Natural Ventilation Strategies for Apartments in Famagusta

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ABSTRACT

Natural ventilation with the aim of achieving desirable indoor air quality has been a part of architectural design since ancient times. Later, development of technology caused replacement of those natural ways by mechanical devices. Discovering air-conditioning by “Willis Carriers”, thermal control was available in all aspects, studies on effects of temperature and humidity on human body got more important and the subject of comfort zone was introduced. However, utilization of mechanical tools faced with some disadvantages including discomfort air flew (for instance air movement caused by air-conditions or coolers bothers in some directions and do not work in some other directions) and undesirable noise which these mechanical machines produce. In order for a building to have that equipment, it needs extra spaces as ducts or channels. Moreover, there are services and energy fees as costs. Because the lifespan of the mechanical equipment is not as long as the lifespan of the buildings, the lifespan of the buildings will be reduced. In addition, those equipment harm the environment. Consumption of energy they cause by using natural sources, creates an issue regarding the protection of the environment. Hence, architects and mechanical engineers reconsidered the utilization of natural ways of cooling, heating and ventilation in buildings in order to reduce the usage of mechanical devices.

Therefore, this study tries to work on the constructions built in recent decade in the city of Famagusta in North Cyprus by focusing on the natural ventilation strategies in hot and humid regions and utilization of them in residential apartments, to specify their problems according to the subject. To reach the aim, the thesis is defined in four chapters. After introduction of the problem, questions, focus, field of study and methodology of the research and also the literature review in chapter one; the natural ventilation strategies and its systems are introduced in chapter two. Chapter three is assigned to the new constructed residential apartments in Famagusta, findings, discussions and suggestions. To extract the characteristics of contemporary residential apartments through their location, section, plan, interior organization, facade specifications and materials, field observation, photography and drawing are techniques which have been used. Disguised and open ended questionnaire technique have been done. Questionnaires have been given to the residents of the chosen sample apartments to see whether they feel comfortable and satisfied with indoor thermal qualities inside their houses or not, specifically ventilation. This questionnaire survey has been done because there were no chance of measuring climatic factors inside the buildings to check whether air qualities inside are in comfort zone or not. Finally, the problems in ventilation of those buildings and methods for utilizing strategies are discussed. Furthermore, chapter four is assigned to conclusion in which it is mentioned that these apartments do not have enough designed natural ventilation strategies and simple architectural design ideas would be helpful to achieve more natural ventilation inside.

Keywords: natural ventilation strategies, residential apartment, Hot-humid climate, Famagusta

ÖZ

Geçmişten beri, kapalı alanlarda iyi hava kalitesi elde etmek için mimaride doğal havalandırma yöntemleri kullanılmıştır. Zaman ve teknolojinin ilerlemesi ile mekanik cihzalar doğal yöntemlerin yerini aldılar. 'Willis Carrier' in havalandırma yöntemlerini bulmasıyla birlikte ısı kontrolu tüm yönleri ile kullanılmaya başlandı. Bu yönde, ısı ve nemin insan vücudu üzerindeki etkisi çalışmalarda ele alınarak rahatlık bölgesi (comfort zone) konu başlığı öne sürüldü. Diğer yandan, havalandırma için kullanılan mekanik aletlerin rahatsız edici hava akışı (soğutucu veya havalandırma sistemleri bazı yönlerde rahatsız edici ve bazı yönlerde etkisiz hava akışı sağladıkları öne sürüldü) ve istenmeyen gürültü gibi bazı dezavantajlarının olduğu kanağatine varıldı. Bu cihazları binada yerleştirmek için fazladan alan ve borular gerekmektedir. Ayrıca ekstra servis ve enerji maliyetlerinin olduğu da gözden kaçmamıştır. Başka bir dezavantaj, mekanik cihazların binaya göre daha az ömürlü olmalarıdır. Ve bu etken, yapının ömrünü düşürmektedir. Başka bir bakış açısından, mekanik havalandırma cihazları doğal enerji kaynaklarını tüketerek çevreye zararlı olduklarının tartışmasına yol açmıştır. Dolayısıyla mimarlar ve mekanik mühendisler yeniden doğal havalandırma yöntemlerini yapılar ve binalarda kullanmayı tercih etmeye başlamışlardır.

Bu nedenlere dayanarak ele aldığımız çalışmada, sıcak ve nemli ortamlarda doğal havalandırma yöntemlerine odaklanarak, bu yöntemlerin kullanıldığı konut daireler incelendi ve Küzey Kıbrıs'ın Gazimagusa şehrinde, yeni yapılan binalarda bu konuya dayalı problemler tartışıldı.

Bu amaçla ele alınan yüksek lisans tezi 4 bölümde nitelendirilmiştir;

1. bölümde literatür taramasına takiben giriş, çalışmanın soruları, hedef, çalışma alanı ve metodoloji hakkında söz edildi ve daha sonra 2. bölümde havalandırmanın doğal yöntemleri ve sistemleri yer aldı. 3. bölümde Gazimagusa'anın iklimi ve rahatlık bölgesi ve ayrıca yeni inşa edilen konutlarından söz edildi ayrıca çalışmanın bulguları, tartışması ve önerileride bu bölümde yer aldı. Bu doğrultuda gizli açık uçlu anket tekniği kullanıldı ve çalışmaya katılamyı kabul eden daire sakinlerine anket soruları dağıltıldı ve yaşadıkları dairelerin havalandırma konusunda memnun olup olmadıkları soruldu. Bu anket çalışması, tek tek binalarda ve dairelerde hava faktorlerinin ölçülmesi mümkün olmadığı için yapıldı. Bu bölümde en son çalışmaya katılan binaların havalandırma sorunları ve bu sorunlara yönelik çözüm stratejileri tartışıldı. 4. Bölümde, Bu binalarda yeterli doğal havalandırma yöntemlerinin olmadığı ve basit mimari tasarımları ile bu sorunun giderilmesinin mümkün olduğunun kanağatine varıldı.

Anahtar kelimeler: doğal havalandırma yöntemleri, orta yükseklikte binalar, sıcak ve nemli iklim, Gazimagusa, Kuzey Kıbrıs.

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Chapter 1

INTRODUCTION

Researches have shown that lassitude can be a result of uncomfortable high or low humidity and temperature, or lack of fresh air movement. To avoid that condition, the control of indoor air quality for spaces is needed. If mechanical systems are used for the control, it will cost a lot. It has monetary cost for occupants and uses up irreplaceable energy resources of the environment. Therefore, utilization of natural systems and reduction in the usage of mechanical devises decrease the expenditures.

Natural ventilation, as a part of design strategy have shown itself in shape of different elements, according to their functions, all over the world. Wind scoops, wind towers, chimneys, embedded ducts, atriums, ventilation chambers, double skin facades and openings in the facade or mixture of them are the most common elements of natural ventilation. Driving forces of all elements are wind, thermal buoyancy or both of them.

To check if natural ventilation strategies are applied or can be applied to a building, that building can be analyzed according to its site orientation and roof type, interior space organization, facade characteristics and its construction materials.

1.1 Problem Statement and Aim of the Research

Utilization of natural ways in order to gain desirable indoor environment, would help replace the usage of limited sources with unlimited ones such as wind and sun. Ventilation as a part of thermal qualities is not an exception in this topic. This can be inserted into new residential constructions and in multi-houses apartments. Moreover, occupants need to feel comfortable thermally inside their homes which usually results in mechanical equipment using mentioned energy sources. Costs of energy bills and repair services in one hand and not making desirable ventilation by mechanical equipment, on the other hand, cause dissatisfaction for residents. As an example, air movement caused by air-conditions or coolers irritate in some directions and do not work in some other directions. Mechanical devices produce undesirable noise and also they make building lifespan shorter. All these problems can be reduced if designer of the building consider them from the early steps of design process.

Famagusta as a developing city, has been faced by apartment construction largely, in recent decade. Therefore, problem of this research is making comfortable climatic condition, as much as possible, inside the houses of apartments in Famagusta by usage of natural ventilation strategies.

Thesis has been done with the aim of recognizing the deficient of architectural design arrangements based on natural ventilation in residential multi-houses buildings located in hot and humid region of Famagusta. Moreover, this research aims to survey whether residents of the apartments are satisfied with natural ventilation inside their houses or not. Thesis also aims to give some general proposals to reduce the usage of mechanical systems with the help of natural alternatives. Some general proposals can be given in order to improve those shortages in future projects to reduce the usage of mechanical systems.

1.2 Question of the Research

According to problem statement and aim of this research, it is trying to find out the answer for the following, as main question:

– What are the advantages and disadvantages of architectural designs of constructed residential buildings which have been built within recent decade, related to their indoor natural ventilation application, in hot and humid region of the city Famagusta?

Two other questions are asked as sub questions for this research:

– Do the occupants of apartment buildings, constructed in recent decade, feel thermally comfortable inside their homes with less usage of ventilation mechanical equipment? In which parts of the interior spaces do they feel satisfied and in which spaces they do not?
– What can be the basic architectural design suggestions, in contemporary mentioned constructions, to assimilate natural ventilation strategies in to them?

1.3 Focus and Field of Study

This research discus on architectural designed natural ventilation strategies, and those strategies are under discussion in hot and humid climate.

Thermal comfort is a condition of mind and body that express satisfied with thermal condition. People's experience of thermal comfort in different places varies depending on the type of usage of those places. According to the activity of people inside a space and the expectations from that space, utilization of natural ventilation technics differs from one function to another. Hence, focus of this thesis is limited on buildings in three to six floors with residential function.

The seaport Famagusta, which is located in east part of Cyprus, has been chosen as the field of study for this research. Figure 1.1 shows the location of that city in the map of Cyprus.

In this city 10 apartments are introduced and explained as case studies. These are selected randomly from different parts of the city and from different construction companies. All these residential apartments have some common characteristics as they are built in recent decade and have between three to six floors.

Figure 1.1: Location of the city Famagusta in Cyprus. (Google earth 2014)

1.4 Methodology

This research is based on survey and problem solving method. Primary assumption is that, there is not enough providing thoughts of natural ventilation in designing apartments in the city Famagusta, which need to be ventilated because of hot and humid weather of the region. Thesis tries to find lacks of these apartments architectural design for natural ventilation and suggest some solution for them. To gain this aim, in the first part as chapter two, natural ventilation rules and strategies, definitions of climate factors, are collected from literatures, books, scientific journals, articles and so on.

Because there were no chance of measuring climatic factors inside the buildings, to check if they are in comfort zone or not, disguised and open ended questionnaires technique have been used. In these questionnaires- which is available in appendix G- residents of the studied apartments, have been asked to say whether they feel themselves in comfort zone inside their homes or not. Moreover, occupants are asked whether they feel comfortable and are satisfied with indoor thermal qualities of their houses, specifically ventilation, or not.

To extract the characteristics of contemporary residential apartments, their location, section, plan, interior organization, facade specifications and construction materials, have been studied. Field observation, photography and drawing are techniques which have been used for that. This part of the research is named findings and discussion which are available as chapter three. Each apartment have been checked within its location through its site, its orientation to wind direction, sun direction and neighbor buildings location also each building have been checked according to its direction toward north and south. All of these have been studied also separately for each interior space as kitchen, living room and bedrooms.

Since this research determine a qualitative study, Number of the houses and apartment which have been observed as samples has been chosen according to subjective judgement. In such research, there exists no fix formula to choose the number of samples, instead they should be estimated empirically before starting; and this number is flexible during the research, till saturation or data satisfaction is gained and researcher finds out that more sample studies does not give extra information which affects or changes the result (Sandelowski, 1995), (Goust, and Bunce and Johnson, 2006).

After classification and comparison of the data in tables, advantages and disadvantages and suggestions for natural ventilation have been given which in final part of the research some methods of natural ventilation have been assimilated to improve the ventilation function inside.

1.5 Literature Review

Allard and Awbi believe that ventilation in buildings which have occupants, has two goals. First is removing polluted indoor air and supplying fresh air to provide an acceptable indoor air quality (IAQ); the second is providing thermal comfort by balancing the heat and moisture inside the spaces; while Hensen, describes that the polluted indoor air can be considered as moisture or odor which comes from humans or human's activities, tobacco smoke and pollution from combustion processes, pollution from outdoor sources or pollutions from building materials, furnishing and etc. (Hensen, 1990), (Allard, 1998),(Awbi, 1991)

Allard and Brown add that in hot times, for instance, in the south of Europe, where mean outdoor temperature exceed the comfort temperature threshold from June to

August, thermal comfort ventilation can have three aspects: first, when outdoor temperature is lower than indoor temperature ventilation can cool dawn the indoor air by replacing the outdoor air. Second, ventilation can cool dawn the building structure. This can affect the indoor temperature indirectly if the ventilation accurse at night time. In this case the thermally massive components of building are cooled during night so they can act as heat sink during the next day. Third, when the outside ambient air temperature is above the comfort zone, ventilation can do direct cooling on human body for evaporation and convection. (Allard, 1998), (Brown, 2001)

Goulding, Lewis & Steemers (1992), in their book named "energy in architecture" express that

> Natural ventilation can produce a significant cooling effect, depending on the configuration of the building on the site and the surrounding spaces, the direction and strength of wind flows and the time of day. The layout of internal spaces in plan and section according to function is important, particularly for air movement indoors and the potential for cross ventilation.

According to Zandi (2006), based on the differences of climatic conditions (temperature, humidity, wind velocity and etc.) in different regions, elements of natural ventilation vary. It shows the importance of recognition different type of climates and be aware of climatic characteristics of design field. Looking at the vernacular architecture in various countries, demonstrate the fact that buildings have been designed in respect to the climate of their environment with those elements of natural ventilation which are suitable for that climate and of course, with the material and technology of their own time. As an example in regions with hot and humid climate humidity and heat cause discomfort thus "utilization of wind for elimination of the accumulation of humidity and increasing the heat dissipation of human body by evaporative cooling through the skin" becomes important.

Olgyay (1963) in the book “design with climate” published in 1963, explains that the building form has been one of the solutions of profiting from natural ventilation. Because the air velocity and wind were one of the available acclimatization strategies, buildings envelope have been designed open as much as possible. For the usage of cross ventilation they usually had an open elongated plan and a single row of rooms and large openings. Also usually the long axis of the buildings was oriented in east west direction.

Another solution developed form of steep pitched roofs. They made a space to accumulate hot and humid air higher than human activity levels and deplete it through the gaps between the roof finishing materials, Said Idham (2005), in his research named “Javanese Vernacular Architecture of Indonesia: Study of Environmental Acclimatization in Warm-Humid Climate”

Lapithis (2005) has done a research with the name of “passive solar architecture in Cyprus”, and based on that he listed the technics which have been used in constructions of traditional and historical houses, created since 7000B.C. in hot and humid climate serving as energy-saving elements of architecture. He mentions that these buildings have the characteristic of: Clear topographical explanations. The positions according to the direction of sun radiation, in order to prevent the entrance of direct sunlight into the building. The ways to exploit the breezes for the purpose of ventilation or cross ventilation within the indoor space. To be aware of the nature of vegetation and its use for functional purposes and to be able to operate accordingly (e.g. medicinal plants, fruit-baring trees). Proper insulation for the walls and roofs. Small openings on the walls facing the exterior spaces in order to maximize insulation. Planting in the courtyards provide natural shading in summer and by the winter let the sun into the courtyard. The openings on the southern walls are mostly providing light and heat. Small openings on top of the exterior walls that let the heat, which is lighter out and be replaced with the cooler air coming from the outdoor.

Michael and Phocas (2010), from the University of Cyprus, faculty of architecture, in the year of 2010, have done a study in which five residential buildings in one and two story, which have been designed with an eye on climate condition, located in the broader area of the city Nicosia, were examined in term of bioclimatic dimensions. They measured the relative humidity and temperature inside the houses for 38 days. They also collected the data on temperature and humidity of the external air from the Meteorological Service of Cyprus; also a reference as a needed comfort zone was imagined. For these five buildings (Theodotos Kanthos Res 1952, Telemachos Kanthos Res 1960, Andreas Koumoulis Res 1966, Panos Eliophotou Res 1966, Nicos Georgiou Res 1968) a table were designed from the maximum, minimum and average internal temperature and humidity, minimum, maximum and average external temperature and humidity, the difference between those items and the reference item, and temperature difference from ground and first floor. They describe the houses according to their field observation as: Residential buildings with southern or southeastern orientation. Major space are located towards the south, and if not skylights are used in order to direct the sunlight from the south into the building. There are no openings on the external walls, facing west and north, and the thermal loss will be minimized and cold wind will not enter the building during the winter. Existence of the small openings is to certify the cooling during summer time. Small openings heighten the indoor wind speed and improve the quality of cooling. Projections, vegetation, pergolas and Venetian shades are the facilities that prepare sun protection for openings. Precise stress was put on the act of avoiding the overheating of indoor spaces during summer time. Openings on interior and exterior walls cause the circulation of the air within the building. During the night the indoor air cools down by vapor that comes from waterfronts or pools going out through the openings on the ceiling. Existing vegetation and water in the center of residential buildings help with the patulous outline of plan layouts to guarantee a better ventilation within indoor spaces.

According to the analysis of their table the mean maximum temperature and the relative humidity in the buildings were lower than the reference also lower than the outside temperature and relative humidity. The mean minimum temperature and humidity inside were lower than the mean minimum temperature and humidity of the reference but higher than the outside temperature and relative humidity (Michael and Phocas, 2010).

An article named "Thermal comfort in proposed tree-story passive houses for warm humid climates", written by Jayasinghe, Attalage, and Jayawardena (2002), discusses on climate comfort in new apartments in Sri Lanka which has hot-humid climate. In this article authors have drawn a table showing that the apartments with no regard to climate in their design stay out of comfort zone while the others with climatic design are in the zone. They describe the reason of their research according to recently increasing of usage of air-conditioners in houses and its bad influence on environment and its economical impositions on families. After analyzing their data the most effective one is introduced as correct orientation of the building regarding the sun and the prevailing wind, correct shading and balconies and light color of the roofs (it is shown that roof has a high effect on indoor temperature, so it is better to have the spaces in vertical flats than in one floor).

A research have been done by Cheung, Fuller & Luther (2004), in Hong Kong-with hot summer climate- on new high-rise apartments, identifies six thermal design strategies: insulation (the maximum result gained when the insulation was placed in outside of the external walls), thermal mass, color of external walls (Color of external walls has linear relationship to heat gain as it goes to dark colors), glazing systems, window size (Windows with double glazing glass are more efficient, the ones which reflect the sun gain less heat) and shading devices.

According to this literature review, in each of the introduced researches, the researchers have done analysis on their selected case areas. Analysis shows suitable architectural design strategies in hot and humid climates to have natural ways of thermal control inside buildings. It is possible to do such studies on the city Famagusta as a selected city also. New type of construction in this city shows itself in body of residential apartments. Natural ventilation also can be studies in that type of buildings. Contribution of this research in this topic would be survey and analysis of natural ventilation subject in residential apartments for the city Famagusta in North Cyprus to find out lacks and advantages of architectural design based on natural ventilation.

Chapter 2

STRATEGIES OF NATURAL VENTILATION FOR BUILDINGS IN THE WORLD

2.1 Components of Natural Ventilation

> "The rate at which air flows through a room, carrying away heat with it, is a function of the area of the inlets and outlets, the wind speed, and the direction of the wind relative to the openings. The amount of heat removed by a given rate of air flow depends on the temperature difference between inside and outside the building". (Brown, 2001)

Rate of the fresh outdoor air which is required for ventilation in residential buildings can be found from the (table 2.1).

Table 2.1: Rate of fresh outdoor air required for ventilation (Brown, 2001)

<table>
<tr><th rowspan="3">Building type/room</th><th colspan="3">Outdoor air required</th></tr>
<tr><th></th><th colspan="2">Liters/sec/m² of floor</th></tr>
<tr><th>L/s/person</th><th>Average</th><th>maximum</th></tr>
<tr><td>Residential multifamily</td><td>7</td><td>0.23</td><td>0.23</td></tr>
</table>

In order to classify components of natural ventilation, they can be categorized in to three specific categories:

2.1.1 Driving Forces

First, the natural force which drives the ventilation. The driving forces for principles of natural ventilation are wind, thermal buoyancy or both of them. Each building with natural ventilation system can work by both wind and thermal buoyancy. However, for designing a system the one that is in optimum efficiency would be determinant.

2.1.1.1 Thermal Buoyancy

When the internal air temperature is different than the external air temperature, there will be a difference between the density of the internal and external air. For instance, when exterior air temperature is higher than interior air temperature, the air pressure outside would be more than air pressure inside. Therefore, air from the place with more pressure moves to the place with less pressure. In this case, from outside to inside.

Another example for that can be given in spaces with high roof levels, in which air temperature near to roof level is more than air temperature near to surface. So that air pressure would be more near the roof and it causes air movement. In such cases, the driven ventilation accurse as thermal buoyancy. It cause air to be pulled in and out.

2.1.1.2 Wind

Wind cause various pressure in different parts of the building. This brings air inside from windward openings of the building by causing higher pressure zone on that side and pulls out air from leeward side openings. This leads to making lower pressure zone there (Daniels, 1997).

Wind follows three principles:

> "As a result of friction, air velocity is slower near the surface of the earth than higher in the atmosphere. As a result of inertia, air tends to continue moving the same direction when it meets an obstruction. Therefore, it flows around object, like water flows around a rock in a stream, rather than bouncing off the object in

> random directions. Air flows from areas of high pressure to area of low pressure" (Brown, 2001).

> "Airflow through buildings should be considered in three dimensions" (Goulding, Lewis and Steemers, 1992).

Air change hourly rates (ACH) inside occupant spaces should not exceed comfort conditions. For instance, candles flicker around 0.5 m/sec or if the air speed reaches 1.5 m/sec loose papers can be blown. (Brown, 2001)

2.1.1.3 Thermal Buoyancy and Wind in Combination

The strategy of ventilation by using the wind force would be ideal if the direction and intensity (greater than 3 m/s) of winds be steady. However, in reality winds direction and intensity are extremely variable also detailed due to microclimates. These two driving forces can be utilized at the same time. Actually thermal buoyancy is used in non-windy or cold days and wind is used in hot times. **(**Andersen et. al. (2000) and Goulding, Lewis, and Steemers, 1992)

2.1.2 Principles Utilized to Exploit Driving Forces

Second aspect is the principle, which is utilized to exploit those natural driving forces, to ventilate the building's spaces. They are single-sided ventilation, cross ventilation, or stack ventilation. These determine that how the outdoor and indoor air are linked together or how the air is supposed to enter and be led out of the space.

2.1.2.1 Single-Sided Ventilation

In this case the openings are in one side of the ventilated space. When the openings are in one level wind can be the driving force and when the openings are in different levels the thermal buoyancy would be effective. As the distance between the height of the openings increases or the temperature difference increases, the ventilation becomes stronger. This kind of ventilation is lower in rate than the others and goes not too deep through the space (Kleiven, 2003).

2.1.2.2 Cross-Ventilation

In this case air flows between two sides of the building, from windward to leeward side. It is more effective when the inlets are placed in the higher pressure zone and the outlets in the lower pressure areas. There is a limitation in depth of the space when it has cross-ventilation. The driving force of cross-ventilation is normally wind (Melarango, 1982).

Effectivity of cross ventilation can be counted up to when the depth of the building is five times of the height of that. In deeper spaces, cross ventilation doesn’t work efficient. So that in deeper spaces to have efficient cross ventilation, there is a need of having higher space height. (Edwards, 2000)

2.1.2.3 Stack-Ventilation

In this case fresh air comes inside from a lower opening and used air is exhausted from openings in higher level. This principle is independent from building orientation as an advantage. The driving force of stack ventilation is normally thermal buoyancy. The rate of air circulation within the room, which carries the heat away as well, is created by the vertical level difference between the inlets and outlets and their scales; and the difference between external temperature and average indoor temperature considering the height of the room. Maximum flow rates happen when the area of inlets and outlets are equal (Brown, 2001).

Effectivity of stack ventilation can be counted up to when the depth of the building from where air incomes to where stack outlet is located, be five time of the high of building from floor to the ceiling of one floor (Edwards, 2000).

