The Evaluation of Medium-Rise Residential Buildings in Famagusta According to Climate Responsive Design Elements

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ABSTRACT

The impact of climate on building design characteristic has existed from the beginning of man's searching for housing till today. However, the way it was expressed changed due to the changing of human needs, development of knowledge, and technology. Nowadays, many buildings around the world are trying to achieve the comfort for the user and the climate, due to the adverse effects on the climate, especially on nature, that appears from the harmful methods of human daily life, such as the uncontrolled use of the natural resources for the buildings sector, whether it is in construction or operation process.

This study focusses on improving the quality of building design for the users and the climate with the consideration of climate factors. This improvement is surely to be achieved by understanding the relationship between building and climate impact by means of climate responsive design strategies. The new residential mid-rise buildings in Famagusta, North-Cyprus, were selected as case studies to analyze how they have been impacted by the climate responsive design elements. Based on the analysis of the compared case studies it was found out that the consideration of climate responsive design elements is limited. The building design of the case studies has not considered the existing climate condition. Therefore, the building design in Famagusta has to be improved by adopting the suggested building design strategies for Famagusta climate conditions.

Keywords: Climate-responsive design, Medium-rise buildings, Design strategies

ÖZ

İklim faktörünün bina tasarımındaki etkisi insanoğlunun barınma arayışına başlamasından bugüne kadar varolmuştur. Fakat, bunun yansıtılış biçimi insanların ihtiyaçlarının değişmesinden, bilgi ve teknolojinin gelişimine göre değişmiştir. Bugünlerde dünyadaki birçok bina, insanların günlük yaşamında ortaya çıkan özellikle doğa üzerinde yarattığı olumsuz etkiden dolayı hem kullanıcı hem de çevresi için konforlu bir yaşam ortamı yaratmaya çalışmaktadır. Örneğin, inşaat sektörü doğal kaynaklar üzerinde gerek binanın yapım gerekse faaliyet işlemlerinde olumsuz etkilemektedir. Bu çalışma, kullanıcıları ve çevreyi dikkate alarak ve mevcut iklim faktörünü göz önünde bulundurarak bina tasarım kalitesini geliştirmeye odaklanmıştır. Bu gelişme kesinlikle bina ve iklim duyarlı tasarım stratejilerinin arasındaki ilişkiyi anlayarak elde edilebilir. Gazimağusa, Kuzey Kıbrıs'ta yeni inşa edilmiş orta katlı konut binaları iklim duyarlı tasarım ögelerinden nasıl etkilendiklerini analiz etmek için örnek çalışmalar olarak seçilmiştir. Yapılan karşılaştırmalı örnek çalışmalar sonucunda iklim duyarlı tasarım ögelerinin kısıtlı olarak göz önünde bulundurulduğu ortaya çıkmıştır. Örnek çalışmaların bina tasarımları mevcut iklim faktörlerini dikkate almamıştır. Bu nedenle Gazimağusa'daki bina tasarımının, bölgenin iklim koşullarına göre önerilen bina tasarım stratejilerini dikkate alınarak geliştirilmesi gerekmektedir.

Anahtar Kelimeler: İklim duyarlı tasarım, Orta katlı binalar, Tasarım stratejileri

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LIST OF ABBREVIATIONS

A/V	Surface Area to Volume Ratio
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning
PVC	Polymerizing Vinyl Chloride
R-Value	Resist the Conductive Flow of Heat
SHGC	Solar Heat Gain Coefficient
UHI	Urban Heat Island
U-Value	Thermal Transmittance of a Material
VT	Visible Transmittance
WWR	Window to Wall Ratio

Chapter 1

INTRODUCTION

The architecture should take into account the factors of compatibility and balance and the determinants of the surrounding environmental factors. These factors represent a necessary need to provide comfort, safety, and privacy and the continuity of harmonious development of humans and their living spaces. In the last decades building construction demand with its negative impact on the environment, increased due to the global population, as it is responsible for 36% of total energy consumption and with nearly 40% of the CO_2 emissions worldwide (Energy Efficiency: Buildings, 2018). Over the past years, many researchers emphasized the importance of the relationship between environment and building. Also, they are looking for solutions for the damages or the problem left behind. This approach is not new, and it is the right step to save the environment with its natural resources. It could be by the use of any design techniques such as the passive design, which is one of the alternatives of current building design practices, but with the help of the new design technology, materials, and inventions, the design approach will become more productive (Santamouris, 2013).

In Cyprus, it was determined the relationship between the architecture and the environmental characteristics and its developments through the civilizations, geography, climate, socio-economic, religious, and ethnic and cultural aspects (Hoşkara & Doratlı, 2007) The neglecting of the environmental factor like the climate consideration through the building envelope can be noticed in the social housing whether, in its multi-story apartment or the row-house types, these neglecting factors will generate a negative impact on the natural environment and the sense of 'local environmental identity’ (Oktay, 2002). In North Cyprus, contemporary buildings in specific newly developed quarters in Famagusta and Lefkoşa neglect the natural environment, with the lack of the primary natural mechanisms for the adequate habitation, which harm not only the humans but also the environment (Iyendo, Akıngbaso, Alibaba & Özdeniz, 2016). Building construction demand in North Cyprus increased due to the student population. This demand led the industry to be new, grow fast, and become under developing with the harm for the environment.

1.1 Research Problem

The problem starts with the damaged environment from the residential buildings, because they do not take in consideration the surrounding environmental factors like the climate when designing. For this research, Famagusta new residential buildings in North Cyprus will be the case study, due to the spontaneous housing project investments. These buildings contributed to an unsustainable development because of the lack of design strategies set for architects to follow in their building design that helps to improve the quality of building and the environment.

According to Statistics and Research Department of TRNC (2016) the study of building construction statistics, the highest total number of approved rural and urban, private and public were for residential buildings from 2014 till 2016. As in 2016 there were 229 residential buildings compared to 60 of all commercial buildings (Statistics and Research Department, 2016). Therefore, to achieve more sustainable residential buildings and a comfortable indoor environment for the user, it is necessary to take into account the climate as natural environmental factor, suitable strategies and appropriate methods throughout the building design process.

Building envelope is a barrier between the surrounding environment and the building indoor environment, which has the most effect on the overall performance of the building. Therefore, focusing on improving the design quality of the building envelope, will help to construct energy efficient building because of the limited energy source in TRNC and to avoid the negative impacts on the environment.

1.2 Research Aims and Questions

The general aim of this study is to improve the quality of building design in specific for Famagusta by clarifying an overview and understanding the climate responsive design and its impact on the building design strategies. Also, to define climatic responsive design strategies to clarify how natural environment such as climate effect building design toward sustainable development, as it is one of the design approaches of how buildings response to certain environments. In sequence to analyze how the medium-rise buildings design of Famagusta dealt with the climate factor. In order to achieve the thesis purposes, the following research questions will be dealt within the thesis:

- What is the definition of climate responsive design?
- What is the importance of climate responsive design strategies on building design?
- How can residential buildings in Famagusta be improved by considering the climate responsive design strategies?

1.3 Research Methodology

This study will apply a qualitative approach to achieve the aim of the study, it will be continuing of previous researches related to environmental factor such as climate and its relation to building design. First of all, the research will depend on documentary collecting data from books, articles, and previous studies, on clarifying the effect of the climate as natural environmental factors on building design, where there are many factors of the environment affect the design, such as the social, cultural, political, etc. In order to develop design strategies that are needed to be compared with the contemporary medium-rise building design strategies relation to environment. The analysis will depend on field visits with photographic evidence of their different locations. This study will analyze buildings envelope of multi-story buildings and how they are affected by the climate. The multi-story building type will be the building type which will be focused on as there are many different building classifications, like the attached row-type of social housing and detached single-family housing of residential buildings in Famagusta / North Cyprus. With the aim to conclude a new design approach for the residential buildings which should be adopted as new developed design strategies.

1.4 Research Structure

The study will consist of five chapters, starting with chapter 1. It contains the introduction part of the thesis, following the research problem, research aim, and objectives, research questions and the research methodology and limitations.

The second chapter will include the information of environmental factor mainly the climate and its relation to building from literature reviews. This information will depend on clarifying important topics starting from sustainable development, sustainability in architecture and the characteristics of climatic responsive design.

In the proceeding, the third chapter will include the case studies in Famagusta as medium-rise buildings and their relationship to climate to define the appropriate design strategies. The building elements which are designed according to the impact of climate will be used to analyze the new residential building envelopes. The analysis will depend on the field visit of the selected buildings. The fourth chapter will include the results and discussions of the analysis based on the developed strategies for the residential buildings. The last fifth chapter will be the conclusion of the thesis with recommendations.

1.5 Research Limitation

This study proceeds to determine the building envelopes of the existing residential buildings and how their design is impacted by the surrounding environment by climate responsive design in Famagusta/ North Cyprus. The analysis will focus only on the vertical development of the contemporary residential buildings and their building envelopes. In conclusion, design strategies will be proposed as a guideline of how buildings should be designed based on the impact of climate as environmental factor for future residential buildings.

Chapter 2

SUSTAINABLE APPROACH OF HOUSING DEVELOPMENT

2.1 Sustainable Development

Sustainability, as mentioned in the Oxford dictionary, is "able to be maintained at a certain rate or level" ("Meaning of Sustainability", 2019).

In the last decade, human behaviors, actions, and population development effected negatively on the environment. They are the ruler of the natural source and contributed to increase climate changes and natural disasters. These negative human's actions led to an awareness of behavior changes to rational effects and management of the natural sources to maintain sustainability mainly environmentally for the future generation. The concept of sustainable development content changed from one era to another since it was known under the name of eco-development in the 1970s, starting from economic theoreticians in the 18th century until it was first introduced as ecological in International Union for Conservation of Nature in 1980. It is not enough to conserve the environment in the present but also not to bring harm to future sources. "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs" by the Brundtland report in "our common future" (United Nations, 1987). Later, it extended to the social and economic development at the Rio de Janeiro Earth Summit in 1992 (Klarin, 2018). Global consciousness for all different categories is the biggest challenge of sustainable development concerning the industrial revolution for limitless human and environmental utilization (Paul, 2008). Social, economic, and environment pillars integrations with balancing between them are the fundamental principles of sustainable development to achieve the conservation of sources and long term stability in specific economic and environmental sources for the future generation (Emas, 2015). Environmental protection, resource management, and habitat restoration are important points to maintain the quality of the environment, which is the main key for both social and economic aspects, see Figure 1. Many methodologies are existing to evaluate sustainable development in many sectors. Developing criteria and sustainability indicators from the individuals, organizations, and societies are important tools to make policy and public awareness. The assessment of the current unsustainable human activities and to transfer countries' performance information in the social, economy, environment, or technological development has to be part of human's daily life behaviors (Sahraiyanjahromi and Mosaberpanah, 2018). Therefore, land and natural resources are essential to maintain the development of cities. When it comes to plan or a guideline to follow for sustainable development, each country identifies its sustainable development plan based on its economic, social, and environmental situation for their need and natural resources.

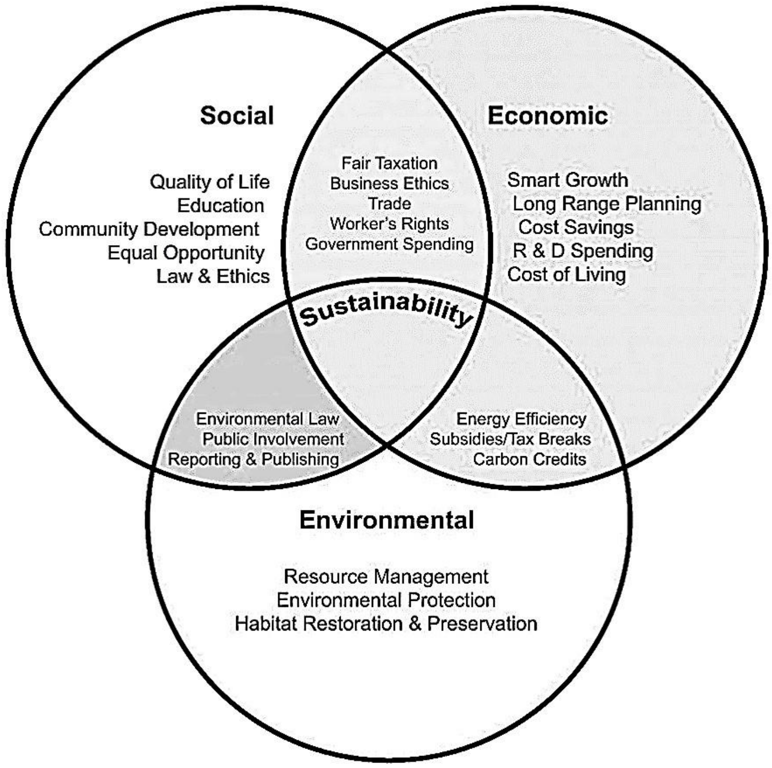


Figure 1: Sustainable Development Three Spheres, (Wanamaker, 2018)

2.1.1 Economical Sustainability

Human civilization challenge is the resolution of an unhealthy relationship of developed economies with the use of natural resources. The lack of financial-economic besides technology is affecting the implementation of the concept of sustainable development. In the contemporary understanding of development, economic growth was linked to development as it is one of the significant purposes to improve the quality of life by increasing the self-sufficient capacity of economies to provide a comfortable, long, healthy, and joyful life (Klarin, 2018). Generally, "Ecological design" or "eco- design" is one of the important concepts being used as a solution to decrease the non- sustainable human behavior to the environment by incorporating the spatial and temporal ecological concerns by providing a framework of perspectives on design and management with the environmental situation. Moreover, ecological economics is one of the economic sustainability that deals with managing the economy within the ecological constraints of natural resources. Ecologically sustainable economic development will be achieved if the eco-design principles are applied strictly (Shu- Yang, Freedman, & Cote, 2004). It can be said that affordability and saving in using natural resources are some of the criteria of building design to achieve economic sustainability.

2.1.2 Social Sustainability

According to Woodcraft (2015), social sustainability is a process based on understanding people's needs. To provide well-being sustainable, successful places, whether they live or work in, to support social and cultural life for a citizen in spaces and areas to evolve, which combines the physical design and design of the social infrastructure. Physical factors are such as sustainable urban design, decent houses, and local environmental quality and comfort, non-physical factors like health, community, safety, education, culture, and traditions. These factors were identified from the UK national government survey more over the literature to understand the relationship between social sustainability and the built environment (Woodcraft, 2015). Social sustainability, with its all factors, "is a positive condition within communities and a process within communities that can achieve that condition" (Mckenzie, 2004). According to Barnett and Casper (2001), the social environment includes many of the physical factors aspects, where the human social processes contributed partially to configure the contemporary water, landscape, and natural resources (Barnett and Casper, 2001). Providing environments that support communities to meet their needs is the contribution of buildings with social sustainability. So, taking into account the factors that affect social values and human comfort without harming the environment are needed to achieve social sustainability through the buildings.

2.1.3 Environmental Sustainability

The environment is a subset of ecological concept, but the word of the environment is better used for the intersection between human activities and the ecosystem. The definition of environmental sustainability, according to Brundtland (1987), is the maintenance of natural capital, it relates the human needs without harming the health of the ecosystem. Therefore, it is important to provide clean water, air, and productive land, to have a sustainably productive environment to achieve the socio-economic aspects of the development. Therefore, it can be said that the social and economic aspects cannot stand alone without the environment, depending on the energy, materials, and environmental resources. In contrast, a sustainable environment can stand-alone (Morelli, 2011). Environmental sustainability is to keep or maintain the environment factors valued things. When it comes to physical and environmental factors as this study focuses on, it means the surroundings to something, as it contains both the natural such as the physical resources, land, water, and atmosphere, including mineral resources and the humans constructed like buildings and roads (Sutton, 2004). The main goal of environmental sustainability is to conserve natural elements (soil, water, air, etc.) and land utilization by encouraging the use of natural and renewable resources, and to develop alternative sources of anything that harms the environment like power and reducing pollution (Abidin & Pasquire, 2007). The factors that minimize the negative use of natural resources and the risk effect of the local and global environment are the use of natural resources with reducing emissions and management of the water and energy, as well as the control and reduction of the negative impact on environment and the promotion of invention technologies (Confindustria organization, 2013). According to Mecca, Correia & Dipasquale (2014), there are five principles with many strategies to achieve environmental sustainability. Such as respect of environmental context, the benefit of natural and climate resources, reduce pollution and waste materials, contribute to human health, and reduce negative natural effects (Mecca, Correia & Dipasquale, 2014). These principles help to understand the relation between environment and buildings toward natural sustainability for this study.

2.2 The Definition of Sustainable Architecture

Sustainable architecture is a subsystem of the whole sustainable development. Still, it interconnects and overlaps with other subsystems like society, politics, education, and industry, not only to reduce negative impacts on the environment but to improve the quality of life (Chansomsak & Vale, 2008). Architecture is an integral part of the factors that affect human well-being, which in turn is one of the principles of sustainable development since the relation between human, environment, and development concept was considered by the scientists in the 1970s and by the World Commission on Environment and Development in 1987. The sustainable architecture term has different names in different periods from environmental design, green design, ecological design, and sustainable architecture repetitively from the 1970s until today (Altın, 2016).

Also, the sustainable architecture concept, as Brundtland's report introduced it is based on two principles to achieve sustainable development aims, firstly buildings and environment impact inverse relation, secondly minimizing the energy consumptions. Reduction in energy use and green buildings are approaches to format the architecture in its stages from its design, process, and manufacturing the materials, to achieve the sustainable development aim due to the environment change. Therefore, sustainable design refers to quality, future, and environmental considerations and connects humans, nature, and architecture itself (Amiri and Vatandoost, 2017). As well as, conservation in using the consumption of non-renewable resources, reducing the harm of the construction industry to environment, and development of natural environment are some of the principles of sustainable architecture since the 19th century. For example, returning to green spaces of courtyards and self-sufficiency of local industries such as materials manufacturing are ways to help to reduce the negative impact of building to the environment (Naseri and Amiri, 2015).

2.2.1 Sustainable Design Criteria

In order to achieve sustainable architecture that deals with environment to provide human needs, it is necessary to use renewable and clean energy resources such as wind and solar energy, and reducing building demand for energy by improving its efficiency as replacing to the polluted resources. The use of non-renewable energy for buildings heating, cooling and lighting effected negatively on the world environment due to its negative emissions such as producing CO_2. Reducing the energy consumption can be achievable by using traditional design methods with new technologies to improve the quality of building and environment. Responsive building design to the environment can be placed for the new copied inappropriate buildings that are not suitable for their surrounding environment (Lechner, 2015). According to Stachura (2014), using recycled materials, water storage, reducing the energy utilizing renewable energy, building orientation for natural lighting and air quality in buildings are measured to achieve sustainable architecture (Stachura, 2014).

One of the main common design criteria for sustainable building is the reduction of non- renewable energy resources, such criteria can be achieved through a strong relation between the environment as an energy resource and building design, which this study focuses on.

2.3 The Definition of Climate-Responsive Design

According to Hyde (2013), the sustainable design with context of environment and the practice of architecture through effective design are what the climate responsive design depends on. Surely with the selection and evaluation of suitable strategies to a particular design problem. Climate responsive design is a part of an environmental approach to building development called ecological sustainable design (Hyde, 2013). According to Looman (2017), climatic responsive design principles are, firstly, the exchange of heat with environment to provide comfort, by letting the outdoor environment to be the source of needed energy to building. Secondly, the building as responsive system, which should be designed as holistic design from its shape, plan, architectural elements, building materials, etc. The last principle is the long term integration of architecture or structure (Looman, 2017).

The environment is consisting of all surroundings, nature, and manmade environment, with its physical and social factors. Understanding the environment and its natural resources, the action and reaction of the ecosystem that will relate to building design will help to integrate and balance the built environment with the natural environment (Anselm, 2006). Natural environmental factors are the main factors to be integrated into the design with all of its stages from site selecting, building orientation, and façade design until the integration of services, under the global, local and interior environment. These factors are important to minimize the negative effect on the environment and the energy consumption that is needed for artificial control for heating, cooling and lighting, as well as to provide comfort (Santamouris, 2013).

