Lee, 1980). In Figure 2.22, each data set comprises Cp values for 14 different wind directions is given based on experiments. Also thermal buoyancy affects pressure over surfaces.

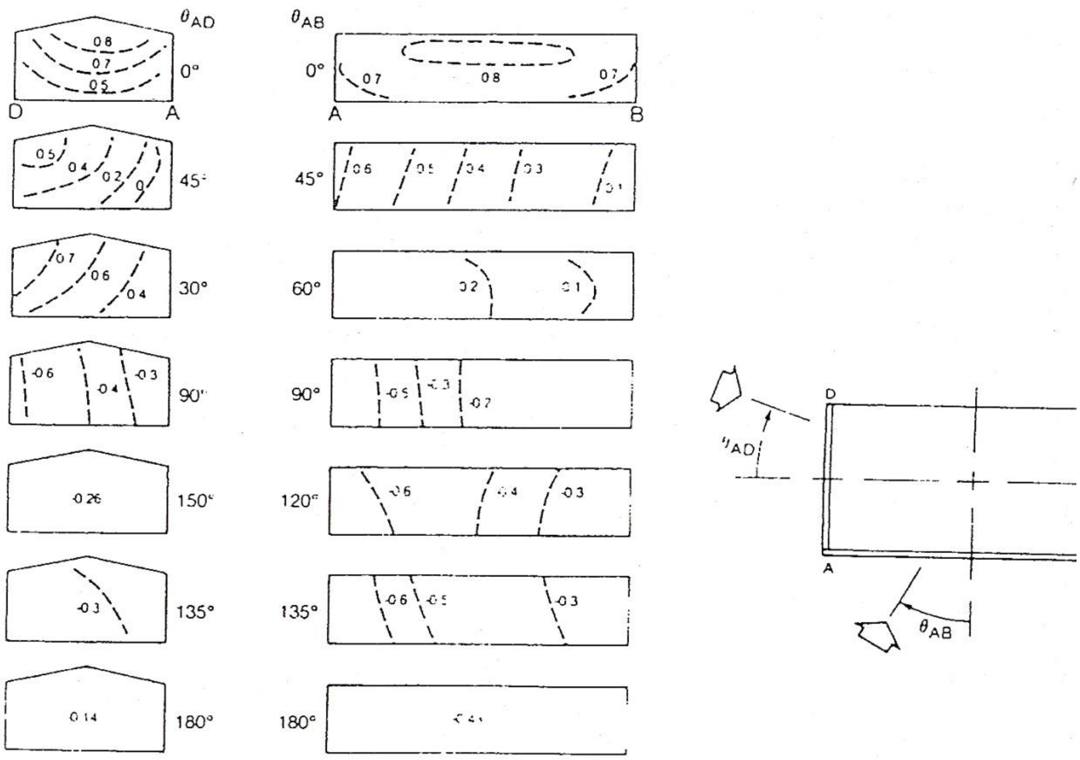
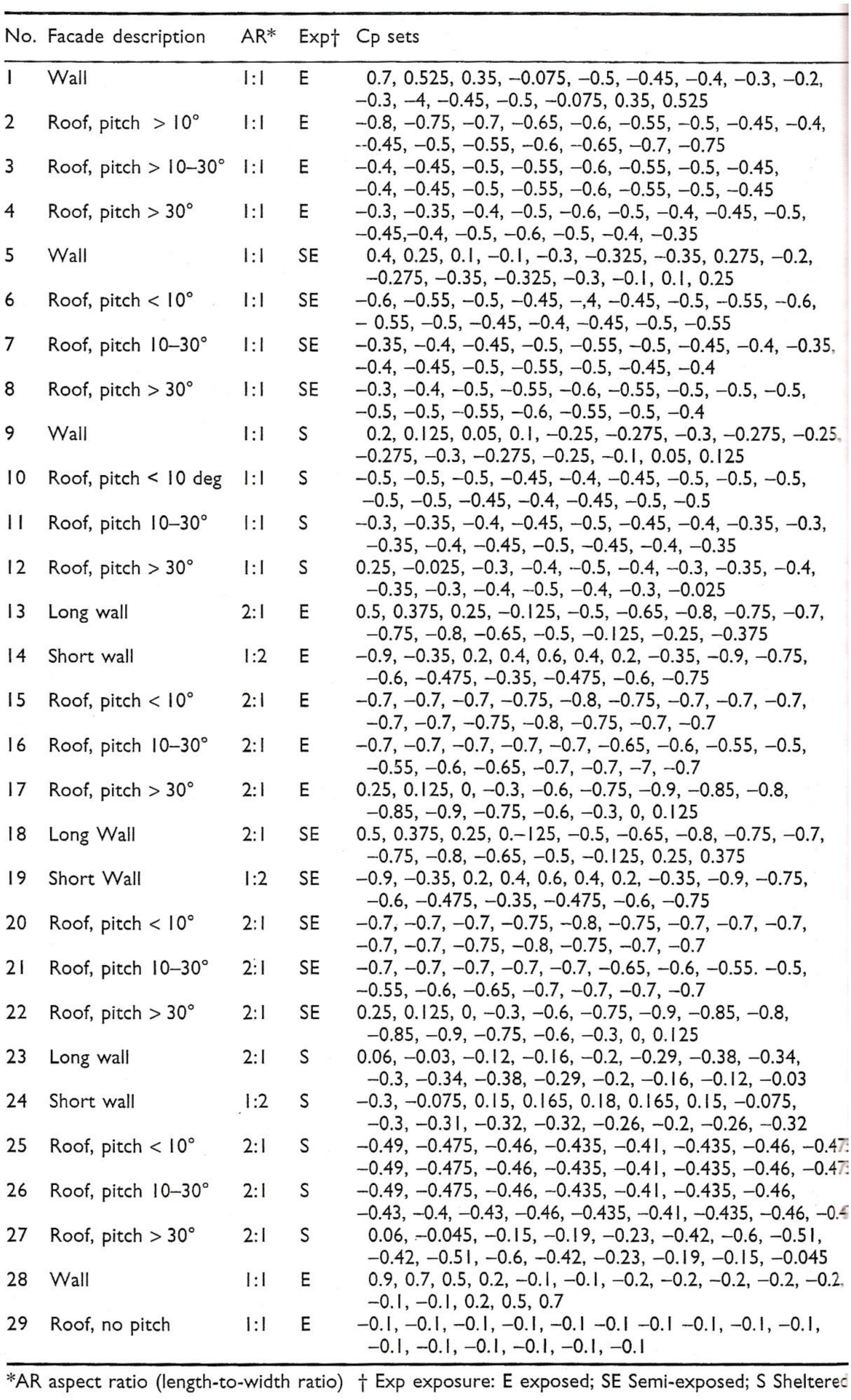


Figure 2.22. Typical design data sets based on experimental results
(Source: Allard, 1998, p. 28)

Table 2.4. Pressure Coefficient sets for Buildings
(Source: Allard, 1998, p. 92)



No.	Facade description	AR*	Exp†	Cp sets
1	Wall	1:1	E	0.7, 0.525, 0.35, −0.075, −0.5, −0.45, −0.4, −0.3, −0.2, −0.3, −4, −0.45, −0.5, −0.075, 0.35, 0.525
2	Roof, pitch > 10°	1:1	E	−0.8, −0.75, −0.7, −0.65, −0.6, −0.55, −0.5, −0.45, −0.4, --0.45, −0.5, −0.55, −0.6, −0.65, −0.7, −0.75
3	Roof, pitch > 10–30°	1:1	E	−0.4, −0.45, −0.5, −0.55, −0.6, −0.55, −0.5, −0.45, −0.4, −0.45, −0.5, −0.55, −0.6, −0.55, −0.5, −0.45
4	Roof, pitch > 30°	1:1	E	−0.3, −0.35, −0.4, −0.5, −0.6, −0.5, −0.4, −0.45, −0.5, −0.45,−0.4, −0.5, −0.6, −0.5, −0.4, −0.35
5	Wall	1:1	SE	0.4, 0.25, 0.1, −0.1, −0.3, −0.325, −0.35, 0.275, −0.2, −0.275, −0.35, −0.325, −0.3, −0.1, 0.1, 0.25
6	Roof, pitch < 10°	1:1	SE	−0.6, −0.55, −0.5, −0.45, −,4, −0.45, −0.5, −0.55, −0.6, − 0.55, −0.5, −0.45, −0.4, −0.45, −0.5, −0.55
7	Roof, pitch 10–30°	1:1	SE	−0.35, −0.4, −0.45, −0.5, −0.55, −0.5, −0.45, −0.4, −0.35, −0.4, −0.45, −0.5, −0.55, −0.5, −0.45, −0.4
8	Roof, pitch > 30°	1:1	SE	−0.3, −0.4, −0.5, −0.55, −0.6, −0.55, −0.5, −0.5, −0.5, −0.5, −0.5, −0.55, −0.6, −0.55, −0.5, −0.4
9	Wall	1:1	S	0.2, 0.125, 0.05, 0.1, −0.25, −0.275, −0.3, −0.275, −0.25, −0.275, −0.3, −0.275, −0.25, −0.1, 0.05, 0.125
10	Roof, pitch < 10 deg	1:1	S	−0.5, −0.5, −0.5, −0.45, −0.4, −0.45, −0.5, −0.5, −0.5, −0.5, −0.5, −0.45, −0.4, −0.45, −0.5, −0.5
11	Roof, pitch 10–30°	1:1	S	−0.3, −0.35, −0.4, −0.45, −0.5, −0.45, −0.4, −0.35, −0.3, −0.35, −0.4, −0.45, −0.5, −0.45, −0.4, −0.35
12	Roof, pitch > 30°	1:1	S	0.25, −0.025, −0.3, −0.4, −0.5, −0.4, −0.3, −0.35, −0.4, −0.35, −0.3, −0.4, −0.5, −0.4, −0.3, −0.025
13	Long wall	2:1	E	0.5, 0.375, 0.25, −0.125, −0.5, −0.65, −0.8, −0.75, −0.7, −0.75, −0.8, −0.65, −0.5, −0.125, −0.25, −0.375
14	Short wall	1:2	E	−0.9, −0.35, 0.2, 0.4, 0.6, 0.4, 0.2, −0.35, −0.9, −0.75, −0.6, −0.475, −0.35, −0.475, −0.6, −0.75
15	Roof, pitch < 10°	2:1	E	−0.7, −0.7, −0.7, −0.75, −0.8, −0.75, −0.7, −0.7, −0.7, −0.7, −0.7, −0.75, −0.8, −0.75, −0.7, −0.7
16	Roof, pitch 10–30°	2:1	E	−0.7, −0.7, −0.7, −0.7, −0.7, −0.65, −0.6, −0.55, −0.5, −0.55, −0.6, −0.65, −0.7, −0.7, −7, −0.7
17	Roof, pitch > 30°	2:1	E	0.25, 0.125, 0, −0.3, −0.6, −0.75, −0.9, −0.85, −0.8, −0.85, −0.9, −0.75, −0.6, −0.3, 0, 0.125
18	Long Wall	2:1	SE	0.5, 0.375, 0.25, 0.−125, −0.5, −0.65, −0.8, −0.75, −0.7, −0.75, −0.8, −0.65, −0.5, −0.125, 0.25, 0.375
19	Short Wall	1:2	SE	−0.9, −0.35, 0.2, 0.4, 0.6, 0.4, 0.2, −0.35, −0.9, −0.75, −0.6, −0.475, −0.35, −0.475, −0.6, −0.75
20	Roof, pitch < 10°	2:1	SE	−0.7, −0.7, −0.7, −0.75, −0.8, −0.75, −0.7, −0.7, −0.7, −0.7, −0.7, −0.75, −0.8, −0.75, −0.7, −0.7
21	Roof, pitch 10–30°	2:1	SE	−0.7, −0.7, −0.7, −0.7, −0.7, −0.65, −0.6, −0.55. −0.5, −0.55, −0.6, −0.65, −0.7, −0.7, −0.7, −0.7
22	Roof, pitch > 30°	2:1	SE	0.25, 0.125, 0, −0.3, −0.6, −0.75, −0.9, −0.85, −0.8, −0.85, −0.9, −0.75, −0.6, −0.3, 0, 0.125
23	Long wall	2:1	S	0.06, −0.03, −0.12, −0.16, −0.2, −0.29, −0.38, −0.34, −0.3, −0.34, −0.38, −0.29, −0.2, −0.16, −0.12, −0.03
24	Short wall	1:2	S	−0.3, −0.075, 0.15, 0.165, 0.18, 0.165, 0.15, −0.075, −0.3, −0.31, −0.32, −0.32, −0.26, −0.2, −0.26, −0.32
25	Roof, pitch < 10°	2:1	S	−0.49, −0.475, −0.46, −0.435, −0.41, −0.435, −0.46, −0.47 −0.49, −0.475, −0.46, −0.435, −0.41, −0.435, −0.46, −0.47
26	Roof, pitch 10–30°	2:1	S	−0.49, −0.475, −0.46, −0.435, −0.41, −0.435, −0.46, −0.43, −0.4, −0.43, −0.46, −0.435, −0.41, −0.435, −0.46, −0.4
27	Roof, pitch > 30°	2:1	S	0.06, −0.045, −0.15, −0.19, −0.23, −0.42, −0.6, −0.51, −0.42, −0.51, −0.6, −0.42, −0.23, −0.19, −0.15, −0.045
28	Wall	1:1	E	0.9, 0.7, 0.5, 0.2, −0.1, −0.1, −0.2, −0.2, −0.2, −0.2, −0.2, −0.1, −0.1, 0.2, 0.5, 0.7
29	Roof, no pitch	1:1	E	−0.1, −0.1, −0.1, −0.1, −0.1 −0.1 −0.1 −0.1, −0.1, −0.1, −0.1, −0.1, −0.1, −0.1, −0.1, −0.1

*AR aspect ratio (length-to-width ratio) † Exp exposure: E exposed; SE Semi-exposed; S Sheltere

Table 2.4 comprises 29 pressure coefficient data sets corresponding to an equal number of different façade configurations in terms of surface aspect, dimensions and exposure. The Cp values given for average values of low-rise façades up to three storeys placed on open ground only. Local (not wall-averaged) evaluation of the Cp parameter is one of the most difficult aspects of air infiltration modeling. (Allard, 1998)

Modeling wind pressure distribution according to a parametric approach means finding an algorithm calculating the variation of Cp over the building envelope surfaces as wind direction and architectural and environmental conditions are varied. As a result of the stochastic behavior of the distribution of pressure coefficients around a building, such an algorithm should be based on empirical correlations of time-averaged Cp values from wind tunnel tests chosen as reference data sets. (Allard, 1998, p. 29)

Table 2.5. Parameters affecting the distribution of Cp
(Source: Allard, 1998, p. 29)

Wind	Environment	Building Geometry
Wind velocity profile	Plan Area Density (PAD)	Frontal Aspect
	Ratio (FAR) exponent ($\forall$)	
Wind incident angle	Relative building height (RbH)	Side aspect ratio (SAR)
	Elements positioning coordinates	
	Roof slope tilt angle (N)	

Although many researches on pressure coefficients with wind tunnel experiments are conducted (Walton, 1982; Swami and Chandra, 1988; Comis group, 1990), real examples are very complex with almost infinite combination of different climatic context, urban morphology and building geometries (See Table 2.5).

Thus, specific studies to describe real or design situations are necessary by means of experimental or numerical methods. For particular cases like sofa cases in urban canyons, wind-tunnel experiments or CFD modeling is mandatory. Studies concerning air flow and pressure distribution in cavities are not numerous and more research on these examples are needed for further literature.

2.3. Building Simulation: Wind Flow and Thermal Comfort Modelling

Knowledge of specific airflow characteristics in a space as well as global airflow effect over buildings is necessary for both comfort and energy reasons. Designers wish to know the airflow rate through large openings to size building windows appropriately, while engineers are interested in the distribution of the air velocity in a zone to size ventilation inlets and outlets. Comfort experts wish to know the air velocity values in a zone to calculate heat convection from or to the human body, while air quality experts are interested in the flow rate, the dispersion of contaminants and the ventilation efficiency (Allard, 1998, p.63)

Simple calculation methods using pre-design inputs have been the most common method for building design by architects and engineers before the development of building design and simulation programs. This approach had frequently led to oversized plant and system capacities and poor energy performance in buildings (Hong, 2000 in Tablada, 2006). On contrary, the methods available to obtain more accurate information about building performance were model scale experiments and full scale measurements, which are considerably costly.

Currently, two groups of computer-based tools in building design exist: computer aided documentation, design and drafting; and computer-based simulation. Energy efficiency in buildings can be investigated and improved better with these more accurate computerized methods (Hong, 2000 in Tablada, 2006). Today these computer based simulation tools are used more common compared to ten years before. However due to the extra costs of efficient computers and the high demand of expertise in the use of building simulation programs, they are still not widely preferred in building design practices.

About the accuracy of the computer- based modeling, it should be mentioned that the complexity of the natural phenomena and also building itself causes some assumptions and approximations to be made in the modeling processes. These approximations inevitably derive accuracy errors. Therefore, the solutions can only meet the user's requirement of accuracy level, which is called, a bounded rationality (Matthews, 2000). Experience of the user and accuracy of input data are key elements for better results besides the quality and suitability of the building simulation program. After the correct simulations, validation is always necessary to avoid mistakes and misinterpretation of results, at least for simple cases from which extrapolation can be made (Tablada, 2006, Santamouris 2001, Allard, 1998)

In this section, two main branches of building simulation programs are described: airflow models with emphasis on Computational Fluid Dynamics (CFD); and Building Energy Simulation programs (BES). Their main advantages and disadvantages are discussed as well as the coupling methods between them in order to obtain more accurate solutions in terms of the thermal conditions inside buildings.

2.3.1. Airflow Modeling

Various prediction models and tools can be used to calculate ventilation efficiency; very simple empirical algorithms (which are mentioned in the previous section as well) to calculate the global airflow rate to computerized fluid- dynamic techniques solving the Navier-Stokes equations. Based on the level of modeling complexity, four different approaches can be distinguished for description of airflow in the case of the natural ventilation of buildings.

- Empirical models
- Network models
- Zonal models
- CFD models (Allard, 1998, p.63)

It is important to note that even the use of deterministic methods to predict natural ventilation airflow rates in buildings is based on assumptions, which frequently may fail to describe the actual conditions with sufficient accuracy. This fact affects accuracy of the results compared to measured values in airflow modeling. (Allard, 1998)

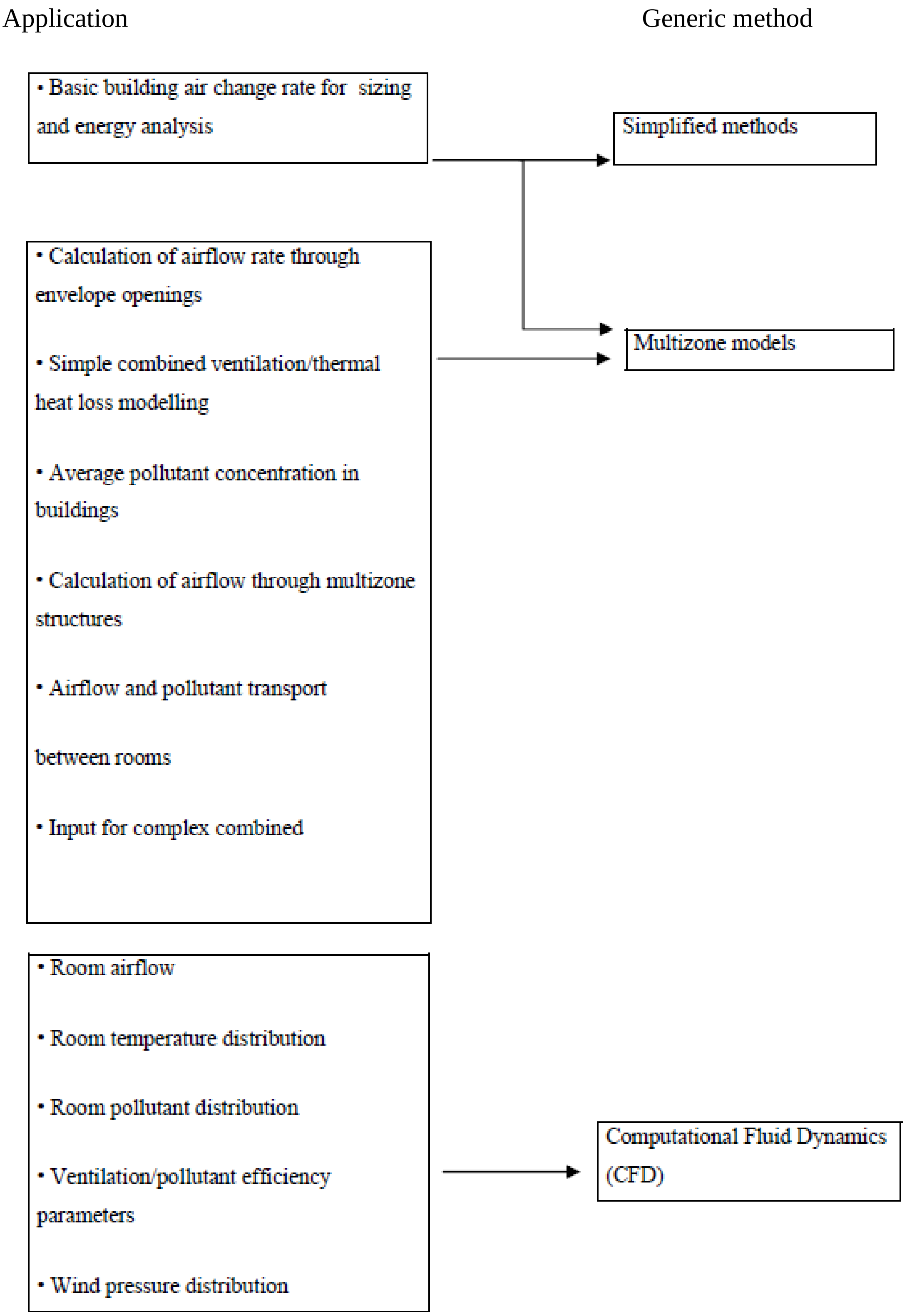


Figure 2.23. Summary overview of typical building airflow applications and modeling (no indication was given to the zonal modeling) (Source: Hensen , 2003 in Tablada 2006, p.73)

Figure 2.23 indicate some of the application models in the field of airflow prediction. Certain applications used for certain predictions in this classification.

2.3.1.1. Empirical and Network Modeling

The simplest models are empirical. These models offer general correlations to calculate, the airflow rate and the mean air speed in the zone separately. They are useful for a preliminary estimation of these airflow parameters. However, empirical models should only be used within the limits of their applicability.

The second modeling approach is a multi-zone airflow network modeling. It helps to predict the interaction of various zones through internal openings. Network calculation models are based on the equation of mass conservation combined with some empirical knowledge. In network modeling, the building is represented by a grid which is formed by a number of nodes that represent a particular room or space and the openings are represented by linking flow paths. Interaction with the outdoor environment is also represented by flow paths linking interior with exterior nodes. (Allard, 1998)

Modeling approaches that have been discussed as empirical and network models are based on the hypothesis of fully mixed zones. Although this assumption is not true in certain situations (i.e. large stratification in heated rooms), the predictions of these models fit well to the real behavior of buildings from an overall viewpoint.

However, physical processes involved in natural ventilation are very complex and the interpretation of their role in ventilation effectiveness is a difficult task. Classical fluid dynamics has described air flow phenomena under well defined boundary conditions in quite satisfactory way. However, taking into account the chaotic character of the wind characteristics, a full knowledge of the boundary and initial conditions is almost impossible, thus misinterpretations are possible in lack of accuracy (Santamouris, 2001, Allard, 1998, Tablada, 2006).

2.3.1.2. Zonal Modeling

The multizone airflow network modeling is efficient for simulating the air flow rate in a building as well as the average concentration of indoor pollutants, when mechanical ventilation techniques are used. However, these tools do not predict or describe the airflow characteristics especially they're inefficient in natural ventilation cases. Network models are easy to conduct while their cost is also low compared to computational models (Vollebregt and Boonstra, 1998).

Basic principles of all kinds of simplified zonal models for predicting indoor patterns of temperature and air velocity are:

- Splitting the studied enclosure into several macroscopic subzones.
- Establishing the mass and energy conservation equations, together with either momentum equations or identification of the main flows.

> Two types of models can be distinguished, which are the temperature and the pressure models. While temperature models needs the indoor air pattern to be imposed, the pressure model adds equations like the Bernoulli-like airflow equations to formulate the missing momentum equations Zonal modeling is an intermediate approach between network and CFD modeling. It has the advantage of providing detailed results regarding temperature and air velocity fields with relatively less complexity than CFD modeling (Allard, 1998, pp 114-115).

Nevertheless, network and multi-zone airflow models need pressure coefficients as input. For specific non-regular buildings for which Cp values have not been provided by wind tunnel experiments, Cp values can only be obtained by using CFD models (Blocken, 2006, Tablada, 2006).

2.3.1.3. CFD (Computational Fluid Dynamics) Modeling

During the last 10 to 20 years, much effort has been put into the development of computational fluid dynamics (CFD) for the prediction of the airflow in buildings. CFD programs are based on the solution of the Navier-Stokes equations, namely, the mass, momentum and energy conservation equations. CFD models are mainly used for steady-state problems to predict the temperature and velocity fields inside and the pressure field outside of a building.

Description of the phenomena is achieved by solving the well-known Navier-Stokes equations combined with equations describing the turbulence effects, under specific boundary and operating conditions. CFD based on the discretization (by meshing) of the building volume into small sub volumes and application of mass, energy and momentum conservation equations to each sub-volume, in order to derive temperature and air velocity fields, as upgrading the network and zonal models. (Allard, 1998) Airflow in each cell must follow the fundamental laws of physics covering conservation of energy, conservation of mass and Newton’s second law (momentum) (Blocken, 2004). Flow, energy propagation and contaminant spread are represented in each of the control volumes by a series of discretized transport equations. Direct solution techniques are not available, therefore iteration is applied. All parameters are initially given arbitrary values from which the iteration can commence. These values are then adjusted until each of the transport equations balance. The process of reaching a balance is referred to as ‘convergence’. Considerable computational effort is normally necessary, with the result that processing times can be lengthy, sometimes taking many hours.

Specific applications of CFD include the simulation and prediction of:

- room airflow,
- airflow in large enclosures,
- air change efficiency,
- pollutant removal effectiveness
- temperature distribution,
- air velocity distribution,
- turbulence distribution,
- pressure distribution,
- fire and smoke movement,
- airflow around buildings.

Air flow is important in the three main areas of building physics, today:

Indoor climate
- Ventilation and indoor air quality
- Thermal Comfort

Building envelope
- Wind-driven rain, rain penetration, weathering
- Surface heat and vapour transfer coefficient
- Energy performance, air infiltration, etc.

Outdoor Climate
- Outdoor air quality (removal of traffic and industrial exhaust gases)
- Pedestrian wind comfort (Blocken & Carmeliet, 2006)

Indoor ventilation study of this work by CFD is given in Chapter 5 with more detailed CFD model and analysis explications.

However CFD methods for buildings have some limitations. They require a substantial amount of user input (model, mesh, boundary conditions, and solution method options) and therefore a good understanding of flow physics is needed. Also, the number of cells that can be incorporated in the available computer space is limited and the representation of the flow fields, generated by natural ventilation and air infiltration, is difficult. (Tablada, AIVC, 1996, pp. 219-222)

Wind tunnel and Computational Fluid Dynamics (CFD) are the most sophisticated and accurate methods to predict airflow in buildings. Before the development of CFD codes, wind-tunnel experiments were the only possible method to obtain accurate information concerning wind interaction with buildings. However, wind tunnel modeling is time consuming, it is expensive and the results are very sensitive to the configuration and details of the wind tunnel itself (Moonen, 2003 in Blocken 2004). Numerical simulation has the advantage of being less time-consuming and less expensive than wind-tunnel modeling. Furthermore, CFD can directly yield detailed spatial distributions of velocity, temperature and contaminants at every point around the configuration studied. However, due to the complexity of CFD modeling, a high level of expertise is needed as in the case of wind-tunnel modeling (Blocken, 2004).

Anderson (2004) defines Computational Fluid Dynamics as the art of replacing the integrals or the partial derivates (as the case may be) in the governing equations with discretized algebraic forms, which in turn are solved to obtain numbers for the flow field values at discrete points in time and for space. The end product of CFD is indeed a collection of numbers, in contrast to a closed-form analytical solution.

2.3.1.3.1. CFD Simulation Alternatives

Turbulent flow can be predicted by several numerical approaches. Three of them are mentioned below:

Reynolds-Averaged Navier-Stokes equations (RANS): in this method, only the mean flow is solved and approximations, called turbulence modes (e.g. k-ε models), have to be made. This is the most widely applied and validated approach in the field of numerical computation of wind flow around buildings and industrial applications (Jiang, 2002, Blocken, 2004). However, it has been reported that RANS cannot correctly predict airflow at certain areas around the building like the separation region on the roof and the recirculation region behind the building (Lakehal and Rodi, 2002).

Large Eddy Simulations (LES): in this method, the Navier-Stokes equations are filtered. LES separates flow motions into large eddies and small eddies, computing the large eddies in a three-dimensional and time-dependent way while modeling the small eddies with a sub grid-scale model. LES solves turbulence problems with higher accuracy than RANS but at the expense of increasing computational requirements (Blocken, 2004).

Direct numerical simulation (DNS): The Navier-Stokes equations are solved for all the motions in the turbulent flow. Therefore, this method is considered 'exact' but it requires very large computational resources. Currently DNS is only possible at low Reynolds numbers and for relative simple geometries (Blocken, 2004). Hence, DNS cannot be used, at present, for the study of natural ventilation due to computer memory and speed limitations (Jiang, 2002).

CFD has been successfully applied for indoor airflow analysis in the last two decades (Chen, 1995, Ladeine, 1997, Emmerich, 1997, Nielsen 1998). Besides, wind flow around buildings has been simulated by many researchers by using CFD modeling (Ayad, 1999; Kovar-Panskus, 2002; Jiang and Chen, 2002; Jiang, 2003; Rajapahsha, 2004; Alvarez, 1998; Shao, 1993; Murakami and Muchida, 1988; Blocken, 2006, 2007; Xie, 2005, 2006, Xiaomin, 2005) However; there are several problematic questionable CFD issues. One of the main problems of CFD simulation is the definition of the boundary conditions that have to be assumed by the user.

> These boundary conditions are crucial for the accuracy of the CFD results (Zhai, 2002). Taking into account the unstable and chaotic character of the wind characteristics, a full knowledge of the boundary and initial conditions is almost impossible (Allard, F., 1998, p.63).
>
> That is why, sophisticated experimental data are needed to validate and assess the CFD results for specific building configurations. (Ohba, 2001, Blocken and Carmeliet, 2004; 2007)

Another disadvantage is that CFD simulation demands high expertise from the users. Recent research has shown that CFD solutions are of high variability inside the limits of uncertainty of the input data. Therefore, at present the use of CFD is not a suitable solution for building design, especially, for small and medium projects. (Vollebregt and Boonstra, 1998). Boundary conditions are the most important detail, which sustains accuracy of various different models.

2.3.1.3.2. Input Conditions in CFD

In almost all CFD simulations of the lower part of the ABL, an accurate description of the flow near the ground surface is required. In such cases, if the wall roughness is expressed by equivalent sand grain roughness ks in the wall functions, four requirements should be simultaneously satisfied. This set of requirements has been distilled from various sources including CFD literature and CFD software manuals (Richards and Hoxey, 1993, Franke et al., 2004, Fluent Inc., 2005, Ansys Ltd., 2005):

(1) A sufficiently high mesh resolution in the vertical direction close to the bottom of the computational domain (e.g. height of first cell >1 m);

(2) A horizontally homogeneous ABL flow in the upstream and downstream region of the domain;

(3) A distance yp from the centre point P of the wall-adjacent cell to the wall (bottom of domain) that is larger than the physical roughness height ks of the terrain (yp > ks); and

(4) Knowing the relationship between the equivalent sand-grain roughness height ks and the corresponding aerodynamic roughness length y0.

First requirement is important for all computational studies of flow near the surface of the Earth. Hence, for pedestrian wind comfort studies, Franke et al. (2004) states that at least 2 or 3 control volume layers should be provided below pedestrian height (1.75 m). The second requirement implies the insertion of (empirical) information about the ground roughness (roughness of the bottom of the computational domain) into the simulation to prevent stream wise gradients in the flow in the upstream and downstream part of the domain, i.e. outside the main disturbance of the flow field by the explicitly modeled obstacles (Richards and Hoxey, 1993). This generally requires the use of wall functions. The third requirement implies that it is not physically meaningful to have grid cells with centre points within the physical roughness height. This requirement is explicitly mentioned by several commercial CFD codes including Fluent 6.2 (Fluent Inc., 2005) and Ansys CFX 10.0 (Ansys Ltd., 2005). Both codes warn the user to abide by the requirement yp > ks. In addition, Ansys Ltd. (2005) mentions that violation of this requirement can lead to inaccuracies and to solver failure but it do not elaborate further on this issue. The fourth requirement concerns a relationship that

> results from matching the ABL mean velocity profile and the wall function in the CFD code and will be discussed later. All four requirements should be satisfied in the upstream and downstream region of the computational domain, while in the central part, only requirements (1) and (3) must be adhered to. However, it is generally impossible to satisfy all four requirements. (Blocken and Stathoupolos and Carmeliet, 2007, p.)

The accuracy of results depend on the features above, thus also on the user's experience and numerical simulation skills. Additionally, the accuracy of results is also affected by the density of the grid that represents the simulated space, which is limited parallel to the power of computering. Computational meshes of sufficient refinement are required in order to resolve local solution gradients. Thus, not only an experienced researcher, but also a large computer is required for a successful application of CFD program. (Allard, 1998)

In conclusion, it is clear that CFD simulations have the potential to make predictions of the air velocity patterns and the temperature distribution in cases of summer cooling. However, natural ventilation for summer cooling is a non-steady-state problem with complex boundary conditions. Flow conditions must be defined at solid boundaries as well as at other boundaries, such as the inlets and outlets of the flow.

In spite of the present limitations of using CFD codes for building modeling and especially, for the description of natural ventilation mechanisms inside buildings, for research purposes, CFD method is, at present, the most accurate numerical method. Furthermore, it allows multiple simulations at relatively low cost in comparison with wind-tunnel modeling. For these reasons, CFD modeling is used in this thesis for airflow prediction in and around courtyard buildings. A more detailed description of the models used is provided in chapter 5.

Wind tunnel and CFD are the most sophisticated and accurate methods to predict airflow in buildings.

Advantages of CFD versus wind tunnel tests are:

- Numerical simulation is less time-consuming and less expensive than wind-tunnel modeling.
- CFD can directly yield detailed spatial distributions of velocity, temperature and contaminants at every point around the configuration studied while the results in wind tunnel modeling are very sensitive to the configuration and details of the wind-tunnel itself.

Disadvantages or Limitations versus wind tunnel tests are:

- Due to the complexity of CFD modeling, a high level of expertise is needed as in case of wind-tunnel modeling.
- Sophisticated experimental data are needed to validate and assess the CFD results for specific building configurations.
- At present the use of CFD is not a suitable solution for building design, especially, for small and medium projects. (Blocken, 2004)

2.3.1.3.3. Verification and Validation of CFD

CFD verification refers identifying and quantifying errors in the model implementation and the solution (sensitivity analyses, e.g. discretization error)

5 types of errors can be seen in CFD models:

1. Physical modeling errors

   Due to uncertainty in the formulation of the model and to deliberate simplifications of the model, e.g., employing the RANS equations I combination with a given turbulence model, the EVM (eddy viscosity model or Boussinesq hypothesis), the use of specific constants in the k-ε model, the use of wall functions, the modeling of the surface roughness in Fluent, simplifications of the geometry of the model, etc. There is no turbulence model that is universally valid. Physical modeling errors can be examined by performing validation studies.
2. Computer round-off errors

   Round-off errors are not considered significant when compared with other errors. If they are suspected to be significant, one can perform a test by running the code at a higher precision.
3. Iteration-convergence error

This error is introduced because the iterative procedure has to be stopped at a certain moment in time. Iteration-convergence errors can be estimated.

4. Discretization error

   Discretization errors are generated from representing the governing equations and the equations of the turbulence model on a mesh that represents a discretized computational domain (for unsteady calculations also time discretization causes discretization errors). This type of error is also called “numerical error”. Grid sensitivity analysis is a minimum requirement in a CFD simulation.

5. Computer programming errors

   Programming errors are mistakes made in writing the computer code. These types of errors can be discovered by systematically performed verification studies and validation studies and by comparing the results of the code with those of a similar code.

Physical modeling errors, iteration-convergence error, discretization error are user-related errors, while computer round-off errors and computer-programming errors are user independent. Physical modeling error can be checked with CFD validation and the other four types of errors can be checked with CFD verification.

As a result: CFD simulation results can only be trusted/used if:

(a) They have been performed on a mesh obtained by grid-sensitivity analysis

(b) They have been performed taking into account the proper guidelines that have been published in literature

(c) They have been carefully validated.

Validation means systematically comparing CFD results with experiments to assess the performance of the physical modeling choices. Validation typically focuses on certain models and/or certain applications (e.g. performance of the k-ε model in predicting wind flow around buildings). The validity of turbulence models for different applications is typically assessed by model validation.

If possible, perform model validation. Often, model validation for complex case studies is not possible. In that case, to perform model validation for similar generic building configurations is proposed by experts.

Only under these conditions, the suitability of CFD with the used approach (RANS, LES, and turbulence model and wall functions) for a specific problem can be judged.

CFD is often unrightfully blamed for poor results. CFD is a valuable tool, but it can also be a dangerous tool if user friendly commercial CFD codes give opportunity for everybody to generate some results and errors can easily be made because of large amount of user input/user knowledge is required.

When the tool is used with precision, Computational Fluid Dynamics is a tool that allows us to solve flow problems that do not have known analytical solutions and cannot be solved in any other way.

2.3.2. Thermal and Energy Modeling: BES (Building Energy Simulation) Modeling

The simulation technologies used for architectural research can be defined under two topics:

a- Prototype model analysis of an architectural design in the pre-design phase; this method is used with concrete 1:1 or different scaled model tests.

b- Computational simulation techniques: Use of computer software.

These two different simulation methods are hard to be compared, yet it is seen that computational simulation techniques are more random in use especially in the last ten years. The reason of this increasing interest in the computational simulation techniques can be interpreted as the deficiency of prototype model analysis in some respects. The subject will be examined in detail in the following part.

Prototype model analysis of an architectural design in the pre-design phase

In architectural research the use of representations is common. “Simulation research involves controlled replications of real-world contexts or events for the purposes of studying dynamic interactions within that setting. Collin Clipson calls these replicated contexts ‘virtual worlds’ and the contents of these contexts ‘synthetic elements’. The philosophical assumption in this approach, in Clipson’s words, is that: ‘synthetic elements of the virtual world are accurate representations of the real world in all effects... The experience of these elements is similar to what one would experience in the real world.’ (1) As expressed in the book of Groat, the representations are effective in experiencing the real world.

The simulations done with the concrete representations of architectural elements are effective and give accurate results in many of the structured simulation studies. In “Urban bioclimatic design strategies for a tropical city” titled article an example of the simulation made with a concrete model is given. The study investigates the method to be followed for the design of an urban fabric. The comparison of scale model and field observations method is been used for analyzing the most suitable urban geometry and land use, in this study. The used method has been taken from the model of Oke T.R. For the simulation experiment two mass models have been prepared, one defining the topography of the empty field studied and the second the topography with the urban fabric elements placed on. The materials used in the model are chosen in relation to the original materials of the defined system. The night and day thermal measurements of the models, which are placed in the same room, are picked and the relative error ranges have been calculated as well.

These simulation techniques can be reproduced and various different scaled model tests of the original system can be analyzed, yet the accuracy of the results are more questionable than the computational simulation model tests. One of the main reasons for this case can be defined as the material properties of an original system can be defined more precisely with computational databases.

Computational simulation techniques:

Computational simulation techniques vary in the field of environmental simulation technologies. One of the easiest ways to classify them are according to their purpose subjects such as; solar climate analysis, indoor air quality, ventilation/air flow, and validation tools. There are more than a hundred computational simulation programs listed in EERE s web page related to the subject.(3) Some programs defined are suitable to be used in all subjects, while some are individualized on only one issue (like the shading of windows; SOLAR 2).

The current stock of environmental simulation systems is categorized in the following part according to more specifically defined architectural subject areas. Under the defined new categories only the most significant simulation techniques will be briefly summarized. Some of these techniques will also be examined according to how they are used in some reviewed studies.

Generally, manual and empirical calculation methods cannot produce accurate results and cannot handle complicated heating, ventilating and air conditioning (HVAC) systems. On the other hand, building thermal and energy simulation programs (BES) can provide detailed energy information for a whole building and HVAC systems.

In BES the impact of the exterior environment is expressed by the parameters: solar radiation; outdoor air temperature; other external temperatures of sky, ground and surrounding surfaces; wind conditions and outdoor air humidity. The impact of the interior environment is expressed by: heat gains from occupants, lighting and equipment; sources of humidity; and sensible and latent effects of existing conditioning equipments.

2.3.3. Coupling CFD and BES programs

Both CFD and BES need input data to calculate airflow around and in the building and indoor thermal conditions respectively. Most BES programs cannot determine accurate airflow entering a building by natural ventilation, while room air temperature, heating-cooling load, and thermal comfort heavily depend on the airflow (Neymark, 2002). Cp values, for instance, are inputs in many thermal programs. But Cp values for non-regular buildings and buildings inserted in a compact urban environment (PAD>0.5) cannot be predicted using the available tabulated methods and parametrical models as the one proposed by Grosso (CPCALC+1). This information can only be provided (numerically) by CFD models which can predict Cp values at any point of the building envelope and also calculate the natural ventilation rate driven by wind effect, stack effect, or both. But CFD and other airflow models need some thermal and flow boundary conditions, such as wall surface temperature (Ts), heating-cooling load or surface heat flux (Qconv) that can be provided by BES. Therefore, as, when a whole building energy and comfort analysis is required, a combination of an air movement model with an energy simulation model is necessary in order to improve the accuracy of both and, hence, to get more realistic results. There are two basic approaches for integrating or coupling a thermal model with a flow model:

1. Thermal model calculates temperatures based on assumed flows or ventilation rates, after which the flow model recalculates the flows using the calculated temperatures, or
2. The flow model calculates flows based on assumed temperatures or assuming an isothermal flow, after which the thermal model recalculates the temperatures using the calculated flows.

This means that either the temperatures (case 2) or the flows (case 1) may be different in both models. Thus, further steps by iteration need to be taken in order to ensure the thermodynamic integrity of the overall solution.

Djunaedy et al. discussed a possible future approach in building simulation in which multiple models are linked. Run-time coupling of distributed applications (as opposed to integration by merging code) would enable multi-level modeling (the modeling and simulation laboratory metaphor), and will allow task-shared development of building performance simulation tools and techniques.

Although empirical validation is mandatory during the development of a program in order to establish a true standard for evaluating the ability of a program to analyze real physical behavior, for building design simple verification methods are more convenient to save time and resources. Comparing parametrically different design solutions using the same program can be the simplest method. For research purposes, according to the complexity of the problem and the modeled building, a combination of validation techniques is advised. Furthermore, the user should follow several verification steps while the model is constructed and the data is entered in the program.

Despite the power of BES, the experience and skill of the user directly determine the quality of the building simulation. Some important steps are proposed by Hong, et al. in order to assure quality and accuracy of modeling in BES:

1. Mastering how to use a program
2. Representing the building and HVAC systems
3. Preparing the input data
4. Running and controlling the program
5. Interpreting the results and making decisions

It is sometimes difficult to judge whether the results are accurate or not. If the quality of the program is checked and the above four steps are carried out properly, the results are prone to be believable. But the user still needs to evaluate the results based on his/her experience. Interpreting the results and making decisions require the user's professional expertise and the knowledge of the real world. Furthermore, different software could be more accurate for different calculations even if a holistic systems approach is taken. Then, knowing the strength and weakness of the programs is also important when interpreting results.

Some validation modules (VLD) for BES have been developed in order to allow potential simulation users to examine the accuracy of the simulation package even before learning how to use the package itself. In addition, professional users can employ VLD to control the accuracy of their simulation results and to compare output from

BES to a set of analytical solutions that constitute a reliable set of theoretical results given the underlying physical assumptions in the case definitions.

CHAPTER 3

CLIMATIC CONSIDERATIONS IN CASE STUDY AREA: ALAÇATI TRADITIONAL SETTLEMENT

3.1. Selection of Case Study Area

Alaçatı is a unique Aegean town (in Çesme-Izmir) on the western coast of Turkey. Traditional architecture of the town is still visible in the old center and makes it possible to study the effect of climate on residential architecture and on the traditional pattern of the town. This place is famous for its architecture, vineyards, consistent and steady wind, and windmills for over 150 years. Now this area is popular in the world as a windsurfing and kite surfing center and Alaçatı is growing around its unique traditional town center enormously.

Figure 3.1. The location of Alaçatı, Izmir, Turkey
(Source: windsurfersparadise, 2010)

Alaçatı is located in Çeşme Peninsula. It is on the highway connecting Çeşme to İzmir and 6km far from Çeşme town center. Alaçatı is 72 km at the west of Izmir according to map reading (see figure 2). It's latitude (DMS) is 38° 16' 53N, longitude (DMS) is 26° 22' 27E and altitude of the town center is 15 meters. Town center is established far from the sea[10] , 1km far from inner bay (See Figure 3.2). The approximate population for 7km radius from the center point is given as 20189 by fallingrain.com. However, according to official data taken from the municipality in 2009, the population living all through the year in the town is approximately 7000, while this number increases over 60.000 people in summer season (http://www.fallingrain.com/world/TU/35/Alacati.html) (Alaçatı Municipality, 2009).

Figure 3.2. The transportation map of Alaçatı, Izmir, Turkey
(Source: manastiralacati, 2010)

Alaçatı is chosen as the case study area for this thesis because it is one of the fastest growing urban sites in the Aegean region of Anatolia. Furthermore, the wind has

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[10] Traditional settlements on the coasts of Anatolia are built away from the seashore, because of floods and climate considerations . Productive plains were always more conducive for the establishment of the towns rather than salty and swampy grounds around the coast. Alaçatı traditional town settled on the skirts of Değirmen Mountain on the north and on the plain towards the Alaçatı Gulf, where the effective wind of the bay access is less. The field between the settlement and the gulf is partly swampy. There are a few dried-out streams running through Alaçatı. During rainy seasons, excess water in those streams may still cause floods in some districts.

always played a significant role in the development of the architectural character of the town and in the morphology of the settlement. These together make Alaçatı a suitable case where it will be possible to study the effect of climatic factors, especially wind, on the thermal comfort.