2.1.3 Elements of Natural Ventilation

The third group is the elements of natural ventilation which can be seen in buildings as Wind scoops, Wind towers, Chimneys, Double facades, Atriums, Ventilation chambers, embedded ducts and Ventilation openings in the facade. According to the shape and organization of a building, merging different ventilation systems is possible at once. Moreover, the design of the building is the complementary part of those elements which instruct the ventilation air from paths through different occupied spaces.

2.1.3.1 Wind Scoop

Wind scoops are located regularly in roof level of buildings. Their inlets are oriented towards the windward side, capturing the wind and driving it down to the chimney. Roof has the strongest wind among the parts of the building and the most different air density and temperature with other parts. Higher volume of air would pass through and down the tower if the height of the tower and the size of the inlet increase. A vaster cross section will provide a smaller rate air circulation. Tower cross section is supposed to be around a half of the inlets area. Outlets that are located at the bottom of the tower, are vertical or horizontal; and their minimum size should be as the tower cross section (Brown, 2001).

Wind scoops catch the fresh air and steer it in to the building. These lead the wind directly to the building or indirectly through ducts. This elements are more useful in large volume buildings or parts of buildings which are enclosed and has large area. If the area is too big or there are different zones in building envelop, then multiple towers may be used.

Wind scoops have the advantages and drawbacks of central supply and local exhaust. Other drawbacks are that the rate of the airflow supply changes based on wind speed. In fixed wind scoops, if the wind changes direction it becomes no more useful. Omni-direction wind scoops do not work appropriate if ice or snow affect them. Rain and snow may enter this kind of ventilation element (Brown, 2001).

Subtypes for wind scoops can be listed as below.

-"Omni-directional" wind scoops are the ones which are independent from wind direction by turning against the wind.

-"Fixed" wind scoops face the prevailing wind direction.

-"Roof crawls" are similar to wind scoops however, they work as exhaust ways and they are central exhausts. Like the wind scoops, the roof crawls can be Omni-direction so that they turn away from the wind direction or fixed with an aero dynamic shape.

- "Venturi element" is an aerodynamic shaped element located on the roof which works as exhaust path by creating low air density by allowing the wind pass from its up not it's beneath. They are also central exhaust with some extra advantages like: They Covering the system from entrance of snow and rain. And they can work independent from wind direction. Moreover, they have other drawbacks. As instance, if the distance between them and outlet was not designed sufficient, they blow the ventilated air back inside. To construct this type, doing the wind tunnel test is obligatory (McCarthy, Christopher; Battle McCarthy Consulting Engineers, 1999).

Beddington Zero in UK is an example of using wind scoop in a building. This building which is built in 2002 comprises 82 affordable dwellings in a mixture of flats, town houses and approximately 2500 m2 of workspace offices.

Omni directional wind scoops are located on the roof of the buildings, leading fresh air inside the interior spaces, regardless to the wind direction. The upper part of the wind scoops are made from cladding and the rest from concrete. When wind scoops are used in conjunction with thick masonry walls, their system becomes even more efficient. Because the heat from outside takes longer to penetrate inside the structure. Figures 2.1 show the wind scoops on the roof of the building envelope (Andrews, 2008).

Figure 2.1: Wind scoop on top of the Beddington Zero building. (Skeele, 2011)

(Figures 2.2, 2.3 and 2.4) show the plan and section of the building and the function of the wind scoop within them.

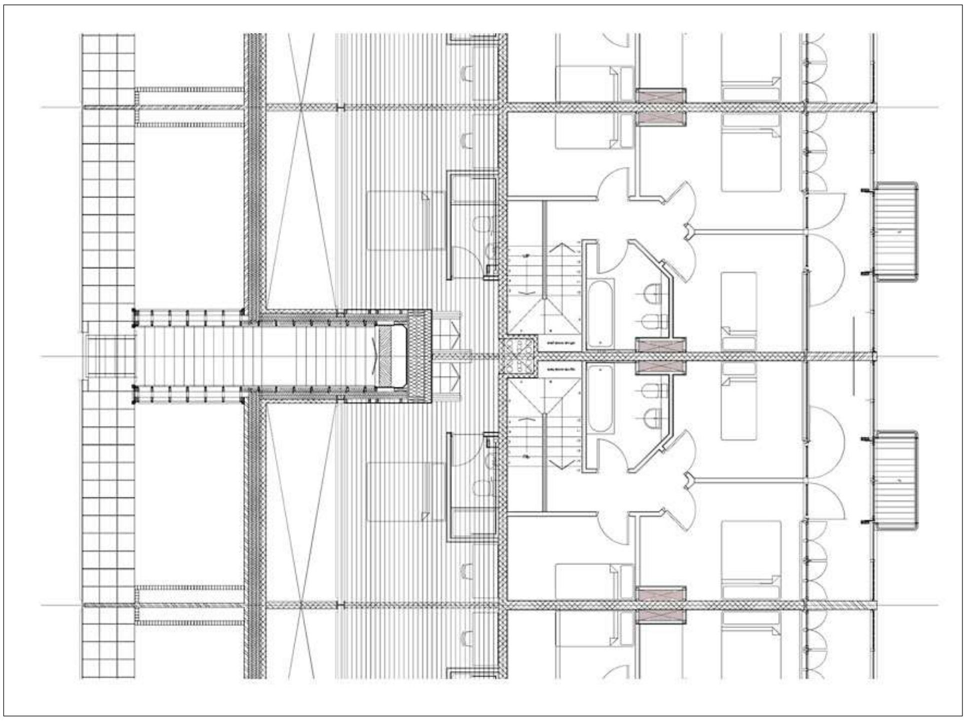


Figure 2.2: Plan of the residential part of the Beddington Zero building. Horizontal section of the wind scoops have been shown in dark gray. (Skeele, 2011)

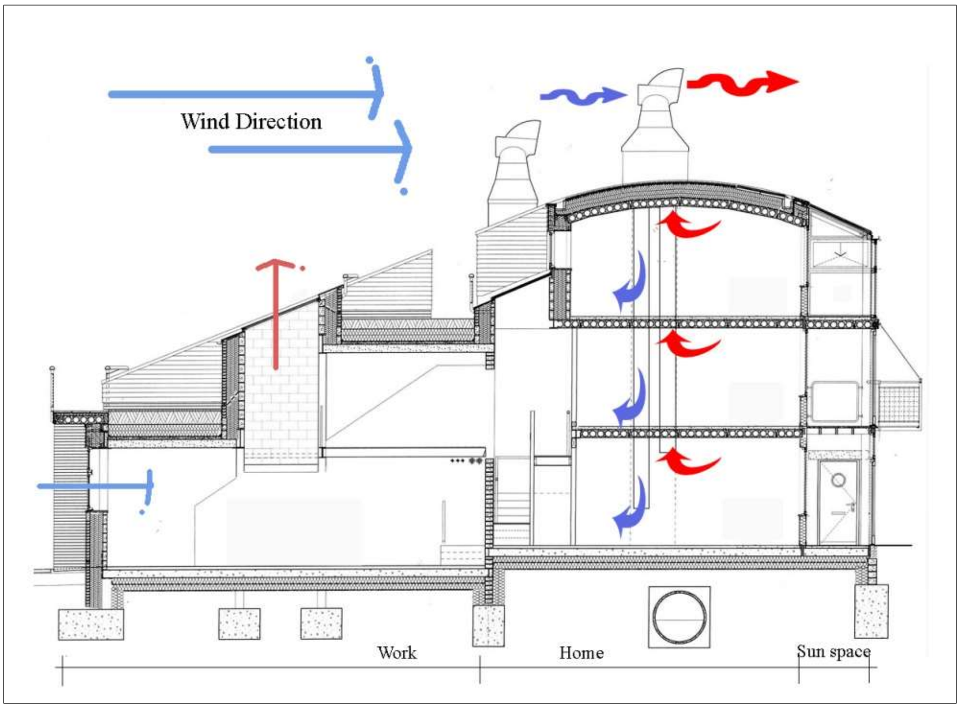


Figure 2.3: Section of the Beddington Zero building. Function of the wind scoops. (Skeele, 2011)

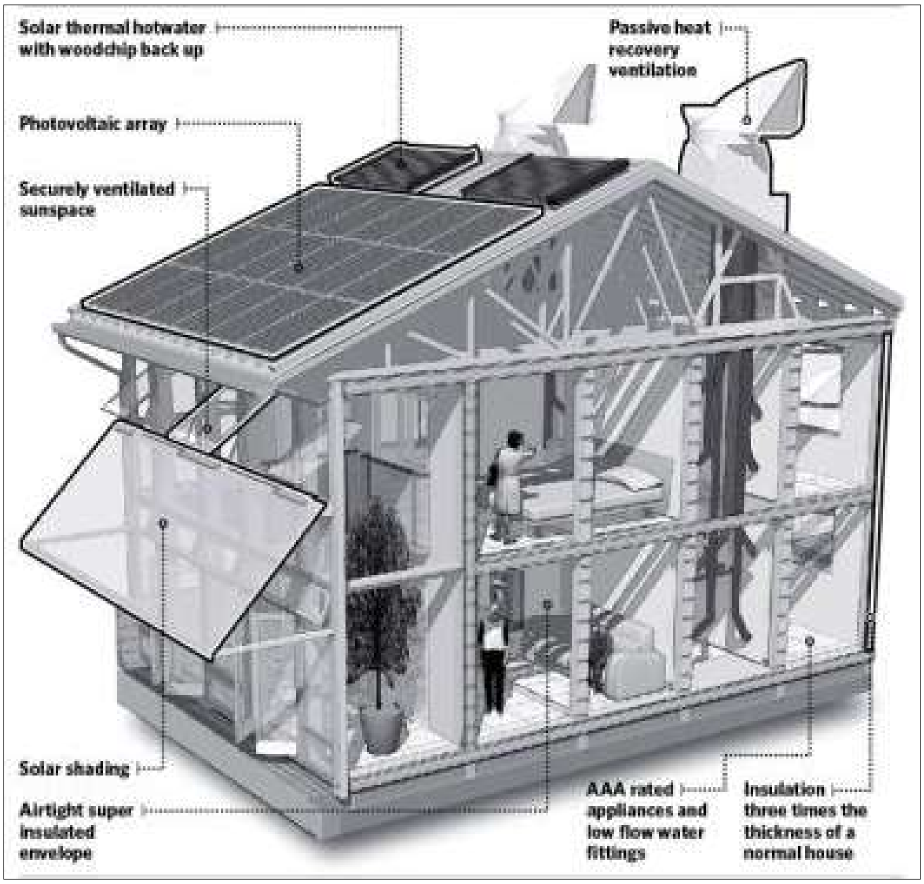


Figure 2.4: 3D-Section of the Beddington Zero building. (Skeele, 2011)

2.1.3.2 Wind Towers

Wind towers generate air movement within the building envelope by the force of the wind. They are located in height of roof level, on roof or near it, or as an extra structure. Their chimney is usually rectangular, square or triangular. They direct wind directly or indirectly by ducts to the space and they have normally openings in several sides. They can work as central supply or at the same time as a central exhaust. The temperature of the incoming air through the wind tower or wind scoops can be decreased by “evaporative cooling”. This strategy has been briefly explain in appendix A.

One of the advantages of wind tower is that it simplifies the decision of designer in orienting the building, whether it should face the wind for summer ventilation or it should face the sun for gaining the winter heat (Brown, 2001).

Based on the months in which the building requires cooling and the wind direction wind catchers has opening in one, two or more sides.

-Egyptian wind catcher has opening in one side and is appropriate when the wind blows from one direction.

-Pakistani type which has openings in two sides of its tower is suitable if the variability of wind direction is within a 90º.

-Iranian two sided type has openings in two sides which are opposite to each other and can be responsible to the winds coming from inverse directions.

-Iranian four sided type captures wind from any direction because it has openings in four sides appropriate for areas which have winds with great variability (Bahadori, 1978). (Figure 2.5) shows the four types of wind towers and the efficiency of those types.

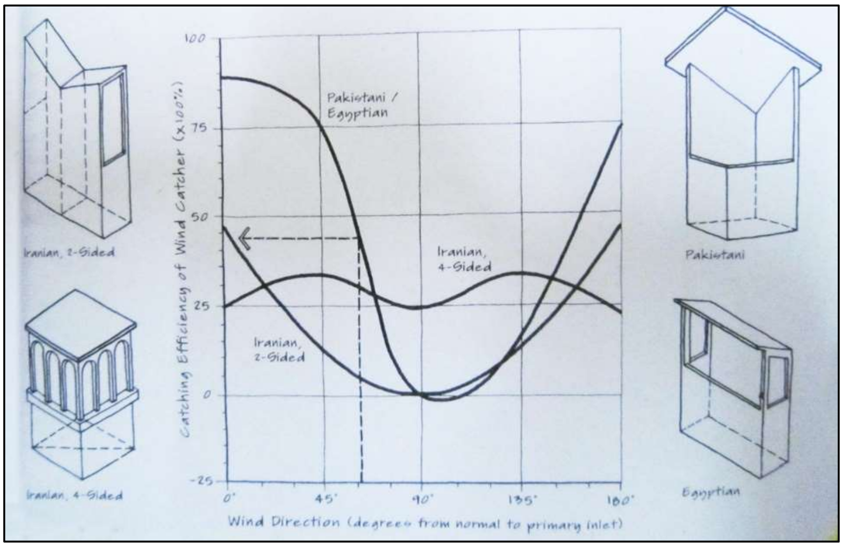


Figure 2.5: Catching efficiency for different wind catchers (Brown, 2001)

Examples of using wind towers can be the residential buildings in the city of Yazd, in Iran. In this city most of the buildings have wind towers which take wind inside the interior spaces. They are made of adobe or brick to have a thick masonry material in outer skin. Inside duct is also decomposed into smaller ducts by the same material. The duct starts from the floor, reaching 1.5-2.2 m high, continue to the ceiling of wind catcher (Mahyari, 1997).

(Figure 2.6) shows the wind catchers which are known as "badgir" on roof level of the building. (Figure 2.7) shows the 3D model of the duct of the wind catcher. (Figure 2.8) shows the plan of the building and also its section in part which the wind catcher is located to show its function.

Figure 2.6: Wind catcher at roof level of the building. (Mahyari, 1997)

Figure 2.7: 3D model of the duct of the wind catcher. (Mahmoudi Zarandi, 2009)

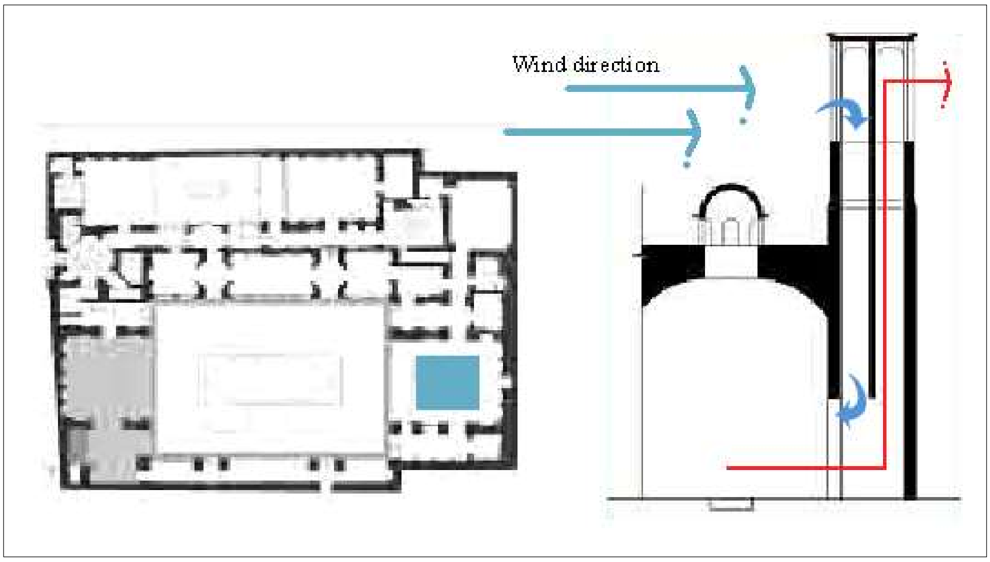


Figure 2.8: Function of the wind catcher in plan and section. (Mahmoudi Zarandi, 2009)

2.1.3.3 Chimneys

Chimneys are located in roof of the building and have normally cylindrical shape. Because of their location which has the most wind blow and their function as an exhaust path, it is important to locate their opening carefully. Usually the top is open to ensure making under-pressure in all wind directions, according to Bernoulli Effect, so gives it the advantage of being efficient for working by thermal buoyancy or wind as the driving forces independent from wind direction. A cover on top can prevent entrance of rain or snow. If there is a cap, it alternatively can be designed to create a low pressure region at the top of the tower, as the result the air pressure become low so it causes air to flow up the chimney (Brown, 2001).

Solar chimney is a type of chimney which its internal surface becomes warm by the sun. The air temperature on top increases and as the result air flows upward along the plate due to buoyancy forces (Mehani and Settou, 2012).

Zero Energy Building in Singapore is an example of using chimneys in a building. This building is a collection of houses, corporate offices and academic classrooms and is a true zero net energy building which is built in year 2009. There is a gap of 300 millimeter between the roof and the solar panels located on the roof, which creates a negative pressure area and draws warm air up from the office spaces and out from the chimneys by stack ventilation. Figure 2.9 shows the chimneys on the roof level of the building. Figure 2.10 shows the chimney function in building section (Yudelson Associate, 2011).

Figure 2.9: Chimneys on roof level. (Yudelson Associate, 2011)

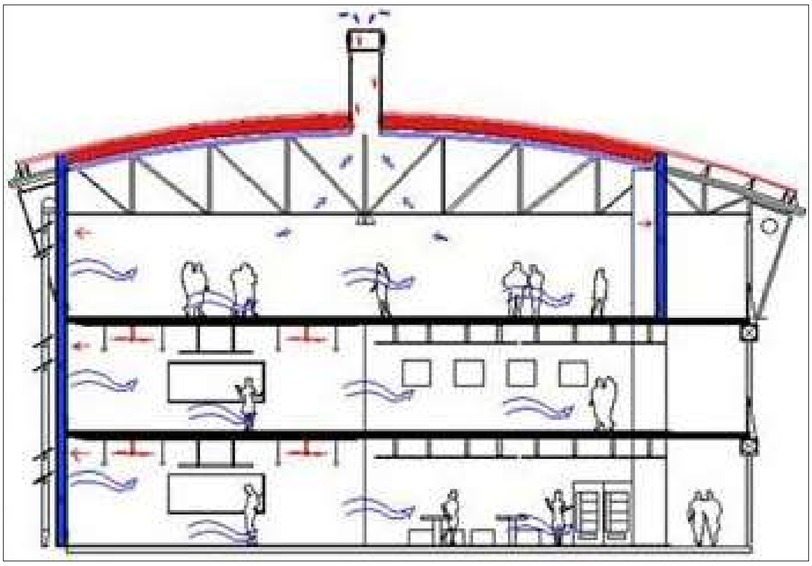


Figure 2.10: Function of the chimneys. (Yudelson Associate, (2011)

2.1.3.4 Double Skin Facades

Double skin facades (formed of two transparent surfaces as internal glazing and external glazing which are separated by an air cavity) or double glazed systems can be utilized as inlet and also outlet for ventilation. The cavity space in double facade buildings is not an offer for occupancy. This system is more applicable under condition of hot climates which have highest solar radiation in roof and east and west facades. “Neveen Hamza” compared an optimized single facade with an optimized double skin facade, in hot climate, and the result indicated that with a careful material selection, a reflective double skin facade achieves better energy saving than a reflective glazing on windows in single skin (Hamza, 2007 and Alibaba and Ozdeniz, 2011).

Ventilation removes excess heat which passes through the outer skin, while the outer secondary skin provides shade for inner opaque walls, roofs or windows. The cavity is more efficient at reducing radiant solar gain subordinating “the absorptivity of the outer skin, the emissivity of the cavity and the rate of ventilation in the cavity.” (Brown, 2001). The system would become ideal with a highly reflective outer skin, outer surface with low absorption and a low remittance inner surface. The ventilation of the cavity should be maximized because as the outer skin temperature increases, heat builds up within the cavity (Brown, 2001).

Poor ventilation can be accrued on double roofs with horizontal cavities. More cross ventilation would happen in a deeper horizontal cavity while the effect of the width of the cavity is little on thermal efficiency. Wall and sloping roof cavities which have low inlets and high outlets can be vented by stack effect (Brown, 2001).

Vegetated sun screen can be used as the outer skin. A high percentage of solar radiation would be absorbed by the leaves. The space between the leaves let the cavity to be ventilated well so that the excess heat would be dissipated. Short wave reflectance and solar absorptance are opposite, while long wave reflectance is inverse with long wave emittance. According to wave lengths of the radiation emittance and absorptance of most surfaces vary. Only surfaces from non-metallic black and polished metals are independent of wavelength in those properties (Brown, 2001). (Figure 2.11) shows some configuration of the cavity space.

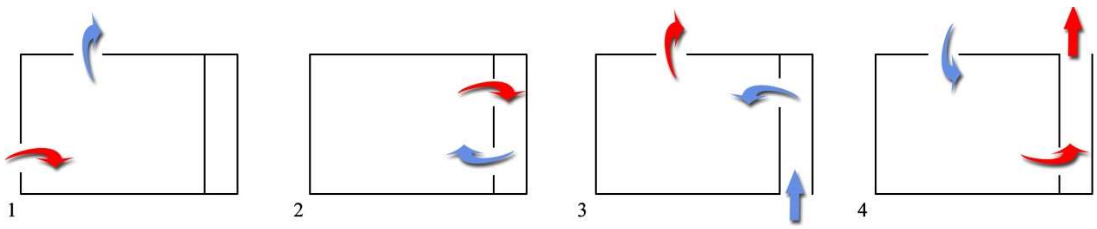


Figure 2.11: Alternative configurations for double facades. 1: Cavity closed. 2: Cavity opens. 3: Cavity serving as supply path. 4: Cavity serving as extract path. (Kleiven, 2003)

The most advantages of double skin facade can be mentioned as the cavity makes the inside spaces protected from wind and noise of the streets. Cavities protect solar shading facilities from the wind. The supply air benefits the solar preheating on sunny days, while the cavity is applied as the pathway for the air supply. Comparing to a common type of external wall, those walls within cavities reduce the waste of transmission. Some of the wasted heat through transmission is recaptured by the inlet flow within the cavity; and it provides heat recovery effect while this heat is used as supply air pathway. Since the climate is protected within the cavity, the surface of inner rooms will be warmer by decreasing cold downdrafts and irregular radiations (Kleiven, 2003).

As drawbacks, if the second glaze cannot be opened, then in hot days the high temperature inside the cavity will be a problem, especially in upper floors. Noise can be transferred in adjacent rooms to the cavity. The cavity needs to be clean as the supply path and it costs more than cleaning a usual facade. Construction of a double facade makes more costs than a normal facade. Not having enough practical information on fire protection (Brown, 2001).

This system based on the arrangement of the cavity can be varied. For instance:

- The space containing air in shaft-box window is divided into vertical sections lengthwise on the height of the facade next to a tall ventilation shaft. The connection between these windows and vertical shafts on the facade creates a stack effect.
- The air space of the corridor facade is divided into horizontal sections, which is usually arranged according to level of the stories of the building. The wide corridor is available to provide space for service if necessary.
- There are large openings at the bottom and top of the double skin facades in multi-story buildings; and ventilation is done through the path between these openings.

- In case of a box-window the facade is divided both in vertical and horizontal directions. Therefore, the facade is portioned into small separate boxes as a result of this division, and there is no shaft to be used. This type is suitable when the sound insulation is needed within partition walls (Alibaba & Ozdeniz, 2011).

- In an integrated facade, "the idea of the double facade underwent consistent further development by integrating functions other than ventilation, such as air-conditioning or control of lighting levels, in the facade. The resulting system was then generally called a modular facade or hybrid facade" (Knaack, Klein, Bilow & Auer, 2007).