According to Santamouris (2013), when designing a building in context to surrounding environment it should take into consideration the following environmental factors such as the climate data of the site, the topography, land use of the site and its surrounding, historic, cultural and social environment of the area and the surrounding environmental conditions such as the access roads, noise, traffic, etc. (Santamouris, 2013). According to Hoşkara, Çavuşoğlu & Öngül (2009), there are many factors that effect on residential building and its design, and environmental development such as the natural factors, which are climate (temperatures, wind, solar radiation, humidity), water, topography, and soil condition, as well as, the physical factors of the surrounding like land utilization and surrounding buildings design approach. These neglected factors when designing, led to negative impact on the environment resources like energy, water, and material consumption (Hoşkara, Çavuşoğlu & Öngül, 2009). Fluctuating environment influences buildings by two main factors, which are the climatic conditions and the availability of building materials. The variable environmental factors which influence on building are climate with air temperature, snow, rain, solar radiation and humidity. In addition to air pollution, noise, site location and its soil moisture (Papamanolis, 2014).

Climate is the main environmental factor that affects other factors such as the topography and building materials use. Therefore, it affects the building design strategies of different climate zones. Climate is the stimulus for responsive design in act to respond to the internal and external environment. Building design as a whole from shape, plan, space, materials, elements, etc. is the mediator between interior and exterior. The responsive design is related to the strategies of the building design elements to provide structural and architectural elements that adapt themselves to the surrounding conditions such as store and transport heat, light, etc. Also, the extended form and envelope of design principles like bioclimatic is to achieve healthy comfortable environment for the user with the potential of the natural resources not only for the energy consumption (Looman, 2017). The ecological and passive design- based principles are developed for the climate conditions, as well as environmental factors by using contemporary technologies (Tönük and Kayihan, 2006).

Climate responsive building design achieves the potential of building envelopes of creating an indoor climate related to the external environment. Climate responsive design element solutions are integrated with passive strategies and sustainable systems, rather than energy systems that consume non-renewable energy. The climatic responsive design strategies are integrated concepts for comfort and energy optimized performance. These building design potentials are different from a climate to another. Climatic responsive design buildings are the building that highly interacts with the changing conditions of the outdoor environment through main energy strategies to achieve the comfort demands see Figure 2. Such strategies are energy conservation (the ability to keep the energy in a building), energy distribution (the transfer of energy throughout the building), energy promotion (the ability to enter the external energy into building and exit the undesirable energy out of the building), energy prevention (the prevention of undesirable external energy to enter), energy conservation (the capacity to keep the energy inside the building without any heat loss whether it is frominfiltration or transmission), energy recovery (the regain of energy partly or fully from waste), and lastly the energy storage (the ability to keep the energy separate from the building but with ability to restore it) (Looman, 2017). These energy strategies will achieve the comfort demands with consideration of climate as energy resource and the help of building material characteristics. The comfort demands are heating, cooling, daylighting, ventilation, hot water and electricity. But only heating, cooling, daylighting, and ventilation will be dealt with in this research, as they are related to the improve of building envelope by climate responsive design strategies.

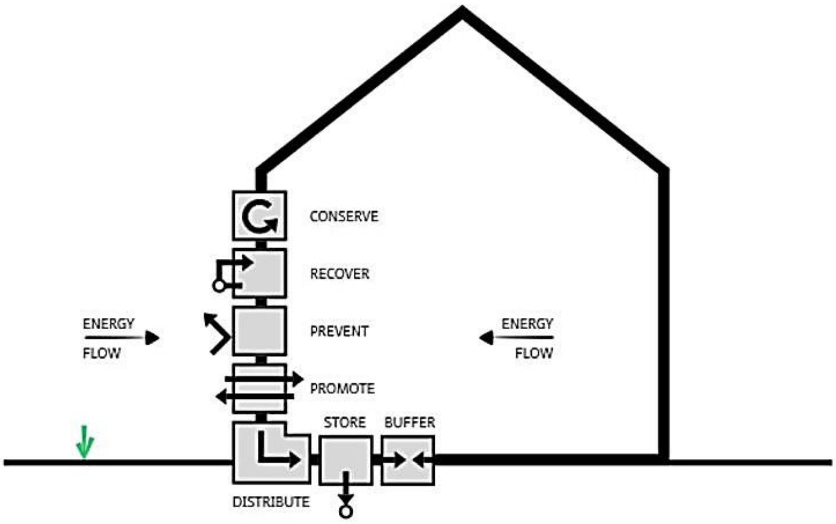


Figure 2: Building Strategies to Interfere with Natural Energy (Looman, 2017)

Buildings react to the surrounding climate conditions through their surfaces. For example, when a building is modifying the absorption and reflection of the solar radiation through its changed surfaces materials which will effect on the change of the radiation and temperature on the site depending on its shading pattern (Bay & Ong, 2006). In the early stage of design, understanding climate components will help to eliminate the negative impact of buildings on the environment. In order to promote an adaptable interior environment that is dealing with climate conditions like solar rays and temperature, wind and humidity. The orientation of the building depends on the climate (wind direction, solar radiation) and topography with its proper direction. Choosing the best direction of the building from the early design stage will help to reduce the negative impact on the environment by reducing the use of artificial energy and using renewable energy to operate the building. This technique is the most fundamental aspect used in passive solar design with space organizations to reduce energy consumption that harms the environment (Vaca, 2015). According to Hyde (2013), solar radiation, temperature, humidity, rainfall, wind velocity and direction are needed climatic meteorological that help to select the suitable climate responsive design strategies (Hyde, 2013). Understanding the climate characteristics will help to relate how climate impacts on building design, through climatic responsive building design strategies.

2.3.1 Climate

Climate is the most important natural environmental factor. It is essential for formatting, reproduction, and continuation of living activities for all creatures. Dealing, understanding, and controlling the climate conditions are some of the most important design criteria. The main principle of architecture is to provide a comfortable built environment for humans to fulfill their activities far away from the exterior environmental conditions. The differentiation of climate conditions in regions generates different architectural characteristics. Therefore, the effect of climate on the building design and on selection of suitable requirements is different from location to another such as the need for openings, orientation, thermal mass, etc. Moreover, is to provide suitable building methods, for example, in hot areas like India and Egypt, projection of balconies and columns, are providing shadow to the walls. Besides, the use of timber or marble lattices fills large openings to eliminate the sun's glare. Regional climate considerations in buildings mostly by means the economical usage of building materials and system effect on the planning and the building design to keep the building minimum heat gain in hottest seasons and heat loss in coldest seasons. Another example is the use of pitched roof in Northern Europe when dealing with rain and heavy snow and of steep roof in tropical rainfall zone, while in hot regions like North Africa, the flat roof is preferable (Fathy, Shearer & Sultan, 1995).

2.3.1.1 Climate Classification According to Geographical Locations

According to the Köppen -Geiger climate classification, which is the widely used climate classification, it relies on the annual and monthly averages of temperature and precipitation. There are five main climate zones, regardless of the regional climatic conditions: Tropical, Dry, Mild temperature, Snow, and Polar. And six sub-types are relying on the precipitation (desert, steppe, fully humid, summer dry, winter dry, monsoonal) and eight classifications depending on the temperature (hot-arid, cold arid, hot summer, warm summer, cool summer, extremely continental, polar forest, polar tundra) (Chen & Chen, 2013) see Figure 3. Air humidity, solar radiation, and daylight, wind direction, and precipitation have an important role in climatic- responsive building design. Hot (humid, dry), temperate, and cold regions will be selected and discussed as four main classifications of the climatic responsive design zones.

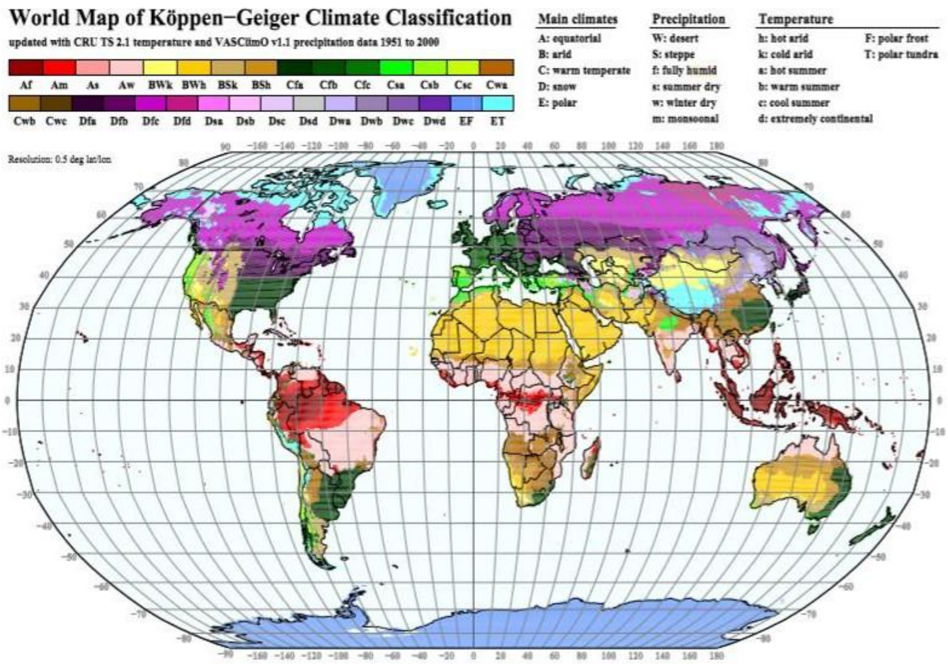


Figure 3: Köppen-Geiger Climate Classification, (Köttek, Grieser, Beck, Rudolf & Rubel, 2006)

2.3.1.2 Sun and Temperature

The sun is the source of light and energy needed for heat in winter and saving energy in summer. A direct and diffuse component is the results of the solar radiation that strikes the earth's surface. The direct radiation is the result without any obstruction and the diffuse radiation is the scattered result of the indirectly strikes of the solar radiation to earth's surface because of existing of obstacle like dust, cloud and water. Therefore, the less reflection of the solar radiation and the shorter distance of radiation to earth are effected by the higher position of the sun. The solar energy resource is depending on these radiations. They are valuable resources of energy whether it's for daylight which comes from the diffuse or as a heating energy of both. The temperature of indoor or external areas is effected due to absorption of solar radiation. Everywhere on earth has minimum 50% available annually of the time daylight (Looman, 2017). Therefore, solar radiation impacts on daylight and heating demand for a building, which are related to building and its windows orientation, windows quality and its shading. The window wall ratio has a great impact on the solar heat gain and transfers. The more WWR, the more solar heat gain or transfer, surely with consideration of the window glazing type. Therefore, it is preferable to have high WWR in cold climate. Still, the U-value should be low to minimize the heat gain in summer or lose in winter (Alwetaishi, 2019).

2.3.1.3 Wind

The distance between building and building height are important either to decrease or increase the amount of air pressure, air flow and air movement. Wind impacts the ventilation and infiltration on building heating transfer. Both are results of an airflow of into and out of a building. Also, the wind speed gets effected by the roughness of urban areas where it drops and cause sudden change for wind speed and flow pattern, see Figure 4. The ventilation impacts positively on a building due to its desirable air flow to either minimize the indoor temperature or to maximize wind speed. If it is suitably provided on a building it will maintain the comfort of indoor air quality of a building. Ventilation impacts building cooling through its openings such as windows or by force like using different techniques such as fan or air-conditioning. For the infiltration it is uncontrolled movement it could be through crack walls of a building or some openings (Santamouris, 2013).

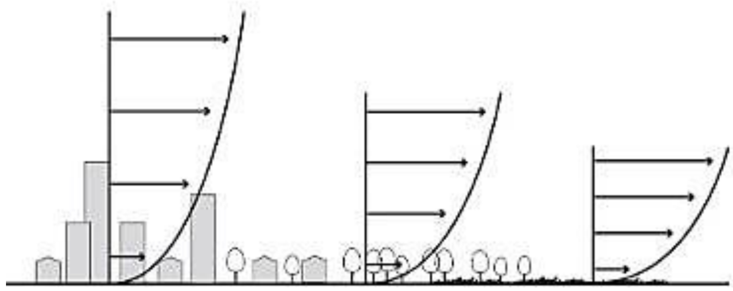


Figure 4: The Relation between Wind Speed and Urban Areas (Looman, 2017)

2.3.1.4 Humidity

Human skin evaporation is related to the air humidity. If the humidity is low, then the evaporation will be high and if the humidity is high then the evaporation is low. Humidity and temperature have converse relation, the increase in temperature allows high evaporation, a dry air highly absorbs the moisture from the skin, so it will result in a high level of evaporation which will highly cool the body. Relative humidity (RH) is the percentage, which represents the amount of water vapor in the air, and the needed amount for saturation at the same temperature. Due to a lot of variables involved in humidity, the comfortable RH is approximated throughout the whole year. RH in summer should approximately be between 20% to 60%, and it should be less than 80% in winter (Lechner, 2015). Such RH percentages can be reached in a building through the proper use of cooling techniques.

2.3.2 Topography

The wind velocity differs between valleys and upper areas. Cool air settles and stays longer in lower areas and valleys, as illustrated in Figure 5, so the wind movement is changeable due to the topography. In mountains and hills, the north and east facing facades are colder than the south and west facing façades. Therefore, the topography will affect the building characteristics in the proportions, orientation, wind load, and how to deal with water at the site and the water drainage (ICAEN, 2004). The topography of the sloppy site, flat or hills, and its orientation effects on the plan and design of a building, as it might need excavation or fill before constructed. For example, if the site is sloped and the building is oriented to the north, it might not get enough sunlight in winter, which will require more heating costs. In cold climates, to avoid the cool air path, it is important not to build in lower areas of the slope. Unlike humid climates, it is important to place it in the windward slope to get the highest air speed. In addition, in the hot climate area, building on the lower side is preferable (Gupta, 2012).

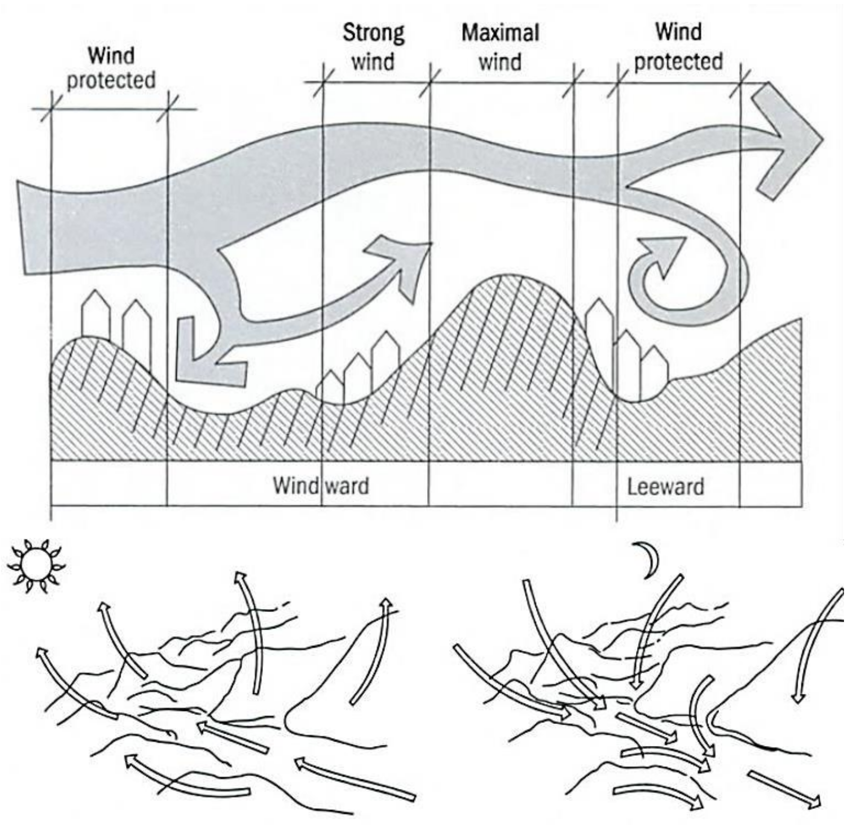


Figure 5: The Difference between Windward and Leeward Side to the Topography in Wind and Wind Velocity, (ICAEN, 2004)

2.3.3 Regional Building Materials

From the beginning of living aspects, the construction was influenced by the useful and available materials in its location. The different requirements of each material and land opportunities helped him to decide which of these materials are suitable for its location. So it affects the differentiation of the construction type, shape of buildings, building materials, and adoption to whether it is a rural or urban area. It can be said that using the local materials promote humans and environment relations and the harmony between buildings and the surrounding environment (Strohmeyer, 1960). Buildings are affected by the natural environment, first, in the environmental consumption, which means the use of its natural resource in building forms and materials, it is considered as the basic concern of the sustainable design. Second is the environmental deterioration, which is related to the use of non-renewable (or conventional) energy resources, which is also related to materials manufacturing besides the greenhouses gases emission to the atmosphere. Environment and materials relation can be controlled according to first, the production of gases that spread of the materials to the air affecting the global environment during the building life cycle such as CO_2, which increases the CO_2 in the atmosphere. The second control is the use of materials and energy with solid waste and air pollution for the local environment. The third control is the indoor environment by means the control of the ventilation to reduce the emissions of the untested materials, which may have a high concentration of toxic substances besides another harmful substance. Use of local materials, renewable materials, materials with low embodied energy, and reusing building materials are preferable rules for the material's life cycle to select environmentally friendly or sustainable building materials (Santamouris, 2013). According to Schultmann & Sunke (2009), insulation and thermal conductivity, reconstructed ability, recyclability, and contamination are the requirements to achieve sustainable development from an ecological point of view. Each region has its own materials' characteristics needed, and whatever was available in a place, people managed it to be a benefit and suitable for their needs and adapted to the environment conditions (Schultmann & Sunke, 2009). For example, in a hot region, a high mass wall was used as it heats up and cools down in a longer time, it helps during day time and losing heat at night (Szoboszlai, 2015). The absorbing heat from the outside surface of a wall and transfers it to the other side gets delay by the low thermal conductivity, to provide comfortable interior conditions. Therefore, using low thermal conductivity will help to reduce transferring heat (Lotfabadi & Hançer, 2019). As well as, buildings materials effect on heat which absorbs, reflects and distributes to surroundings. The heat causes the urban heat island effect (UHI), buildings can influence the urban climate with lack of vegetation and also by buildings that block each other, which result in the release of artificial heat and materials emission. UHI found in cities as a result of the direct absorbed radiation which is emitted as long-wave radiation during the night to the surroundings. It is related to the absence of wind that transfers away the accumulated heat (Bay & Ong, 2006). Therefore, building materials impact the building envelope design and the roof, walls, windows and shading materials characteristics, to provide the suitable needed materials that deal with the climate conditions.

To sum up, the impact of the climate will be analyzed for the building envelope that separates the outdoor spaces from the indoor spaces. Therefore, building envelope strategies will be discussed in the coming section to clarify how the envelope is affected by the climate to provide the comfort demand.

2.4 The Impact of Climate Responsive Design in Different Main Climate Zones

The relationship between the climate and building design will be discussed to achieve the climate responsive design solutions. The determination of the needed or preventing climate as a resource differs from climate zone to another, like the need for airflow in hot and humid regions, whereas the need for a shadow to prevent solar radiation in hot and dry regions. The undesirable need for the humidity in the tropical climate and low rate of humidity is preferred in dry climate Figure 6. Climate affects building location, building orientation, building form, building envelope and its buildings component characteristics (Biket, 2006).