Traditional settlements in Turkey such as Alaçatı are under a growing danger of either destruction and despair or tourism. The historical character of the town is attractive for tourists, but as in many of these kinds of settlements this interest causes the character of Alaçatı to get degenerated if not ruined and the town is increasingly surrounded by new imitative examples. The buildings of the old settlements are demolished or repaired with inappropriate methods according to new needs and the new settlement areas cannot integrate morphologically with the old heritage. The problem in the design of these new dwellings is that they do not follow the design principles of the traditional settlements and when they seem to follow the design principles they do that only at the level of image without any concern for traditional techniques of employing wind in improving the thermal comfort. These new houses, even though they are made to look old and traditional by extensive and exquisite use of stone, are cooled and heated by inefficient air conditioning.

As stated by Oktay (2001):

> Each region has its own climatic conditions and cultural patterns, which must be the basis for the solutions in each individual case. In fact, each country or region has a traditional settlement and building form or ‘vernacular architecture’. Since these cases embody a great deal of experience, wisdom, and cleverness, the layout, basic design, and orientation of older buildings are worth studying in some detail for valuable clues and ideas. In particular, vernacular architecture is almost always climatically appropriate. (p. 1003)

Thus, especially new design examples should better follow the spatial design characteristics of climatically more responsive traditional architecture in places where there are still surviving traditional construction practices.

3.1.1. General Climatic Conditions in Alaçatı Region

The climate in Alaçatı generally follows the features of the Mediterranean climate coupled with effective sea breezes of the Aegean Sea. The consistent and steady winds, topography and location of Alaçatı make this town an interesting case within the Aegean region. Furthermore, these same natural features create suitable conditions for an ideal windsurfing spot in Europe. Both, the shape of the bay and the thermal water pressures, create steady and consistent winds blowing side-shore from North to South (North eastern wind-Poyraz) in summer and from South to North (South wind-Lodos) in winter months. The dominant wind direction in Alaçatı is North-west and annually 300 days; the wind blows over 5m/s in the area. (http://www.windsurfersparadise.com/route.asp)

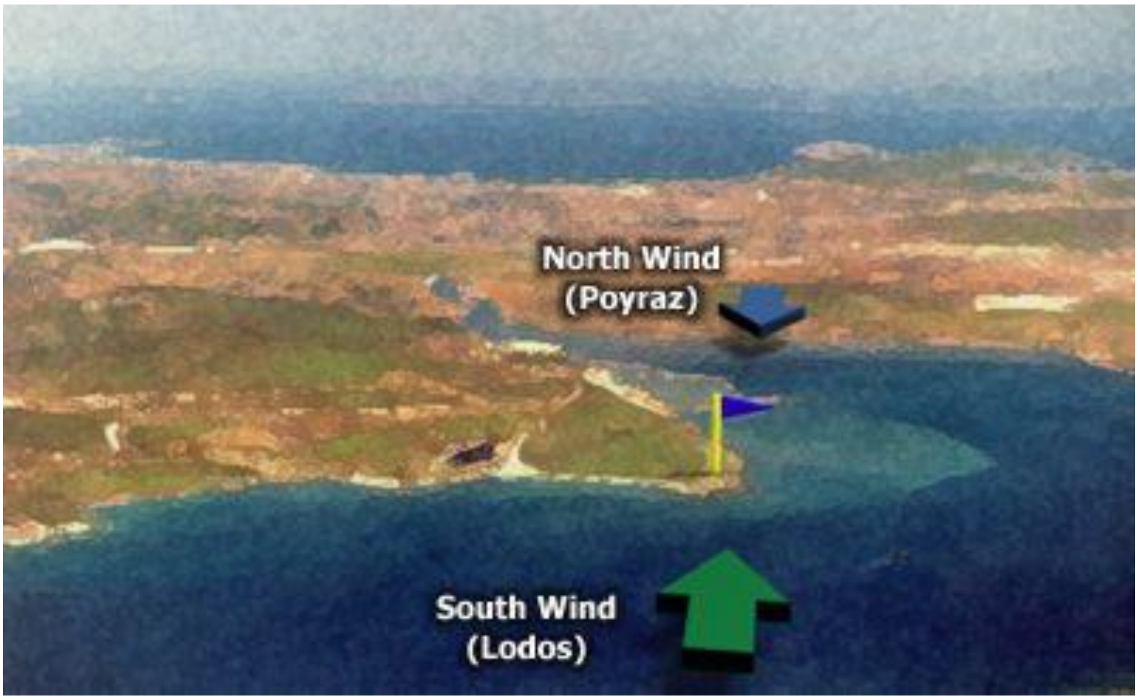


Figure 3.3. Alaçatı Bay Wind Map
(Source: windsurfersparadise,2010)

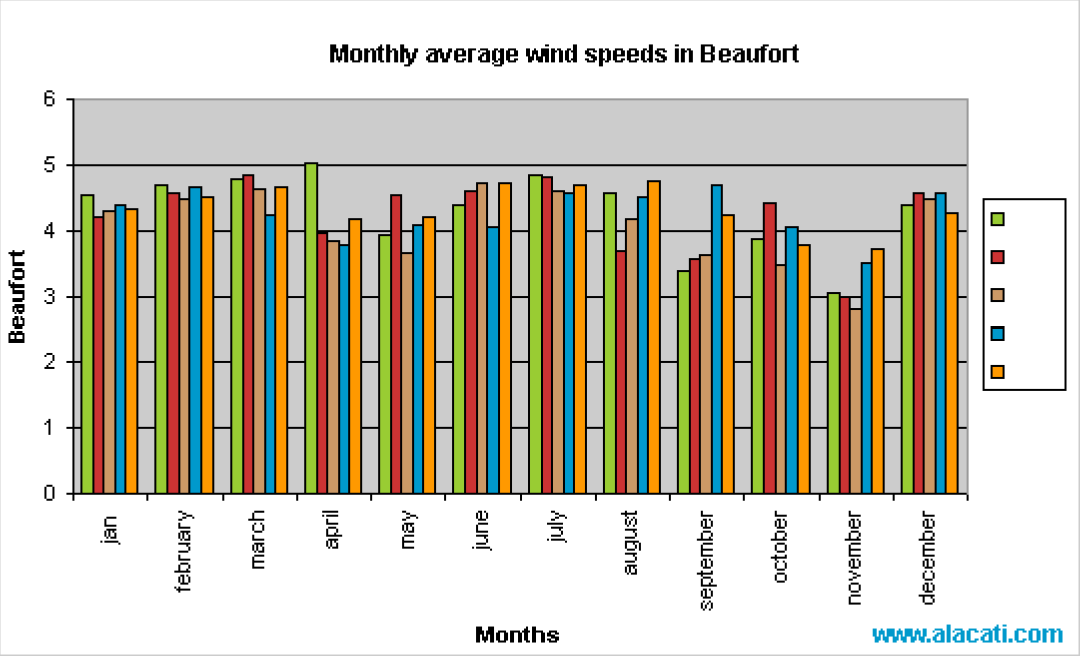


Figure 3.4. Monthly average wind speeds of Alaçatı in Beaufort Scale (Source: winsurfersparadise, 2008)

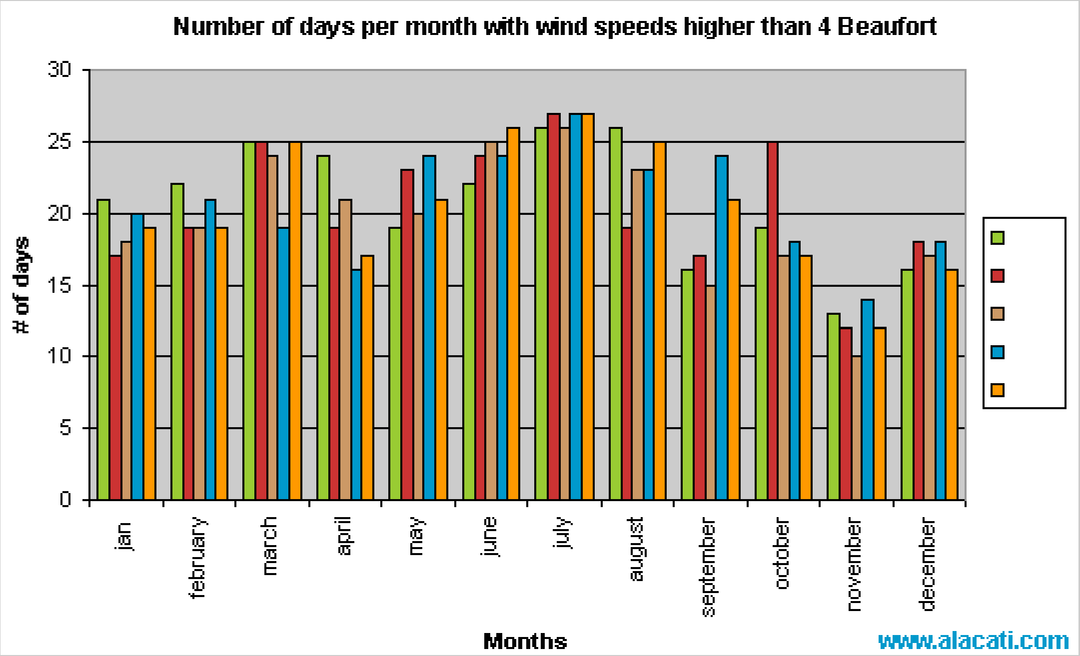


Figure 3.5. Number of days per month in Alaçatı with wind speeds higher than 4 Beaufort (Source: windsurfersparadise.com, 2008)

In Figure 3.4 and Figure 3.5, the wind regime of Alaçatı in 2000-2001 years are summarized. These measurements are taken by Ocean Company in America for Engin Kalafatoğlu, a private enterprise for wind surf availability research.

The climate in Alaçatı is Mediterranean. It is hot and dry from May to October, whereas from October to May it is mild and rainy. The average temperature in January is 7°C and in July 32 °C. Relative Humidity stays within average limits %20-%80, not as humid as it is in tropical zones (Izmir Meteorology Department, 2006).

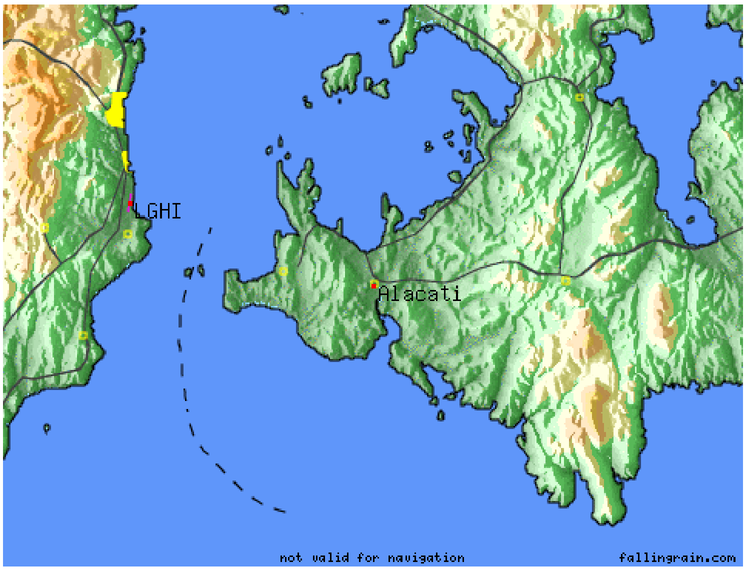


Figure 3.6. Altitude Map of Alaçatı
(Source: fallingrain.com, 2008)

3.1.2. Morphological Generation of Alaçatı Historical Settlement

There is a variety in the physical environment and landscape in Alaçatı and its surroundings. Among others, we can see examples of traditional architecture, new housing developments, second houses, touristic establishments, green areas and crop fields. Özgönül (1996) states that the traditional fabric of Alaçatı covers almost 15.5% of the whole settlement including new developing areas and fields (p. 98). Today it covers only 10% (Alaçatı Municipality, 2009).

As Olgyay (1973) defines the morphological formation of traditional settlements:

The ‘tissue pattern’ of town layouts is an interwoven synthesis of many factors. Its organism reflects political and social tendencies as much as materialistic and technical requirements. From all those shaping factors which are merged together into a composite picture, sometimes it seems difficult to analyze the climatic environment as a separate element. However, in a town layout the same tendencies and characteristics can be found which were influential in determining single building units. As it is influenced by the same forces, its texture not only is built up as a conglomeration of different shapes, but also reflects mass-building tendencies on a larger scale. The density of a city layout will vary according to friendly or adverse climatic conditions. (p. 23)

Alaçatı’s location and layout can be examined with both friendly and adverse behavior of climatic note: the details about the wind effect on morphological settlement are described in detail in section 3.1.4.1. Here, the morphology of three main quarters, namely Hacı Memiş, Topoğlu and Yeni Hamidiye quarters will be described according to street and parcel relations.

When the traditional settlement area is analyzed, 3 main streets; Kemalpaşa Street, Hacımemiş Street, and Cemaliye Street are shaping the pattern. These main streets are wider than the other secondary streets of Alaçatı. They are 7 to 8 meters wide, while the secondary streets are 4 to 6 meters wide. All three main streets end in the central square of Alaçatı. The main streets all break sharply at small distances and form the transportation network of the organic tissue of Alaçatı. There are no sidewalks in the street structure. The smaller streets shaped in the old section of the town are 3 to 4 meters wide at some parts especially in Hacı Memiş Quarter. Secondary streets open to wider axes, which are defined as commercial axes by Özgönül(1996). There are also cul-de-sac streets linked to these secondary streets. Özgönül (1996) states that the traditional buildings in Alaçatı are mostly located in the attached order. Their façades are adjacent to each other and form a continuous façade group. Almost none of those buildings have front gardens or courtyards. These types of open spaces are mostly placed in back of or next to the buildings placed along the roads.

The parcels are side to side in the old section, where the houses are located side to side as well. This helps to canalize the wind throughout this settlement. Nearly all houses are two-story high and have gardens at the back, which do not have any direct visual relation with the streets. However, there are also one-story examples, called bağ evi (country house), which still exist (See section 3.1.3.2).

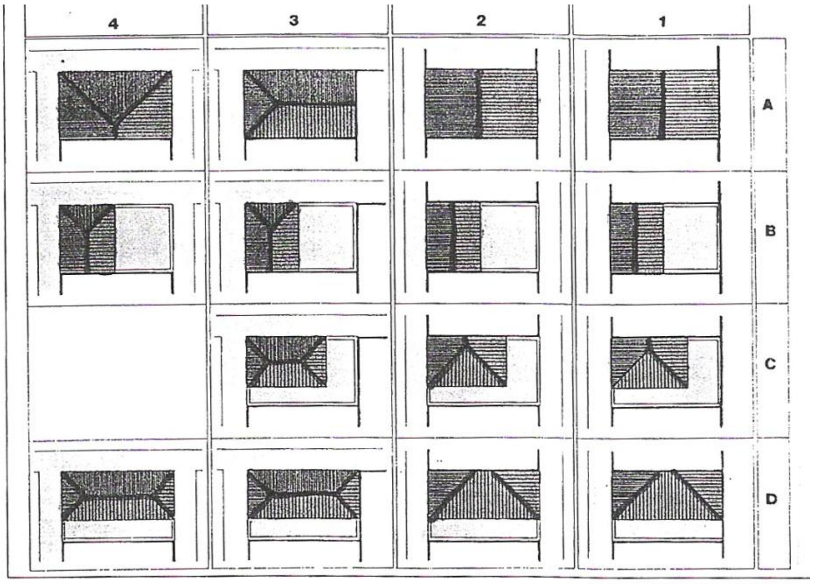
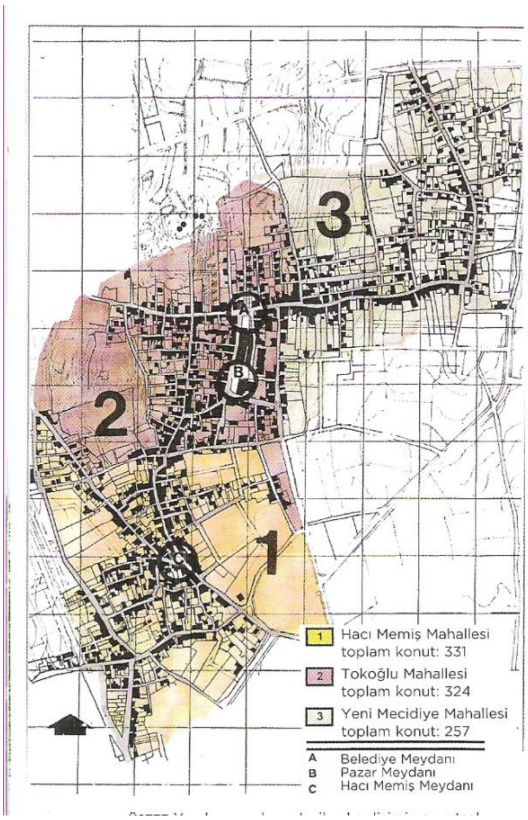


Figure 3.7. Building/Lot relationship due to building location on street
(Source: Özgönül, 1996)

In Figure 3.7, building lot relations are categorized by Özgönül. According to her categorization, the most common parcel relation is the back garden parcels defined with 4A in this figure.

Two main patterns can be read in morphological tissue pattern growth in Alaçatı historical settlement, which is shaped by different ethnic groups. Organic smaller road organization and following parcel organizations can be identified in the south part of Alaçatı settlement (Hacı Memiş Quarter), which covers a quarter of the total area of traditional settlement as seen in the following maps of Alaçatı(See Figure 3.10). According to Özgönül, Topal, Hersek, this quarter was built first in the 18th century (Hacı Memiş Mosque). Ottoman community of the time built houses and settled in this area. Then workers from Chios migrated and started building new quartiers at the north of this area after they became the majority in the population. These quartiers are seen in Figure 3.8.



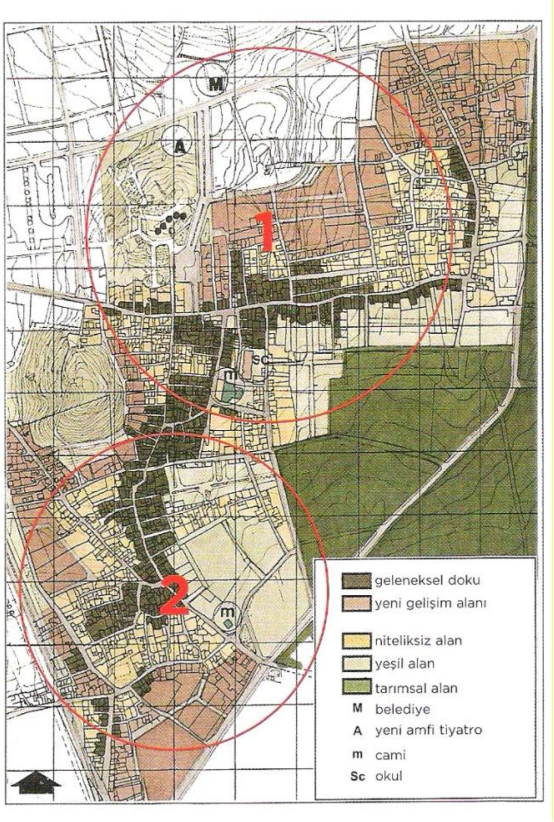


Figure 3.8. Quartiers in Alaçatı
(Source: Özgönül, 2010, p.19)

Figure 3.9. Tissue Pattern of Alaçatı
(Source: Özgönül, 2010, p.19)

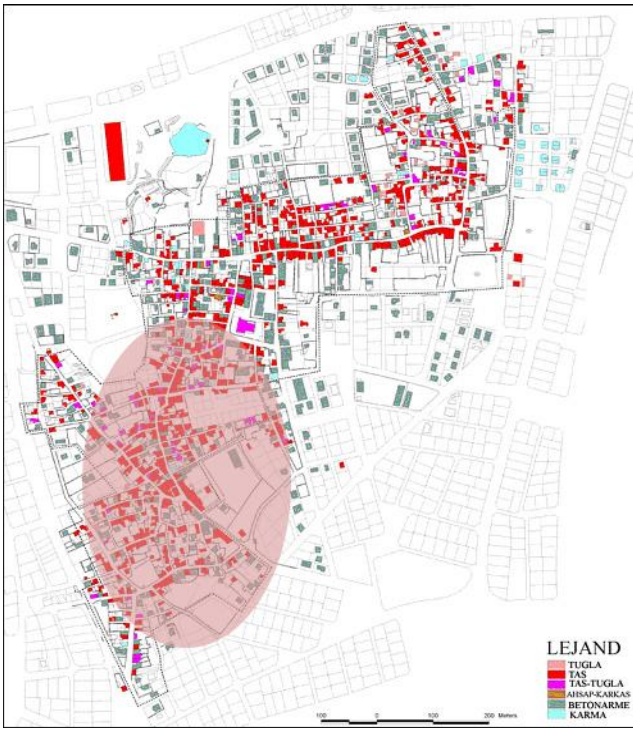


Figure 3.10. Hacı Memiş Quartier with its organic pattern
(Source: IYTE study, 2004)

3.1.2.1. Settlement Patterns in Alaçatı Historical Settlement

There are two main types of settlement patterns in the old section of Alaçatı. The first type is shaped by an underlying grid order (Yeni Mecidiye and Tokoğlu Quarters), while the second one is shaped with a more organic geometrical organization. This organically shaped part is the Hacı Memiş Quarter[11] , where the Muslim[12] population of the town used to live, which now occupies a quarter of the traditional settlement. In order to perceive a complete vista of the traditional settlement and the new housing areas shaped around this periphery, the most suitable point is the hilltop of Değirmenli.

The most interesting thing about Alaçatı town pattern is the changing character of the urban fabric, which may have been shaped by different communities in Alaçatı. Greek community, who lived in this place until 100 years ago, is thought to be living in the area where we see traces of a grid urban plan (especially Yeni Mecidiye Quartier), while the more organic section was occupied mainly by Turkish communities in different time sections (Tosun, DEU study, 2000, Özgönül,1996, Topal, 2008). Both sections consist of attached row houses to canalize the strong wind effect. Also, street characters and aspect ratios are similar in both sections. Only orientations with respect to sun differ in the two sections.

3.1.3. Building Typologies and Classification

Building typologies in Alaçatı historical settlement can be identified by different classifications. In the studies evaluated (Classifications of Özgönül, 1996 (parcel/street

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[11] According to the interview made with İbrahim Topal on the 25th of January 2008, the arrival of Hacı Memiş (an admiral of the Ottoman Empire) to Alaçatı, changes this town dramatically. He nestles to the Alaçatı harbor with his fleet after a big storm. The community living in Alaçatı asked his help for draining the river in the swampy area, which causes malaria epidemics. It is known that Buca and Osmanağa river channels were opened to dry out swampy areas in the first half of the 19th century. During this process Greek workmen are brought from Chios (Sakız) island, because they had better knowledge of this type of work. Then these workmen were settled in Alaçatı and the lands of Hacımemiş area in the south of Alaçatı were given to these immigrants for agriculture. The lands were only given for a certain period of time by Muslim native community. The exact date of this migration is not definite (1810 according to Özdeniz's study, before 1850's according to İbrahim Topal)., İbrahim Topal (Alaçatı population, third generation member).
After the Balkan Wars in 1912, the Muslim Balkan citizens were located in Alaçatı. At the same period, the Greeks, who are afraid of the upcoming Christian-Muslim conflict (Uran, 1959,69-72), left the town suddenly.

[12] Hacımemiş Mosque in Hacı Memiş Quarter (See figure 8) is almost the only evidence of Turkish presence in the town, which dates back to 18th century (Hersek, 1986). While Pazar (Tokoğlu) Mosque that was originally built as a church dates 1874 in Tokoğlu Quarter.

relation, spatial organization); Hersek, 2001 (façade organizations); DEU, (2000) (types defined according to Eldem); IYTE CP 302, 2004 (material classification), there are different classifications, which will be reinterpreted for certain new classifications of the town.(3.1.3.1 Material Classification, 3.1.3.2 Turkish House types, 3.1.3.3 Classification according to spatial organizations)

For the purpose of this study, classifications according to spatial organization of traditional buildings are the most suitable one to study the relation between house and urban morphology and climate.

3.1.3.1. Classification According to Material Use of Traditional Alaçatı Houses

Material use is an important factor in the classification of traditional houses in Turkey (Aksoy, 1963). The materials used in the traditional houses of Alaçatı are a factaffecting the indoor thermal comfort. Thermal mass related to construction material and material characteristics change the thermal comfort in indoor spaces considerably. Thus, houses built with different materials in Alaçatı can be quantitatively tested. Material classification is important for all quantitative thermal experiments, yet it is more suitable to be analyzed in further BES simulations[13] conducted with packages such Energy Plus, TAS, Ecotect, etc. Material characteristics could also be investigated in laboratory settings. For example, traditional plasters used in Alaçatı houses are worth to study in terms of their effect on indoor thermal comfort.

Stone is the main construction material in Alaçatı houses. There are also structures built with hybrid construction materials, such as stone walls on ground floor level and wooden frame structure filled with stone or adobe for the second floors. Thermal mass difference of these houses caused by material difference affects thermal comfort levels. Stone walls' thermal mass is greater than both brick walls and hybrid structures (Tosun (DEU study), 2000).

The historical houses that are in better condition are also the stone examples. The examples of stone houses were selected as the cases of this thesis. Houses defined for case study are masonry stone examples, thick in ground floor while smaller sections adapted for floor walls.

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[13] For more information see Section 2.3.2

Figure 3.11. Hybrid construction (cut-stone masonry in first floor, wooden brace structure filled in between with rubble stones in the second floor walls, wooden roof with tiles (alaturka) on top, in Hacı Memiş Quartier)

Stone walls in the traditional masonry construction are 100cm thick in the basement level and 50 cm thick (rubble or cut-stone masonry) in the second floor. In this construction system wooden beams are used for window door openings and in between different floor levels. Also, the use of cut-stone with iron bonds in between is seen in some Alaçatı houses. Roof system is always wooden construction (kırma or beşik çatı) covered with roof tiles (alaturka shingle) and the slope of the roofs is around 25%-30% levels.

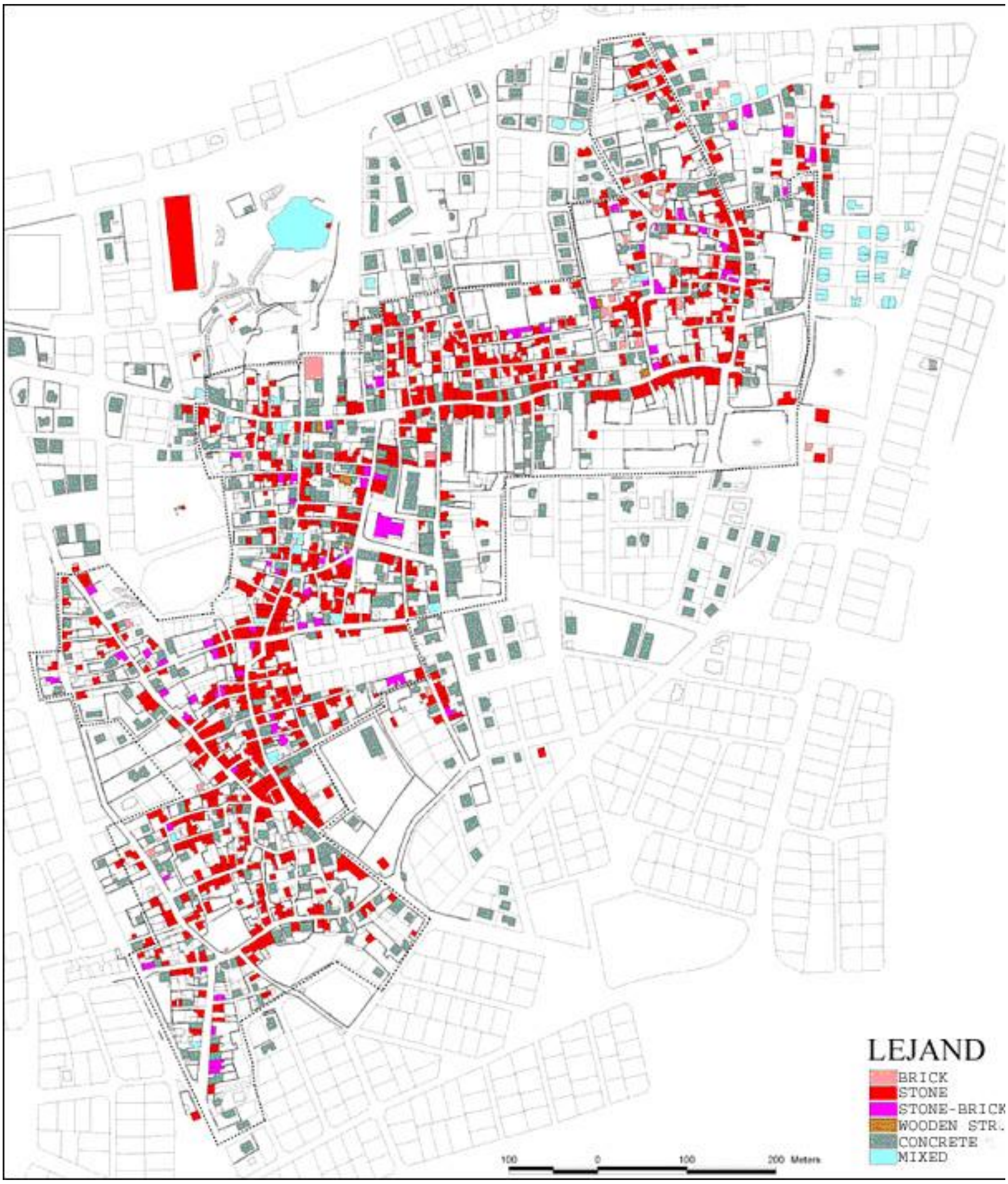

Figure 3.12. Map of the Buildings in Alaçatı according to their Construction System Typologies (Source: CP 302, IYTE: Field Study, October 2004)

Material information of Alaçatı traditional settlement is defined in Figure 3.12 as a course field study conducted in fall 2004 semester.

The bonding lime material of Alaçatı houses have been collected from lime wells of Urla, Izmir and Uzunkuyu, a village near Alaçatı. Marbles have been acquired from Nohutalan village, near Alaçatı, and the beige-brownish marbles have been acquired from the roots located in the south-east of the town.

3.1.3.2. Classification According to Study by Eldem: Island House/Turkish House/Wineyard-Country House

Alaçatı houses vary in typology, when they're analyzed according to the categories defined by Sedad Hakkı Eldem in his "Türk Evi" book. It is expected that different quarters in Alaçatı will show different housing characteristics, yet the houses built in these quarters are mixed examples of island house (sakız chios type) and Turkish house (Türk Evi) typology defined in a study on Alaçatı done by Dokuz Eylul University (2000). According to this study; the house types in the traditional town is classified in three typologies: 1) Island type (Sakız/Chios type houses), 2) Turkish houses (Türk evi as characterized by Sedad Hakkı Eldem); 3) Country houses (Bağ evi/vine yard houses). This classification needs to be revisit with respect to relationship between climate and house morphology.

Different housing types given in this classification are mostly defined by façade characteristics. A certain distinction between house characteristics of different quarters cannot be selected at the end of this classification analysis. Thus, hybrid examples repeated all around the town are more dominant in the historical fabric.

The spatial organization variations of all differently classified houses in previous classification group are not related with façade based characteristics. However, according to study of Özgönül it is possible to categorize all houses in Alaçatı with spatial organization patterns (sofa organizations), which is more effective to use for further steps of this study.

3.1.3.2.1 Island House (Sakız Type House)

Island (Sakız type) houses differentiate from other houses with respect to their elevations. The sakız type house was first defined by Sedad Hakkı Eldem[14] in 1952. This classification is used to define the houses seen in the Aegean Region, especially the ones close to coasts both in Greece and Turkey and on the islands, such as Chios, Rhodes, Midilli, Crete, Mikonos, of the Aegean Sea.

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[14] Sedad Hakkı Eldem started the research on Turkish House in 1950s in Anatolia and then in the Balkans, where Ottoman Empire had greatly influenced the construction practice. He continued this research over 20 years. Türk Evi (1952) is the first published work on the issue

Typical island houses are attached row houses, which face the street with their main entrance on street facade and elevated from the street level with few steps. They either have basements with openings to the street with small windows or have a shop at the street level. Their gardens are located at the back of the house giving no physical or visual access to the street. They typically have bay windows (cumba) on the second floor. However, the island houses in Alaçatı show different characteristics. The entrance doors of these houses are at the street level, some of them show the typical characteristics, but there are many others, which seem to be shaped with different interactions at different time periods. The houses in the old section of Alaçatı mostly have two doors on the street facade, even three at some examples: One for a shop placed at the street level; the second for the house. Some hybrid houses also have an extra third bigger door for the animals and carriages.

Figure 3.13. Typical Island house on Kemaliye Street

Figure 3.14. Typical Island house on Hacı Memiş Street

Figure 3.15. Typical Island house in Topoğlu Quartier

3.1.3.2.2. Turkish House

Turkish type houses in Alaçatı mostly have eaves and sometimes have cantilevers instead of bay windows. The houses mostly have two entrance doors on the street facade, where one of them is the entrance of the house, while the other is entrance to the garden (avlu/ courtyard). However, in most cases even the Turkish houses in Alaçatı have back courtyards or gardens, which are shaped by the parcel configuration. Visual access from the garden or terrace to the street is more common. More flexible street garden relation can be observed.

Figure 3.16. Typical Turkish house in Topoğlu Quartier

Figure 3.17. Typical Turkish house in Hacı Memiş Quartier

Figure 3.18. Typical Turkish house in Topoğlu Quartier

3.1.3.2.3. Vineyard-Country House

Vineyard Houses are not a part of the inner fabric of the original town. They are located at the periphery. Some of these houses are the last ones of attached housing order at the boarder of the old town and few are attached houses just located at the ends of the old fabric, near the agricultural fields in the surroundings. These houses cannot be part of the case study because of their location. It is more appropriate to consider them as a completely different type than the in-town houses.

The following two vineyard housing examples are both located at the edge of the old town (Figure 3.19&3.20). These houses have simple elevations, where the rubble masonry work of either one story or two story houses may easily be observed. They can simply be identified as stone examples with very simple façade and geometry.

Figure 3.19. Country/vineyard house
(one story cut stone)

Figure 3.20. Country/ vineyard house
(two stories rubble stone)

3.1.3.2.4. Hybrid house

Neither according to Sedad Hakkı Eldem’s classifications, nor according to later classification attempts of Küçükerman (2003), Sözen (2004), Eriç (2005), Asatekin (2005) it is possible to provide a clear and unquestionable definition and typology of houses in Turkey. There is not even a common recollection of typical houses within Anatolia. There are certain ways to classify and identify various types of houses in Turkey and in Balkans (Asatekin, 2005), however, the varieties and unusual examples abundant. Thus, Alaçatı houses that can’t be classified by previous classifications can be just defined as hybrid examples.

These types of houses mostly show the parcel characteristics of traditional Greek/Rum, Island/ Sakız (Chios) type. However, the relation of the house with the street is different than the ones in the other parts of the Aegean region. Some of these houses cannot be classified according to their elevation schemes, but it is possible to characterize them with respect to their common spatial relations such as courtyard, hall, and room configurations.

Figure 3.21. Hybrid type house in Hacı Memiş Quar.

Figure 3.22. Hybrid type house in Hacı Memiş Quar.

Figure 3.23. Hybrid type house on Topoğlu Quartier

Alaçatı offers a valuable case, because it gives us the chance to compare the behavior of different housing typologies under the same climatic conditions. In this respect, what matters most is the plan configuration rather than other features which were taken as primary classification criteria. In this study, the differentiations in the spatial organization are accepted as the main determining factor for identifying different typologies.

3.1.3.3. Classification According to Plan Organization of Traditional Alaçatı Houses

Plan configurations of all houses in Alaçatı are influenced by each other at different times. The studies conducted by Özgönül (1996) and Dokuz Eylul University (2000) identified a wide variety of houses. Özgönül's studies on the plan typologies (spatial organization) of various houses constitute the basis of this thesis
(See Figure 3.7).

The historical houses in the Aegean region, which have sofas and courtyards, have different plan schemes, which create different ventilation regimes in the house. According to Özgönül (1996), the spatial characteristics of the traditional Alaçatı houses can be summarized as:

Two main activities namely commercial and residential affect the design principles of the traditional building stock. The ground floors are usually used for retail. The buildings on the main street which are constructed in adjacent order have shops and workshops opening to the street and have storage spaces at the back of their ground floors. Shops and storage rooms are in connection with outdoor facilities, whereas the entrance hall and stable serve to the family. There is usually an access between these two parts. Since daily living activities and in some cases some other activities such as threading tobacco leaves are done in the courtyards, gardens and terraces, these spaces are most important elements of daily life and all daily domestic activities except sleeping take place there.

Especially the ground floor plans are based on the street/building/courtyard-garden relations and divided into two sections according to their functions. In some cases upper floors are completely independent from ground floors and their entrances are from the gardens.

The upper floors of the traditional dwellings are for living purposes. The main space is the hall, “sofa”, which is surrounded by rooms. Sometimes the halls, “sofas” have openings to the street with balconies, and projections (bay window/ cantilever). If the stairs are placed outside the building at the courtyards, then they give access to the terraces. Those terraces serve as “hayat” and they may be open or semi-open. In all courtyards there are fruit trees, flower pots and always a water source like a well or a cistern/water tank (sarnıç) as well as furnace place. (Özgönül, 1996, p. 137, translated by the author)

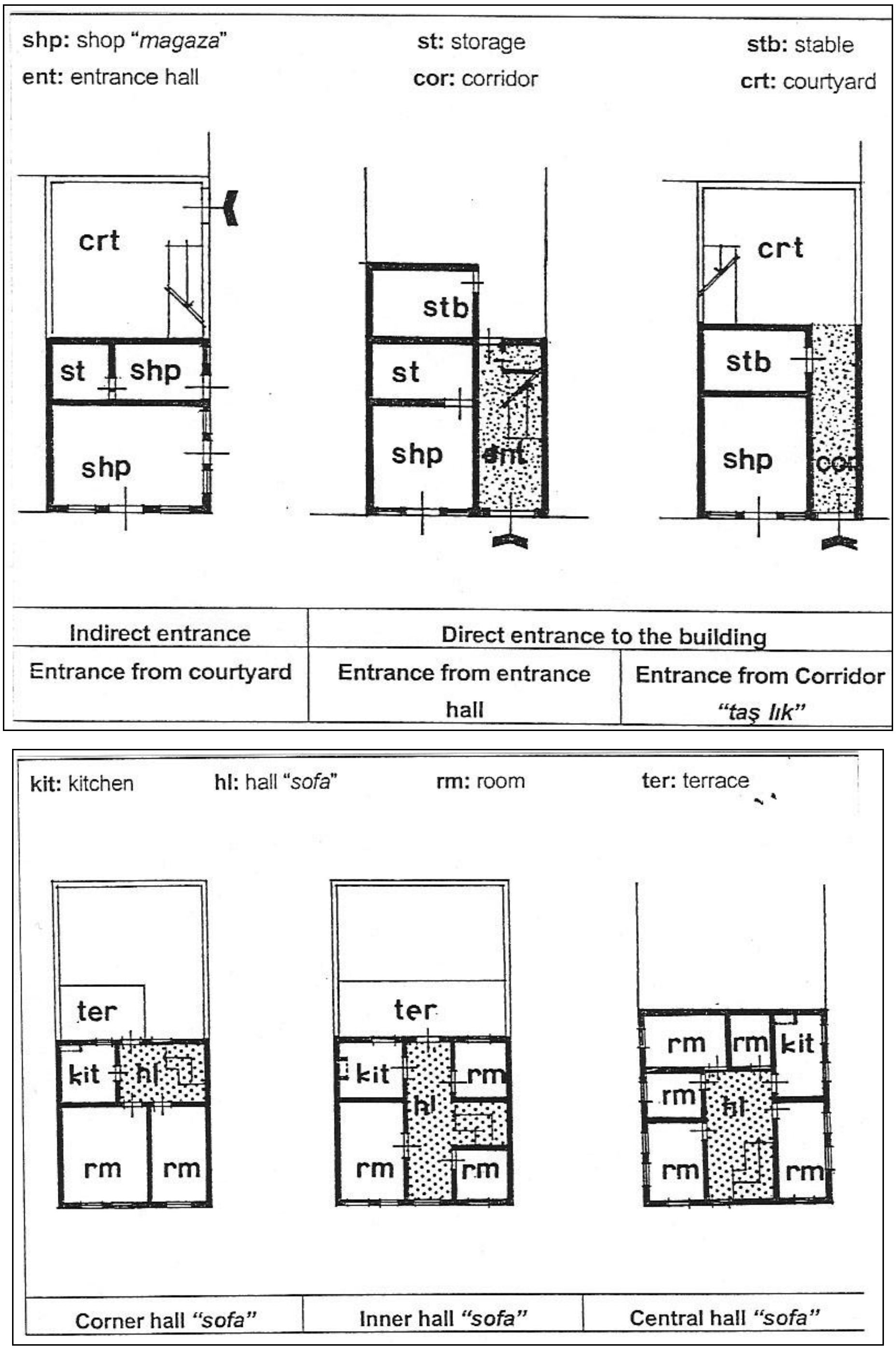

Figure 3.24. Ground & First Floor Plan Types in Alaçatı classified according to Sofa Organization (Source: Özgönül, 1996)

First floor plan organization schemes are depicted in Figure 3.24 are effective plan schemes with respect to using the natural ventilation for cooling. Both corner hall and central hall examples are representing single side ventilated spaces, while the inner hall sofa represents the cross ventilated space, and this space which is the heart of the house can be questioned in thermal comfort manner under different ventilation patterns. Also the hall dimensions would affect the technical effect of natural ventilation on thermal comfort in indoor spaces.

The variety of plan schemes plot relations within the same settlement and its effect on hall shapes makes Alaçatı an interesting case study area. However, the most important fact that differentiates this historical settlement from other Aegean settlements is the strong Alaçatı wind reaching 5.5-6 m/sec level. The dynamic historical background of the town and the variety of different house types created by different ethnic groups, mostly show similar spatial organizations in response to the harsh climate of the area. The study will be the first one working quantitatively on thermal comfort within this historical context in the temperate-hot climate of the Aegean Region.

This thesis study will investigate the most effective plan (hall/ sofa) typology for this region. The alternative planning options about the relation of open, semi-open and closed spaces of houses will be studied to improve the summer thermal comfort conditions in living spaces of the houses under ventilation effect.

3.2. Detailed Analysis of Climatic Considerations in Architecture of the Traditional Alaçatı

Climate can be considered as one of the major elements in the settlement, morphology and dynamics of a city (Santamouris, 2001). Architecture has been strongly influenced by local climatic conditions. Precipitation, availability of sunlight, temperature and wind has clearly influenced the design of houses and other buildings. Aspects that have been affected include choice of the raw materials, opening areas, the slope of the roof and the mass of the building (Santamouris, 2001).

In hot regions like Alaçatı, the summer is the most stressful season. Cooling degree days in Alaçatı are higher in number compared to heating degree days. Minimizing the cooling needs of buildings by appropriate architectural design is the pioneer aim, which means minimizing the solar load and the conductive daytime heat gain through the envelope. Designs in the traditional settlement therefore aim enabling effective natural ventilation when ventilation is available in summer. However, this region also experience cool winters. In such regions winter performance should also be considered carefully. Architectural design features that affect the solar load on a building are discussed below for the case of Alaçatı historical settlement.

3.2.1. Settlement Layout

Urban morphology in Alaçatı has also been defined by taking into account climatic considerations. Matters affected include the width and the orientation of the streets as a function of wind direction and urban design so that natural water flow is also allowed in older periods.

Settlement layout is shaped according to street and parcel relation, aspect ratio, orientation according to sun and wind (prevailing winds), which are analyzed in detail with respect to climatic considerations.

3.2.1.1. Shaping of the Street/Parcel Pattern

In Alaçatı, the grid street layout creates linear streets, which offers natural ventilation throughout the town. Orthogonal structure (urban systems) grid held two grid structures combined by main roads.

In areas where summer comfort is the main consideration, a thinner parcel group and more linear houses may take advantage of natural flow-through or cross ventilation. The buildings in these regions should be open and airy to facilitate the passage of breezes, and should have overhangs and other shading devices to protect it from the sun (Bradshaw, 2006: Givoni 1994, Olgyay 1964, Santamouris 2006, Steemers 2004).

3.2.1.2. The Location of Buildings: Relation with Streets

Buildings in Alaçatı are linearly organized in attached order with their narrow façades facing the streets, which are mostly oriented in north/south, where prevailing wind can be taken indoors. Streets are blocking the wind, while buildings are welcoming (See Figure 3.10 & 3.12).

Air circulation and temperature distribution within urban canyons are significant for the energy consumption of buildings, and heat and mass exchange between the buildings and the canyon air (Santamouris, 2001).Therefore, studies on energy potential of natural ventilation techniques over buildings are a case of interest and needed for Alaçatı.

3.2.1.2.1. Side to Side Parcel and Adjacent Building Relations

Parcels and buildings are adjacently configured in traditional Alaçatı settlement. This organization helps to canalize and control the strong wind effect and allows shadow control on the streets (See Figure 3.23). In clustering, the amount of heat gain from sunlight, the heat gain and loss due to outside air temperature, is directly dependent on the exposed surface area of the building (Bradshaw, 2006). Clustering of attached buildings both horizontally reduces the total exposed surface areas of walls and roofs in Alaçatı as well with short façades facing the streets. Rows of skin-load-dominated buildings are most energy efficient when they share east and west walls, so that only the end units are exposed in the east or west face. In hot climates, even internal-load dominated buildings should have a minimum exposed surface area so as not to aggravate the cooling problem as in Alaçatı example.

3.2.1.2.2. Building and Garden Relations

Open spaces (gardens) and semi-open spaces (outer hall/sofa) are generally located on the south of the parcel, which allows people to enjoy sunlight within garden walls especially in winter period (See Figure 3.27 & Figure 3.28). However, there are also examples of gardens placed on north part of the house parcel; these gardens are more protected compared to southern examples. Gardens should be considered as linear openings which allow the isolated roughness flow at the back parts of the parcels, whereas controlling the canyon layout through the streets.

3.2.1.2.3. Street Aspect Ratios and Major Minor Street Relations

Street aspect ratios allow shadow especially in narrow roads (h/w ratio may reach 1.5), where trade function is not dominant. These roads are aligned at south/north direction and avoid solar impact of the sun especially in summer sun (reaching earth with an angle of 71˚ in summer -Latitude (DMS) is 38° 16' 53N, Longitude (DMS) is 26° 22' 27E-) (Okutucu, 2005).