- In a second-skin facade a "second layer of glass is applied over the whole outer surface of building. It has the advantage of simplicity in terms technical-structural. Since it does not deal with a large number of moving parts, ventilation mechanisms only have to be provided at the top and bottom zones of the facade. Few possibilities of controlling the indoor environment of the building are its disadvantage. Therefore, risk of overheating will be increased" (Divsalar, 2010). (Figure 2.12) shows different types of double skin facade.

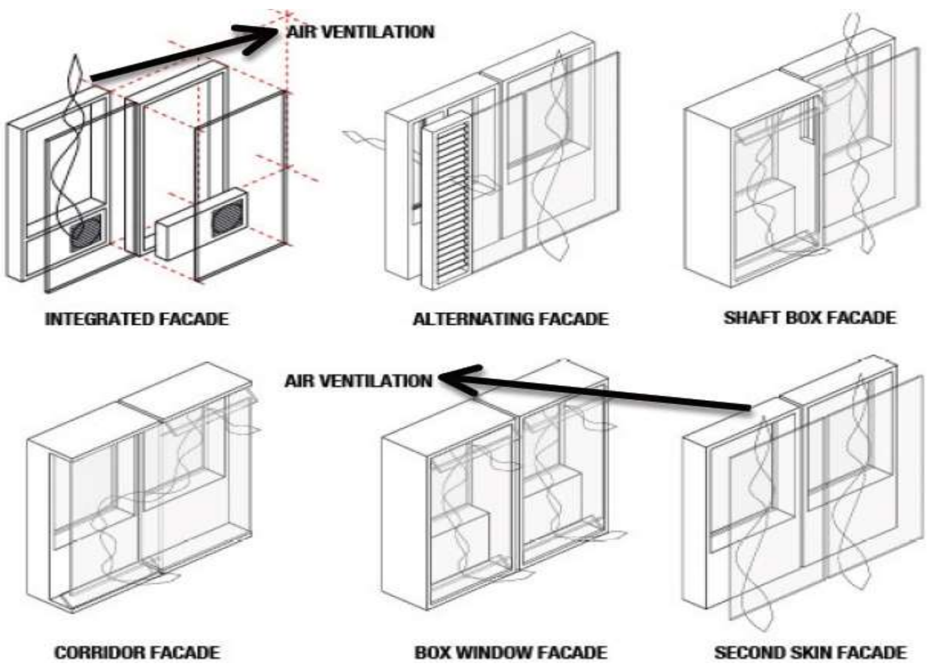


Figure 2.12: Types of double skin facade (Divsalar, 2010)

Minerva building, in eastern edge of London, can be mentioned as an example of using double facade. This office sky scraper, planned in fifty three floors, has double skin-glassed facade with eighty centimeters gap between the layers. Figure 2.13 shows the building and (figure 2.14) shows the function of facade in that building (Arnold, 2009).

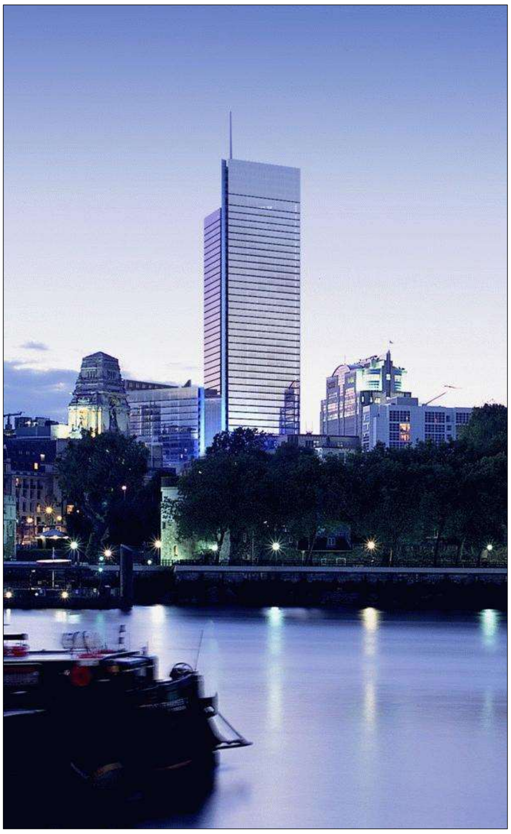


Figure 2.13: Minerva skyscraper. (URL 4)

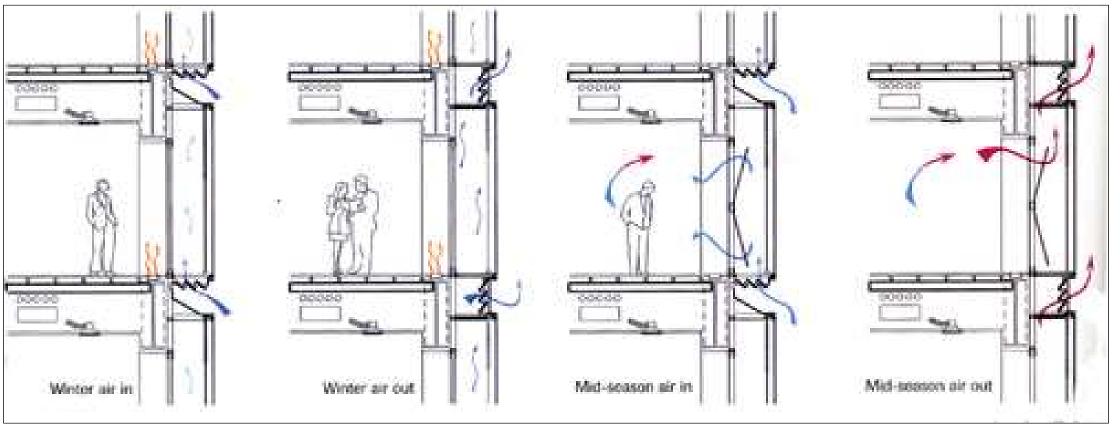


Figure 2.14: Function of the Double skin facade (Arnold, 2009).

2.1.3.5 Atrium

Atrium is a space with glazed roof which can be considered as a new usage of courtyard which is covered. (Bednar, 1986) “The advantages of that in northern latitude are more obvious” (Goulding, Lewis and Steemers, 1992).

Atriums can be considered as air supply or exhaust or both at the same time. They are classified based on thermal response to the climate into warming atriums, which gain heat and supply it to the occupied spaces, cooling atriums, which cool down the occupied spaces, and convertible atriums, used for both purposes. Latest type is assisted with operable shading devises which avoid sun rays, opened to provide cooling or closed to make an insulation. With some control systems, chimneys or wind scoops or windows at opposite sides of the atrium can be added to it to improve the functionality (Zandi, 2006).

In general, ventilation in atriums depends on some factors; orientation of the building and also orientation of the atrium within that, which for the best result ranges between 30° to 45° to the prevailing wind, shape and height of that, natural forces created in, and openings of the building. Moreover, it depends on shape of the roof of atrium. Mono pitched roof which is faced to the prevailing wind, associated with baffle walls, is one of the best shapes for the roof of atriums (Zandi, 2006).

Cooling type of the atrium which is used in warm climates should be oriented north or central to illuminate the solar gain. Moreover, shading devices should assist the roof as fixed, according to the direction of the sun, or movable. In this type the openings in the windward side positioned in the highest level than the openings in the leeward side which suck the indoor warmed air. The leeward side openings can be closed in the case of having wind to increase the positive pressure inside and introduce more fresh air, and can be opened in the case of not having wind or having weak one to create suction by the stack effect and have cross ventilation through the spaces. Warming type atrium, in cold climates, should be south oriented to gain the heat or central (Kleiven, 2003).

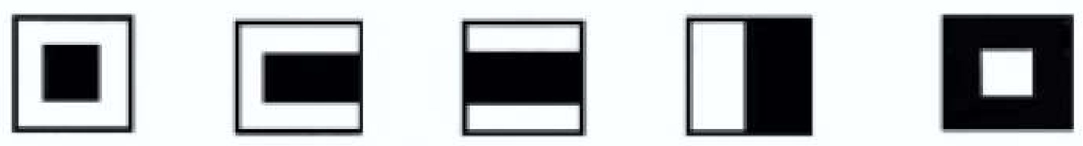
Pools and greenery can be used inside the atrium as conventional ways; or paper honeycomb evaporative pads can be installed on the openings which intake air inside the envelope to have the strategy of evaporative cooling inside the atrium. Moreover, by placing the openings used during night time lower than the height of the parapet walls, which surround the roof, nocturnal cooling can be utilized. Cool air generated on the roof surface of building, due to long infra-red radiation toward the sky, acts like liquid and flow down in to the atrium through the openings. The parapet diverts the cool air inside. As the result the structure become cooled ready to absorb the interior heat in the next day (Goulding, Lewis and Steemers, 1992).

The buoyancy forces are related to the height of atrium as the temperature difference is roughly proportional to that. However, because the flow through an opening is adequate to the area of the opening, the rate of the air change in short atria is more than tall atria, although the volumetric flow is greater (Goulding, Lewis and Steemers, 1992).

Atrium has advantages and drawbacks in common with double facade systems. These advantages can be mentioned as: In atrium windows can be opened face to it so that they are protected from outside noise or cool air or wind. As supply path there is a chance of preheating the income air in sunny days. In cold seasons the temperatures of the surface which is toward an atrium is higher than the outdoor facing side of the window which results in making the thermal discomfort and risk of cold downdraft – which is caused by asymmetric radiation in the rooms-lower. Besides, by collecting solar heat and also providing protection against the wind, Atria lower the transmission losses from the rooms toward the atrium in comparison with the rooms toward outdoor climate (Kleiven, 2003).

As drawbacks of atrium, High temperature can be a problem in hot days and rooms adjacent to atrium may be annoyed because of the sound transmission (Kleiven, 2003).

According to where the atrium is located, it can be classified as Envelope, Integrated, Linear, Attached and Core type atrium (Kleiven, 2003). Figure 2.15 shows different types of an atrium based on its location in building envelope.



Envelope Integrated Linear Attached Core

Figure 2.15: Various types of atrium (Kleiven, 2003).

Gregory Bateson building in California, is an example of using atrium in a building. In this building a closed or four sided type atrium is located in the core of a four story office spaces in a way that all of them face into that. The atrium has a multiple, glazed sky light which is oriented toward the south and the north direction and south-facing vertical louvers are located on its outside. In hot seasons, according to stack effect and by the force of wind or thermal buoyancy warmer air exhausts through the atrium. Also during the night wind is allowed to enter the offices from the openings in the facade and cool down the structure. Warmer air moves out from the openings of the atrium. Moreover, a rock bed underneath the atrium assists this night cooling. In cold seasons, the openings on top of the atrium are closed and the south facing louvers are open to gain the heat from solar radiation. Figure 2.16 shows the atrium located inside the building envelope (Brown, 2001).

Figure 2.16: Atrium of the Gregory Bateson building. (URL 3)

2.1.3.6 Ventilation Chambers

Ventilation chambers can be defined as spaces which collect the polluted air from ventilated area to exhaust it; or receive the fresh air and parcel it to other parts. They can be considered as central supply and exhaust path. They have all advantages and drawbacks of that kind of paths. In addition, another drawback for them is that they occupy extra space (Goulding, Lewis and Steemers, 1992).

IONICA Headquarters in Cambridge of UK is an Example of using ventilation chamber in a building. This building is a distinctive mark by its glass canopy extract chamber and the row of six wind towers. The curved glass canopy and the wind-towers are located in a way that none of them will come in the wind shadow of another, regardless of wind direction (Zimmermann, and Andersson, 1998). Figure 2.17 shows the chamber and wind towers at the roof while figure 2.18 shows the function of that.

Figure 2.17: The wind towers (McCarthy, 1999)

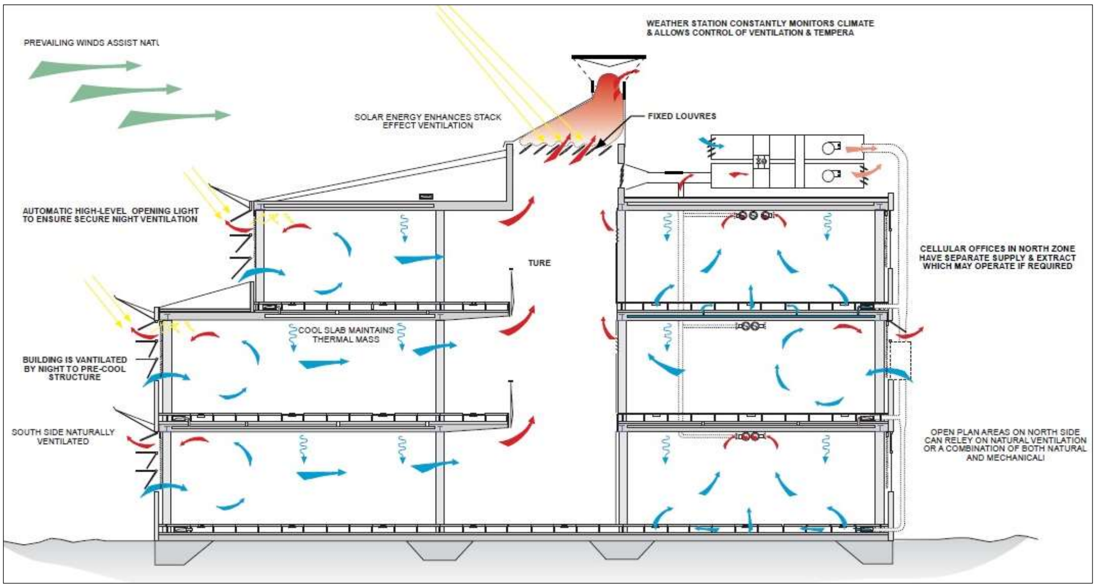


Figure 2.18 Natursl ventilation strategy of IONICA Headquarters.
(McCarthy, 1999)

2.1.3.7 Embedded Ducts

Embedded ducts work as supply path and most of their characteristics are like ventilation chambers with the difference that most of the surface of them is in contact with the ground. According to the constant degree of ground in which, In several feet under the ground, the temperature does not change following up the exact daily basis, in fact the temperature there lags about a month behind the air temperature in any season, thus its cooler in summer and warmer in winter than the surface (Brown, 2001).

The thermal mass of the walls of the duct cool down or warm up the incoming air. "Ventilation air passed through tunnels or pipes below ground can be appreciably cooler than the air surrounding buildings" (Goulding, Lewis and Steemers, 1992).

The amount of heat transfer, is based on the temperature difference between the ground and air, the soil type and dampness, the volume of air mass moving through the duct, and on the length and diameter of the duct. The length of the duct ought to be 0.3-0.2m in diameter and 90-10m long. Although thermal performance is improved by more ducts in shorter length, we should remember that it increase cost. The depth of placement is recommended to be 3-1.5 m. it is recommended to place the ducts as deep as it is practically possible due to the increase of the ground-to-air ΔT with depth. The velocity of the air passing the duct has to be 2.5-8m/sec. at least 5 cm of sand should surround the duct to make sure of good thermal contact and prevent any damage. The ducts might be made of any material such as metal, concrete, ceramic or plastic with little impact of performance. It is possible to break the total length of a duct into several ducts according to the requirement, it is important to mention that these ducts have to be spaced 3 or more meters apart by using a few turns as practically conceivable

(Brown, 2001). In traditional buildings around the Persian Gulf, Embeded ducts were used mixed with wind towers.

Embedded ducts have advantages and drawbacks of central inlet paths. Moreover, they are constructed separately from the building envelope, so that the best place based on the wind and noise is possible to be selected. Large particle and pollen are filtered through its way under the ground. On warm days condensation might happen on the surface inside the duct and a possible results are either the further growth of fungus or evaporation of the water that is possibly accumulated inside. Once a duct which is embedded has been built it is inherently fixed and stable and if the usage of the building changes and the building requires another supply air path layout or if any reason make the inlet spot unsuitable, another supply solution should be implemented and this kind of duct should perhaps be abandoned. Relatively high costs in construction process is the result of choosing embedded ducts (Kleiven, 2003).

Lycée Charles de Gaulle in Damascus of Syria is an example of using embedded duct in a building. In this school, chimneys at the roof level pull out the warm air out of the classrooms by thermal buoyancy and stack effect. They force the cooled air to come inside from the miniature ducts embedded under the ground level. During the winter ducts act reverse and make the outside cold incoming air warmer according to the steady temperature of the soil. Incoming air volume is controllable through the louvers installed at the inside entrance of the ducts. Figure 2.19 shows the school building while figure 2.20 and 2.21 show the function of embedded ducts in combination with the chimneys (Elgendy, 2010).


Figure 2.19: Lycée Charles de Gaulle (Elgendy, 2010)

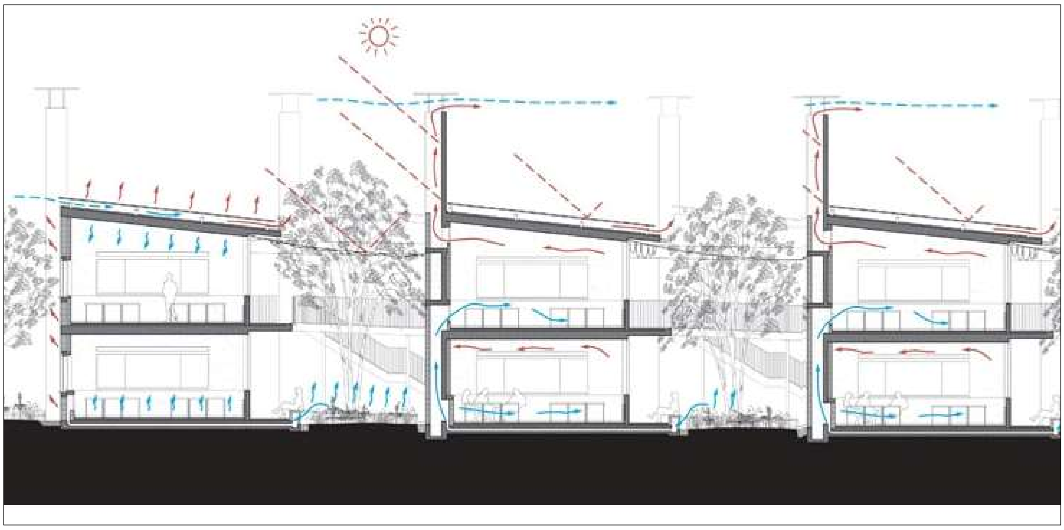


Figure 2.20: Embedded ducts in combination with the chimneys (Elgendy, 2010)

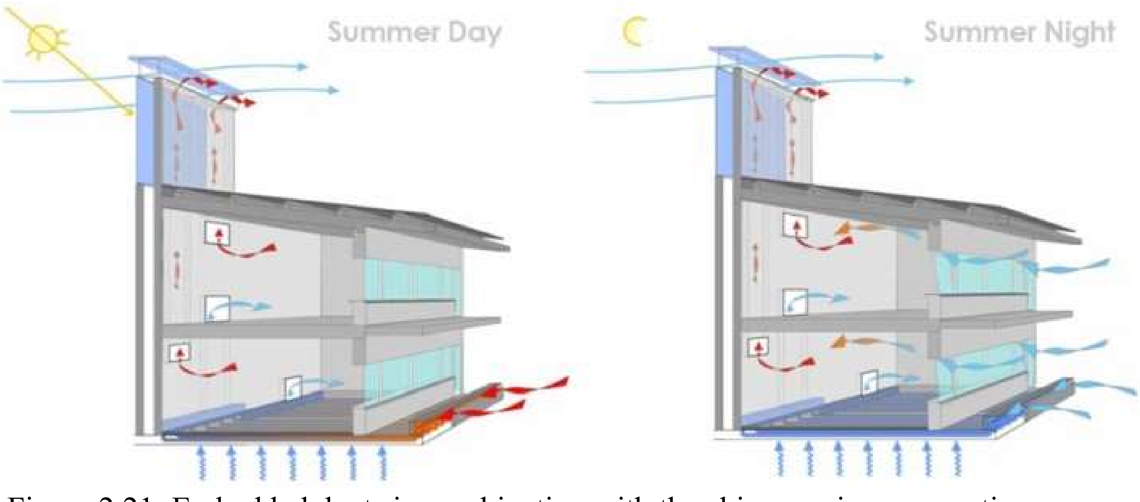


Figure 2.21: Embedded ducts in combination with the chimneys in summer time. (Elgendy, 2010)

2.1.3.8 Opening in the Facade

Building components have a better chance of accomplishing when they are designed to perform a single function; Such as windows which their orientation, size and location might vary according to ventilation, solar gain or lighting based on the climate and the building type. Openings in the facade are made just for the purpose of ventilation as incoming or out coming paths and have certain sizes. They are different from the usual windows which have other aims like day lighting or providing outside view. Location and the size of these openings are important in both leeward and windward side of the building, where negative and positive pressure zones are. By locating the openings in the positive and negative pressure zone sides, air flows from the windward side, where the pressure is positive, to the leeward side, where the pressure becomes negative. This air flow is affected by the size, orientation and location of the openings embedded in facade and between the interior spaces. Moreover, it can be directed by louvers, sashes or obtain additional pressure zone by canopies and other overhang elements. The average interior air velocity is subordinate to the size and location of the openings, the angle between the wind direction and the inlets and velocity of the exterior free wind (Brown, 2001).

Due to venturi effect[1], when the inlet openings are smaller than the outlet ones the speed of air flow increases. The openings which are oriented in 45° toward wind, create larger velocity along the windward side and more wide shadow on the leeward side.

[1] increase in fluid speed due to a decrease of the flow section in confined flows, which applies to confined flows and refers to the increase in fluid speed or flow rate due to a decrease of the flow section, where flow rate and flow cross-sectional area are inversely proportional (Venturi 1799) (Blocken & Moonenb & Stathopoulosc & Carmeliet, 2008)

Therefore, it makes more powerful negative pressure zone and stronger suction (Zandi, 2006).

Rabah, K. in his article named “Development of energy-efficient passive solar building design in Nicosia Cyprus”, believes that it is suitable to have windows covering 20% of floor area (Rabah, 2004).

Ajibola.k in his article named “ventilation of spaces in a warm, humid climate- case study of some housing types” discuss that houses with windows with a location faced toward wind or oriented up to 45°, with the size 30-50% of the exposed wall area or 20-30% of the floor area and also windows in front walls can achieve most ventilation (Ajibola, 1995).

By adding wing walls to the openings wind can be directed as desired. Wing walls effectiveness is limited to windows which are located on the wind ward side and they do not have any result on the leeward side openings. “The depth of wing wall protrusions should be at least 0.5-1 times the width of the window. The spacing between wing walls should be at least 2 times the window width” (Brown, 2001).

Openings in the facade have drawbacks and advantages of local supply and exhaust paths. Moreover, they affect the design of the facade as architectural point. Openings in the facade as local system do not need any special distribution system in the interior (Goulding, Lewis and Steemers, 1992).

Esherick house in USA is an example of openings in the facade designed with aim of natural ventilation for a building. The ventilation shutter panels of the house which are made of wood are separated from the glass windows that are simple stable. These ventilation locations are inside the niches along the south and north walls which are thickened and allow well cross-ventilation. Combining the shutters that are closed and those that are opened by separating them into multiple sections that are high and low inside the wall lets a variety in view, daylight, ventilation and also privacy in relationships with outdoors (Brown, 2001).

Figure 2.22: Esherick house (Meijer, 2013)

(Figure 2.22) shows the building and (figure 2.23) shows the cross ventilation utilization for natural ventilation inside the house.