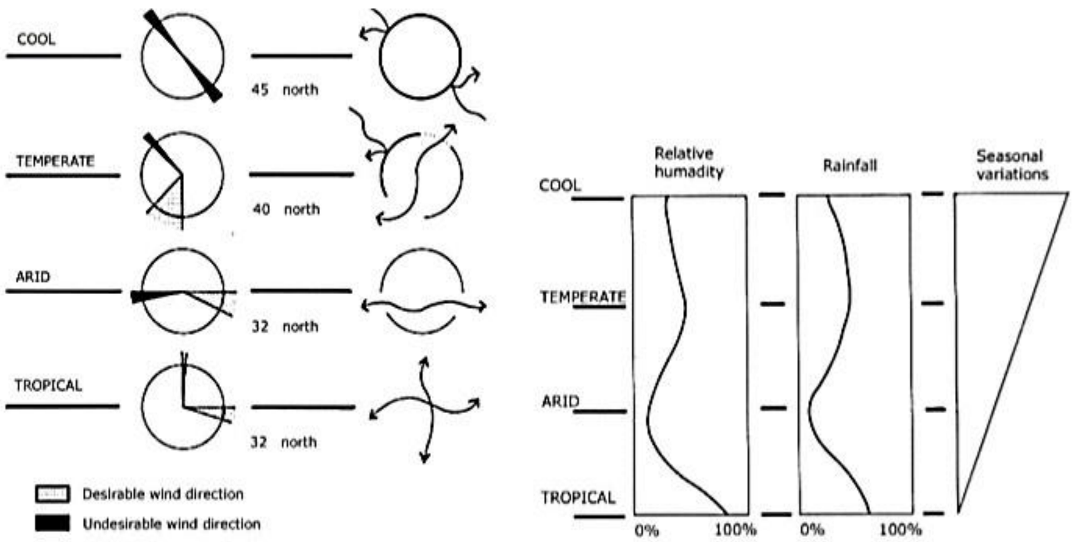


Figure 6: Wind Directions, Humidity and Rain of Different Main Climates Zones, (Biket, 2006)

-Building Orientation

Different needs affect the orientation and form of a building for different regions. For example, in cold regions to reduce exposure to low temperatures, it is needed to reduce the heat loss, minimize the building surface area, and maximize exposure to solar radiation. In temperate regions, maximum south wall area is preferable in comparison to east and west wall area of a building, to minimize solar exposure as they are warmer in summer and cooler in winter. Using shades are a technique to balance between needs in a different season by gaining solar heat in winter and encouraging the wind in summer. Also, for hot- humid regions, buildings form elongated along the east-west axis to reduce solar heat gain, besides promoting natural cooling with providing solar shadings for windows and outdoor spaces. For hot-arid regions, the courtyard will help to reduce solar conductive of heat gain besides, it provides outdoor space, and it promotes space for cooling by evaporation with water features and vegetation (Ching, 2008). Figure 7 shows building forms in different climate zones:

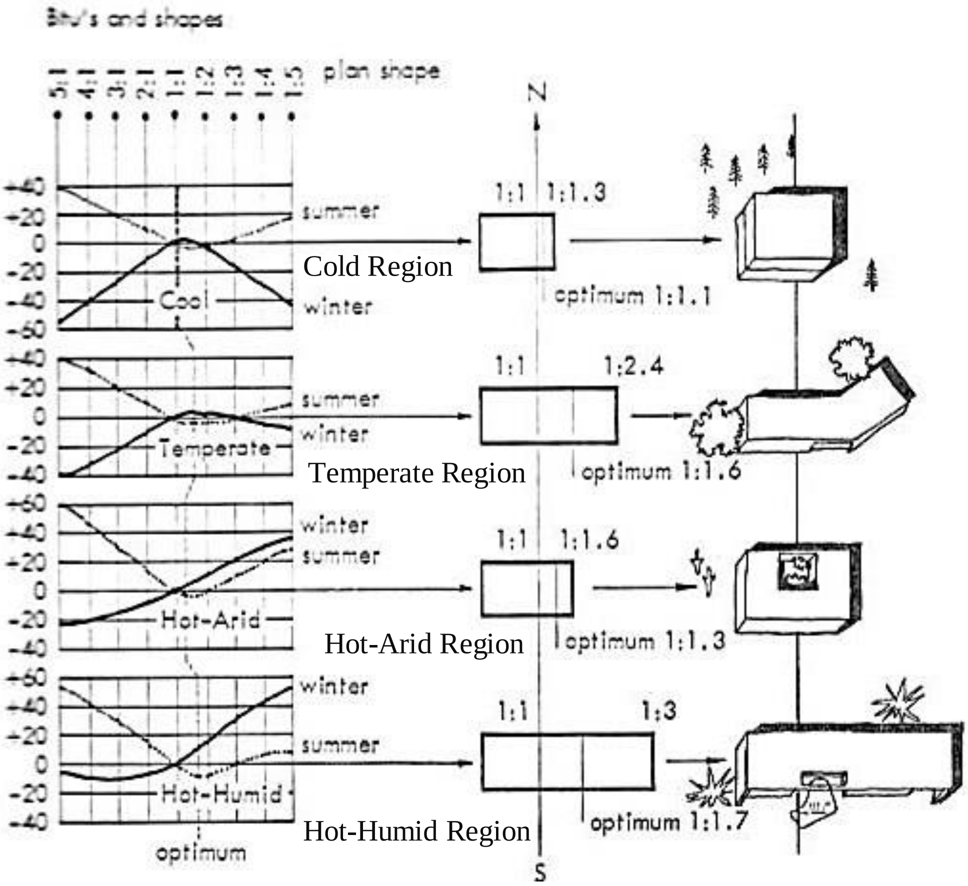


Figure 7: Relation between Building Form and Orientation in Different Climate Zones, (Vaca, 2015)

-Building Form

The building mass development is related to the environment by the impact of its solar and wind factors. Energy savings of building by its form and orientation, is one of the important aspects to be ecological and harmless to the environment (Rosenlund, 2000). As it defines the size, orientation, space zoning, and building envelope, which are responsible for the amount of solar radiation, heating loss and gain, and airflow around it. Figure 8 shows the suggested building form for the different climate as a result of their climate component. For example, in hot-humid areas it is preferable to have opening walls with balcony to provide maximum ventilation. Besides, the importance of building surfaces that are attached to the environment, roof form is another important architecture component element that is affected by the environmental factors such as in transferring the heat, due to its materials and its height that affects the building volume, in addition to its length and width. For example, area and coefficient heat of the curved roofs like domes are higher than the flat roof (Rosenlund, 2000). Building design and its envelope are affected by the environmental conditions, while the building includes thermal insulation, structural support, and weather protection. Therefore, building design will affect the use of energy consumption to maintain comfort for building's thermal heat losses or gains.

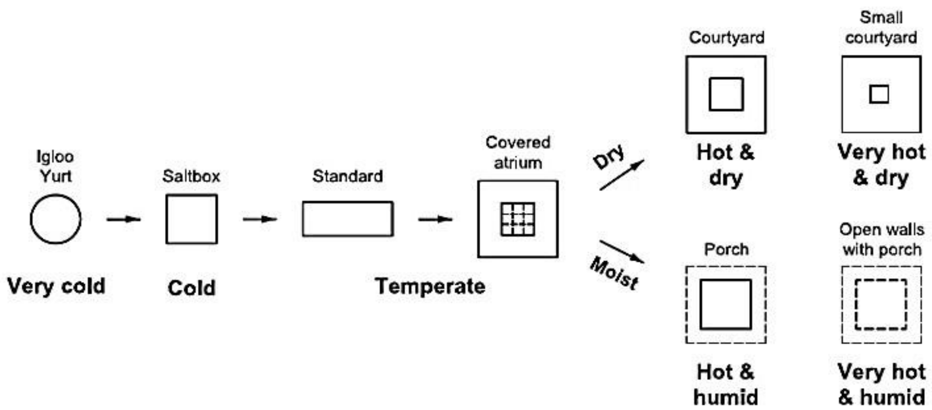
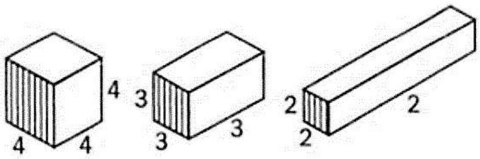


Figure 8: Building Form Influenced by Different Climate Zones, (Lechner, 2015)

- A/V-Ratio (compactness)

According to Tönük and Kayihan (2006) to maintain positive effect of thermal comfort to environment, it is depending on The European Commission criteria in 1999, buildings have to take into account the climate condition, orientation and building use, as well as, minimizing surface area to volume. For example, in a hot, dry, and cold climate, surface area to volume (S/V) should be minimized to prevent loss/gain heat. Also, an average of a window-to-wall ratio of 30% of the building is a positive impact of the design approach to the environment (Tönük and Kayihan, 2006). The use of building surface area to volume-ratio is called building compactness (S/V). According to Lylykangas (2009), the S/V factor for typical single-houses is between ≤.0.8 – 1.0

m2/ m3, and S/V of 0.2 m2/m3 only can be achieved in a large and very compacted building (Lylykangas, 2009). According to the Federal Ministry of Construction of North-Rhine Westphalia for solar houses in solar settlements in Germany A/V ratio is ≤0.65 (Grauthoff.et, 1999). Therefore, building shape affects the compactness, the lower S/V ratio, the more building compactness see Figure 9. Building compactness beside the space zoning affects the building mass proportion, surfaces to volume ratio. It gains less heat during the day, and loses heat at night (ICAEN, 2004).



Solid shape type	Surface area	Volume	Ratio S/V
a	96.0	64	1.50
b	103.2	64	1.61
c	136.0	64	2.13

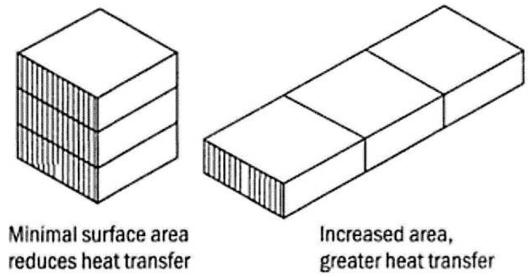


Figure 9: Different Buildings Surface to Volume Ratio Relation to Heat Transfer, (ICAEN, 2004)

So, different building surface areas with the same volume will effect on the energy loss. The smaller the external surface area, the lower the energy loss, therefore, lower environmental impact see Figure 10. In a hot-humid climate, it might not be necessary to lower the S/V ratio as its concern with having space for ventilation.

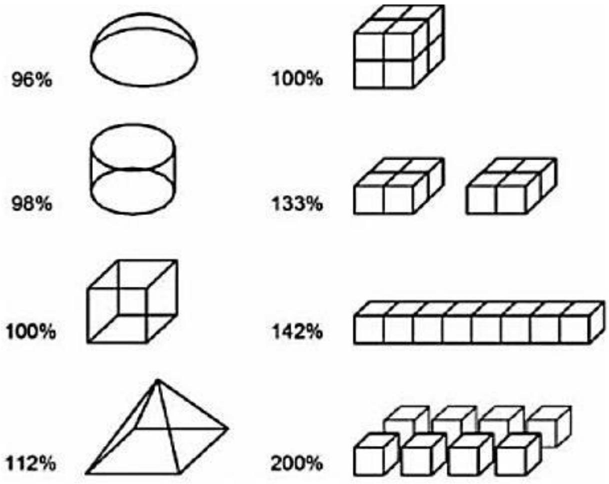


Figure 10: The Relation between Different Building Surfaces with Same Volume to Energy Loss, (Hegger et al., 2012)

2.4.1 The Characteristics of Climate- Responsive Design

This part of the study will clarify how different climates and their characteristics result in variable strategies. It is attempting to find out strategies which are needed for each climate, especially for the research case study toward determining the interaction between buildings and the environment toward environmental sustainability. Climatic responsive design is chosen as it acts in balance with the surrounding environment as an environmental filter.

2.4.2 Appropriate Design Strategies for Hot-Arid Climate Zone

The main characteristic of the arid region, in general, is the dryness at the soil, air, and the low annual precipitation. It ranges between the hot and dry desert with very limited precipitation. Also, it can be cold and dry like the Sahara Desert, where it is extremely hot in summer and extremely cold in winter, with big daily temperature change (hot daytime and cold night time). It is not limited to the desert. It can happen on the mountain, where the downwind (leeward) of a high mountain is usually dry as the rain gathers in the windward side, because of the moisture receiving from a storm (Iqbal, 2018). The monthly temperature average is between 29°C and 35 °C and between

43℃ and 46 ℃ in midday and gets higher in the desert. In winter, the temperature is between nearly -2 to 20 ℃. Temperature is high with no precipitation. Therefore, keeping the building cool in summer and warm in winter is the main aim of the hot-arid climate zones. The wind speed in this climate is too low, with a low rainfall amount.

There are three main strategies for the hot-dry climate to avoid solar gain and high temperature. First, using the air for cooling in the daytime with taking the low air temperature in the night might be affective, with providing a window. Still, it is necessary to be more in the north faced as it receives less solar radiation, due to the high temperature in the daytime. Secondly, the use of the night-time air mass, as it can be stored to cool the building in the night and reduce the high internal air temperature in the daytime, it can be achieved by the compact form of the building. The third strategy is the use of evaporative cooling, where the water is the well-known cooling medium with its evaporation absorbs the heat and lower the temperature. In this climate zone, the human body will not sweat like in the humid area, so providing indirect evaporative cooling is needed, such as water bodies, landscaping, or mechanical systems. As mentioned before, the courtyard can provide a place for the water bodies and vegetation see Figure 11. For the winter season, solar heating control strategies such as shading devices, space organization, and mass storage can moderate the under-heated period. Also, it is preferable to reduce the dry wind and heat gain by having small openings, light colors, and thick roofs and walls (Hyde, 2013). See Figure12.

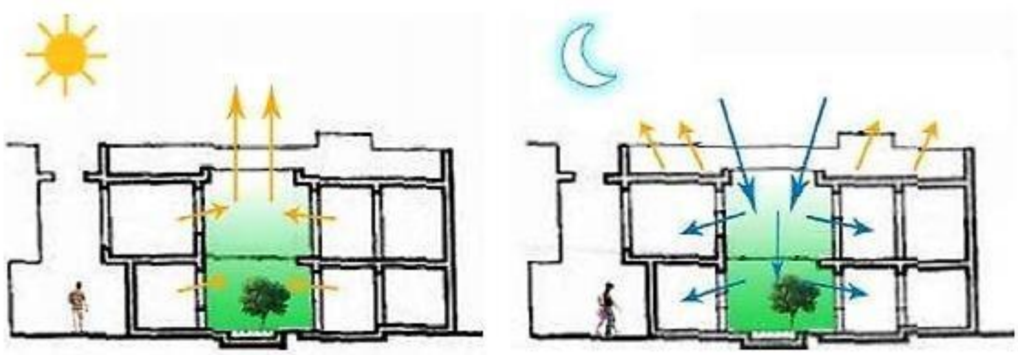


Figure 11: Courtyard for Evaporation and Ventilation Cooling System, (Sarswat & Kamal, 2015)

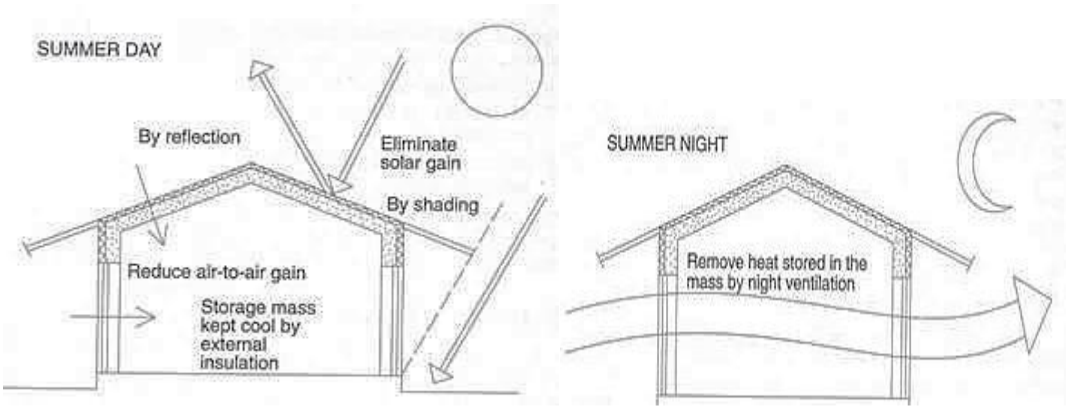


Figure 12: Example of Reducing Heat Gain/Loss Strategies, (Ahmed, Khan, Maung Than Oo & Rasul, 2014)

2.4.3 Appropriate Design Strategies for Hot-Humid Climate Zone

The annual humidity of this climate is around 75%, and 27 ℃ to 32℃ for the maximum air temperature with high intensity of solar radiation, but still lower than in hot and dry climates and with 2000-5000 mm of precipitation are the general characteristics. It is preferable to allow air circulation in buildings to minimize and control the humidity as much as important to minimize the direct solar radiation and day temperature. The excessive humidity with the warm temperature and high solar radiation exposure are the general characteristics of the hot-humid climate zone. Mostly this climate building design is elongated plan shapes along the east and west axis, as mentioned before, but it might compete with the wind need for low-rise buildings. A building site can be constructed in extended ground level if it is sloped land topography or left up if it is flat land see Figure13 (Biket, 2006).

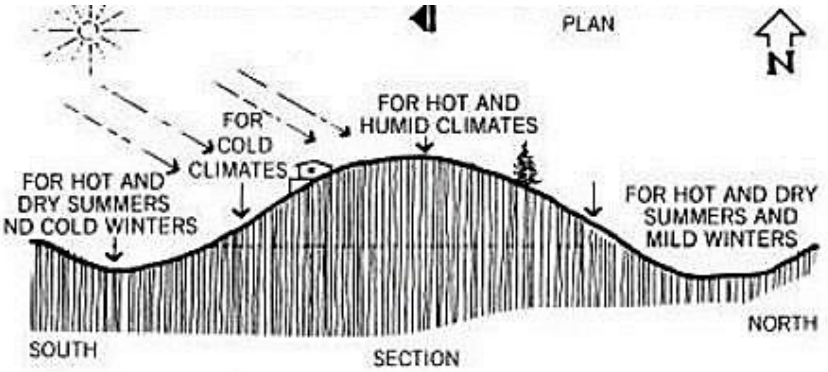


Figure 13: Preferred Site Selection for Different Climate Zones Including Hot and Humid Climate, (Lechner, 2015)

Secondly, the design of the building should include an insulated roof or with sloped angles to allow air circulation. Additionally, cross ventilation inside the building, could be provided with large openings, in a multistory building it can be improved by increasing the height of the atrium, using wind, and/or exhaust fans see Figure 14 or court formation with shadows to allow wind but with control and with the avoiding of water bodied, as the evaporative cooling can be provided by the high amount of the humidity. Also, the projection roof is to prevent direct sun rays and glare and to provide sun-control. In addition, the vegetation for this climate is important to maximize the airflow but should be planted suitably, or it will reduce the airspeed. Between buildings, it is important to provide street width, with separated space between the buildings. It should be oriented to allow natural cool wind movement to reduce the humidity and sun exposure (Biket, 2006). Besides humidity, avoiding of overheating is an important issue of this climate. Even though the intensity of radiation is normally lesser than in hot-dry regions, but it is a source of heat. So it could be reduced beside the above strategies by preventing the use of thermal mass materials, light colors, high insulation, if the walls are no fully shaded with high reflecting surfaces.

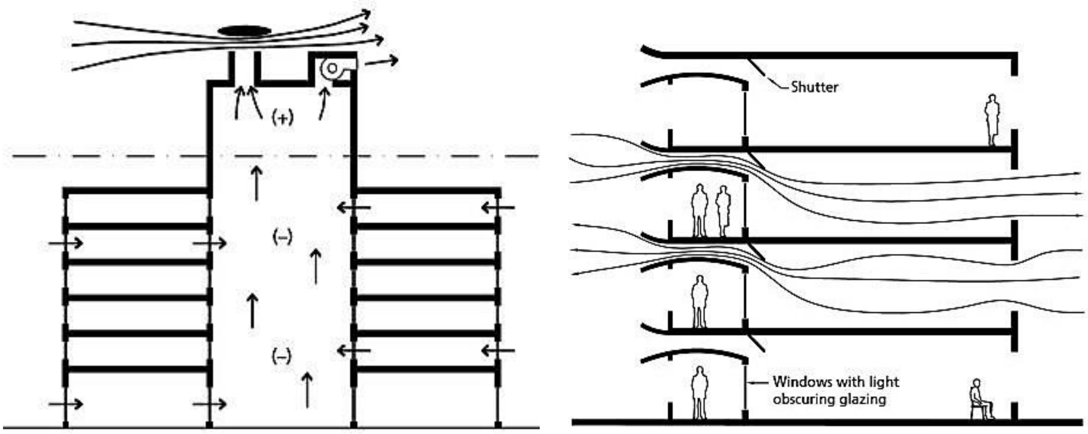


Figure 14: Building Strategies to Allow Cross Ventilation and Airflow in a Building, (Lechner, 2015)

2.4.4 Appropriate Design Strategies for Temperate Climate Zone

Temperate climate zone areas are located between the tropical and the polar zones. It is a relatively comfortable climate, neither hot nor cold, which exists between 40 and 60-degree north and south latitude. The regions could also be classified depending on their seasonal change and rainfall. There are subtropical regions that mostly have cool winter, but are relatively mild and wet, warm and have stormy summer, while the moist-continental regions have cool summer and are cold with plenty of snow and strong wind in winter (Hyde, 2013). Different climate conditions of the four seasons appear in this climate. The need for heating and solar gain in winter is more needed than the cooling in summer as the wind in summer exists. Therefore, building design should provide wind direction in summer and avoid solar radiation, while the wind is prevented, and the sun is provided in winter see Figure 15. Also, using suitable materials such as grass, soil, asphalt, stone, etc. between building spaces to strength the need or prevent the wind is needed, and reflect the sun rays with providing balanced absorbent heat surface (Biket, 2006).

