Evaluation of the Solar Energy in Street Spaces Quality Exemplified for Famagusta

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We certify that we have read this thesis and that in our opinion; it is fully adequate in scope and quality as a thesis for the degree of Master of Science in Urban Design.

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ABSTRACT

This thesis investigates on optimizing street spaces by evaluation of the solar energy exemplified for Famagusta. Quantitative and comparative research methods are used in this thesis. The focus of the thesis is on solar issues including climatic and geographic factors (radiation and land cover), and street issues consisting of orientation, H/W ratio and landscape. Then, Konak street in Sakarya district and Cahit street in Gülseren district in Famagusta, North Cyprus, are analyzed. Decisive parameters in solar energy including the sky clearness coefficient, albedo, altitude, latitude, orientation, azimuth rates are calculated based on Famagusta using Ladybug for Grasshopper in Rhino software program. On the other hand, thermal discomfort time is analyzed for both of the streets based on Stephenson`s Cosine methods using Microsoft Excel software program. Finally, it has been asserted that the poor landscape of Famagusta streets is not capable to provide sufficient shadow for sidewalks. Greenery percentage is very low, trees are planted in inappropriate areas. Poor landscape caused declining albedo value of the streets. However, H/W ratio of the streets are regular that provide direct daylight. Thermal analysis of the street orientation discovers that both Konak street and Cahit street have discomfort in summer from 14:00 to 17:00, and from 09: to 11:00 respectively.

Keywords: Street space, Solar radiation, Albedo, Landscape, H/W-ratio, Shading

ÖZ

Bu tezde; güneş enerjisi dikkate alınarak Gazimağusa Şehrinin sokak mekanlarının iyileştirilmesi incelenmiştir. Tezde; nicelikli ve kıyaslamalı araştırma metodları kullanılmıştır. Tezin odak noktası; iklimsel ve coğrafi faktörleri belirleyen "güneş" konusu (güneş radyasyonu ve arazi örtüsü) ve güneşin yönlendirilmesi, yükseklik/genişlik orantıları ve peyzajı parametrelerini inceleyen "sokak" konusu olmuştur. Bu bağlamda; Kuzey Kıbrıs'ta Gazimağusa Şehrinin, Sakarya Semtinde, Konak Caddesi ve Gülseren Semtinde, Cahit Caddesi analiz edilmiştir. Bu analizlerde belirli güneş enerjisi parametrelerini oluşturan gökyüzü berraklık katsayısı, yansıtılabilirlik (albedo), güneş yükseklik açısı, enlem, yönlendirme, azimut değerleri Rhino Bilgisayar Proğramında ''Ladybug for Grasshopper'' ile hesaplanmıştır. Diğer yandan bu iki sokak için yüksek güneş enerjisinden kaynaklanan termal rahatsızlık, Stephenson`s Cosine metodu ile Microsoft Excel bilgisayar programı kullanarak irdelenmiştir. Sonuç olarak; Gazimağusa'daki peyzaj dokusunun ve yaya kaldırımlarının, gölgeleme için yetersiz olduğu sonucuna varıldığı gibi, hem yeşillik oranı çok düşük hem de ağaçlandırmaların uygun olmayan yerlere yapılmış olduğu, gözlenmiştir. Ayrıca yetersiz peyzaj dokusu, sokakların yansıtabilirlik (albedo) değerlerinin yükselmesine neden olmuştur. Buna karşılık Mağusa sokaklarının, yükseklik/genişlik orantısı düzenli olduğundan doğrudan güneş ışınlarına maruz kalmaktadır. Sokak yönlendirmesi ile yapılan ''termal analiz'' sonucunda; yazın Konak Caddesinde 14-17 Saatleri arası ve Cahit Caddesinde 9-11 Saatleri arası güneş enerjisi yoğunluğu termal rahatsızlığa yol açtığı ortaya çıkmıştır.

Anahtar kelimeler: Sokak Mekanı, Güneş Radyasyonu, Albedo, Peyzaj, Yükseklik/Genişlik Orantısı, Gölgeleme

DEDICATION

I would like to express my immense gratitude to all hardworking people who work zealously and help honestly.

To All Hardworking People

ACKNOWLEDGEMENT

I would like to express my immense appreciation to all hardworking people, without their constant attempts and achievements, non-problem could have been realized. A roommate or a housekeeper was also effective to conclude of this thesis like scholars and authors who guided me directly or indirectly. On the other hand, my supervisor Assist.Prof.Dr. Harun Sevinç and my family have some undeniable role in this regard.

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LIST OF ABBREVIATION

EJ	Exajoule (The exajoule is equal to 10^{18} one quintillion joules)
KWh	Kilowatt-hour (unit of energy equal to 3.6 megajoules)
TW	Terawatt (the terawatt is equal to one trillion 10^{12} watts)
Wh/m2	Watt-hour per square metre per unit time

Chapter1

INTRODUCTION

1.1 Problem Statement

Famagusta is located on latitude 35 degree and has almost long sunshine duration nearly in all seasons because of its Mediterranean climate, but the streets of Famagusta have discomfort as well. Therefore, this thesis is based on the orientation concept of streets and blocks according to the solar potential on its latitude which should be considered in planning stage. In addition, the global warming crisis and environmental pollution have caused the significance in urban design related to environmental sustainability.

Moreover, avoiding inappropriate street orientation which is aimed to optimize the performance of different streets, façades and thermal discomfort is one of the aims of sustainable urban design, but can restrain the design process, for which this research is conducted. Orientation concept for different climatic conditions needs different requirements for the purpose of any street spaces related to solar energy, but such a purpose cannot be reached without regarding the aspects such as diagonal orientation of roads, exposure of façades and the axis. For achieving sustainable development and solar energy efficiency of cities in planning stage, these aspects should achieve a significant enhancement in landscape by onsite solar energy potential and urban form.

1.2 Research Aim and Question

The aim of this study is the evaluation of street spaces in Famagusta City in North Cyprus in terms of solar energy potential. To reach this aim, a comprehensive research of the related literature is presented, and some examples are used for giving a better illustration of the subject. Orientation of streets dramatically declines energy consumption by implementing design strategies for urban energy-efficiency. In this regard, the questions are given as follows:

- How much solar energy potential does Famagusta have?
- Which type of streets are more efficient in Famagusta City?

1.3 Research Methodology

Literature review is regarded to clarify the solar energy and urban streets to evaluate the streets with different orientations comparatively and analytically. The research is conducted to highlight the issues with the analysis of street organization, use of materials and response to the environmental concern in urban design.

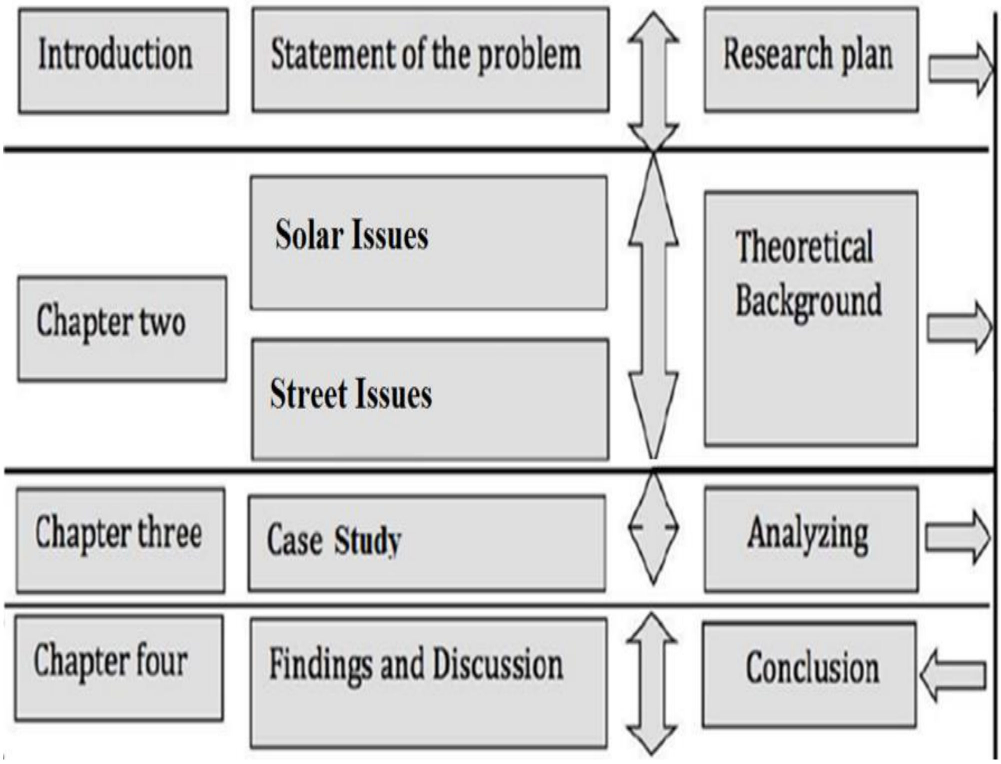
In this study, two streets in Famagusta City whose streets have been orientated differently were compared. The solar energy potential of Famagusta has been numerically modeled using quantitative methods. The role of environmental, meteorological and climatic factors on the rate of solar energy transmitting from orbital space to urban space has been computed numerically using Stephenson`s Cosine methods. Qualitative and comparative methods have been used to analyze orientation techniques of streets and surfaces.

1.4 Research Structure and Organization

The thesis investigates solar urban spaces, which is considered according to the desired and current situations. According to the scope, this study has been divided into two parts. Firstly, it is aimed to focus on theoretical background on solar irradiance in urban spaces, and its mechanism. It includes two different sections discussing the evaluation of energy in urban space affected from orbit space; principles of physics and urban design issues, and finally the definition about how to use solar energy in sustainable urban design in Famagusta.

The second part is originated in two sections by analysis of physical spaces of Famagusta. The results of findings and recommendations are formulated in chapter four. Chapter five is based on conclusions. (Table. 1)

Table 1. Research Organization (by author 2017)



The first chapter of the thesis is the introduction part.

The second chapter is the literature review part which basically includes a wide-range of literature review on books, PhD and Master theses, researches from papers of scientific journals and technical researches or documents.

The third chapter is the analysis of selected case studies from Famagusta in Cyprus.

The fourth chapter is the analysis part of the results from case study and discussions.

The fifth chapter presents the conclusions in this part.

1.5 Scope and Limitation

The scope of this study is concentrated to evaluate solar energy absorption by orientation techniques of streets. The optimized solar energy used in urban spaces with appropriate orientation has to be considered in planning stage, which has to have enough data that comes from observation analysis.

Quantitative analysis of physical spaces including specific features makes the limitation of the research to discuss the nominal qualities of city comprehensively. On the other hand, qualitative analysis of solar energy potential illustrates some tangible dimension on the space qualities.