Figure 3.25. South-north minor street of Kemaliye Main Street
Covered with plants for shadow in summer)

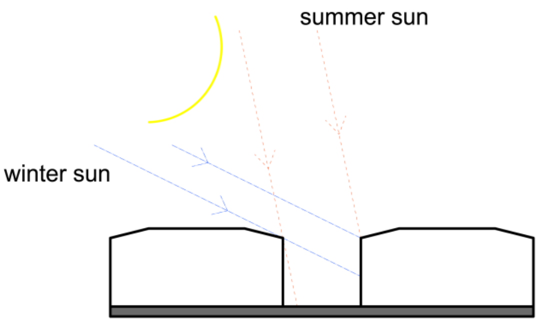

Figure 3.26. W/H= 1.0 ratio canyon & its behavior with winter/summer sun

3.2.1.3. Orientation According to Sun

The main issue in the orientation of building is the orientation of the windows according to sun (Givoni, 1994). Solar energy penetration through large windows in summer can elevate building's indoor temperature higher than outdoors in daytime because of significant thermal stress. Problems of direct solar gain through walls can be minimized through the use of a reflective (white) color or through shading plants, as well as by adequate thermal resistance (insulation) of the walls and the roof (Givoni, 1994, Bradshaw, 2006, Sözen & Gedik, 2007). Orientation of windows defines the potential of solar penetration through in summer. Figure 31 shows the solar gain potential of window oriented in different directions.

Houses in traditional Alaçatı settlement are row houses which mostly faces the street with the shorter façade (minimum 1/3 of the longer side, maximum 1/5th), which minimizes the heat gain through wall areas. Also this organization gives opportunity to minimize solar gain through glass surfaces with small window areas. Only the cantilevers and bay windows increase solar gain from the street side with their hanging out character (see Figure 3.25, 3.27, 3.28, 3.29 & 3.30). The windows of these spaces can all be kept open in summer for reducing the greenhouse effect.

Most of the main streets in Alaçatı are oriented on east-west direction, which blocks the strongest wind coming from north at pedestrian level. Yet this organization causes these streets to take the sunlight all day, which is not preferable for easy access in summer daytime. Major streets are more preferable in winter period with blocked character of prevalent wind and openness for winter sun.

Figure 3.26. Winter Sun on Kemaliye St.

Figure 3.27. Shadows on Kemaliye St. in winter

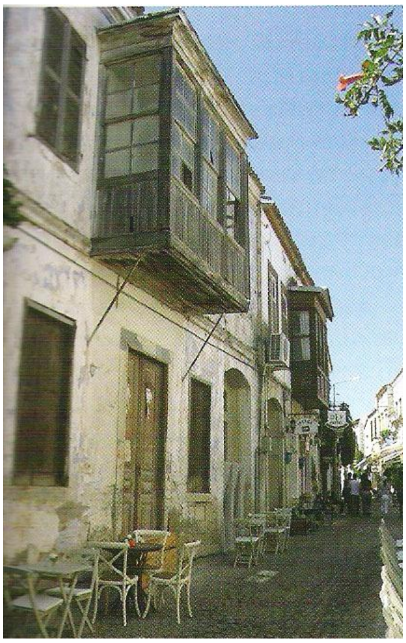

Figure 3.28. Hacı Memiş Street, summer

Figure 3.29. Shadows on Mektep Street in summer

3.2.1.4 Orientation According to Prevailing Wind

In hot humid regions the provision of effective cross ventilation under the local wind direction is the major factor that may affect the building's orientation, the location of main rooms, such as the living and sleeping rooms, in the plan configuration as in the Alaçatı houses.

Minimizing solar penetration through the windows and solar absorption at the surfaces of the walls and the roofs is important in hot and humid regions, but when wind and solar considerations conflict while decisions about building orientations are made, ventilation should be the primary factor (Givoni, 1991; 1994, Bradshaw, 2006, Olgyay 1964, Santamouris 2006, Steemers 2004, Brown 1992; 2000, AIVC 1995). Once the building is cross ventilated during the daytime hours its indoor temperature tends to follow the outdoor pattern. In this case, the heat flow through the envelope is small and the larger surface area does not significantly affect the daytime indoor temperature. On the other hand, during the evening and night hours, when winds usually subside, the envelope’s larger area permits faster cooling (Givoni, 1994, Bradshaw, 2006).

As will be discussed below, the issues of orientation with respect to the sun in Alaçatı had been taken care through such measures as shading devices and the color of the envelope. Sun factor seems to be a secondary consideration in major orientation. Interior spaces are laid out on a linear plan to facilitate natural ventilation. Interior layouts are conductive to natural ventilation. Partitions were arranged so as to channel prevailing summer breezes straight through the building. Opening on the leeward side should be higher than the ones on the windward side (See 3.31).

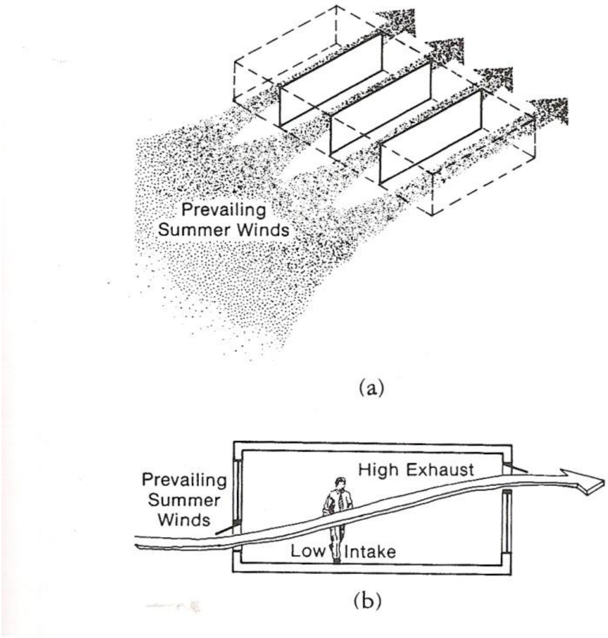

Figure 3.31. Interior layouts conductive to natural ventilation
(Source:Olgyay, 1964 in Bradshaw, 2006, p. 225)

Angle changes in the parcel relation in Alaçatı can be implying on ventilation effectiveness. Oblique winds at angles 30 and 120 degrees to the wall can provide effective cross ventilation if openings are provided in the windward and leeward walls. As houses facing streets oriented in organic pattern of Hacı Memiş Quartier (See Figure 3.10 & 3.12).

3.2.2. Design Decisions in the Buildings

House and sofa (circulation and communal living area) and garden (avlu) relations are given in section 3.1.3.3. Geometric orientation of these spaces is related to house and parcel relations at different parts of Alaçatı (See Figure 3.8, Figure 3.10 & Figure 3.12). Common design decisions made in all houses of Alaçatı are Sofa/hall originated: the rooms are defined around circulation spaces, which are wider than today’s corridor systems. All houses are not placed facing the main wind direction, because of available parcel positions, yet all facades are oriented according to promote natural ventilation opportunity (most are).

3.2.2.1. Orientation of Main Rooms and Windows

Plan configurations vary according to parcel size and shape and the needs of the family living and working in the house. Plans are always arranged around communal spaces such as sofa, hayat or avlu. The most commonly used space is sofa, which is located in all interiors, where all rooms are opening to. All room spaces open to outdoor by windows. In main rooms/ upper floor bedroom configurations basically only single sided window configuration is available. In larger roomed houses with longer façade distances, or corner roomed houses more than one window in a room could be configured, however even two windowed rooms have access to street from one available façade. It is possible to attain cross ventilation in these closed spaces by doors opening to sofa (corridor) spaces.

3.2.2.2. The Plan Organization Inside Buildings

A variety of configurations exist in the organization of shops, animal sheds, storage areas, rooms of the houses, halls, and gardens. There are various different open and semi-open space organizations (sofa, hayat or avlu/taşlık) held in all traditional examples, which provides opportunity of occupancy in different seasons. South terrace and courtyard/taşlık in gardens are available for occupancy in spring and fall, indoor sofa and shaded garden areas are available for summer comfort, and interior halls, rooms, bay windows and cantilever areas are preferred for short winter seasons. Rooms of houses are arranged around the sofa, which mostly enables cross ventilation for summer conditions and avoiding solar penetration to interior area. All spaces permits fresh air access and ventilation by providing ventilation even in the circulation spaces, thus circulation spaces' natural ventilation potential becomes an interesting question in this type of plan organization (Santamouris, 2001).

Interior spaces are laid out on a linear plan around sofa space to facilitate natural ventilation. Partitions were arranged so as to channel prevailing summer breezes straight through the building (See Figure 3.31).

3.2.2.3. Summer/Winter Rooms

Winter rooms are arranged on the south edge of the houses, whereas summer rooms on the north edge (Sözen, Gedik, 2007). This separation is clearly defined for very few examples in Alaçatı (Özgönül, 1996; DEU, 2000), winter season is short and not as effective as summer cooling in the design of these houses. The distinction between rooms according to season is not common, where winter period is considerably short, yet availability of multiple space organization as closed, open, and semi-open spaces maintains variation for human thermal comfort in different seasons. (See section 3.2.1.2.2)

3.2.3 Opening Size, Location, and Details

Naturally ventilated building design has to combine permanent openings, for background ventilation, with controllable openings to adjust ventilation to users' needs. Natural ventilation components include: operable windows, air-vents, automatic inlets: mechanically automatically adjusted inlets (Santamouris, 2001).Building envelope must be as airtight as possible so that air focuses specifically through designed openings.

The volume of the enclosed space[15] is a key element of natural ventilation design. Under certain circumstances a building can play the role of an air-quality reservoir, compensating for the variable nature of the natural ventilation and ensuring outdoor air quality without a constant ventilation rate (Santamouris, 2001).

Amount of windows increases the solar load on the building, which isn't especially preferable for Alaçatı summer. How windows are designed and detailed is analyzed in detail in the following two parts.

3.2.3.1. Shaping of the openings

There are windows placed across on two façades; opened on south/ north (YeniMecidiye Quartier) in most of the Alaçatı houses and southwest/northeast (HacıMemiş Quartier) in others, which facilitates cross ventilation when needed. Openings in a hot humid climate play a major role in determining the thermal comfort of the occupants as their location and size determine the ventilation conditions of the building. In this respect, large openings in all the walls can create effective cross ventilation. However, solar radiation can penetrate directly through unshaded openings into the interior of the building and elevate the indoor temperature above the outdoor level. Therefore, utmost care should be taken in ensuring that all openings in the envelope of the building are effectively shaded (Givoni, 1994) as in window designs in Alaçatı. Figure 3.32 give us the effect of windows with different orientation with unshaded surfaces on thermal loads over a structure.

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[15] See section 3.2.3.2 for exact size ratios.

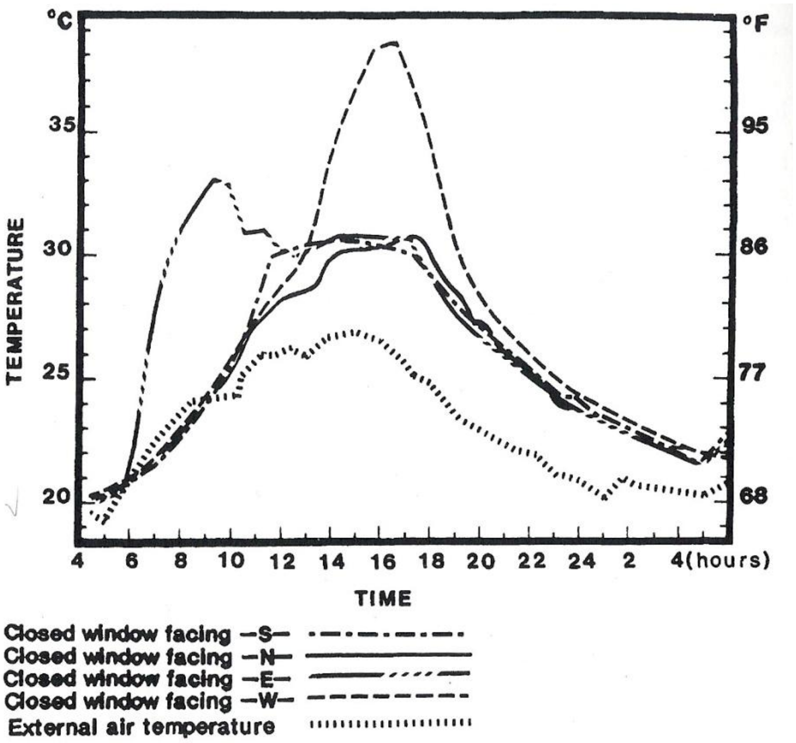

Figure 3.32. Indoor temperatures of unventilated thermal models with unshaded windows facing the four cardinal directions (Source: Baruch, 1994,p. 22)

The windows are preferably vertical (narrow and high) for maximum ventilation and minimum solar access in Alaçatı houses. With this characteristic, the wind coming from any direction across an angle of down to about 15˚ from the wall, one window will be in a wind pressure zone, acting as inlet, and the other window will be in the suction zone, acting as outlet (Givoni, 1994). It is important to make sure that air can flow in and out of every room, passing through a series of rooms or hall in the building on its way to the outlet openings. Also all window and doors are placed in the interior part of wall section for eliminating the strong sun effect. Types of different windows in Alaçatı traditional architecture are classified and identified by Özgönül (1996), which significantly shows vertical emphasis.

Figure 3.33. Door detail placed in the interior edge of corridor space

On the other hand, bay windows are the spaces affected most by the solar impact. Bay windows, especially southern faced ones cause greenhouse effect inside these spaces, where in winter helps heating in these spaces at daytime. However, in summertime these spaces are hard to be controlled with operable shading elements and increase the solar load of indoor space considerably. Another important effect of these transparent spaces is the pressure difference created by green-house effect enabling cross ventilation even when the airflow effect is considerably low. Air moves from positive pressure zone to negative pressure zone, where greenhouse effect of bay windows creates this naturally by temperature differences.

3.2.3.2. Natural Ventilation Details

In hot climate zones like Alaçatı, ventilation has particular importance as a remedy against high temperatures and humidity. Natural ventilation[16] is the movement of air in and out of a space through openings such as windows and doors intentionally provided for this purpose. This enables the maintenance of both fresh air ventilation and

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[16] Natural ventilation is caused by naturally produced pressure differences due to wind, temperature difference or both... The effectiveness of natural ventilation depends upon the wind speed temperature difference, size and characteristics of the openings and their orientation to prevailing wind direction (Santamouris, 2001).

a cooling effect by replacing hot interior air with cool outside air. If the temperature is too warm i.e.as in dry-hot desert settlements, this hypothesis cannot be stated.

The simplest natural circulation technique, which is to ventilate a space through window and door openings, is used in Alaçatı houses. Locations of buildings, which rely on prevailing breezes for cooling, are mainly selected according to local wind direction: south-north and northwest-southeast.

For proper cross ventilation two openings facing each other is necessary: as one acts as the inlet (on windward side of the building), while the other act as the outlet (on the leeward side of the same building). The inlets and outlets should be roughly the same size, or the outlet can be larger than the inlet. Obstacles in windward direction may decrease the ventilation effect, so roof overhangs and tree locations are controlled in order not to obstruct the incoming wind (Olgyay, 1962, Bradshaw , 2006, Santamouris, 2000).

In Alaçatı roofs do not have eaves and there are few high trees to obstruct the wind effect, even these trees were placed in the gardens replaced far from façade plane. Openings of cross ventilation are shaped as vertical elements allowing maximum suction of air (See 3.33 & 3.34). For natural ventilation through operable windows, doors, and louvers, the total open able area should be at least one-twenty-fifth of the floor area served for single sided ventilation operation. In choice of examples this detail will be evaluated on the ones chosen.

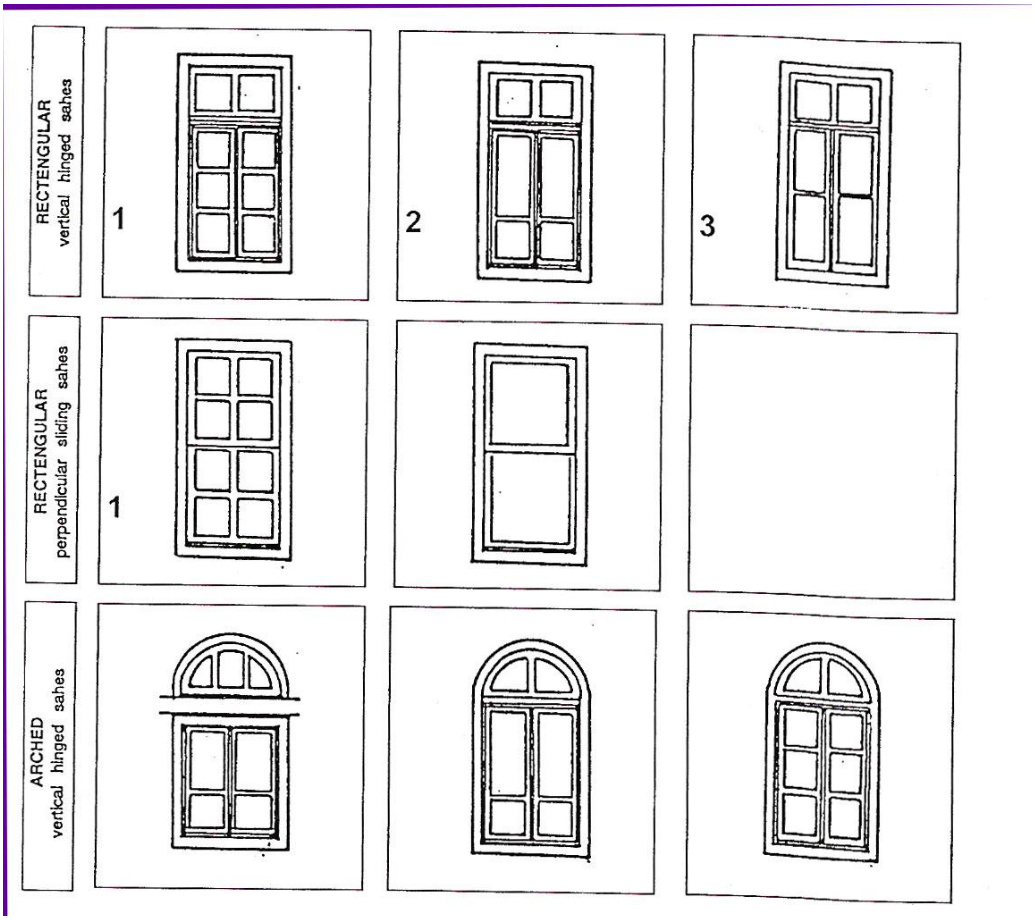

Figure 3.34. Window details in Alaçatı
(Source: Özgönül, 1996)

3.2.3.2.1 Window/door Sash Details

Operable windows provide natural ventilation and take advantage of cooling breezes. Various types of operable sash are available to canalize air into or above occupied areas. Casement and pivot operable window types in Alaçatı give opportunity of full openings for letting airflow in. For cooling purposes, the outdoor air stream should be directed toward, where people are actually located. Personal manual control of openings allows the occupants to control wind velocity so that it is sufficient to enhance the evaporation of sweat from the skin, but not so great that it can become irritating[17] (Olgyay, 1962, Givoni 1994, Bradshaw 2006, Santamouris 2000).

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[17] See section 2.1.5& 2.1.6 for further information of limits of comfort level of natural ventilation

Figure 3.35. An example of door sash detail of an Alaçatı House (Taş House)

The details of the window and door sashes in the site are seen in Figure 3.35 and Figure 3.36, designed for strong wind conditions of winter, which do not allow any leakage[18]. These details, which are repeated in both window and doors also avoids rain water to penetrate between sashes under high wind conditions (wind-driven rain) in winter.

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[18] Different elements have to be focused to ensure good natural ventilation performance.Building air tightness is one important element to ensure, which the building envelope must be as airtight as possible so that air focuses specifically through designed openings.

Figure 3.36. Door sash detail from İncirli House

3.2.3.2.2. Air-vent/ Menfez Details

Air-vent details mostly seen in entrance doors, where cross ventilation between street and courtyard is available at ground floor level. In Figure 3.37 entrance door examples are expressed. The small window replaced over the doors gives opportunity for ventilation when entrance is kept closed. They offer a permanent moderate area of opening and provide limited uncontrolled ventilation. There are only a few window examples seen with this detail (Figure 3.38), these smaller windows can be kept open when wind is high to keep bigger window panels open. This organization also gives opportunity of small inlet and larger outlet access in cross ventilated ground floor entrance halls.

Another point to be mentioned about these small openings is that they provide ventilation of indoor heated spaces for winter period. If heated mass of the building cannot be ventilated well in all season’s condensation, which is described as the sweating of the building, this becomes a major problem for the building (sick-building syndrome[19]).

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[19] See Section 2.1.5.2 for sick-building syndrome

Figure 3.37 Examples of natural ventilation openings (menfez) over door detail of Alaçatı Houses

Figure 3.38. Example of NV opening detail (menfez) over a window from an Alaçatı House

3.2.3.2.3. Operable Sun Control Elements (Window shutters)

For minimizing the heat gain, the use of shading devices is of primary importance in all types of hot climates (dry or humid). The effectiveness of shading in minimizing the solar effect and the minimizing effect of window’s orientation is illustrated in Figure 3.39 (Givoni, 1976). The temperatures of all models in the figure closely follow the outdoor pattern (Givoni, 1994).

Shading devices can be of two major types: fixed or adjustable. Adjustable shading devices can be applied either outside the glazing (external shading) or inside (internal shading). As operable external shading devices, shutters (hinged, sliding, etc.) rotatable fins, horizontal plates, retractable venetian blinds, or canvas awnings can be stated (Givoni 1994; Bradshaw 2006).

In Alaçatı, adjustable shutters are most commonly used examples. Hinged external shutters and canvas awnings are variations of these shading elements. Detail of operable shutter construction is found to be a specific characteristic of Alaçatı. It is probably designed resistant to strong wind conditions in the site. The holders placed on four edges of the window are seen in Figure 3.40, which are designed for keeping the shutters resist able under the forces of wind.

Many of the operable shutter types can also intercept solar radiation reflected from the ground, in addition to intercepting the direct and most of the diffused radiation from the sky. Operable shading devices can admit all of the solar radiation when this is desirable, as it is in winter. Therefore, they are inherently more effective than the fixed shading. Operable external shading devices can reduce solar heat gain through windows and other glazed areas down to about 10 to 15% of the radiation impinging on the wall (Givoni 1994).

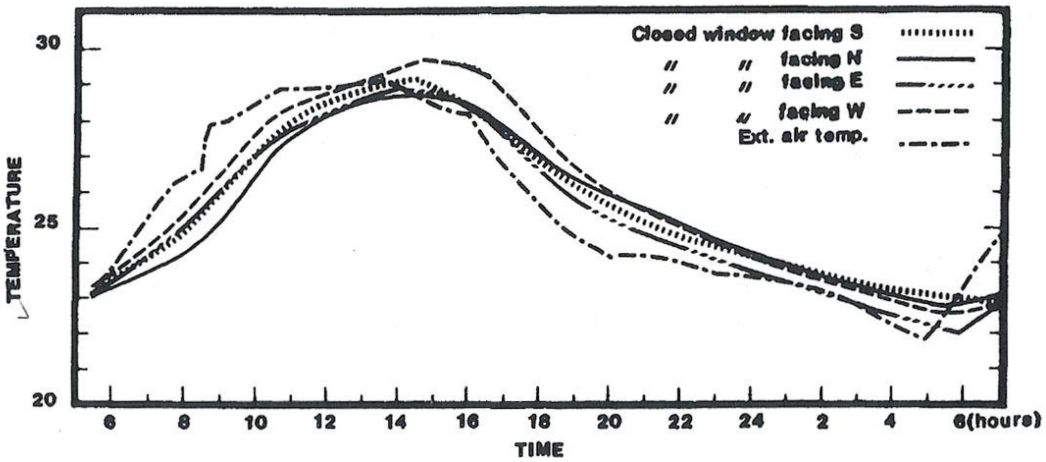

Figure 3.39. Thermal loads on shaded windows oriented on four cardinal directions (Source: Baruch, 1994, p.28)

The colour of external operable shading devices may have little effect on their thermal performance unless they are completely closed. With dark shading most of the solar radiation is absorbed at the outer surface of the shades and then mostly dissipated to the outdoors by convection. With white shutters most of the radiation is reflected away, only a part is reflected inward. The net gain is almost the same in these two cases. However, the solar radiation reflected indoors by white shutters provides much more day lighting than is allowed indoors through dark shutters. Therefore, from the day lighting point of view, white shutters are preferable. (Givoni, 1994). Alaçatı traditional examples are painted with darker colours, but newly renovated examples mostly for summer habitation are coloured with lighter colour scale (mostly white).

Figure 3.40. Window shutter attachment to elevation detail of two Alaçatı Houses

3.2.3.2.4. Fixed Sun Control Elements (Worked Façades)

Characteristic sun break details are found in south elevations in Alaçatı settlement (See in Figure 3.41 & Figure 3.42). These elements can be defined as fixed sun control elements, however, they are part of the façade and not very low to shade effectively so can be accepted as ornamentation of the façade (further study needed for analytical critique). They give opportunity of the access of winter sun, while avoiding summer sun especially from the hottest south direction.

There is a consensus with respect to the appropriate fixed shading for southern and northern windows. In the northern hemisphere a horizontal overhang above a southern window, extending sufficiently on both sides, can be designed to provide complete shading during midsummer (April through August) and to permit solar penetration in winter (October through February). Vertical fins protect northern windows in summer from the low sun in the mornings and late afternoon hours.

Figure 3.41. Sun control detail from a terrace (hayat) door of an Alaçatı House (Photo taken on 7thof Sep 2008 at 11:00)

Figure 3.42. Sun control detail from outdoor terrace (hayat) door of an Alaçatı House Photo taken on 7thof Sep 2008 at 11:00

3.2.4. Color of the Building's Envelope

Exterior color of surfaces affects the amount of heat that penetrates into the interior (See Figure 3.44). The more sunlight is reflected off the building surfaces, the less is absorbed into the building materials. Since dark colors absorb much more sunlight than light colors do, white surfaces should be preferred in hot climates and even in temperate climates where protection during warm spells is necessary (Bradshaw, 2006, Givoni 1994, Olgyay 1964, Santamouris 2006, Steemers 2004). As in

Alaçatı, the houses are plastered and painted with light colors and the stone examples without plaster are also light beige in color (natural stone of Nohutalan). No dark colors can be seen in the town.

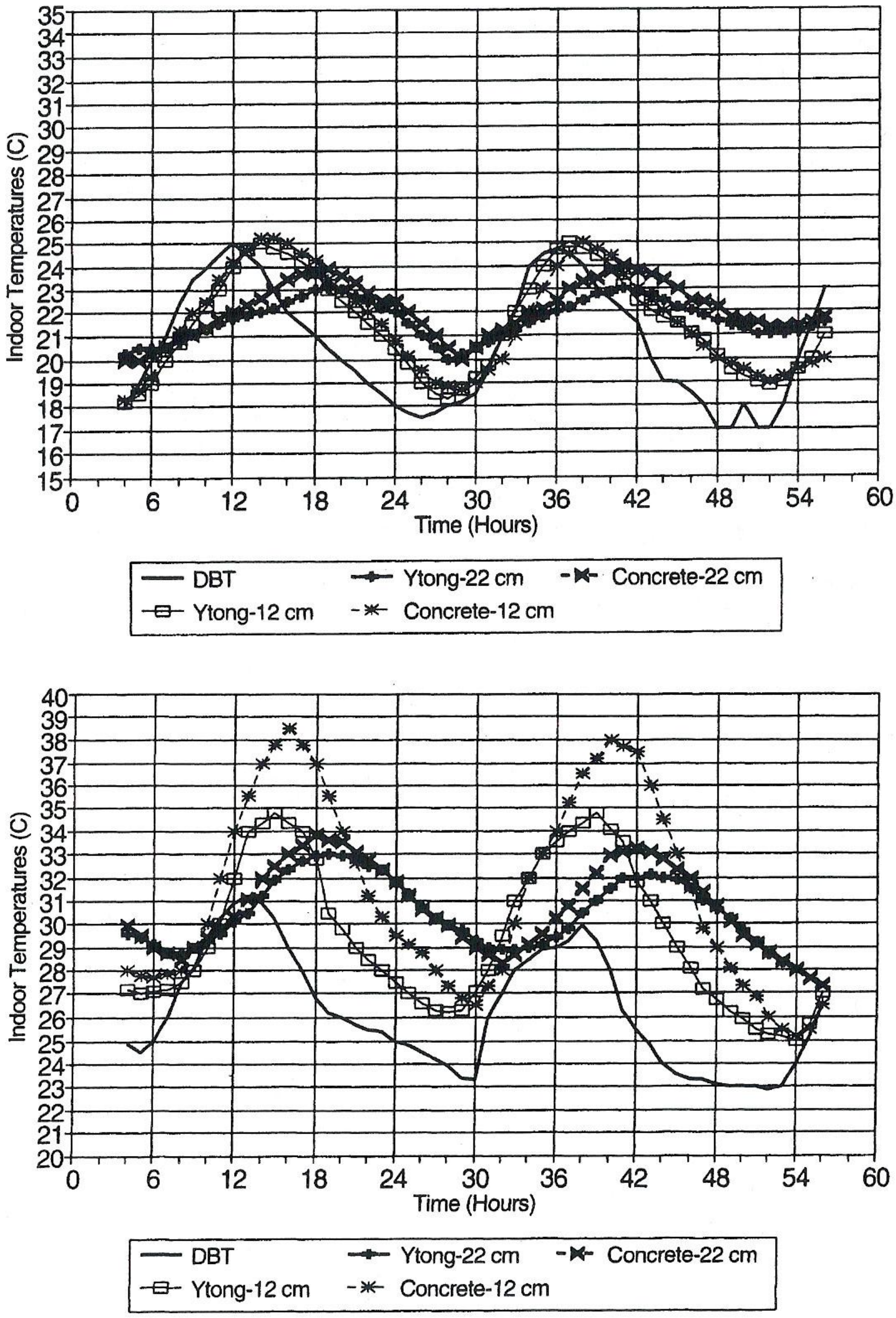

Figure 3.43. Thermal loads on different wall examples
(Source: Baruch, 1994, pp.32-33)

Roofs are also tiles of natural material (cooked earth,) light orange in color. Roofs with light colors show tremendous effect on lowering the impact of sun over the building (Givoni, 1994). (See Figure 3.44) Shingles on the roof causes absorption of sunlight in Alaçatı, which can be eliminated by use of lighter material options for future new designs (Akbari, 2001, 2007).

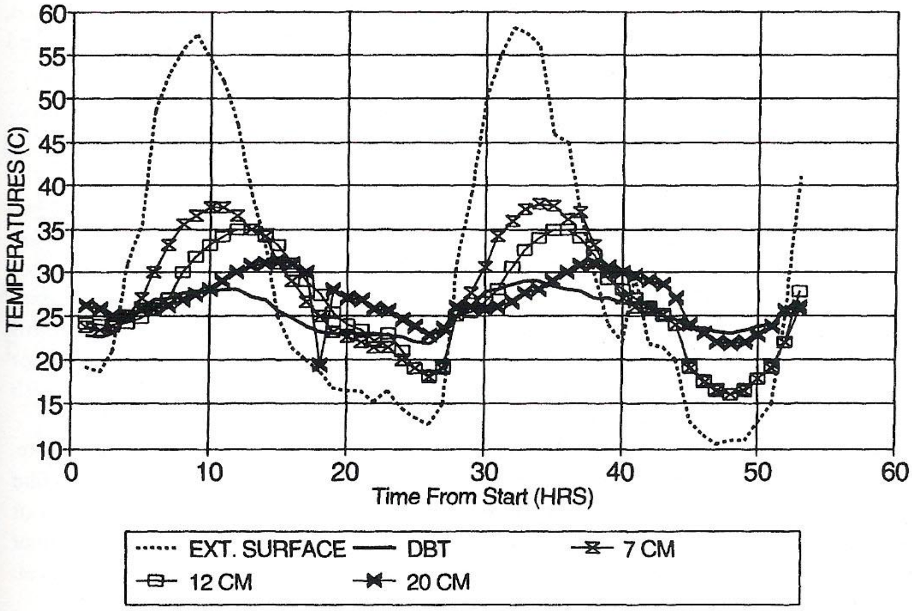

FIGURE 2.3 Ceiling temperatures of Ytong roofs, 7, 12, and 20 cm thick, painted gray, together with the outdoor temperature and the average external surface temperature of the roofs.

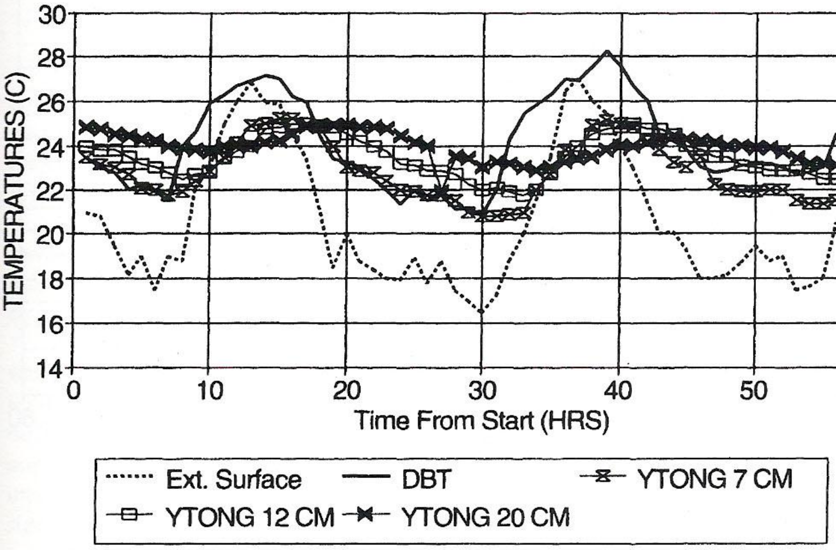

Figure 3.44. Thermal loads on ceilings with different roof material example
(Source: Baruch, 1994, p.31)

3.2.5. Material Usage

The technical characteristics of the materials used determine to a high degree of energy consumption and comfort conditions of individual houses, as well as of open spaces. In particular, the optical characteristics of materials used in urban environments, and especially the albedo[20] to solar radiation and emissivity to long-wave radiation, have a very important impact on the urban energy balance (Santamouris, 2001). Darker building and urban surfaces absorb solar radiation. Multiple reflections and airflow through the canyons reduce the effective albedo.

The decision of material usage was limited with availability of the material in Alaçatı at the time buildings were constructed. However, the structural system created with available materials is appropriate to the environmental conditions as well. High thermal massed materials such as stone and brick makes houses to be thermally comfortable. Especially, white plaster coating, light colored surfaces and tiles reduces emissivity and radiation within the town. Detailed explanation about the material characteristics is previously given in section 3.1.3.1.

3.2.5.1. Usage of Stone (Rubble Stone, Cut Stone Techniques)

Usage of stone creates thick exterior walls, which allow high insulation in summer and winter months. Massive constructions result in thermal time lags (building temperature lags behind the outdoor temperature), which tend to produce more stable interior conditions (Bradshaw, 2006, Givoni 1994) (See Figure 3.44). Greater the mass and thermal capacity of traditional buildings, the more stable are their indoor temperature.

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[20] The albedo of a surface is defined as its reflectivity, integrated hemi spherically and over wavelength. The materials used in the external facades of buildings and in streets and pavements either absorb or reflect the incident solar radiation. Use of high-albedo materials reduces the amount of solar radiation absorbed through building envelopes and urban structures and thus keeps their surfaces cooler (Santamouris, 2001). For more information check Chapter 11 in Enregy and Climate in the Urban Built Environment, 2001, Edited by Mat Santamouris. Albedo values of typical urban materials and albedo and emissivity of surface values are available in Table, 11.1&11.2 on pg. 162-163.

3.2.5.2. Usage of Wooden Frame Filled-in with Filling Materials

Natural materials are used for secondary floors of stone Alaçatı houses. Mainly for smaller sectioned lighter walls for upper floor are preferred in Bağdadi examples. Again efficient insulation is possible with this traditional technique both for winter and summer conditions. In winter the heated air in the interior cannot be taken out by thermal mass and in summer the solar heat gain from the skin is at minimum levels. White coating over the wooden framed system (bağdadi) also affect the radiation pattern for summer months positively. Side to side housing also gives opportunity for energy conservation for all seasons (Bradshaw, 2006, Givoni, 1994, Olgyay, 1964).

3.2.6. Water Collecting Details

Gutters on the roof collect water and this is moved to ground level, to the water tank (sarnıç) in the garden (avlu) by vertical pipes. Use of rain water is a common feature in traditional housing examples in Turkey (Şerefhanoğlu, 2006). In most of the traditional Alaçatı houses survived today, the water tanks in the gardens are removed, because of the new underground systems of water. There are still existing examples, which the water tank system works in the gardens for reuse of rain water. According to interviews about Alaçatı, public people of the town given information about this traditional water system in houses, this was common in all Anatolian houses previously.

3.2.7. Vegetation Near the Building

Plants can affect the indoor temperature and the cooling load of buildings in several ways: vines climbing over walls and high shrubs next to the walls, while providing shade, also reduce the wind speed next to the walls appreciably (shading insulation effects). Plants near a building can lower the air temperature next to the building’s skin, thus reducing the conductive and infiltration heat gains. In winter of course, they reduce the desired solar gain and may increase wall wetness after rains, yet shrubs or ivies which patch off do not cause any problem for winter. Field measurements have shown that through shading trees and shrubs strategically planted next to buildings can reduce summer air conditioning costs typically by 15 to 35 percent, and by as much as 50 percent or more in a certain specific situations. Simply shading the air conditioner- by using shrubs or a vine covered trellis- can save up to 10 percent in annual cooling energy costs (Taha and Akbari 1989, 1992).

On hot sunny late-summer days the average temperature of walls shaded by trees or by a combination of trees and shrubs was reduced by 13.5 and 15.5 ˚C. Climbing vine plants (ivies) reduced the surface temperature by 10 to 12 ˚C. In Alaçatı, it is possible to see garden plantation and shrub usage in certain street tops and very few façades are effective solar control details (See Figure 3.25). Trees in this windy climate are hard to grow and affect the ventilation patterns in critical areas, so they can only be seen in protected gardens' sheltered corners.

3.2.8. Summary of Climatic Relation and Design in Alaçatı Historical Settlement

- Alaçatı has two different settlement patterns, where one pattern reflects the geometric grid order, and the other the organic grid order.
    - The geometric grid order covers the two third of the traditional town with south-north ordered housing located along main streets and secondary road organizations perpendicular to this main order
    - In this part of the town the main streets (where trade is common today as well) are aligned on east-west direction. Here the sun can be enjoyed in cool winter and fall-spring seasons without the disturbance of the prevailing winds.
    - Attached housing pattern in the town allows canalizing the prevailing winds through the south-north oriented narrow minor streets, whereas blocking the extreme effect on the major larger street orientations.
    - From the total picture of Alaçatı, historical settlement parcels are narrow facing the streets with a narrow façade. There are gardens at the back of the houses again as part of a narrow parcel organization.
    - Houses located along south-north axes gives opportunity of cross ventilation along the prevailing wind (north) and also south winds as well. Main streets' width and garden length at the back gives possibility of the flow on the second floor where rooms and living spaces are placed.

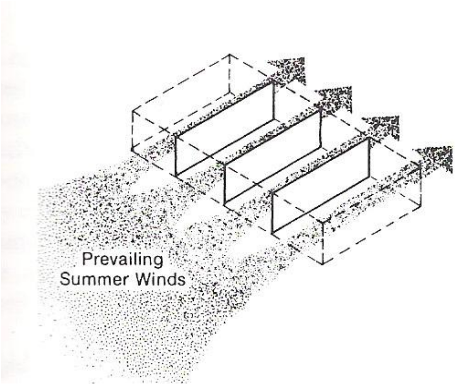

Figure 3.45. Cross ventilation effect in attached housing order (row houses)

- Ventilation effect is also needed more on secondary floors, because the solar heat gain from the roofs creates extra heat load than first floors. Also, first floors have more thermal mass (50 cm minimum stone walls) because of high numbers of masonry structural system in the area. Thus, secondary floors in Alaçatı historical houses have effective ventilation potential in this street organization.

Figure 3.46. Bay windows from Kemaliye Street Houses, Alaçatı

- Attached housing order also minimizes the heating load with fewer walls facing the outdoor conditions in both summer and winter months.
- The façades facing outdoors also have high thermal mass with efficiently used small glass openings (at most possible in masonry structural system), which are all protected by shutters when needed.

- Casement and pivot windows are characteristic of traditional Alaçatı houses. They allow all windows to be kept open causing fewer glass surfaces, thus solar radiation effect is less.
- Characteristic shutter elements help to protect windows from solar loads in summer and strong wind effect in winter. The hinged shutters are controlled with fixed iron details replaced on four edges of windows over the façade, which is characteristic to Alaçatı, again considering the windy environment.
- Only bay window (cumba) or cantilever (çıkma) elements cannot be covered with solar control elements as shutters. These glass elements are open to solar penetration (especially facing south along the street) in winter as a glass house and this effect can be minimized by opening these windows in summer.

Figure 3.47. Bay window opening to sun

- The other important characteristic details of Alaçatı related to climatic conditions are gutters on the roofs taking down the rain water to the garden alleys and and collecting it in the garden sarnıç.
- Strong sun effect also shows itself with fixed sun control elements.

3.3. Selection of the Houses for Field Measurements

Two different ventilation methods; cross and single side, were selected for a comparative study in this thesis. Two houses need to be selected for measurements to understand the ventilation effect on thermal comfort standards in Alaçatı traditional settlement according to plan organization classifications. Thus, two attached houses on

Kemalpaşa Main Street as a part of geometric grid order that give opportunity to question different ventilation methods under the same wind environment.

Specific characteristics of the houses selected for the measurements can be listed as:

- Positions of the parcels of the houses (both on Kemalpaşa Street facing the street with narrow south façades)
- Parcel sizes
- Similarity in the spatial organization
- Size ratios of hall spaces
- Availability of measurements
  (Less used spaces needed for effective measurements)
- Opening areas' ratio to ventilated sofa areas (1/7 and 1/9)

One of the chosen houses was a corner house, because of availability reasons. Yet sofa position of this house is placed between as it is a spatial element placed in attached order, so similarity expected could be conducted. Materials of measured houses are similar, although one was partially demolished at roof level these examples were firm stone houses available for experimenting.

CHAPTER 4

MICROCLIMATIC MEASUREMENTS IN THE CASE AREA: ALAÇATI

Microclimatic measurements were performed during August 2008. One measurement campaign with duration of two weeks in summer was carried out. Two houses with different sofa types in Alaçatı were measured between August 4 and August 20, during the extreme summer conditions with high wind capacity (Figure 4.3 & 4.4). Both houses chosen for measurements are located on Kemalpaşa Street and are within the row houses aligned on east-west direction (Figure 4.1). The two houses have different sofa arrangements and ventilation characteristics. One of the houses has an open sofa and cross ventilation while the second one has an inner central sofa, with single side ventilation (see Chapter 3).

According to the weather data analysis; the main wind direction of Alaçatı region is North (N) and North West (NW), therefore, measurements of indoor airflow is most efficient in houses aligning in south-north direction as the two houses selected for measurements. Furthermore, sofas located on the second floors vacuum the outdoor airflow and generate cooler indoor environment for hot summer days. The effect can be investigated in different ventilation regimes and in houses with different sofas to find out the most effective traditional living space organization.

The measurements in both houses were conducted the noon and afternoon hours with ventilated state. Sofas were not occupied during the measurements. One of the houses is measured under cross ventilation condition while the other under single sided ventilation. The effect of Alaçatı wind (see Chapter 3) in hot summer afternoon conditions had been examined. In order to examine the airflow inside sofas during the hottest and windy hours of summer time, measurements were held between 11 am to 5 pm during the two weeks of hot August month. In addition to indoor measurements, outdoor measurements were taken by a portable weather station mounted on a rooftop on the same street with and near to the two houses selected for measurements. The results are compared after the measurement data has been displayed.

In the following figure; the house represented with I is cross-ventilated sofa example, the house represented with II is single side-ventilated sofa example, and the point represented with III is the rooftop, which the portable weather station is mounted during one month. Point III is chosen in reference to availability of the rooftop and closeness to the main measured indoor spaces. Details about this choice will be explained in further Section 4.2.