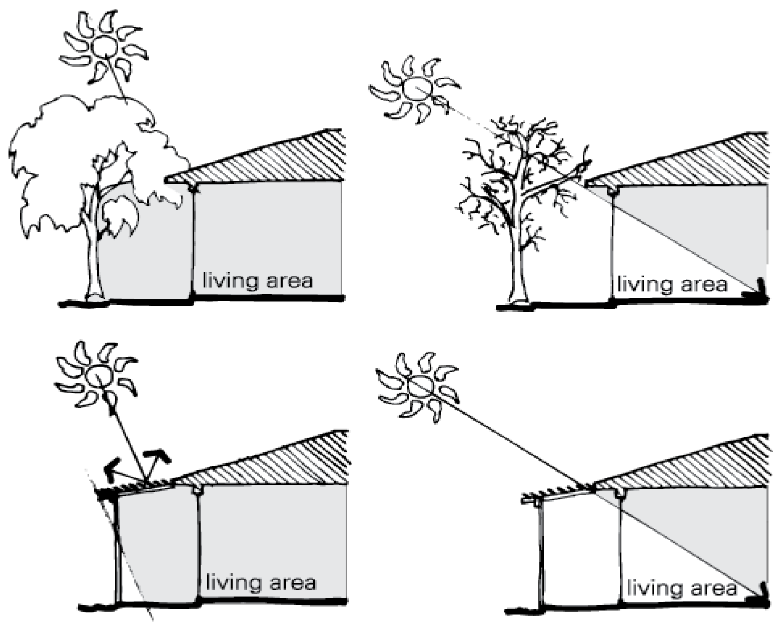


Figure 15: Controlling The Solar Radiation by Shading in Summer (left) and Winter (right), (Reardon, Mcgee & Milne, 2013)

2.4.5 Appropriate Design Strategies for Cold Climate Zone

In this climate classification, it could include both the continental and the polar climate, as shown in the Köppen Climate Classification. The continental has a very cold winter with snowstorms, strong wind, and lower temperatures, mostly around -30 °C with cool summer, whereas, to the polar, all-seasons are extremely cold. The highest temperature never increases above 10 °C (Köttek, Grieser, Beck, Rudolf & Rubel, 2006). In these climate regions, maximum heat gain and minimum heat loss are the most important strategies needed due to the extreme climate weather. Firstly, it can be achieved by the compact building shape to reduce heat loss. Even in the urban scale, it is preferable to avoid the segmented architecture and go with compactness texture to prevent wind movement. Secondly, the orientation of the building is to gain heat. So, it is preferred to be toward the south and south-east facing façade, with the use of thermal mass to store the heat by using of dark materials colors, that provides higher heat storage ability and higher heat absorption capacity see Figure 16 and 17. Pitched or curved vaulted roofs are one of the main climate solutions to prevent extreme weather conditions (Biket, 2006).

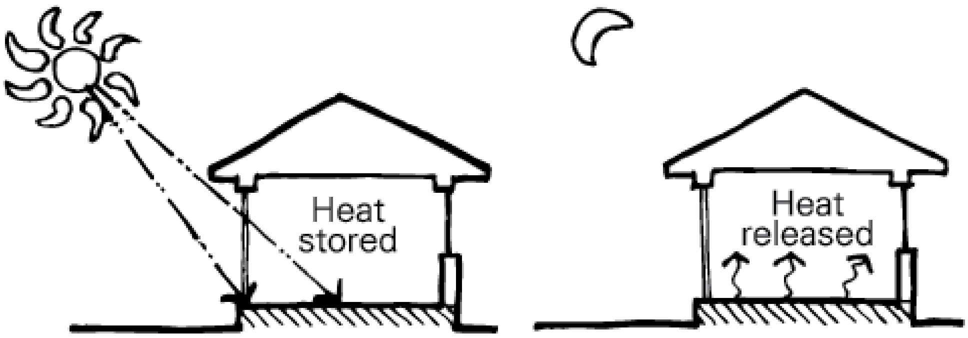


Figure 16: Solar Heat Gains and Stores in Winter, (Reardon, Mcgee & Milne, 2013)

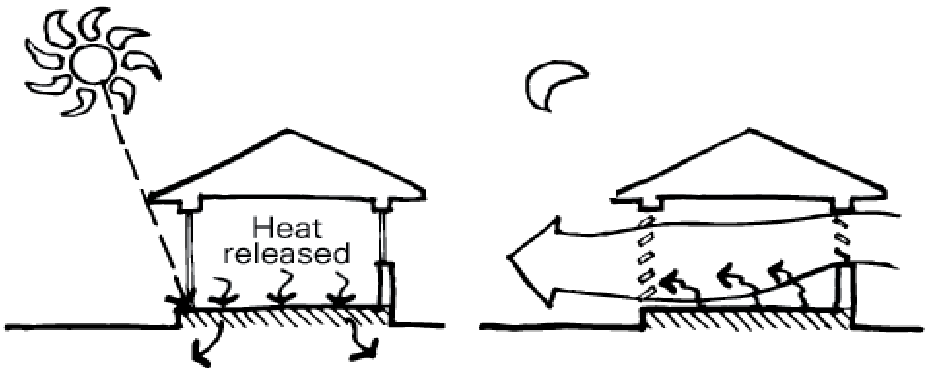


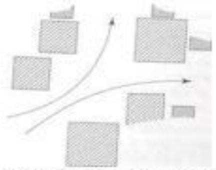
Figure 17: Heat Releases in Summer, (Reardon, Mcgee & Milne, 2013)

Table 1 illustrates the building strategies of climate responsive design for different climate zones categorized. The aim of presenting different strategies is to have an overview on how environmental factors are impacting design strategies in different climate zones

Table 1: Climatic Responsive Design Strategies for Different Climate Zones, by Santamouris (2013), Gupta (2012) and Hyde (2013), (summarized by Author)

Climate Responsive Design Elements	Cold Climate Zone	Moderate Climate Zone	Hot-Dry Climate Zone	Hot-Humid Climate Zone
Compactness	Compactness is needed, minimum A/V ratio Greater the A/V ratio the greater the radiative heat gains during the day and the greater the heat loss at night. Minimizing the building area would be less than in hot-humid climate			Compactness is not necessary to provide axis for cross ventilation. Building area is large
Preferred wind	Winds avoided. Sheltered to avoid the path of the cool air	Sheltered to avoid the path of the cool air	Expose to prevailing wind	Provide air movement
Building orientation	South east	South, south east	South	South toward prevailing wind
Building shape, form	Preferable square plan, high compactness	Smallest building aspects to east and west to reduce solar gain	Courtyard provides a beneficial area for this climate	Rectangular shape with open space, elongated plan on east-west.
Semi-open spaces	Could be close area to store the solar heat	Rain and sun protection to walls, external space for extreme heat and provide light	Dust and sun protection to walls, external space for extreme heat and provide light	Rain and sun protection of walls, external space for extreme heat and light
Water bodies	Beneficial only if their heat gain and loss can be controlled and enclosed by the building		also water bodies to promote the evaporation cooling as well as minimizing heat gain	Most avoided

(Table continuous)

Vegetation	Might cut off breezes. But they would also absorb solar radiation thereby, cool the place	Vegetation could be applied as shading element to reduce the solar gain in summer	Preferable to have vegetation also water bodies to promote the evaporation	Can be employed to maximize airflow with well plant or it could reduce air flow
Orientation on the site	South, south-east	South , south-east	East, south-east	South
Position on the slope	Low preventing the wind	Middle-upper for solar radiation	Low for cool air	High for wind
Urban cluster	 Wide east-west streets maximize the scope for south winter sun. In compact building heat loss is high even though the heat gain is reduced.	N.A	 Narrow north-south streets minimize radiation.	 Maximum air flow
Materials	Dark, high thermal mass materials.	Mass or lightweight materials	Light materials well shaded	Light materials well shaded
Materials coloration	Medium to dark	Medium	Light on exposed surfaces, dark to avoid reflection	Light
Wall	Dark, high thermal mass materials.	Light colors reflecting solar radiation	Heavy weight with small well shaded windows in summer	Avoid window to the east and west

(Table continuous)

	It is preferable to have smooth surfaces that would increase absorption and reflection to gain heat			
Roof	Pitched roof or half sphere vaulted mostly applied to prevent the extreme weather conditions	Light colors reflecting solar radiation. Insulation to improve the thermal performance. Minimize roof area for overheat.	Solid and light color reflecting solar radiation. Minimize roof area for overheat.	Light colors reflecting solar radiation. Insulation to improve the thermal performance. Minimize roof area for overheat.
Openings	Large. Shaded is optional but sealed is important to prevent Infiltration	Avoid window to the east and west	Small well shaded for ventilation	Maximum window - wall ratio (WWR) than other climate zones but avoid window to east and west

2.5 The Impact of Climate-Responsive Design on the Architectural Elements of the Buildings Envelope

This section will focus on the elements of building envelope (exterior wall, roof, window) to fully understand how they are impacted by the climate. The architectural elements of the building envelope are highly affected by heating, cooling, daylighting and ventilation. For example, if a building has light transmittance of sunlight, it might cause visual and thermal discomfort by the increase of solar gain in summer and heat losses in winter from the large windows without taking in consideration window opening, orientation, shading devices, material, etc. (Hidirov, 2009). The prevention of overheating and providing of ventilation can be achieved through the elements of the building envelope (exterior wall, roof, windows) in a hot-humid climate, which is related to the research case study (Famagusta).

2.5.1 Exterior Walls

The exterior surface characteristics are important, since walls and roofs are the most exposed building elements to solar radiation, their surface temperature gets higher than the air temperature itself. Therefore, the excessive heat of the exterior wall transfers to the interior spaces. The exterior wall materials respond differently to the climate conditions. For example, some walls are conductors with little resistance against the heat transmittance, like glass and metal, the heat is equal on both sides of these materials. Some materials prevent the heat transfers from one side to another as a thermal insulator, where the temperature differs on both sides of the material, these materials have low conductivity and high thermal resistance like marble. Moreover, other heavy wall materials like concrete and brick are consider as heat savers or capacitors, since the heat is stored and saved in the material and is released at a later time (Emadi, 2014).

Building exterior wall characteristics should respond to the different climate need. One of the important characteristics of materials is the reduction of heat transmission. Materials provide insulation through their R-value, which is the rate at which heat is lost or transferred, it measures the material's resistance to heat flow. So, the higher the heat resistance and insulation of a material the higher the R-value. Another measure of heat transfer in materials is the U-value, which is the rate of heat transfer through a material, the lower the value the better the material insulation. According to ASHRAE Standard 1997 the U-value of exterior wall material should not exceed 0.3 W/m^2K and roofs should not exceed 0.15 w/m^2k to provide a comfortable interior environment (Khatibi, 2015). According to European Energy Conservation Act requirements Max, U-Value (Energy Transmittance) 0.45 W/m2 K for external wall and for renewed external wall 0.35 W/m2 K (Hegger, Fuchs, Stark & Zeumer, 2012).

As mentioned before, the building envelope in hot climates compared with cold climates should have less transparency with appropriate shading to prevent undesirable heat transfer from solar radiation. According to Baglivo, Congedo & Fazio (2014), in order to deal with thermal variations, whether it's from indoor or from outdoor spaces, materials as thermal mass should store the heat and releases it gradually to achieve a stable internal environment. In the same study, the performance of different exterior wall materials which are currently available in market in Mediterranean climates are analyzed based on their heat capacity and eco-friendly percentage, as shown in Table 2 (Baglivo, Congedo & Fazio, 2014). Another important characteristics of the walls materials is the material coloration. ASHRAE handbook-fundamentals stated that the walls should have a light color and the roof should be white, where the heat gain through a white wall is two- thirds that of a black wall, and it is half of that of a black roof, see Figure 18. Solar reflectivity percentage is describing how much of the solar radiation is reflected from a surface is varying based on materials and color, such percentage a material having an albedo value of 0% means that that all sunlight is absorbed and none is reflected (Lechner, 2015).

Table 2: Examples of High Performance External Walls, (Baglivo, Congedo & Fazio, 2014)

Wall	Type 1	Type 2	Type 3
Layer 1	10 cm, Concrete Ms>300 kg/m^2	10 cm, Concrete Ms>300 kg/m^2	10 cm, Concrete Ms>300 kg/m^2
Layer 2	7 cm, Cellulose fiber	3 cm, Cement mortar	3 cm, Cement mortar
Layer 3	3 cm, Cement mortar	12 cm, Polyurethane exp.	12 cm, Polyurethane foam
Layer 4	16 cm, Cross-laminated timber panel	10 cm, Tuff	16 cm, Cross-laminated timber panel
Layer 5	3 cm, Cement mortar	6 cm, Cross-laminated timber panel	1.5 cm, Plaster
U (W/m^2)	0.28	0.15	0.15

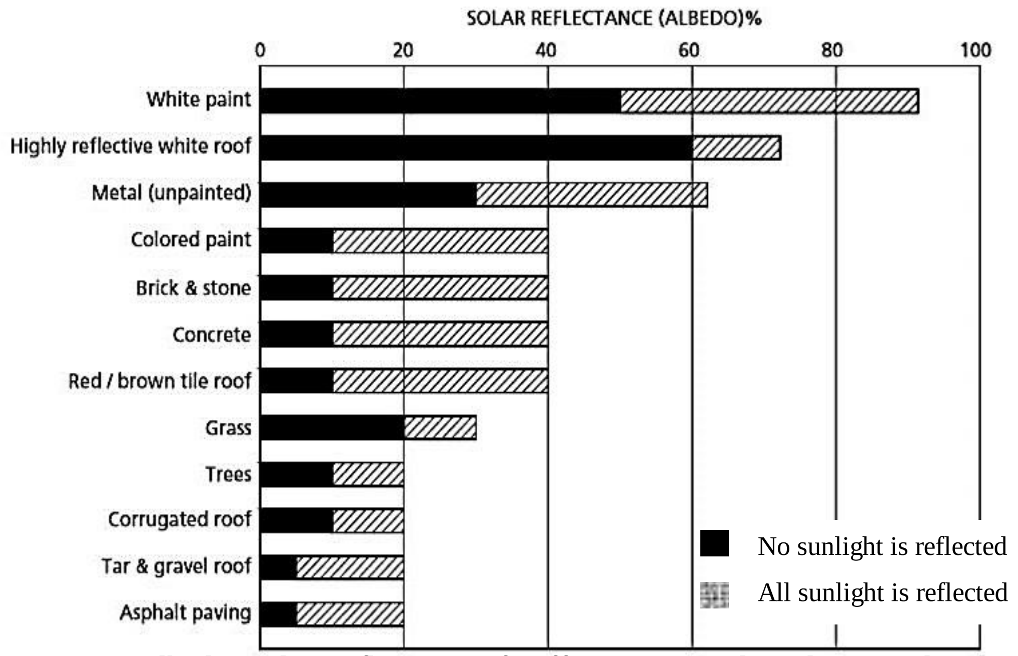
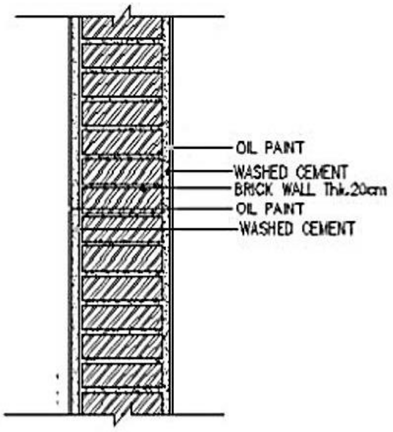


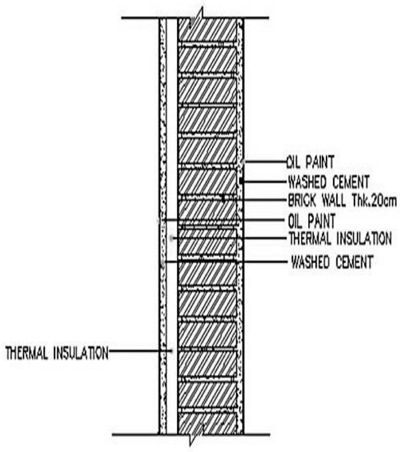
Figure 18: Albedo, Solar Reflectivity of Different Materials and Material Coloration, (Lechner, 2015)

In a study by Emadi (2014), external wall materials and their impact on the human comfort and energy consumption in Famagusta was analyzed, which concluded that wall with thermal insulation is 3 times more effective than the exterior walls that do not have thermal insulation. Figure 19 shows the performance of external wall materials without insulation, which are commonly used in Famagusta has a U-value (Thermal Transmittance) of 1.66 W/m^2K according to the formula U-Value = 1/R, while R-Value (Surface Resistance) is 0.6 W/m^2K. The external wall consists of 20 cm thick clay blocks, and a layer of cement sand mortar which covers the both sides of the wall with 2 cm thickness. Figure 20 shows the performance of the same external wall materials but with an added layer of polystyrene thermal insulator having 5 cm thickness, the wall resulted in a U-value of 0.6 W/m^2K according to the formula U-Value = 1/R, while R-Value is 1.66 W/m^2K (Emadi, 2014). The difference in the U-values between these two walls shows that insulators and thick walls are better for thermal absorbers for Famagusta climate conditions. The U-value for Famagusta studies is still higher than 0.3 W/m^2K and 0.45 W/ m^2K, compared to ASHRAE Standard 90.2 and European Energy Conservation Act requirements of the maximum U-Value for exterior walls. These international studies are more general rules but the Famagusta studies are more specific where they take in consideration the specification of Famagusta such as the climate and the availability used materials. According to the difference in U-Values it could be stated that Famagusta exterior walls should not exceed 0.6 W/m^2K, the lower U-value the better the performance of the exterior walls.



Layers	d	Λ [W/mK]	d/λ -R
Indoor Air	-		0.11
Cement	0.02	1.15	0.017
Clay Block	0.20	0.51	0.39
Cement	0.02	1.15	0.017
Outdoor Air	-		0.06

Figure 19: External Wall Materials and their R-Value 0.6 W/m2K without Thermal Insulation, (Emadi, 2014)



Layers	d	Λ [W/mK]	d/λ=R
Indoor Air			0.11
Cement	0.02	1.15	0.017
Clay Block	0.2	0.51	0.39
Thermal Insulation (polystyrene)	0.05	0.047	1.06
Cement	0.02	1.15	0.017
Outdoor Air			0.06

Figure 20: External Wall Materials and their R-Value 1.66 W/m with Thermal Insulation, (Emadi, 2014)

2.5.2 Roof

The roof is one of the most exposed building element to solar radiation, 15 % of the solar radiation can be absorbed by white coated roof whereas 95% is absorbed by black asphalt roof (Harvey, 2006). Many researchers around the world studied how building envelope is affected by environment and how it dealt with variable climate conditions to save energy. One of the study of Hong Kong high-rise apartments in a hot-humid climate resulted that 31.4% of energy saved through achieving passive heating and cooling strategies. These strategies were achieved by adding extruded polystyrene (EPS) thermal insulation material in exterior walls and roof with light color finishing and with proper shading of the windows. Another study in Greece also using thermal insulation for walls, roof and floors, as well as applying light color on external and roofs, resulted in the reduction of cooling loads by 30%. Moreover, UK building~~s~~ regulations require~~s~~ and European Energy Conservation Act requirements a U-value (Thermal Transmittance) of 0.25 W/m^2K or less for flat roofs for all new buildings. There are many strategies for improving roof design such as using light colors of the external roof surfaces to reduce solar absorptivity, or covering the roof with vegetation and shading elements to provide ventilation and reduce heat absorption from solar radiation (Sadineni, Madala & Boehm, 2011). Figure 21, illustrates how different building roof strategies react to solar radiation in summer seasons. The most important strategy for roof design is to have a high insulation to reduce solar heat gain into a building. A study by Kamali (2014), focused on the proper selection of materials for roofs in Famagusta to improve the quality of thermal comfort of indoor spaces. The study showed that roofs with 15 cm thick reinforced concrete slab, asphalt cover and plaster having no insulation had a U-value of 1.04 W/m^2K, whereas roofs with same materials but with 5 cm thermal insulation had a U-value of 0.51 W/m^2K. For Famagusta, it is recommended for buildings to have a ventilated attic space and a flat roof with thermal insulation on the inner surface see Figure 22 to get the best performance during the summer (Kamali, 2014). As mentioned in the exterior walls, the U-value for the Famagusta study is too high compared to European Energy Conservation Act requirements, but this value is based on the specification of Famagusta. Therefore, the U-Values of new residential building in Famagusta should not exceed 0.51 W/m^2K for better performance.