Chapter2

LITERATURE REVIEW

2.1 The Need for Solar Energy and its Importance

The Earth takes energy around 174,000 TW of radiation energy from the sun (Smil, 2003). The total power used by humans worldwide is commonly measured in terawatts and is equal is equal to one trillion (1012) watts. Around 30% of the insolation is reflected into orbit space (a regular, repeating path of the Earth around the sun), the remainder is obtained by landmasses clouds and oceans.

The irrational energy transmitted to the surface of the earth consists of a spectrum ranging from the observable to (near-infrared) and a small proportion in (near-ultraviolet) (IPCC, 2001). The population of the earth mostly inhabits lands with insolation range of (150 to 300 $W/m^2.h$), which is equivalent to 3.5 - 7.0 kilo Watt per square meter in hour per a day.

Solar radiation is absorbed by three different terrains of the Earth: land surface, oceans the mass of 71% of the atmosphere and the planet. The evaporated water on oceans as warm air causes atmospheric circulation (convection). The water cycle reaches completion when the vapor, condensed into clouds, descends as rain onto the surface of the earth.

Photosynthesis causes converting radiation beams into energy, which is later harnessed by humans as various forms, such as food, wood, and biomass – produces fossil fuels (Vermaas, 2007). The total energy absorbed by the various terrains of the earth from the sun surmounts to 3,850,000 EJ/year.

In 2002 alone, the rate of energy absorbed in an hour exceeded the rate of the world implemented in the same year (Smil, 2003) (Morton, 2006). The amount of biomass that photosynthesis captures per year is approximately 3,000 EJ. (Lewis & Nocera, 2006)

"The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined." (Food and Agriculture Organization of the United Nations, 1997)

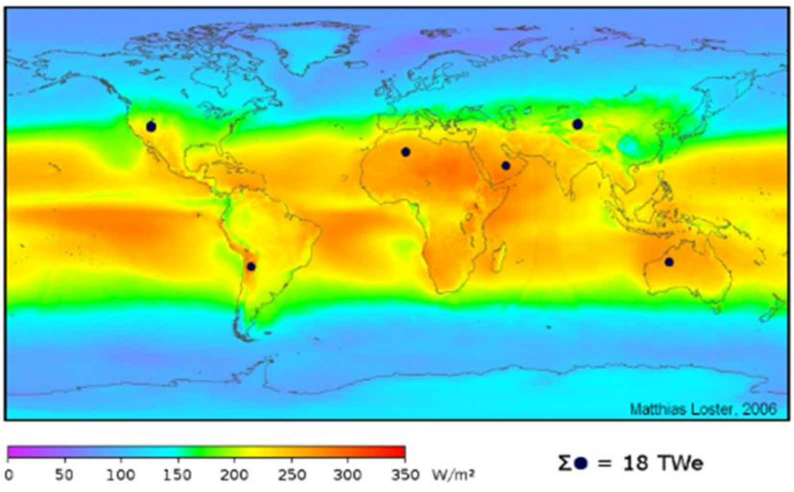


Figure 1. The Theoretical Area of the World's Total Solar Power (Loster 2006)

2.1.1 Energy and Sustainable Development

It was after the publication of the World Commission`s initial report on Environment (1987) that the concept of sustainability became universally accepted. The United Nations established the commission as an attempt to level economic development and to find ways to decrease the pressures of population growth on the planet's waters, lands and other scarce resources (Bongaarts, 2009).

Accordingly, the foreseen pressures can be alleviated under political (i.e. community) measures, before severe social and economic changes (Twidell & Weir, 2016). The annual energy demand by the regions is presented as follows:

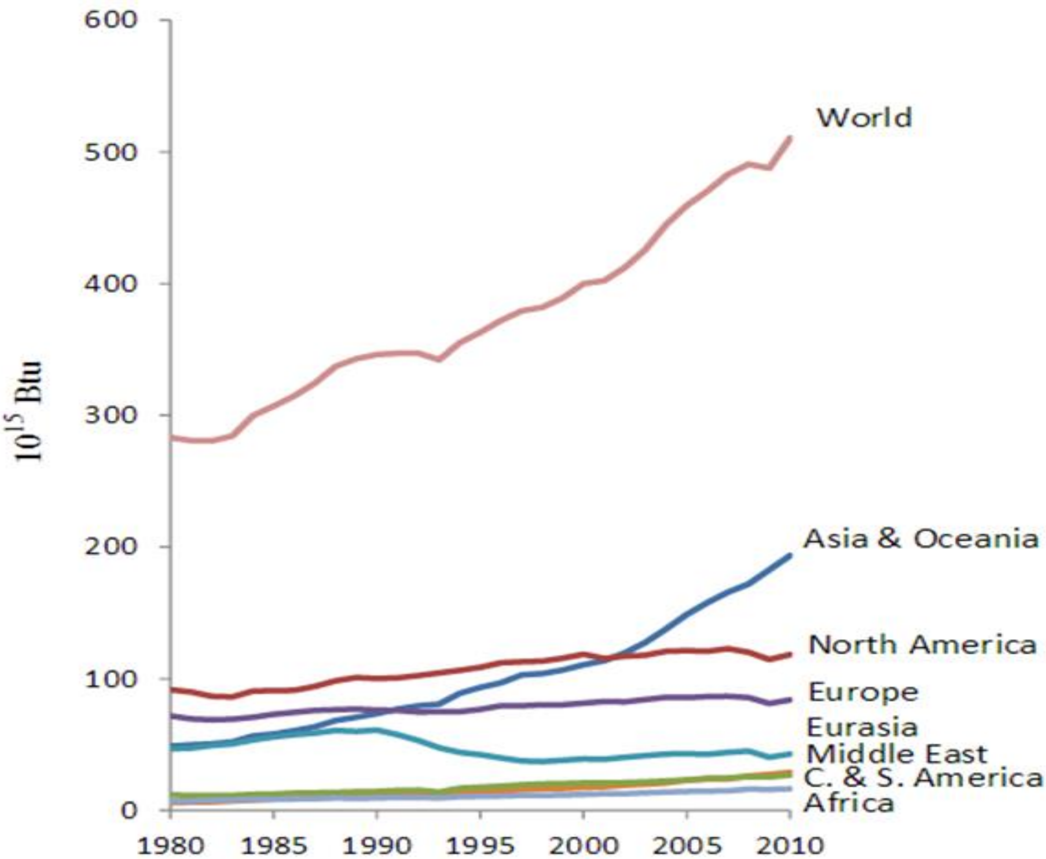


Figure 2. Annual Energy Demand by the Regions *(BP, 2016)*

According to data given in the figure 2, the annual energy demand has been increased since 1980. The rate of demands is more noticeable in Asia and Oceania after 2002. On the other hand, it is decreased in Middle East and Eurasia since 1989. In America and Europe, the amount of demands increased after 2008.

Briefly, aligned with sustainable development aims, renewable energy wins over fossil or nuclear energy sources, regarding to the limitations of resource and negative impacts of environmental factors (Figure 3).

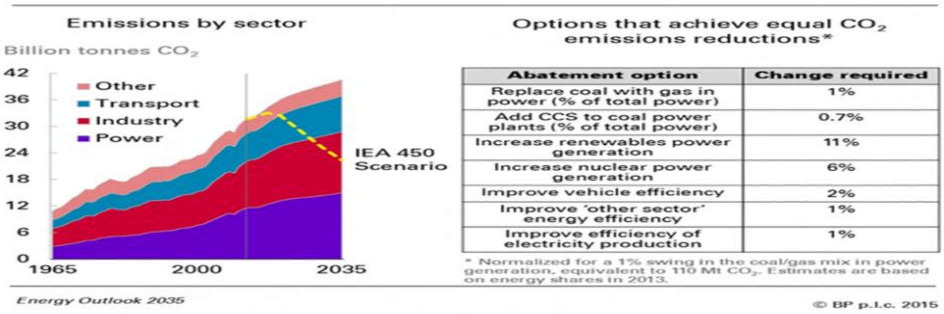


Figure 3. World`s Emissions Rate (Muttitt 2015)

2.1.2 World Fuel Consumption and the Need for Solar Energy in Cities

At the urban scale, restructuring the energy economy is imperative to forming any strategy with solving the challenges in dual energies and climate change. The amalgamation of humans in cities results in activities that cause not only high rate of emissions and energy consumption but also pertain to consumption of existing resources and infrastructures, which, in sum, calls for immediate transition to a greener energy economy (Eicker, 2012). The role of urban energy consumption is significant, as majority of populations already live in the urban areas or cities. To become climate neutral is a far-fetched goal that many municipalities have decided to adhere to, however, there is little to no experience available for this unprecedented phenomenon – that is, the experience of implementing local renewable energy resources in an urban scale. Intermittent analyses of current CO2 emission levels are conducted by municipalities, but fail in consistency and continuity (Byrne, Taminiau, Kurdgelashvili, & Kim, 2015).

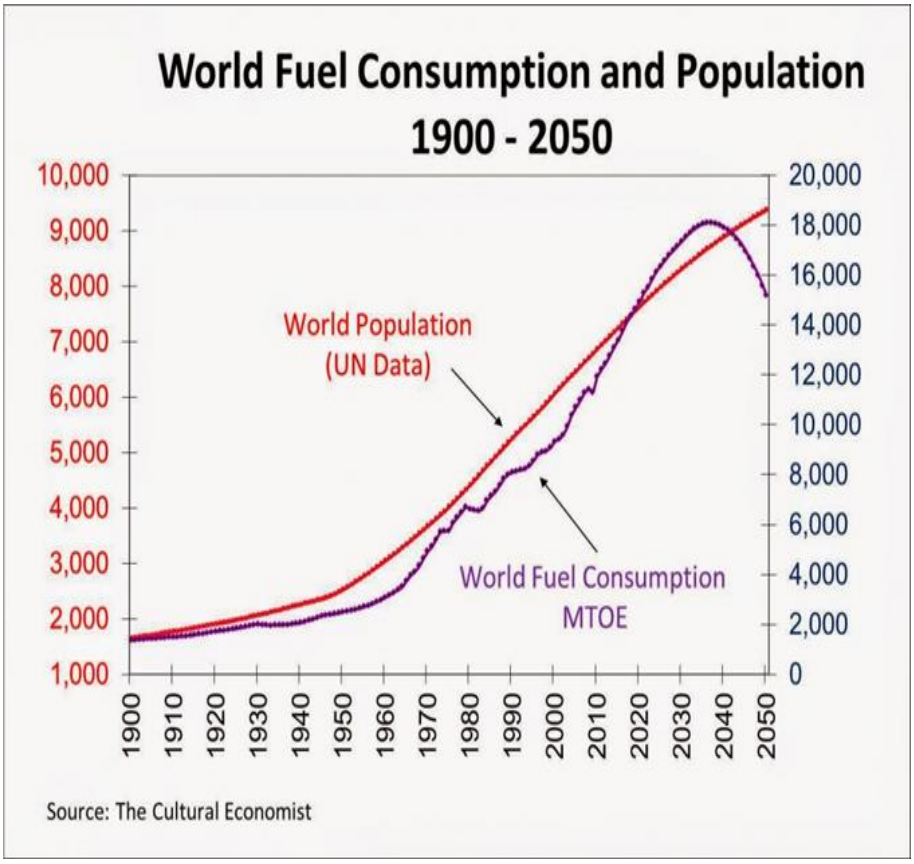


Figure 4. World Fuel Consumption and Population, 1900 to 2050.
Source: The Cultural Economist (*http://nea-polis.net*)

It is clear that the world`s population and fuel consumption is increasing dramatically, which is going to hit a peak at 18.2 Million Tonnes of Oil Equivalent (MTOE) with 9.2 billion people by 2040. Environmental impacts of such a huge rate of fossil fuels consumption will certainly be irreparable (http://nea-polis.net).