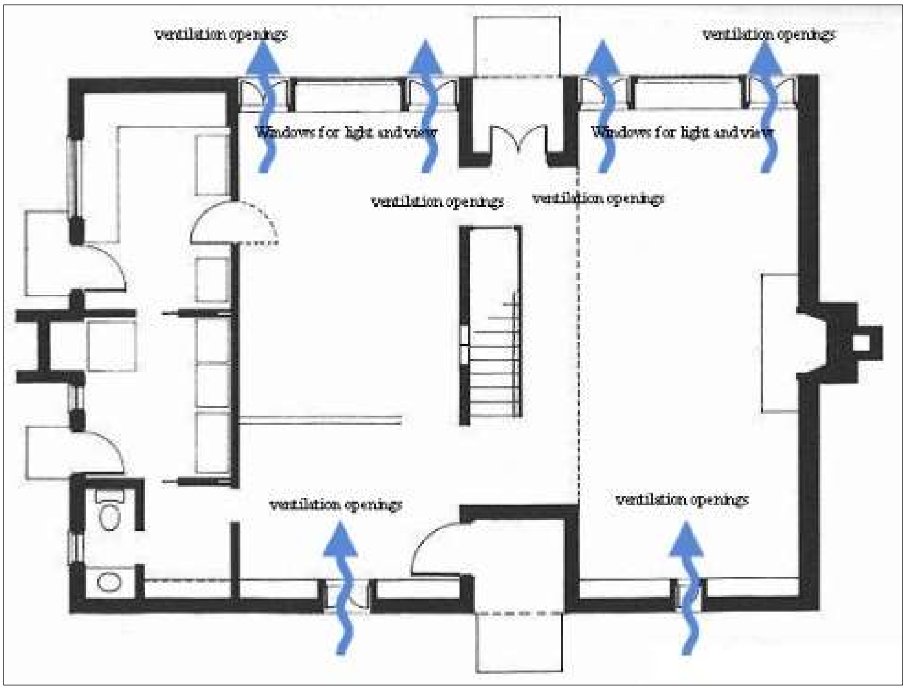


Figure 2.23: Cross ventilation (URL 3)

2.2 Classifications of the Natural Ventilation Parts

The natural driving forces drive a certain ventilation principle. To utilize these ventilation principles as single-sided, cross, or stack ventilation successfully, the shape of the building and its plan layout should be designed proportional to them. On the other hand, these various ventilation principles are associated with certain ventilation elements. For instance, when a space has ventilation openings in the facade, on both sides of the building, cross-ventilation is the principal which is wind driven. "The cross- and stack ventilation principles put certain directions on layout and use of the plan, as there should be as little obstruction in the air path from inlet to outlet as possible" (Kleiven, 2003). Table 2.2 shows a brief classification of the natural ventilation parts.

Table 2.2: Classification of the natural ventilation parts. (Kleiven, 2003)

Classification criteria	Sorting category
Natural driving force	Buoyancy
	Wind
Ventilation principle	Single-sided
	Cross
	Stack
Characteristic ventilation elements	Wind scoop
	Wind tower
	Chimney
	Double facade
	Atrium
	Ventilation chamber
	Embedded duct
	Ventilation openings in the facade
Supply and exhaust air paths	Local
	Central

2.3 Local and Central Paths

The supply and exhaust air path is the route ventilation air travels between the outside and the occupied spaces inside a building. The supply and exhaust paths can be local or central. A local supply and exhaust air path typically implies that several inlets/outlets are scattered on the building envelope. A central inlet/outlet in most cases need horizontal and/or vertical ductworks and/or chambers inside the building to distribute the ventilation air to the desired locations. Central air flow paths facilitate heat recovery, preheating and filtering, whereas this is harder to achieve with local airflow paths. Local paths offer on the other hand greater flexibility for the future changes as they usually are organized in a modular manner and are not encumbered with being linked to a dedicated distribution network in the interiors. (Awbi, 1991).

(Table 2.3) shows the relation between characteristic ventilation elements and ventilation principles and (Table 2.4) shows the Advantages and drawbacks of central and local paths.

Table 2.3: Relation between characteristic ventilation elements and ventilation principles (Kleiven, 2003)

Characteristic element	Ventilation principle	Supply or exhaust
Wind scoop	Cross and stack	Supply
Wind tower	Cross and stack	Supply and extract
Chimney	Cross and stack	Extract
Double facade	Cross, stack and single	Supply and extract
Atrium	Cross, stack and single	Supply and extract
Ventilation chamber	Cross and stack	Supply and extract
Embedded duct	Cross and stack	Supply
Ventilation opening in	Cross, stack and single	Supply and extract

Table shows that in local paths compared to central paths there are better flexibility to future changes because it has a lower space demand. According to that believe which ventilation air should be fresh and have minimum risk of low quality, having local inlets is considered as an advantage. Whereas, having local inlets make the situation in which outside fresh air can be led through the inside spaces passing shorter distance. Conversely, outside noise is transferred easily to interior spaces by local inlet paths. Moreover noises can be transferred from one interior space to the other. This is a disadvantage for local paths. In this type of ventilation it is difficult to gain help from fans if it becomes necessary. Moreover, filtering and tempering the incoming air become complex. In the situation of having local paths, interior spaces should be limited in depth while, having central paths give the opportunity of designing more deep spaces to the architects. Because in local paths air should come inside and be led out of the spaces separately.

Table 2.4: Advantages and drawbacks of central and local paths. (Kleiven, 2003)

Factors	**Local paths**		**Central paths**	
	Supply	**Exhaust**	**Supply**	**Exhaust**
Pre-heating/ draft risk	drawback		Advantages	
Distance from air source	Advantag		drawback	
Filtering	drawback		Advantages	
Fan assistance option		drawback		Advantages
Fire and smoke			drawback	drawback
Outdoor noise	drawback	drawback	Advantages	Advantages
Flexibility	Advantag	Advantages	drawback	drawback
Heat recovery	drawback	drawback	Advantages	Advantages
Space demand	Advantag	Advantages	drawback	drawback
Noise between rooms			drawback	drawback

2.4 Tempering the Fresh Air for Ventilation

In condition of having outside fresh air temperature under or above the comfort zone, there would be a conflict between increasing demand for good thermal insulation and requirement of ventilation to create a healthy indoor environment, so there will be a need of heating or cooling the incoming air before letting it inside the occupied zones.

One way of catching that aim is using the heat or cold air escaping from the building to heat or cool down the incoming air albeit using fans. This strategy reduces the energy which would be used to temper the incoming air without decreasing its flow (volume per unit time). As an example, ducts from thin metal panels can be used to pass the exhausted air from the building through, using fans, giving off its heat or cold to that. Incoming air would pass by the same panels picking up the heat or cold. “Air to air heat exchangers can recapture 70-90% of the outgoing heat or cold” (shurcliff, 1981).

Ventilation air can be heated or cooled also passing the exterior surfaces of the building such as windows. Although this strategy is not efficient yet has the advantage of omitting or reducing the ducts of fresh air also supplying that at the needed point (Brown, 2001).

Supply air ventilation window, is another strategy might be used to warm up the incoming fresh air by pre-heating the incoming air, utilizing an air flow between panes to bring the outside air temperature near to the interior temperature. “The air temperature change and heat exchange efficiency depend on the R-values[2] of the glass layers, the ΔT between inside and outside, the amount of solar radiation incident on the window and whether or not a layer of blinds is used to absorb solar gain in the cavity” (Brown, 2001) and (McEvoy and Southal, 2002). (Figure 2.24) shows the principle of supply air ventilation window design.

[2] The ‘R value’ measures how good the insulation material is at containing heat. The higher the R-value, the better the insulation will be. (Divsalar, 2010)

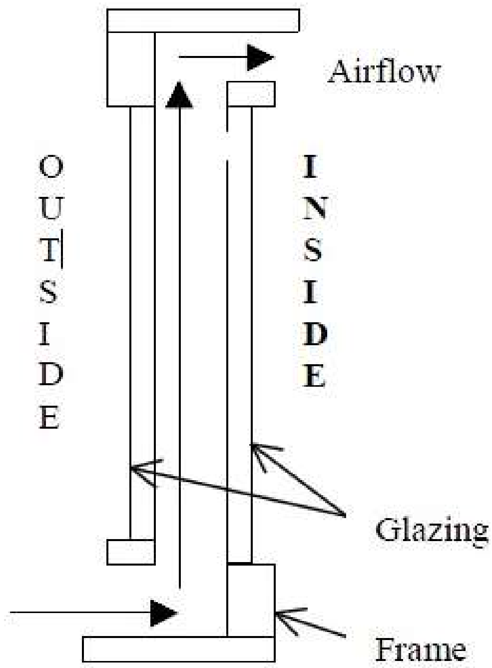


Figure 2.24: Principle of supply air ventilation window design (McEvoy, Southal, 2002)

A dark perforated, south facing metal wall which is installed with a gap of 15cm air space to the structure, known as “transpiring wall” can reduce conductive heat losses and preheat fresh air for ventilation. The metal surface absorbs the solar radiations making the air between the gap raise 6-22 °C and the fans, located at the top of the wall pull warmed air up to the ducts into the building. “The amount of heat collected is dependent on the solar radiation available, the absorptance of metal plate, the area of the wall, and the air flow rate through the wall” (Brown, 2001).

Earth air heat exchange, sun spaces and atria, which have typically warmer air temperature than the outside air in winter, or unconditioned buffer zones can be used also in strategies (Brown, 2001).

2.5 Climate and Comfort Zone

2.5.1 Climate Factors

The state of the atmospheric environment of a place over a brief period of time can be represented through the weather of that place. Climate or more specifically macro-climate is generally referred as integrated weather condition over several years. Analyzing the climate of a particular region assess to identify the climatic elements and its severity which cause discomfort and find out the seasons or period of time during which there might be comfortable or uncomfortable condition for a person to experience. To design a building, this information, playing a pivotal role, would help the designer to filter out the inappropriate climatic effects while allowing the ones which are beneficial. Thus designer should be aware of the climatic characteristics of the working environment (Bansal and Minke, 1988) & (Saymanlier, 2001).

First climate classification was done by "Koppen-Geiger". Later "Olgay" did another one which declared four climatic zones: Cold climate, Warm humid climate, temperate climate and Hot-dry climate. Specifications of a warm-humid climate have been defined as two seasonal characteristics. One rainy season and the other one is dryer. Temperature usually swings between 0° C/-3° C and 20° C /34° C.

Climatic factors, as certain variables which characterize the weather or climate, can be enumerated as solar radiation, ambient temperature, air humidity, precipitation, wind, and sky condition. (Bansal and Minke, 1988) each factor is explained separately in Appendix B.

2.5.2 Thermal Comfort

Early studies related thermal comfort directly to temperature while later ones discussed it in relative to cultural, social and in general climatic experiences and expectations (Nicol, 1974) & (Auliciems, 1981).

As a result, literatures give the definition as “the Heat Balance model and the model of Conceptual Thermal Adaptation.” (Michael Jones, 2010). First one defines comfort as “universally definable state of affairs”, while the other one says that “it is a social-cultural achievement” (Chappells & Shove, 2005).

In brief “Thermal comfort is that condition of body and mind which expresses satisfaction with the thermal environment.” (Fanger, 1970) and is effected by: acclimatization, metabolism and levels of activity, clothing, age, sex, shape of body, health condition and its thermal resistance, air temperature (DBT), mean radiant temperature, relative speed of the air (R) and humidity (RH). (Michael, 2010) and (Szokolay 1980) these factors and their effect on thermal comfort are introduced in appendix C.

“The psychological satisfaction of mind depends on the condition of the physical environment. Thus, the body’s thermoregulatory control system tries to maintain the energy balance, keeping the body core temperature at about 37ºC.” (Zandi, 2006). To feel the thermal comfort human body should produce and gain heat in balance to the amount that it loses (ASHRAE, 1997).

To identify the comfort level zone, and heating and cooling strategies, “Olgyay” created a bioclimatic chart which was developed later by “Givoni” and later by

“Arens” et al. although several thermal index scales, empirical ones (effective temperature, psychometric chart, corrected effective temperature, equivalent warmth, operative temperature, equatorial comfort index, resultant temperature and the bioclimatic chart) and analytical ones (predicted four hour sweat rate, heat stress index, index of thermal stress, predicted mean vote and predicted percentage dissatisfied) exists; However, the most important and effective ones are the temperature and the relative humidity of climate data; which all passive cooling strategies presented in bioclimatic chart are based on them (Zandi, 2006). Appendix D shows the bioclimatic chart and appendix E shows the psychometric chart and gives information on those.

Chapter 3

ANALYSIS AND EVALUATION OF NATURAL VENTILATION IN APARTMENTS OF FAMAGUSTA

3.1 Climate and Comfort Zone of Famagusta

Cyprus as an island located within the Mediterranean Sea with the latitude of 35º7´N and longitude of 33º55´E, follows the characteristics of the Mediterranean climate. Average temperature is around 19.5ºC while maximum temperature raises approximately 36 ºC in the hottest month during summer and it falls down nearly to 6 ºC in the coldest times. Average humidity sustains between 60-62% with the maximum of 72%. Temperature ranges maximum up to 18 ºC Between night and day. (Lapithis, 2005)

If a region has 19.5° C temperature in 3000 or more hours or 23° C temperature in 1,500 or more hours during the warmest six months of the year, or an annual precipitation around 500 mm, that region has hot-humid climate (Hancer, 2005).

Rabah (2004), in his article named "Development of energy-efficient passive solar building design in Nicosia Cyprus", says:" Cyprus has a widely variable and complex Mediterranean type climate, which ranges from warm-humid to hot-dry summers to cool-wet winters".

3.1.1 Climate of Famagusta

Ozay (2004) describes the climatic condition of Famagusta as "hot-humid climate with composite characteristics during night and early morning which have very high relative humidity weather".

Appendix F shows the tables from the factors of climate in Famagusta, Cyprus. Average maximum temperature rises to 34 °C and average of minimum temperature falls down to 6 °C, and relative humidity ranges between 33-72% in different months of the year maximum in Jan and minimum in Oct. There are an average of 9 hour of sunlight per day and an average of 3328 hour of sunlight per year; while there is an average of 403.5 mm of rainfall per year and an average of 33.6 mm per month (URL 1).

3.1.2 Comfort Zone in Cyprus

Based on the analysis of Olgyay's bioclimatic chart, psychometric chart, Humphreys' comfort chart and Szokolays' equation, an average comfort zone limited on the following characteristics can be defined for Cyprus.

-Temperature between 19.5 to 29 ºC

- Average relative humidity between 20-75%

- Months of April, May, October and November remains on the best condition of providing comfort, months of December, January, February and March need extra heating while months in summer (June, July, August and September) stay out of comfort zone, needing cooling and ventilation. (Lapithis, 2005),

The olgyay's bioclimatic chart for Cyprus is shown in (Figure 3.1). Vertical axis shows the temperature while horizontal axis refers to relative humidity. There are twelve lines showed in dark gray and light gray whereas each line shows one month of the year at the beginning by its minimum temperature and humidity and at the end in maximum temperature and humidity of that month. The parts of those lines which are out of comfort zone, shown with hatch in the center of the chart, show the times of the months which need cooling and heating strategies. Besides cooling part of ventilation, it is obvious that ventilation is needed in the hot times of Nov, Apr, Mar, Feb, Des, Jan to remove extra humidity and in the hot times of mentioned months it should be tempered to remove the moist without bringing the temperature down.

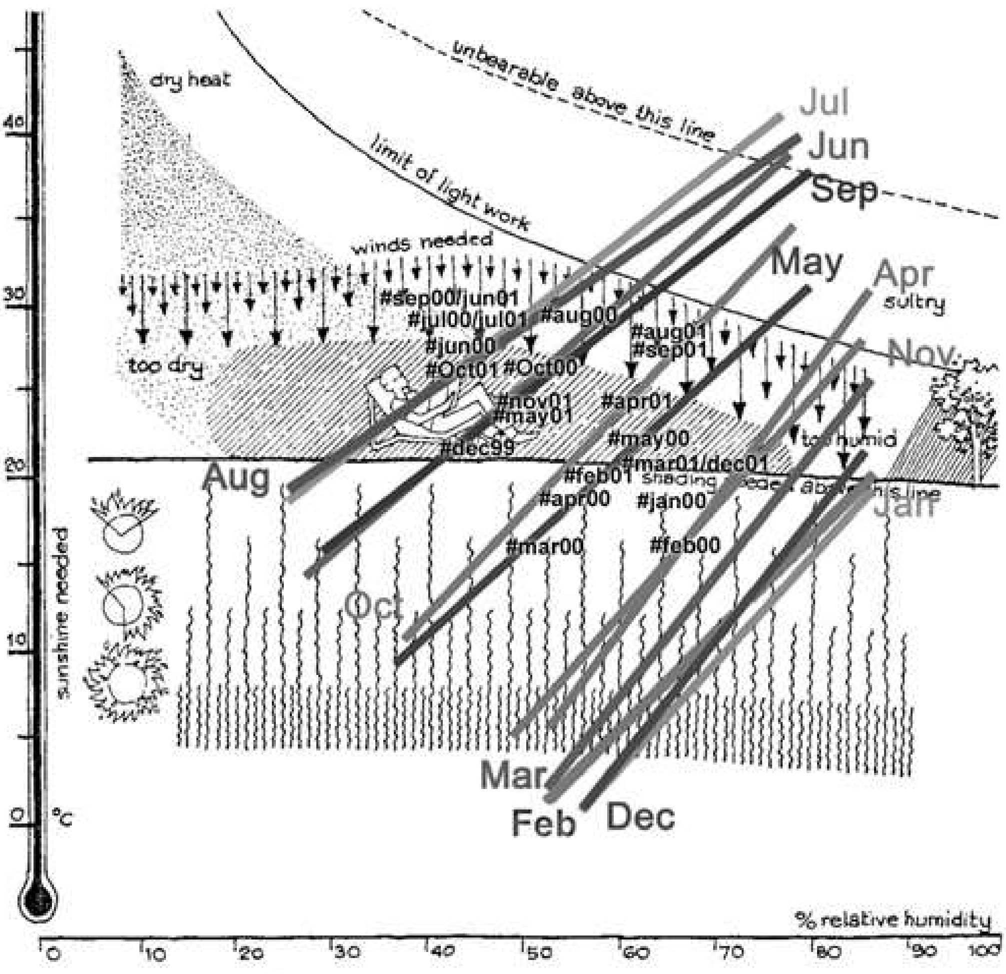


Figure 3.1: Bioclimatic charts for Cyprus (Lapithis, 2005)

3.2 Selected Case Studies; Apartments of Famagusta

Building can be divided in eight components to be investigated. Site and context, which is effective on selecting the driving forces of natural ventilation and also is affected by natural ventilation elements, orientation, shape, plan, section (exterior and interior), facade (two dimensions and three dimensions), materials, interior spaces (relation of the rooms, room's height, materials, light and views) and relation between ventilated spaces. However, the most important ones are plan and section as the shape and proportion of those, vertical air paths/stacks, and internal layout and organization of rooms and functions inside them; facade for the openings of ventilation inlets and outlets in that, type of that as double or normal and defining the solar shadings; roof for its shape and silhouette and accommodating of characteristic ventilation elements; and interior spaces for their materials and their quality of spatial connection and hierarchy (Kleiven, 2003).

By this thesis, author aimed to analyze sample buildings from new constructed apartments in Famagusta from usage of natural ventilation strategies point, to find out advantages and lacks of architectural design of these building in mentioned topic. To gain this aim, thesis analyzed orientation and roof types, design and interior spaces organization, facade characteristics and material of those sample buildings.

Number of the apartments chosen as sample to be studied are based on subjective judgement. In subjective judgment there is no fix formula to choose the number of samples, instead they should be estimated empirically before starting; and this number is flexible during the research, till saturation or data satisfaction is gained and researcher finds out that more sample studies does not give extra information which affects or changes the result (Sandelowski, 1995), (Goust, Bunce and Johnson, 2006).

Twenty buildings have been analyzed after field observation through their component. As samples ten of them are introduced in this chapter. These buildings are being compromised on first, their location in their sites, orientation toward the wind and sun, and their roof characteristics; second, their plan design and placement of interior spaces; third, the materials in their construction and finally their facade specifications to give a general schema of contemporary apartments in the city Famagusta. These residential buildings which are common in being constructed in recent decade and have between four to six stories, have been chosen randomly from different parts of the city and from different construction companies to give a general result.

The location of the sample buildings in the city of Famagusta are shown in (Figure 3.2). In center whole map of the city is given while location of each building is zoomed in. Sample apartments are introduced in (table 3.1). This table gives name of the apartments, number of stories and their location in city. Later, in this chapter, name of these buildings are used to discuss them.

Table 3.1: Introduction of the buildings in Famagusta selected as the case studies. (By Author, 2015)

Name of the building	Location in the City	Number of Stories
Erbatu 1	West part of the city	Six floors
Erbatu 2, 3 & 4	West part of the city	Five floors
Oncel	East part of the city.	Three floors
Erozan	Central part of the city.	Four floors
Dovec No:37	West part of the city.	Four floors
Dovec No:33	East part of the city with the distance of 200m far from the sea.	Six floors
Mezkoop	East part of the city with 80m distance from the sea.	Three floors
Uzun 12	East part of the city.	Five floors
Uzun 14	North-west part of the city.	Six floors
Uzun 10	North part of the city.	Five floors

Figure 3.2: Location of the cases in the city Famagusta. (Google earth, 2015)

3.3 Findings

Existing situation of the sample apartments are given here. Thesis survey started with the premium thought that natural ventilation strategies are not applied in new constructed apartments in Famagusta.

Questionnaire survey given to the residents of the sample apartments was first step of thesis research to find out their point of view. Because natural ventilation strategies are not enough and reliable in all times of the year and usage of mechanical devices are inevitable, in the questionnaire residents were asked to answer to the questions imagining minimum usage of mechanical devices inside their homes. If nowadays usage of mechanical devices is first option to cool down, warm up or ventilate places, this questionnaire ask residents to put it in second place and instead putting natural ways in first place. In this situation do they feel themselves in comfort zone during hot months and cold months of the year were asked. Sample of the questionnaire is given in appendix G.

Orientation and roof types, design and interior space organization, facade characteristics and material of the buildings are introduces in separated parts.

3.3.1 Results of the Questionnaire Survey

Residents of the selected case study apartments were asked to answer to the questioner (appendix G). Each family filled one questionnaire form and in total 132 answered questionnaire were collected. Results have been analyzed and shaped in to tables and graphs. These graphs will be used as reference to the comfort and discomfort times people feel inside their homes in conjunction with temperature, humidity and ventilation.

Results of the first questions in the questionnaires are shown in table 3.2. This group of questions give general information of the dwellings, residents and mechanical equipment and energy type used for cooling and heating. Table shows that all apartments use heating and cooling devices in order to make inside temperature of their home appropriate; and the price of the energy they use for these devices is expensive.

Table 3.2: Answers to the first part of questionnaire (By author, 2015)

Area(m^2)	People in One apartment	Most Used space In day time	Heating device	Cooling device	Used Energy type	Energy prices
75-150	2-5	Living room	Heater AC	ventilator AC	electricity Gas	Expensive

Second group of the questions were in terms of indoor temperature, relative humidity and fresh air inside the homes and resident's satisfaction with that. As a result if occupants use mechanical equipment less than usual, temperature and relative humidity would not be tolerable except in months of May, Sep and Oct. As seen in figures 3.3 to 3.5, these charts show the evaluation of the questions in a condition if residents use mechanical devices less than usual. Charts show the percentage of the total answers to the questionnaires. According to the charts indoor temperature is not appropriate in hot months (Jun, July, and August) and in cold months (January, February, March, April, November, December). Relative humidity is durable during cold times and not satisfaction in hot days. Interior spaces can gain fresh air during summer times. In letting fresh air inside, in winter, does not meet satisfactory level. Table 3.3 shows answers to the questionnaires in detail for each interior space as living room, kitchen and bedrooms which have been organized according to geographical direction of interior spaces.