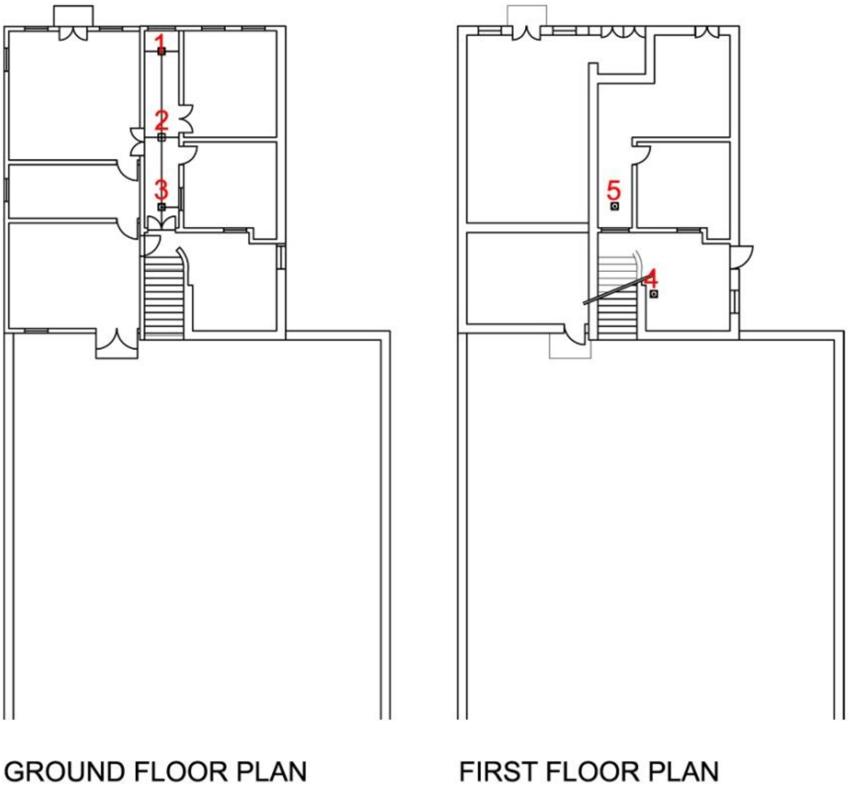

Figure 4.1. Measured house I cross ventilated Sofa area

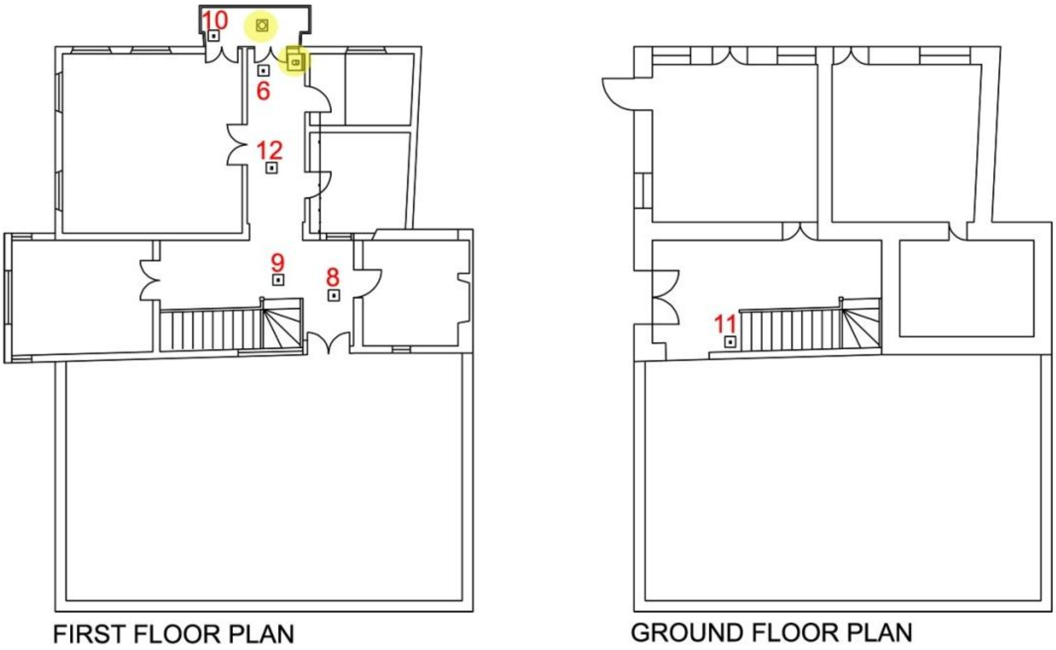

Figure 4.2. Measured house II Single side ventilated Sofa area

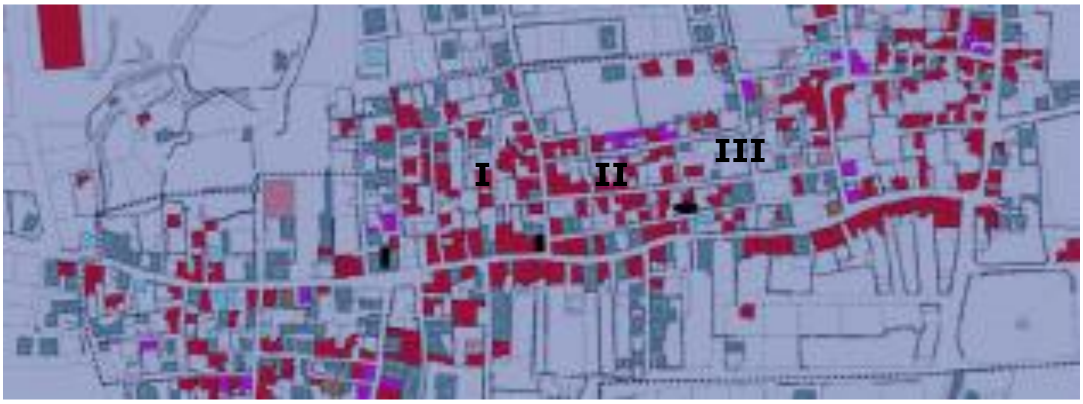

Figure 4.3. Measured Houses shown on the map of Alaçatı Kemalpaşa Street. (The house represented with I is cross-ventilated, the house represented with II is single side-ventilated sofa example, and the point represented with III is where the rooftop measurements are taken)

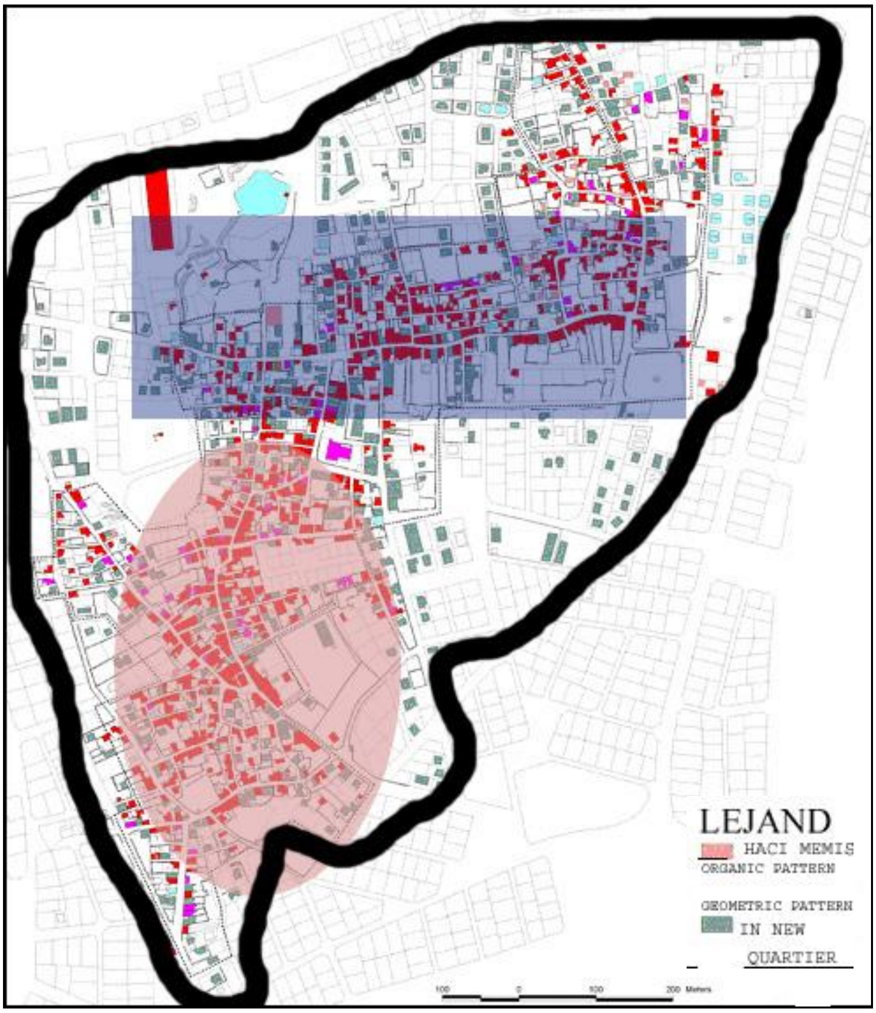

Figure 4.4. Alaçatı Map of Different Quartier Patterns

Analysis of the sofa space is specifically important for understanding the thermal comfort conditions of living space characteristics of traditional houses. This common space, where all main rooms (upstairs for Alaçatı) open to have the potential of increasing ventilation with its positioning, sizing and organization. In the chosen two examples, sofas are facing south and north and the shape and size are chosen similar to allow comparison. Sun effect on the south façade, which cannot be neglected, is decreased by ivies planted on the façade in the first example (Figure 4.5) and cumba[21] (Figure 4.6) element in the second example. Sunlight cannot penetrate, therefore, directly into the sofa spaces. This is also proven with surface temperature measurements taken at both houses. The indoor surface temperatures of stone walls are homogeneous and it differs from indoor dry bulb temperature at 0.1-0.2 ˚C level, which can be neglected in final temperature calculations.

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[21] Defined in Chapter III, Section 3.4

Figure 4.5. Measured House I

Figure 4.6. Measured House II

4.1. Measurements in Alaçatı

Measurements were planned and organized in detail considering accuracy with limited equipment potential. The measurement campaign needed to be defined with extra care, because the measured spaces were kept empty during measurements and no opportunity for survey technique was available. To define the space character totally, temperature, relative humidity (RH), and airflow measurements needed to be taken at various points for accurate results and comparisons, and finally thermal comfort analysis.

4.1.1. The Measurement Campaign

The measurement campaign hours were determined based on 2006-2008 weather data of Çeşme peninsula. Outdoor dry-bulb temperature and wind speed reaches the maximums for summer time according to same data between 11am - 5 pm. Since the aim of the study is to define the effect of wind in different sofa organizations during hot summer conditions, the campaign hours were defined according to effective high wind conditions in Alaçatı.

In the later steps of the study, Çeşme Meteorological station's data needed to be controlled to understand its correspondence with measurements from the portable weather station. Adjustments were needed and they were worked out to determine the annual weather conditions of Alaçatı. Exterior point measurements were used to compare the data in the field with the data taken from the meteorological station and to calibrate and adjust them for the measurement site (See Section 4.3 for details).

4.1.1.1. Wind Averages

The formula for power law and log law calculated with 2006-2008 data for pre-decisions will be given with explanation. This value is recalculated with the final data defined for the studied site. This inlet file defines the boundary wind conditions of the case for CFD calculations (further information is in Appendix A).

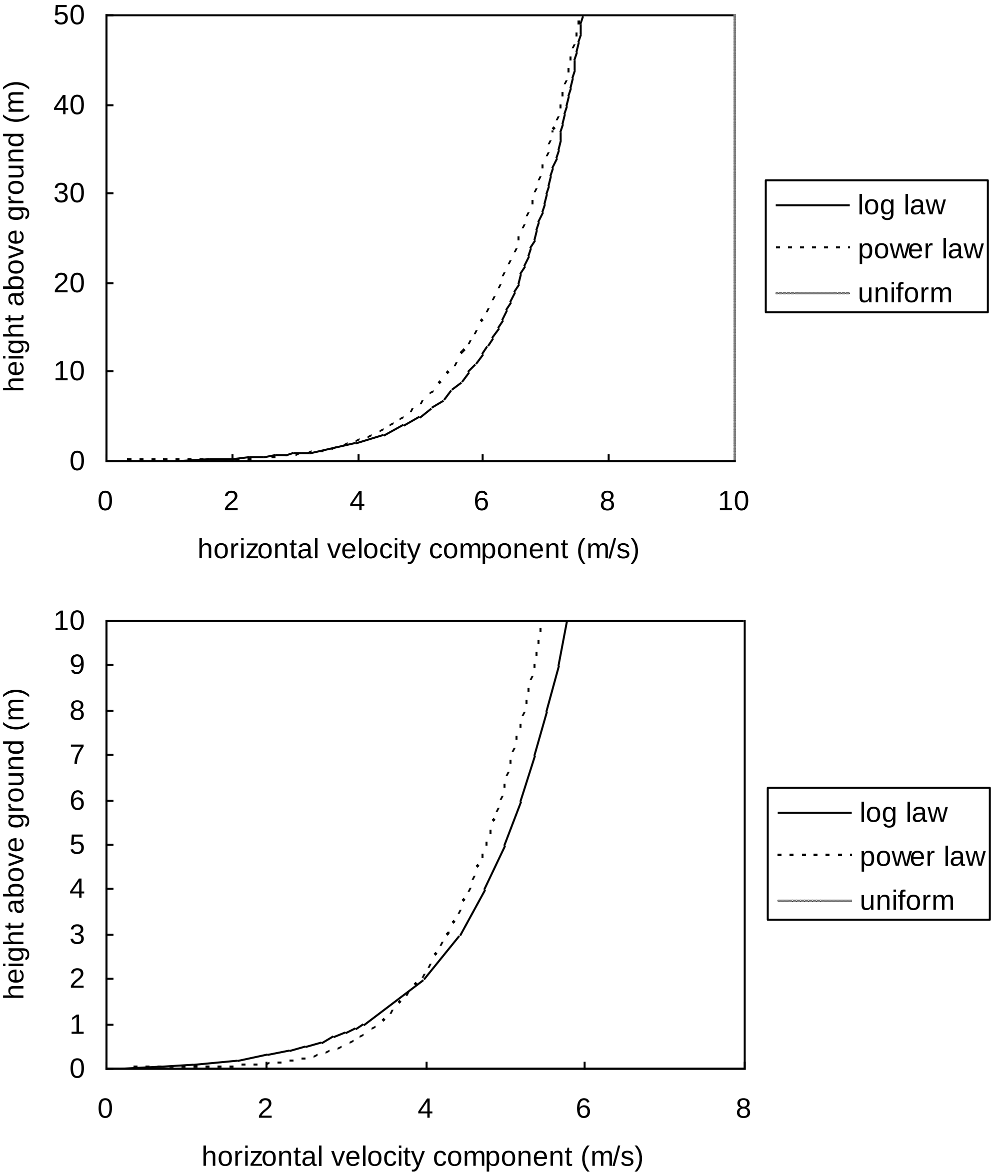

Figure 4.7. Inlet example of wind velocity according to height of the site

ASHRAE power-low formula (ASHRAE, Fundamentals Handbook (SI), 2001, pp. 163) calculates the hourly average wind speed Uz at wall height z in the undisturbed wind approaching a building in its local terrain from Uref:

$$U_z = U_{ref}\left(\frac{h_{ref}}{z_{ref}}\right)^{\alpha_{ref}}\left(\frac{z}{h}\right)^{\alpha} \quad \mathbf{(4.1)}$$

Values of the wind boundary layer thickness h and exponent α is shown in Table 4.1, Uref is the wind speed at the meteorological station and generally correspond with values of αref=0.14 and href=270m.

Table 4.1. Atmospheric Boundary Layer Parameters
(Source: Tablada, 2006, p.51)

Terrain characteristics	Exponent α	Layer thickness h
Flat, unobstructed areas exposed to wind flowing over water for at least 1.6 km, over a distance of 500m or 10 times the height of the structure inland, whichever is greater	0.1	210
Open terrain with scattered obstructions having heights generally less than 10m. including flat open country typical of meteorological station surroundings	*0.14*	*270*
Urban and suburban areas, wooded areas, or other terrain with numerous closely spaced obstructions having the size of a single-family dwellings or larger, over a distance of at least 2000m or 10 times the height of the structure upwind whichever is greater	0.22	370
Large city centres, in which at least 50% of building are higher than 21m, over a distance of at least 2000m or 10 times the height of the structure upwind whichever is greater	0.33	460

Considering the chaotic behavior of wind, the wind conditions specific to the studied canyon (Kemalpaşa Street) needed to be redefined especially during the campaign period. Outdoor measurements were taken by the portable weather station at the rooftop to calculate the outdoor conditions and specifically the wind speed.

After the wind data was accurately defined, the wind speed average and direction in Kemalpaşa Street of Alaçatı was calculated for afternoon hours (11 am-5 pm) of July and August months.

4.1.2. Method of the Measurements

Measurements were performed according to the model of Gail S. Brager and Richard J. de Dear (1998, pp. 83-96). Temperature and humidity were measured according to measurement criteria of Brager and de Dear,

Class I. However indoor wind speed measurements was performed partially with simple hand anemometers instead of omnidirectional anemometry system, because of maintenance of multiple equipment (only in the second house hot-wire omnidirectional anemometer could be used). The indoor wind speed measurements of House I were performed with simple hand anemometers in cross ventilated sofa instead of omnidirectional anemometry system. According to literature on measurements, three broad classes of thermal comfort field investigation can be discerned, based on the standard of instrumentation and procedures used for indoor climatic measurements.

Class III: Field studies based on simple measurements of indoor temperature and possibly humidity at one height of measurement above the floor. Possibly asynchronous and non-contiguous physical (temperature) and subjective (questionnaire) measurements. The majority of field studies used in the derivation of the early adaptive models by Humphreys and Auliciems were Class III. While the quality of this data class does not necessarily allow explanatory analyses, if the research questions being asked require only simplified statistical techniques, then this class offers the widest range of published data. Class II: Field experiments in which all physical environmental variables (ta, tr, v, rh, clo, met) necessary for the calculation of heat balance SET and PMV/PPD indices were collected at the same time and place as the thermal questionnaires were administered, but most likely only at one height of measurement. Humidity measurements are taken by aspirated psychrometer or absorption RH sensors. Air speeds measured by hot wire probes with threshold above 0.1 m/s and/or directional sensing elements and/or time constants exceeding the threshold required for turbulence intensity assessment of the impact of behavioral adjustment and control on subjective responses. Class I: Field experiments in which all sensors and procedures are in 100% compliance with the specifications contained in ASHRAE Standards 55 and ISO 7730. Three heights of measurements above floor level as specified in ASHRAE and ISO standards (0.1, 0.6 and 1.2m). All done with laboratory-grade instrumentation, including fast-response omnidirectional anemometry capable of turbulence intensity assessments

(Brager and De Dear, Thermal Adaptation in the Built Evironment: A Literature Review, 1998, p.89).

4.1.2.1. Measurement Equipment Used

Punctual measurements consisted of daily recording of air temperature, relative humidity, globe temperature and air speed in the sofas simultaneously. Measurements were conducted only with mechanical equipment while survey technique was not used. All data collection was performed with 33 Hobos (temperature and humidity measurement equipment), six anemometers (indoor wind speed measurement equipment), and a portable weather station (placed on the roof in order to perform a comparative analysis with permanent weather station placed during 25.07.2008-27.08.2008). Anemometers are not omnidirectional.

4.1.2.1.1. Indoor Measurement Equipment

- Indoor measurements taken in:

House I: inner hall (sofa) and downstairs

- 15 Hobo U 10 Temp/RH data loggers used for the measurement of indoor temperature (Measuring range : Temperature: -20 °C to 70 °C (-4 ° to 158 ° F), RH: 25% to 95%, Accuracy: Temperature: ±0.4 °C from 0° to 40 °C , RH: ±3.5% from 15% to 45% over the range of 15 °C to 45 °C RH: ±5% from 25% to 95% over the range of 5 °C to 55 °C) & 4 Testo Pocket Pro 410-1/2vane anemometers for the measurement of air velocity.(Measuring range: 80 to 4000 fpm 0.41-20.32 m/sec, Accuracy :+/-40 fpm + 2% of reading +/- 0.2 m/sec)

House II: central hall (sofa) & downstairs

- 18 Hobo U 10 Temp/RH data loggers used for the measurement of indoor temperature (Measuring range : Temperature: -20 °C to 70 °C (-4 ° to 158 ° F), RH: 25% to 95%, Accuracy: Temperature: ±0.4 °C from 0° to 40 °C , RH: ±3.5% from 15% to 45% over the range of 15 °C to 45 °C RH: ±5% from 25% to 95% over the range of 5 °C to 55 °C) & Testo 454 Multifunctional Instrument, which measures and records Temperature, Relative Humidity, Air

Velocity and Differential pressure (Measuring range: +5 m/sec, Accuracy:+/-40 fpm + 2% of reading +/- 0.2 m/sec)

Placement of the equipment is shown in the photographs below (Figure 4.8 & Figure 4.9) and how the helping wooden sticks are located can be seen in the drawings (Figure 4.1 & Figure 4.2).

Figure 4.8. Measured house I_ cross ventilated sofa Measured house II_ single-side ventilated sofa

Figure 4.9. Measurement Campaign image

4.1.2.1.2. Outdoor Measurement Equipment

Portable weather station is used to determine the average deviation values according to meteorological climate stations. Davis Portable Station[22] of Building Physics Laboratory is taken to site.

Measurements were taken from the level of 24.75 m portable station is mounted at 1.75m[23] above the ground level of terrace roof and 11.75m above the street level. House III's roof is at the altitude of 16m., over 7m terrain height (over sea level) with a concrete terrace roof, which is a new house and not traditional. Portable station is protected from solar radiation.

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[22] Accuracy defined in Manual: 7603 Davis Weather Station Specs_Rev_D_Web.fm

[23] It is defined that the minimum height for the wind elements to be placed as 1.50m on terrace floors. (Schmitt, Heinrich, Hochbaukonstruktion, Friedr. Vieweg& Sohn Braunschweig/Wiesbaden, P. 662) Under this limit, solar irradiation and surface temperature causes a complex field over the terrace roof floor.

4.2. Long Term Weather Data of the Site

Meteorological Data had been collected from Izmir Meteoroloji Müdürlüğü, Çeşme Ilıca Region and Güçbirliği and Mare Private Companies (Alaçatı Bay, wind-mill analysis), also personal archive of Engin Kalafatoğlu (private measurements done by Alaçatı tourism investors in 2001-2002 years for investment of first wind-surf facilities).

4.2.1. Data Established from Meteorology

From Turkish State Meteorological Service, Ankara (Tümas)

- Weather Data of station:17221 (Çeşme, Big Climate Station)
    - Daily maximum temperature (2005-2008)
    - Daily minimum temperature (2005-2008)
    - Daily average temperature (2005-2008)
    - Daily average Relative Humidity (2005-2008)
    - Daily maximum wind speed and direction (2005-2008)
    - Daily average wind speed and direction (2005-2008)
    - Hourly maximum temperature (2007-2008)
    - Hourly minimum temperature (2007-2008)
    - Hourly average temperature (2007-2008)
    - Hourly average humidity (2007-2008)
    - Hourly measured wind speed and direction (2007-2008)

From Turkish State Meteorological Service, Regional Center,Izmir

- Weather Data of station: 17221 (Çeşme, Big Climate Station) (July-August 2008)

for comparison purposes with the collected data during the measurement campaign.

- Temperature at 10min. intervals (July-August 2008)
- Minimum temperature in 10min. intervals
- Maximum temperature in 10min. intervals
- Relative Humidity at 10min. intervals
- Maximum wind speed in 10min. intervals
- Maximum wind direction in 10min. intervals
- Average wind speed in 10min. intervals

- Average wind direction in 10min. intervals

4.2.2 Data Established from Private Energy Companies

- Average wind speed in 10min. intervals (Mare) (2008-2009)
- Average wind direction in 10min. intervals (Güçbirliği) (2007-2008)

4.3. Comparative Analysis of Weather Data of the Çeşme (Meteorological) Station and Alaçatı Portable Station

Reasons for data from multiple sources were described in Section 4.1.1, where the measurement campaign is briefly defined. Long term meteorological measurements give the most accurate and well-defined data and it is always the first choice in various studies in the literature. However, in a study investigating the wind conditions in detail, especially wind data of the studied locations should be determined precisely.

Weather data from portable station and from permanent station of the meteorological service were compared. Temperature, relative humidity, and wind speed values were analyzed sequentially. Comparisons were finally given with monthly average values of daily changes of the selected parameter.

Then, the wind data of private enterprises were also compared and proved to be used comfortably (see Chapter 5).

4.3.1. Comparison of Temperature between Alaçatı and Çeşme (Meteorological) Station

According to the temperature graph given in Figure 4.10, outdoor average temperature range of 27 July - 27 August 2008 changes in the interval of 23-31 ˚C both for Alaçatı outdoor portable weather station and Çeşme meteorological station. According to the results, dry-bulb temperature of the Station is 1.5 ˚C (average) above the portable station between 4 AM and 2 PM and 1.5 ˚C (average) below in between 2 PM and 4 AM.

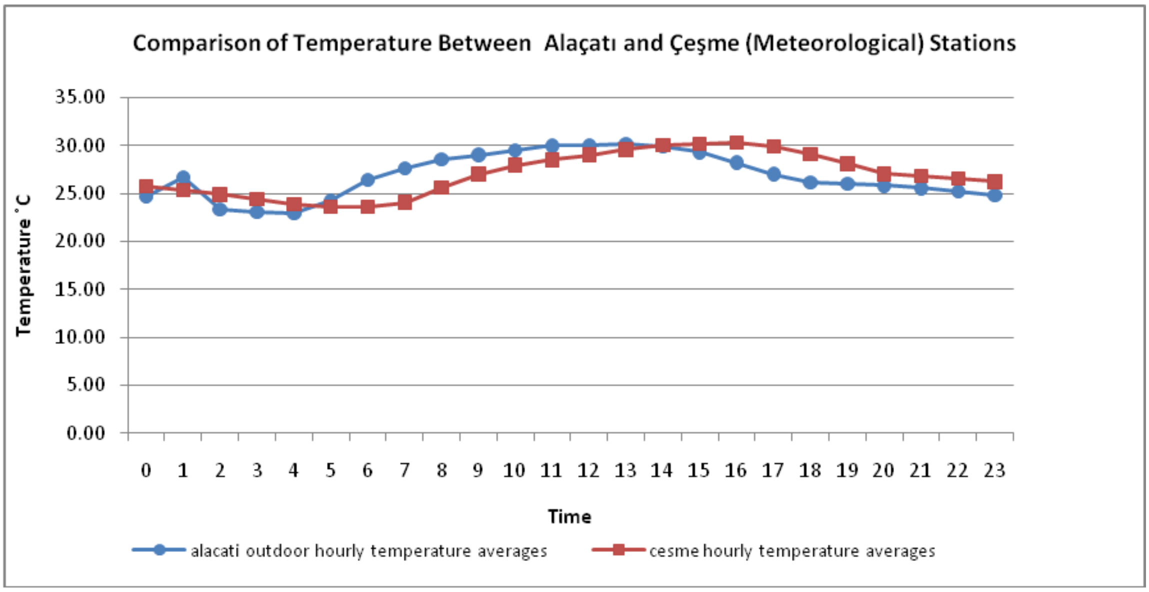

Figure 4.10. Comparison of Temperature between Alaçatı and Çeşme Stations

4.3.2. Comparison of Relative Humidity (RH) Between Alaçatı and Çeşme (Meteorological) Station

Outdoor hourly average humidity range in the selected period changes in the interval of 47-67 % for Alaçatı center and 51-72 % for Çeşme meteorological station (Figure 4.13). According to these results, relative humidity values of Çeşme station is 5% higher when compared to the values of Alaçatı. Between 6 AM to 1 PM average relative humidity value of Alaçatı center is slightly (~5 %) higher than the Çeşme Station, while in the other periods of the day RH value of Çeşme is 7-10 % higher than Alaçatı. It should be mentioned that meteorological station is closer to seaside in Ilıca District (See in Figure 4.32).

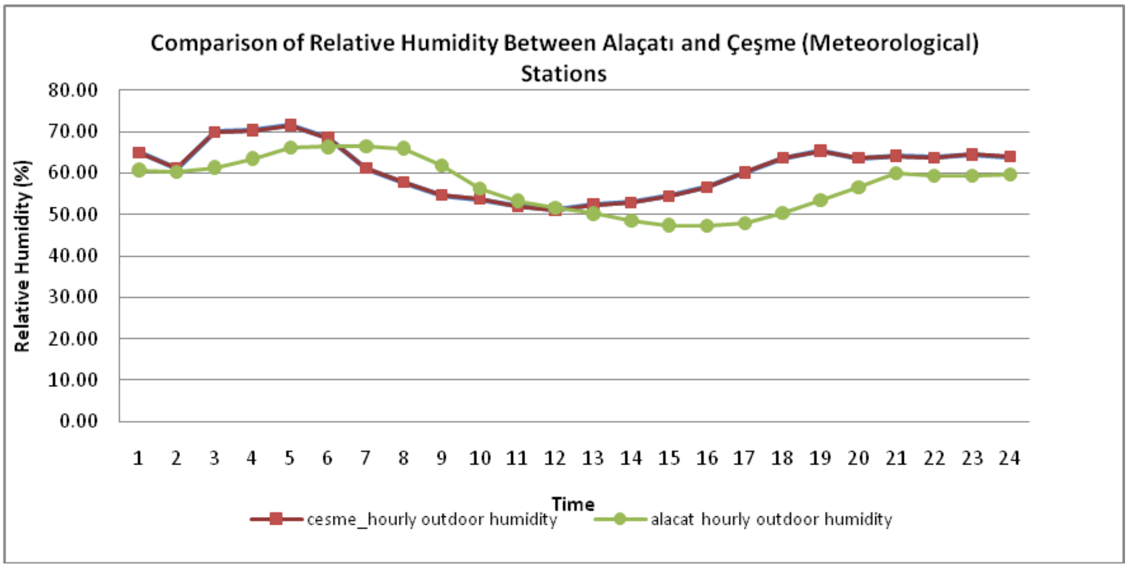

Figure 4.11. Comparison of Relative Humidity between Alaçatı and Çeşme Stations

4.3.3. Comparison of Wind Speed and Direction Between Alaçatı and Çeşme (Meteorological) Station

The wind speed graph depicts both wind speed and high wind speed averages (Figure 4.12). Thus, outdoor hourly average wind speed range in the selected period changes in the interval of 1.5-4.3 m/sec for Alaçatı Center and 1.4-2.9 m/sec for Çeşme meteorological station. Çeşme catches the wind speed range of Alaçatı from 9 PM to 10 AM (morning hours), however between 10 AM to 8 PM the wind speed difference average is -1.38 m/sec especially in the afternoon hours. This difference reaches the level of 2 m/sec, which is mentioned in the previous chapter. At the same hours (1 PM-5 PM) the high wind speed difference reaches the level of 4 m/sec as well, which is definitely a critical outcome for wind analysis data. Mean hourly wind speed average difference is calculated as 1.27 m/sec (Figure 4.14).

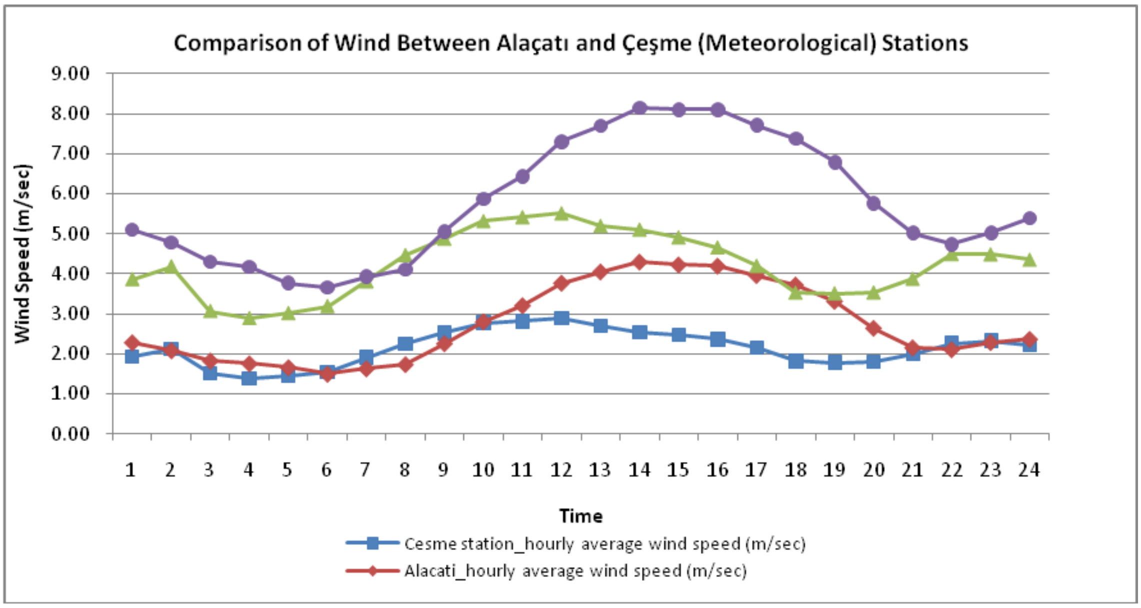

Figure 4.12. Comparison of Wind Speed Values between Alaçatı and Çeşme Stations

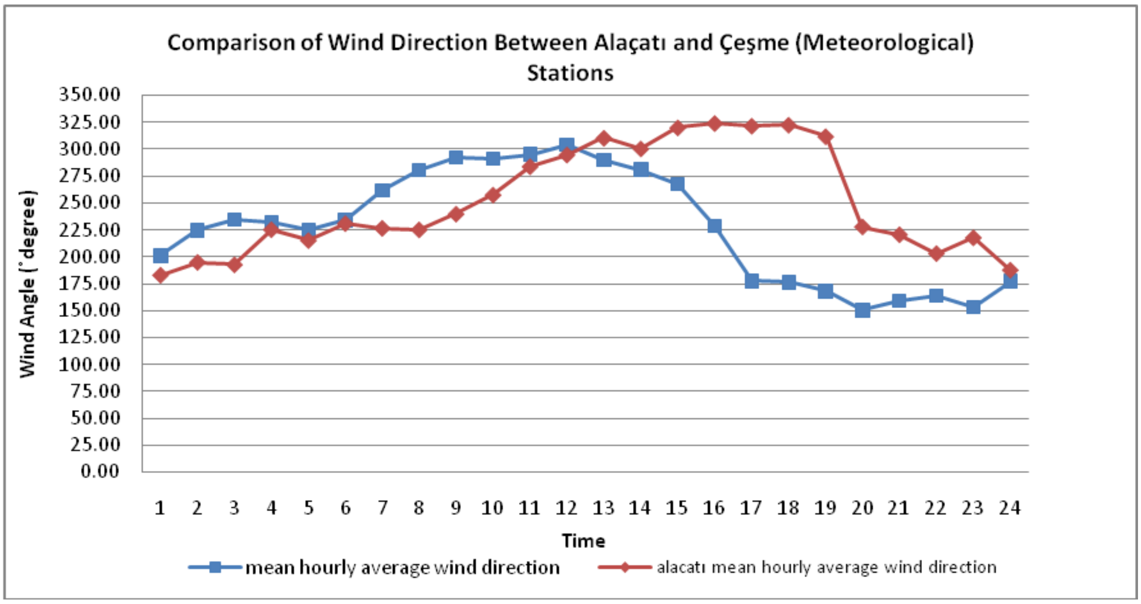

Figure 4.13. Comparison of Wind Direction Values between Alaçatı & Çeşme Stations

To analyze the wind direction, the wind angle graph alone does not give satisfactory information. So, the mean hourly wind direction analysis of both outdoor measurement points and the station were calculated and simultaneously. Mean hourly wind speed and directions are graphed together in order to analyze the chaotic behavior of the wind.

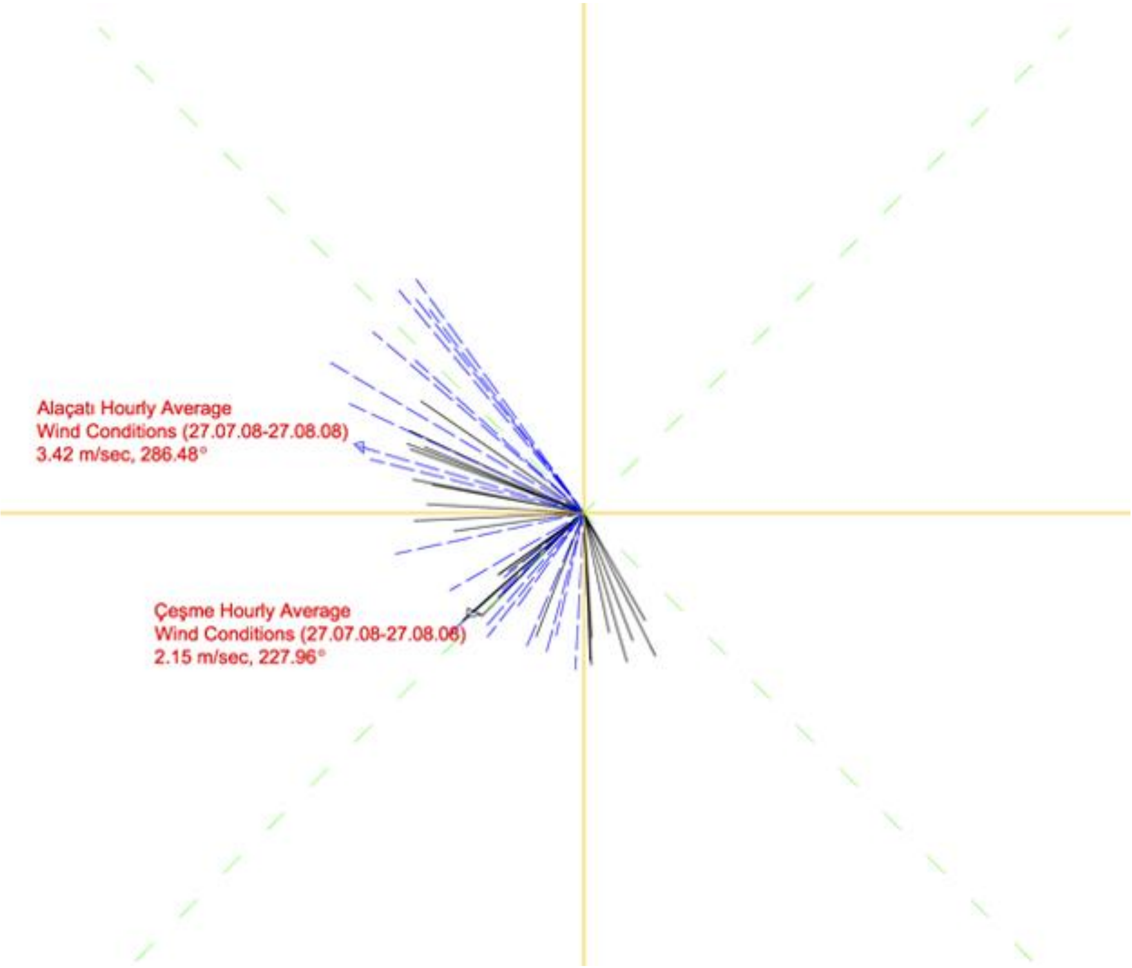

Figure 4.14. Comparison of Wind Direction and Wind Flow Values between Alaçatı and Çeşme stations

When the values found out were calculated, average wind directions are southwest (227.96 WSW) for Çeşme and northwest (286.48 WNW) for Alaçatı Center. This can lead us to say that the wind direction changes because of the topography and coastal behavior. As seen from the well-defined monthly values of 27July-27August 2008 (See Table 4.2), the wind direction changes to north with an average degree of 49.5˚, especially starting from 12PM till 12AM wind shows a different behavior, which can be identified with 140˚ change in the 3-6 PM hours. Afternoon wind shows different characteristic, which can be defined as opposites of each other.

Table 4.2. Mean Hourly Çeşme and Alaçatı Wind Speed and Directions

		çeşme				**alaçatı**			
		wind	wind	Hi	Hi	wind	wind	Hi	Hi
Date	Time	Dir. aver	Speed aver	Dir. aver	Speed aver	Dir. aver	Speed aver	Dir. aver	Speed aver
27.07-08.08	0	201.19	1.93	186.73	3.86	183.13	2.29	210.72	5.10
27.07-08.08	1	224.79	2.13	196.37	4.18	195.08	2.09	214.06	4.78
27.07-08.08	2	234.33	1.52	199.37	3.06	192.79	1.83	191.04	4.30
27.07-08.08	3	232.39	1.39	214.09	2.88	225.49	1.76	233.40	4.17
27.07-08.08	4	225.10	1.46	194.17	3.01	215.33	1.66	232.79	3.77
27.07-08.08	5	234.04	1.55	209.05	3.19	231.11	1.50	240.78	3.66
27.07-08.08	6	262.03	1.91	213.41	3.81	226.72	1.64	242.71	3.93
27.07-08.08	7	280.49	2.25	242.52	4.46	225.33	1.74	229.84	4.11
27.07-08.08	8	292.38	2.52	247.13	4.87	239.94	2.26	245,7	5.05
27.07-08.08	9	291.34	2.77	251.80	5.32	257.70	2.81	263.67	5.88
27.07-08.08	10	295.22	2.81	255.11	5.42	284.06	3.21	285.55	6.44
27.07-08.08	11	304.40	2.88	270.44	5.52	294.96	3.77	296.02	7.30
27.07-08.08	12	290.13	2.70	250.55	5.20	310.61	4.05	310.08	7.70
27.07-08.08	13	281.05	2.54	248.80	5.11	300.66	4.29	310.43	8.14
27.07-08.08	14	267.30	2.48	209.93	4.91	320.27	4.22	309.73	8.10
27.07-08.08	15	228.45	2.36	199.92	4.66	324.32	4.19	319.57	8.10
27.07-08.08	16	177.60	2.15	164.87	4.20	321.86	3.96	319.57	7.71
27.07-08.08	17	176.44	1.82	149.75	3.52	322.80	3.72	314.09	7.37
27.07-08.08	18	168.19	1.78	153.75	3.51	312.10	3.32	310.28	6.79
27.07-08.08	19	150.42	1.80	148.02	3.53	228.08	2.65	250.77	5.76
27.07-08.08	20	159.10	1.99	119.82	3.87	220.83	2.16	254.58	5.02
27.07-08.08	21	163.90	2.26	149.09	4.49	203.23	2.11	223.55	4.73
27.07-08.08	22	153.47	2.33	146.14	4.48	217.92	2.29	234.25	5.03
27.07-08.08	23	177.21	2.22	157.60	4.35	187.80	2.37	213.39	5.39
	max	304.40	2.88	270.44	5.52	324.32	4.29	319.57	8.14
	min	150.42	1.39	119.82	2.88	183.13	1.50	191.04	3.66

4.3.4. Final Results of Comparative Analysis of Outdoor Data of Çeşme and Alaçatı (Calibration decisions)

Deviation Interval between Weather Data of station: 17221 (Çeşme, Big Climate Station) and Portable Weather Station in Alaçatı (27July-27August 2008) can be listed as:

- Temperature ±1°C
- Minimum temperature ±1-1.5 °C
- Maximum temperature ±1-1.5 °C
- Relative Humidity +5-20%
- High wind speed ±0.1-4.0 m/sec
- High wind direction may change (vary)
- Average wind speed ±0.1-1.7 m/sec
- Average wind direction may change (vary)

According to these results, the calibration of the long term temperature and RH values of Çeşme station can be calibrated to the values of Alaçatı. Daily average temperature values are close, although temperature slightly changes throughout the day, so the temperature values were the same for the annual value needs for BES (Building Energy Simulation) software package.

The relative humidity value shows 5% average highness in the meteorological station, thus the RH value will be lowered by 5% for yearly values. When wind conditions of these stations are analyzed respectfully, problem with wind direction and speed variances becomes obvious, as previously explained.

The town is settled on the skirts of Değirmen Dağ on the north and on the plain towards the Alaçatı Gulf (Özgönül, 1996). Değirmen Dağ (Figure 4.33) is the earth ridge that causes the changes in the wind direction and speed, although Ilıca Big climate station is only 2-3 km. far. The wind data is accurately defined with the data taken from Mare and Güçbirliği Energy Companies. The windmills facing Alaçatı town center without any obstacles in between, gives us the exact wind values needed for further simulations.

The formula for power law and log law was recalculated with the final data (See Section 4.1.1.1). This inlet file defines the boundary conditions of the case.

4.4. Comparative Analysis of Indoor Data and Outdoor Data (06-19 August 2008)

Average Temperature and Relative Humidity Values of 3 Hobos placed on different levels (0.1 m, 0.6 m, 1.2 m) of defined spots (points) were calculated and analyzed for each point (Figure 4.15). Air Velocity values measured by hand anemometers (1.3m) at the defined spots were also analyzed. The Steps of Comparative Analysis of Cross-ventilated and Single side-ventilated sofas are organized as:

- Point to point referenced evaluation
- Total space evaluation
- Comparative means hourly studies
- Reconsideration of different relations
  - Hourly values' analysis defined according to wind and airflow rates
  - Hourly depicted values of indoor spaces

4.4.1. Point to point Evaluations of Different Sofa Types

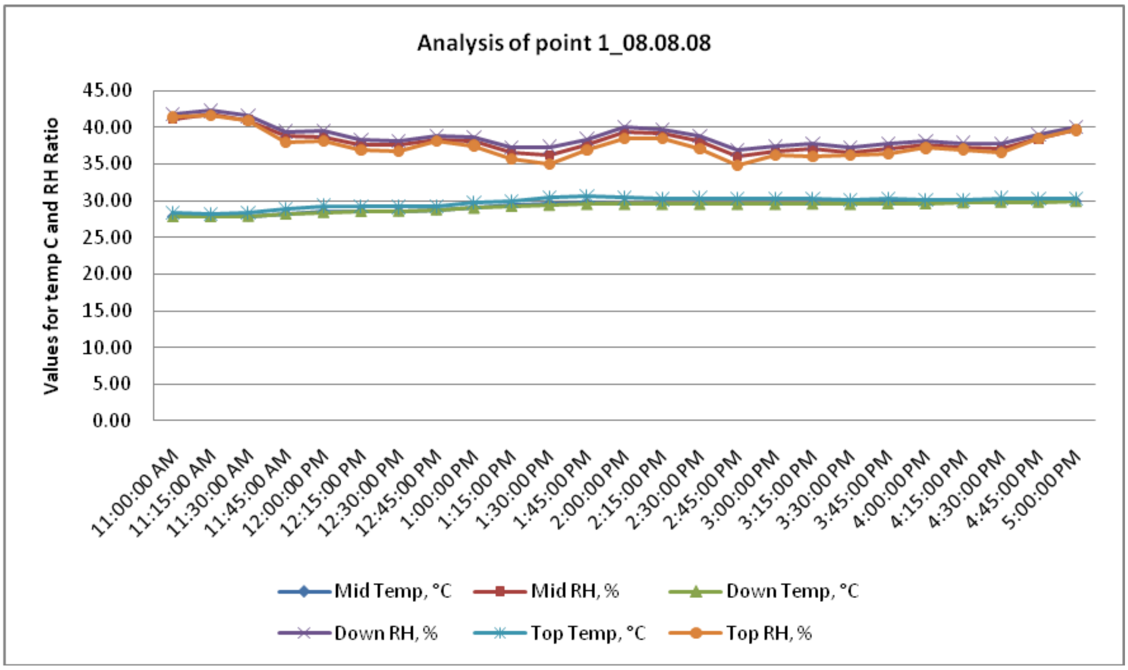

Figure 4.15. Comparison of Relative Humidity and Temperature Values of Point 1_08.08.08

According to the graphic representations of points, defined levels at different measurement points, the top, down and middle values are very close to each other. According to measurements, temperature increases from ground to upper level and relative humidity decreases from ground to upper level. The represented graph point 1 dated as 08.08.08 is an example of the close relation of values measured. The rest can be followed from the appendix. For further studies, the average values of top/middle/down values of temperature and RH were calculated and used.

In the following graphs, similar points defined for cross ventilated and single side ventilated sofa areas are analyzed.

In Figure 4.16, Figure 4.17 & Figure 4.18, temperature and relative humidity values show similar values in the same sofa spaces. Also, the dry-bulb temperature trend of indoor and outdoor do not show an effective change in behavior, while airflow rates between south and north points act totally different. This effect repeats itself in the other point or total space comparisons, so dry-bulb temperature trend is not found significant to be further evaluated by comparison in most of the cases. Rest point to point comparison graphs can be followed from appendix.