2.2 Solar Strategies to Estimate the Quality of Urban Areas

The solar potential of urban areas corresponds to their various local and geographical features; therefore, are to be measured and estimated accordingly. Subsequently, in order to maximize active and passive solar heating, production of photovoltaic electricity as well as daylighting, calls for quantifying the potential of building materials, such as facades and roofs. Building materials should be tested in simulations to assign values for the solar irradiation and illuminance they absorb, reflect and transmit (Paulescu, Paulescu, Gravila, & Badescu, 2013). In this regard, different processes are noted as follows:

- Estimating the rate of solar energy
- Analysis of climatic and geographic factors
- Analysis of materials and feature of their colors
- Analysis of site geometry

2.2.1 Estimating Solar Energy

The total solar irradiance (Gt) descended by a surface which is tilted with (β) in respect to the horizontal plane, is the total beam flux density, diffuse flux density (Paulescu, Paulescu, Gravila, & Badescu, 2013). Also, (G_r) the additional flux density of reflected radiation from the Earth ground equals as:

$$G_t = G_n \cos\theta + R_d G_d + G_r$$

The incidence angle (Ɵ) is the angle between the surface to the direction of the sun. (R_d) is treated differently in differing models global solar irradiance on tilted surfaces estimation, which is the key potential source of errors. Conversion coefficient (R_d) is taking into rate the sky view factor. The radiational energy flux density (G_r) reflected by the ground is intercepted by the tilted surface (Paulescu & Badescu, 2013). By summing up over a finite time period ($\Delta t = t_2 - t_1$) is used to acquire solar irradiation as follows:

$$\int_{t1}^{t2} G(t)dt$$

G(t) is solar irradiance components, measured either in in J/m^2 or Wh/m^2, dt is the differentiation of time and H refers to the corresponding solar irradiation component (Paulescu, Paulescu, Gravila, & Badescu, 2013).

In order to characterize the state of the sky, the sum of the cloud cover rate (C), is the fraction of the celestial vault covered by clouds (estimated in oktas or tenths), which describes the amount of indirectly the state of the sky depends sunshine (also known as fraction of sunshine), it is defined as:

$$\sigma \equiv s_{pr}/s_{br}$$

Where, (S_{pr}) is the period of given time interval, and (S_{br}) is the duration of bright sunshine (Paulescu, Paulescu, Gravila, & Badescu, 2013).

2.2.1.1 Sun Path Diagram

The sun rises and sets from different points on sky (the horizon). It moves across the sky along different paths. Measuring altitude and azimuth is essential to analyse the sun path. ``Altitude is the angular distance above the horizon measured perpendicularly to the horizon. It has a maximum value of 90 degrees at the zenith, which is the point overhead. Azimuth the angular distance measured along the horizon in a clockwise direction. The number of degrees along the horizon corresponds to the compass direction`` (Jin You,, 2017).

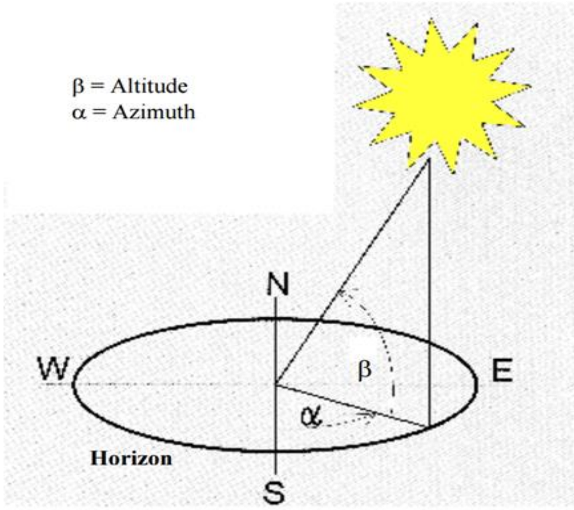


Figure 5. Altitude and Azimuth (Jin You, 2017)

2.2.1.2 The Stereographic Diagram

The stereographic diagram shows the changing position of the sun in the sky. This diagram represents sun`s positions above latitude during a year in detail. Stereographic diagram works by latitude and solar time, and shows the sun`s altitude and azimuth.

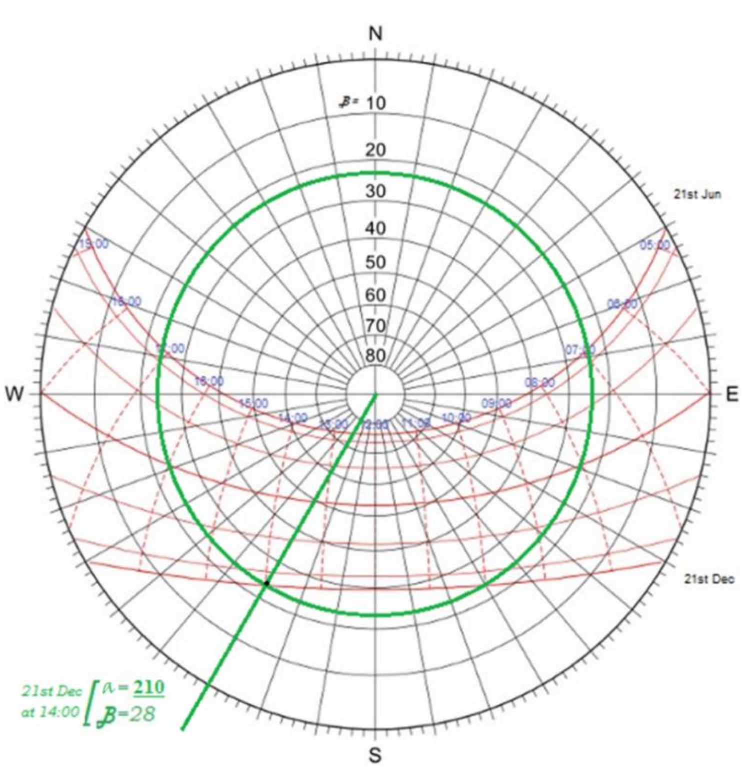


Figure 6. The Stereographic Diagram (Ozsavas and Ouria 2014)

2.2.1.3 Solar Irradiance

There are some parameters to measure the solar radiation in sites such as: Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance (DHI) and Global Horizontal Irradiance (GHI).

2.2.1.3.1 Direct Normal Irradiance (DNI)

Direct Solar Radiation or Direct Normal Irradiance (DNI) is the quantity of received solar radiation per unit area. The area of surface is normal/ perpendicular to the sun beams which come directly. DNI is the maximum rate of radiation that could be measured (Paulescu, Paulescu, Gravila, & Badescu, 2013).

2.2.1.3.2 Diffuse Horizontal Irradiance (DHI)

Diffuse Solar Radiation or Diffuse Horizontal Irradiance (DHI) is amount of the radiation which is scattered by dusts, aerosols and particles. DHI does not have any unique or especial direction.

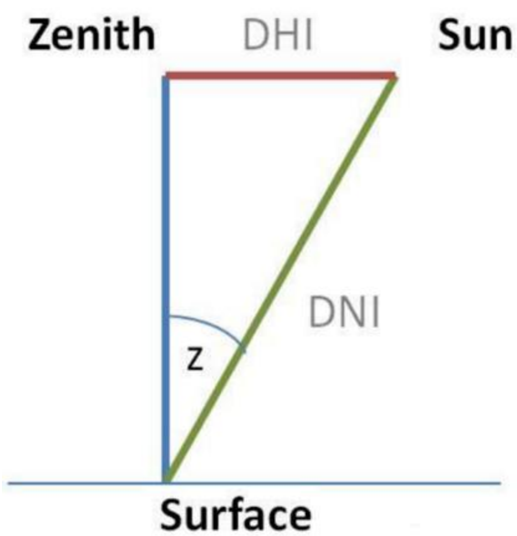


Figure 7. Direct and Diffused radiation, GHI = DNI. Cos (Z) + DHI

(www.omanpurp.com n.d.)

2.2.1.3.3 Global Horizontal Irradiance (GHI)

Global Solar Radiation or Global Horizontal Irradiance (GHI) it is the total rate of the diffuse and direct solar radiation it means sum of the received and scattered radiation on horizontal surface.

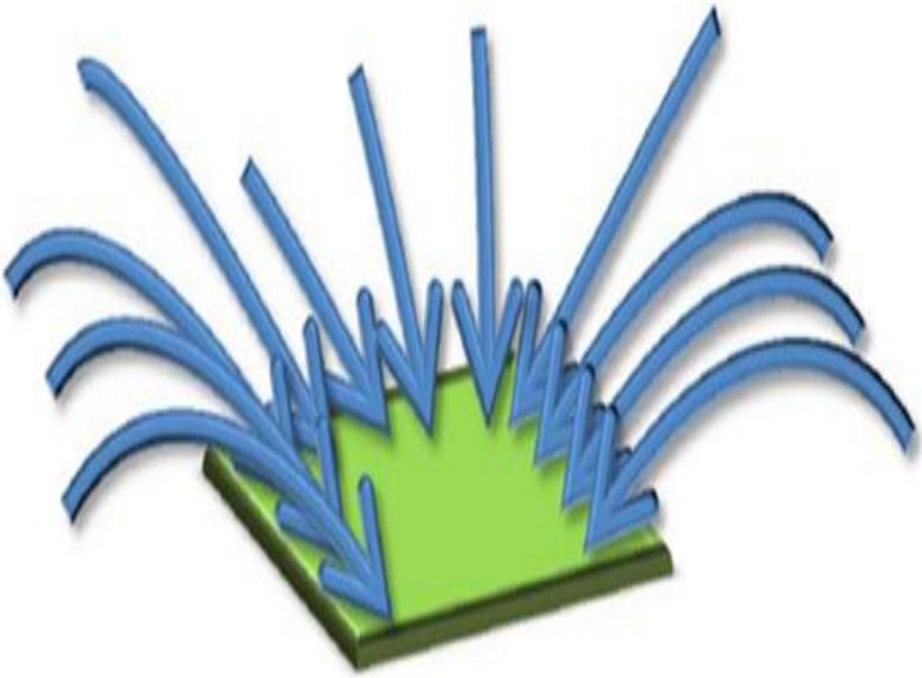


Figure 8. Global Horizontal Irradiance (GHI) (www.omanpurp.com n.d.)