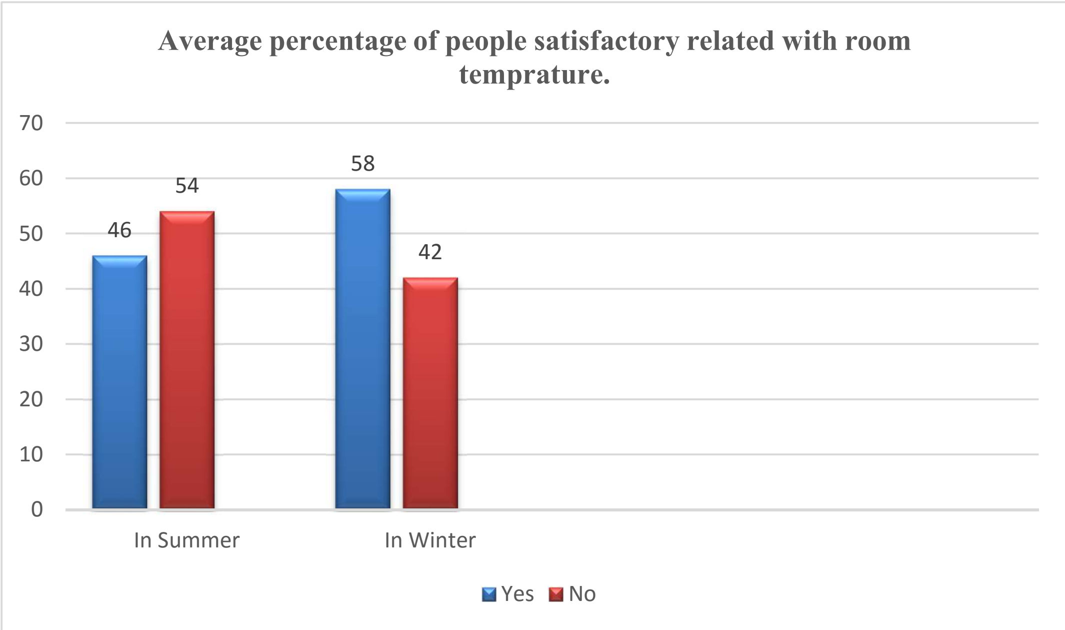


Figure 3.3: Is the indoor temperature appropriate in summer and in winter (By author, 2015)

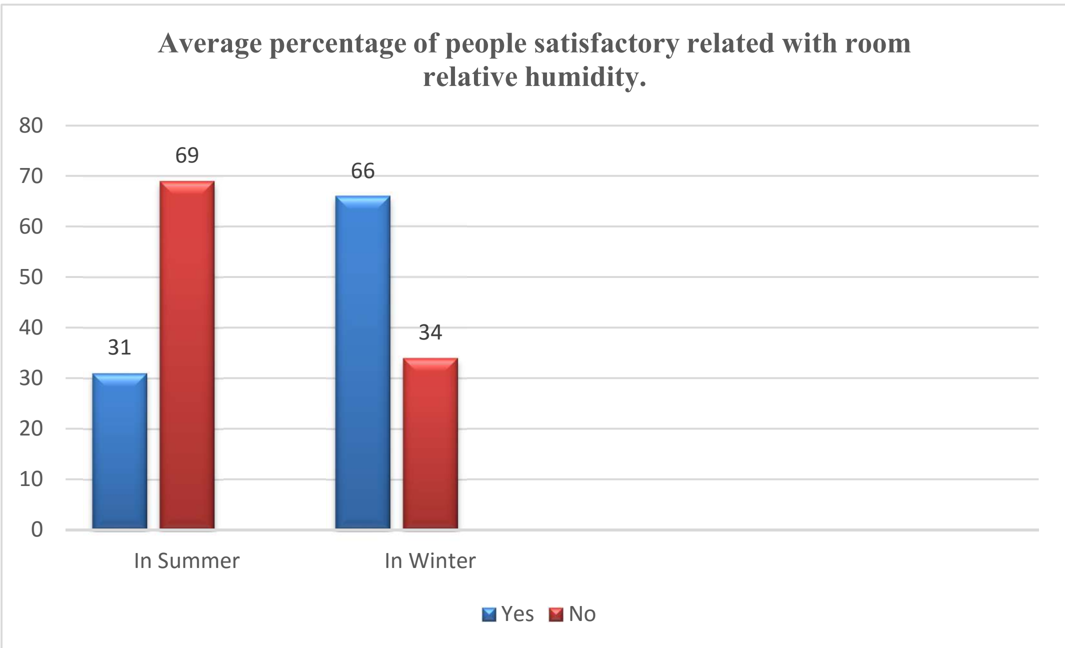


Figure 3.4: Is the indoor relative humidity appropriate in summer and in winter (By author, 2015)

The residents expressed that in summer time by opening the windows, air movement makes the indoor relative humidity endurable and it brings fresh air inside. In winter time because of the cold weather outside, residents do not open the window so that the humidity becomes annoying, wet washed cloths are not dried and smells caused by making food or smoking remains inside.

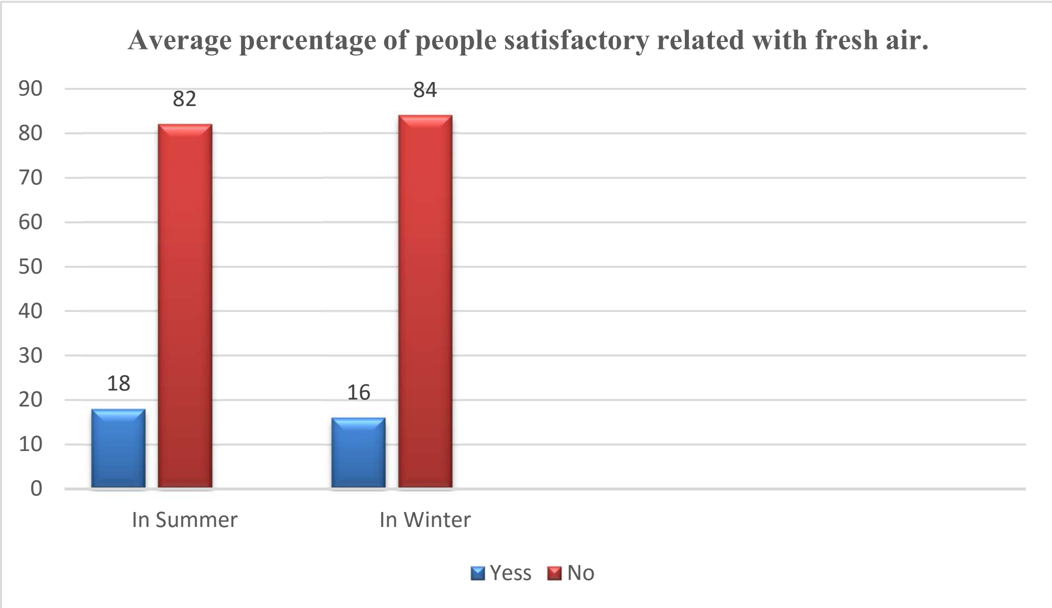


Figure 3.5: Does indoor spaces have fresh air in summer time and in winter time (By author, 2015)

Referring to introduction part and questions of the research (table 3.3) is prepared to discuss about levels of people satisfactory. Information for this table has been collected from the evaluation of the questionnaires. Interior spaces are categorized based on orientations toward geographical directions. In this case in addition to understanding levels of residents satisfactory of existing internal thermal condition of their homes, gaining the best organization of the interior spaces is the aim. Also, in the last column of this table people's suggestions in order to improve ventilation and thermal condition are given to see what residents expect and think about the current position.

Table 3.3: Residents' satisfactory level of internal climatic situation and their suggestions and solutions. (By author, 2015)

Interior Space	Opening orientation	Satisfactory in Hot months (Cooling)	Satisfactory in cold months (Heating)	Satisfactory of ventilation in hot months	Satisfactory of ventilation in cold months	Resident Suggested solution
Living Room	North	Satisfied	Unsatisfied	Satisfied	Unsatisfied	• Improvising windows in south part. • Changing the size of the windows to smaller ones. • Improvising more than one window in one room. • Improvising void near bathrooms and toilets. • Having windows inside one home in two opposite walls.
	East	Satisfied	Unsatisfied	Satisfied	Unsatisfied	
	South	Unsatisfied	Satisfied	Satisfied	Unsatisfied	
	West	Satisfied	Unsatisfied	Unsatisfied	Unsatisfied	
	South-West	Satisfied Unsatisfied	Satisfied Unsatisfied	Unsatisfied	Unsatisfied	
	South-East	Unsatisfied	Unsatisfied	Satisfied	Unsatisfied	
	North-West	Satisfied	Unsatisfied	Satisfied Unsatisfied	Unsatisfied	
	North-East	Satisfied Unsatisfied	Unsatisfied	Satisfied	Unsatisfied	
Kitchen	North	Satisfied	Satisfied	Satisfied	Unsatisfied	
	East	Satisfied	Satisfied	Satisfied	Unsatisfied	
	South	Unsatisfied	Satisfied	Satisfied	Unsatisfied	
	West	Satisfied	Satisfied	Unsatisfied	Unsatisfied	
	South-West	Satisfied	Satisfied	Unsatisfied	Unsatisfied	
	South-East	Unsatisfied	Satisfied	Satisfied	Unsatisfied	

Interior Space	Opening orientation	Satisfactory in Hot months (Cooling)	Satisfactory in cold months (Heating)	Satisfactory of ventilation in hot months	Satisfactory of ventilation in cold months	Resident Suggested solution
Kitchen	North-West	Satisfied	Satisfied	Satisfied	Unsatisfied	
	North-East	Satisfied	Satisfied	Satisfied	Unsatisfied	
Bed Room	North	Satisfied	Satisfied	Unsatisfied	Unsatisfied	
	East	Satisfied	Satisfied	Satisfied	Unsatisfied	
	South	Satisfied	Satisfied	Satisfied	Unsatisfied	
	West	Satisfied	Unsatisfied	Unsatisfied	Unsatisfied	
	South-West	Satisfied	Unsatisfied	Unsatisfied	Unsatisfied	
	South-East	Unsatisfied	Satisfied	Satisfied	Unsatisfied	
	North-West	Satisfied	Unsatisfied	Unsatisfied	Unsatisfied	
	North-East	Satisfied	Unsatisfied	Unsatisfied Satisfied	Unsatisfied	

3.3.2 Findings on Orientation and Roof Type

In this category wind pattern and its direction toward building envelopes are shown. Moreover, sun and shadows buildings make on other buildings in neighbors are displayed. In general orientation of buildings toward wind, sun and shadow costs created on neighbor buildings are investigated through site plans and pictures. In given figures of this part wind direction needed for ventilation especially in hot months which due to climatic information (Appendix F) is mostly from east, has been shown on plans as parallel vectors. North direction would help to realize the orientation of buildings toward sun.

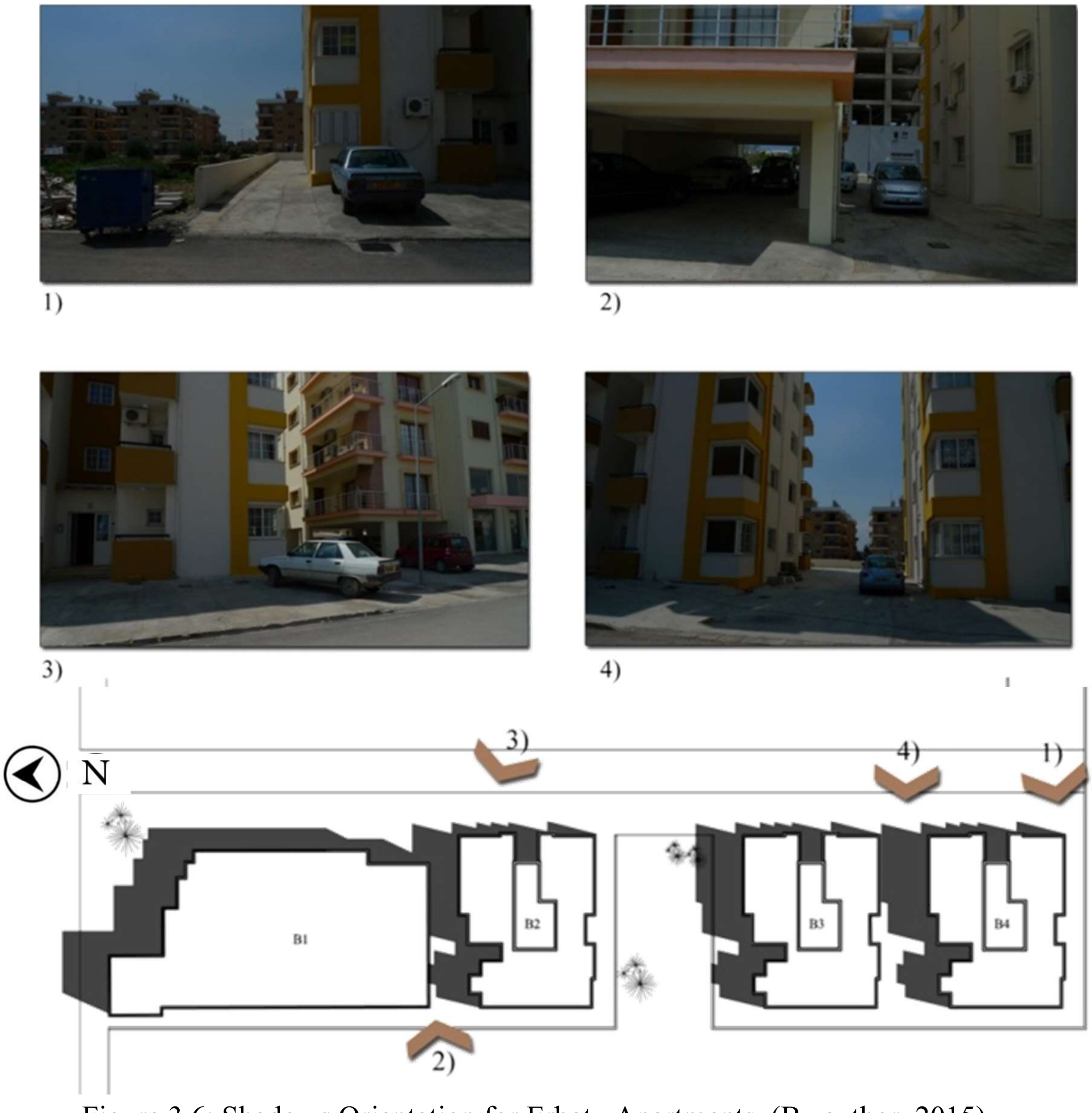


Figure 3.6: Shadows Orientation for Erbatu Apartments. (By author, 2015)

Shadow casts buildings create on each other are shown in (figure 3.6), while figure 3.7 is about the wind direction on top and sun radiation angles in the bottom. As it is shown shadow casts buildings make on each other are larger in winter time because of sun radiation angles.

Section below also shows the roof type of the buildings which are flat. Any elements of natural ventilation strategies have been seen in roof level.

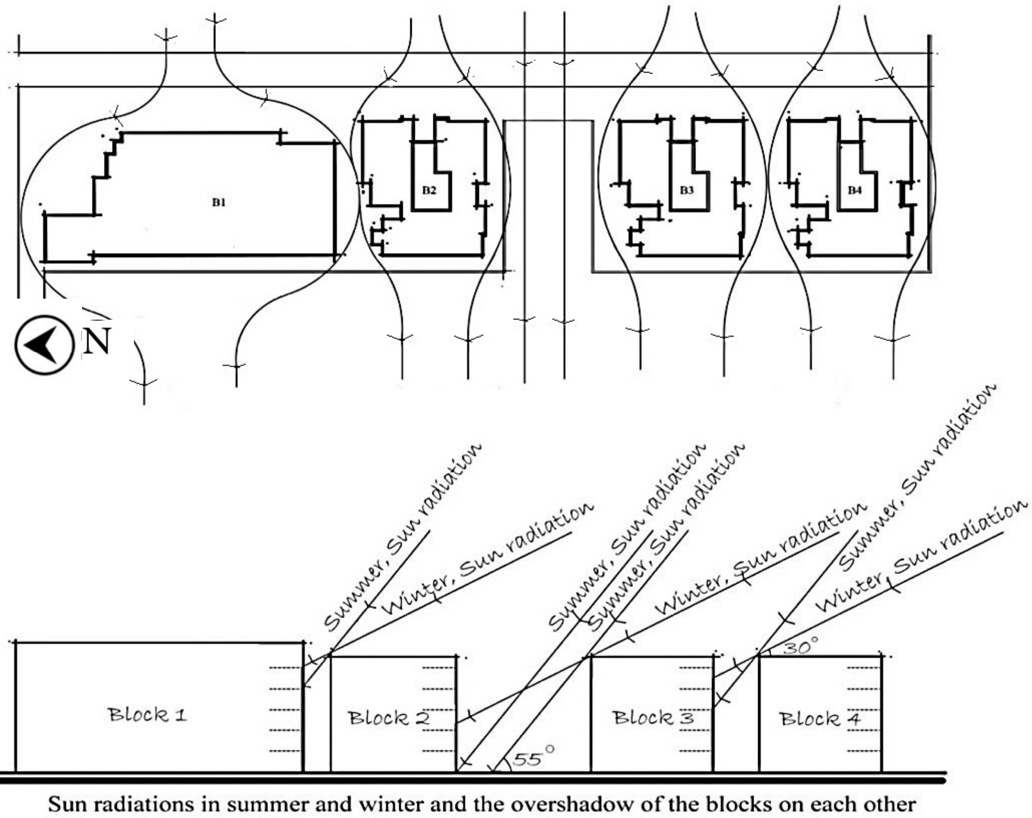


Figure 3.7: Wind patterns for Erbatu apartments (on top) and solar angles in summer and winter, roof types. (On bottom) (By author, 2015)

Wind pattern for Oncel apartment and Erozan apartment are shown in (figures 3.8 and 3.9) in site plans. Pictures show shadow casts in one hand, and roof types which are flat, on the other hand.

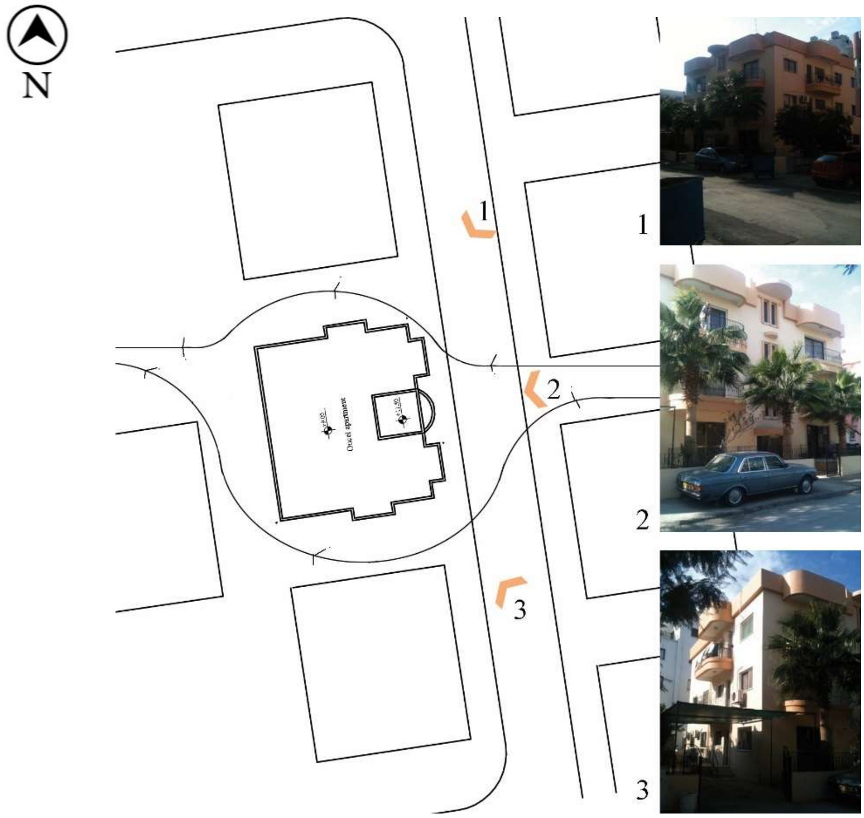


Figure 3.8: Wind pattern, solar shadows and roof type for Oncel apartment. (By author, 2015)

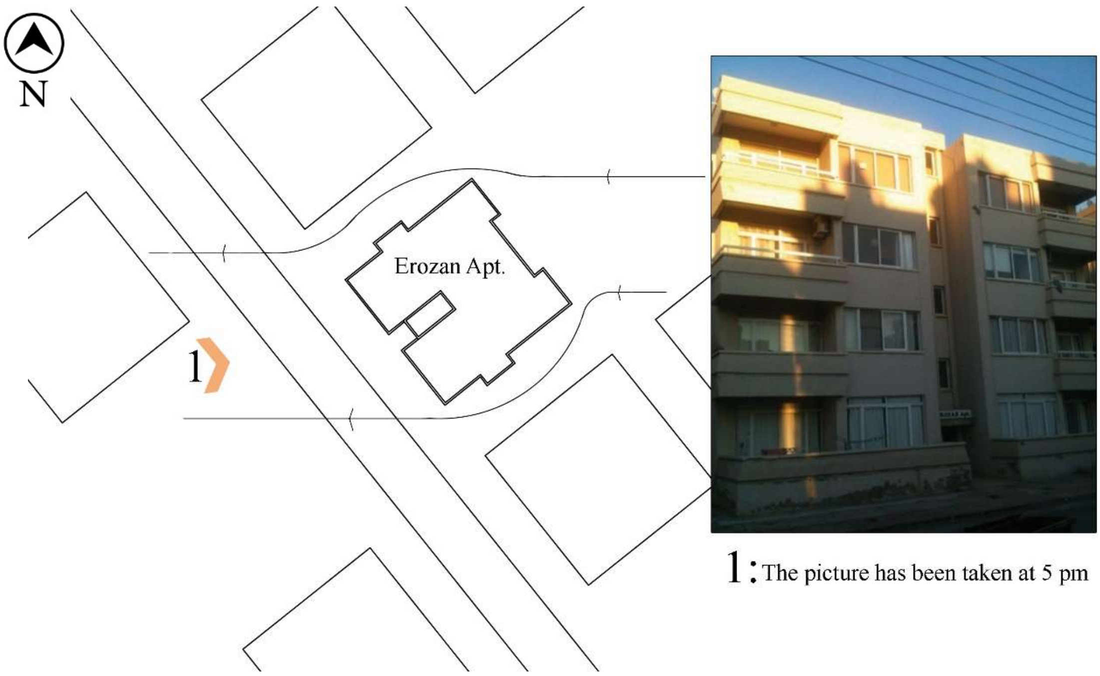


Figure 3.9: Wind pattern, solar shadows and roof type for Erozan apartment. (By author, 2015)

Figure 3.10: Wind pattern and roof type for Dovec no37 apartment. (By author, 2015)

Figure 3.11: Wind pattern and roof type for Dovec no33 apartment. (By author, 2015)

Wind patterns in site plans for Dovec NO: 37 apartment and Dovec NO:33 apartment are shown in figures 3.12 and 3.13. Pictures beside can display the roof types which are flat with no sign of natural ventilation elements on them. Same flat roof type can be seen in figure 3.14 for mezkoop apartments. Also wind pattern, distance between the buildings and shadow casts have been tried to be shown in mentioned figure.

Figure 3.12: Wind pattern, shadow casts, distance between apartments and roof type for Mezkoop apartments. (By author, 2015)

Flat roof with no natural ventilation element, wind patterns in site plan and shadow casts for Uzun12 apartment, Uzun14 apartment and Uzun10 apartment are shown in figures 3.13, 3.14 and 3.15.