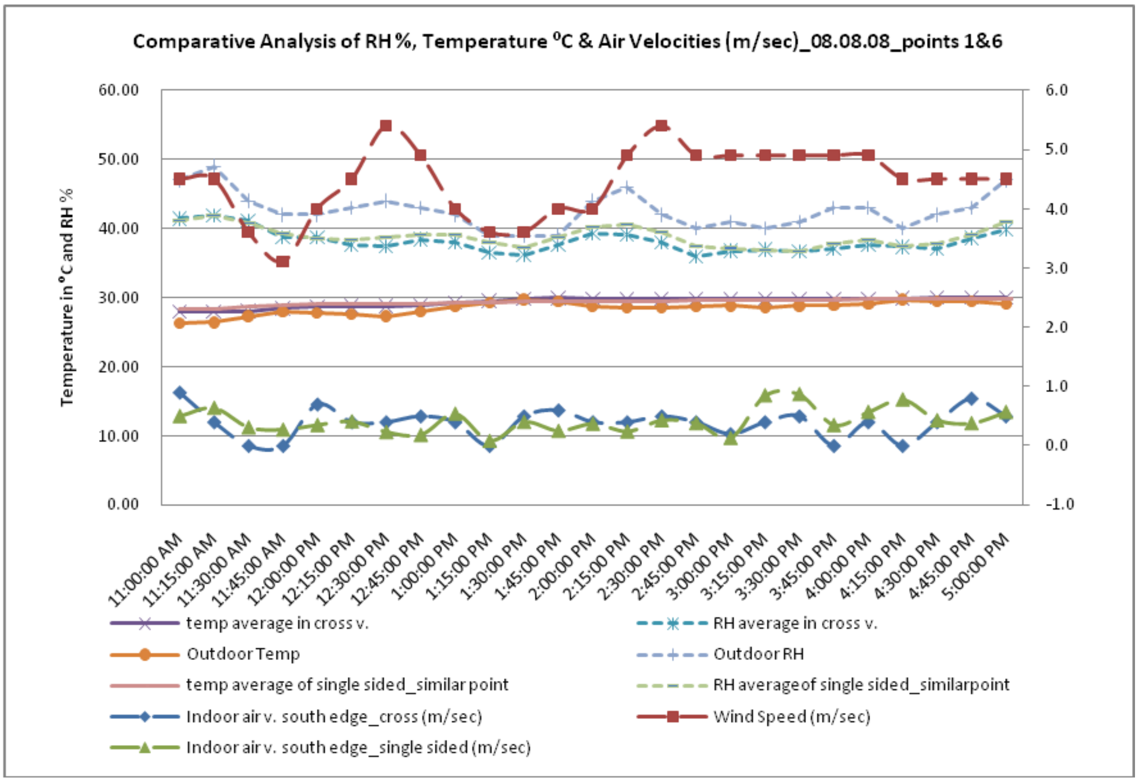

Figure 4.16. Comparison of RH and Temperature and Air Flow Values of Points 1&6_08.08.08

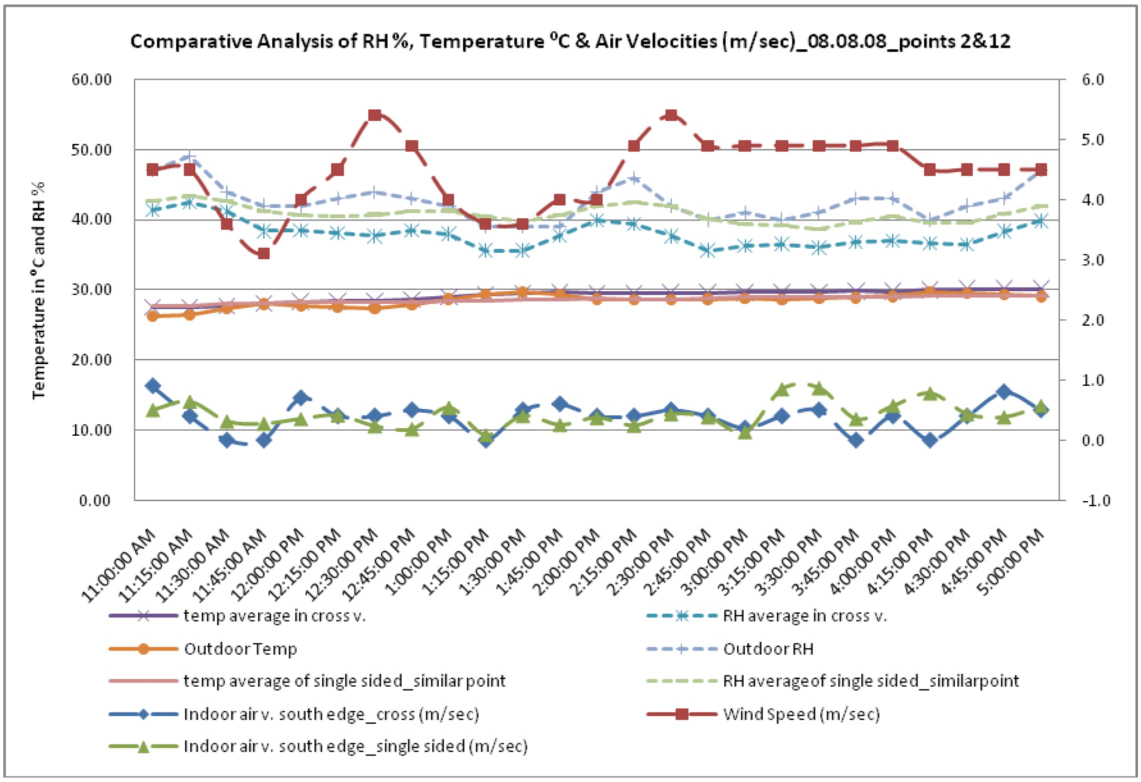

Figure 4.17. Comparison of RH and Temperature and Air Flow Values of Points 2&12_08.08.08

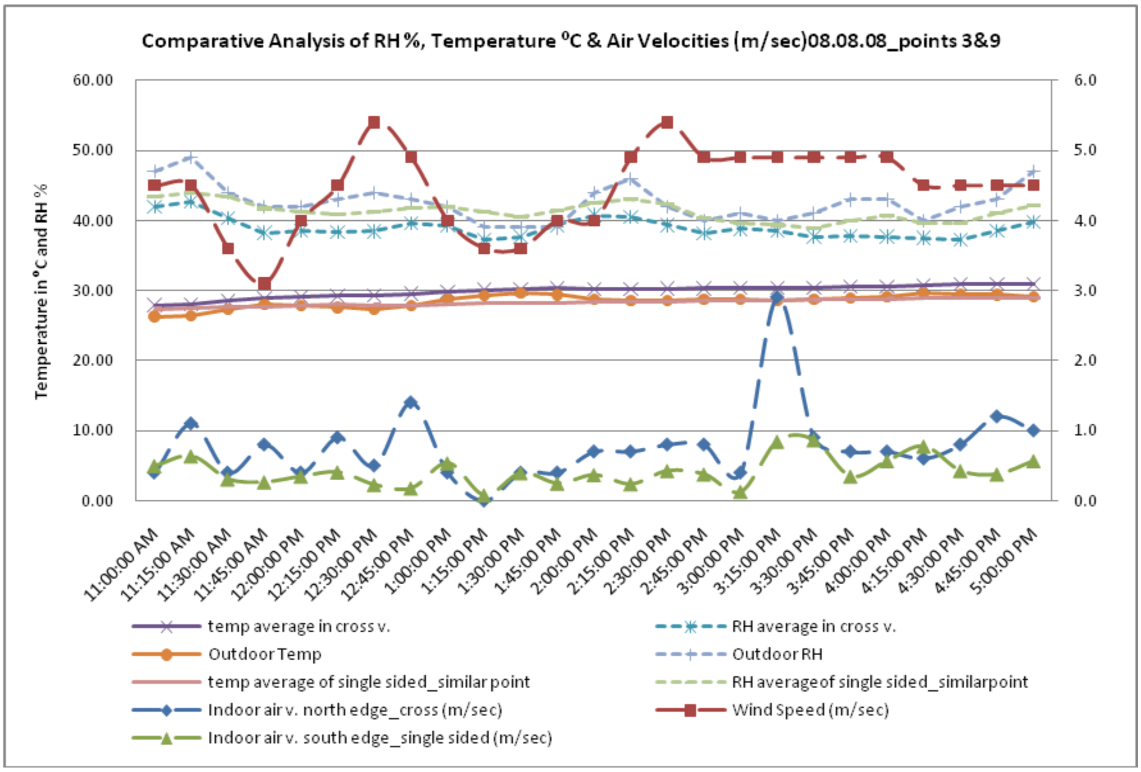

Figure 4.18. Comparison of RH and Temperature and Air Flow Values of Points 3&9_08.08.08

4.4.2. Total Space Evaluations of Different Sofa Types

First, Average Temperature, Relative Humidity and Air Velocity values of sofas were calculated and plotted on different graphs. Then, they were combined in more comprehensive detailed versions.

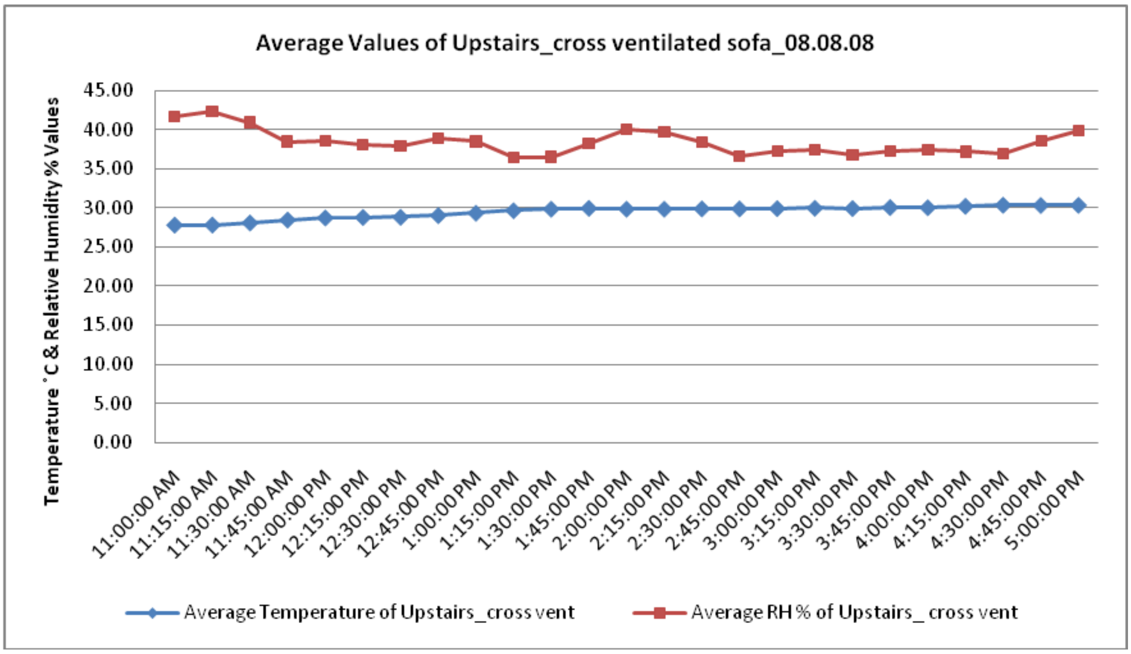

Figure 4.19. Average Values of Sofa Space in Cross Ventilation_08.08.08

The values of different points measured on the same sofa are averaged in order to get an average condition value of temperature and relative humidity. Data of points 1, 2, 3 are averaged for cross ventilated sofa example and data of points 6, 12, 9, 8 are averaged for single side ventilated sofa. Different points were evaluated comparatively before as well, such as 1 and 6, 2 and 12, 3 and 9 briefly for comparative analysis in previous section.

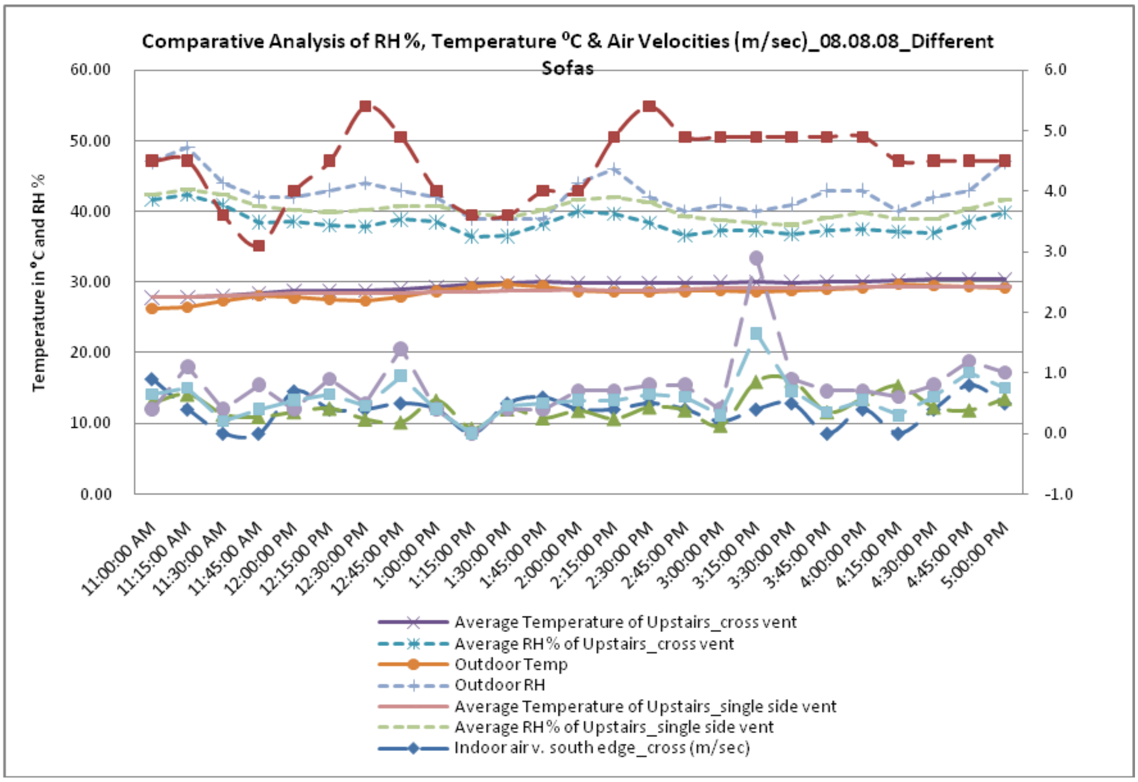

Figure 4.20. Comparison of RH and Temperature and Air Flow Values of Sofas_08.08.08

Again temperature and RH values follow the same trend in indoor spaces and outdoor values during ventilated hours of the campaign. However, airflow rates show more differences and needs more evaluative detailed comparisons.

4.4.2.1. Mean Hourly Temperature Comparative Evaluation

The mean hourly temperature values of campaign days were analyzed for two indoor sofa (total space) cases and outdoor situation. The following chart reflects the daily behavior of temperature (Figure 4.21). Reason for the low start of cross-ventilated space can be explained by closing openings of sofa after the measurement hours, because of security reasons. Within the first two hours of the campaign, temperature of cross ventilated sofa increases to the level of outdoors and stays in the same range with the other sofa and outside.

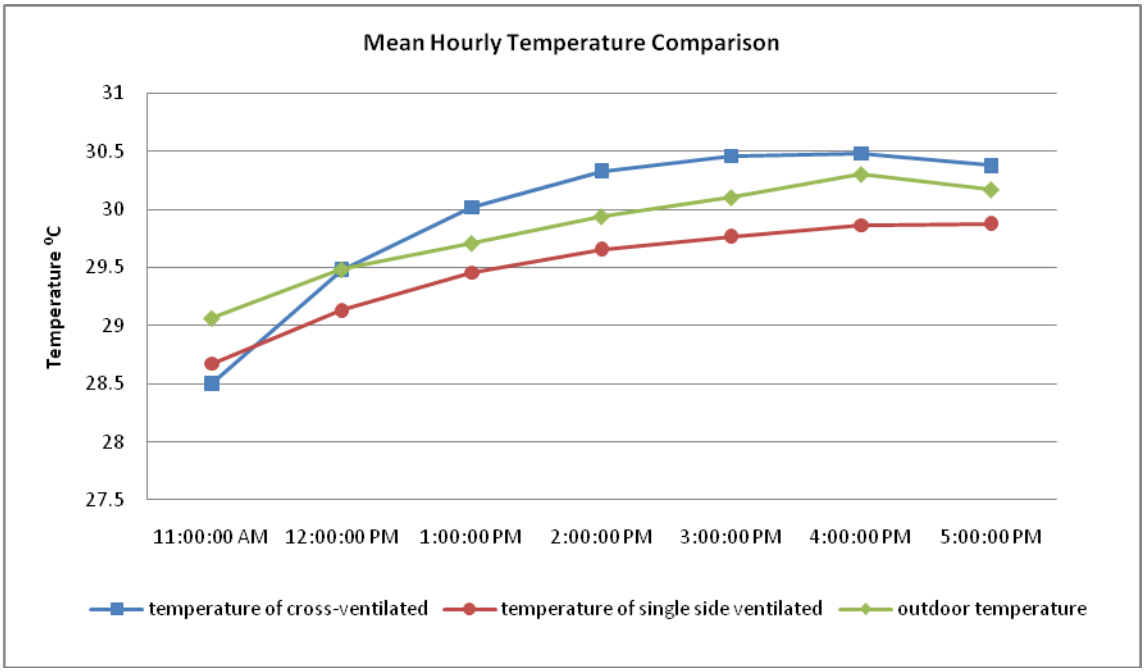

Figure 4.21. Mean Hourly Temperature Comparison of Campaign Period_06-19.08.08

Comparative results can be summarized as:

- ±1 to 1.5 ˚C difference in temperature comparison of indoor and outdoor
- Cross Ventilated Sofa Temperature is slightly higher (±0 to 0.5 ˚C) than Single Side Ventilated Sofa
- All temperature differences, indoor/outdoor can be neglected. Temperature value ranges between 29-30.5 ˚C.
- Dry-Bulb temperature differences of indoor spaces can be explained or discussed with thermal mass differences and solar radiation load on the roofs affecting indoor space of two different sofa examples. Further surface temperature measurements is conducted and no extra surface temperature effect on temperature is determined. Difference can be neglected.

4.4.2.2. Mean Hourly Relative Humidity (RH) Comparative Evaluation

Indoor relative humidity values are 5 to10 % lower compared to outdoor according to daily graphed charts.. Mean hourly values in Figure 4.22. **Mean Hourly Relative Humidity (RH) Comparison of Campaign Period_06-19.08.08** shows that Relative Humidity value of cross ventilated sofa is lower than single-side ventilated one at 3% level and outdoor RH at 5% levels respectfully. Only in the first two hours of the campaign the RH value of cross-ventilated sofa shows a higher percentage, again which can be explained by the ventilation activity starting at 11.00 AM.

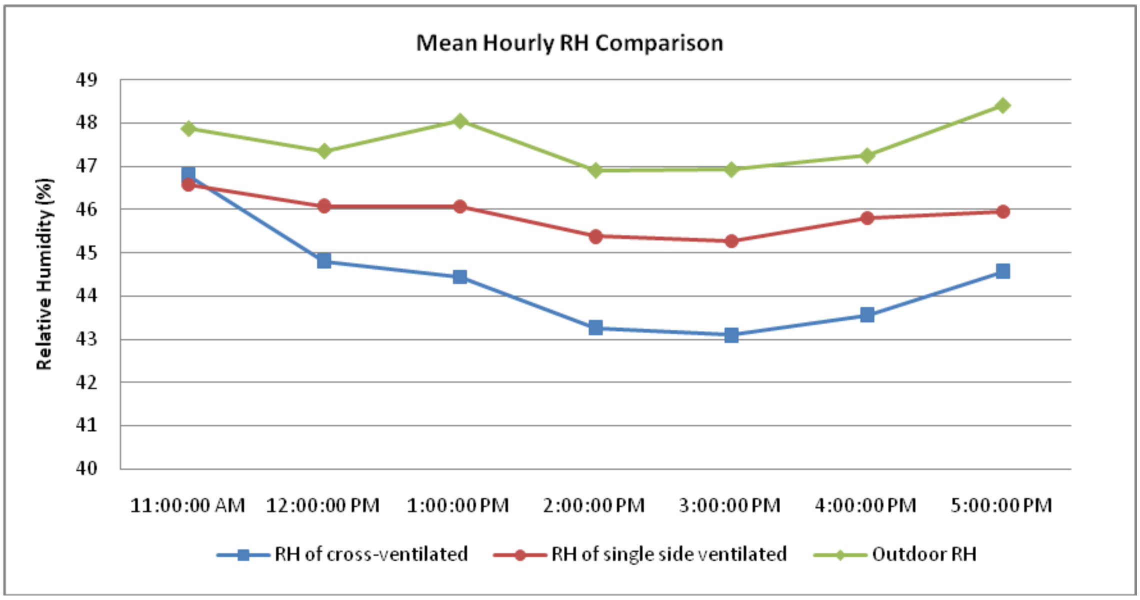

Figure 4.22. Mean Hourly Relative Humidity (RH) Comparison of Campaign Period_06-19.08.08

Comparative results can be summarized as:

- Indoor RH percentage values are always lower than outdoor values
  - Single-side ventilated sofa ~3% less than outdoor
  - Cross ventilated sofa ~5% less than outdoor
- Indoor and outdoor RH Values show the same trend throughout the day
  - RH value of cross-ventilated sofa shows a higher percentage trend;
    - Reason can be explained with ventilation activity blockage at night time
- Cross ventilated indoor space have lower RH percentages compared to single side ventilated space at 3-4% level

4.4.2.3. Mean Hourly Air Flow Comparative Evaluation

Comparative analysis of cross-ventilated and single side-ventilated sofas and outdoor values are given below with one representation of point to point referenced analysis chart, which gives us an idea about different airflow behavior at different parts of the sofa. It should also be mentioned that the airflow fades away in the middle part of both and deeper part of single-side ventilated sofa spaces.

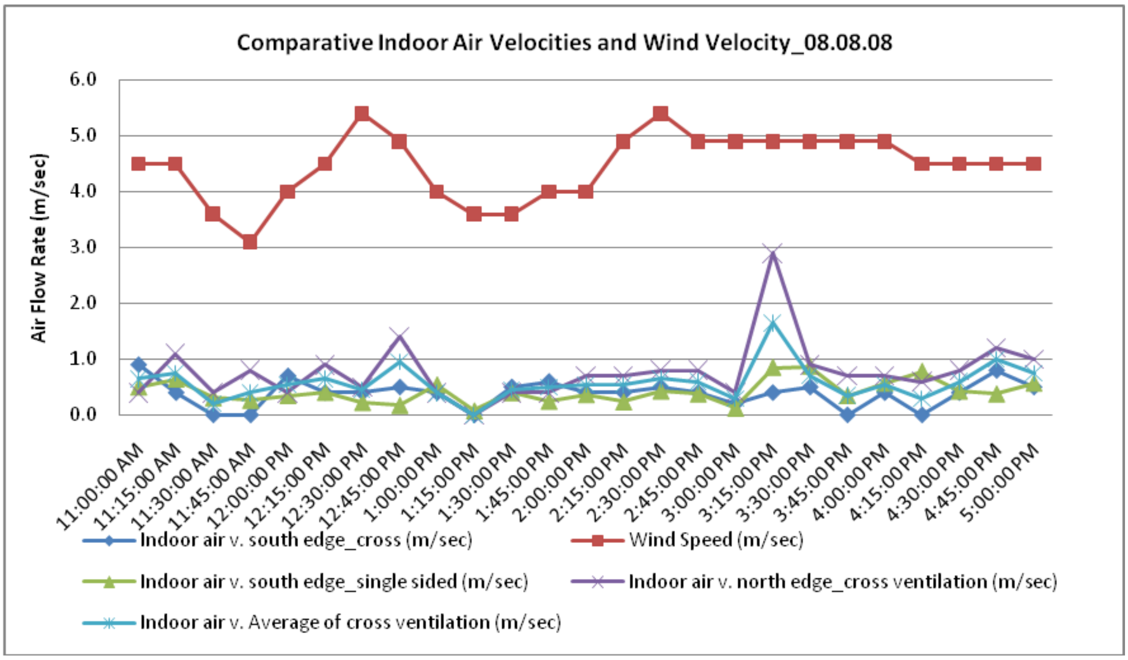

Figure 4.23. Comparison of Air Flow Rates of Sofas and Outdoor_08.08.08

The Air Velocities of indoor and outdoor are not directly related because of changing wind directions. When the wind changes its direction the amount of air reaches indoor may change according to its angle with respect to the façade. Indoor air velocities of similar points (south entrance) of different sofa types show mostly similar characteristics, while different points' (north entrance) averages show mainly different behaviors.

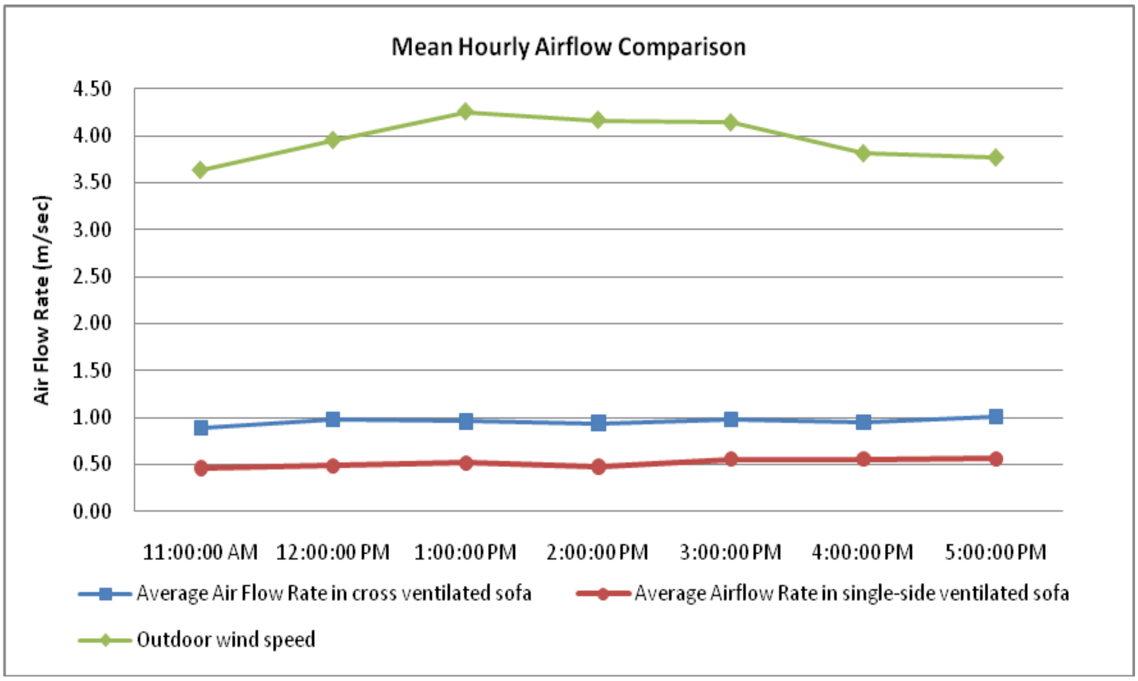

Figure 4.24. Mean Hourly Air Flow Comparison of Campaign Period_06-19.08.08

According to mean hourly airflow comparison of the campaign days, the average airflow rate of cross-ventilated sofa is at 1m/sec level while it is at the range of 0.5 m/sec level in single-side ventilated sofa. This proves that cross ventilated space with similar sofa dimension characteristics gives a higher (doubled) airflow opportunity. Again exploring the graph in Figure 4.24, in the period of the campaign the change in the outdoor wind speed and direction does not have an exact effect on airflows in sofa spaces, yet this will be an inaccurate assumption knowing the chaotic behavior of the wind and also thinking that these values are the averages of low and high airflow values in the only defined period of the campaign.

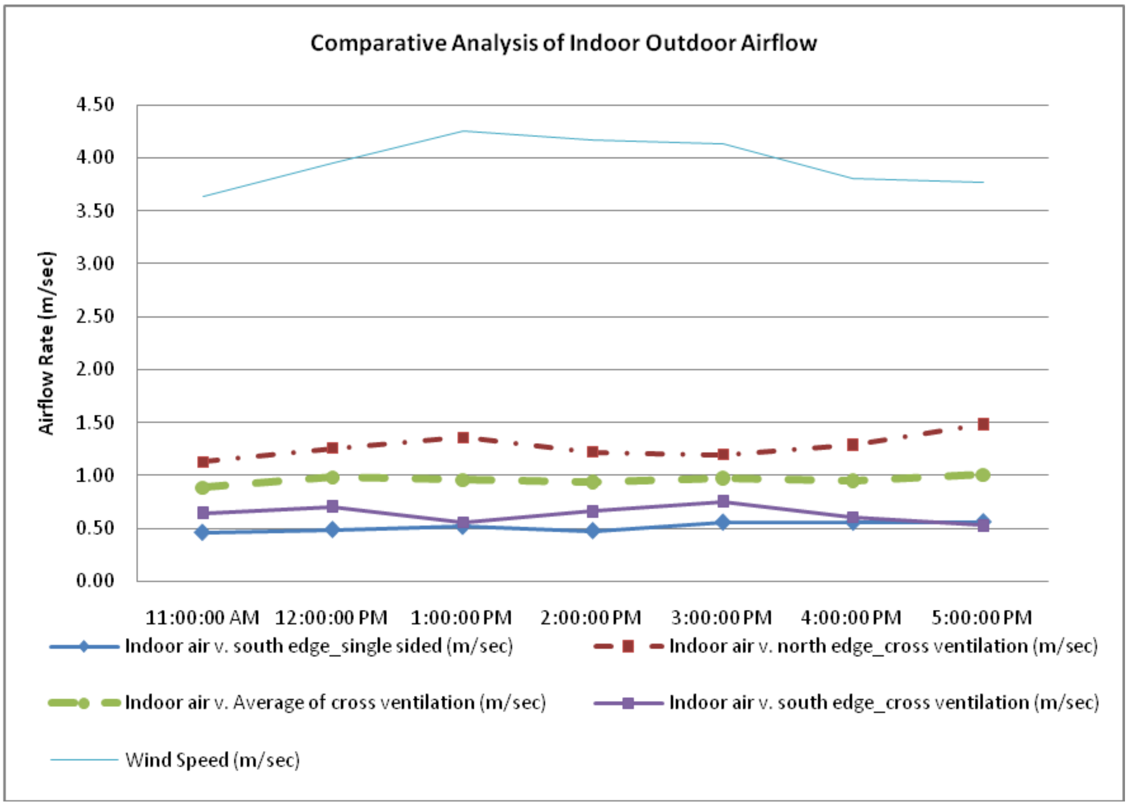

Figure 4.25. Mean Hourly Air and Wind Flow Comparison of Campaign Period_06-19.08.08

This inadequate assumption can be disproved with the graph in Figure 4.25, which defines the change of airflow received from different sides of a cross ventilated sofa. Indoor and outdoor values differ in relation to morphological (especially height) and directional differences. Air Velocity charts of point to point daily values, reflect that there’s not a direct relation between indoor and outdoor values.

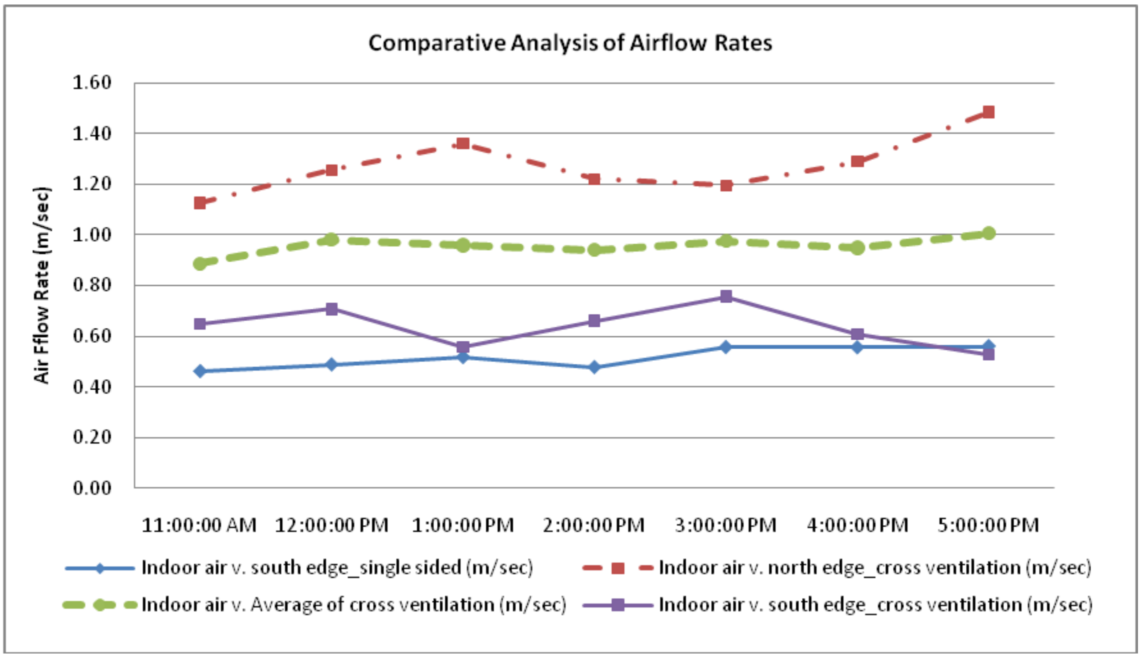

Figure 4.26. Mean Hourly Air Flow Comparison of Campaign Period_06-19.08.08

According to different wind speed and airflow rate analysis:

Mean hourly Wind-Speed average value is calculated as 4.5 m/sec during campaign hours, air velocity of cross ventilated sofa is 3 to 4 m/sec lower than outdoor air velocity/ average wind speed. In daily comparisons, average difference between cross and single side ventilated indoor spaces vary between 0 and ±1 m/sec at most (Figure 4.26).

Comparative results can be summarized as:

- Mean hourly outdoor wind speed average rate changes between 3.6-4.4 m/sec during campaign hours
  - Indoor mean hourly airflow values do not follow the outdoor wind speed trend, because of simultaneous changing angle of the wind
- Air flow characteristics show different instantaneous values and non-linear trends in daily representations
  - Indoor air flow of sofas' similar points (south entrances) show similar characteristic
  - Indoor air velocity of sofas' different points (south & north entrances) show different characteristics
  - Indoor air flow rate coming from different entrances/sides (south & north) changes in relation with outdoor wind direction

- Mean hourly air flow rate averages of cross ventilated sofa is higher than single side ventilated sofa
    - South entrance airflow rates are close at 0.5-0.7 m/sec level, but cross-ventilated space's averages are higher
    - North entrance airflow rate is at 0.9-1.5 m/sec level and are generally higher than rates of south entrance
    - Average air flow rate (0.9-1 m/sec) of cross-ventilated sofa is higher than single side ventilated sofa rate (0.4-0.5 m/sec) and in single side ventilated sofa airflow fades in the middle of sofa cannot reaching the back part.

4.4.3 Reconsideration of Final Outcomes: Details and Comparisons

- Temperature and Relative Humidity charts show that there is a direct relation between indoor and outdoor values.
- Indoor Relative Humidity Value of cross ventilated sofa space is lower each day and the temperature is higher at the start of the measurements. This can be explained by lack of ventilation. This space needed to be locked at nights for security reasons, while the other house window was kept open. When the ventilation started, in all daily cases cross ventilated sofa's RH was lower compared to single side ventilated one.
- About Relative Humidity, this simple detail gives us an idea about the possibility of cross ventilation decreasing the relative humidity percentage. The following graphs (Figures 4.29-4.32) of daily comparison of similar points on different sofa types give us the trend of the air velocity and RH.
- Daily spot evaluations can be found in the appendix; they do not give us any direct relation between RH and air flow. However we can visualize the decrease of RH with high airflow values especially in four specific days (Figure 4.27, Figure 4.28, Figure 4.29 & Figure 4.30).
    - Reasons of this decrease needed to be questioned with different analysis and visualization techniques.

      The average hourly values of RH in relation with air speeds were plotted on scatter charts to be able to make a more comprehensive analysis. South and North wind effects are needed to be questioned with RH trends.

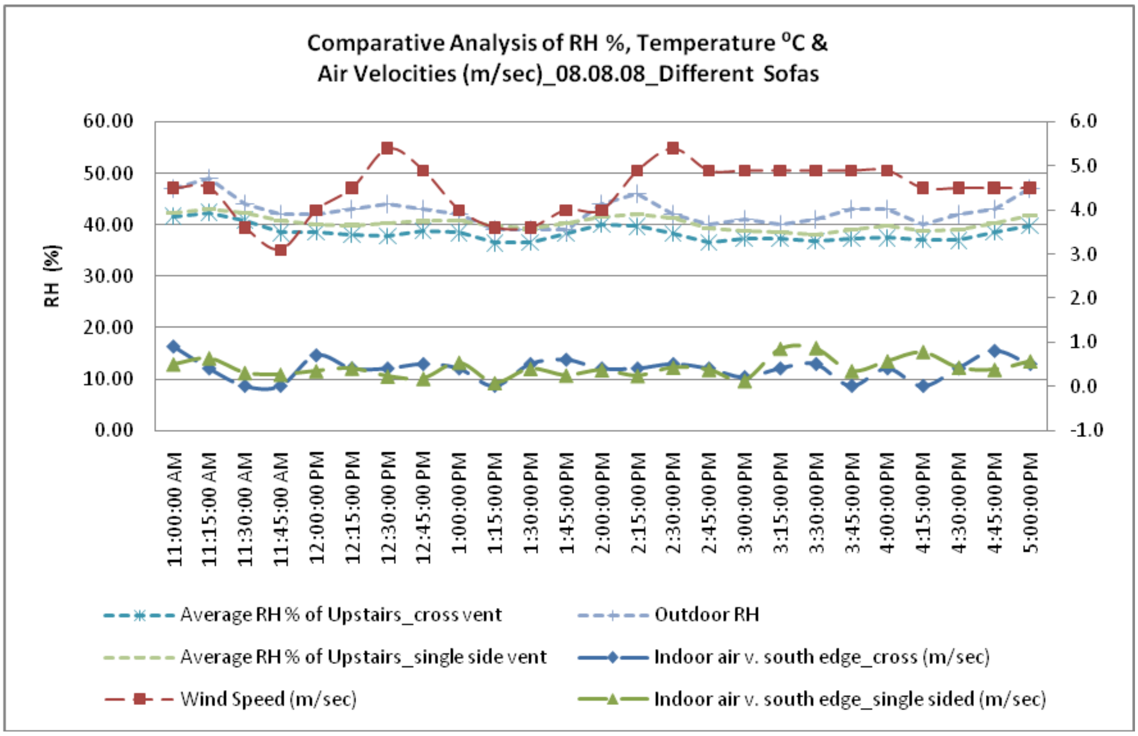

Figure 4.27. Comparison of Relative Humidity and Air Flow Values of Sofas_08.08.08

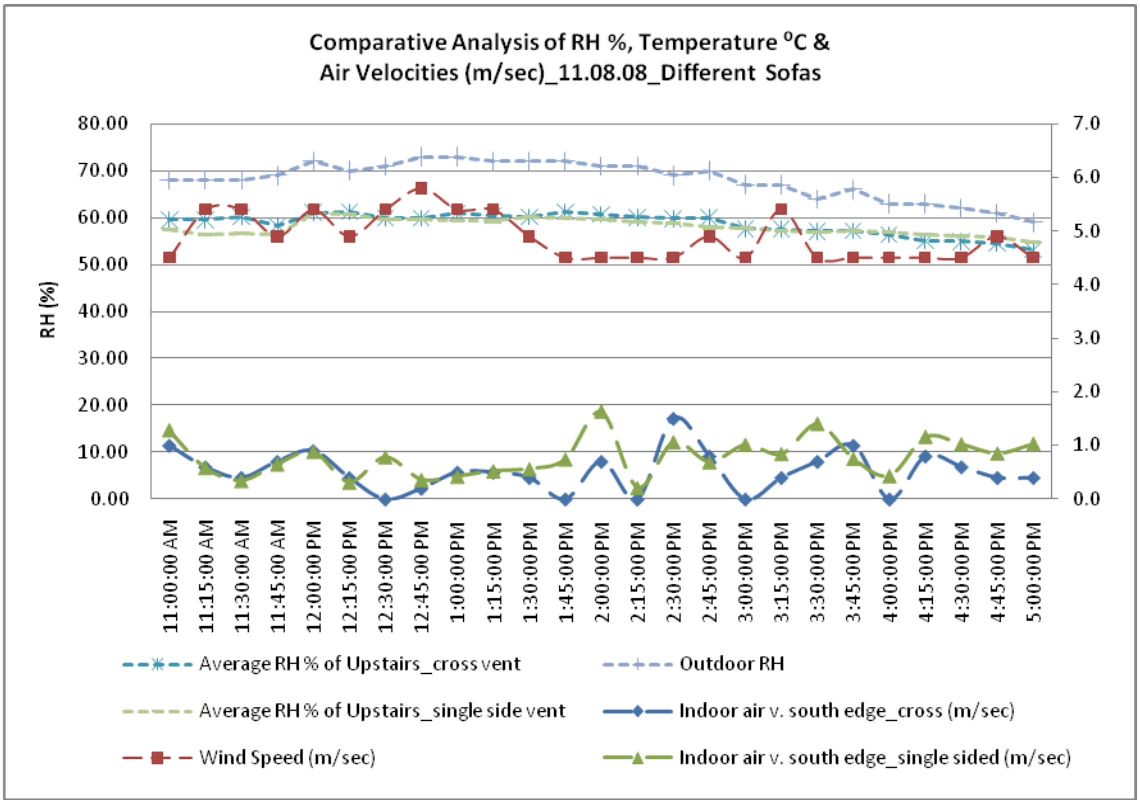

Figure 4.28. Comparison of Relative Humidity and Air Flow Values of Sofas_11.08.08

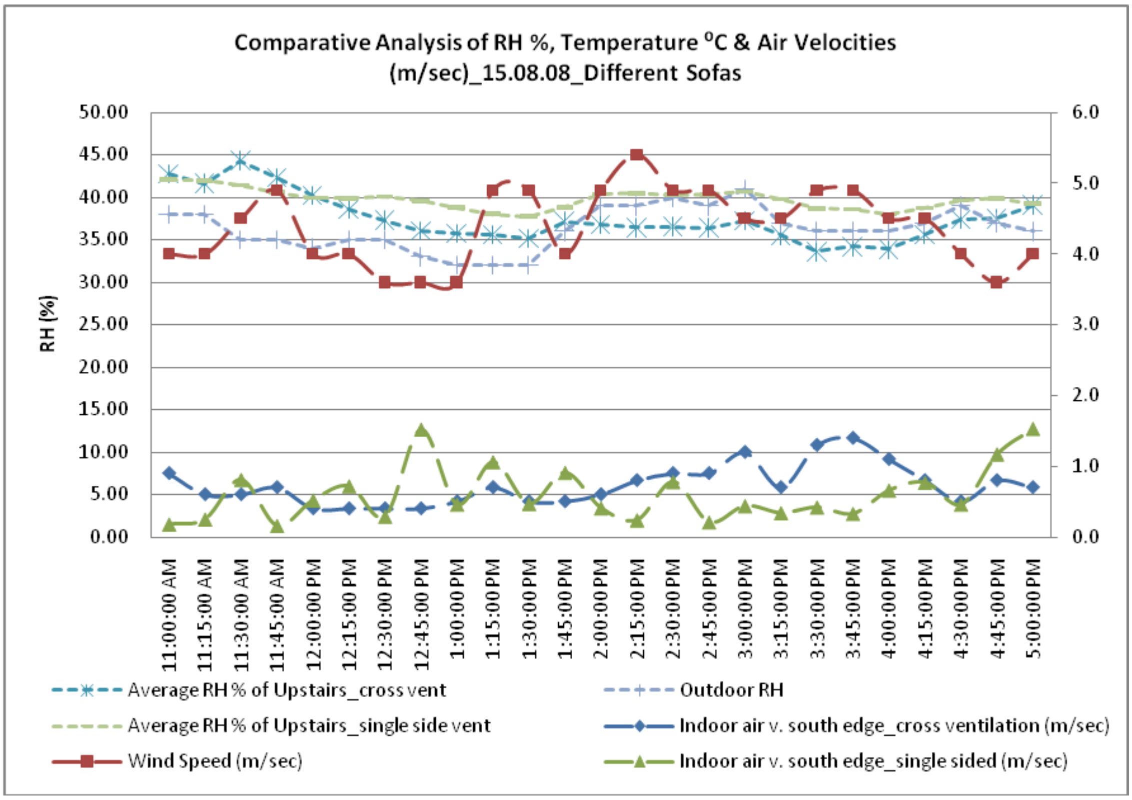

Figure 4.29. Comparison of Relative Humidity and Air Flow Values of Sofas_15.08.08

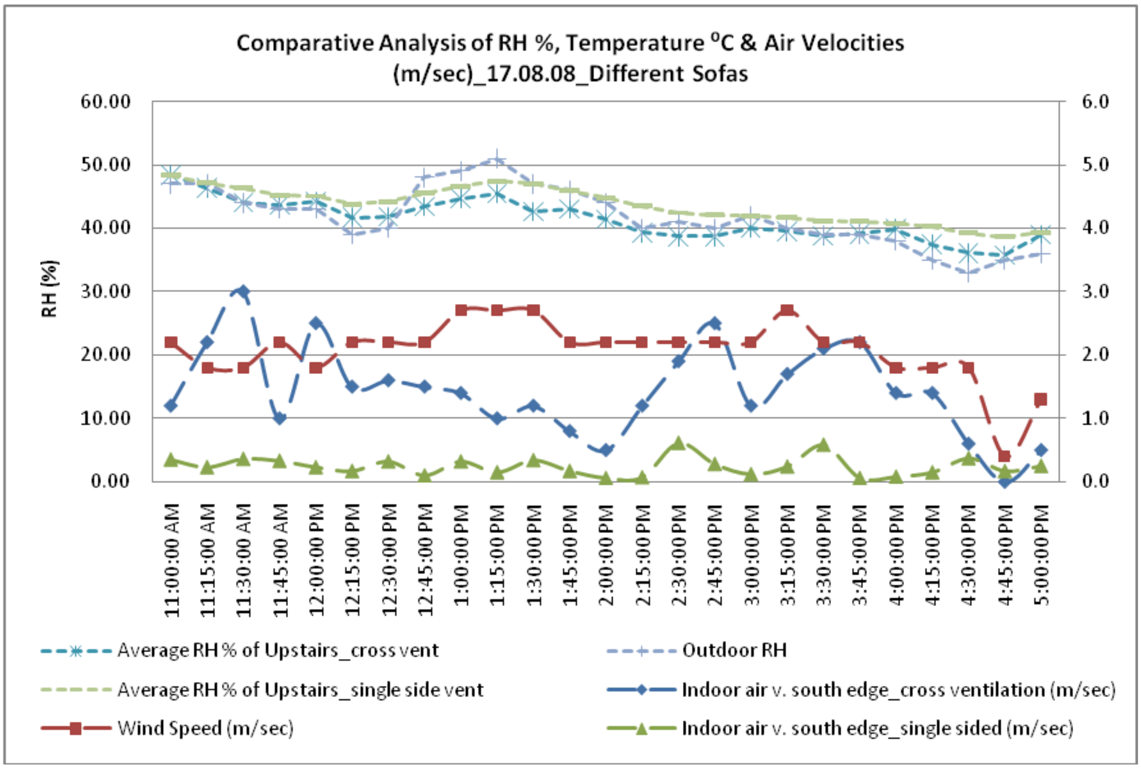

Figure 4.30. Comparison of Relative Humidity and Air Flow Values of Sofas_17.08.08

4.4.3.1. Hourly Average Outdoor Wind Speed/RH Relations

In the scatter graph in Figure 4.31, North wind is assumed as positive wind and South wind as negative. Outdoor RH and wind speed values show different behavior under the effect of north and south wind. Outdoor RH value increases with the increase of Northern wind, and reversely it decreases with the increase in the Southern wind. This effect can be explained by the morphology and geography of the area.