2.2.2 Climatic and Geographic Factors in Solar Energy

The solar is largely determined in climatic factors. Subsequently, the climate of different regions is bonded to four geographic aspects: attitude/ sea level, latitude, direction of the prevailing winds.

2.2.3 Solar Radiation and Site Geometry

Careful analysis of location is the indispensable first step in any solar urban design. An inappropriate site selection, leads the most discreetly outlined solar system to failure. Thus, paying appropriate attention to the solar geometry is considered here (Cooper, 1969). There are two important parameters to describe the relation of Earth and Sun. One of them is the declination angle (δ), another one is the sun height/ altitude/radiation angle (β).

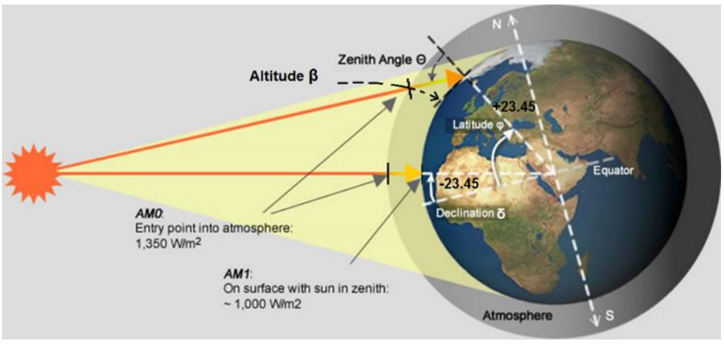


Figure 9. Solar Geometry (http://www.greenrhinoenergy.com/solar/radiation n.d.)

The sun`s angular position at solar noon is shown by declination angle with respect to the equator. The angle varies between -23.45° in Dec-21 (winter solstice) and +23.45° June-21 (summer solstice) for the northern hemisphere.

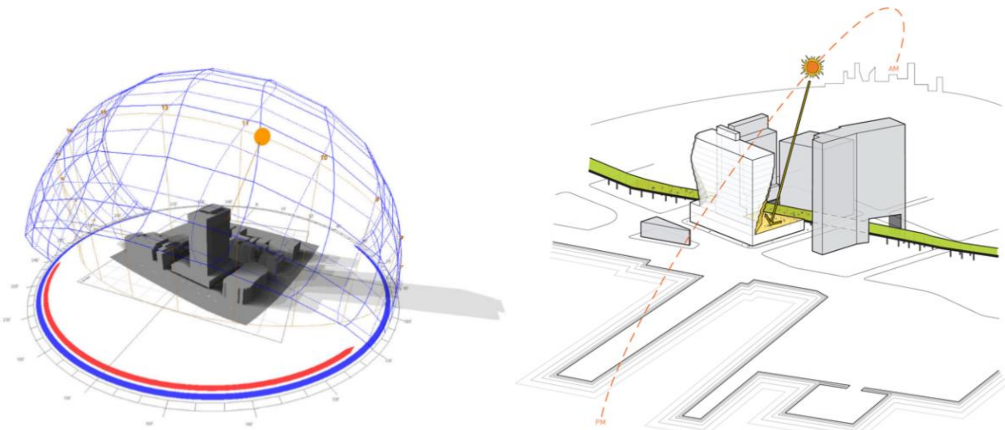


Figure 10. Exposure of Blocks and Orientation in Urban Areas (www.asiagreenbuildings.com/wp-content/uploads/2015/07/pireaus-context_solar_path.jpg n.d.)

2.2.4 Ideal Site Orientation

For living areas (urban areas), the ideal orientation is a range between (15°W–20°E). Also, the orientation range between (20°W–30°E) is acceptable of true north (‘solar’ north), it excludes summer sun and admits winter sun to keep the heat and lighting to an optimal. On the other hand, poor orientation can cause overheating in summer, forging a greenhouse effect at the wrong time of the year. Therefore, a good orientation should be selected, or one that can be adapted to these conditions with the least possible costs incurred. Living spaces with access to the winter sun with south-facing outdoor living areas will have optimum use of natural heat and lighting of the sun (www.yourhome.gov.au).

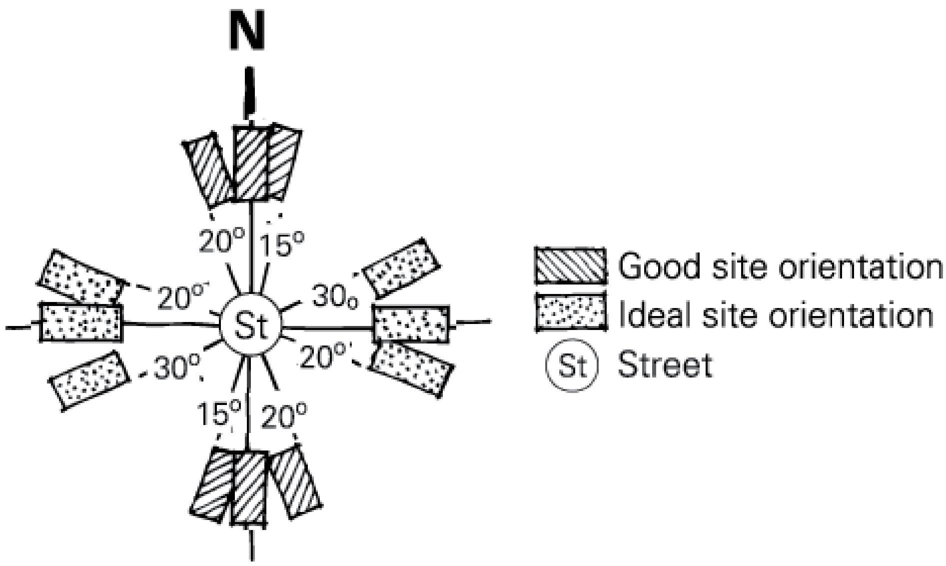


Figure 11. Ideal Site Orientation.

(www.yourhome.gov.au/sites/prod.yourhome.gov.au/files/pdf n.d.)

2.3 Analysis of Street Orientations

There are many theories for buildings or streets axis orientation, which can be according to Barraqué classified in two broad groups of the hygienists on the one hand and the climatists's on the other hand (Harzallah A. , 2007).

2.3.1 Orientation of Streets in North-South Direction

The first group to advocate north-south direction of orientating roads and the façades exposure in east-west direction consists of physicians, engineers and a few architects who lived in the late of the nineteenth century. They were in fact followers of Dr.

Adolphe Vogt of Berne's idea that claimed that solar heat would be uniformly distributed in homes because of the north-south orientation of roads, providing a solar optimum with antimicrobial properties (Montavon M. , 2010). His work is supported and cited by the Putzeys Brothers, Dr. Clément, Trélat and Duchesne in their research, in support of the north-south axis (Montavon M. , 2010). Dr Richardson also lays out the north-south-oriented streets in his utopia city model, Hygeia City. Some of the French authors including Juillerat & Bonnier also support this view (Montavon M. , 2010).

According to Montavon (2010) the French architect Henry Provensal (1905/1908) notes that sunbeams are almost horizontal in winter, oblique in autumn and in spring, while nearly vertical in summer. Following the same statement, he notes that almost horizontal beams are the most valuable for they are penetrating, but infrequently during winter.

A more recent architect writes that the claims of Provensal are not scientific since he ignores the shading of these low beams by buildings, whose height must be studied. Harzallah (2007) also criticizes that the chequered American street system would result in producing secondary roads perpendicular to north-south roads and eventually lead to an inadvisable exposure to the north. Buildings, according to Harzallah (2007), must be directed on the north-south axis, letting the sun disinfect the allbacteria-infested zones.

According to Montavon (2010) Leroux considered a study of the daily thermal alternation between two types of façades, the positive effects tangible in lightweight and lessened in heavier construction houses. The east-west axis orientation, would induce an unpleasant thermal imbalance all year long, regardless the type of the construction of the building. Marcotte, on the contrary, denounces the disadvantages associated with the north façade and suggest it as a tradeoff of the north-south axis of lanes, in spite of his preference the south façade for isolated houses. The east-west streets which have a lower mortality rate on the side exposed to the sun should be formed as well. The width in proportion to the height of the houses in designing new urban areas should expose to the sun.

According to Montavon (2010), compares and contrasts the supporters of the streets orientating north-south direction and which supports the axis of east-west directions, in which the second associate the southern faced façade for its larger sunbeam intensity.

According to Montavon (2010) the English urban planner Unwin in 1909 emphasized that the north exposure pose disadvantages by plotting a diagram, which depicts London’s latitude to defend his choice for east-west exposures. To further support his claims, he shows a French diagram that portrays main north-south ways, perpendicularly cut out by secondary ways to realize Howard's fifteen points (Figure 12).

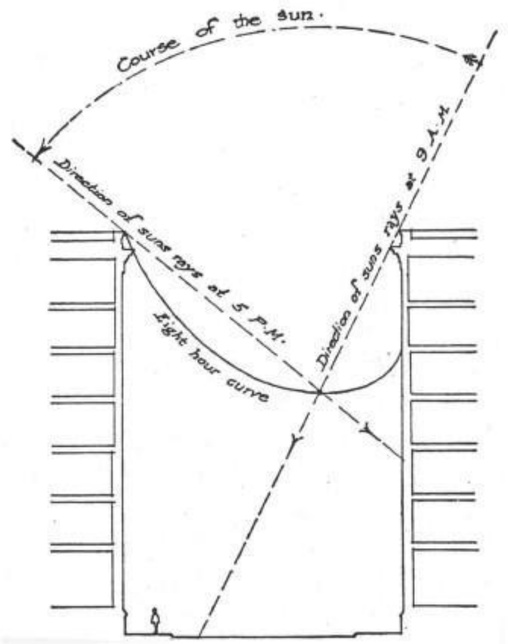


Figure 12. Profile of a South-East–North-West Oriented Street Facing North-West. The Sunbeam Directions are Drawn for the Summer Solstice, Latitude 42°0‘North according to William Atkinson (Montavon, M. 2010)

2.3.2 East-West Orientation of Streets (Exposure of South Façades)

Physicians, architects and engineers on the 19th century who were supporters of the east-west orientation of roads discovered the benefits of north exposure, but eventually concluded that the south exposure offered the best advantages.