Moreover, another study by Özdeniz and Hançer (2005) for Famagusta, resulted that all roofs should have ventilation to prevent heat and humidity storage. Thermal resistance and solar reflectance of the roofing material effect on roof thermal performance. Although all roof layers with thermal insulation have better performance but the location of thermal insulation whether it is located toward exterior or inner layer has different effect on the roof performance. The appropriate selection of roof construction for Famagusta are the roofs which have the least amount of heat gain in overheated periods, such roofs are the inclined timber roof with a ventilated attic space, terrace roofs, and the roofs that place the thermal insulation materials towards the inner surface. In addition, the use of white and bright color helps to reduce undesired heat gain (Özdeniz and Hançer, 2005).

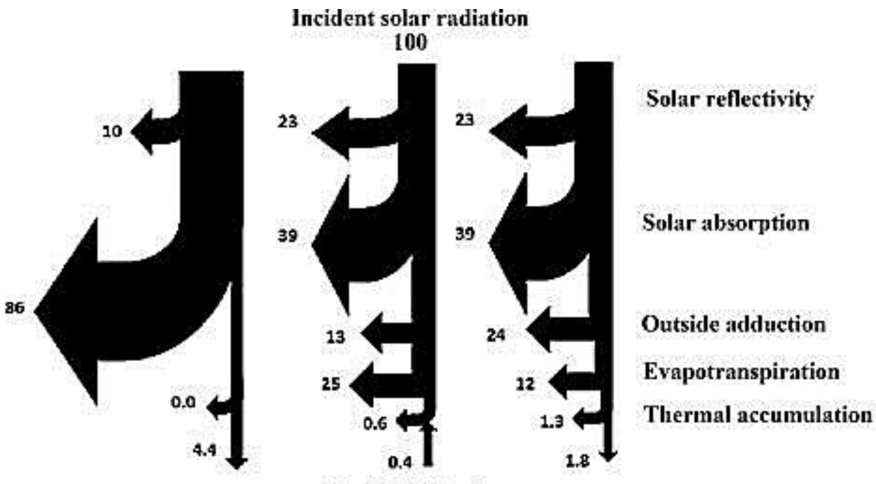


Figure 21: Different Roof Strategies React to Solar Radiation, (Sadineni, Madala & Boehm, 2011)

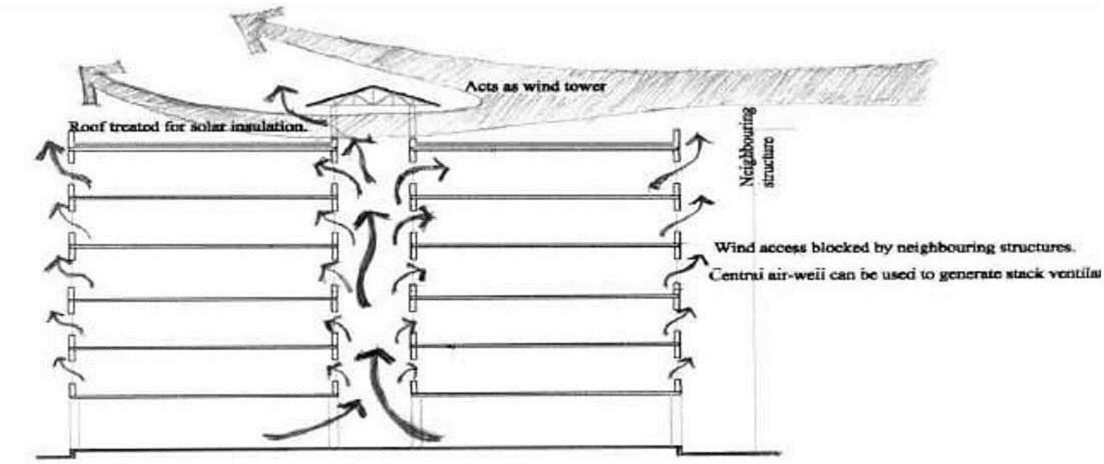


Figure 22: Roof with Insulation and Ventilated Attic Space to Allow Wind Access, (Ahmed, 2003)

2.5.3 Windows / Apertures

Windows that provide sufficient daylighting and ventilation, highly enhance the building design relation to its surrounding natural environment and it helps to reduce energy usage in the building (Rabah, 2005). Provision of solar heat gain and air movement inside the building are important functions of windows beside transmission of sunlight.The performance of windows is determined by window elements such as the glazing and framing material. Reducing the heat transmission is the main goal of window efficiency. It is achieved by the materials performance which determined by various properties, like U-value, solar heat gains coefficient (SHGC), visible transmittance, low-emittance coating and air leakage. U-value is the thermal transmittance of window glazing material the lower U-value of the glazing the higher the insulation. As for SHGC the higher the value the higher the heat gain. Visible transmittance is the amount of visible light transmitted through the window, as it is desirable to maximize the sunlight, so it is better to have a higher VT value, with a low-emittance coating to reduce the heat gain from solar radiation, Table 3 (Carmody & Haglund, 2012). Therefore, the window elements such as the frame, number of panels, the air spaces between, as well as, its material characteristics all affect the energy efficiency of window. Transparent glass with low-emittance coating is the suitable selection for providing sunlight and reflecting the heat. Triple glazing has the best performance between the single and the double glazing with 30% of solar heat reduction. Furthermore, windows that have the flexibility to react to the changing conditions of solar radiation and environment condition can be achieved by using a movable louvre, light shelves see Figure 23 for the double or triple glazing panels (Rahbariayazd & Raswol, 2018).

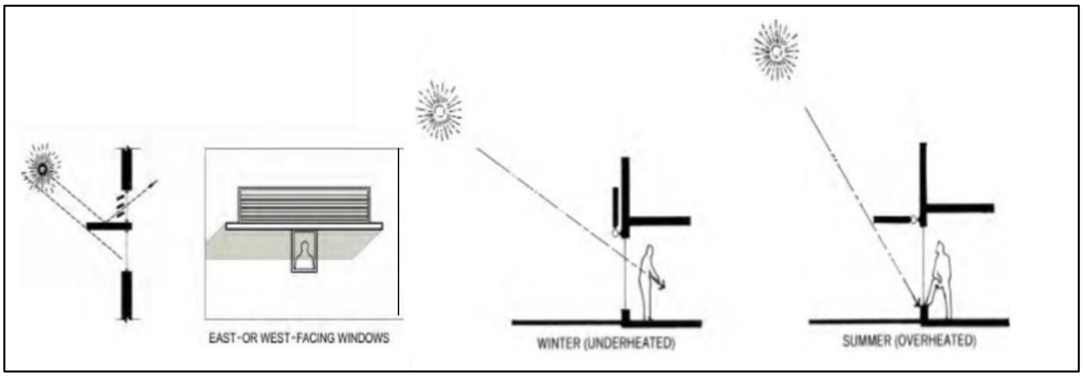


Figure 23: Flexibility Strategies for Windows, (Lechner, 2015).

Table 3: Proprieties of Window Materials, (Carmody & Haglund, 2012)

Glazing	Frame	U	SHGC	VT
Single, clear	Metal	1.29	0.73	0.69
Double, clear	Metal	0.83	0.65	0.63
Double, tint	Metal	0.83	0.54	0.47
Double, low-e, high SHGC, argon	Metal	0.65	0.58	0.61
Double, low-e, medium SHGC, argon	Metal	0.64	0.38	0.56
Double, low-e, low SHGC, argon	Metal	0.63	0.26	0.49
Double, clear	Metal, thermal break	0.60	0.62	0.63
Double, tint	Metal, thermal break	0.60	0.51	0.47
Double, low-e, high SHGC, argon	Metal, thermal break	0.42	0.55	0.61
Double, low-e, medium SHGC, argon	Metal, thermal break	0.42	0.35	0.56
Double, low-e, low SHGC, argon	Metal, thermal break	0.41	0.23	0.49
Single, clear	Nonmetal	0.88	0.64	0.65
Double, clear	Nonmetal	0.52	0.57	0.59
Double, tint	Nonmetal	0.52	0.47	0.44
Double, low-e, high SHGC, argon, improved	Improved nonmetal	0.29	0.50	0.57
Double, low-e, medium SHGC, argon, improved	Improved nonmetal	0.28	0.31	0.52
Double, low-e, low SHGC, argon, improved	Improved nonmetal	0.27	0.20	0.46
Triple, low-e, high SHGC, argon, improved	Improved nonmetal	0.20	0.41	0.50
Triple, low-e, medium SHGC, argon, improved	Improved nonmetal	0.19	0.28	0.45
Triple, low-e, low SHGC, argon, improved	Improved nonmetal	0.19	0.18	0.37

It is recommended to use triple-glazed windows, low SHGC with a proper size and orientation, to achieve a positive impact on the environment through minimizing the energy demands for North Cyprus residential buildings (Bavafa, 2015). According to Khatibi (2015), which researches on ventilation systems in Famagusta buildings, concluded that the building should be located in the middle of the site, so that the building does not block the east wind direction and the south sun radiation. Providing at least two windows on each side of the building envelope will help to provide ventilation across the interior spaces for summer. South facing windows should have horizontal overhangs shading. In addition, it is suggested to use maximum window opening for summer to provide ventilation and for winter to provide solar heat gain, but for ventilation in winter the same window could have small openings see Figure 24, (Khatibi, 2015).

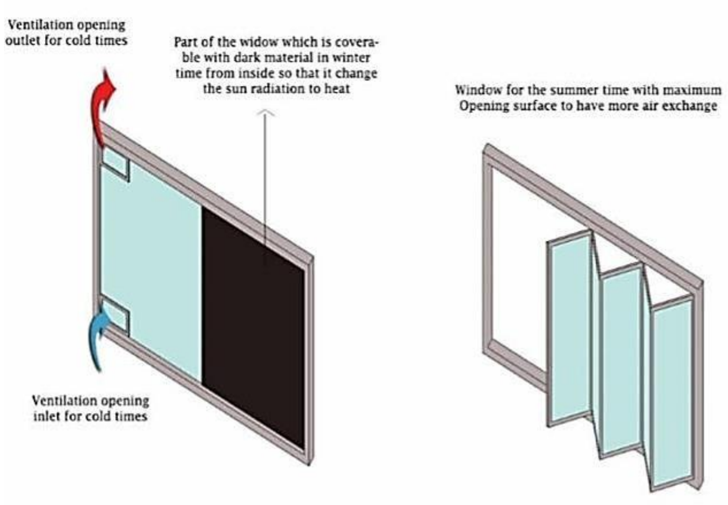


Figure 24: Suggested Window Solution for Winter (right) and Summer times (left), (Khatibi, 2015)

Another suggested solution for North Cyprus is the high leveled glazed opening in a building, which is called the clerestory windows see Figure 25. It is used to provide natural daylight in the building, as well as, natural ventilation. Clerestory windows are generated by the differences in air pressure and humidity, which results in air circulation around the building. Clerestory windows are more preferable than skylight, since it controls the sunlight access in the building better than skylight (Hidirov, 2009).

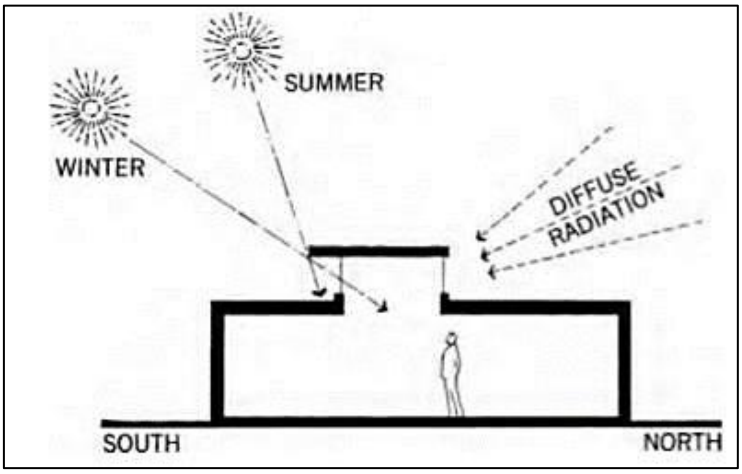


Figure 25: Clerestory Window, (Lechner, 2015)

2.5.3.1 Appropriate Shading Devices as Sun Control Elements

Shading device is an important element of window design as it controls the sun radiation. The various shading systems prevent direct, diffuse and reflected radiations, Figure 26, and they are used for the interior or the exterior of a building. Shading devices can be fixed or movable such as vertical fins, horizontal overhangs and a mix of both which is called egg-crate.

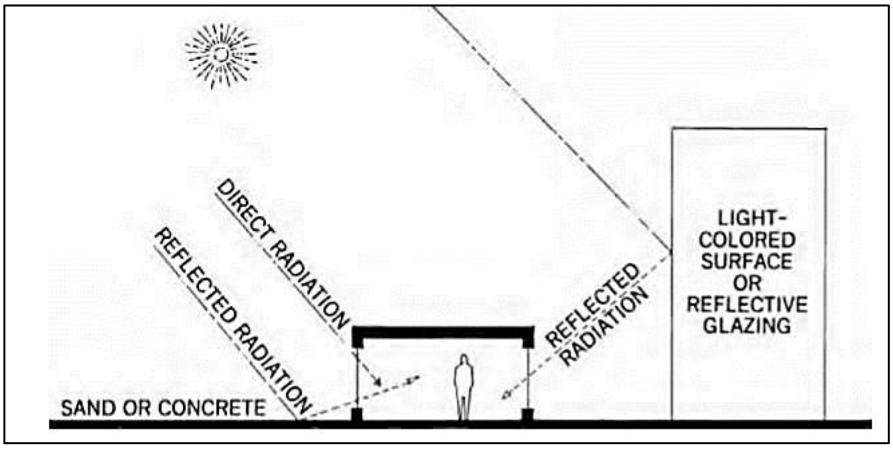


Figure 26: Direct and Reflected Radiation, (Lechner, 2015)

Solar radiation intensity is different in each orientation. In the northern hemisphere, in winter the south orientation gets the most amount of solar radiation as it reaches its maximum intensity at 12pm. The amount of solar radiation is the same in east and west facing windows but sometimes it depends on the specific local conditions such as shading from surrounding building. Whereas, north windows have the least amount of solar radiation in the northern hemisphere since it is not facing to the equator. In summer, the east and west windows have higher amount of solar radiation than south windows, hence, they require more shading. Moreover, the north window receives enough solar radiation, so it is preferable to provide vertical shading for north facing windows (Lechner, 2015). A study by Hidirov (2009), recommends appropriate climatic responsive design strategies for North Cyprus, like the use of horizontal overhangs in south facing windows. They are used as a shading device to protect the windows from sun radiation in summer with respect to the altitude angle which is the sun angle that determine the north–south position of a point on the earth's surface. The altitude angle effect on the depth of the shading devices designed. At the same time, properly sized openings and proper selection of thermally massive materials are strategies to provide sun penetration in winter. Horizontal overhangs with louver whether they are fixed or movable block the view and sun in winter but they allow free air movement. However, the vertical fins also restrict view but the view is even more restricted with movable vertical louvers.

Shading can be done by devices or sometimes by vegetation, for example deciduous plants, which allow solar heating in winter by shedding their leaves, while in summer the leaves grow and protect south facing windows from solar radiation. Such plants also have the ability to reduce glare and cool the air with visual privacy, but it needs a lot of care (Hidirov, 2009). Another vegetation strategy for a building can be vines plants, as they grow by hanging on a building, it has benefit in shading not only for windows but also walls, Figure 27.

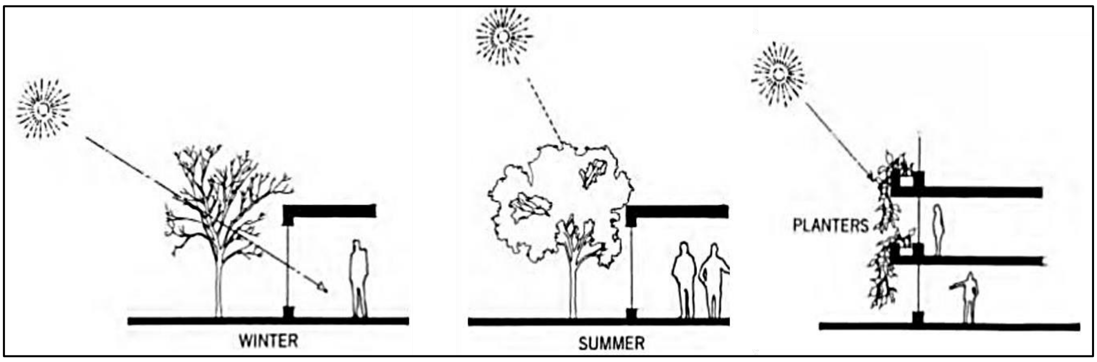
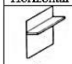
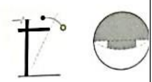
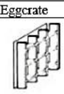
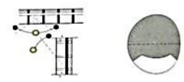
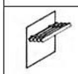
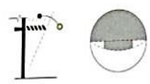
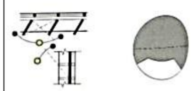
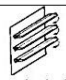
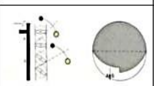
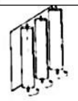
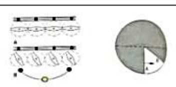
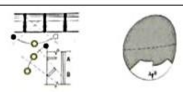


Figure 27: Vegetation Strategy for Shading as Solar Control Element, (Lechner,2015)

Each shading system has a various type and each shading device system has a different way to provide ventilation and shading. In general, the horizontal shading devices are better than vertical fins for blocking reflected solar radiation. Because of the high solar radiation and the low solar altitude, horizontal shading devices are recommended for south. East and west facing windows can have horizontal overhangs and vertical fins according to the solar geometry of the site and surrounding shades (Rungta and Singh, 02011). To choose the suitable shading device for a building, it is important to define the azimuth and altitude angles to decide which shading device will serve the building in its highest demand, Table 4.

Table 4: Different Shading Devices and Their Different Shading Masks, (Rungta and Singh, 2011), (summarized by author).

Horizontal Over hang			Vertical			Eggcrate		
 panel or awning	South East West		 Vertical fin	North		 Eggcrate	East, west	
 louvers horizontal plane	South East West		 Vertical fin slanted	East, west		 Eggcrate with vertical rotating louvers	East, west , south	
 Rotating horizontal louvers	South East West		 Fin Rotating fins	East, west		 Eggcrate with horizontal rotating louvers	East, west, North, South	

Chapter 3

THE ANALYSIS OF CONTEMPORARY RESIDENTIAL BUILDINGS IN FAMAGUSTA/NORTH CYPRUS ACCORDING TO THE IMPACT OF CLIMATE-RESPONSIVE DESIGN

3.1 Historical and Social- Cultural Background of Famagusta

This chapter will include the history of Famagusta to understand the historical development of the architecture, as well as the analysis of the relationship between contemporary buildings and the environment by the selected case studies in Famagusta North-Cyprus. Cyprus is located on 35° N latitude of the equator and 34° E longitude; it is one of the largest islands in the Mediterranean Sea Figure 28. Due to the history of Cyprus, many cultures of different empires were reflected on the urban and built-up environment areas, which has been impacted on its architecture periods from the Egyptian, Roman, Islamic, Byzantine, Gothic, Renaissance, Ottoman Turkish and British Colonial times (Dincyurek & Turker, 2007). According to Hoşkara & Doratli (2007), Famagusta's geographical location, climate, inhabitant socio-economic situation, religious and ethnic characteristics, and culture values, along with civilization and the empires who lived in Cyprus, are affected and developed the Cyprus architecture and environment (Hoşkara & Doratli, 2007). Gazimagusa (Famagusta) is one of the main cities of TRNC at the eastern coast of Cyprus. According to Famagusta Municipality and due to the historical development, the main development period of Famagusta lies between 1910 and 1974. It started in 1910, where Famagusta was small, with a population of 5000 people. By the high population increase, and the city became a dynamic district center in 1930 and after the construction of the main port for goods and passenger transportation until 1974.