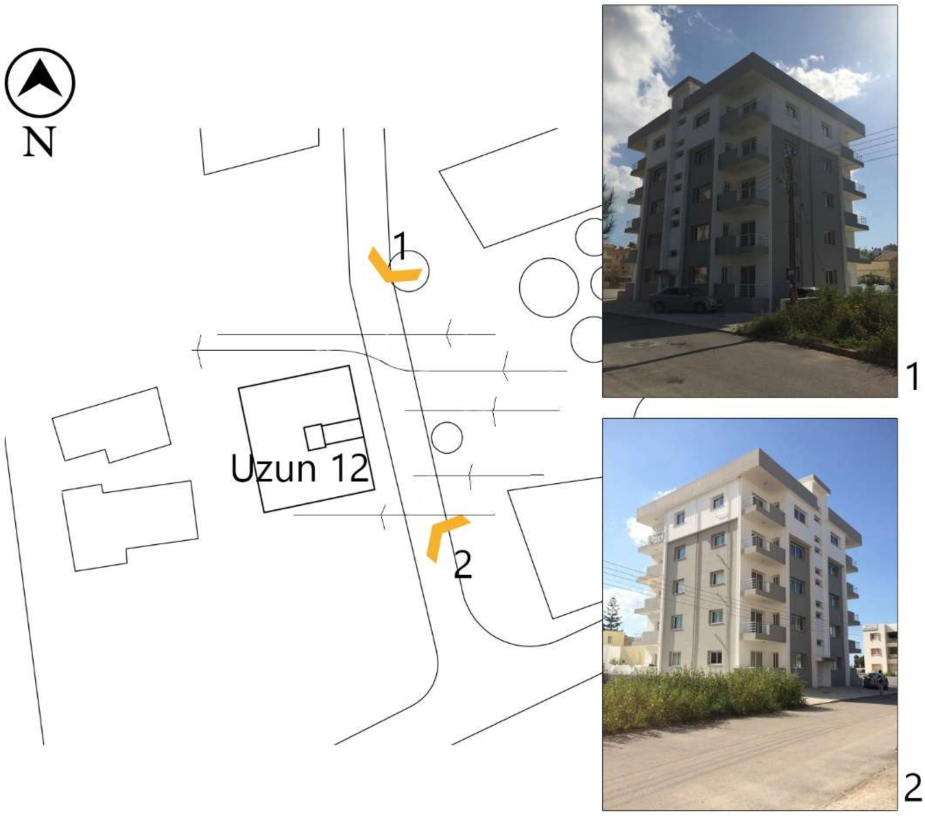


Figure 3.13: Wind pattern, solar shadows and roof type for Uzun 12 apartment. (By author, 2015)

Figure 3.14: Wind pattern, solar shadows and roof type for Uzun 14 apartment. (By author, 2015)

Figure 3.15: Wind pattern, solar shadows and roof type for Uzun 10 apartment. (By author, 2015)

As a result in general, buildings are located in the middle of their sites. Total shape of them is cubic, rectangular or foursquare with no longer axis or if they have a longer axis, it is west-east oriented or north-south oriented with maximum 45° rotation, so that it does not follow any specific rule. Distance between one building and the building beside it is around 4.5-9m. Each building is surrounded maximum with three other buildings. Roofs are flat and there is no sign of any natural ventilation strategy's symbol on them.

3.3.3 Findings on Design and Interior Spaces Organization

In all sample apartment interior space organization is typical (repeated) in each floor. In some buildings according to building height rules from municipality and in order to make a penthouse, only the interior design organization of last floor is different from the other floors. Typical plan of the buildings are given in this part trying to show the relation between the interior spaces and their organization. Study of these plans may clarify which of the spaces can absorb direct sun radiation or is facing the wind direction. Since windows as openings are shown in plans, and effective wind direction is from east, plans may demonstrate also the situation of interior spaces toward air movement and ventilation.

Figure 3.16: Design and interior space organization of "Erbatu" apartmen 1. (By author, 2011)

No horizontal shading and balconies is seen in south side of Erbatu1 apartment envelope as shown in figure 3.16. Three home units are located in each floor of the building with interior space organization as displayed.

Organization of interior spaces and wind direction for Erbatu 2-4 apartment and Oncel apartment can be seen in figures 3.17 and 3.18. Except the balcony beside kitchen space of Oncel apartment, there is no balcony or vertical shadings in south part of the buildings. Any element of natural ventilation strategies can be recognized in architectural design of those.

Balcony as a vertical shading can be seen in south part of the Erozan apartment in (figure 3.19).

Figure 3.17: Design and interior space organization of “Erbatu” apartment 2-4. (Erbatu co., 2011)

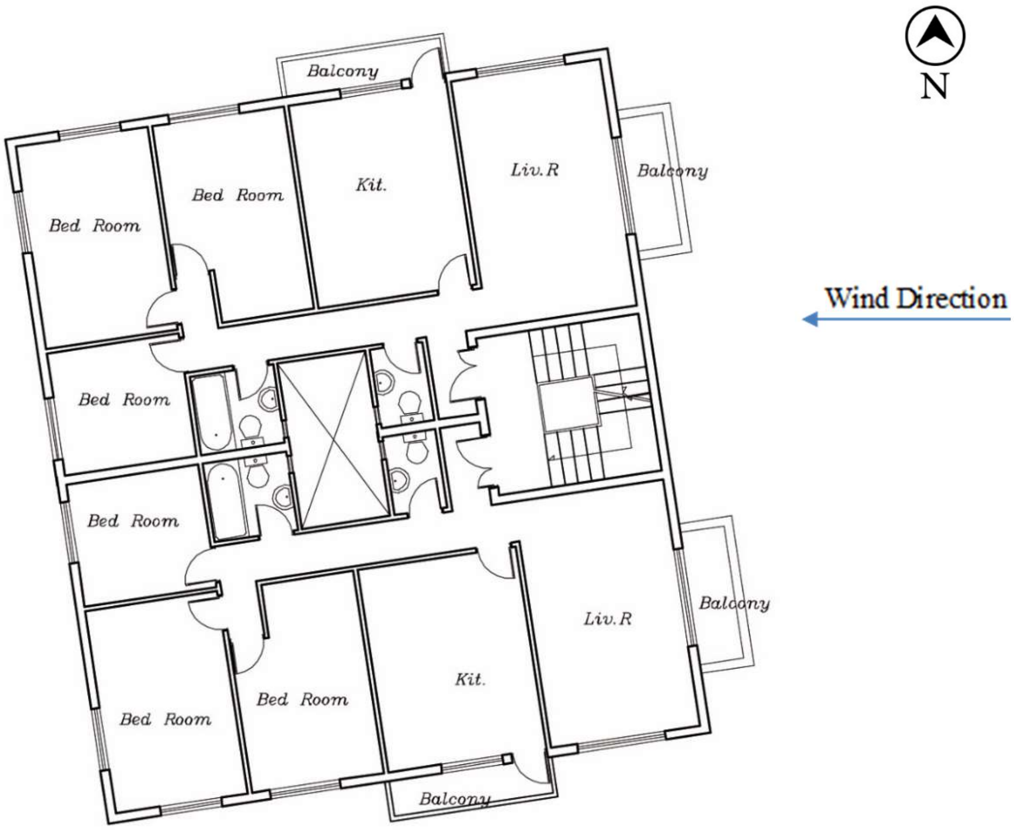


Figure 3.18: Design and interior space organization of “Oncel” apartment. (By author, 2013)

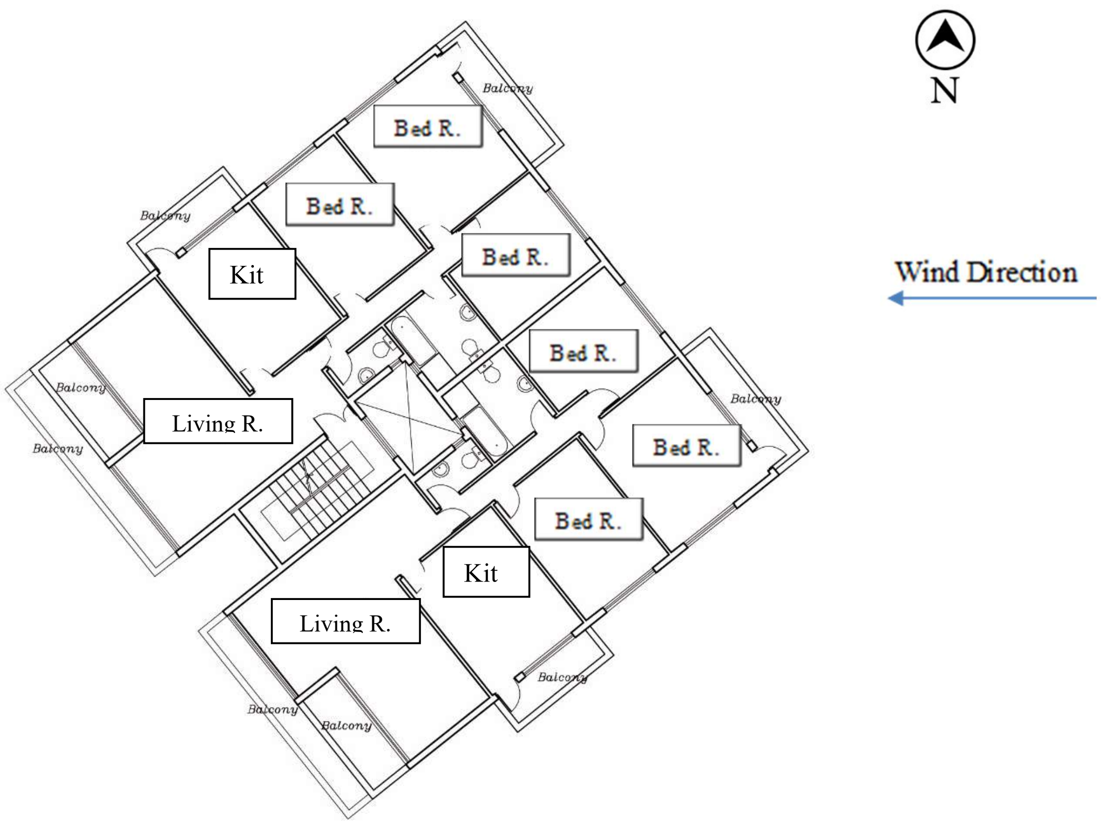


Figure 3.19: Design and interior space organization of “Erozan” apartment. (By author, 2013)

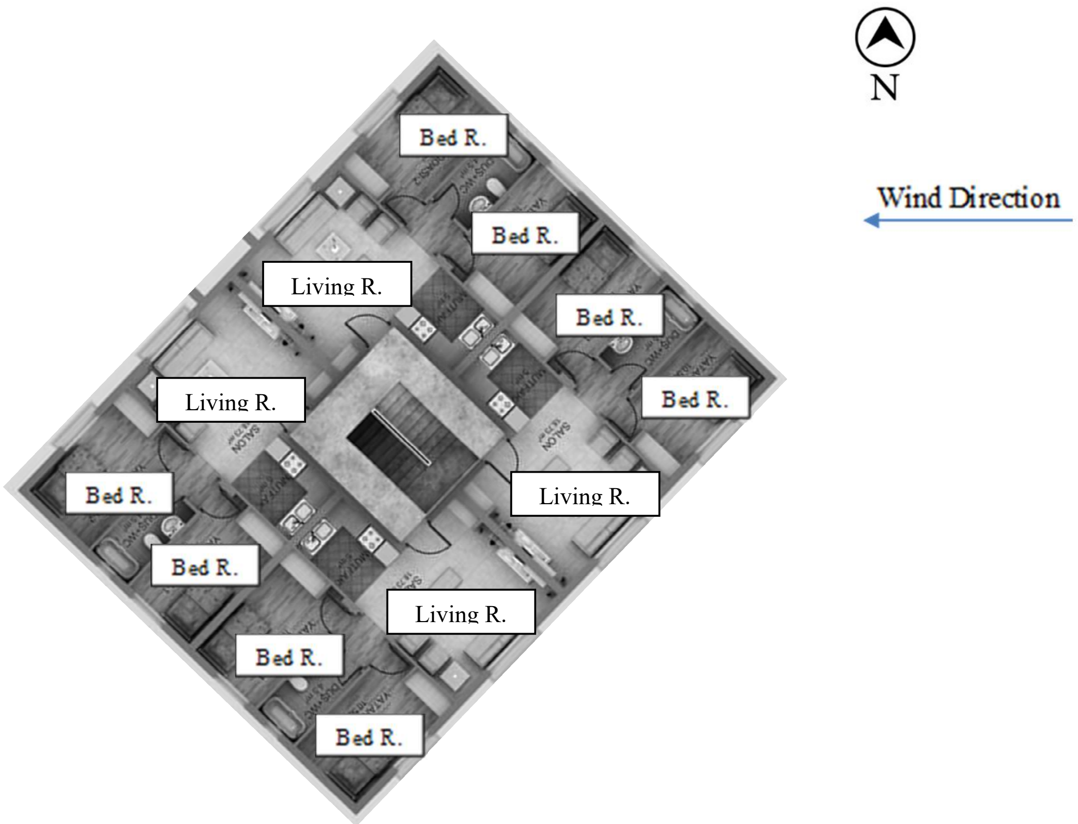


Figure 3.20: Design and interior space organization of Dovec no37Apartment. (Dovec co., 2013)

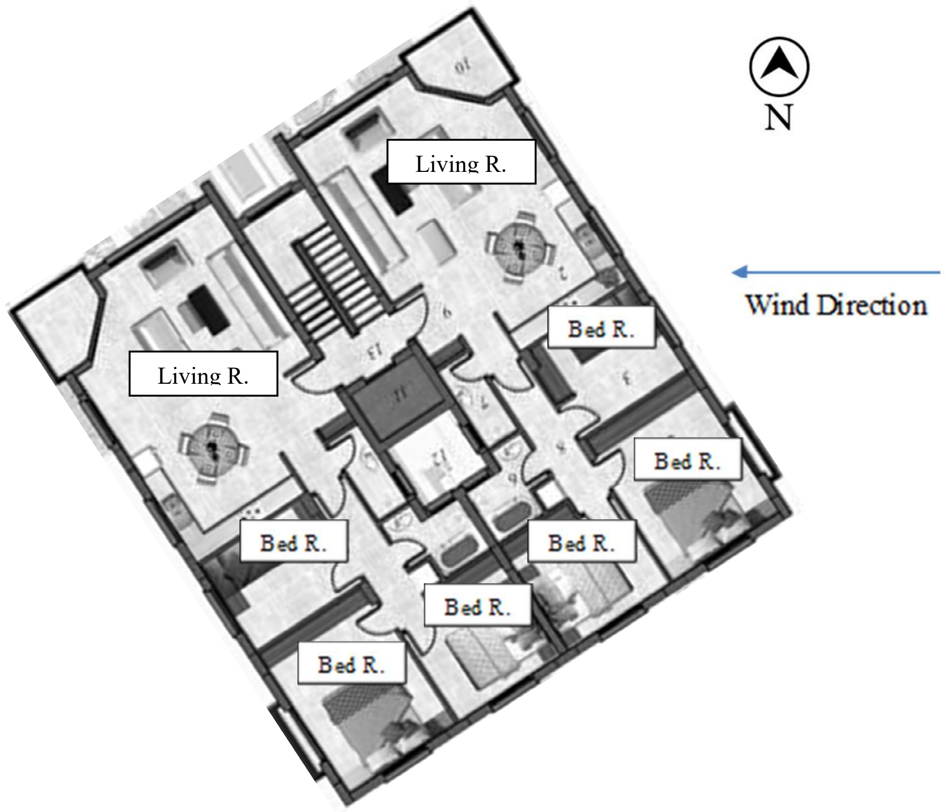


Figure 3.21: Design and interior space organization of Dovec no33Apartment. (Dovec co., 2013)

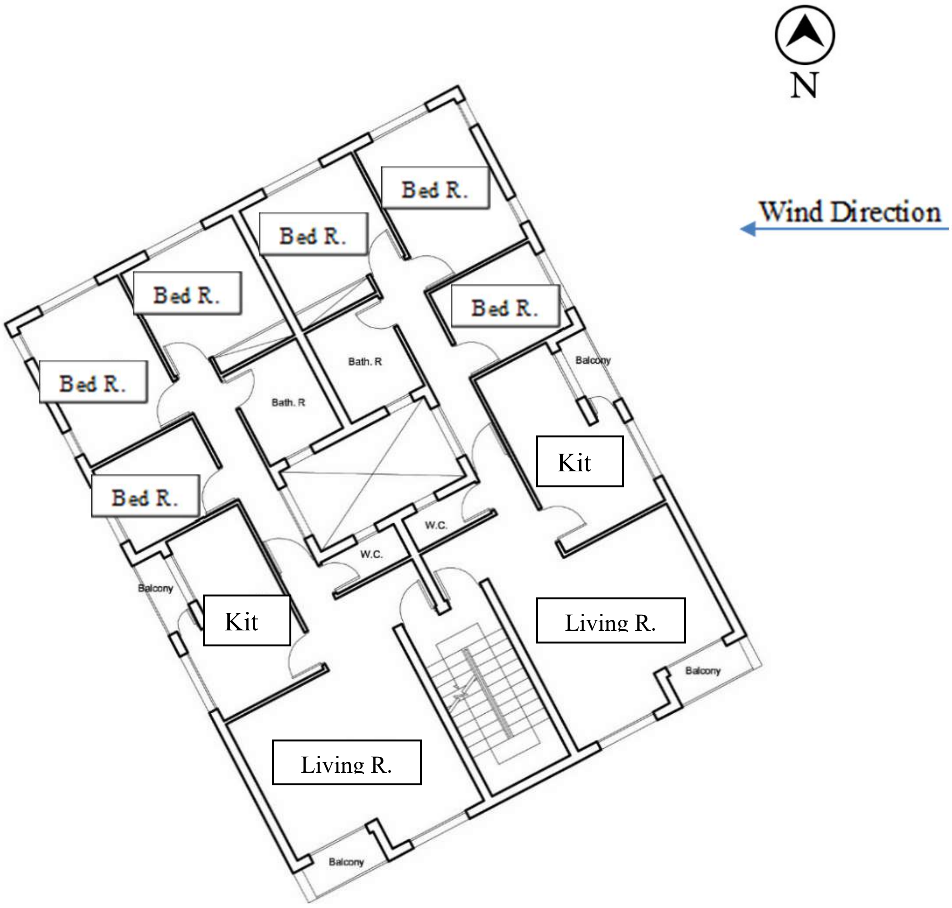


Figure 3.22: Design and interior space organization of Mezkoop. (By Author, 2015)

Figure 3.23: Design and interior space organization of Uzun 12 apartment. (Uzun Co., 2015)

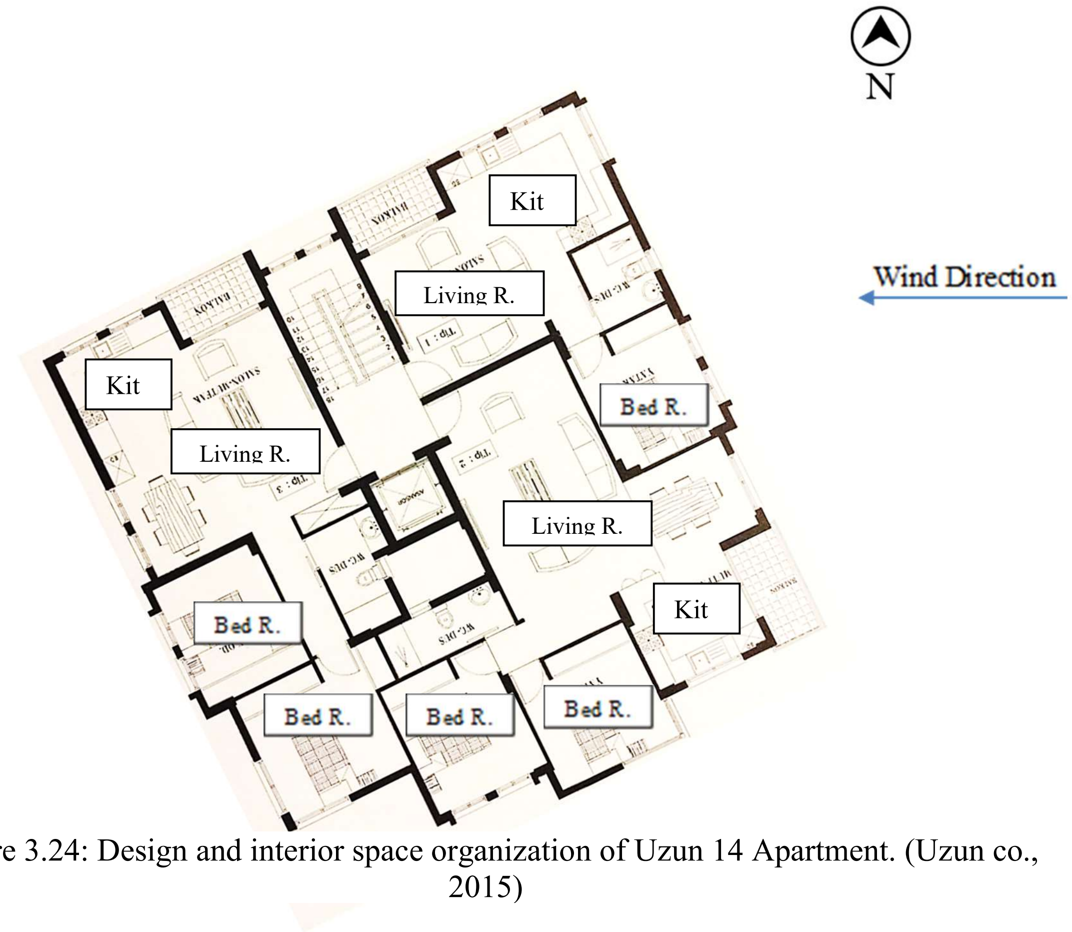


Figure 3.24: Design and interior space organization of Uzun 14 Apartment. (Uzun co., 2015)

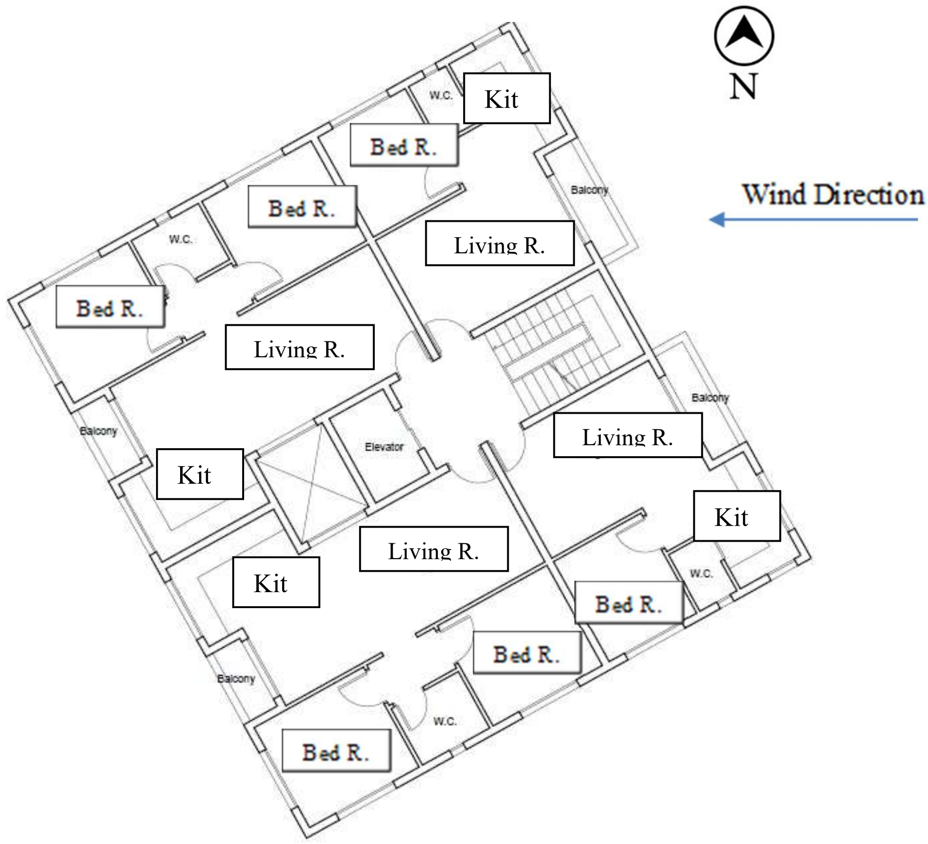


Figure 3.25: Design and interior space organization of Uzun 10 Apartment. (By author, 2015)

No elements of natural ventilation strategy can be seen in figures 3.20 to 3.25 which shows design and interior space organization of other sample apartments.

To sum up, in each floor there are two or more houses designed beside each other and in most of the cases they are symmetry. shape of the plans are aggregated while zone of the kitchen and living room are separated from the bedroom and bathroom zone which in most of the cases are divided or dividable with a door. There is a vertical duct in core of the buildings which can be conceived as a vertical air path. Each space, inside, has openings in one side or more depending on the side or edge in which they are located. Half of the windows surfaces are open able vertically.

3.3.4 Findings on Facade Characteristics

Facades for all apartments are very simple. Window openings and shadings on them which can be seen on south and west side windows, are the only characteristics of the facades. The only natural ventilation strategy element which can be seen in facades are the openings as windows. Following the topic discussed in 2.1.3.8 part of this thesis about size of the openings in the facade, as instance, in table 3.4, average ratio of window surface to the wall surface which it is embedded and average ratio of window surface to the floor surface of the space which it is located, in four samples (case 1, 2, 3 and 4) are given as an example.