This axis orientation for Europe’s grandiose buildings, such as first class resorts/hotels, public spaces/buildings was to have a main façade include important offices, and a secondary one include staircases, outbuildings and secondary offices. The north exposure for the main façade suits better to hot countries while south exposed façades only for the southern countries in the southern hemisphere.

According to Montavon (2010) Leroux advises south and north exposures for hot regions, however, also states that in temperate regions, what makes the rooms unhealthy, is humidity rather than the absence of sunshine.

He further notes that rooms facing north are desirable only if it is dry and decently heated during winter.

According to Montavon (2010) Stübben in 1890, Juillerat in 1921 and Raymond in 1933 absolutely renounce the claims of the supporters of the east-west axis because of the disadvantages incurred to the north façade. Raymond notes that east-west roads are to be avoided in temperate climates because their south sides would receive insufficient sunlight.

2.3.3. Diagonal Orientation of Roads

Some authors conclude a synthesis of the two alternatives and propose an alleviated solution that is conceived to allow for differing orientations and reduces the number of compromise made. The common orientation is a preference for a 45 degrees positioning. Although, there are some suggestions about the probability of turning blocks/house to solve the previous problem about orientating façades.

According to Montavon (2010) Clément in 1887, Stübben in 1890, Atkinson in 1894, and Unwin in 1922 are also amongst the supporters of the orientation of 45 degrees, which to them means and evenly distribution of direct sunlight. For Proust, Provensal and Courmont this orientation stands strong against the severe cold that the north faced façade can provide and the western one because of its winds and rain, therefore, reduces costs.

According to Montavon (2010) William Atkinson in 1894, a Boston architect, constructs a novel method for Boston’s 42° north latitude, which allows a correct estimate of the ratio between orientations and street outlines by monitoring the development of sunshine duration curves in various orientations of street setups. (Figure 12, Figure 13 and 14).

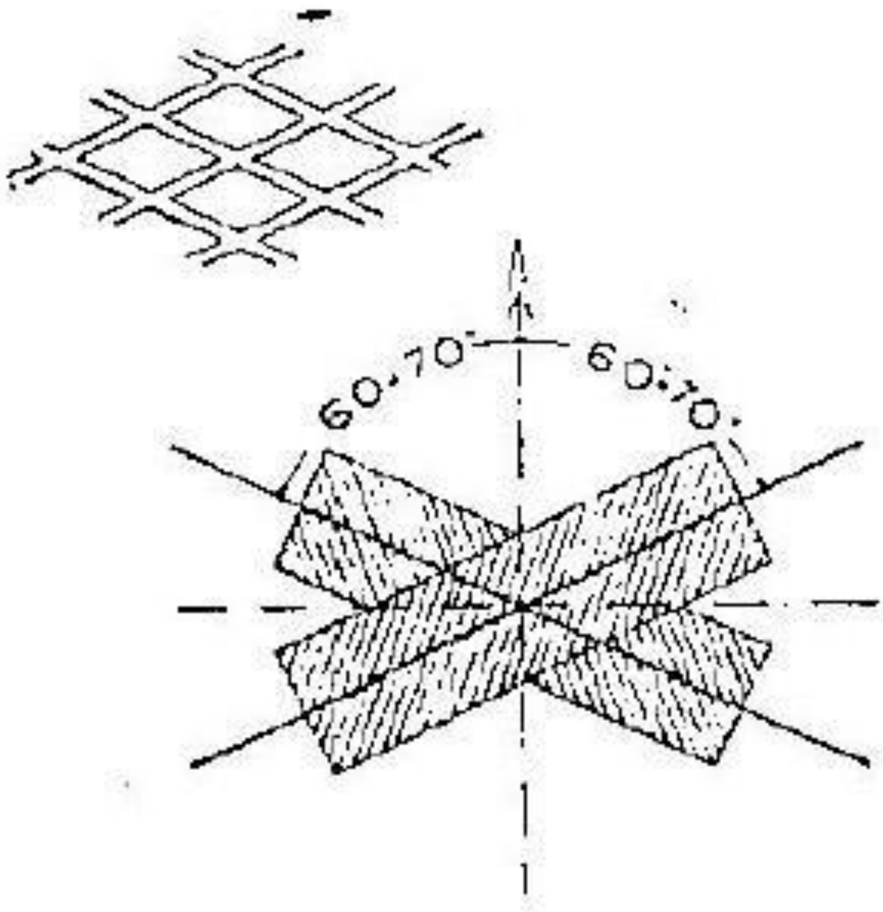


Figure 13. Angle Comprised between 60° and 70° on both Sides of the North-South Axis According to Felix Marboutin. (Montavon, M. 2010)

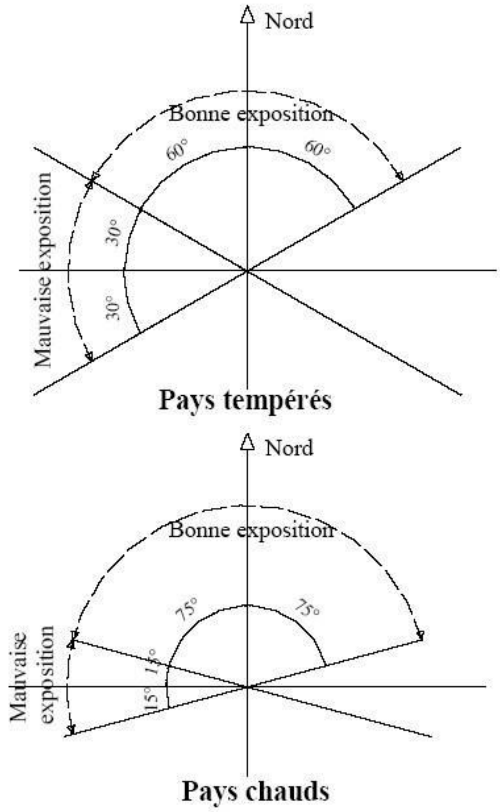


Figure 14. Sketch Reproducing Jean Raymond's Diagram Showing the Best Street Orientations. (Harzallah, A. 2007).

2.3.4 Heliothermic Axis

In Rey, Pidoux and Barde model, the product of sunshine hours with thermal degrees result in the heliothermic unit, which is rejected due to methodological errors by Bardet, in the Revue Techniques et Architecture that this calculation is physically meaningless (Montavon 2010), (Figure 15). Bardet notes that a temperature can be multiplied by a mass but not by a duration.

An assessment of the heliothermic axis can be made such as the heat factor follows the light factor with a given delay, the thermal wave reaching its maximum in the afternoon (varies between 2 to 3 p.m., according to the season of the year). The difference between the thermal axis and the light axis is approximately 45 degrees.

The heliothermic axis, more or less at the bisecting line, is 19 degrees north-east for Paris, with a moderately fluctuating value according to latitude and the climate of the location of interest (see Figure 16).

Its designers report a maximal annual solar radiation by using this axis. The revolutionary heliothermic theory drew fierce controversies among urban planning theoreticians, as it attracted Marcotte, an engineer, as well as the architects Le Corbusier and Gutton to accept and follow the heliothermic axis. Le Corbusier made the highest form of contribution to Rey's theory by announcing the heliothermic axis as the framework of the city plan, and by implementing it in a couple of his urban projects before the year 1945 (Montavon 2010).

Le Corbusier displayed his La Ville radieuse project – plates 3 and 4 were specifically devoted to building insolation – during C.I.A.M III in Brussels in 1930 (C.I.A.M.3, 1930). Le Corbusier used the heliothermic axis principle for the layout of his building in plate 3, he did not mention or cite Rey, Pidoux or Barde for the principle.

Le Corbusier held this principle very dear, as the first step that every urban planner should take in design, but dropped it completely after a few years for unknown reasons.

Another French project, Marseille's housing unit, was also planned to implement the heliothermic axis back in 1945; but then under Dourgnon's recommendation two years later, the unit used a north-south axis implemention.

Nonetheless, Rey’s theories were not left undisputed, as Bardet in 1943 described the effects of Rey’s theories disastrous on French and abroad projects, where they endured catastrophic variations in temperature – especially the east and west façades (Chiri & Giovagnorio, 2015). Vinaccia in 1943, also disputes the heliothermic axis, and calls it the native urban planners’ wrongfully use to justify any other designs as an attempt to portray it as up to date (Chiri & Giovagnorio, 2015). Hermant in 1943 and Leroux in 1946, on the other hand, take less harsh approach by admitting the relevance of heliothermic axis, but renounce its absolute necessity (Chiri & Giovagnorio, 2015) & (Montavon M. , 2010).

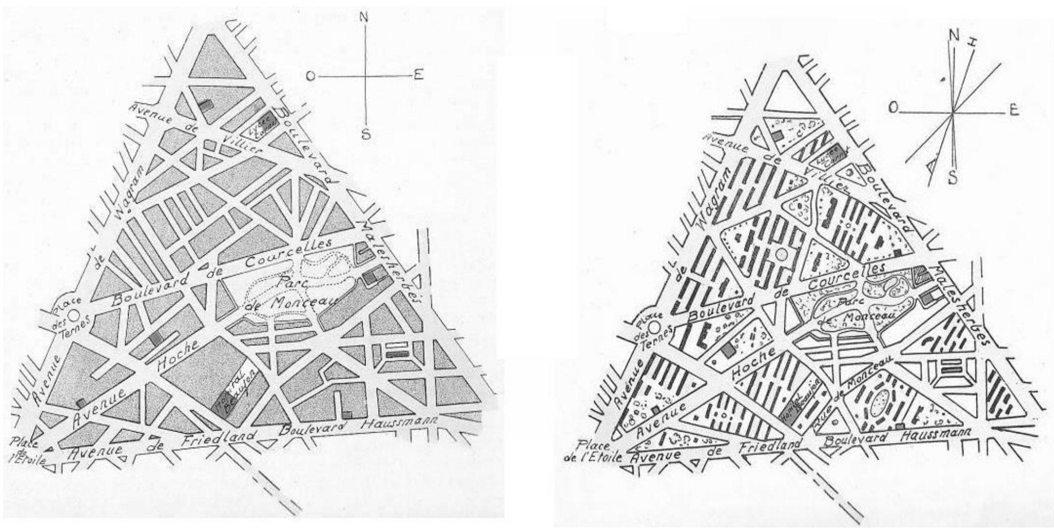


Figure 15. Heliothermic District Reorganization in Paris according to Rey, Pidoux and Barde in 1928. (Montavon, M. 2010)