Figure 28: Cyprus and Famagusta Location, (Oktay, 2007)

The population reached 35000 people in 1960 and increased to 39000 people within 13 years until it reached mostly 45000 of the population today. The city contributed in the island economy in many sectors, like agriculture, as it was known for its citrus gardens and was one of the leading export products of Cyprus. The industry sector employed 9.2% of the total number of people in the industrial sector throughout the island in 1972. Also, for the business activities, Famagusta holds around 19, 5% of business units. Undoubtedly, Famagusta was the most famous tourism center in Cyprus until 1973 (Famagusta Municipality, 2015). Nowadays, according to the world population (2019), Famagusta is the fourth city of the highest population, with 42,526 of the whole Cyprus. It is after Nicosia, Limassol, and Larnaca, with 200,452, 154,000, and 72,000, respectively and before than Kyrenia city which has 26,701 number of population. The estimation of the growth rate of the Cyprus population is 0.65% until the year 2025 ("Cyprus Population," 2019). Due to the population, the building construction demand has been increased, especially for foreign student accommodation needs, in and around Famagusta.

3.2 Environmental Sources of Famagusta Region

3.2.1 Climate

According to the Köppen-Geiger Climate Classification, Cyprus generally is defined as a hot-summer Mediterranean climate (Csa). The C letter stands for warm temperate climate as the main group with -−3 ◦C < Tmin < +18 ◦C, then S letter stands for the precipitation with less than 40 mm, and the A is the average temperature of the summer less than 22 ℃ (Köttek, Grieser, Beck, Rudolf & Rubel, 2006). However, the local conditions of each city are different depending on climate characteristics and its location from the sea, from hot- humid, hot - arid, and composite climates. Famagusta has an average temperature in the warmest months above 20 ℃, with an average temperature of 18°C in the coldest months. It has a hot with high humidity climate because of its proximity to the Mediterranean Sea (Oktay, 2002). It has a highly relative humidity with its annual report of more than 50 % see Figure 29 and 30, its average temperature is between 27 C˚ and 32 C˚ see Figure 31, with more than 50 mm of precipitation in the winter season see Figure 32, it is high exposure to solar radiation see Figure 33. Sun path of Famagusta is shown in Figure 34. The altitude angle on 21^{st} of December is 31° at 12pm and on 21^{st} of June the angle is 74°. Climate as environmental factor will impact on the orientation of building design strategies to get maximum benefit of sunlight and wind direction.

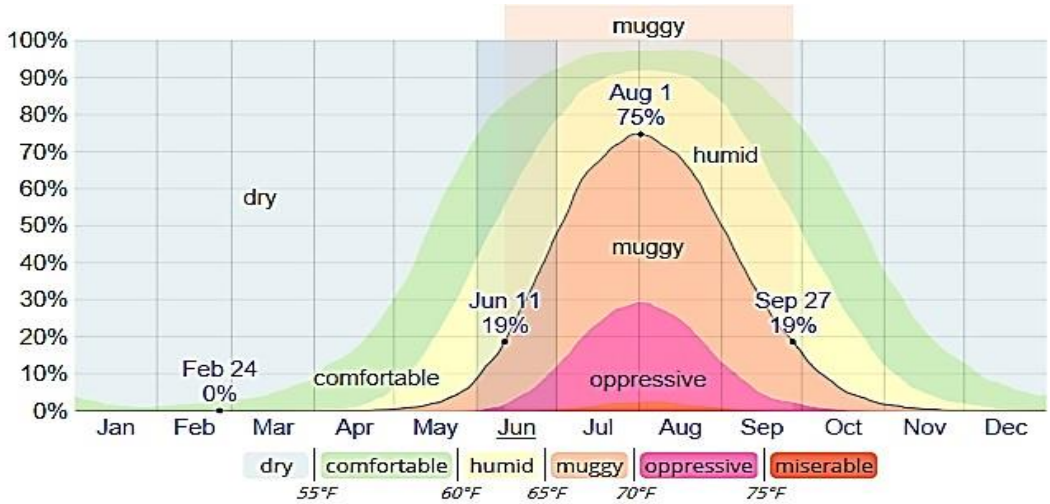


Figure 29: Muggy (Hot and Humid), Humidity Comfort Level in Famagusta of (2016), ("Average Weather in Famagusta", 2016)

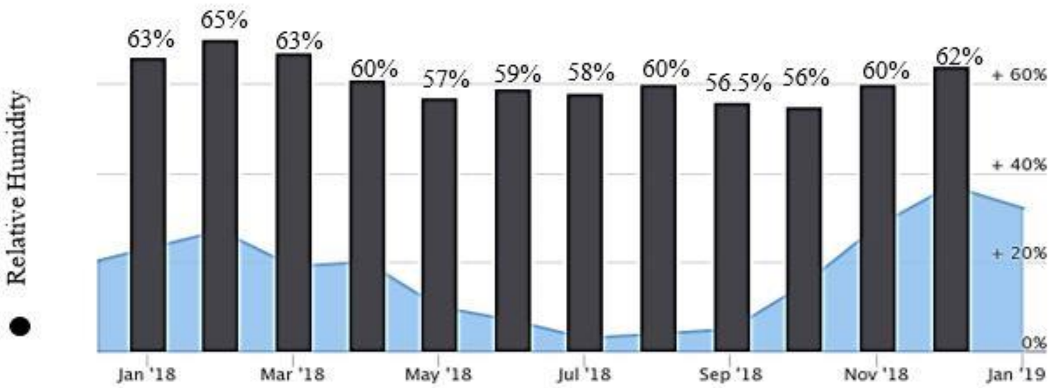


Figure 30: Average Monthly Humidity Report of Famagusta, ("Famagusta Monthly Climate Averages", 2019)

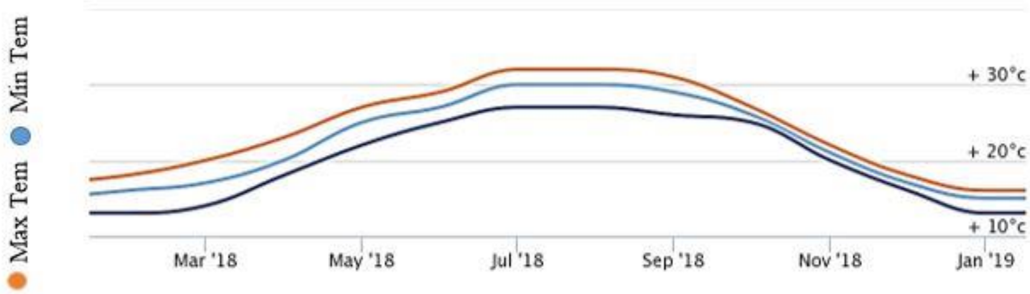


Figure 31: Average Max and Min Temperature of Famagusta, ("Famagusta Monthly Climate Averages", 2019)

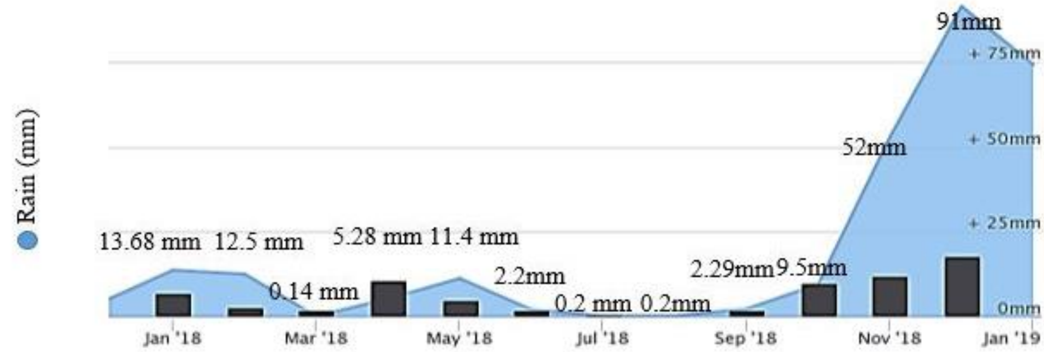


Figure 32: Average Monthly Precipitation Report of Famagusta, ("Famagusta Monthly Climate Averages", 2019)

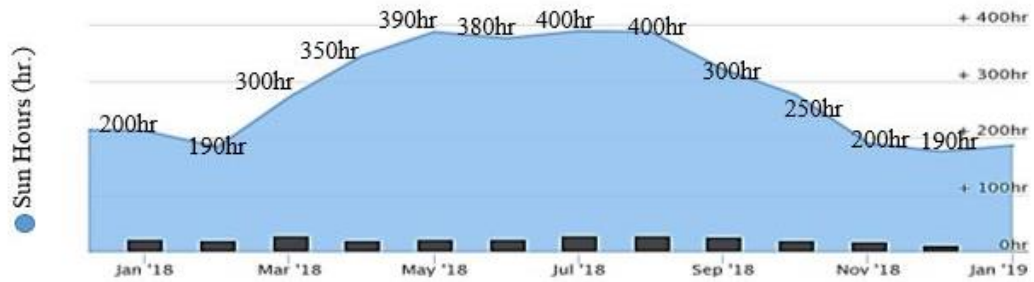


Figure 33: Average Monthly of Sun Hours and Sun Days of Famagusta, ("Famagusta Monthly Climate Averages", 2019)

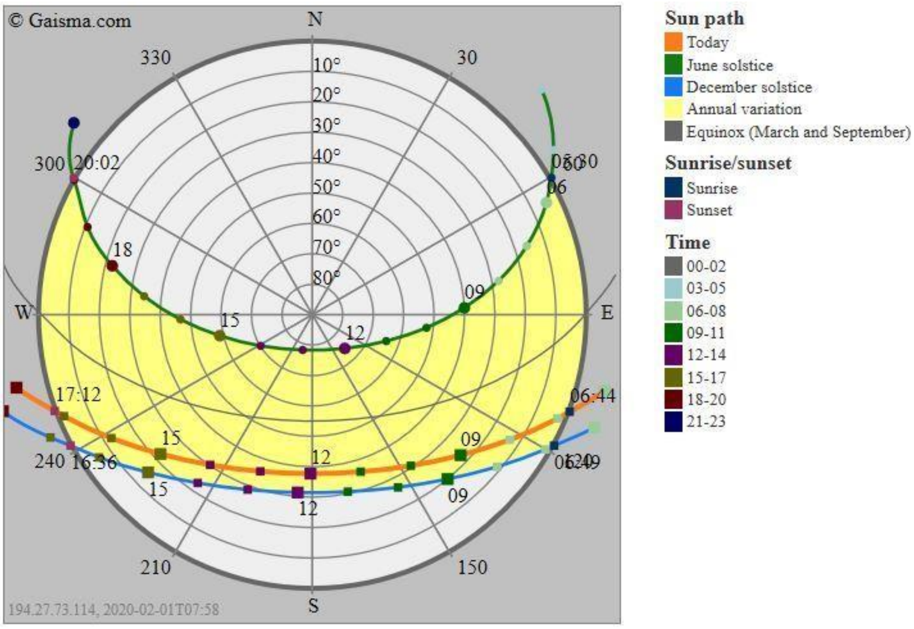


Figure 34: Sun Path Diagram for Famagusta -Cyprus, ("Gaisma", 2020)

3.2.2 Topography

Famagusta is located about 25m above the sea level. It is located in smooth topography, with maximum elevation of 809 m, average elevation of 36 m and minimum elevation with 0 m, shown in Figure 35. Topography of the site will impact on the building design by the density of the site, the height of surrounding buildings and position on the site.

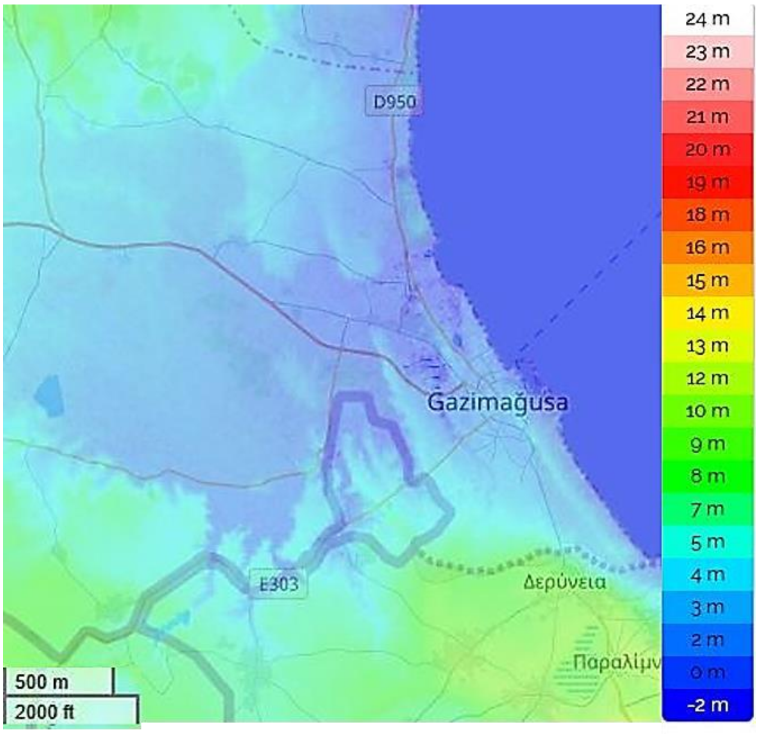


Figure 35: Famagusta, Cyprus topography, (Maps, Cyprus & notice, 2019)

3.2.3 Regional Available Building Materials

Building materials used to be economical through the use of local materials made of limestone and adobe massive walls, made from mud and straw blocks of about 50 cm in thickness which have low thermal conductivity of thermal mass to keep cool in summer and heat inside in winter. Stone and timber are used mostly for every element in the house. Reed, straw, and mud are used for the roof. Local marble is for floors, while the gypsum is mostly used for finishing materials for roof and decoration.

Local materials have greater adaptability, economically and durability. Moreover, they have less embodied energy and less environmental impacts than other materials. Nowadays, reinforced concrete is the mostly used building material for apartments, exterior walls are made with 25 cm thickness of block with cement plaster plus color covering both sides. Table 5, illustrates the development of different building materials in Famagusta. Thermal conductivity of the local materials is low which reduces the heat between outside and interior areas. For example, the double layer roof in traditional buildings was made of timber and has been acted as a great insulation during hot summer and cold winter.

Table 5: Different Building Materials in Famagusta, (Lotfabadi & Hançer, 2019)

Construction materials	Adobe, Sandstone, Limestone, Timber	Sandstone, Limestone, Timber		Sandstone, Limestone, Timber, Concrete	Reinforced Concrete, Break
Approximate Ceiling to Ground Height	~5.9 m	~4.7–5.4 m		~4.1 m	2.6–3.5 m
Materials	**Conductivity (W/m-K)**	**Specific Heat (J/kg-K)**	**Density (kg/m^3)**	**Thermal Absorptance (Emissivity)**	**Thermal Diffusivity (m^2/s)**
Adobe (Soil, Earth, Common)	1.280	880	1460	0.900	9.9×10^{-7}
Adobe with Straw	1.800	609	1640	0.910	1.8×10^{-6}
Sandstone	2.320	710	2150	0.970	1.17×10^{-6}
Limestone	1.280	909	2750	0.960	6.2×10^{-7}
Timber	1.300	2500	850	0.870	8.2×10^{-8}
Concretes	2.270	837.36	2321.40	0.920	1.2×10^{-6}
Brick	0.840	800	1700	0.860	6.1×10^{-7}

3.3 The Development of Housing Settlements in Famagusta

The Walled city of Famagusta is recognized by UNESCO as an ancient area. It became no longer the urban development of the social activities and building development, since the development during the British period, where it grew outside the walls because of the population and because of the political situation after 1974. As the Greek population was settled in Varosha (Maraş), while the Turkish stayed in the Walled City. The beginning of the development was toward the south, centered around the

Varosha district, with the new residential district, new commercial, touristic and recreational areas. Till the development of Eastern Mediterranean University 1986, with a temporary population pulled the economic center and all the sectors from south to the north of Walled City. Therefore, all the buildings, commercial, and sprawling development grew toward west and north as shown in Figure 36 (Cömert & Türsoy, 2015).

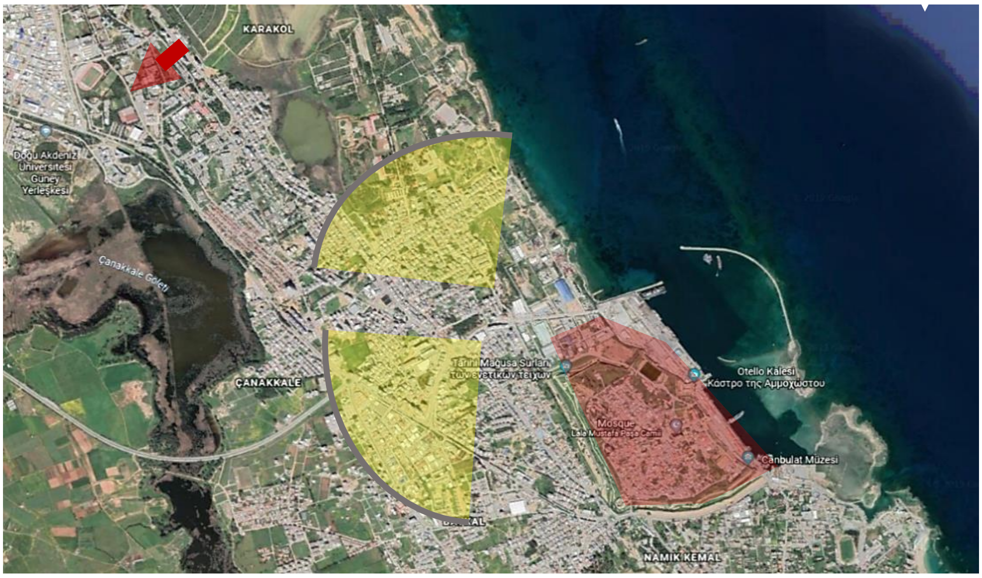


Figure 36: Famagusta Development toward North and West of the Walled City, the EMU (Red Point), (modified by Author)

With Famagusta rapid urban growth, it is considered as one of the rapidly developing cities on the island. According to Oktay and Conteh (2007), urban expansion and morphological point of view which is the study of how buildings and urban area changes in characteristics from area to another, Famagusta can be divided into three zones. Firstly, it is the walled city as it is the first ancient area. Secondly, the development directly outside the Walled City, and third is the new developments in the suburbs (Oktay and Conteh, 2007). Figure 37 illustrates Famagusta residential building development in sequence to time periods due to the population. From the traditional part in blue, the

British period in red, 1957-1981 in pink and 1981- 2015 in yellow the new development (Nia, Atun & Rahbarianyazd, 2017). This map will help in choosing the case study of the new residential area in order to analyze their building characteristics related to the environment.