In general, facades are simple (not double skinned or anything special) and there are solar shadings usually on their south and west sides. Openings are the only natural ventilation strategy characteristic of the facades. Surface of these openings are generally between 13-37 percent of the wall surface they are located in and sometimes rarely more than that, and between 10-37 percent of the area surface they serve.

Table 3.4: Percentage of windows to floor and wall surface areas (By author, 2013)

		Surface Percentage of window to wall	Surface Percentage of window to floor
Erbatu 1	Kitchen	13.6	10.9
	Living room	24.9	37.2
	Bed room	17.2	16.8
	Master bedroom	25.6	29.2
Erbatu 2-4	Kitchen	20.0	34.8
	Living room	21.5	14.5
	Bed room	17.5	13.0
Oncel	Kitchen	26.8	35.7
	Living room	31.8	19.8
	Bed room	20.6	13.9
	Bed room	14.7	24.3
	Master bedroom	20.0	20.2
Erozan	Kitchen	73.3	45.7
	Living room	37.5	23.9
	Bed room	23.8	15.2
	Bed room	25.1	30.0
	Master bedroom	22.2	17.9

3.3.5 Finding on Materials of Buildings

Contemporary apartments of Famagusta has reinforced concrete structure. Exterior walls are made of 25 cm blocks with cement plaster plus color covering both sides. Internal walls from blocks have 10 cm thickness and are covered by cement plaster and color. Concrete slabs with thickness of 15 cm create floors which are covered usually with ceramic or mosaic tiles. Slab of the roof is covered by moisture insolation from outside and color pain from inside. Table 3.5 shows the U-value of wall, floor and roof of the buildings.

Table 3.5: U-value of wall, floor and roof of the apartments (Ozdenefe and Dewsbury, 2005)

material	wall	floor	roof
u-value[3] w/m^2k	0.69	1.9	3.5

It should be notified that a good insulating surface has a u-value near to zero. According to ASHRAE a good u-value for wall is not more than 0.3 w/m^2k and for roof it is not more than 0.15 w/m^2k. As these numbers increase, quality of insulation decreases. Table shows that u-value calculated for wall and roof of the case studies is more than expected numbers (ASHRAE, 1997).

3.4 Discussions

3.4.1 Discussion on Results of Questionnaire

According to the table residents feel comfortable with internal climate condition in hot months, inside North, west, east, north-west and north-east located living rooms. Matching the answers with plans of the houses shows that living rooms located in south parts does not have balconies behind windows so that direct sun radiation inters those spaces in summer times, windows are too big which convert sunlight to heat or are too small which does not let air movement happens easily.

[3] "A U value is a measure of heat loss in a building element such as a wall, floor or roof. It can also be referred to as an 'overall heat transfer co-efficient' and measures how well parts of a building transfer heat. This means that the higher the U values the worse the thermal performance of the building envelope is. A low U value usually indicates high levels of insulation." The unit is w/km2 as watt/kelvin sq. meter. (Brennan, 2013)

Satisfactory situation, about kitchen, in hot times is in all directions except in south and south-east directions which according to resident's opinion this unsatisfactory is because of high temperature inside those directions.

In bedrooms finally, in hot times all directions feel thermally comfortable except south-east directed ones which the reason mentioned by residents is uncomfortable and hot early sunlight in the mornings.

In cold seasons, according to resident's point of view, living room climate feels comfortable when it is located in south part. They emphasize that kitchen does not give uncomfortable feeling in relation to climate in any direction and bedrooms are too cold when they are located in west, north-west, and north-east or south-west side of the building.

Ventilation in hot time acts satisfactory while windows are located in east, north-east, and south-east edges of the building. Moreover, residents are satisfied by air movement of south, north and north-west located rooms. In cold times, ventilation never met satisfactory level. Residents believe that ventilation is necessary in cold times to remove interior pollution (which is made from smoking tobacco and cooking) and humidity; however, it makes inside thermal situation to become low and cold.

According to the space orientation inside the building envelope, toward geographical directions and the answers have been compromised with the interior plan organization of the buildings and the site planes which shows the buildings orientation toward sun and wind direction, some results and conclusions can be gained:

Because residents spend their day time inside living room, when it is located in south part of the building envelope, they feel satisfied inside in cold times and dissatisfied in hot times when there is no horizontal shadings above the windows. So that if living room be located in south part it meets satisfactory level in cold times and if it have a vertical shading above its opening it can meet the satisfactory levels in hot times also. Paying attention to the ventilation factors show that there is a need of at least two openings inside this space to let air movement easily. These minimum inlets should not be located both in the west side of the building envelope.

Residents spend lots of time in kitchen during day time. Because of cooking kitchen does not become too cold during winter time, however, if it is located in south part it will be too hot in summer times. So any direction except south, with at least one opening in its wall can be appropriate for locating kitchen.

Due to night time usage of bedrooms, these spaces need to be warmed during day in cold months and be ventilated during hot times. Residents believe that when bedrooms are located in south-east, early warm sunlight irritates. Therefore, referring to their opinion best bedrooms location is in east side of the building.

Answers related to ventilation shows that spaces with more than one opening could be ventilated better. Large openings helps better ventilation in hot times however it makes inside spaces cold in winter time. Spaces with no openings, or houses which have all openings in leeward side of the building envelope does not become ventilated in satisfactory level. Ventilation during cold times is always a problem, residents believe. Because opening the windows are the only way to ventilate inside air and it makes inside temperature lower than comfort level.

3.4.2 Discussion on Orientation and Roof Type, Design and Interior Space Organization, Facade Characteristics and Material of the Buildings

Five criteria can be categorized according to chapter two of this research raising as: Single ventilation, Cross ventilation, Stack ventilation, Night cooling ventilation and tempering incoming air to clean indoor pollution ventilation

Checking those in cases will clear three topics as: Ability of building envelope to control over heating in hot months to ventilate inside when outdoor temperature is below indoor temperature by air exchanging, Ability of building envelope to control over heating in hot months to ventilate inside when outdoor temperature is equal or more than indoor temperature by increasing the air speed and Ability of building envelope to control air pollution coming from cooking, smoke and etc. in cold months as comfortable air exchange which does not lessen the indoor temperature tangibly.

To find out these, sample buildings are judged on their: Glass glazing area (windows), Openable windows, Building orientation toward wind and sun directions, Height of the floors, Height of the whole building and its distance from other buildings in south and east side, Thermal mass capacity and Existence of natural ventilation strategies.

(Table 3.6) shows advantages and disadvantages of the apartments studied as selected cases, in relation to architectural ventilation design parameters. These parameters rely on initial architectural design of a building which can be counted as architect's responsibility in line with designing building exterior and interior spaces; It is noteworthy to remind that these arrangements aim to help reducing usage of mechanical equipment and as mentioned, are not quantified (not modeled and computer based analyzed) answers for internal thermal situation and they are qualified ones as experienced key solutions from literatures.

Table 3.6: Advantages and disadvantages of the apartments chosen as case study. (By Author, 2015)

Name of Apartment	Advantage	Disadvantage
Erbatu 1 apartment	- Openable glazing areas. - Building located in middle of the site. - Free land in east part of the building.	- Single sided ventilation for most spaces. - Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having south facing spaces in all units. - In one unit all windows are in the leeward side and in one unit all windows are in the windward side. - Not enough space between two buildings in the south part. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor.
Erbatu 2,3&4 apartment	- Openable glazing areas. - Building located in middle of the site. - Free land in east part of the building.	- Single sided ventilation for most spaces. - Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having south facing spaces in all units. - . Not enough space between two buildings in the south part. - Not having any natural ventilation system. - Not having insulation in exterior walls.

Name of Apartment	Advantage	Disadvantage
Erbatu 2,3&4 apartment		- One glazed windows. - Not having heating insulation in roof floor.
Oncel apartment	- Cross ventilation for most of the spaces. - Openable glazing areas. - Building located in middle of the site. - Free land in east part of the building.	- Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having south facing spaces in all units. - Not enough space between two buildings in the south part. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor.
Erozan apartment	- Enough window surfaces area percentage to wall and floor surface area for summer ventilation. - Balconies working as shading on south part. - Openable glazing areas. - Building located in middle of the site. - Free land in east part of the building. - Free land in south part of the building.	- Single sided ventilation for most spaces. - Not having south facing spaces in all units. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor. - Not coverable glazing surfaces for winter times.
Dovec no37 apartment	- Openable glazing areas. - Building located in middle of the site.	- Single sided ventilation for most spaces. - Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having south facing spaces in all units.

Name of Apartment	Advantage	Disadvantage
Dovec no37 apartment		- In one unit all windows are in the leeward side and in one unit all windows are in the windward side. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor. - Not enough space between two buildings in the south part.
Dovec no33 apartment	- Cross ventilation for most of the spaces. - Having south facing spaces in all house units in one floor. - Openable glazing areas. - Building located in middle of the site.	- Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor. - Not enough space between two buildings in the south part.
Mezkoop apartment	- Balconies working as shading on south part. - Having south facing spaces in all house units in one floor. - Openable glazing areas. - Building located in middle of the site. - Free land in east part of the building. - Free land in south part of the building.	- Single sided ventilation for most spaces. - Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor.

Name of Apartment	Advantage	Disadvantage
Uzun 12 apartment	- Openable glazing areas. - Building located in middle of the site. - Free land in east part of the building. - Free land in south part of the building.	- Single sided ventilation for most spaces. - Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having south facing spaces in all units. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor.
Uzun 14 apartment	- Cross ventilation for most of the spaces. - Openable glazing areas. - Building located in middle of the site.	- Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having south facing spaces in all units. - In one unit all windows are in the leeward side and in one unit all windows are in the windward side. - Not enough space between two buildings in the south part. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor.
Uzun 10 apartment	- Cross ventilation for most of the spaces. - Openable glazing areas. - Building located in middle of the site. - Free land in east part of the building.	- Small window surfaces area percentage to wall and floor surface area for summer ventilation. - Not having shading on south windows. - Not having south facing spaces in all units.

Name of Apartment	Advantage	Disadvantage
Uzun 10 apartment		- Not enough space between two buildings in the south part. - Not having any natural ventilation system. - Not having insulation in exterior walls. - One glazed windows. - Not having heating insulation in roof floor.

According to this table some disadvantages such as small window surfaces area percentage to wall and floor surface area for summer ventilation and not having south facing spaces in all units are noteworthy in most of the cases and not having any natural ventilation system, not having insulation in exterior walls, one glazed windows and not having heating insulation in roof floor are mentioned in all studied cases. In some cases, homes in one floor just have cross ventilation when doors are open and all spaces have direct connection to each other, otherwise each space just may have single sided ventilation. Another disadvantage for some buildings is the way homes are oriented in one floor which makes some units have all windows in leeward side and other unit having all windows in windward side.

Advantages and disadvantages of the apartments, in one hand, and general characteristics of the apartments, given before, in the other hand, lead us to some conclusion about typical positive points and negative points of the new constructed middle raised apartments of the city Famagusta.

Small distance between buildings block wind when it is in east-west direction and blocks sun radiation gain when it is in south-north direction. On the other hand, being located in the middle of the site, openable glazing areas in all cases and having free land in south part to gain the south direct sun radiation also having free land in east part to get wind direction has been counted as advantages. There should be distance between buildings according to height of them in a way that in south part one buildings shadow does not stop the other building from gaining direct south sun radiation, also in east part so that all buildings get summer wind from east side. In case studies, some buildings have shadow of other buildings in south which brings low temperature in cold times and some, because of having other building close in east part, does not get wind directly. In addition to all mentioned subjects of the list it should be stressed that locating building in middle of the site can be counted as an advantage which were seen in all case studies.

Having home units with all windows in a side of building which is in the leeward side, causes lack of ventilation in that units, so that it is not a good idea. Also it is better to have home units which have windows in at least two side of the building unit to have a good air movement by opening the windows. Some case studies with more than two units in one floor face this problem. There is a serious need of windows and openings in south side of the building. These openings should be supported by horizontal shadings to prevent over heating in hot times. Balcony can act as a shading which defines a space. Not all units in the cases have spaces in south parts, and if there are south facing oriented windows, there is no vertical shadings or balconies improvised. Mentioned before, for organizing interior spaces, designers need to follow an order and pay attention to where locate which space. Based on residents' point of view, having living room in south, kitchen in north and bedroom in east in a home is appropriate. In case studies there is not such an organization in interior spaces.

There is a need of big openings for enough air exchange in hot times to remove humidity and reduce air temperature. These openings should be coverable in cold times to prevent a big glass surface which cause air temperature loss in all sides of building envelope except day time south sunlight. Some case studies suffer from lack of enough opening in summer and some others from too much glass surface in winter time.

Material of wall and roof should be chosen from the ones with more heat capacity. Insulation can help to reduce u-value and increase R-value. Also double glazed windows should be used.

3.5 Suggestions for Better Natural Ventilation Based Design in Famagusta

Since it should not be forgotten that the focus of this study is on ventilation, it should be highlighted that in none of the cases have been studied, natural ventilation system or strategy exist. Even openings as windows are not efficient to play the role of natural ventilation element for building envelope. This note causes to not having enough air exchange in hot time or cold time without help of mechanical devices.

This far, surveys about middle raised apartments in North Cyprus, the city Famagusta, clarified advantages and lacks of these constructions in relation to internal climate condition of the buildings. List of problems in one hand, and the natural ventilation systems and strategies, which have been introduced in chapter two, on the other hand, help this research to give some solutions based on the suggested solutions and appropriate natural ventilation strategy, to decrease design lacks of those apartments, as much as possible.

It is appropriate that building be located in the middle of the site. Orientation of the buildings and the distance between them should be in a way that they do not block each other from east wind direction and south sun radiation.

According to residents' opinion, Order of the interior spaces are better to be in preferred directions. Each home unit should have at least windows in two sides of the building envelope to ease cross ventilation across the spaces. In hot times by opening the door between spaces, ventilation can be possible while in cold times by closing the door each space may get controlled separately.

South windows should have balconies as horizontal shadings. Opening sizes should have been calculated to be appropriate for air exchange in summer time. Part of these openings are suggested to be covered by a good insulating material in winter. Openings for ventilation in cold times are considered to be separated from window openings and summer ventilation openings. Winter ventilation openings are suggested to be in a way that they can increase the incoming air temperature and bring it near to interior air temperature.

Wall and roof materials should have been tried to be collected from the ones with big thermal capacity and small u-values.

Between the natural ventilation strategies introduced in chapter two, in addition to opening in the facade, chimney and wind scoop are suggested to be used for middle raised apartment buildings natural ventilation in Famagusta. Small ducts, located between the rooms can be an efficient space to act as local exhausts for the chimneys while openings act as the local inlets or it can act as a local inlets while openings act as local exhausts. Openings in the top of the chimneys or wind scoops are suggested to be controllable so that they can be opened as much as need of air exchange amount in summer and it be possible to close them in cold times to prevent air exchange. In letting outside fresh air to the building envelope can be helped by locating controllable fans inside the inlets to use in needed times. Location of the small ducts which can be improvised between interior spaces of the homes depends on space organization design. As an instant duct can be located between two bedrooms or between bedroom and living room. It should be mentioned that the building is better to be located at the middle of the site to have air movement in all around. Ventilation openings in the façade can be mixed with windows. This kind of window should be divided in small parts to be controllable for opening surface and it can be opened completely in summer time to have maximum air exchange. This window can be coverable in some parts in winter time with a dark material. This material can get the heat from the sun radiation which have passed through glass in daytime and give it to the interior spaces during night time. Small openings for winter ventilation can be located in top and bottom of the window. These small openings give more speed to the air exchange while amount of exchanged air would not be big.

Table 3.7 shows a schematic plan and section of the building envelop where ducts are located and the openings in the facade which work together. In sections, in the case that the wind scoop faces wind. It can take wind inside and lead it outside from the openings in the facade. This wind collects heat in the way outside.

In the same section, in the case that chimney does not face the wind direction, so there will be negative pressure on top of it. This makes air movement from positive pressure of the openings in the facade to negative pressure by stack ventilation. This air movement collects heat on its way out. Finally the same section works in a position that there is no wind and not enough wind speed. If the material of the top of the chimney be in a way that it gets warm by sun radiation, there will be higher temperature on top of that. So air moves from lower temperature in openings of the facade to the chimneys by stack ventilation taking heat outside with it. Result of the suggestions based on this research can be seen in this table.

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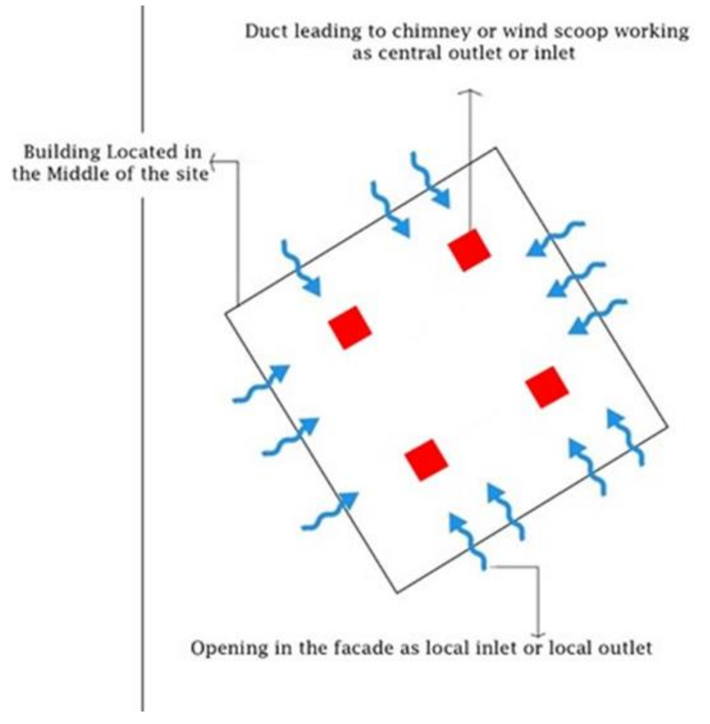
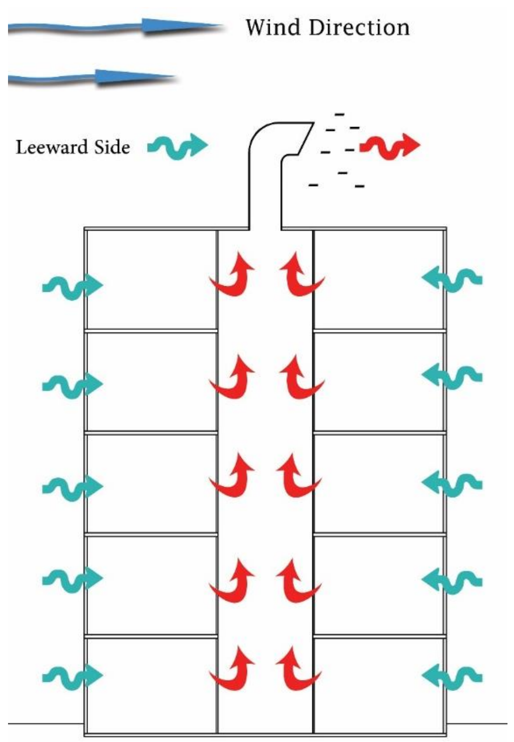
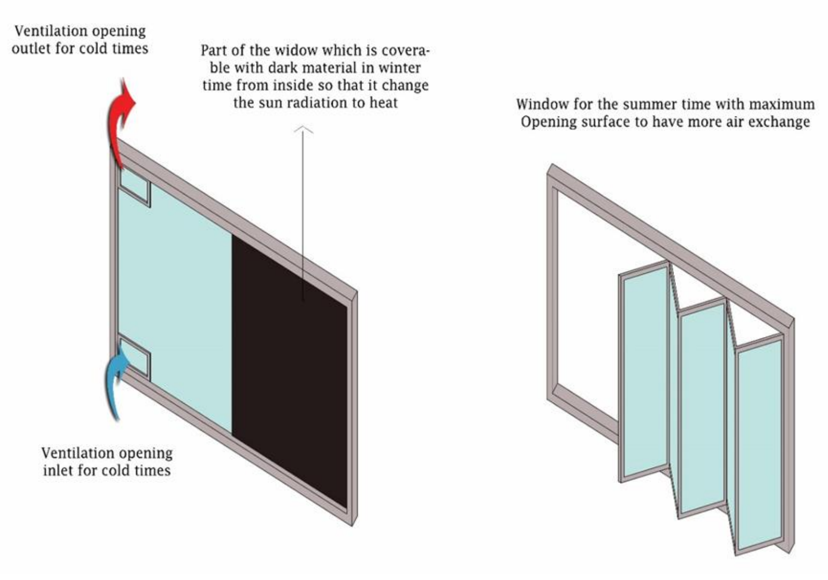
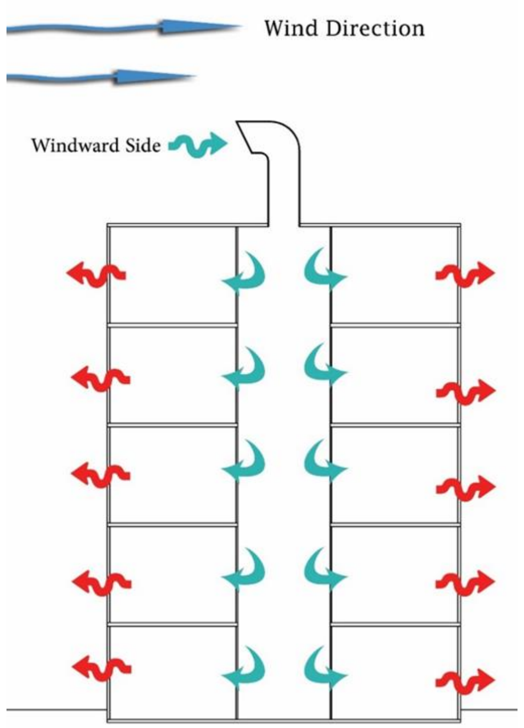
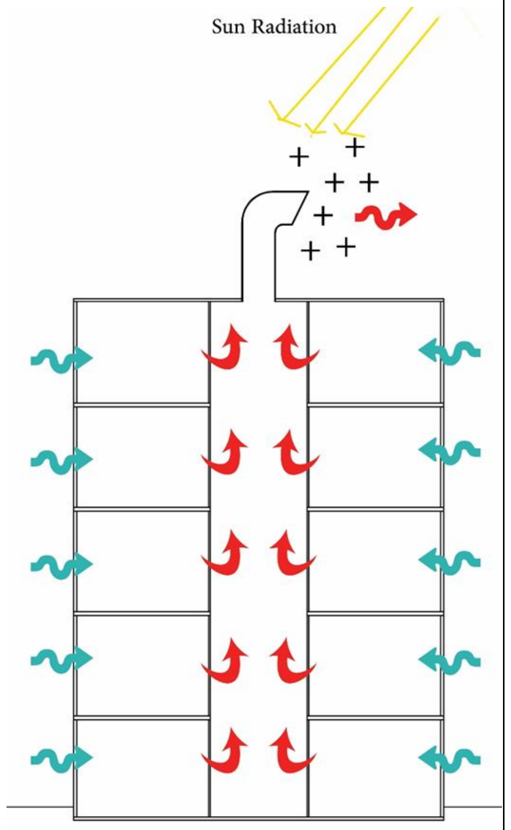
Table 3.7: Suggested natural ventilation strategy for residential apartments in Famagusta (By author, 2015)

Suggestion	explanation	Suggestion	explanation	Suggestion	explanation
	Schematic plan of the floors showing imaginary ducts and openings in the facade.		Section of the suggested apartment building with chimney not facing the wind direction.		Window type for ventilation in summer (right), same window works as ventilation inlet at winter time (left).
	Section of the suggested apartment building with chimney facing the wind direction.		Section of the suggested apartment building with chimney in a situation of not having wind.		