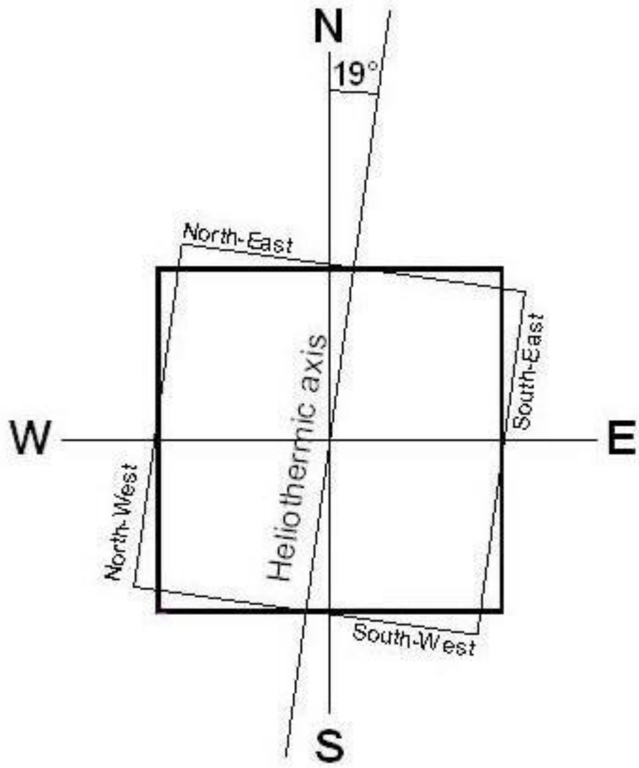


Figure 16. Heliothermic Axis (Montavon M, 2010)

2.3.5 Experimental Suggestions about Roads Orientations

In addition, some urban planners suggested different orientation angles for streets. For example, Clément in 1887 suggests a variable between 15 to 20 degrees as a function of latitudes between the Equator and 30 degrees. It was an ultimate goal to produce an equilibrium of insolation, not too excessive in summer and sufficient in winter (Harzallah 2007).

Similarly, De Souza in 1908 notes that the extension plan of Barcelona carried out by Jaussely in 1904, dealt with the orientation problem by adjusting a declination right or left of the meridian from 15 to 35 degrees for a north-south plan. An increase of 2 to 3 hours and a 15 minute is achieved by tilting from the north-south axis by 30 degrees, causing the façade to receive sunlight by more than an hour. The angles nevertheless vary by latitude and location. The search for the highest sunlight time and avoiding the north exposure continued with Juillerat, proposing angles range varying from 0 to 45 (later 60), and with Marboutin, an angle from 60 to 70 degrees of the meridian (Montavon 2010).

The street plans of the latter architect eventually form a lozenge-shaped draught board seen in Figure 17. The engineer Jean Raymond who preferred the 66 degrees' angles suggests different orientations for temperate, hot and tropical climates. Figure 17 depicts his views. Harzallah approves Raymond's discoveries as sufficiently carrying out the optimal orientation of city streets for urban planners to implement. Lebreton in1945 is more detailed in the variety of possible orientations for different spaces, varying 0 to 45 degrees (Montavon 2010):

- 25° max. deviation toward south–south-east: living rooms, kitchen;
- 45° max. deviation toward south-east: all rooms;
- 45° max. deviation toward south-west: daytime rooms, unfavorable for bedrooms.

Lebreton believed that all other orientations must be avoided for residential rooms – either daytime or nighttime (Montavon 2010).

Another orientation to consider is founded by Vinaccia in 1939 (Giovagnorio & Giovanni , 2016) designated as Equisolare. The latter ponderates sunlight homogeneously for the four exposures (Table 2). He compared heliothermic axis to the Equisolare orientation, to measure surface energy obtained, and calculated the optimum at 48 degrees for the city of Paris.

Table 2. Surface Energy (calories/m²) Received by Exposed Façades (Montavon, 2010)

Heliothermic orientations	Winter solstice	Summer solstice
Façade parallel to the axis	460	3000
Façade perpendicular to the axis	1200	1900
Total	**1660**	**4900**
Equisolare Orientation	1100	2000
Façade parallel to the axis	850	1600
Total	**1950**	**3600**

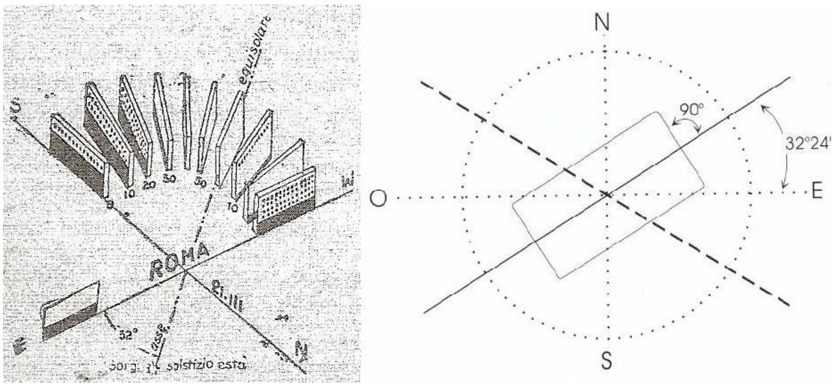


Figure 17. Study of facades in Rome according to Orientation of Roads (H = L, equinox); Equisolare Orientation Provides more Sunshine according to Vinaccia in 1939 (Giovagnorio and Giovanni 2016)

2.3.6. Analyses of Building Outlines and Streets

Devising regulation policies as building height proportionate to street width is an important moment in the history of urban design. An optimal aspect ratio between 1:1 and 3:1 based on human psychology is suggested (the closer to 1:1 the more preferable) by James Howard Kunstler (Kunstler, 1996). Setting the low buildings far back from the street delivers a feeling of isolation and vulnerability to the people, whereas tall buildings convey a feeling of discomfort. Solar considerations have shifted the meaning of street outlines to the next level. The methods used in making these recommendations fall into two main categories: through mathematical calculations; and by how proportions in simplified building outlines correspond to the aspect ratio between the width of the streets and façade heights.

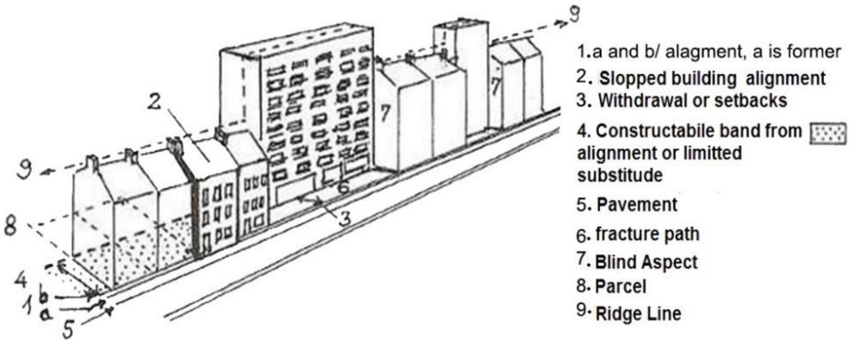


Figure 18. Street Profiles Along a Perspective Elevation. (Allain 2004)

2.3.6.1. Simplified Building Outlines

Many solar recommendations have changed the way to be looked at the ratio of building heights to the street widths. Here, it should be noted that the building outline is the virtual number that must not be outstripped by buildings. This is usually defined by the number of floors, which denotes the vertical height that starts from the wall plate to the crown. The rooftop can be flat or sloped. Except for common houses, the height a building is most of time defined by missioned rules (e.g. height of buildings = width of street) and accordance to the distance of the site boundaries (e.g. width of street = height of buildings /2 ≥ 3 meters). Regulations, however, can vary to differ or to be more specific (Figure 19).

Decrease in the level of sanitation in poorer districts caused many hygienists to theorize that the low width of streets and the high height of facades played an important role in the unhealthiness of the neighborhood.

The first authors who were concerned with these issues devised a ratio, suggesting the need to associate façade heights to street widths. These regulations were subsequently enacted but not sufficiently enforced and applied, partly because of their novelty.

Refining this ratio and establishing new regulations was the next step taken by these authors. A summary of the various theories of building outlines and streets are shown in Figure 19.

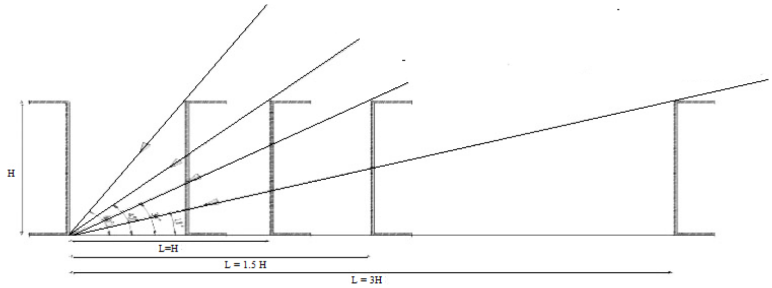


Figure 19. Juxtaposition of Proposed Building Outlines and Streets. (Harzallah, A. 2007).

Arguments put forward by Harzallah, (2007) recommending an aspect ratio of 1:1 lead to systematic research for finding proper airing and proper insolation for façades. According to Harzallah (2007) the interest of Proust in maintaining this ratio is more related to its social implications, while the proposition made by Hénard differs as he suggests the angle of the solar beams hitting the façade should exceed or equal 45 degrees, disregarding a social interest in this matter. A cast shadow arriving at 45 degrees' angle, according to Cloquet & Cobbaert does not let one building shade another one (Harzallah, A. 2007).

Also, it is pointed out the path of streets that are too wide and erecting very high buildings and, with the following outlines:

- If height = 7-8 metres → street width = 8-10 metres;
- If height = 16 metres → street width = 20 metres.

Finally, it steps forward to point out the correct relationship between street orientations and outlines. His methods accurately calculate the sun-related consequences of a given outline with a given orientation.

Goulding (1986) explains that in order to provide a proper solar access during the heating season one has to calculate the correct slopes and the effects of solar gains corresponding with the opposite buildings that provide a proper solar access during the heating season.

Sloped south-directed terrains are likely to be made denser compared with the flat ones. Sloped west-directed terrains in southern Europe have proven to be less adequate in terms of energy efficiency (Figure 20).