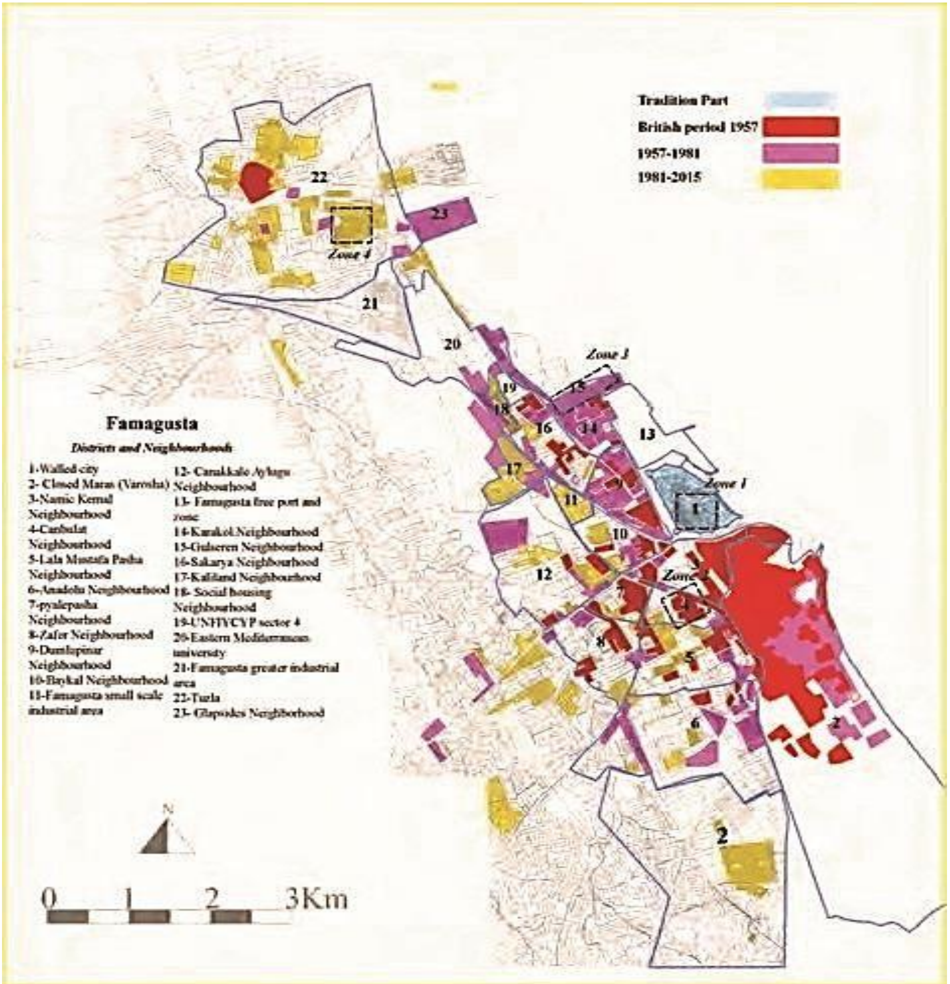


Figure 37: Residential Building Development in Famagusta, North Cyprus (Nia, Atun & Rahbarianyazd, 2017)

3.4 The Contemporary Residential Buildings in Famagusta as Case Studies

The new buildings are the main focus of this study, because the older ones have already been studied by their aesthetic urban characteristics in their different time period of housing settlement development of Famagusta study by Nia, Atun & Rahbarianyazd (2017). The selected buildings of this research are chosen as new buildings due to their construction year in different area locations, which is still not have been studied see Figure 38, heights and designs regardless of their construction companies to give a general result. These residential building are common constructed building type in Famagusta. In order to collect the data for each building, it required field visit study with photos about the buildings of Famagusta streets and neighborhood and the use of available data of these buildings from the official website of each construction company. Famagusta is still a developing city, and some of the official maps are either not available or cannot be taken. The selected case studies of Famagusta residential buildings are:

1. Golden residency apartment 2016.
2. Subway park 2016.
3. Northernland center apartment 2018.

Figure 38: The Selected Different Case Studies Areas from Different Locations Around Famagusta (modified by Author)

Case 1: Golden Residence Apartment, 2016.

Location: behind the Mağusa Arena building, Hasan Barbocolli St.

Figure 39: Location of Case Study 1: Golden Residence

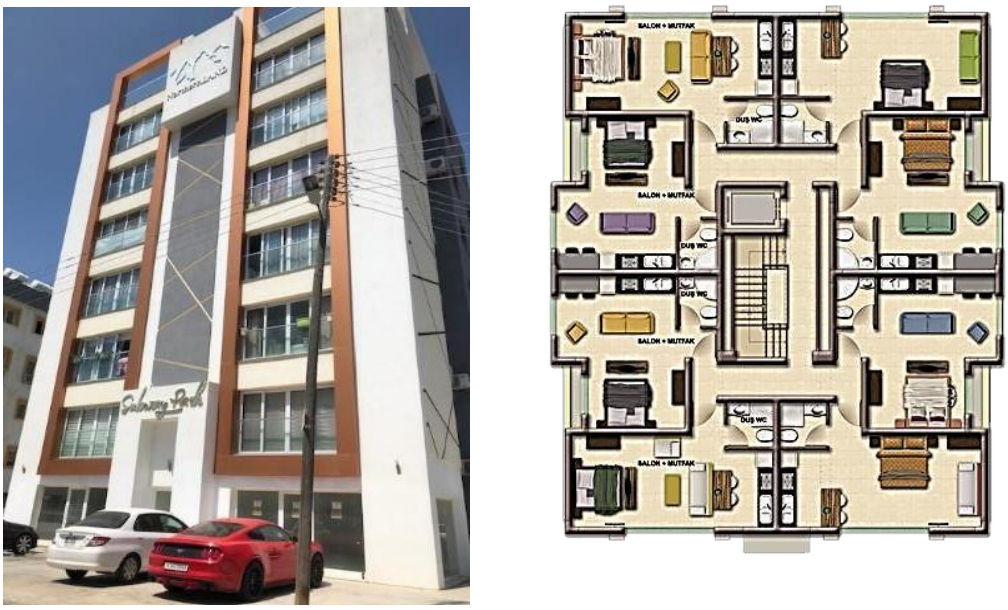
a) Main façade for Case 1 (taken by author) b) Typical floor plan for case 1

Figure 40: Plan and Street View of Case Study 1: Golden Residence

Case 2: Subway Park, 2016.

Location: at Abdide Bayram St. east the Salamis Road.

Figure 41: Location of Case 2: Subway Park



a) Main façade for Case 2 (taken by author)   b) Typical floor plan for case 2

Figure 42: Plan and Street View of Case Study 2: Subway Park

Case 3: Northernland Center Apartment, 2018.

Location: in front of Uzun twin apartments at north of Salamis Road.

Figure 43: Location of Case Study 3

a) Main façade for Case 3 b) Typical floor for case 3

Figure 44: Plan and Street View of Case Study 3: Northernland Center

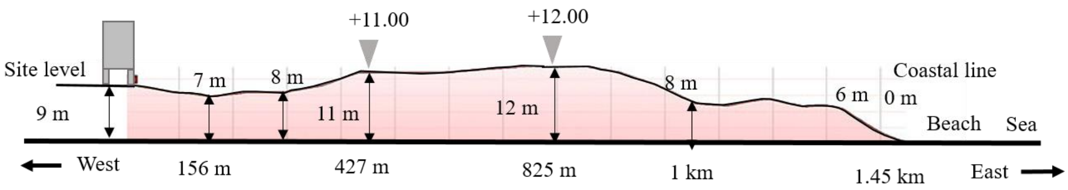
3.4.1 The Analysis of Selected Case Studies According to their Building Design

In the upcoming parts, the analysis will focus on the building designs and how they are affected by the climate responsive design elements.

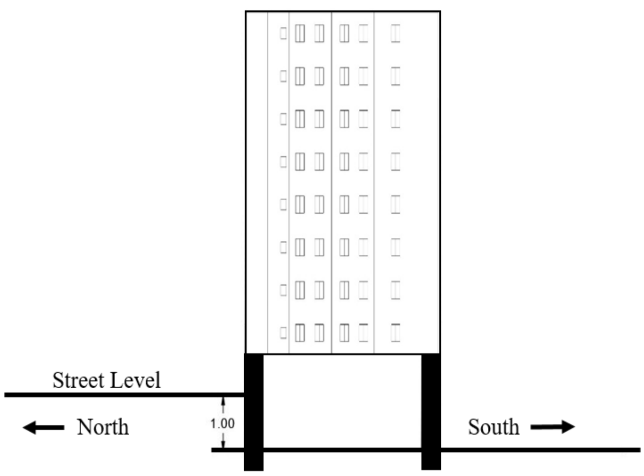
3.4.1.1 Topography/Site Selection

Due to the topography of Famagusta all the selected case studies are on a flat site with nearly 1 to 2 m differences. All the selected case studies are located in the middle of the site with setbacks. The topography is reflected on the climate responsive design strategies through the position on the site, shading from surroundings and orientation.

-Case 1 is lifted above the street level with 2.30 m for parking use. The slope in the site is only 1 m from the street level (north). The distance between the selected site and sea is 1.5 km, Figure 45. The site selection has no high density, there is only a high building on the east side that provides shade.



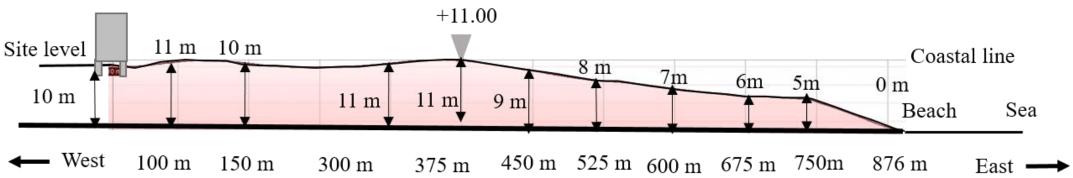
a) Cross Elevation from Site Selection (West) Till the Sea Level (East)



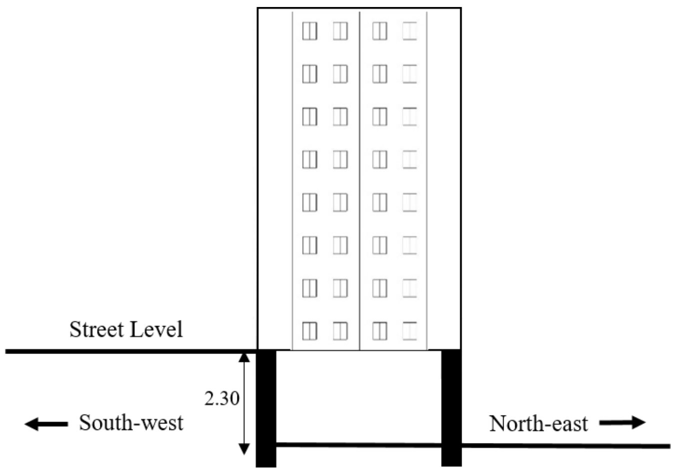
b) Sketch Section for case 1(author)

Figure 45: The Topography of Case Study 1

-Case 2 is located toward south-west orientation. It is on the street level but the north-east façade dropped with -2m for parking use. The distance from the west between the selected site and sea is 876 m, Figure 46. The density of the area is high but there are no close high buildings that could block the selected building or provide shades.



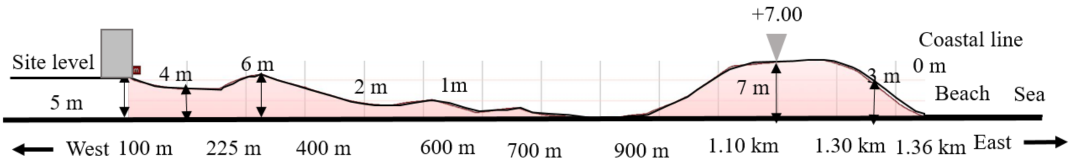
a) Cross Elevation from Site Selection (West) Till The Sea Level (East)



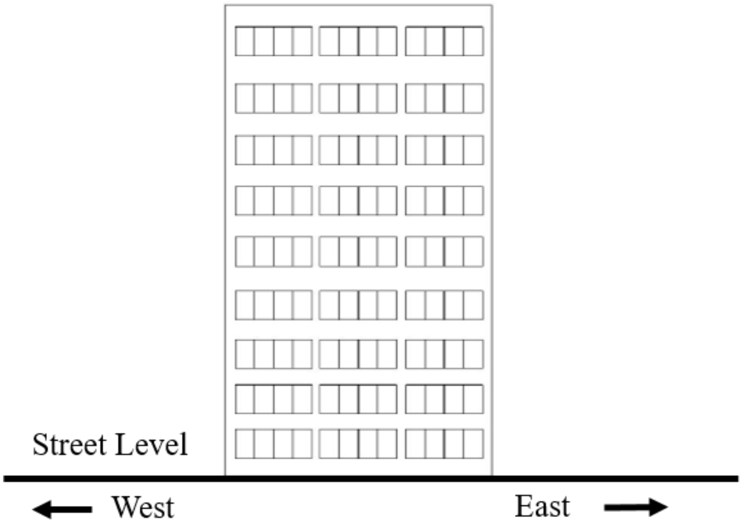
b) Sketch Section for Case 2 (author)

Figure 46: The Topography of Case Study 2

-Case 3 is located on the street level. The slope from the street level (east) is only 1m. The distance between the site and the sea level is 1.36 km. The slope from the site is 5 m till the sea, Figure 47. The site has no density only but the building is attached to another building close to the north facing façade.



a) Cross Elevation from Site Selection (West) Till The Sea Level (East)



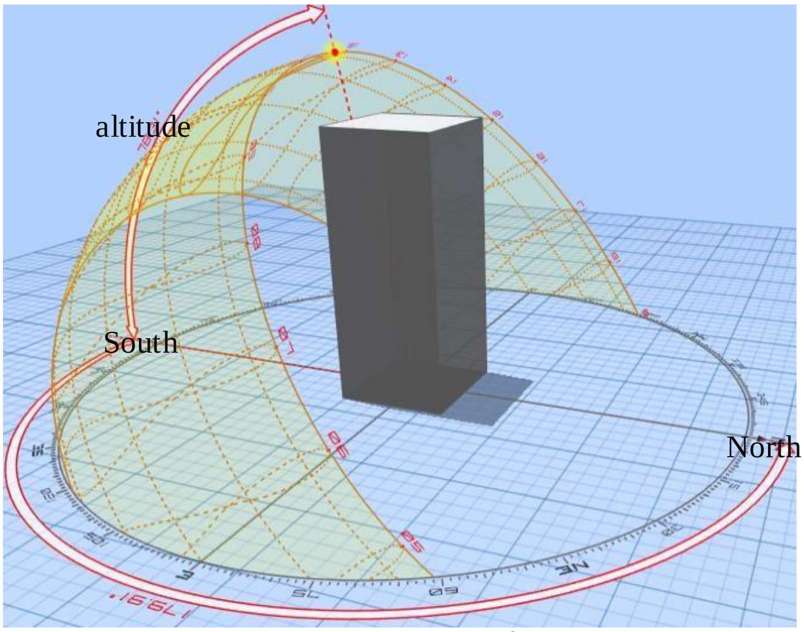
b) Sketch Section for Case Study 3(author)

Figure 47: The Topography of Case Study 3

3.4.1.2 Building Orientation/ Passive Solar Energy Gain

-The main façade for case 1 is toward north Figure 48. The building has cubic shape all the units are organized around double volume space. The building has the same exterior wall design for all the building orientations with no consideration for shading devices. All the units which are facing south facades are exposed to passive solar gain with maximum of two windows for each unit with no shading devices. All the windows are operable with sliding to 50% and the WWR for the whole building is 13%. East side of the building is shaded from the surrounding building. East and west facing facades have small windows with no consideration for the desirable wind in summer. Each unit has small balcony of 2 m as semi-open space.

a) Building location

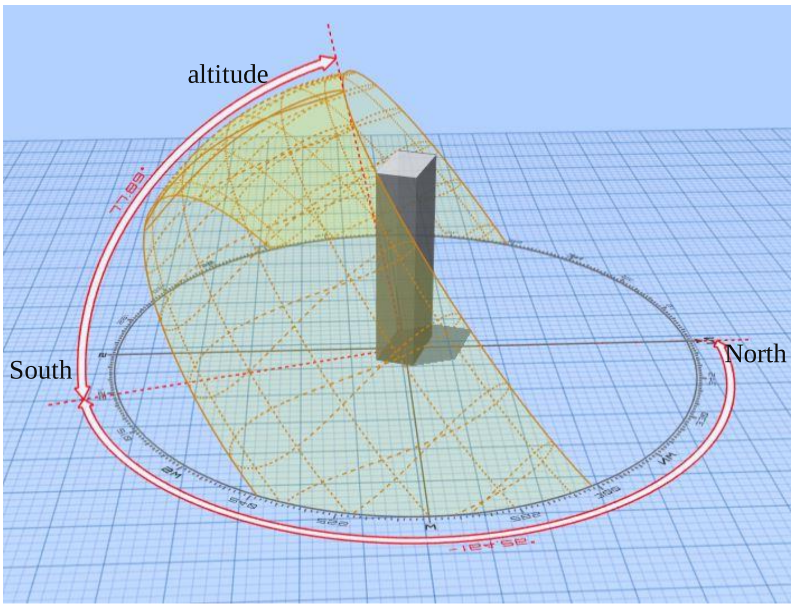


b) Altitude and Azimuth angles for Case Study 1

Figure 48: Sun Path for Case Study 1 (21st June Summer Solstice)

- The building has a rectangular shape along with east-west axis toward south-west see Figure 49. The building has the same exterior wall design for south-west and north-east facing façade and same design for south-east and north-west facing façade with no extended roof. Each unit has only one window. For north-west and south-east facades, the units have only small windows with no balconies to consider natural ventilation and there is no consideration to prevent overheating in hot season. For north-east and south-west, the units have large windows also with no balconies. All the windows are operable with sliding to 50% and the WWR for the whole building is 11%. There is no consideration for shading devices especially for north-east and south-west facing facades as they have large windows and no shading from the surrounding.

a) Building location altitude



b) Altitude and Azimuth angles for Case Study 2

Figure 49: Sun Path for Case Study 2 (21st June Summer Solstice)

-Case 3 has rectangular shape along north-south axis see Figure 50. The building has the same facade design for east and west. Each unit has only one large window of 2 m x 1.2 m with WWR of 16% for the whole building. The windows are toward sea view from the east and street view from the west. There is no shading device for east and west facades, which means overheating for the east facing facades and unwanted wind for west facing façade. The south and north facing facades are solid, which means there is no solar heat gain from the south facing façade. The south façade is used for vertical circulation. The building has extended balconies with 5 m length to all the levels for east and west elevations while the other elevations are solid and there are no windows.

Figure 50 a) Building location

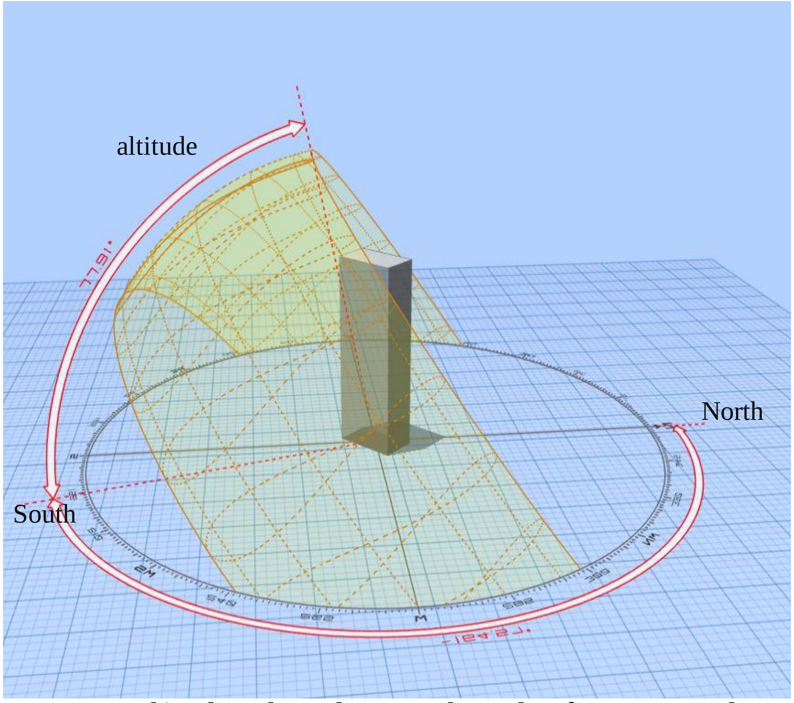


Figure 50 b) Altitude and Azimuth angles for Case Study 3
Figure 50: Sun Path for Case Study 3(21st June Summer Solstice)

3.4.1.3 Building Form / Compactness

For hot-humid climate, it might not be necessary to lower the A/V ratio as its concern to provide ventilation and to prevent overheating. Table 6 illustrates the compactness of each case study. All the case studies have flat roof. Each case study has its own roof area and can be considered as same built-up area.

Table 6: Building Compactness A/V- Ratio of the Case Studies, (author)

Case studies	Building Surface Area (A)	Volume (V)	A/V-ratio	A/V-ratio is ≤0.65 (Grauthoff.et, 1999)
Case Study 1	4,202 m2	18,150 m3	0.23	Low compactness reduces heat transfer
Case Study 2	1,926 m2	5,670 m3	0.34	
Case Study 3	2,622 m2	8,415 m3	0.31	

3.4.1.4 Building Martials/Thermal Mass

The window materials for all the case studies are PVC double glazing. Contemporary buildings of Famagusta have reinforced concrete structure with 24-25 cm of exterior walls made of hollow blocks of 20cm as the massive part with cement plaster and color covering both sides with 2.0- 2.5cm see Figure 51. All buildings are painted with white color as finishing material. Case 1 has majority of dark gray color painted. Building roofs are made with 15 cm of reinforced concrete floor slab covered by moisture insulation from outside and color pain see Figure 52. All the case studies have no shading device or greenery in their building design roof, wall and areas around the building that would provide shade and allow air flow to maximize ventilation and prevent solar heat gain in summer.