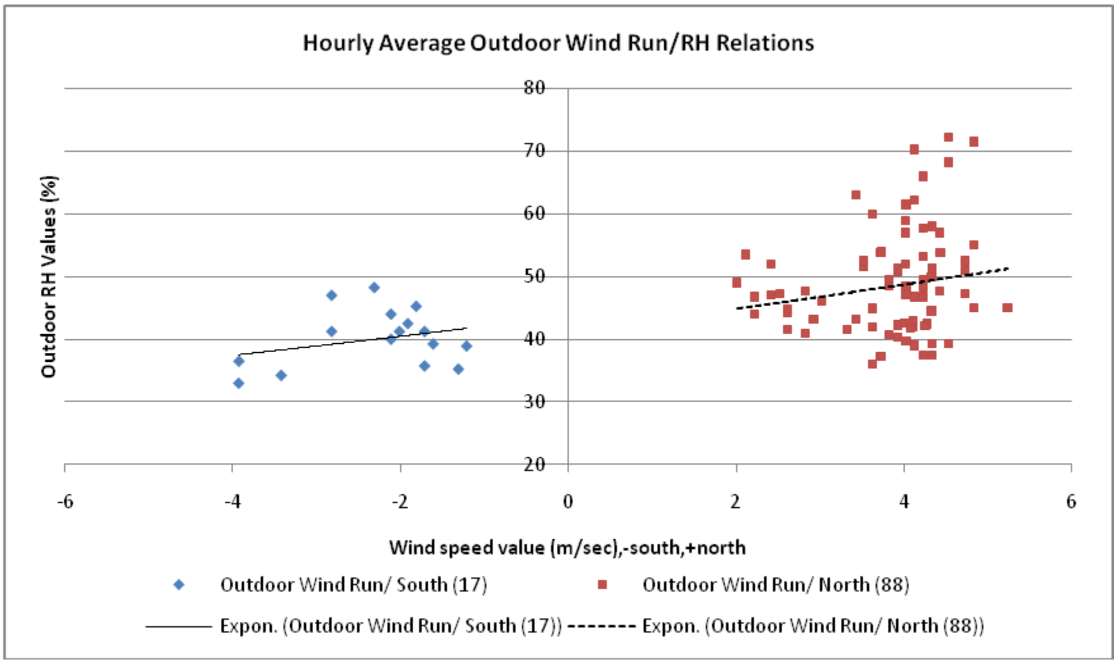

Figure 4.31. Hourly Average Outdoor Wind Run & Relative Humidity Relation _27.07.08-27.08.08

South and Southwest winds are blocked by Değirmen Mountain and sea breeze is more effective from North side of the settlement.

- Outdoor RH value increases with the increase of Northern wind, and reversely it decreases with the increase in the Southern wind.
  - This can be explained by topography: South and Southwest winds are blocked by Değirmen Mountain and sea breeze is more effective from North side of the settlement

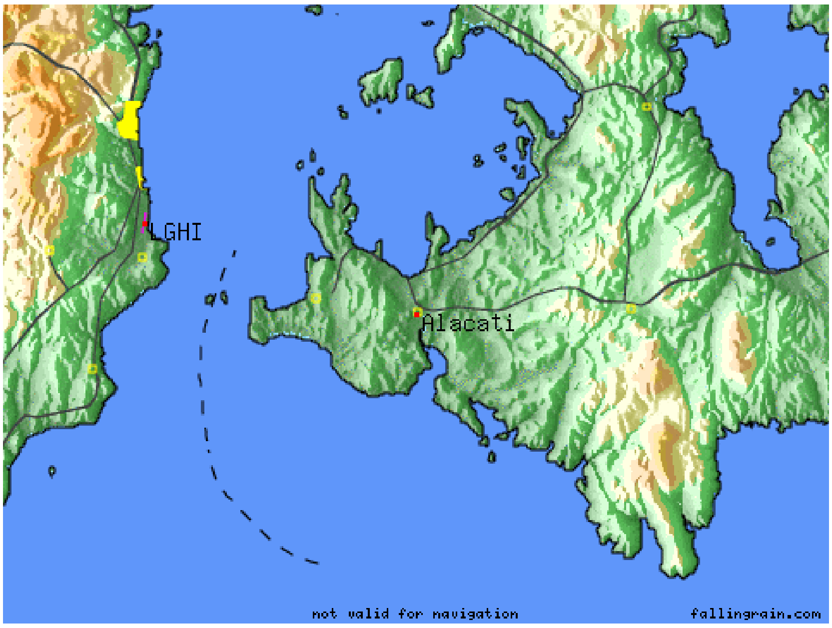

Figure 4.32. Altitude Map of Alaçatı
(Source: fallingrain, 2010)

3-D image in Figure 4.33 shows the mountain assumed as the blocking element of south wind. It is also possible to speculate that the South wind brings the dry desert effect from the south dry regions (Africa and Arabia) as the reason of this occurrence.

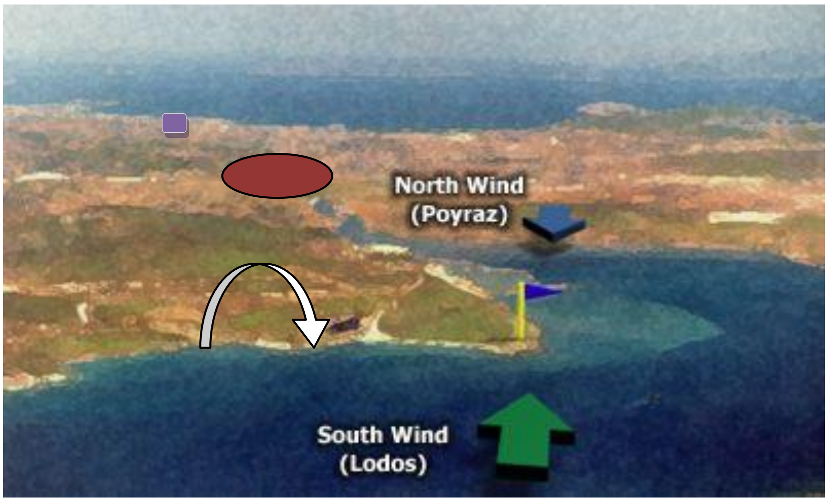

Figure 4.33. Alaçatı Bay Wind Map
(Source: windsurfersparadise, 2010)

4.4.3.2 Hourly Average Outdoor and Indoor Wind Speed/RH Relations

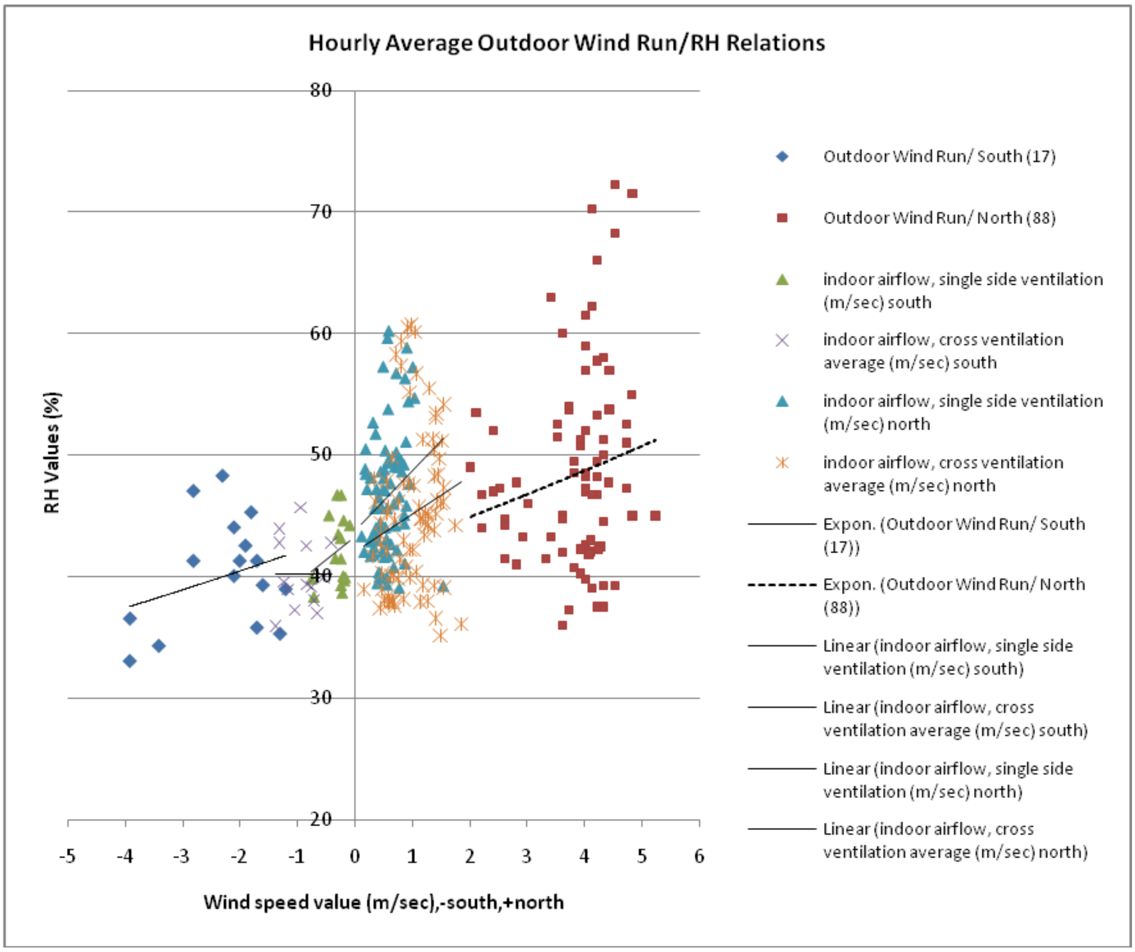

Figure 4.34. Hourly Average Outdoor Wind Run/Indoor Air Flow & RH Relation _27.07.08-27.08.08

The indoor airflow values plotted in relation to RH values give us similar trends with outdoor wind speed and RH relation. Indoor RH values increase respectively when the airflow inside sofas increase under northern wind conditions, while they decrease when the airflow increases with the effect of southern wind conditions. In single-side ventilation the increase or decrease of RH shows a higher trend then cross-ventilation example. Cross-ventilated sofa shows a more linear trend and RH values do not show sharp increases in Northern or decreases in Southern wind conditions. Also, it is possible to say that the trend of cross ventilation is similar to outdoor conditions, especially in northern wind conditions. Thus, cross ventilated sofa’s air flow conditions mostly follow the outdoor air flow conditions

- Indoor airflow values and RH give us similar trends with outdoor wind speed and RH relation.
    - Indoor RH values increase respectively under northern wind conditions
    - Indoor RH values decrease respectively under southern wind conditions
    - In single-side ventilation the increase or decrease of RH shows a higher trend then cross-ventilation example
- Cross-ventilated sofa shows a more linear trend; it is possible to say that the trend of cross ventilation is similar to outdoor conditions following outdoor.

4.4.3.3. Hourly Average Outdoor Wind Speed/Temperature Relations

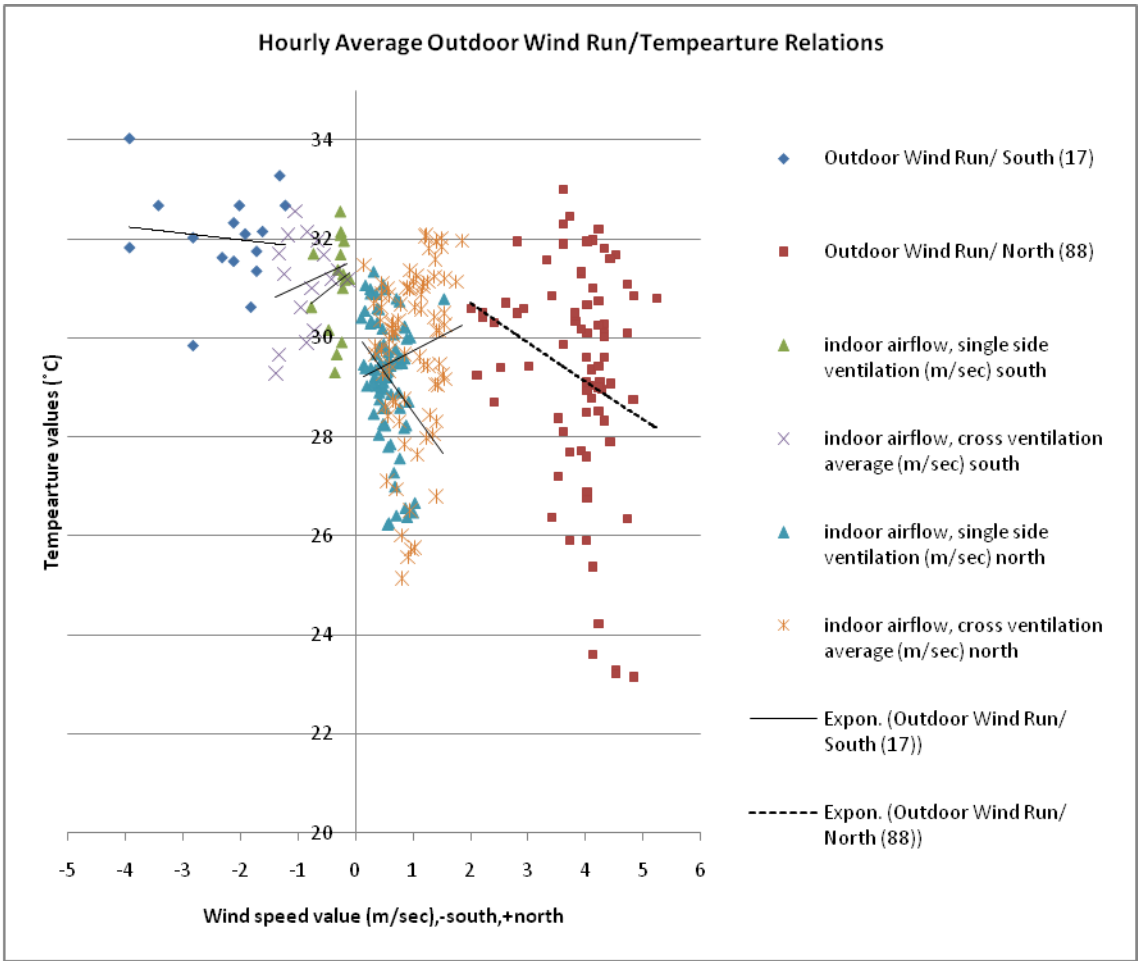

Figure 4.35. Hourly Average Outdoor Wind Run & Temperature Relation _ _27.07.08-27.08.08

When temperature airflow analysis is conducted similarly to RH/Wind Speed analysis, outdoor temperatures decrease with increasing Northern wind speed, while under Southern wind conditions temperature shows very small increase with the increase of wind speed (can even be considered as steady –linear).

Checking the indoor sofa conditions, the effect is so small that it can be neglected. Thus, according to simple interpretation of the graphic data, cross ventilated space's temperature is not really affected by southern wind. Cross ventilated sofa temperature increases slightly (1-1.5 ˚C) by the effect of 2m/sec northern wind and decreases slightly (0.5 ˚C) by 2m/sec southern wind. Single side ventilated sofa follows the temperature trend of outside temperature under Northern wind conditions; decreases by up to 2˚C under airflow up to 2m/sec. However under southern wind conditions airflow up to 1m/sec affects the single-side ventilated temperature with a decrease of 2˚C.

- The effect of air flow on temperature is mainly so small that it can be neglected
  - Cross ventilated space's temperature is not affected by southern wind; decreases slightly (0.5 ˚C) by 2m/sec southern wind
  - Cross ventilated sofa temperature increases slightly (1-1.5 ˚C) by the effect of 2m/sec northern wind
  - Single side ventilated sofa follows the temperature trend of outside temperature under Northern wind conditions; decreases by up to 2˚C under airflow up to 2m/sec
  - Under southern wind conditions airflow up to 1m/sec affects the single-side ventilated temperature with a decrease of 2˚C

Comparative air velocity of indoor spaces shows that the comparison of spots gives more reasonable comparative results. Thus the comparative spot evaluation of daily values can be explanatory for the chaotic behavior of the wind and its relation with RH and temperature respectively and can be followed from the appendix.

4.5. Thermal Comfort Analysis

Measurements are evaluated with the spread sheets prepared by Prof. Frank De Troyer (KUL, Catholic University of Leuven) under Alaçatı weather conditions. The data collected is processed for evaluation. The spreadsheets are prepared with Olgyay charts (1950-1967) and ASHRAE (2005) thermal standards.

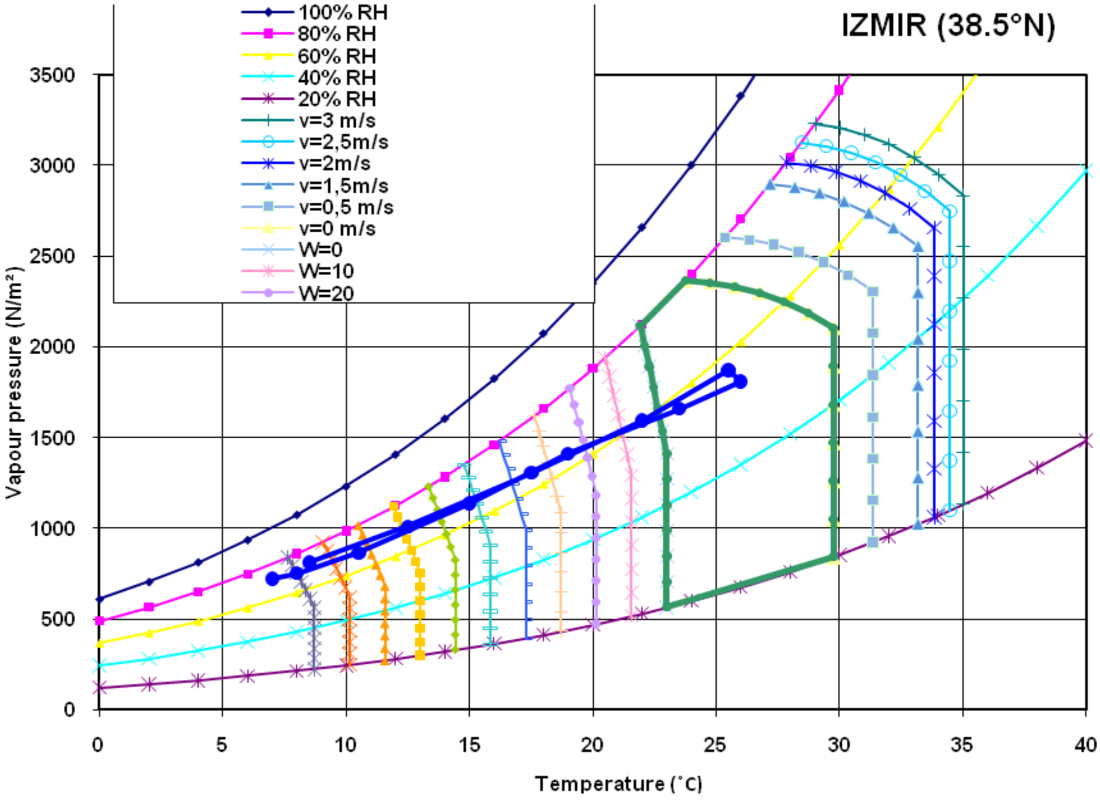

Figure 4.36. ASHRAE Comfort Chart and Mean Monthly Comfort Analysis for Izmir 38.5º

Comfort zone and mean monthly average Test Reference Year, TRY[24], values are given in the ASHRAE Comfort Chart for Izmir (Figure 3.36). Mean monthly average values of summer are in the comfort zone. Winter months have acceptable outdoor conditions with increased body work (W). Also, with increased air velocity, hot conditions over 30˚C are tolerable.

ASHRAE chart (Figure 4.36) is more explanatory to define thermal comfort conditions, which gives the temperature and RH range of TRY monthly averages. As read from the comfort chart, July and August months are critical for Izmir. Ranges are slightly over the comfort zone limits. Izmir is within the thermally comfortable zone throughout the year.

Again, colder conditions under the limit of comfort zone are acceptable with extra work of body (W), and with increase of air velocity hotter conditions over the limit of comfort zone are tolerable.

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[24] Test Reference Year is chosen as the representative annual weather data of a place selected in between 30 year weather data.

4.5.1 Thermal Comfort Defined According to ASHRAE Standards for Izmir

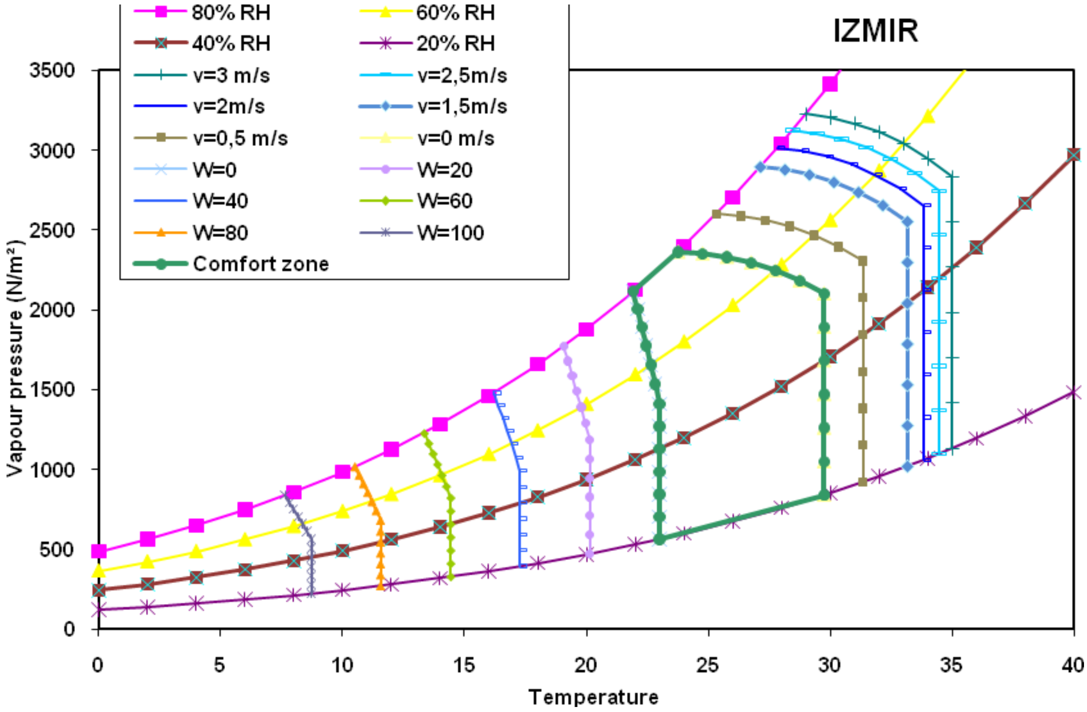

Figure 4.37. ASHRAE Comfort Chart for Izmir 38.5º

ASHRAE follows Fanger's Model (see Section 2.1.1.2.2). According to both model charts the comfort zone in Izmir is between 23-29.8 ºC, %20-80 RH, and W=0. clo value is accepted as 0.5 (light clothing: cotton T-shirt and shorts) for summer conditions. This interval may change with the effect of wind velocity, where the comfort temperature can increase to 35 ºC level by the effect of wind speed over 3.5m/sec, which is effective in summer months with sea breezes (Figure 4.37).

4.5.2 Thermal Comfort Limits and Field Measurement Data Analysis

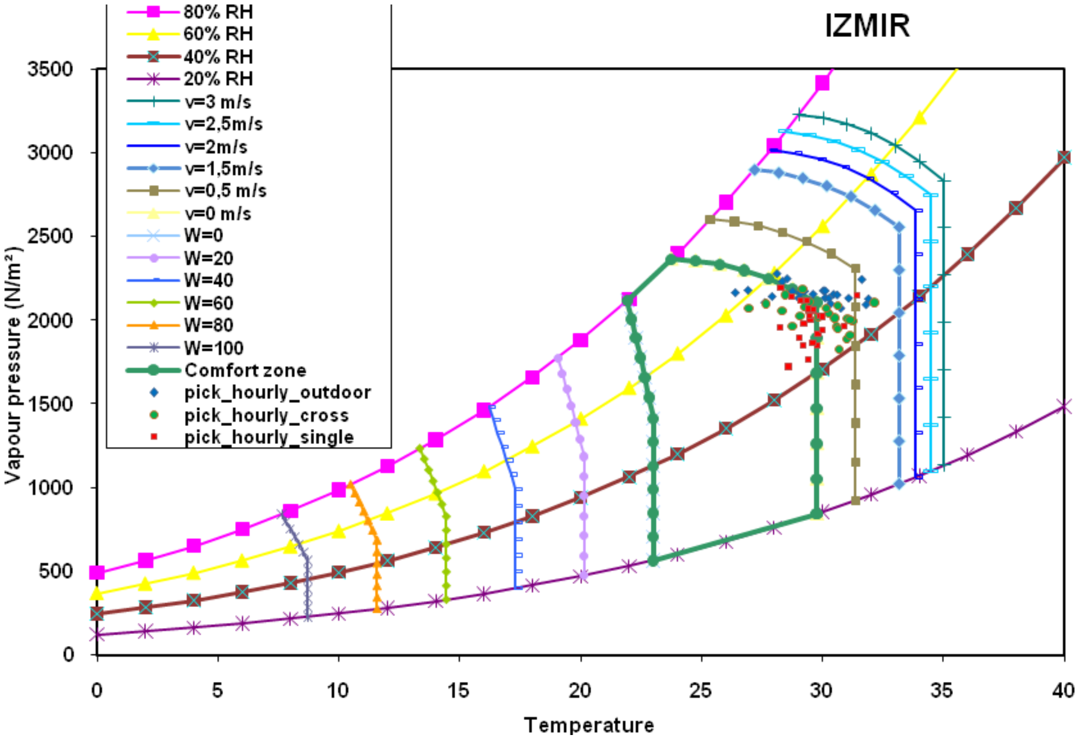

Figure 4.38. ASHRAE Comfort Chart and Campaign’s Thermal Comfort Analysis for Izmir 38.5°

Critical field measurement data is depicted over the comfort chart; according vapor pressure (calculated with RH and temperature) and temperature (Figure 4.38). One quarter of the data is found to be critical according to temperature and RH values. These critical values (outdoor, cross ventilated sofa, single side ventilated sofa) were analyzed according to comfort limits:

- Outdoor values’ (4/5th of critical data) 1/5 th of all data is accessing the comfort limits and velocity of 0.5-1 m/sec needed for tolerable conditions. Extra terrestrial and solar irradiation is not considered in these results and this is not trustable as a final conclusion of outdoor thermal comfort.
- Indoor values of cross ventilated sofa space show an exceeding behavior in the half of the critical data. Therefore, 1/8 th of the whole data exceeds the tolerable defined comfort zone limits and velocity of 0.5 m/sec level is needed to cool down this indoor sofa space naturally.

- 1/4 th of indoor values of single side ventilated sofa space exceeds the limits of critical defined range. Therefore, 1/16 th of the whole data exceeds the tolerable defined comfort zone limits and velocity of 0.5 m/sec level is needed for tolerable limits.

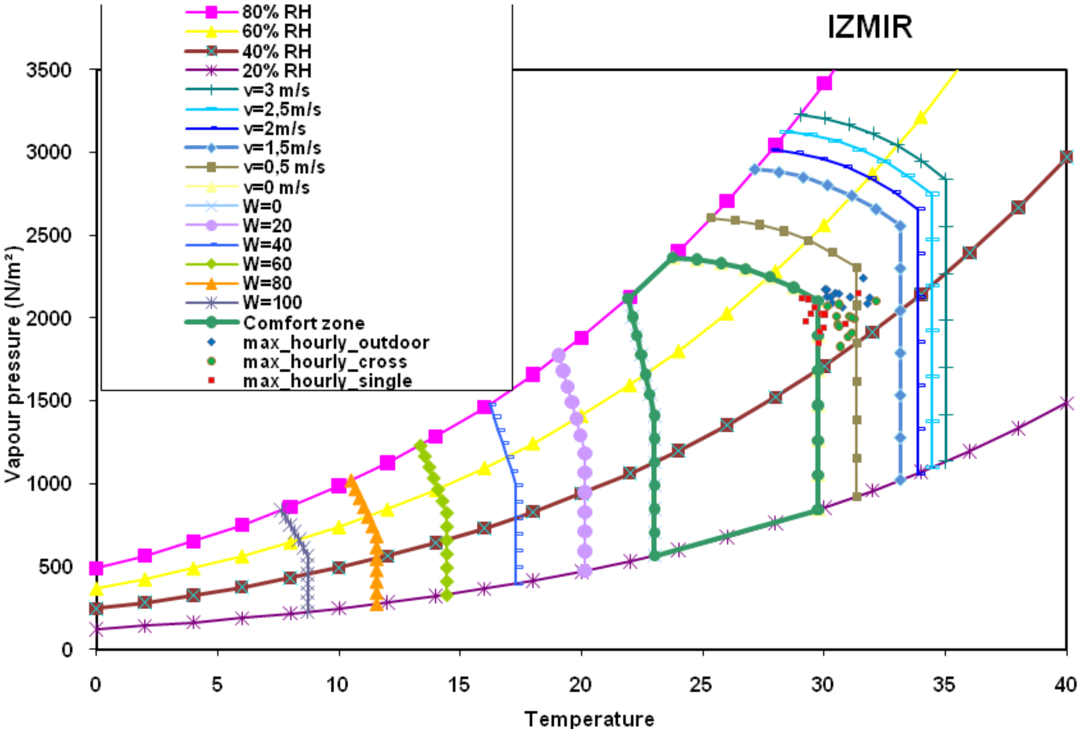

Figure 4.39. ASHRAE Comfort Chart and Maximum Values' Thermal Comfort Analysis

Most critical values are seen in this chart (Figure 4.39); 1/5 th of outdoor data, 1/8 th of cross ventilated sofa data, and 1/16 th of single side ventilated sofa. It should be mentioned that cross ventilated sofa example house was an older house, with no treatment. The cracks of the roof can even be seen from the indoor figures of the house (Figure 8) and this could have caused a slight increase in dry-bulb temperatures. Also the second floor walls of this house are 5cm less in size according to the other example. Both houses' upstairs were not used at the time of the measurements, so they represent the worse conditions among the traditional houses on Kemalpaşa Street.

4.6. Final Results and Conclusion

4.6.1. Results of Comparative Analysis of Outdoor Data of Çeşme and Alaçatı (Calibration decisions)

Deviation Interval between Weather Data of station: 17221 (Çeşme, Big Climate Station) and Portable Weather Station in Alaçatı (27July-27August 2008) can be listed as:

- Temperature ±1°C
- Minimum temperature ±1-1.5 °C
- Maximum temperature ±1-1.5 °C
- Relative Humidity +5-20%
- High wind speed ±0.1-4.0 m/sec
- High wind direction may change (vary)
- Average wind speed ±0.1-1.7 m/sec
- Average wind direction may change (vary)

According to these results, the calibration of the long term temperature and RH values of Çeşme station can be calibrated to the values of Alaçatı. The RH value will be lowered with 5% for yearly values. Wind data is accurately defined with the data taken from Mare and Güçbirliği Energy Companies.

4.6.2. Results of Comparative Analysis of Indoor Data and Outdoor Data (06-19 August 2008)

4.6.2.1. Results of Point to point Evaluations of Different Sofa Types

- Temperature values show similar values in the same sofa spaces.
- Relative Humidity values show similar values in the same sofa spaces.
- Dry-bulb temperature trend of indoor and outdoor do not show an effective change in behavior, while airflow rates between south and north points act totally different.
  - This effect repeats itself in the other point or total space comparisons
    - Dry-bulb temperature trend is not found interesting to evaluate by comparison in most of the cases.

4.6.2.2 Total Space Evaluations of Different Sofa Types

4.6.2.2.1 Mean Hourly Temperature Comparative Evaluation

- ±1 to 1.5 ˚C difference in temperature comparison of indoor and outdoor.
- Cross Ventilated Sofa Temperature is slightly higher (±0 to 0.5 ˚C) than single side ventilated sofa.
- All temperature differences, indoor and outdoor, can be neglected. Temperature value ranges between 29-30.5 ˚C.
- Dry Bulb temperature differences of indoor spaces can be explained or discussed with thermal mass differences and solar irradiation effect from the roofs of two different sofa examples.

4.6.2.2.2 Mean Hourly Relative Humidity (RH) Comparative Evaluation

- Indoor RH percentage values are always lower than outdoor values
  - Single-side ventilated sofa ~3% less than outdoor.
  - Cross ventilated sofa ~5% less than outdoor.
- Indoor and outdoor RH values show the same trend throughout the day. RH value of cross-ventilated sofa shows a higher percentage trend; Reason can be explained with ventilation activity blockage at night time.
- Cross ventilated indoor space have lower RH percentages compared to single side ventilated space at 3-4% level.

4.6.2.2.3 Mean Hourly Air Flow Comparative Evaluation

- Mean hourly outdoor wind speed average rate changes between 3.6-4.4 m/sec during campaign hours.
  - Indoor mean hourly airflow values do not follow the outdoor wind speed trend, because of simultaneous changing angle of the wind.

- Air flow characteristics show different instantaneous values and non-linear trends in daily representations.
  - Indoor air flow of sofas' similar points (south entrances) show similar characteristic.
  - Indoor air velocity of sofas' no similar points (south & north entrances) show different characteristics.
  - Indoor air flow rate coming from different entrances and sides (south and north) changes in relation with outdoor wind direction.
- Mean hourly air flow rate averages of cross ventilated sofa is higher than single side ventilated sofa
  - South entrance airflow rates are close at 0.5-0.7 m/sec level, but cross-ventilated space's averages are higher.
  - North entrance airflow rate is at 0.9-1.5 m/sec level and are generally higher than rates of south entrance.
  - Average air flow rate (0.9-1 m/sec) of cross-ventilated sofa is higher than single side ventilated sofa rate (0.4-0.5 m/sec) and in single side ventilated sofa airflow fades in the middle of sofa cannot reaching the back part.

4.6.2.3. Reconsideration of Final Outcomes: Details and Comparisons

- Temperature and Relative Humidity charts reflect that there's a direct relation between indoor and outdoor values.
- Indoor Relative Humidity Value of cross ventilated sofa space is lower each day and the temperature is higher at the start of the measurements. This can be explained by lack of ventilation. This space needed to be locked at nights for security reasons, while the other house window is kept open. When the ventilation start, in all daily cases cross ventilated sofa's RH is lower compared to single side ventilated one.
- About Relative Humidity detail gives us an idea about the possibility of cross ventilation decreasing the relative humidity percentage. The following graphs of daily comparison of similar points on different sofa types give us the trend of the air velocity and RH.

- Daily spot evaluations can be examined in detail from the appendix; they do not give us any direct relation between RH and air flow. However we can see the decrease of RH with high airflow values especially in 4 specific days.
  - Reasons of this decrease needed to be questioned with different analysis and visualization techniques.

4.6.2.3.1 Hourly Average Outdoor Wind Speed/RH Relations

- Outdoor RH value increases with the increase of Northern wind, and reversely it decreases with the increase in the Southern wind.
  - This can be explained by topography: South and Southwest winds are blocked by Değirmen Dağ Mountain and sea breeze is more effective from North side of the settlement

4.6.2.3.2 Hourly Average Outdoor and Indoor Wind Speed/RH Relations

- Indoor airflow values give us similar trends with outdoor wind speed and RH relation.
  - Indoor RH values increase respectively under northern wind conditions
  - Indoor RH values decrease respectively under southern wind conditions
  - In single-side ventilation the increase or decrease of RH shows a higher trend then cross-ventilation example
- Cross-ventilated sofa shows a more linear trend, It is possible to say that the trend of cross ventilation is similar to outdoor conditions.

4.6.2.3.3 Hourly Average Outdoor Wind Speed/Temperature Relations

- The effect of air flow on temperature is mainly so small that it can be neglected
  - Cross ventilated space’s temperature is not really affected by southern wind; decreases slightly (0.5 ˚C) by 2m/sec southern wind

- Cross ventilated sofa temperature increases slightly (1-1.5 ˚C) by the effect of 2m/sec northern wind
- Single side ventilated sofa follows the temperature trend of outside temperature under Northern wind conditions; decreases by up to 2˚C under airflow up to 2m/sec
- under southern wind conditions airflow up to 1m/sec affects the single-side ventilated temperature with a decrease of 2˚C

4.6.2.3.4 Hourly Average Comparison of Indoor Values

- Comparative air velocity of indoor spaces reflect that the comparison of spots (See Figures 4.3 & 4.4) give more reasonable comparative results.

4.6.2.4 Thermal Comfort Analysis

4.6.2.4.1 Thermal Comfort Defined According to ASHRAE Standards for Izmir

- Izmir is between 23-29.8 ºC,
- %20-80 RH,
- W=0,
- clo = 0.5 (light clothing: cotton T-shirt and shorts)

  for summer conditions.

(This interval may change with the effect of wind velocity; where the comfort temperature can increase to 35 ºC level by the effect of wind speed over 3.5m/sec).

4.6.2.4.2 Thermal Comfort Limits and Field Measurement Data Analysis

Critical field measurement data is depicted over the comfort chart; according vapor pressure (calculated with RH and temperature) and temperature. 1/4 th of the data is found critical according to temperature and RH values. These critical values (outdoor, cross ventilated sofa, single side ventilated sofa) are analyzed according to comfort limits:

- Cross ventilated sofa space establishes higher indoor airflow rates compared to single side ventilated sofa and especially in deeper parts of single side ventilated sofa airflow rate loses its effectiveness.
- Cross ventilated space gives more efficient ventilation and better thermal comfort effect under worse climatic–low wind speed- conditions. (Indoor values of cross ventilated sofa space show an exceeding behavior in the half of the critical data. Therefore, with 0.5 m/sec airflow level is needed to cool down this indoor sofa space naturally. 90% of the data of cross ventilated sofa space sustains thermal comfort.)
- Single side ventilation sustains thermal comfort half of the critical period of measurements. (1/4 th of indoor values of single side ventilated sofa space exceed the limits of critical defined range. Therefore, with 0.5 m/sec airflow level is needed to cool down this indoor sofa space naturally again. Yet, 82% of the data of cross ventilated sofa space sustains thermal comfort.)
- Behavior of airflow within the sofa space cannot be maintained with single side ventilation measurements (limited measurement equipment).

Thermal comfort in indoor sofa spaces of the study is at acceptable limits with 0.5 m/sec ventilation level for both ventilated space examples. However, cross ventilated sofa space establishes higher indoor airflow rates compared to single side ventilated sofa and especially in deeper parts of single side ventilated sofa airflow rate loses its effectiveness. Thus, cross ventilated space gives more efficient ventilation and better thermal comfort effect under worse conditions.

CHAPTER 5

CFD ANALYSIS & COMPARITIVE EVALUATIONS

Computational Fluid Dynamics (CFD)[1] is a computer modeling technique for simulating fluid flow. CFD can predict air speed and direction, temperature, humidity, pressure, turbulence levels and concentrations of contaminants at every location within the computational domain.

In this chapter, airflow modeling of the case study houses measured and analyzed in the previous chapter is performed. These houses are simulated for measurement validation. Further sofa/stair designs alternatives are simulated in order understand how airflow changes according to the design of linear sofas. Computational Fluid Dynamics (CFD) is used by commercial code Fluent 6.3.26 and Gambit2.4.6 for 2D simulations. The airflow predictions are isothermal, expressing steady state conditions, where only airflow is simulated. Computational Fluid Dynamics (CFD) is a computer modeling technique for simulating fluid flow. CFD can predict air speed and direction, temperature, humidity, pressure, turbulence levels and concentrations of contaminants at every location within the computational domain.

The objectives of this chapter are as follows: first to perform CFD model verification and comparative validation with experimental data of both literature study and existing case; second, to compare different turbulence models and simulation methodologies; and third, to perform 2D simulations of different house/sofa geometries and staircase relations to analyze the character of changing airflow speeds.

CFD simulations for this thesis are firstly carried out at the at the Laboratory of Building Physics of the department of Civil Engineering of the Katolieke Universiteit Leuven (2008) and Laboratory of Building Physics of the department of Architecture in Izmir Institute of Technology under the supervision of Dr. Abel Tablada de la Torre and Assist. Prof. Dr. Ünver Özkol.

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[1] "CFD is the art of replacing the integrals or the partial derivatives (as the case may be) in the Navier-Stokes equations by discretized algebraic forms, which in turn are solved to obtain numbers for the flow field values at discrete points in time and/or space." (Anderson, 1995)

5.1 Elements for Maintaining Accurate CFD Solutions

CFD in building physics is a more recent concept compared to its usage in other fields (e.g. aerospace engineering, mechanical engineering). The commercial tool is not suitable to model large size building configurations by non experts. Before starting simulations, CFD model for building physics and elements for making it ready for accurate predictions must be stated.

Accuracy of the solution depends on various different elements such as; the model defined, computational domain, computational grid (mesh) quality, boundary conditions, etc.

5.1.1. The Model

Model quality depends on the expertise modeler. Extent of including geometric details is important; however models need simplifications when allowed in order to obtain the grid economy (computering cost and time). How an expertise builds the model defines the quality, so the accuracy and the solving opportunity of the model.

5.1.2. Computational Domain (Domain Size)

The purpose of the domain (computational domain) is spatial discretization of building model volumes. This volume is divided into a large number of control volumes (cells) for solutions.

There should be a distance between building models and domain boundaries. Maximum allowed blockage ratio is also an issue of domain size[2]. For urban context building models, following figure explains the boundary ratios need to be concerned which is the accepted domain definition in this thesis as well.

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[2] For further information see paper of Blocken & Carmeliet. (Elements for Accurate solutions in CFD based on Urban Physics lectures in KUL, by Prof. Carmeliet in 2007)

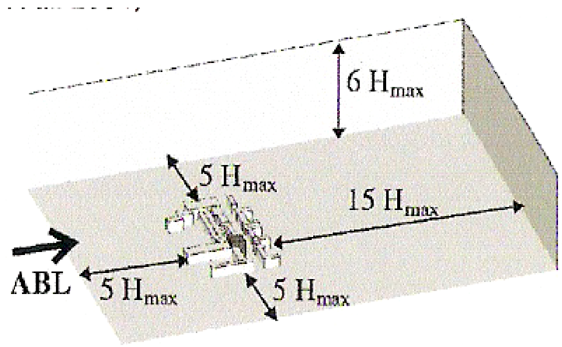


Figure 5.1. Minimum distance between building model and domain boundaries
(Source: Hall, 1997, Franke et al., 2004)

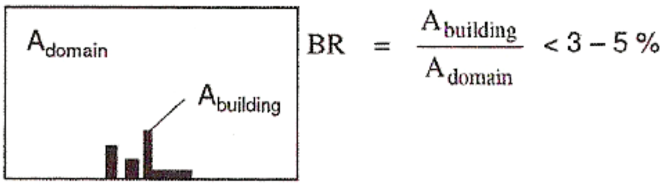


Figure 5.2. Maximum allowed blockage ratio
(Source: Baetke et al., 1997 in Carmeliet, 2007)

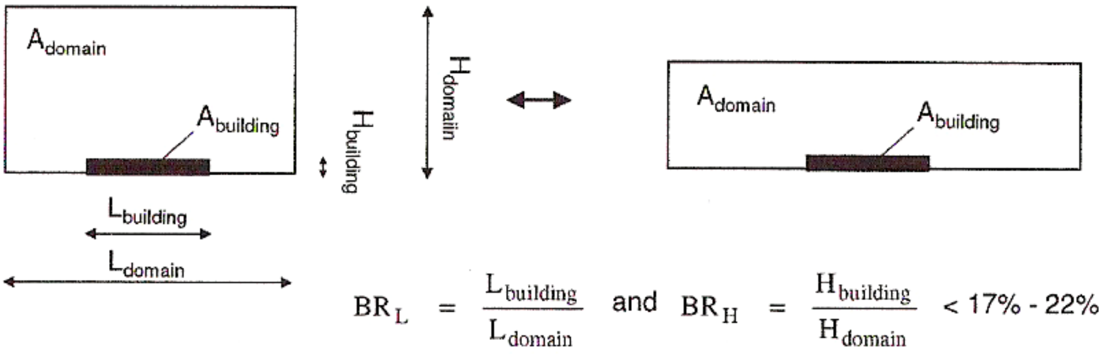


Figure 5.3. Directional blockage ratio
(Source: Blocken & Carmeliet, 2004)

5.1.3. The Computational Grid (the Mesh)

CFD models are numerical methods that discretize the enclosure (3D or 2D) by a number of -control volumes- or -cells-. Cells build the mesh of the model to be used for calculations.

Typically, the enclosure may be divided into 30 000 to 50 000 elements or more (In figure 5.7, Urban dwelling I, ~1730000 mesh used). Therefore each element represents only a fraction of the total enclosure volume. This system of discretization, which is done with Gambit termed as meshing.

Airflow calculation in each cell must follow the fundamental laws of physics covering conservation of energy, conservation of mass and Newton's second law (momentum). Flow, energy propagation and contaminant spread are represented in each of the control volumes by a series of discretized transport equations. Direct solution techniques are not available; therefore iteration is applied in the subsequent computer simulation stage (done with Fluent). All parameters are initially given arbitrary values from which the iteration can commence. These values are then adjusted until each of the transport equations reach a balance. The process of reaching a balance is referred to as 'convergence'. Considerable computational power is necessary, which makes the processing time lengthy, sometimes taking many hours, even days. (Blocken Carmeliet, 2007).