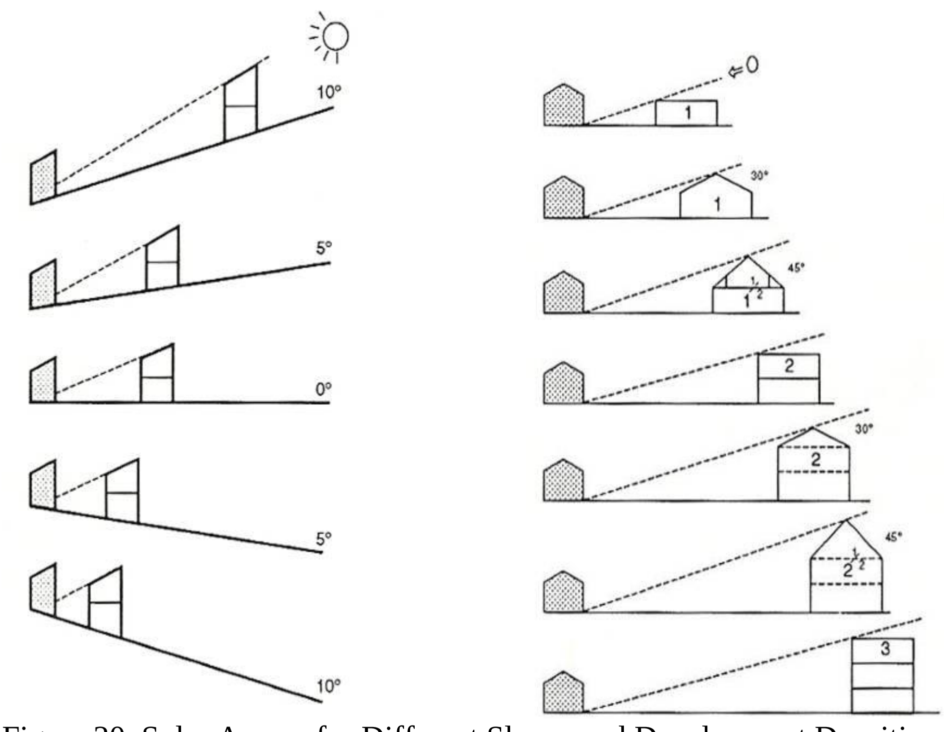


Figure 20. Solar Access for Different Slopes and Development Densities (left) and the Effect of Neighbouring Building on Solar Access (right). Source: Goulding, John R., Lewis, J. Owen, Steemers, T. C. (1986).

On the other hand, the inter-building distance must be adapted to and aligned with the street orientation. Figure 21 shows the relevancy of the inter-building distance on useful solar gains during the heating season. The application of proper distances also has a positive effect on the daylighting of rooms.

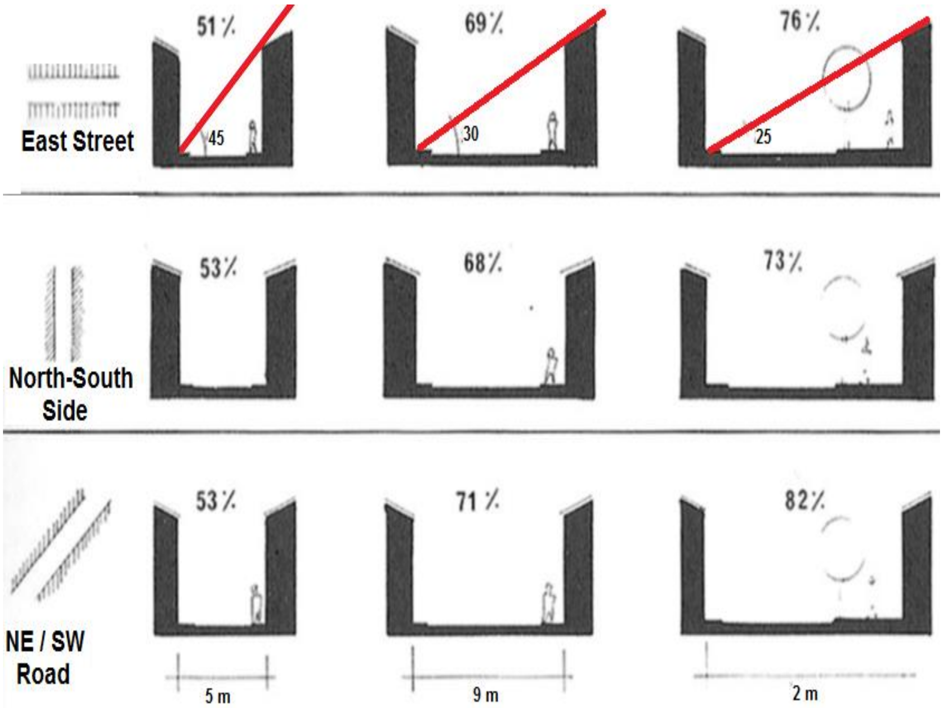


Figure 21. Useful Solar Incomes during the Heating Season according to Ganz in 1990) (Klemm and Heim 2009)

Based on the assumes that the ratio of the height of the buildings and the width between them are 1:1 (street width=height), then the solar penetration will decrease accordingly as the width between the buildings is reduced (about 25% for ½h and 50% for ¼h).

The result of this study, on cases A, B, C and D showed that during the heating season (September through April) there was relatively superior insulation in case C, where the existing building was more exposed on the east side. In cases B and D, on the other hand, the east façade received only half as much sunlight. From May until

August, the differences between the amounts of direct solar energy received by the four cases was not very significant. There was a noticeable shading effect throughout the year in each case (A, B, C and D). Case C, once again, received a higher level of sun penetration from the south-east during the winter months.

The conclusion of this study portrays that except for the summer months where there is little difference in all four cases, case C is far more susceptible to solar penetration for the remainder of the year, compared to other cases.

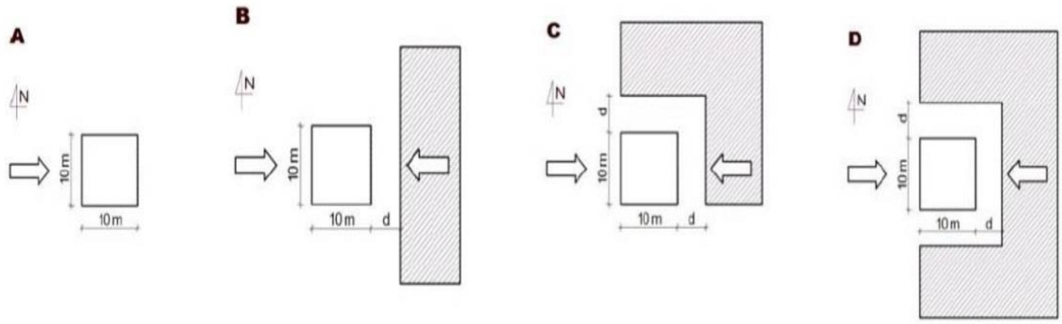


Figure 22. Analysis of a Main Building and its Surroundings (Klemm 2009)

2.3.6.2 Mathematical Formulations

The mathematical formulations of the problem had a more systematic approach to the question. According to Montavon (2010) some authors devised proposals that adopted mathematical formulas such as Von Camerloher in 1829, Vogt in 1885, Dr Clément in 1887, Bertin-Sans in 1902, Rey in 1908 and 1928, Courmont in 1913, Marboutin in 1910 and Leroux in 1948 to correspond to this problem.

Coumont’s and Bertin-Sans’s proposals attempt to find a correlation between the street orientation and the incidence angle of sunbeams, whereas Marboutin’s aim at avoiding the orientation factor altogether.

Most authors were impressed by a theory proposed by Dr. Adolphe Vogt from Berne, Switzerland. Harzallah (2007) writes in appraisal that Dr. Vogt was the pioneer that first solved the solar radiation problem for houses.

Vogt integrates several variables in order to assess for any given location the street width suitable for the house insolation, which weave together a scientifically mature formula. Latitude and orientation considered, as the outcome value is dependent on both of them. Concisely, Vogt highlights the sunbeams' incidence angle based on the place of interest and street direction.

Table 3 is a summary of standard values assessed for east-west and north-south streets. Vogt applies his theory in order to come up with this suggestion that layouts of north-south-oriented street blocks cut through by infrequent and wide equatorial crossroads and narrow meridians.

Table 3. Synthesis of Adolphe Vogt 's Recommendations (Allain 2004)

Rules	Latitudes	East-West Streets	North-South Streets
Street width / Building Height = sin (30° + δ) cotg α	Under 40°	H : L = 1 : 1,3263	H : L = 1 : 2,2971
	Under 45°	H : L = 1 : 1,7121	H : L = 1 : 2,9654
L : Street width	In Berne	H : L = 1 : 1,9243	H : L = 1 : 3,3333
H : Height of the neighbouring houses	Under 50°	H : L = 1 : 2,3778	H : L = 1 : 4,1184
δ : Direction of the street from North	Under 55°	H : L = 1 : 3,8238	H : L = 1 : 6,6230
α : Incidence angle of the sun rays	Under 60	H : L = 1 : 9,5027	H : L = 1 : 16,4591

2.3.6.3 Analyses of Façade Exposures

The often confusing and contradictory theories that analyzed façade exposures were disparate from east to south because of the differences pertaining to sun-related ideas.

2.3.6.3.1 East Façades Exposures

Supporters of east exposure like Vitruvius's Dr Adolphe Vogt's, feared heat waves in the cities and stated that "in summer, in south-exposed locations, the sun is especially hot when it rises, and burning hot at noon. so that health is highly affected by these sudden changes from hot to cold. Table 4 also shows a chronological list of the authors of east façade orientation theories, alongside the mentors who guided and inspired them.

Table 4. East Façades Exposure Authors (Allain 2004)

Theories	Years		Authors
East Exposure mentors	4th Century B.C.	–	Hippocrates
	1st. Century B.C.	–	Marcus Vitruvius Pollio
East Exposure authors	1844/1897	–	Isidore Bourdon
	1846	–	Jean-Baptiste Monfalcon
	1846	–	Isidore-Augustin-Pierre de Polinière
	1869	–	Michel Lévy (+ west exposure)
	1885	–	Adolphe Vogt
	1886/1887/1905/1887	–	Emile Trélat (east + west both in moderate countries)
	1887	–	Emile Clément (+ south and west)
	1838	–	Pierre-Adolphe Piorry
	1897	–	Achille Bourbon
	1911	–	M. Bousquet
	1913	–	Cloquet & Cobbaert (+ south-east)

2.3.6.3.2 South Façades Exposures in Different Orientations

According to Harzallah (2007) Marboutin in 1910, adopts nebulosity and radiations of the sky vault as evidence to deduce that façades facing streets, as well as main façades of isolated buildings, need to face south in order to provide optimal housing conditions; that is, heat during winter and cool during summer. In his view, the optimal exposure is at an angle between 60 and 75 degree with the meridian (Figure 23).