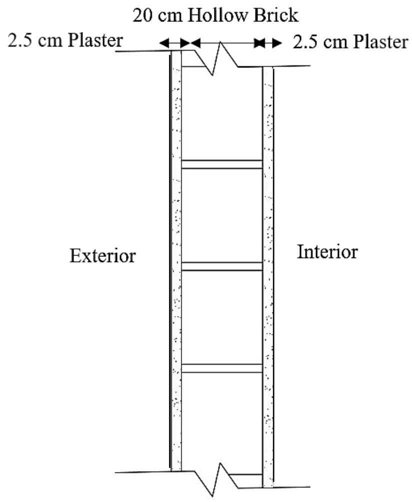


Figure 51: Wall Section, (Author)

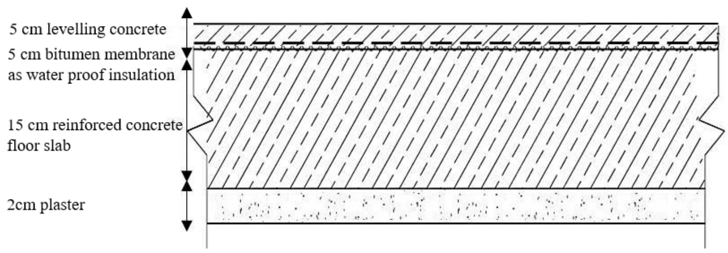


Figure 52: Roof Section, (Author)

3.5 Summary of the Analysis of Case Studies

Table 7: Case Studies Analysis Based On the Climate Responsive Design Elements for Famagusta

Climate Responsive Design Elements		Case 1	Case2	Case 3
Building form and orientation		Foursquare shape oriented toward North	Rectangular shape along with East-west axis toward South-west	Rectangular shape along North-south axis.
Semi-open spaces		The building itself lifted with one floor for parking use, and there are small balcony with 1.5m for each unit	From North-east elevation the building is dropped with -2 m for parking using. There are no balconies	The building has no connecting to outside except the balcony for each unit
Roof design	Minimize solid Areas	The roofs are on different levels due to the different height with approximately 300 m2	Flat roof with one level approximately 300 m2	Flat roof with one level approximately 600 m2
	Extended roof	No	No	Only from the east and west elevations
Windows	Orientation Shading Window-to-wall ratio	Each unit has almost three windows oriented toward the apartment facing direction with no exterior shading element. Approximately around 13% of WWR*	Units which are facing North-west and the South-east elevation contains only one window with no exterior shading element. Approximately around 11% of WWR*.	All units are studios and orientated toward East and West. Each elevation has a balcony extended to all the levels and gives shade for each other. The other orientations facing facades are solid there are no windows. Approximately around 23% of WWR*.
Cross ventilation		In most of the units, the rooms have one window	Each unit has only one window. For North-west and South-east facades, the units have only small windows	All the units face to outside with four openings of (2x1.2)m in one elevation toward only east and west elevations
Passive solar gain		Only for the south facing windows		There are no South facing windows
Vegetation		There is no vegetation around the building and on the roofs		
Orientation on the site		The main faced toward North	The longitude façade of building toward South-east	The longitude façade toward South
Position on the site		In the middle of the flat site		
Density of the site		Low-density area around the buildings, there is shade from the surrounding building on the east	The area has many buildings around but not dense, and there are no high buildings near that could block the building or provide shades	The area has low density
Exterior wall		Blocks with cement plaster and color covering both sides / cement is imported from other countries		
	Coloration	White roof color		
Roof		Concrete slab with plaster/ / cement is imported from other countries		
Windows		PVC double glazing		
Regional materials (stone, timber, adobe, etc.)		Not used		

Chapter 4

DISCUSSION AND RECOMMENDATIONS

4.1 Results of Analysis

This part of the study will include the results of the analysis of the residential buildings design strategies affected by the climate responsive design elements. The aim is to define the problems that contemporary buildings have, in order to improve the quality of building design for new residential buildings in Famagusta toward environmental sustainability. As there are no regulations and design strategies that are set for architects and their buildings to follow in their design considering the surrounding environment and climate factors. These design strategies are related to each other based on the natural energy sources such as climate to provide the energy needs for comfortable living. The application of these strategies will impact positively on the relationship between building and environment.

4.1.1 Climate

The climate factor effects on the solar heat gain and ventilation in the building through orientation, semi-open spaces, roof design, windows, solar gain for daylighting and vegetation. For case 1 (Golden Residence) the building has square shape facing north orientation, while the buildings for case 2 (Subway Park) is rectangular with elongated plan shapes toward south-west. Case 3 (Center Apartment) has rectangular shape along with north and south axis. According to Santamouris (2013), Gupta (2012) and Hyde (2013), buildings in hot-humid climate should have elongated plan shapes along the east and west axis, and also semi-open spaces to maximize the cross ventilation and minimize the solar gain. Therefore, case 1 (Golden Residence) is not impacted by the climatic responsive design through its building shape and orientation strategies. It has the same façade design for all the orientation without taking into consideration the different needs of the design to deal with climate such as the need of applying shading device or not. The case study 2 (Subway Park) and Case 3 (Center Apartment) achieved the elongated plan shapes but they did not achieve the orientation of the building, while they are oriented toward south-west. So, part of the building will need different measurements to deal with high solar gain toward the east side.

Semi-open spaces are an important strategy to enhance the natural ventilation and to reduce excess heat loss for hot-humid climate zone. Case 1 (Golden Residence) and case 2 (Subway Park) are lifted above the street level for parking use, which partly achieved the semi- open space strategy. Case 1 (Golden Residence) provided semi-open spaces for all the units as small balconies, they are designed similar to each other in all the orientations. Case 2 (Subway Park) did not achieve the semi-open spaces for the units, as there are no balconies for the units. Also, case 3 (Center Apartment) has partly achieved the semi-open space only for the east and west facades but the balconies are not open to each other, they are blocked by the separating walls (Santamouris, 2013), (Gupta, 2012) and (Hyde, 2013).

According to Biket (2006), minimizing the roof with sloped angles and well insulated roof are some of the important hot-humid climate design strategies (Biket 2006). The roof design for all the case studies is not achieved. All case studies have flat roofs, without attic space. Also, there is no roof design to minimize the roof space, which is not suitable for hot humid climate as it increases the heat for interior, where it allows more direct entry of the sun’s rays into the building. Roof is the most critical building element that exposes to environmental conditions. Extended roof can be seen in some of the cases but as design element and not measured to act as shading element. From the climatic responsive design strategies an extended roof, well-designed slight slope roof, roof penetrations as clerestory window and high insulated roof materials and vegetation are suggested strategies for roof design in hot-humid climate which help to enhance natural ventilation to modulate the indoor temperature (Lechner, 2015).

According to The European Commission, WWR of 30% is suggested for good impact to environment. For Famagusta climate conditions, windows should be large to provide as much air flow to maximize the ventilation. All the case studies did not achieve the impact of climate on windows, as they have WWR less than 30%. Depending on total wall area of each case study, case 1 should have at least 930.6 m2 total window area to its wall area. Also, Case 2 should have at least 415.8 m2 and 633.6 m2 for case 3 of total window area to achieve the 30% of WWR.

In addition, the case studies do not achieve the climate responsive design strategies on providing shading for the existing windows. Their windows have the same design and distributed for all the units without having any differences for all the orientation based on the climatic conditions, such as avoiding of overheating by solar heat gain but not the ventilation and daylight for east, west and south façade. As seen in case 1 (Golden Residence), all the windows on north-west and south-east facades are small without any shading, and on south-west and north- east facades some windows are large with shading of horizontal balconies. For case 2 (Subway Park) all the windows are small for north-west and south-east facades and for north-east and south-west, the units have large windows with 5 m of balconies, while the small windows do not have any shading devices in the same facades. Case 3 (Center Apartment) has only one large window for each unit. Each unit should have at least two windows in two sides of the building envelope to allow cross ventilation to maximize natural ventilation. Also, it is suggested to use maximum opening for summer time, at the same time the window will provide solar heating for winter, but for ventilation in winter the same window can have small openings (Khatibi, 2015). According to Hidirov (2009), clerestory window is also a solution to provide natural ventilation for hot-humid climate, where it generates the differences of air pressure of the air flow and relative humidity around the building (Hidirov, 2009).

It is shown in the case studies how the climate responsive design strategies are neglected for solar gain and ventilation. The impact of climate is not measured due to the lack of different window strategies for all orientation of a building. For hot-humid climate buildings should be designed with options to allow air movement and oriented with due regard to the prevailing wind direction. So, windows should be large for ventilation but should have as much shading as possible for all orientation to prevent solar heating but not ventilation or daylight. Providing solar radiation for daylight or for needed heating and sun control can be achieved through the suitable shading devices. Solar gain is related to pervious window strategies. Different shading techniques should be provided for different orientations in specific for east and west windows for low sun. Shading can be provided for south façade as horizontal shading, louver vertical plane or light shelves to protect the window from sun radiation in summer with respect to the solar altitude angle. Also, it could have vegetation, as vegetation enhance the cool air, where the south gets the maximum intensity of sunshine. For north façade it is preferable to have vertical shading devices. East and west can have the egg-crate shading device type. The louver vertical plane is recommended for balconies as they are already horizontal and have depth, but the length for the vertical plane should be more than the one in south façade due to the low sun angles for east and west. The shading devices should be chosen according to the solar geometry of the site and surrounding shads not spontaneously selected (Hidirov, 2009) and (Rungta and Singh, 2011). Since the case studies were not affected by the previous strategies hence the climate responsive design did not impact their building design.

4.1.2 Topography

The selected case studies have different locations. Case 2 (Subway Park) achieve the rectangular shape plan along east and west axis, which is the recommended shape for building in hot-humid climate. Case 3 (Center Apartment) has rectangular shape plan but it is along north-south axis. All of the case studies have a center position on the site, which is appropriate for the hot-humid climate. The surrounding for all case studies is not dense which allows natural ventilation by allowing air flow movement. There are no buildings that block air flow or provide shades for the case studies except case 1 (Golden Residence), it is effected by surrounding building on east side. These strategies might be affected by the urban development as there are still many vacant sites. It can be said that the case studies were affected by position on the site but the high vertical development is not suitable for the natural consideration for Famagusta. As there are problematic soils exist in many parts of the North Cyprus and a lot of researchers and engineers are trying to keep the weight of the building structures at a minimum possible level for better performance (Celikag & Naimi, 2011).

4.1.3 Regional Building Materials / Affordability

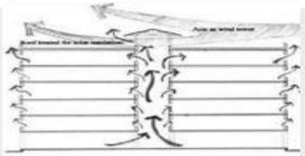
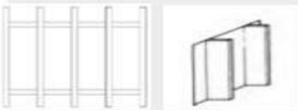
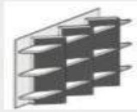
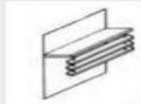
Exterior walls of all case studies are infill walls of reinforced concrete frame structure with 25 cm of brick with cement and plaster with color covering. Concrete has higher thermal conductivity with 2.270 W/m-k comparing to other regional materials such as adobe, limestone, and timber. The high thermal conductivity of concrete increases the transfer absorbing heat from the outside surface of a wall to the inner side, leading to uncomfortable interior conditions in the buildings. Improving the concrete by low thermal conductivity will help to reduce temperature transfer between indoor and outdoor (Lotfabadi & Hançer, 2019). Another issue is that cement is a main important concrete material and steel is another important material to make reinforced concrete constructions which both are imported from other countries. The high demand of building construction in North-Cyprus leads to poor building construction quality, because of the low inadequate attention from designers and engineers to some of the design and construction details. Lightweight construction materials, such as structural steel and wood frame can be used instead to reinforced concrete because of the negative use of sand and aggregate, which cause serious environmental problems such as construction waste and limited natural resources in North Cyprus. Also, using alternative materials like wood may impact positively on construction time which leads to save in the total cost of the project therefore positively contributes to country's economy (Celikag & Naimi, 2011). However, local materials such as timber, limestone, adobe, etc. were used before, because of the availability and the import of materials was difficult and expensive in comparison to nowadays, but using wood is not suitable for the mid-rise buildings as steel or reinforced concrete. In addition, imported materials cannot be reused or exported again, therefore, improving the existing building materials in Famagusta will achieve the positive relation to environment for case studies. When building materials act upon the exterior conditions that fulfills the comfort demand it means that these materials are impacted by the climate responsive design strategies.

According to Karimizadeh (2015) study of Comparison Building Material in Northern Cyprus, using concrete in North Cyprus is positive compared to steel, because of some concrete ingredients in North Cyprus, such as sand and gravel. However, cement and steel bars for reinforcement, as main materials of reinforced concrete frame structure, have to be imported from other countries. In contrast, to construct steel structure where there is not any steel production in the Northern Cyprus and whole steel elements have to be imported (Karimizadeh, 2015). Therefore, improving the existing building materials in Famagusta to achieve the positive relation to environment for case studies can be improved by their exterior walls, by using a layer of insulation as the U–value will decrease from 1.66 W/m^2K. to 0.6 W/m^2K for clay block. This U-value is still higher than EU Energy Conservation Act for 0.35 of the renewed exterior walls but it is based on local condition of the existing materials in Famagusta. Applying of thermal insulation will reduce the electricity costs for heating in cold months to half of the electricity cost for walls without insulation (Emadi, 2014). The exterior wall can be even more improved with the available materials in the market by reducing the use of 25 cm of concrete and cement to the use of 10 cm of concrete but with 7cm of cellulose fiber insulation, 3 cm of cement mortar, since their U-value is 0.28 W/m^2K. Also, it can be even more improved by using the concrete as the most common used material with 3 cm of cement mortar, 12 cm of polyurethane foam as thermal insulation, with U-value of 0.15 W/m^2K. These types of exterior wall have a high performance for the hot-humid climate of U-value better than 0.69 W/m^2K of the existing one (Bavafa, 2015). The exterior wall coloration of the case studies should be more improved with white color surfaces. It is the highly recommended as wall color for hot-humid climate zones.

The roof materials of the residential buildings in Famagusta are 15 cm of reinforced concrete floor slab covered by moisture insulation from outside and color pain from inside with U-value of 3.5 W/m2K. Thermal insulation should be added to minimize the U-value which minimizes the heat gain in summer or loss in winter. Using 15 cm reinforced concrete floor slab thickness with 5 cm thermal insulation and plaster has 0.51 W/m2K, therefore less heat gain (Kamali, S, 2014). Even though the U-value is higher than 0.25 W/m2K according to the standard EU Energy Conservation Act for flat roofs, which is a better result and available material in Famagusta. As well as using light color as white to reflect solar gain with vegetation is important to provide wind that transfers away the accumulated heat to help to reduce UHI (Urban Heat Island) (Bay & Ong, 2006).

All the case studies use the PVC double glazing window material. This material nearly has U-value 2.8 W/m2K. The window can be improved by using triple glazing, low-e, low SHGC and argon with non-metal frame material. These window materials will allow sun light to penetrate into interior spaces, prevent the summer solar heat and keep in winter hot-air stays as an insulating layer between the glazing layers. This window type has the low U-value 0.19 W/m2K (Carmody & Haglund, 2012).

4.2 Design Strategies for Famagusta Residential Buildings According to Climate Responsive Design

Climate responsive design elements	Design Strategies
Building Form and Orientation	No compactness needed, Building should be along east and west axis toward south
Semi-open spaces	Spaces are needed for sun protection of walls, external space provide ventilation
Roof Design	Minimize roof area for overheating. clerestory roof , Ventilated Attic Space 
Windows	Double or triple glazing with low-e, low SHGC Large windows with shading devices for each orientation to prevent over heating. Each orientation has different design of the shading device respect to the altitude. Theses are the general shading recommendation for each orientation. For north to have Vertical fins type with wide spacing  For south facing façade it is recommended to use horizontal  For east and west facing facades it is recommended to use egg-crate shading type  The louver vertical plane type is recommended for balconies as they are already horizontal and have depth  Case 1 should have at least 930.6 m2 of total window area Case 2 should have at least 415.8 m2 of total window area Case 3 should have at least 633.6 m2 of total window area
Cross Ventilation	Minimum two large windows for each unit to allow cross ventilation 
Passive Solar Gain	Triple glazing, low-e, low SHGC and argon with nonmetal frame material. These window materials will allow sun light penetration, prevent the summer solar heat and keep winter hot air as insulated layers stays between the glazing layers
Vegetation	Provide vegetation for maximize air flow
Position on the site	For flat site in the middle of the site with setbacks to allow airflow
Density of the site	Buildings away from each others to maximize air flow for ventilation
Exterior wall	Materials with low thermal conductivity but with high insulation to prevent overheating. U-value should not exceed 0.45 W/ m²K for new mid-rise buildings and for Famagusta existing building should exceeded 0.6 W/ m²K by adding the insulation material
Roof	Materials with low thermal conductivity but with high insulation to prevent overheating U-value should not exceed 0.25 W/m2K for the new buildings and should not exceed 0.51 W/m2K for the existing building by adding the insulation material

Chapter 5

CONCLUSION

The thesis aims to contribute to improve the quality of building design toward environmental sustainability in Famagusta North Cyprus, which focusses on the climatic responsive design strategies. In order to achieve that, the thesis followed a sequence in answering the research questions.

First, the thesis clarified the climate responsive design by reviewing literature on the environmental factors that have been neglected in the design process such as climate. As it is essential for architecture to provide a comfortable built environment for human activities with the consideration of environmental conditions.

The study was to understand how climatic responsive design strategies impact on building design. The relationship between building design and climate responsive design was discussed in chapter 2 by clarifying different climatic responsive design strategies based on different climate zones, as it is a design approach that deals with the surrounding natural environment. The climatic responsive design solutions are integrated with passive design strategies and generating of the building by renewable energy sources rather than consuming fossil fuels to improve the quality of indoor and outdoor spaces.

The research aimed to identify how residential buildings in Famagusta can be improved based on the climate responsive design strategies. The selected residential buildings in Famagusta were analyzed based on climate responsive design elements to define if the contemporary residential buildings are impacted by the surrounding environment or not. For example, it was seen in all the case studies how their building design are not considering the climate conditions such as the design of windows and the lack of shading devices without any consideration to the different orientations for passive solar energy gain and to provide ventilation. Also, it was seen how the residential buildings were designed as a high vertical development with no consideration to surroundings, which is disturbing the local identity of the city. The vacant areas are used to have vertical development to include as much units as they can for the student without any consideration of the environment, such as they should be constructed away from the coastal areas to conserve the natural environment. As well as, the vertical development of the residential buildings is not considering the position and orientations to site to enhance air flow for ventilation. Also, the heavy weight structure is not suitable due to the low soil bearing capacity in North Cyprus. The use of heavy structure also effects on the regional materials, where local materials can be used instead of the brick and reinforced concrete like sand stone can be used as cladding material instead of imported building materials. Using local materials have a lot of advantages as it was discussed how they have the ability to deal with the surrounding conditions such as the use of stone and how it can keep the cool air during the day and release heat at night the opposite of the used concrete without insulations. In addition to that, the local materials can be easily used as building material through recycling, either by re-using old stone blocks or bricks (which are made of damp soil compressed at high pressure to form blocks). The use of local materials suitable for the local climate conditions has less embodied energy and less environmental impacts than other conventional materials. They are more adaptable, economical and have more durability. In addition, appropriate design strategies in chapter 4 were proposed for Famagusta, to consider the climate responsive design strategies on building design.

In general, the impact of climate as surrounding environment on building design should be considered when a building is designed to improve the quality of the building design and can lead to a more sustainable environment. The buildings should be adapted to the surrounding natural environment, it should act and react upon the surrounding conditions. For instance, this study focused on how the climate impacts on building design through passive strategies by climate responsive design strategies. Further studies can improve these strategies with different solutions in a more detailed way. Also, awareness in the future construction development building towards achieving more sustainable buildings should be presented as a goal for construction companies. In addition, it is necessary to establish local design standards which are more realistic to be used in design for local conditions to improve the local and global environment. The new residential buildings in Famagusta should therefore consider the climate responsive design to improve the quality of building and reduce the energy usage.

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