Chapter 4

CONCLUSION

Thermal comfort, like many other factors of a space, defines the characteristics of that space and also the activity taking place inside it. Feeling thermally comfortable inside home gives residents the opportunity to rest and act without dissatisfaction. Paying attention to this fact gives the responsibility to architects to incorporate climate based design rules with other thoughts of design process from the beginning of concepts and drawings.

New type of constructions in North Cyprus, the city Famagusta shows itself in the body of middle raised apartments recently. This research did a survey on some randomly selected apartments of that city. Selection was from different parts of the city and from different construction companies. Number of selected apartments were based on subjective judgment. All apartments were observed according to their directions and orientations of the buildings envelope toward sun direction, wind direction and neighborhood locations. Drawings of the plans and interior organization of spaces, used materials in construction of apartments and facade characteristics have been done. All of these have been done to survey whether natural ventilation strategies have been planned in these apartments or not. Moreover, open ended questionnaires were given to residents of those selected case study buildings trying to find out whether inside temperature, humidity and moisture, generally interior climate, is in comfort zone or not and if not what do residents think about the solution.

Three question were asked as research questions. First, with less usage of mechanical devices, does residents of apartments feel thermally comfortable inside their homes or not? Second, what advantages and disadvantages apartments built in recent decade have related to natural ventilation strategies? And finally, what are architectural suggestions to improve natural ventilation inside residential apartments?

Evaluating the result of the questionnaire survey showed that there is not enough architectural measures in apartments design based on natural ventilation. Moreover, answers residents gave to the questions were classified and were put in a table according to orientation of interior spaces toward geographical directions. Discussion on this table leaded to guides for architectural design to locate living room on south with balconies added and not locating bedrooms on east-south and not locating kitchen on south part.

Evaluation of the observation of the site orientation, plan, interior space organization, material used in construction of the apartments and facades were given in one table. In this table advantages and disadvantages of those apartments were discussed. Common disadvantages between apartments were mentioned as first window sizes is not calculated. Second, used materials doesn't have appropriate u value. Third, space organization doesn't let cross or stack ventilation inside homes and finally there is no natural ventilation strategy used in apartments.

To answer the research questions, at the end this research has concluded that first, there is a lack of architectural design in terms of natural ventilation topic in designing of these apartments which cause dissatisfactory of the residents from internal air qualities.

Second, surveying on the existing situation of samples of these apartments showed some disadvantages and some advantages, based of natural ventilation, for interior spaces which somehow clarified which parts of the design should be reconsidered. In result part it was mentioned that there should be attention to orientation and location of the building envelop and the interior spaces. Moreover, size and location of the windows are important.

Materials using to construct these buildings should have high thermal capacity. If such materials cannot be chosen so having enough layer of heat insulation in exterior walls is necessary. Windows glasses should be double glazed also to act as insulation.

Third, according to mentioning advantages and disadvantages of the buildings in terms of natural ventilation, this research refers to natural ventilation strategies used in world architecture. Between different strategies of natural ventilation introduced in chapter two of this thesis, three strategies named as opening in the facade, wind scoop and chimney have been chosen as strategies which can be assigned to these apartments to increase natural ventilation and reduce usage of mechanical devices in order to get more residents satisfactory of these homes.

Last table of chapter three suggested a method, according to literature review of this research, to use mentioned strategies in middle raised residential apartment as a combination of openings in the facade as local air exhausts or inlets and ducts ending to chimneys (wind scoops) as local air inlets or exhausts. This strategy tries to apply natural ventilation by help of the wind or thermal buoyancy as driving forces and stack ventilation as principle of ventilation. Windows used in openings in the facade, are suggested to be designed in a way that there be possibility of opening them fully during hot months. In cold times, there can be a possibility of covering some parts of these windows and natural ventilation openings used can have small sizes to increase speed of air exchange and lessen the amount of it.

So far, this research has been giving suggestions based on literature review and samples of natural ventilation based design in different parts of the world. This thesis suggests further studies to focus on aforementioned solutions for lack of natural ventilation based design and strategies taking further steps and give efficient solutions by testing these results in models by the help of appropriate software and computer programs. Moreover, there can be a research done on this topic to clarify why natural ventilation strategies are not applied to new constructions.

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URL1 Www.Climatemps.com

URL2 Www.Googleearth.com

URL3 Www.greatbuildings.com

URL4 Www.Skyscraper.com

APPENDICES

Appendix A: Evaporation Cooling

Evaporation cooling which “accurse whenever the vapor pressure of water, in the form of droplets or a wetted surface, is higher than the partial pressure of the water vapor in the adjacent atmosphere.” Goulding, J, R., Lewis, J, o., Steemers, T, C, (1992). Change in the phase of water from liquid to vapor; always make the surrounding air of that releases a quantity of sensible heat. The efficiency of this process depends on the temperature of the water and the air also the vapor content of that, the rate of airflow which passes the surface of the water. (Goulding & Lewis & Steemers, 1992)

In direct evaporative cooling, the dry bulb temperature of the air decrease, while the moisture content of that increases. In this system performance is acceptable in the condition that: “first: a saturation efficiency of the cooling process of 70% or better. Second: a maximum indoor air velocity of 1 meter per second. Third: the air temperature of the indoor space should be around 2k higher than the discharge air temperature and its RH should be below 70%. Forth: the resulting temperature of the indoor space should be around 4K below the outdoor dry bulb temperature.”.”(Goulding & Lewis & Steemers, 1992)

“When evaporative takes place on the internal surface of a sealed container such as a tube, the surface temperature decreases. Adjacent air outside the container is also cooled without any increase in this moisture content. This process is called indirect evaporative.”(Goulding & Lewis & Steemers, 1992) cooling mechanism of evaporation is very powerful in which the occupants may feel comfort in hot conditions when the humidity of the surrounding air is not too much or relatively less than 85%.

Vegetation or wet pads can be used also as well as water. (Goulding & Lewis & Steemers, 1992)

Appendix B: Climate Factors

Solar radiation

Radiant energy received from the sun or the severity of sunrays falling per unit time per unit area is called as solar radiation which is usually expressed in Watts per square meter (W/m2). Atmospheric condition, time and day, season, orientation and geographic location as latitude and longitude of a place, cause the radiation incident on a surface to vary. (Bansal and Minke, 1988)

Ambient temperature

Ambient temperature is the temperature of air in a ventilated and shaded enclosure which generally is expressed in degree Celsius (ºC). Temperature of air close to ground is strongly influenced by wind and also local factors such as shading. (Bansal and Minke, 1988)

Air humidity

Ratio of the mass of water vapor in a certain volume of moist air at a given temperature, to the mass of water vapor in the same volume of saturated air at the same temperature is called air humidity or relative humidity and represents the amount of moisture available in the air; normally expressed as a percentage. High humidity reduces the transmission of solar radiation because of atmospheric scattering and absorption. (Bansal and Minke, 1988)

Precipitation

Dew, rain, snow, hail or in general water in all shapes is referred as precipitation and is usually measured in millimeter (mm). (Bansal and Minke, 1988)

Wind

Rotation of earth and solar radiation ultimate differential heating of water mass and land on the earth's surface, which cause different atmospheric pressure and consequently air movement called wind. With an anemometer the speed of the wind can be measured and expressed in meter per second (m/s). (Bansal and Minke, 1988)

Sky condition

Duration of sunshine or extent of cloud cover can be generally called sky condition. (Bansal and Minke, 1988)

Micro-climates

Micro-climate refers to results which come from Investigating and analyzing of the climate locally for a specific site and is affected by landform, water bodies, vegetation, open spaces and built forms, and also street width and orientation. (Markus and Morris, 1980)

Topography of a site is represented by its landform. Fountain, pound, river, lake or sea can be referred as water bodies. To evaporate, water absorbs a large amount of heat from the surrounding air, according to its relatively high latent heat of vaporization, as a result, cooling the air while raising the humidity level. Large water bodies act as heat sinks, reducing the difference between day and night temperatures so that there would be less temperature variation between day and night, as well as between summer and winter in lands near to them; Also in such sites, wind blows from water to the land in day time, according to faster heating up of the ground in compare to water, and get the inverse direction (from land to water) in night time, because of faster cooling down of soil. (Markus and Morris, 1980)

Vegetation

Trees, shrubs and plants for their photosynthesis, absorb radiation though cooling the environment, while raising the humidity because of releasing moisture. (Markus and Morris, 1980)

Open spaces and built forms, Street width and orientation

The airflow in and around a building and the radiation falling on it is affected by the form of a building and the open spaces in its neighborhood. In an urban area, the amount of direct radiation which buildings and the streets receive can be affected by the street width and its orientation. (Markus and Morris, 1980)

Appendix C: Thermal Comfort Factors

Air temperature: between the human body and the air surrounded it, there is always a heat exchange. This heat would be comfortable according to clothing and performing human activities, while the exchange is equal to zero. (Szokolay, 1980)

Air movement: dissipation of heat from human body get increased by air movement or air velocity in two ways. First when the temperature of the moving air is less than the skin temperature its movement causes heat loose. Second, it increases evaporative cooling. In the hot and humid conditions if the air temperature which is moving is less than human skin, it will cause comfort while when it is more than human temperature it causes discomfort. Also when the velocity increases it may cause discomfort. When the velocity of the air is up ti 0.25 m/s human body does not understand that, when it is between 0.25-0.5 m/s it becomes pleasant while when it goes more than 1 m/s it is not pleasant any more. (Zandi, 2006)

Air Humidity: The humidity, which in another word is the percentage amount of moisture present in the air, has less influence in human comfort than other factors of thermal comfort. However, its effect on evaporation from the skin and feeling of a person cannot be neglected. The mentioned effect appears particularly when the relative humidity is less than 20% in hot dry or arid zone or when it is more than 60% in the warm zones. Besides when the relative humidity increases in a cold zone, the skin feels cooler because of the increasing evaporation from the skin and unwanted cooling effects. “For being in the thermal comfort level, the relative humidity should be above 20% all the year, bellow 60% in the summer and below 80% in the winter.” (Zandi, 2006)

Mean radiant temperature: Mean radiation temperature -the average of the all surface temperatures around a person- is a highly effective factor on human comfort. When directly exposed to the solar radiation, the sensation of warmth by radiation in a space can be felt much higher than the actual air temperature, by a person. Meanwhile touching or facing a cooler surface causes an unpleasant sensation of coolness. Therefore either a warmer surface or a cooler one can cause discomfort. (Zandi, 2006)

Subjective factors: The subjective factors which objective ones also depend on them can be classified in two (clothing and metabolic) categories:

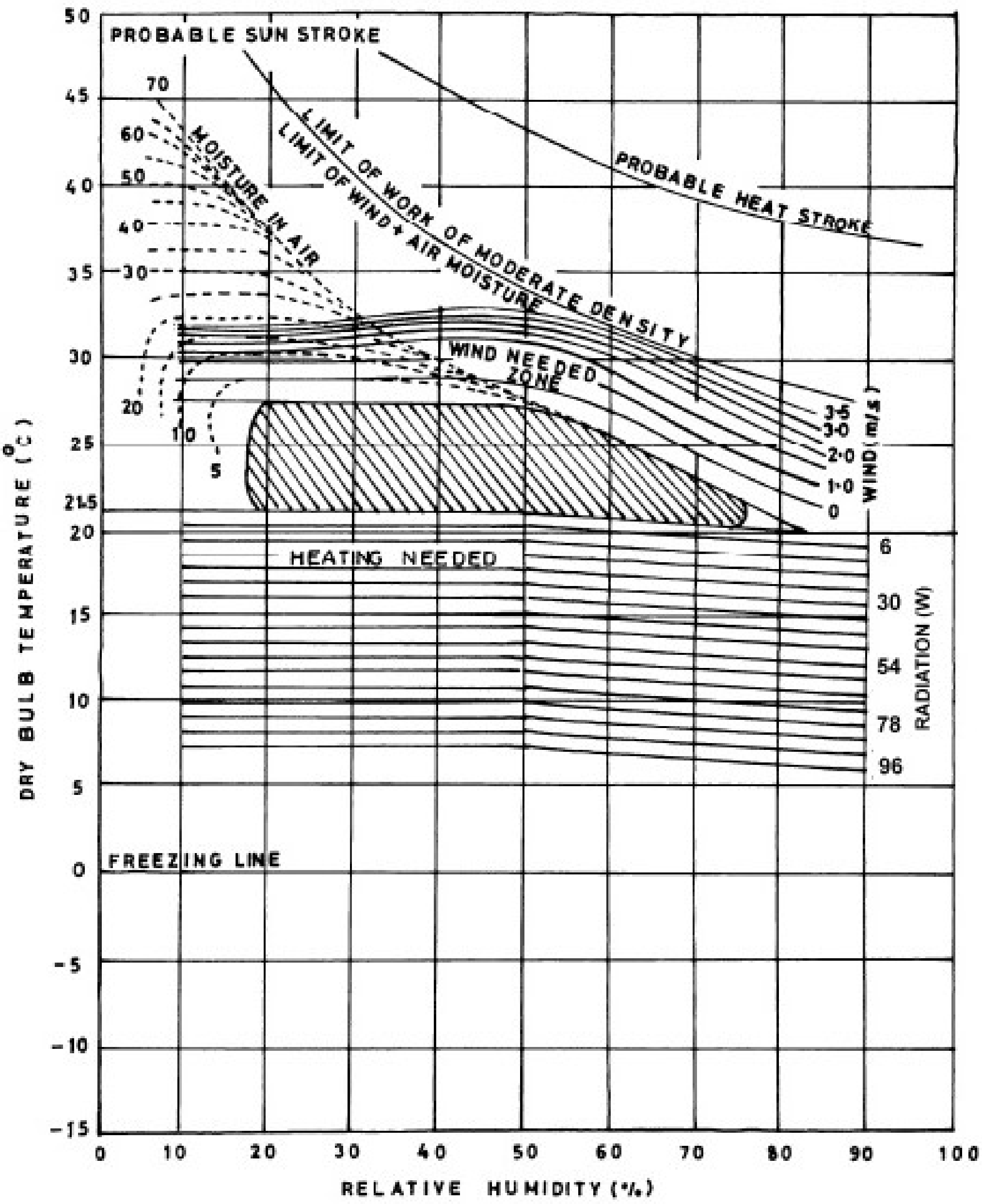
Clothing: Clothing as an insulation, which affects the amount of heat exchanged between the environment and human body, plays an important role in the thermal comfort of human's body. As the layers of the clothes increases, the amount of heat exchanging decreases. (Zandi, 2006)

Metabolic rate: Metabolic rate is defined as the amount of energy produced per unit of time by the conservation of food by "Gouldin" and it depends on individual physical characteristics factors –such as age, sex, shape of the body, condition of health and etc. - of a person. (Zandi, 2006)

Appendix D: Bioclimatic Chart

Bioclimatic chart works based on minimum and maximum air temperature and humidity. Givoni (1969), describes this chart as “zone of human comfort in relation to the ambient air temperature and humidity, mean radiant temperature, wind speed, solar radiation, and evaporative cooling.”

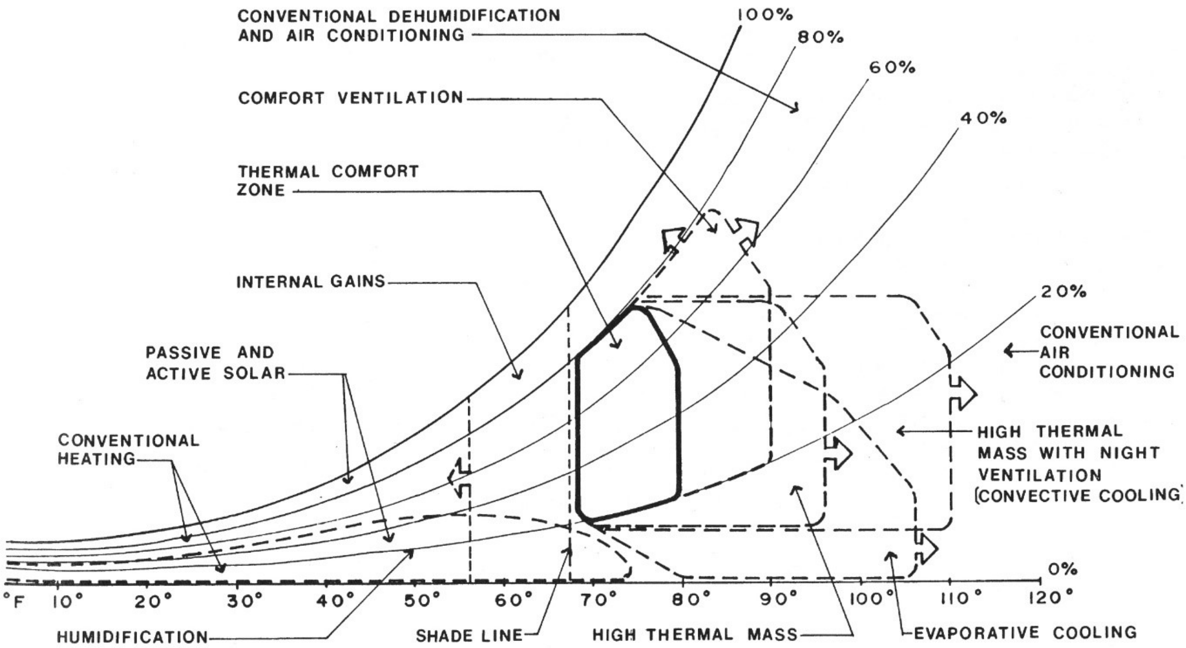
To work with this chart for each month two points, one as mean minimum temperature and humidity and the other one as mean maximum temperature and humidity are needed and connected to each other with a line. So there will be twelve lines presenting separate zones. In the center of the chart there is a specific zone which shows the comfort area. Lines out of this area would need different heating or cooling strategies. The ones above and right, for instance, need cooling and ventilation and the ones in left and up need evaporative cooling while the lines under that zone show the heating needed times. This graph is shown in following page.



Bioclimatic Chart

Appendix E: Psychrometric Chart

This chart, first created by Houghton and Yaglou in 1923 and later modified by Yaglou in 1947, suggest cooling and heating strategies. In this chart each axis represents a climatic data as dry bulb temperature, wet bulb temperature, absolute humidity, relative humidity, saturation humidity, specific volume, enthalpy and sensible heat, and each zone represents a cooling or heating strategy as sensible cooling and heating, cooling and dehumidification, heating and humidification, humidification, dehumidification, evaporative cooling and chemical dehydration. (Zandi, 2006) and (Szokolay, 1980)



Psychrometric Chart

Appendix F: Tables of Climate Condition in Famagusta

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Average max temp ºC	16	17	19	23	28	32	34	34	32	28	23	19	25.4
Average temp ºC	11	11.5	13	17	21.5	25.5	28	28	25.5	21.5	17.5	13	17.5
Average min temp ºC	6	6	7	11	15	19	22	22	19	15	12	8	13.5
Average sea temp ºC	16	17	17	19	21	24	26	28	27	25	22	19	22

Average temperatures in Famagusta Cyprus (climatemps.com (2013)

	Jan	Feb	Mar	Apr		May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Average precipitation mm	90	52	36	16		13	4	0.5	1	3	33	49	106	403
Number of wet days	11	7	6	3		2	0.5	0.5	0.5	1	3	5	9	48.5

Precipitations in Famagusta Cyprus (climatemps.com (2013)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Relative humidity %	72	68	67	62	59	56	52	53	57	33	59	64	70

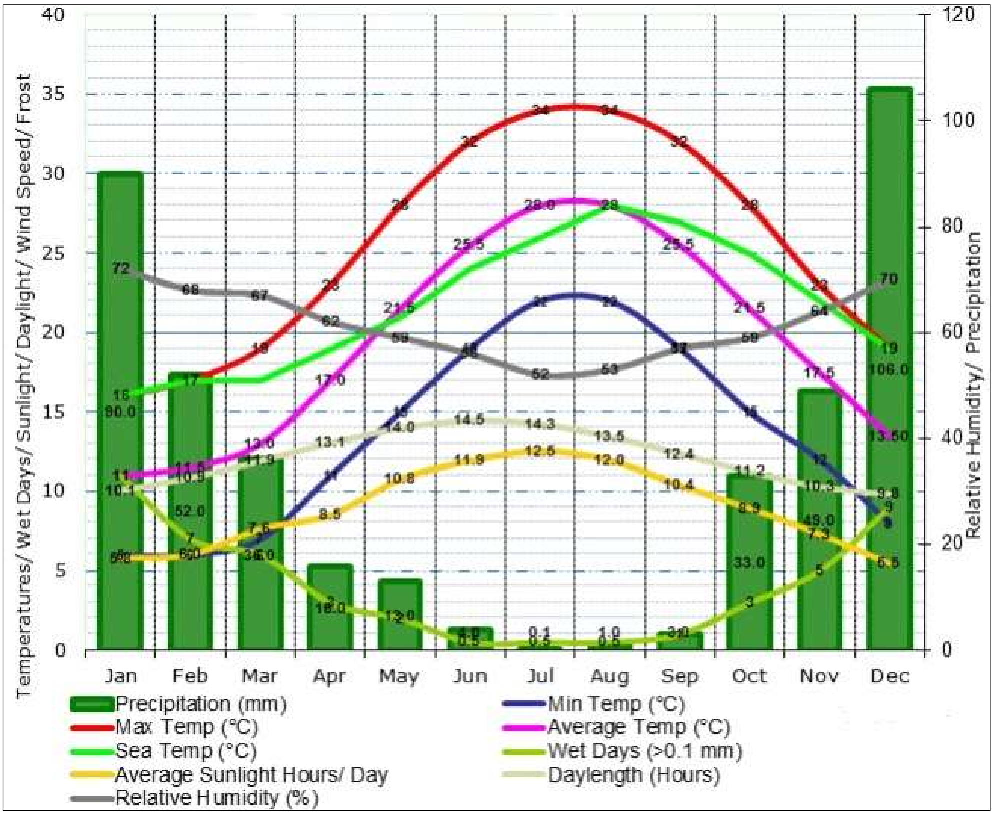
Precipitations in Famagusta Cyprus (climatemps.com (2013)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Percentage of sunny daylight hours	59	62	65	68	78	86	89	90	88	81	75	57	76

Sunshine and daylight hours in Famagusta Cyprus (URL 1)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Dominant wind dir.													
Average wind speed km/h	10	11	9	8	8	8	8	8	8	8	9	9	8

Wind speed and direction in Famagusta Cyprus (URL1)



Climate of Famagusta Cyprus (URL 1)

Appendix G: Questionnaire

1. How many occupants does this home have?

☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

2. In which space, inside home, you spend most of the day time?

☐ Living room ☐ Kitchen ☐ Bedroom

3. Which mechanical device is used as heater inside your home?

☐ HVAC ☐ Electronic Heater ☐ Gas Heater

4. Which mechanical device is used as cooler inside your home?

☐ HVAC ☐ Electronic Fan

5. Is the energy bill cheap☐, average☐ or expensive☐ ?

6. Is the indoor temperature and humidity appropriate if you do not use mechanical devises in hot months?

☐ Yes ☐ No

7. Is the indoor temperature and humidity appropriate if you do not use mechanical devises in cold months?

☐ Yes ☐ No

8. Is the indoor temperature appropriate if you use mechanical devises less than usual in hot months?

☐ Yes ☐ No

9. Is the indoor temperature appropriate if you use mechanical devises less than usual in cold months?

☐ Yes ☐ No

10. Is the indoor humidity appropriate if you use mechanical devises less than usual in summer time?

☐ Yes ☐ No

11. Is the indoor humidity appropriate if you use mechanical devises less than usual in winter time?

☐ Yes ☐ No

12. Is there fresh air inside, in hot months?

☐ Yes ☐ No

13. Is there fresh air inside, in cold months?

☐ Yes ☐ No

14. Are you satisfied with natural ventilation of the kitchen/ bedroom/ living room of your home in hot months?

☐ Yes ☐ No

15. Are you satisfied with thermal qualities of the kitchen/ bedroom/ living room of your home in cold months?

☐ Yes ☐ No

16. If you are not satisfied with thermal qualities, what do you think can be the solution?

☐ Using smaller window sizes

☐ Using bigger window sizes

☐ Locating windows in front of each other

☐ Locating south facing interior spaces

☐ Improvising more than one window in one room