5.1.3.1. Cell Quality

The general guideline for cell quality is to try to avoid extreme distortion of cells: e.g. angles >90° for triangles. Quadrilateral (structured) mesh gives better solutions, however when the geometry is more complex triangular or hex mesh (unstructured) helps to simplify the calculation and this approach do not affect the accuracy of the final solutions.

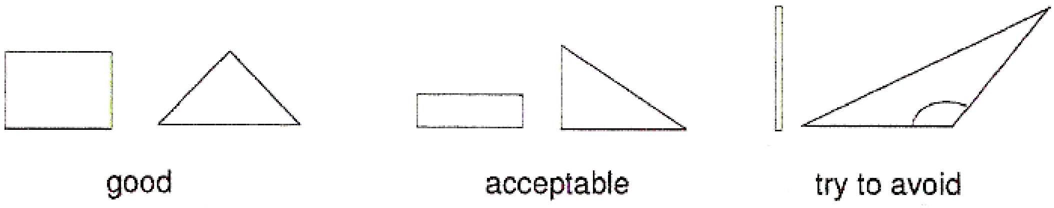


Figure 5.4. Cell quality (quadrilateral & triangular)
(Source: Carmeliet, 2007)

5.1.3.2. Grid Stretching/Compression

For the meshing type (e.g. figure 5.11), a choice could be made between an unstructured mesh (= triangular: composed of triangular cells) and a structured mesh (= quadrilateral: each line only intersects with another once).

In cell type distribution, first gridlines near the wall should preferably be parallel to the wall. Use of quadrilateral cells give better solutions, then for further preference hexahedral or prism/wedge cells can be counted.

General guideline for the growth rate for cells from the wall surface to top level (upper boundary layer), is to keep the expansion ratio lower than 1.3 (sometimes 1.2) as seen in figure 5.5. Especially in the regions of interest (large flow gradients), the growth rate must be kept constant.

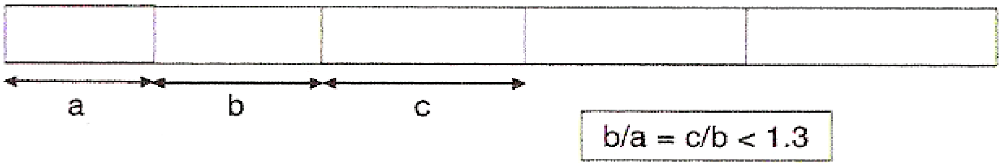


Figure 5.5. Growth rate proposal
(Source: Carmeliet, 2007)

Thus, grid resolution should be higher in regions where large flow gradients are expected. Resolution should be higher in regions of interest, which should be at least 10 cells along length, width and heights for each building. For passages between buildings in region of interest, there should be at least 10 cells across the passage. (Blocken & Carmeliet, 2004, 2007)

5.1.4. Boundary Conditions

Representation of real boundaries is needed (e.g. building surfaces, ground surface). Representation of reality beyond finite computational domain (cut-off) is important (Blocken, Carmeliet, 2004, 2007).

Important problem in CFD studies of ABL (Air Boundary Layer) flow with commercial CFD codes is the horizontal in homogeneity with the implemented wall functions. The near-wall physics have to be taken into account in modeling the near wall region. (See sections 2.3.1.3.2. and 5.2.4 for boundary conditions of this study)

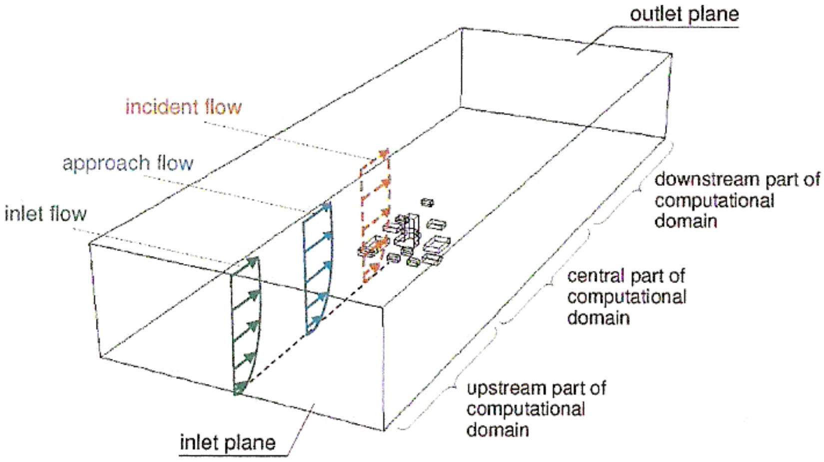


Figure 5.6. Terminology given on example model
(Source: Blocken & Carmeliet, 2004)

5.2. Verification and Validation of Model for CFD

According to the Guide for Verification and Validation of Computational Fluid Dynamics Simulations (AIAA 1998),CFD validation refers to identifying and quantifying errors by comparing simulation results with experimental data, whereas CFD verification refers identifying and quantifying errors in the model implementation. As a result: CFD simulation results can only be trusted/used if:

(a) They have been performed on a mesh obtained by grid-sensitivity analysis

(b) They have been performed taking into account the proper guidelines that have been published in literature

(c) They have been carefully validated by experimental data. (Carmeliet, 2007)

5.2.1. Verification of CFD Model Simulations

For verification of CFD models, elements defined for maintaining accurate CFD solutions (see section 5.1) need to be verified first. Then the verified model must be validated for final outcomes.

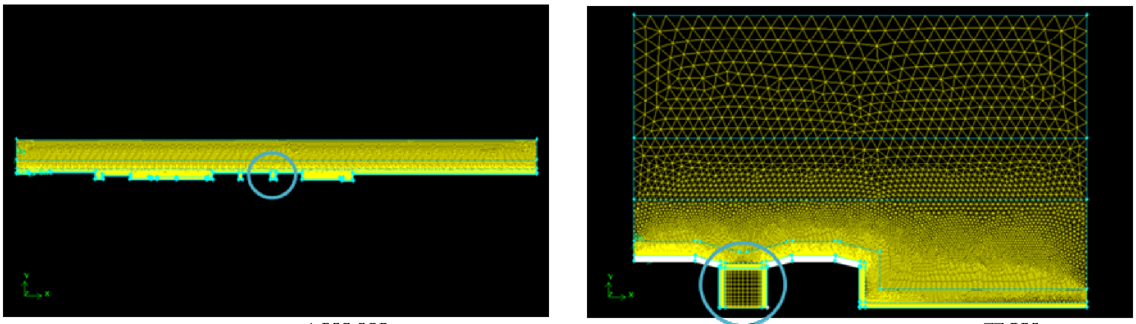
Only under these conditions, the suitability of CFD with the used approach (RANS, LES, and turbulence model and wall functions) for a specific problem can be judged. CFD is often unrightfully blamed for poor results. CFD is a valuable tool, but it can also be a dangerous tool if user-friendly commercial CFD codes are used direct ahead, then everybody can generate results. Errors can easily be made because large amount of user input or user knowledge is required before starting with commercial version. (Blocken & Carmeliet, 2004, 2007, 2009)

Also different sizes meshing are repeated for same model in order to get the most accurate finalized results, which is the Grid Sensitivity Analysis

Finally, these simulations can be compared with real experimental data for validation.

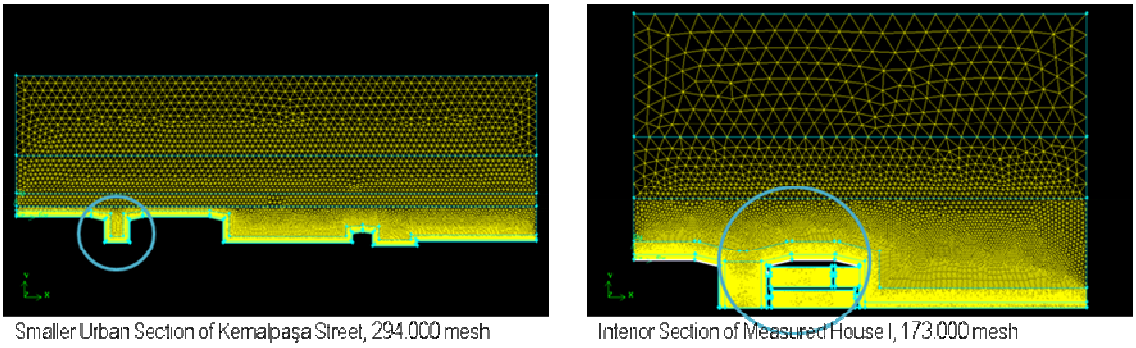
5.2.1.1. The Model

Models for case houses are configured in steps. Firstly an urban model section is studied and simulated, then smaller models are configured with boundary conditions of the bigger scale section simulations. Finally, the urban canyon houses and canyon are modeled and computed for further validation steps.



Urban Section of Kemalpaşa Street, 1 000 000 mesh

Canyon Detailed Section of Kemalpaşa Street, 77.000 mesh



Smaller Urban Section of Kemalpaşa Street, 294.000 mesh

Interior Section of Measured House I, 173.000 mesh

Figure 5.7. Mesh models for Urban study of the Site with Gambit 2.4.6

Urban effects are observed over the low dense traditional urban area. Data of this large scale simulation analysis is integrated to smaller scaled sections.

5.2.1.2. Computational Domain

Computational Domain in this study is 50m in height. Boundary conditions are defined according to -8 & 42 y coordinates, where the urban canyon in question is considered as a cavity hole. The computational domain size defined with respect to the configuration pattern introduced in section 5.1.2, where distance until the canyon (upstream) given as 12 meter and the total x axis distance is 72meter.

Computational domain is separated in growing sized layers while reaching upper boundary level. Thus, domain have maximum amount of cells in the needed parts.

5.2.1.3. Computational Grid (Mesh)

A structured mesh (quadrilateral) was used in important canyon and roof intersection relations. Only at higher boundaries unstructured (triangular) mesh is used for decreasing the calculation time. This is as accurate as a structured mesh, because of unobstructed behavior, which makes the computing time significantly shorter.

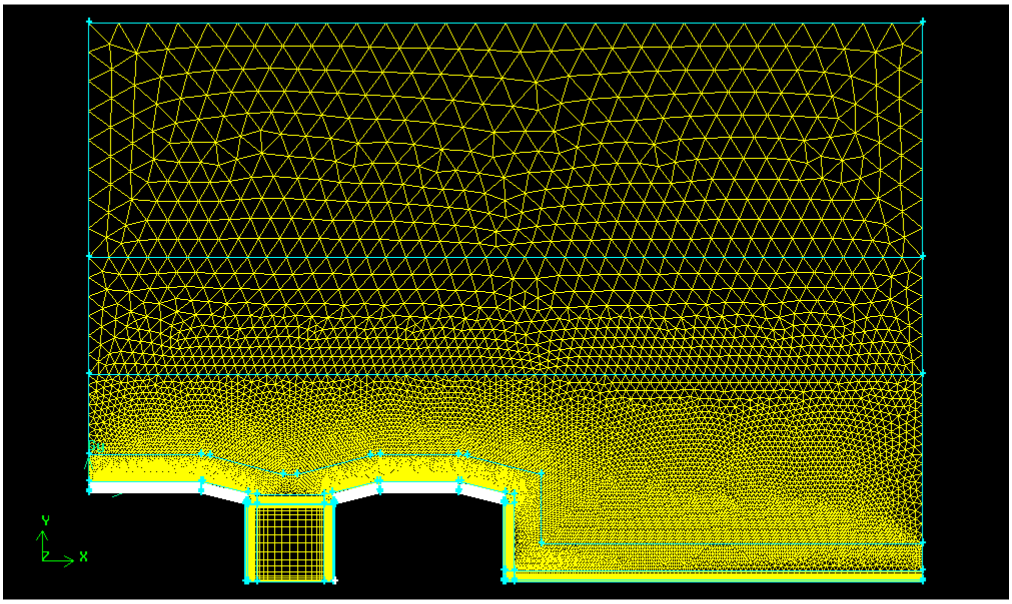


Figure 5.8. Representation of a structured and unstructured mesh on one of the 2D mesh models

In Figure 5.8, it is possible to see the enlargement of the top of the canyon with unstructured mesh, which also shows the closer structured meshing close to the walls. The gradation of the triangle size can be observed. Finally, the connections between the triangles and their shape should be controlled. When the meshing is completed, the solver (Fluent 6.11) has to be selected.

A high resolution mesh is used near the walls (fig. 5.9), because these zones have to be calculated more profoundly. The faces can be meshed directly or the choice can be made to mesh the edges first and then the faces based on the edges' mesh. Here, the second approach was used.

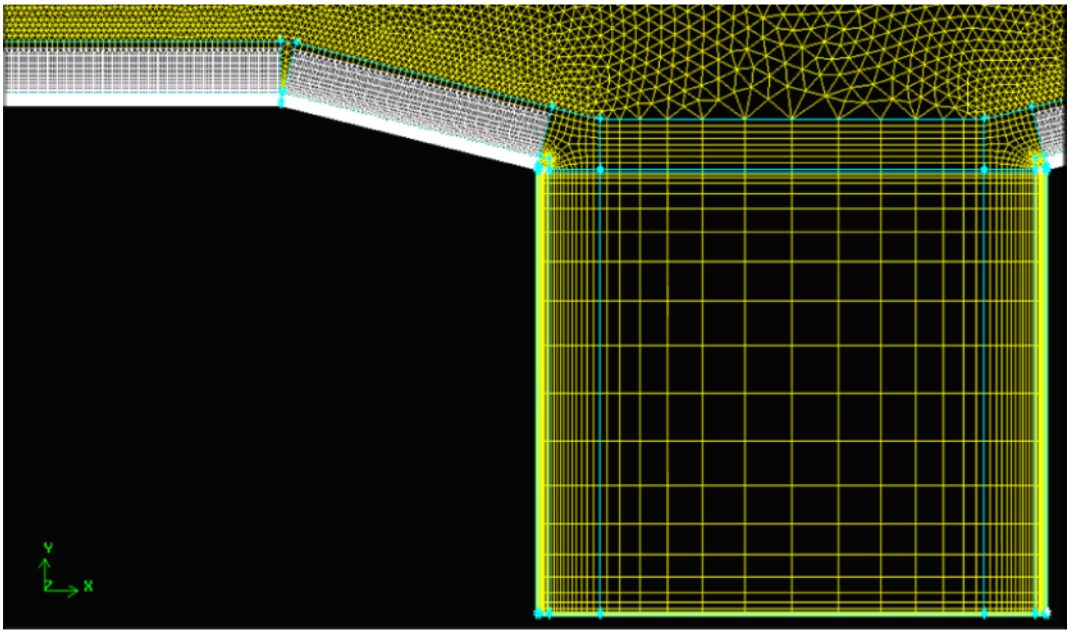


Figure 5.9. Canyon Grid (structured mesh optimized)

Edges where the pitched roof and canyon intersect are the parts where the structured mesh is hard to build properly. However cell quality of the final model is sustained with low skewness[3] values, whereas the maximum skewness value is below 0.25 level. Thus, grid stretching and compression is controlled manually and kept at a lower level.

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[3] Defines the quality of the mesh, where mesh cell angles are lower than or equal to 90° for triangular

5.2.1.4. Boundary Conditions

According to the power law and log law optimization with following reference values boundary conditions are defined. (See appendix A)

Table 5.1. Boundary reference values for site

yref =	Boundary layer height	42	m			
Uref =	Free-stream velocity	7.9	m/sec			
Alfa=	Exponent in power law	0.2				
y0=	Roughness length	0.06	m	u* =	Friction velocity	0.31m/s

5.2.1.5. Grid Sensitivity Analysis

Grid sensitivity analysis is defined as "systematically refining or coarsening the mesh –grid- by a constant factor" (Blocken &Carmeliet, 2007). For grid sensitivity analysis method, the grid check is maintained by reworking the model by constant factor of √2 or 2, where in this study is worked as well:

- Standard interval
- Smaller interval (divided by √2)
- Bigger interval (multiplied by √2)

The goal is to maintain a grid independent solution, where the grid enlargement in the domain is defined well and grid size loses its importance.

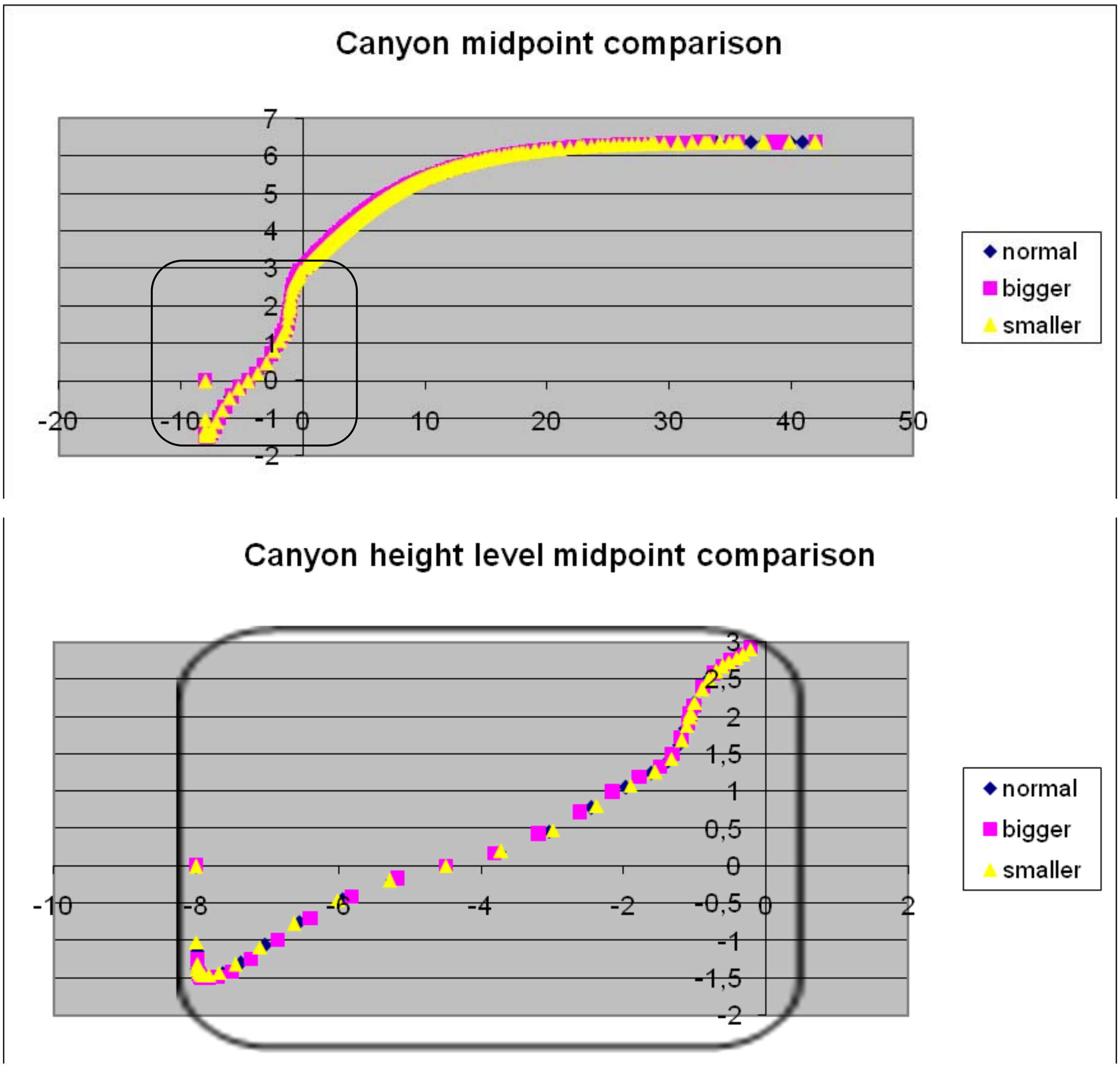

Figure 5.10. Grid sensitivity analysis (Grid independent solution)

According to grid sensitivity analysis of urban canyon model seen in figure 5.10. The correlation between different cell size distribution is $R^2 = 0.9886$, where the solution is grid independent in this 2D model study. Thus further simulations are also built with this mesh study character seen in figure 5.11.

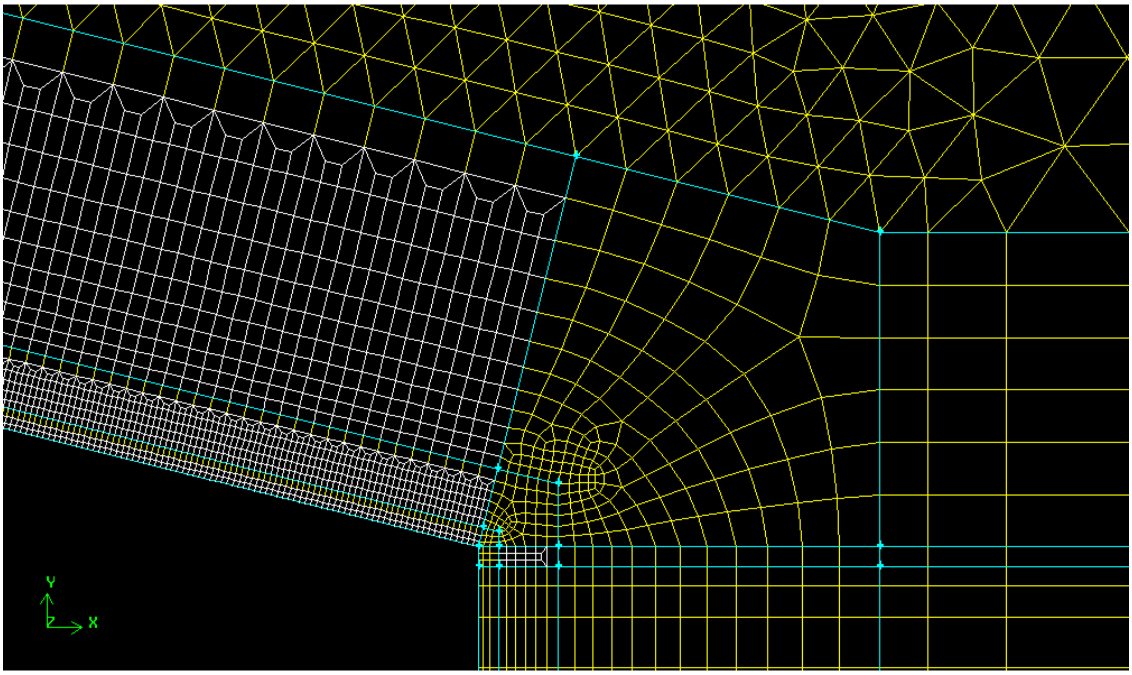

Figure 5.11. Grid quality at roof canyon intersection point

5.2.2. Validation of CFD Model Simulations

Validation means systematically comparing CFD results with experiments to assess the performance of the physical modeling choices. Validation typically focuses on certain models and/or certain applications (e.g. performance of the k-ε model in predicting wind flow around buildings). The validity of turbulence models' choice for different applications is typically assessed by model validation as well. (Blocken & Carmeliet, 2006, 2009)

According to examined several cavity studies[4] reported in literature, wind tunnel experiments are available for testing the CFD model structures' behavior better with the visualized airflow material. Before defining the simulations in this study, the validity of the model is searched in the related literature. In the examined studies, there are only a few (Xie) questioning pitched roofed urban cases, where roof slope is 45˚. Alaçatı, Kemalpaşa Street urban case is closer in airflow relation to flat roofed cavity models with regards to. The wind tunnel experiment study of Kovar-Panskus, which tests

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[4] Huang, Jiang, Kovar-Panskus, Xiaomin, (both numeric calculation studies and wind-tunnel studies) etc.

different ratio canyon geometries, is the most suitable study for validation (already done by Tablada, 2006).

The study of Abel Tablada de la Torre's comparative validation [5], which compares Kovar-Panskus et al. (2002) wind tunnel experiment study with CFD modeling (by CHENSI program) of similar cavities is concerned for simulations. In Kovar-Panskus wind tunnel experiment, various cavity ratios (W/H= 0.3, 0.5, 0.7, 1.0, 1.0, 2.0) are modeled and experimented in a wind tunnel, where airflow rates and behavior are tested according to changing cavity ratio. For comparison Tablada modeled similar cases with CFD modeling and compares the outcomes by line/rake studies with tunnel experiment data. In this validation study, mesh structure (quadrilateral, triangular), 2D-3D model behavior, solver choice (RANS/Realizable k-ε model, first order/second order upwind, enhanced/non-equilibrium wall treatment) are questioned by comparisons.

The structure of the urban study model and cavity model in this thesis are also individually designed with the same testing techniques and grid sensitivity analysis is done for accuracy as described in previous section. Cavity studies aimed to provide data concerning airflow conditions in urban canyon geometries, where airflow for indoors is maintained.

Main decisions about cavity model taken after this validation can be stated as follows:

- Quadrilateral mesh gives solution closer to experiment studies. When these validation analysis of experiment and wind tunnel experiment is done, the secondary recirculation flow in the canyon (W/H= 0.7) cannot be predicted with triangular mesh (See figure 5.12). By using a structured mesh closer results with the wind tunnel experiment can be sustained. Importance of grid quality must not be neglected for further simulation studies. Yet, flow in the canyon (W/H= 1.0) give good results with both quadrilateral and triangular meshing.

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[5] For detailed information see section 5.3 in *Shape of Residential Buildings in Old Havana* named thesis, also Building and Environment

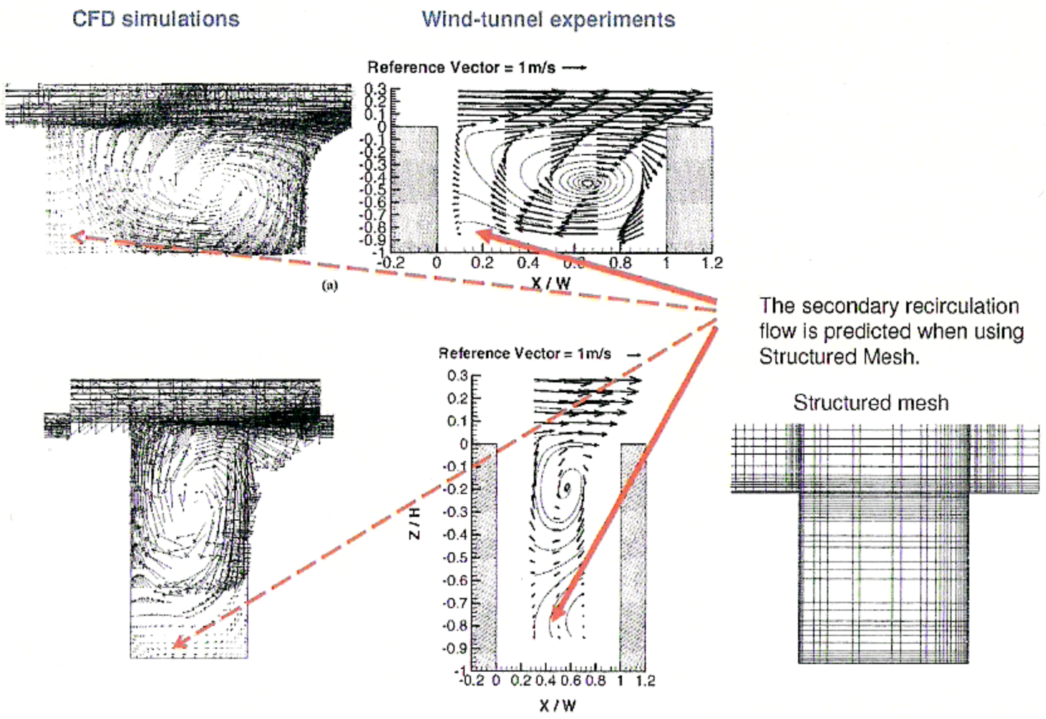

Figure 5.12. Comparison of Kovar-Panskus and CFD modellingwith structued mesh by Tablada (Source: Tablada in urban Physics Lecture of Carmeliet in KUL, 2007)

- According to simulation validation studies in guideline study, the results of the 3D simulation indicate that there is a very good agreement between the values of U in the 2D and 3D simulations having R^2 equal to 0.999 for all cavity (canyon) points. Simulations in this study will be simulated by 2D CFD models and simulations[6].
- RANS k-ε model with second order upwind and non-equilibrium wall treatment is the chosen as model after comparisons of different models worked in reference study (Tablada, 2006). However, Realizable k-ε model give even better solutions and will be preferred for this study after comparing with other solvers (is tested and used for this study.

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[6] With simple geometric model option and horizontal diameter calculations, these simulations are realistic, accurate, thus trustable.

5.2.2.1. Validation of CFD Model Simulations with Experiments

Validation of CFD model was planned to be done by comparisons with measurements conducted at the site. This section reports the results from comparison, however because of limitations in the experiment, only at certain points this comparison can be made and behavior of airflow (not possible to show by limited measured data) cannot be compared.

Before explaining comparisons, it should be mentioned that “validation can only be successful if the basic guidelines for CFD simulation are carefully adhered to, which means high quality experimental data is used for comparison”(Carmeliet, 2007, lecture notes).

Validation requires carefully selected and complete experimental data such as:

- Wind speed and turbulence profiles and specification of where they were obtained (approach flow versus incident flow)
- Description of the measurement equipment (hot-wire measurements in regions of high turbulence intensity Iu> 30% are not suitable for model validation)
- Detailed description of building geometry and surroundings
- Measurements around model at locations of interest (Carmeliet, 2007)

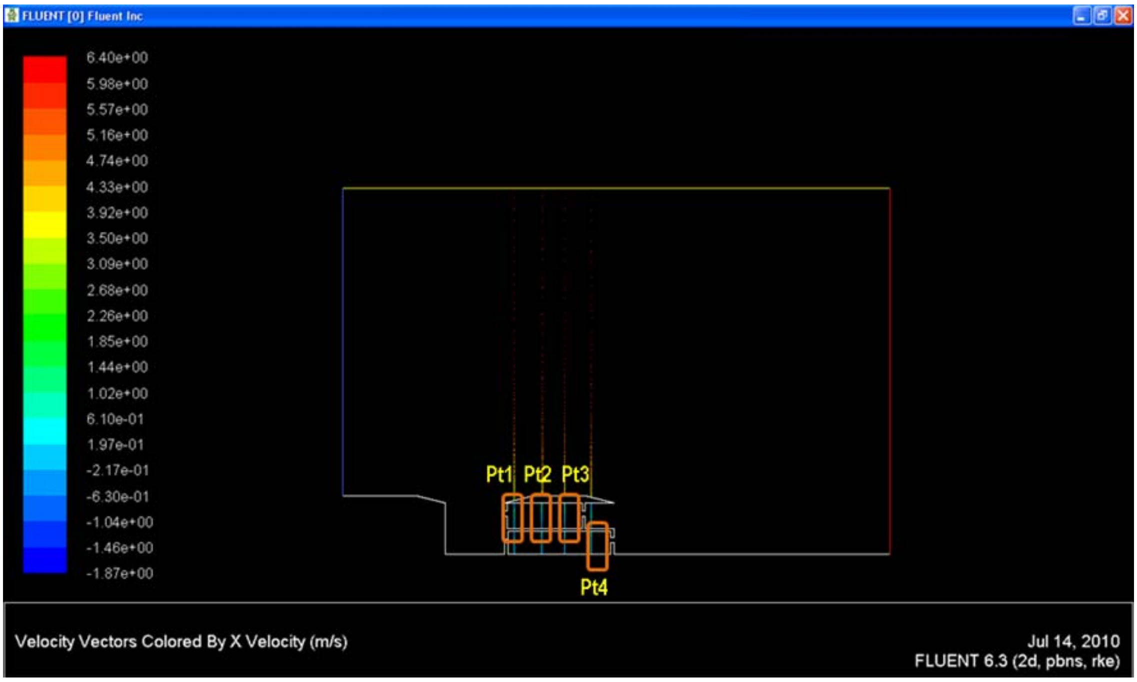

Figure 5.13. Points of comparison (Measured points of case study-chapter4-)

Measured points are as given in figure 5.13. Comparative lines are drawn on fluent graphic on the measurement points in order to make comparative analysis with the previous data.

The results of the comparison of second floor values of the experiment given in chapter 4 and simulations are done by line/rake velocity (U value) comparisons (see figure 5.19 for drawn rakes and lines), which are summarized in the following table 5.2.

Table 5.2. Comparison of airflow values (CFD simulation & experiment) at measured points

CROSS VENTILATED	**Height (m)** 1st floor	**Pt1 airflow (m/s)**	**Pt2 airflow (m/s)**	**Pt3 airflow (m/s)**	**Height (m)** Groundfloor	**Pt4_downstairs airflow(m/s)**
2D simulation	-2.7494	0.67193	0.0230655	0.37213267	-6.7435	0.469059667
experiment	-2.75 (1.25m)	0.939583	---	0.5097222	-6.75 (1.25m)	0.416541
comparison	-2.75 (1.25m)	**+0.27**	---	**+0.12**	-6.75 (1.25m)	**-0.05**

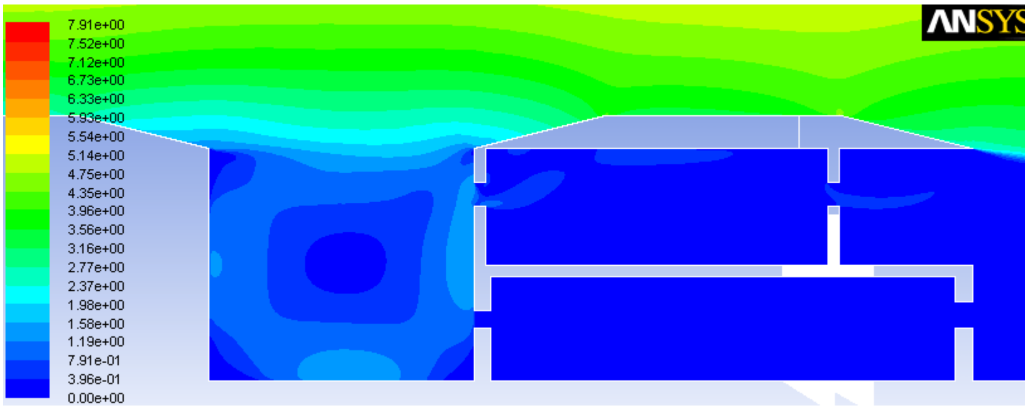

Figure 5.14. Airflow Modeling of Measured House I (cross ventilation)

According to analysis with lines at measured points airflow at point 1 have the highest potential airflow rate. Airflow enters from point 1 on second floor with a 0.67 m/ sec value, diminishes at point 2 (mid-sofa) to the rate of 0.02 m/sec level and comparison is not possible at point 2. At point 3 there’s an airflow of 0.37 m/sec, which is caused by the wind circulation (recirculation vortex in downstream part) at the outer sofa, where staircase reaches from the garden. Point 4 is the comparison from ground floor level (interior only in ground floor), where indoor space airflow rate is measured as 0.42 m/sec again entering from the openings at the downstream part of the model. Other points in ground floor are not compared here because they are at a very low level and cannot be compared with measured low value data.

According to these results, there's a deviation of 10 to 30 percent. This deviation can be caused by inability of using hot wire anemometers, thus the turbulence level could not been measured. Measurement data is not available for accurate comparison. It is analyzed to be sure if measurements and CFD simulations show similar airflow pattern. The results show that they are close and trustable to express.

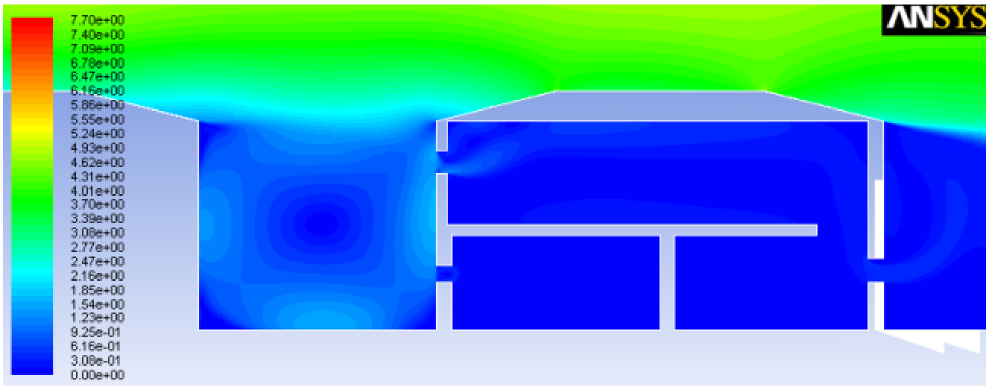

Figure 5.15. Airflow Modelling of Measured House II (single-sided ventilation)

5.3. Simulation Model Definition of CFD studies

Standard and Realizable models[7] are simulated for both enhanced wall treatment and equilibrium wall functions by both first order and second order discretization schemes. Steady-state conditions are simulated. Thermal effects are not considered in

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[7] CFD and turbulence modelling: Realizable and the k-e turbulence model is used in the simulations. This combination is the most widely used and validated solver. Furthermore, the k-e turbulence model is the "simplest turbulence model for which only initial and/or boundary conditions need to be supplied" (Versteeg, H.K., Malalasekera, W., 2) .
"The k-e turbulence model has several advantages. It has an easy implementation, it has a low computational cost associated with the computation of the turbulent viscosity and it can provide reasonably good results for many flows. However, the k-e turbulence model cannot accurately predict airflow around complex building forms." (k is the turbulent kinetic energy, it is a measure of the energy associated with the turbulent fluctuations in the flow, E is the dissipation and it is caused by the work done by the smallest eddies in the flow against viscous stress. in Blocken, B., "wind-driven rain on buildings- measurements, numerical modelling and applications.", 2004, p103.)

the following simulations. Realizable, enhanced and second order upwind model results are used for final results given for this study

Table 5.3. Models used for cases

Cases	Type of turbulence	Type of wall function	Discretisation scheme
1	Standard	Non Equilibrium	1st Order
2			2nd Order
3		Enhanced	1st Order
4			2nd Order
5	Realizable	Non Equilibrium	1st Order
6			2nd Order
7		Enhanced	1st Order
8			2nd Order

5.4. Final Results of CFD Simulations

In between various study models, model group given in figures below are the final airflow models. Boundary condition[8] is 7.8 m/sec (50 m level) as the average wind blow in the period of measurements (3.5 m/sec average at roof level measurements of wind speed, see Chapter 4.3) from measurements done at the site.

5.4.1. Final Results of Urban Canyon Study

Limitations of the model can be defined as simplifications that have to be made when 2D models are constructed. This is not easy since it still has to be realistic. Also in the previous models, simplifications had to be made. Sometimes, different details are modeled and reworked for obtaining better final results.

For urban canyon study different sections of the urban site (Kemalpaşa Street canyon) in north-south direction are modeled. Main purpose of this study was to refine the boundary conditions (wind speed reaching the canyon). As shown with mesh numbers in Figure 5.7, the 2D modeled sections are becoming smaller and more detailed (pitched roofs are added in smaller section model). The simulations of these sections are shown through Figures 5.16-5.18 and will be explained respectively.

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[8] See Appendix A for final boundary condition calculations.

In the largest urban model (See Figure 5.16), the wind entering the site decreases (obstructed) with urban geometries. At entry of 8m height[9] the wind speed is 3.8 m/sec level and its value does not change at the canyon top levels (3.4 m/sec at 8-10m height over ground 0&-2m in simulations). While it reaches the canyon of interest (Kemalpaşa Street) at lower level and in the canyon with obstructed cavity behavior, the wind speed decreases grandly. In back part of the row house, where garden is located, the wind speed decreases as in an open ground (rural site). Compact urban geometry increases wind speed inside the canyon, yet it must be kept in mind that in such suburban non-dense areas wind speed in rural site is usually higher than urban sites. However, in highly dense city centers, this balance cannot be obtained, especially under high-rise, highly built regions of urban texture, urban wind speed can multiply the wind in rural areas (Allard, 2002, Santamouris, 2000, Carmeliet, 2007).

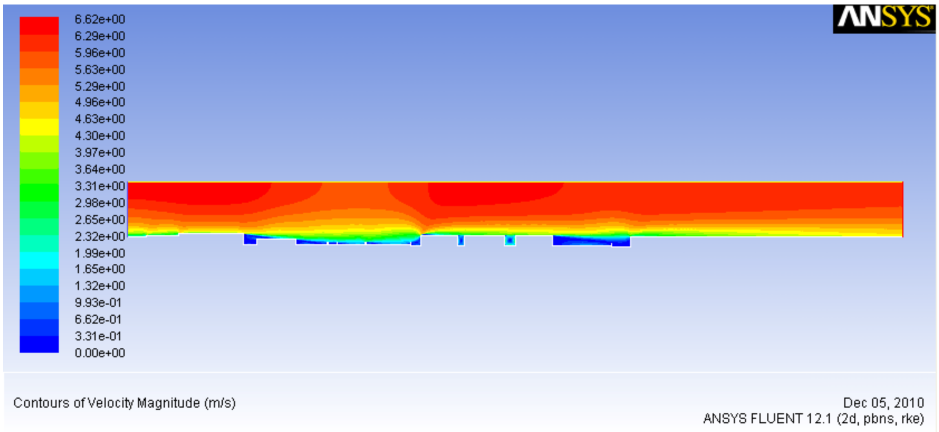

Figure 5.16. Airflow Model of Urban 2D Section Model of Kemalpaşa Street

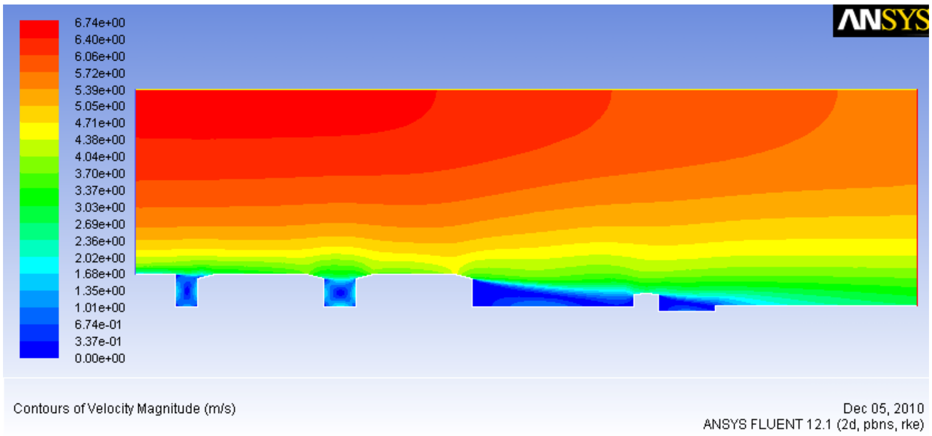

Figure 5.17. Airflow Model of Smaller Urban Model of Kemalpaşa Street

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[9] 0 m level according to simulation technique, thus all street canyons are considered as cavities

In smaller sections, where pitched roof is included in model (Figure 5.17 & 5.18), pitched roof decreases the wind speed over the canyon slightly. In 4-6 m above the canyon, the wind speed decreases from 4.4 to 3.7 m/sec level.

Inside the canyon, character of the canyon vortex (symmetric circular one vortex; only at downstream edge where pitched roof corner intersects the canyon) do not changed by the effect of pitched roof as seen.

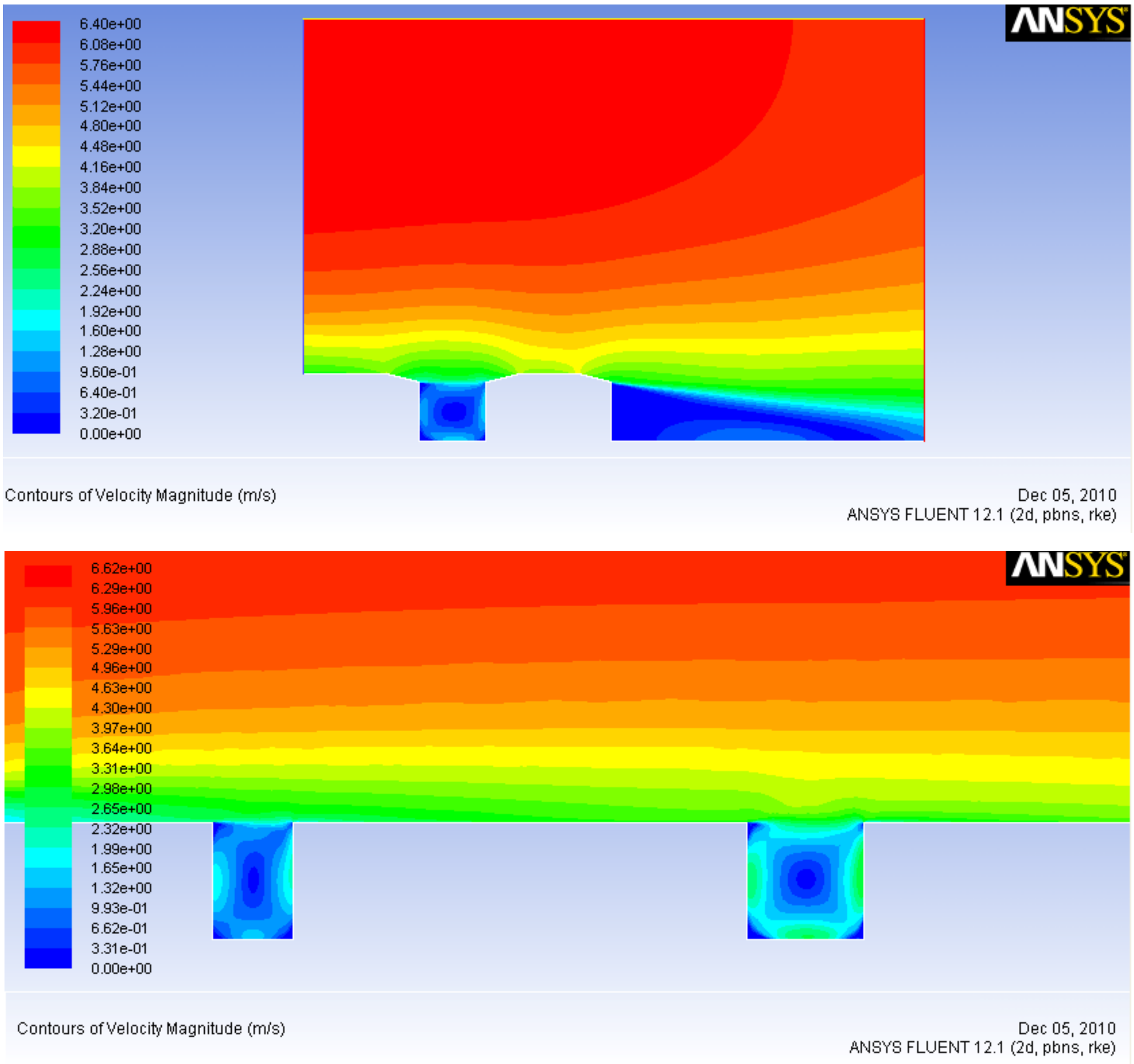

Figure 5.18. Comparison of Kemalpaşa Street Canyon and same Part from Bigger Urban Model

The multi section analysis sustained an adjustment of 0.5-0.6 m/sec in canyon and especially in downstream part where the house openings of interest are located (Figure 5.18). Wind speeds inside the canyon show same flow behavior (one main vortex in centre) with a decrease in smaller refine boundary conditioned section.

5.4.2. Results of Sofa/Staircase Alternative Simulations

For validation of CFD model of the case with experimental study (see section 5.2.2.1), linear sofa space is modeled for both cross-ventilated house (Measured house I) and single-sided ventilated house (Measured house II).

For further analysis, the sofa (circulation hall/space) and staircase relation is investigated. As mentioned previously (in section 3.1.3.3) traditional houses in Alaçatı have variations, with outside or inside staircases. As a moderate climate example, staircase can be used outside of the house, especially when trade function or warehouse need is implemented on ground floors. The effect of taking the staircase out should be simulated for single-sided ventilated house (measured house II) and vice versa for cross-ventilated house (measured house I). How these alternative models are conducted can be visualized in Figure 5.20, whereas Figure 5.19 are the original measured cases. The openings of the original cases are not changed (as they were previously calculated with hydraulic diameter) in order to only observe the effect of staircase change.

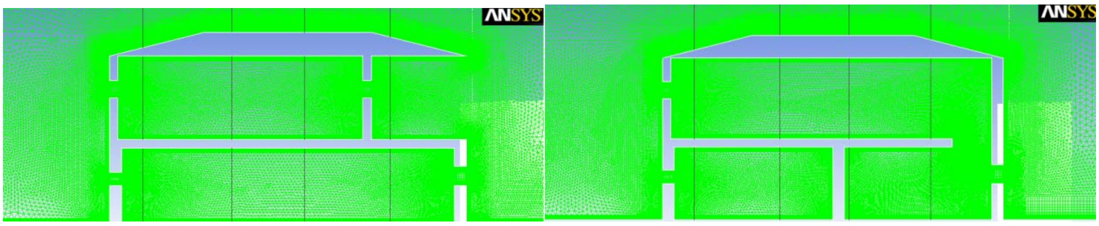

Figure 5.19. Original Houses (Measured House I & Measured House II with 4 measured points)

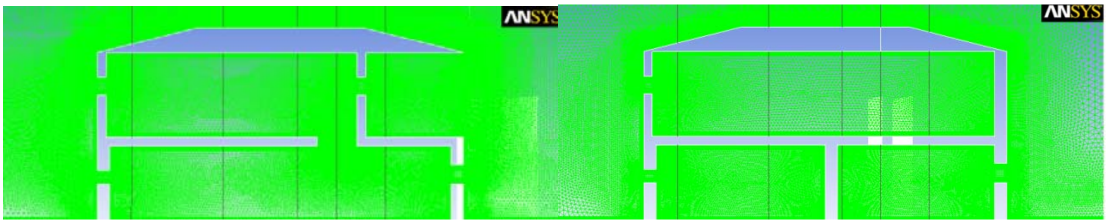

Figure 5.20. Houses where staircase placement changed (Measured House I & Measured House II)

After further simulations conducted, grid sensitivity analysis is finalized. Then airflow characteristics are analyzed by velocity (U m/sec) contours. As seen in figure 5.21 and 5.22, the airflow characteristics through sofa space do not change much with staircase change in cross-ventilated example while in single-sided ventilated sofa airspeed increases. Around the stairwell, airflow increases meaningfully.

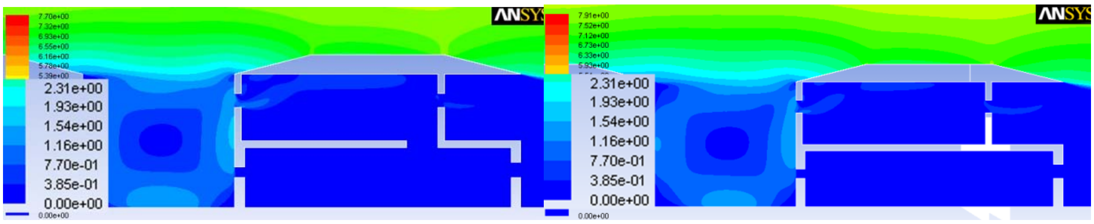

Figure 5.21. Houses where staircase placement changed –for Comparison-(Measured House I)

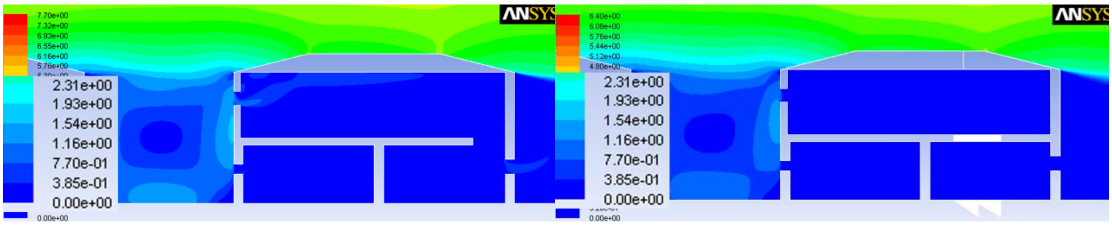

Figure 5.22. Houses where staircase placement changed –for Comparison-(Measured House II)

For comparative analysis, lines are drawn on alternative house examples at points where measurement comparisons are made (See figure 5.20 for comparative lines). According to the analysis of four points (See figure 5.23-5.24 and 5.25-5.26), the airflow increase with staircase addition can be seen specifically around inlet and outlet openings at these line studies. Yet, these points are not critical points for staircase analysis, so extra lines are drawn at staircase locations (See Figure 5.19 and 5.20). Further lines drawn to understand the behavior at the staircase are line for point 5 is drawn for measured house I, line for point 6 is drawn for measured house II (Values seen graphs in Figures 5.23-5.24, 5.25-5.26).

As seen in figure 5.23, the airflow value at the 2nd floor (ranges between 0.7-0.06 m/sec) is higher than the airflow value at the ground floor (changes between 0.01-0.3 m/sec). In ground floor, it only reaches 0.3 m/sec. When staircase is added to design as seen in figure 5.24 airflow at second floor increases (ranges between 0.9-0.05 m/sec), however as total sofa airflow analysis in ground floor shows, there is not a big change in airflow pattern for ground floor.

According to figure 5.23 and 5.24, in second floor the most effective ventilation happens in point 1 (reaching 0.7 m/sec, 0.9 respectively). The second effective point is point 4 (reaching 0.48 m/sec level, 0.42 m/sec respectively), it is followed by point 2 (reaching 0.45 m/sec level, 0.55 m/sec respectively closer point to inlet) and least is seen at point 3 (reaching 0.37 m/sec, 0.44 m/sec respectively closer point to outlet) at 2nd floor's sofa space. Through all points measured, the most effective ventilation always occurs around openings height (1.25-1.30m, -2.75 in graphs), then at roof level (8m, ±0 in graphs) at outlet part (where alternative staircase is placed).

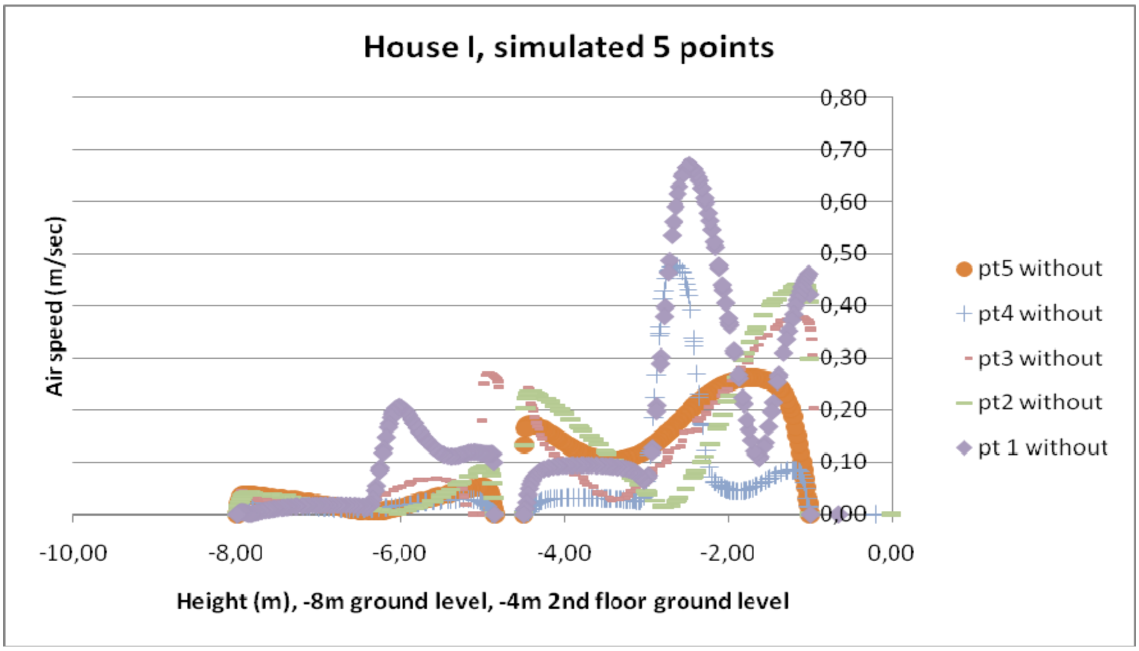

Figure 5.23. Airflow Representation of other Alternative for Measured House I (without staircase)

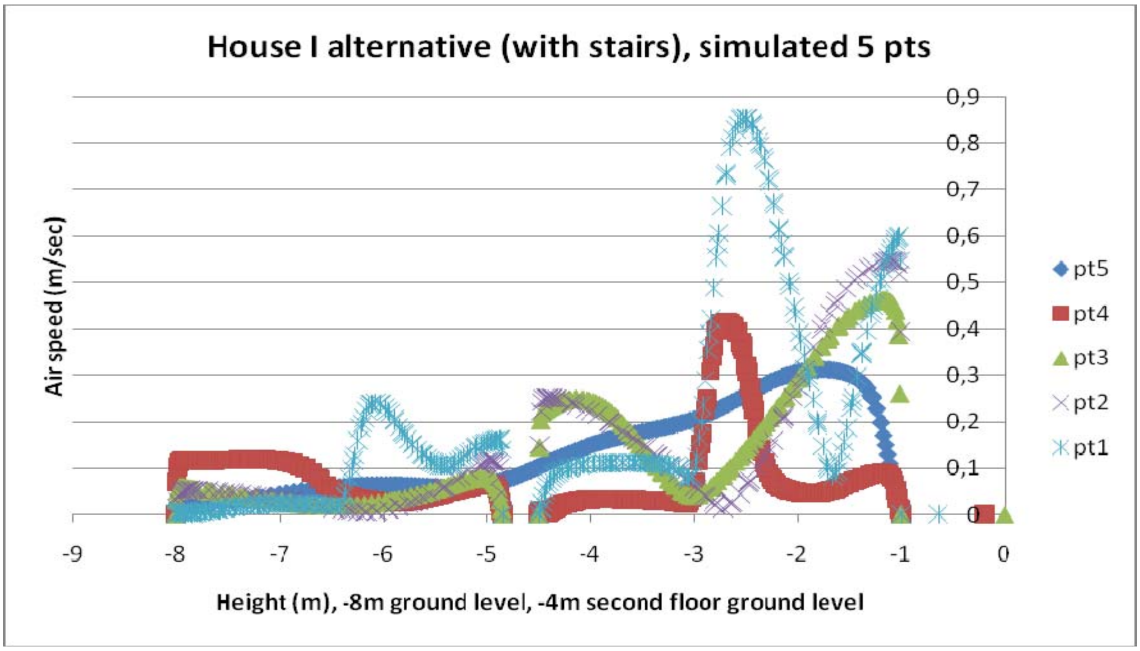

Figure 5.24. Airflow Representation of Measured House I (with staircase)

These analyses for top floor (2nd floor) give us a more detailed understanding of airflow behavior that increases at inlet and outlet of the house openings and diminishes at midpoints of the sofa (6m distant from openings; point 2 and point 3). Also, the airflow increases close to upper parts of the sofa, whereas when staircase is added to design, this effect is augmented as well (See figure 5.21 &5.22 for visual details).

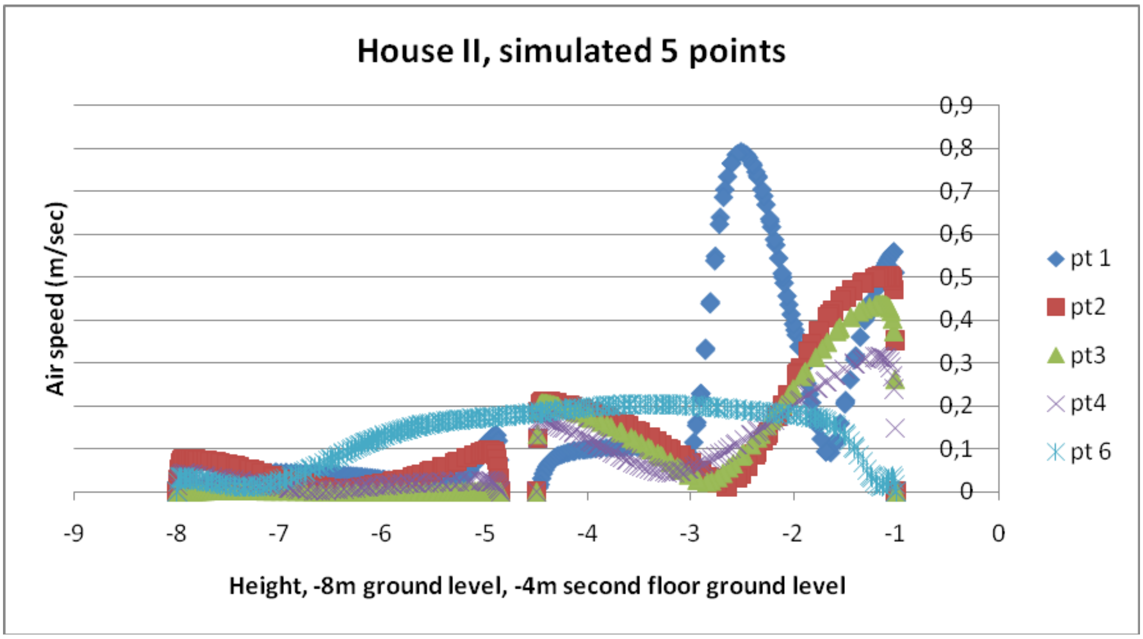

Figure 5.25. Airflow Representation of other Alternative for Measured House II (with staircase)

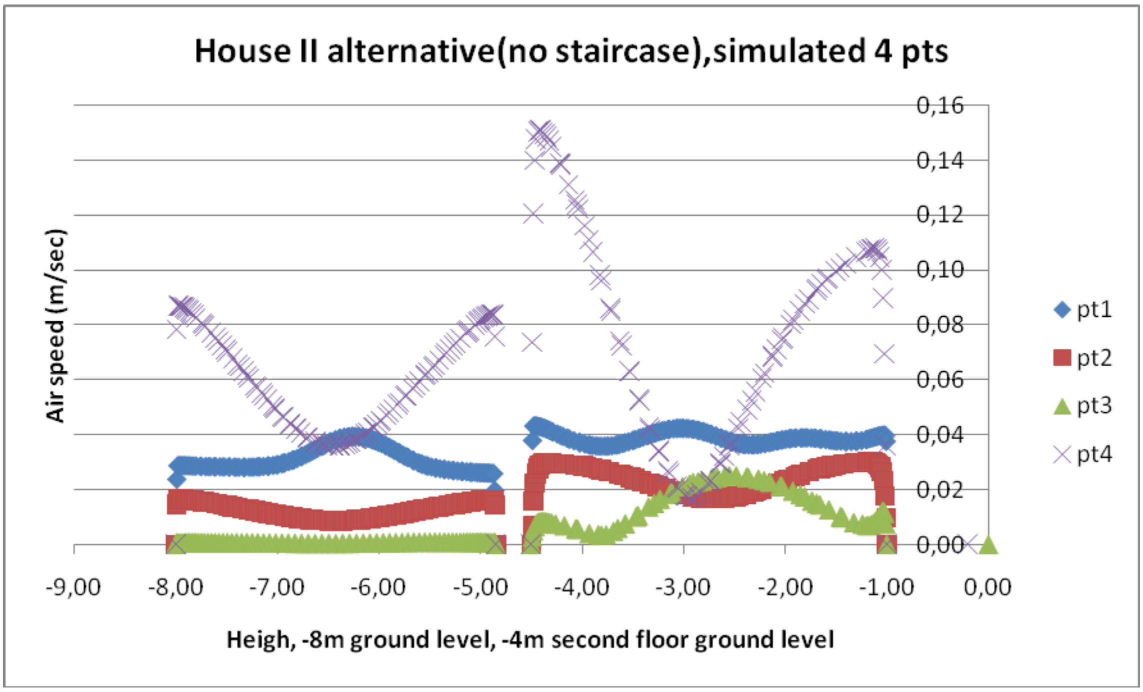

Figure 5.26. Airflow Rate Representation of other Measured House II (with staircase)

In single-sided ventilated 2nd floor sofa space of measured house II, where natural ventilation reaches 0.78 m/sec level at peak points, average ventilation potential is slightly lower (0.15 m/sec lower) than cross-ventilated measured sofa space (see figure 5.25). The airflow rates are very low at most 0.15 as 25% of airflow rates of cross-ventilated one when the existing staircase is removed (see figure 5.26). An interesting outcome from this graph is that the highest ventilation potential is at outlet part whereas natural ventilation inlet point is point 1.

In figure 5.25, it is seen that airflow value at 2nd floor (ranges between 0.78-0.01 m/sec) is higher than ground floor's (changes between 0.2-0 m/sec). When staircase is taken out from the design as seen in figure 5.26, airflow at second floor decreases sharply (0-0.16 m/sec). As total sofa airflow analysis in ground floor, there's not a big change whereas ventilation potential is limited, yet in second floor airflow ventilation potential and behavior is similar to the behavior of cross-ventilated sofa space (see combination of 5.23, 5.24 and 5.25).

House II have a much higher ventilation potential when compared to the house with no staircase alternative (see figure 5.25) According to this analysis, the airflow rate close to cross-ventilated sofa is depending on ventilation potential caused by the staircase and opening at the ground floor in relation to this stairwell. The most efficient ventilation is at point 1 for both floors, only in House II with no stairs alternative, point 4 shows slightly higher airflow rate than point 1.

To understand what really happens at the stairwell points, an extra point (point 5, vertical line behavior) is drawn on simulation representation of House I and an extra point (point 6) drawn for House II gap (see figure 5.20). Comparisons in these vertical lines are represented in following graphs (see figure 5.27 & 5.28).

According to graph 5.27, where House I do not have a stairwell in sofa space, the alternative with this gap shows higher ventilation potential (reaches 0.5 m/sec) at opening zone. The airspeed makes a peak around the ventilation opening. Effect of stairwell is smaller compared to opening (even if it is an outlet one) at this case. In conclusion, the staircase increases ventilation potential throughout sofa, at outlet region no big increase at the 2nd floor plan seen, air moves down towards outlet opening.

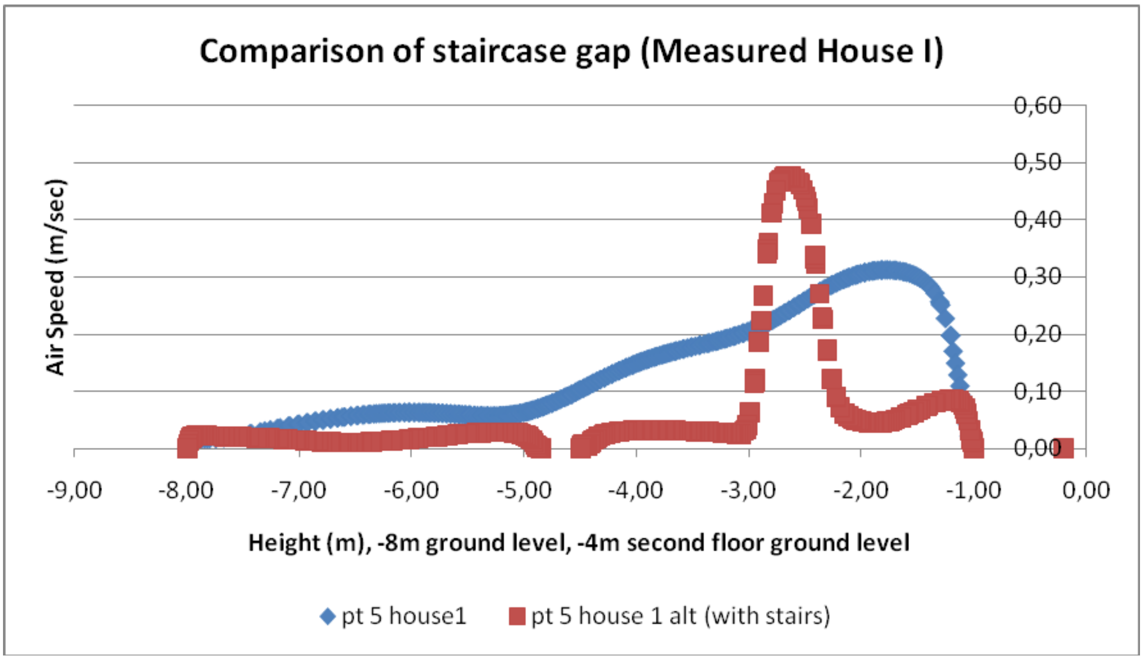

Figure 5.27. Airflow Representation of Stairwell points for Measured House I (with& without staircase)

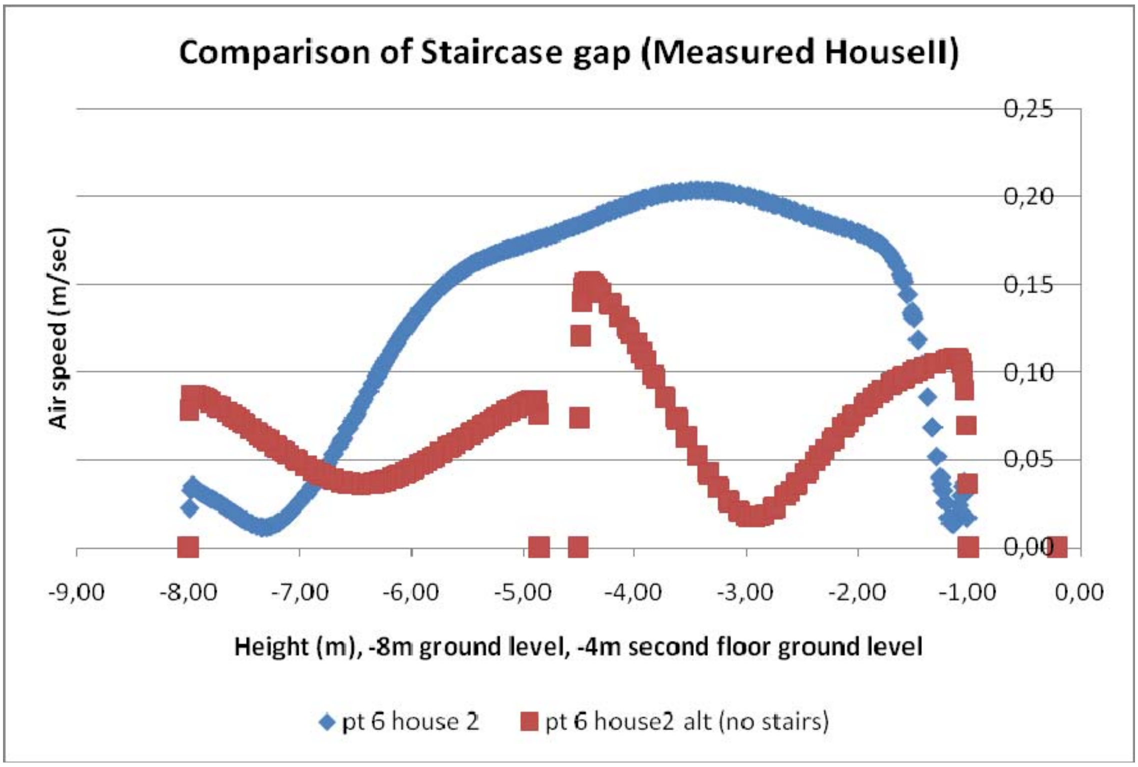

Figure 5.28. Airflow Representation of Stairwell points for Measured House II (with& without staircase)

According to Figure 5.28, where House II has a stairwell in sofa space, the alternative without this gap shows lower ventilation potential (reaches only 0.15 m/sec). The airspeed makes a peak around the roof level in the example where stairwell exist.

Effect of stairwell is at 0.2 m/sec increasing airflow close to the roof level. Natural ventilation potential in single-sided ventilated sofa spaces can be augmented by placing stairwell, where an opening reinforces related to this gap.

These analyses show us that stairwell increases the airflow at spaces around when there are openings working with. House II has an opening at the ground floor at the edge of the stairwell to interact with, thus ventilation increases at the roof level. Only under the opening level, airflow decreases at this gap analysis (figure 5.27).

Cross-ventilated sofa shows better ventilation average with stairwell than the one with single-sided ventilation staircase example. Finally, the staircase with single-sided ventilation shows similar behavior with cross-ventilated sofa space with no stairwell, thus airflow only reacts through sofa space along the floor.

5.5. Results of 2D CFD Analysis and Comparative Evaluations

Verification of the CFD canyon model is performed with grid sensitivity analysis. R^2 obtained is 0.9886, when mesh (grid) is enlarged or coarsened with a constant of $\sqrt{2}$.

Validation of the CFD model with experiment data proves that there is a deviation of 10 to 30 percent between comparisons. This deviation can be caused by limits in measurements (lack of instruments). Sufficient measurement data is not available for accurate comparison. The analysis investigates whether the measurements and CFD simulations show similar airflow patterns. The results show that they are similar. The results from the wind tunnel experiment of Kovar-Panskus (2002) also support this finding.

According to airflow simulations (CFD), under average wind flow (11:00-18:00, august 2008), it is possible to list the following findings:

- According to simulations of site section models at different scale:
    - There are obstructions in the largest urban model of Kemalpaşa Street.
    - Wind speed decreases with urban geometry in all CFD simulations.
    - Canyon size W/H=1.0 have one central vortex, where wind speed ranges between 0 to3 m/sec.
    - Pitched roof decreases the wind speed over the canyon slightly.

  - Inside the Kemalpaşa Street canyon character of canyon vortex does not change by pitched roof effect.
  - Multi-section analysis sustained an adjustment of 0.5-0.6 m/sec in canyon wind speed by boundary condition adaptation.
- According to airflow simulations (CFD) of two measured houses:
  - At second floor the most effective ventilation happens in point 1 (reaching 0.7 m/sec). Point 4 is the second effective one (reaching 0.5 m/sec level), which is followed by point 2 (reaching 0.45 m/sec level) and the least effective ventilation is observed at point 3 (reaching 0.37 m/sec).
  - Through all points measured, the most effective ventilation always occurs around openings' height (1.25-1.30m).
  - Analysis for 2nd floor, gives us a more detailed understanding of airflow behavior, where it is received from inlet moved from upper part of the room through outlet of the house openings and diminishes at midpoint of the sofa at human scale level (5m distant from openings; point 2 and point 3)
  - In single-sided ventilated spaces the airflow rates are very low (at most 0.15 m/sec level, as 25% of airflow rates at second floor), if no other opening or pressure changing detail helps the design.
  - Airflow rates are highest at the level of opening heights in single-sided ventilated sofa too.
  - Natural ventilation potential is very low and limited in single-sided ventilated sofa space, thus thermal comfort level can be critical according to CFD analysis. However in House II, single-sided ventilation is supported by stairwell and the opening at the ground floor outlet wall.
  - Suction caused by staircase is higher in single-sided ventilated opening side, so ventilation potential at point 1 (inlet) is lower than the ventilation potential at stairwell point 5 (outlet).
- According to airflow simulations (CFD) of two alternative houses where sofa/staircase relations were changed:
  - Stairwell increases the airflow at the nearby spaces even if there are no openings working with.
  - Cross-ventilated sofa shows better ventilation with stairwell compared to single-sided ventilated sofa with stairwell.
  - Variation of openings can affect these results

CHAPTER 6

CONCLUSION

6.1. Summary of the Study

The steps of this study can be listed as follows: (1) understanding climate considerations in the design of traditional settings; (2) determination of a traditional setting for case study (where the impact of natural ventilation could be questioned); (3) measurements conducted in and out of the case study houses (sofas and roof); (4) definition of the thermal comfort zone of the site by adaptive approach; (5) examination of thermal comfort level inside the houses at time of measurements (hot summer period, August 2008); (6) conducting CFD simulations after verifications and grid sensitivity analysis; (7) validation of CFD simulations ; (8) simulation of sofa/staircase opening alternatives in single-sided and cross-ventilated houses' sofas.

At the beginning of this study, an in-depth literature review on the impact of climatic considerations in the formation of traditional settings was conducted. Then, the site for study is chosen among some possible traditional settings. This decision is ensured by the natural ventilation (NV) potential within and around the setting.

After the traditional setting and the specific houses within which measurements were going to be conducted was determined (i.e., area of interest and two similar yet different NV behaving houses), measurements at the site are conducted in two parts (indoor and outdoor measurements). It was necessary to define the thermal comfort zone for selected site to examine the comfort level in these houses (in reference to Izmir Adaptive Thermal Comfort Chart). Then, thermal comfort status in different sofa alternatives was analyzed.

For CFD (Computational Fluid Dynamics) studies, the studied houses were modelled (by Gambit 2.4.6) and simulated (by Fluent 6.3.26). Before starting the simulations, verification of the model was sustained by literature reviews and by grid sensitivity analysis. Finally, these simulations were used for validation of the measurements previously conducted.

After the on-site measurements and CFD simulations, further simulations were conducted for alternative house schemes for improving NV potential of house designs in traditional built environments. Sofa/stairwell relation is found worth investigating; hence further combinations of these two were modeled and simulated by CFD.

6.2. Findings and Contributions

6.2.1. Findings

Findings can be grouped in three main parts. First group indicates findings of the measurements conducted at the site (Chapter IV).The second group is about findings gathered from CFD simulations (Chapter V). Finally third group will be defined with comparative evaluation of measurements and CFD simulations (first group and second group of findings will be comprehensively given by comparative analysis).

First group of Findings (Measurements):

- Thermal comfort in indoor sofa spaces of the study is at acceptable limits with 0.5 m/sec ventilation level for both ventilated space examples.
- Outdoor values' (4/5th of critical data) 1/5 th of all data is accessing the comfort limits and velocity of 0.5-1 m/sec needed for tolerable conditions.
    - Cross-ventilated sofa space offers higher indoor airflow rates compared to single-sided ventilated sofa. Especially in deeper parts of single-sided ventilated sofa, airflow rate loses its effectiveness.
    - Cross-ventilated space gives more efficient ventilation and better thermal comfort effect under worse climatic conditions, i.e., under low wind speed. (Indoor values of cross-ventilated sofa space show an exceeding behavior in the half of the critical data. Therefore, with 0.5 m/sec airflow level is needed to cool down this indoor sofa space naturally. 90% of the data of cross-ventilated sofa space sustains thermal comfort.)
    - Single-sided ventilation sustains thermal comfort half of the critical period of measurements (1/4th of indoor values of single-sided ventilated sofa space exceed the limits of critical defined range). Therefore, 0.5 m/sec airflow level is needed to cool down this indoor sofa space naturally. Yet, 82% of the data of cross-ventilated sofa space sustains thermal comfort.)
    - Behavior of airflow within the sofa space cannot be maintained with single-sided ventilation measurements (limited measurement equipment).

Second group of Findings (CFD simulation analysis):

- •According to different site section models at different scale:
  - In the largest urban model of Kemalpaşa Street, obstructions at the urban site are observed.
  - Wind speed decreases with urban geometry in all CFD simulations.
  - Canyon size W/H=1.0 have one central vortex, where wind speed range between 0 to3 m/sec.
  - Pitched roof decreases the wind speed over the canyon slightly.
  - Inside the Kemalpaşa Street canyon character of canyon vortex does not change by pitched roof effect.
  - Multi-section analysis sustains an adjustment of 0.5-0.6 m/sec in canyon wind speed by boundary condition adaptation.
- According to airflow simulations (CFD) of two measured houses:
  - At second floor, the most effective ventilation happens in point 1 (reaching 0.7 m/sec). The second most effective is point 4 (reaching 0.5 m/sec level), which is followed by point 2 (reaching 0.45 m/sec level) and the least effective ventilation occurs at point 3 (reaching 0.37 m/sec).
  - Through all points measured, the most effective ventilation always occurs around openings height (1.25-1.30m).
  - Analysis of 2nd floor gives us a more detailed understanding of airflow behavior, where it is received from inlet moved from upper part of the room through outlet of the house openings and diminishes at midpoints of the sofa at human scale level (5m distant from openings; point 2 and point 3).
  - In single-sided ventilated spaces the airflow rates are very low at most 0.15 m/sec as 25% of airflow rates at second floor if no other opening or pressure changing detail helps the design.
  - Airflow rates are highest at level of opening heights in single-sided ventilated sofa too.
  - Natural ventilation (NV) potential is very low and limited in single-sided ventilated sofa space, thus thermal comfort level can be critical according to CFD analysis. However in case of House II, single-sided ventilation is supported by stairwell and opening of it on the ground floor outlet wall.

    - Suction caused by staircase is higher in single-sided ventilated opening side, so ventilation potential at point 1 (inlet) is lower than ventilation potential at stairwell point (outlet).
- According to airflow simulations (CFD) of two alternative houses where sofa/staircase relations were changed:
    - Stairwell increases the airflow at nearby spaces even if there are no openings working with.
    - Cross-ventilated sofa with stairwell shows better ventilation compared to single-sided ventilated sofa with stairwell.
    - Variation of openings can affect these results.
    - Thermal comfort in indoor sofa spaces of the study is at acceptable limits with 0.5 m/sec ventilation level for both ventilated space examples. However, cross-ventilated sofa space offers higher indoor airflow rates compared to single-sided ventilated sofa. Especially in deeper parts of the single-sided ventilated sofa the airflow rate loses its effectiveness. Thus, cross-ventilated space gives more efficient ventilation and better thermal comfort effect under worse conditions.

Third group of Findings (comparative evaluation of measurements and CFD simulations):

- According to simulations, the ventilation potential of the single-sided ventilated sofa is lower compared to comparative evaluations conducted (average airspeed is 0.5 m/sec in cross ventilation; average airspeed is 0.1 m/sec in single-sided ventilation). Therefore, thermal comfort level in single-sided ventilated sofa cannot be maintained in critical hot days (as proved both in measurements and simulations).
- Stairwell increases airflow rate around it if there are opening nearby. Both in single-sided and cross ventilation cases, the increase in air flow rate is been analyzed by simulations.
- Variation of openings can affect stairwell results and can further been studied. (It is hypothesized that it will increase more if it is placed at the inlet side -upstream part- of the canyon side of the design).
- Pitched roof in low dense urban site do not change urban wind flow behaviour (the single central vortex inside the canyon). It only affects airflow just over the canyon (at pitched part where canyon and open air intersect).

In the light of these findings and with the contributive knowledge of literature and site observations (Chapter 2 & Chapter 3 respectively):

Alaçatı is a traditional settlement shaped according to climatic considerations. The ventilation canyon formed through Kemalpaşa Street enables the row houses to take advantage of ventilation in sofa spaces. If cross-ventilated, these houses can be naturally ventilated by both northern and southern winds. Linear cross-ventilated (inner sofa) sofa organization with staircase is advised for future designs.

Proposed principles for Further Design Decisions (General recommendations for cross ventilation)

1. Ideally row houses should be oriented diagonally with respect to the prevailing winds if not possible at an angle of 22.5-45°. Wind-induced ventilation should be maximized by orienting the longitudinal axis perpendicular to the prevailing summer winds.
2. Naturally ventilated buildings should be narrow. The maximum width that one could expect to have natural ventilation is estimated at 13-14 m. Consequently, buildings that rely on natural ventilation often have an articulated floor plan.
3. Each room should have two, separate supply and exhaust openings. Locate exhaust high above inlet to maximize stack effect. Orient windows across the room and offset from each other to maximize mixing within the room while minimizing the obstructions of airflow within the room.
4. Windows should be operable by the occupants.
5. Differentiate window placement in accordance with the cooling strategy. For occupant cooling purposes, operable openings should be placed at occupant height.
6. Allow adequate internal airflow. Airflow between the rooms of the building is important. When possible, interior doors should be designed to be opened to facilitate whole building ventilation. If privacy is required, ventilation can be provided through high louvers and transoms.
7. Open staircases provide stack ventilation, but observe all fire and smoke precautions for enclosed stairways.

(Santamouris, 2002, Olgyay, 1963, Allard, 1998, Givoni, 2000, 2004)

6.2.2. Contributions

Among various other studies done on traditional built environment, this study differentiates itself with its analytical approach and comprehensive methodology. While many studies only try to observe and define climate relations in traditional settings, this study testes certain assumptions and hypotheses (e.g. cross-ventilated sofa space is thermally comfortable). Furthermore, the comprehensive method (summarized in section 6.1) used in this thesis have the potential to be used in other studies. The method offered in the study contributes to the field of traditional vernacular architecture.

In terms of thermal comfort literature, this study offers a thermal comfort chard for Izmir for the first time. This chart can be used for other cases at the site.

In terms of its contribution to airflow modeling (CFD) in building physics, pitched roof/canyon (W/H=1.0) relation at a low density urban site is analyzed and central one vortex behavior is obtained as flat roof examples in literature.

The sofa (circulation hall) and staircase relation is investigated for the first time. Circulation space, which is used as a living space as well, gives a similar case with hallway studies. Yet this study is unique with its pitched roof low dense configuration.

6.3. Concluding Remarks

In conclusion, the analysis of the effects of climatic considerations on traditional built-environments is possible by using analytical methods. Beyond all findings of this study, this study offers a novel analytical method to investigate the impact of ventilation on thermal comfort.

By this method, 2D variations of different sized canyon section models can be worked by measurements and simulations for urban canyon alternatives' analysis. Various different sofa/room organizations can be combined with different sized canyon models for future urban pre-design decisions. Also, the pressure compression dispersion through indoor and outdoor spaces around the canyon can be retested by a holistic approach, as well.

A set of steps offered give opportunity to test the impact of other architectural featured cases such as: opening variation (position and size) in cross ventilation, different size sofa alternatives in combination with rooms around, additive shutter organizations attached to opening variations, effect of bay windows (cumba or çıkma) as more detailed architectural cases of wind and comfort.

The proposed methodology elicits several analytical research opportunities for other traditional built environment studies. In the light of given methodology, different traditional settlements can be studied in Turkey especially in the windy environments of Aegean region. Also, different architectural features in traditional regions can be studied in combination with opening/ sofa relation for further study options.

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APPENDIX A

ADJUSTMENT OF BOUNDARY CONDITIONS

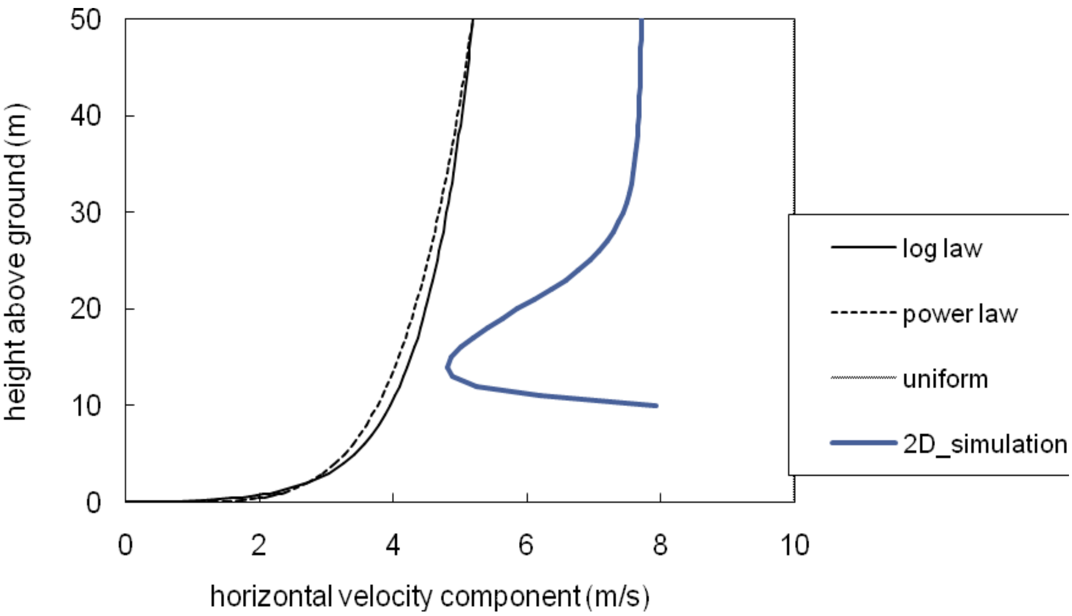
FITTING OP 10 M HOOGTE

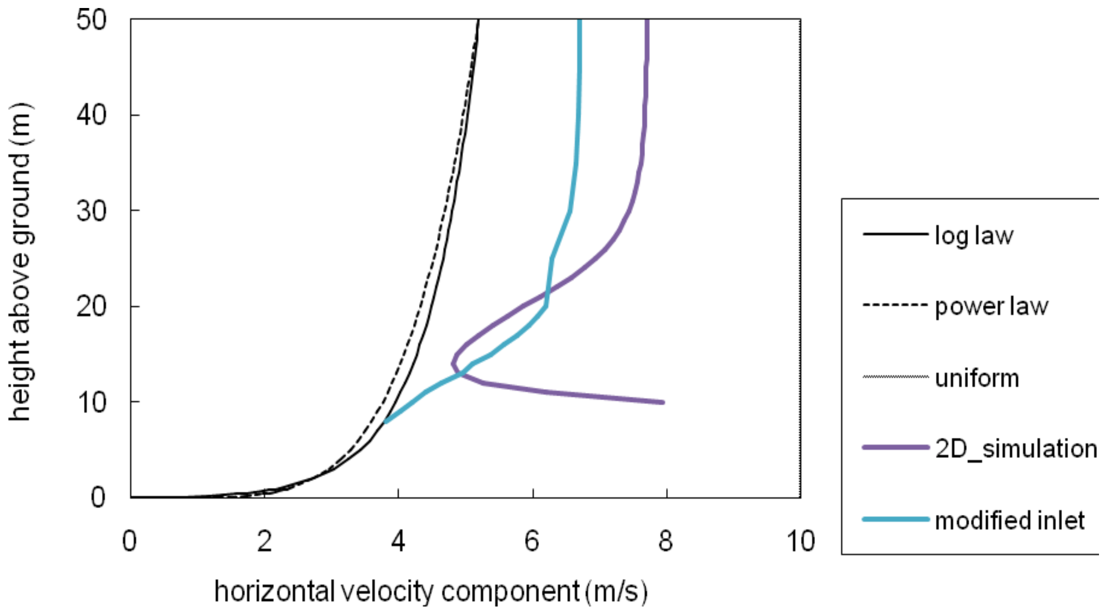
yref = 12 m

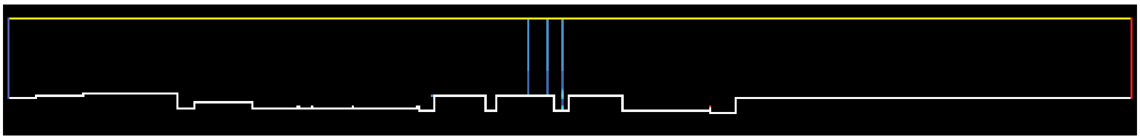
Uref = 3.9 m/s

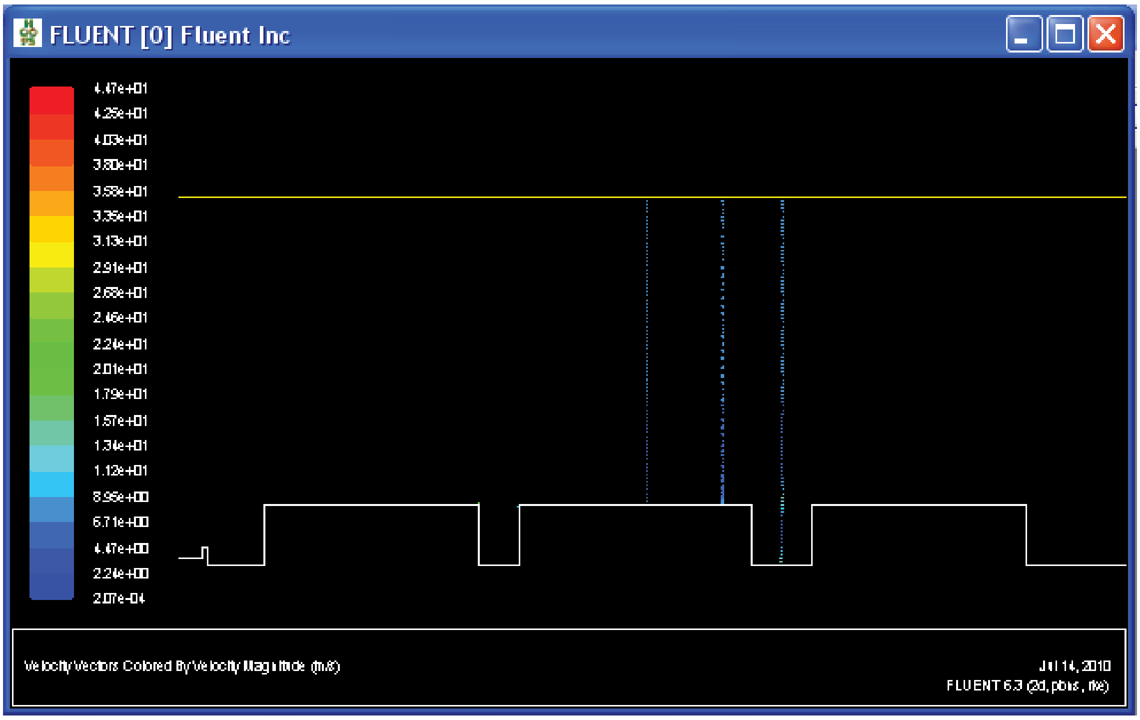
Alfa= 0.2

y0= 0.06 m u* = 0.31 m/s Kappa 0.42









Velocity Vectors Colored By Velocity Magnitude (m/s)

Jul 14, 2010
FLUENT 6.3 (2d, pbns, rke)

VITA

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