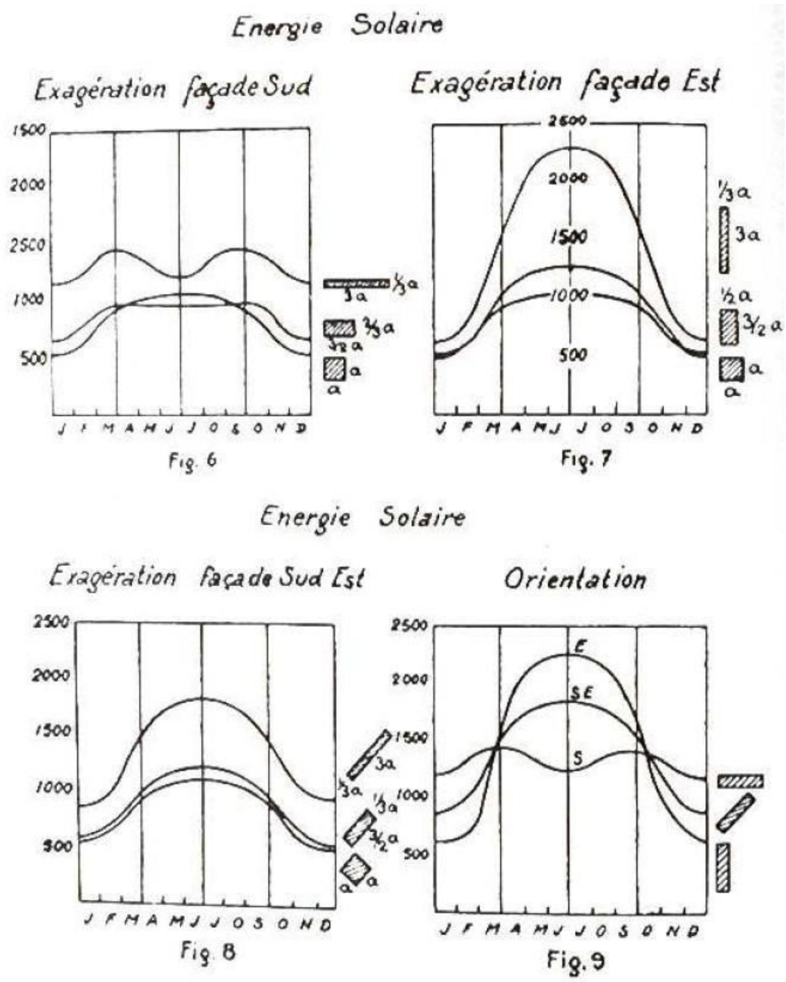


Figure 23. Study of the Influence of Façade Orientation on Solar Energy According to Félix Marboutin in 1910. (Harzallah, A. 2007).

The supporters of the south exposure, especially Deschamps in 1930, Dourgnon in 1936, Hermant in 1934 and 1943), Bardet in 1941, Lebreton in 1945 and Leroux in 1952 constantly acknowledge Marboutin's works (Giovagnorio & Giovanni , 2016).

Leroux, in particular amongst others, provides a general overview of Marboutin's works and assesses the insolation of buildings in temperate climates.

Parallel to Marboutin's studies, Hermant reported other investigations; one carried out in Copenhagen by Wolmer, another in the United States by the American Society of Heating and Ventilating Engineers (A.S.H.V.E) and last but not the least, by the

John B. Pierce Foundation in 1936. Lebreton in 1945 refines by indicating orientation angles that must not exceed at 42 degrees north in order to benefit from a proper sunshine upon in case of a bright weather (Montavon M. , 2010).

2.4 Height per Width Ratio and the Right for Daylight in Urban Spaces

Daylight is a medium that enables the use and empowers the joy of our homes and workplaces, and provides the safety and comfort necessary for people to live and work in. The right for daylight recognizes the importance of lighting in the workplace and at home.

For example, because of worker’s psychological well-being workplaces must have suitable and sufficient daylighting; provides a mechanism to resolve complaints between neighboring citizens with regard to impeding access or high hedge lights; assesses applications of permission for planning considers daylight and sunlight as factors examined by local authorities. Citizens, therefore, are entitled to various rights associated with daylight.

Daylight is essential in urban design in order to allow solar energy systems to heat the buildings in winter and for the betterment of the people`s conditions in streets, walkways and open public spaces.

A design that neglects the daylighting of buildings and open spaces is destined to create delicate conditions indoors and outdoors respectively.

The length of horizontal shadow of an element on the ground is a function of its height and the angle of radiation (Ouria and Özsavaş 2016):

$$L = \frac{h}{\tan \beta}$$

→

$$L = \frac{h}{\tan(ArcSin(Sin\phi . Sin\,\delta + Cos\phi . Cos\delta . Cos\omega))}$$

The length of shadow (*l*) depends on the height of the element (*h*), and radiation angle/altitude (β).

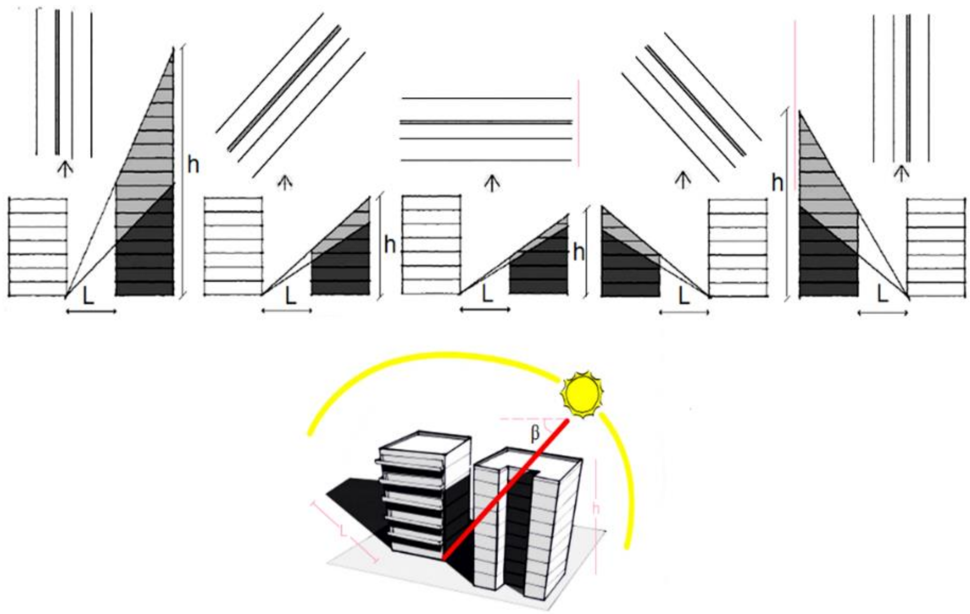


Figure 24. The Right for Daylight in Urban Areas (Sotiris and Fisher 2003)

Theoretically a street canyon is a narrow road/street with high buildings on both sides of the street. However, the concept of street canyon or H/W ratio is used more geometrically. H/W is the basic geometrical detail about a street canyon which is defined as the aspect ratio (Sotiris & Fisher, 2003). The rate of the H/W ratio can implement to categories street canyons as mentioned below:

- Regular canyon - aspect ratio ~= 1 and no major openings on the canyon walls
- Avenue canyon - aspect ratio < 0.5
- Deep canyon - aspect ratio ~=2

2.5 Solar Reflectance and Urban Materials

The urban elements and materials are characterized according to their performance about heat capacity, albedo, reflectance and emission of solar energy.

Albedo/solar reflectance is the reflection percentage of solar energy from surfaces. Visible wavelengths include the majority of the solar energy (Figure 25). However, solar reflectance is mutually related with color of materials.

For instance, the reflection value of dark surfaces is lower than the lighter ones. Scholars are concurrently investigating on developing novel cool colored materials which implement specially engineered pigments to reflect well the infrared wavelengths.

Thermal emittance (or emissivity) is another variable that goes hand in hand with solar reflectance in determining the temperature of a material’s surface. High rate of emittance values cause surfaces staying cooler, due to their innate capability of diffusing heat.

Most contemporary construction materials, with the exception of metal, are designed and constructed to have high value of thermal emittance. However, this property appeals to individuals who want to install cool roofs.

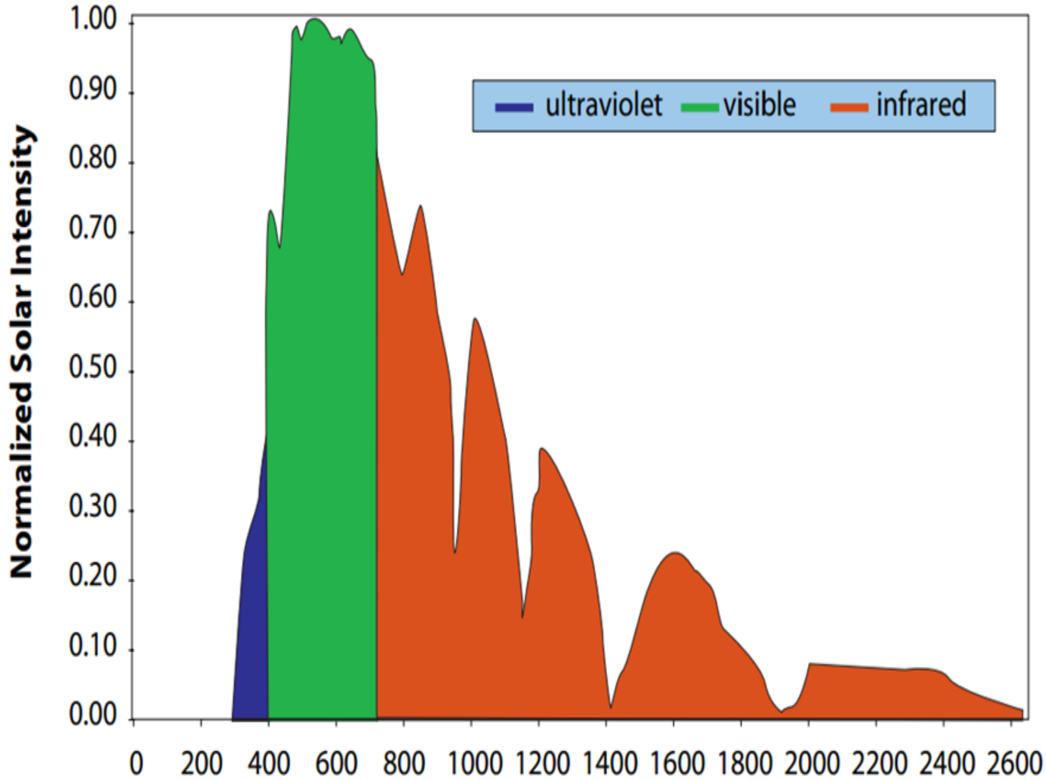


Figure 25. Versus Wavelength of Solar Energy on Earth's Surface (https://www.epa.gov)

On the other hand, another essential property which directly impact is heat capacity of material. Heat capacity (or thermal capacity) is a material's ability to store heat. Many building materials used in urban areas such as stone and steel have much heat capacities in comparison to sand/dry soil. These materials cause differences of albedo value in urban and rural areas. As a result, cities have a higher capacity for storing solar energy in their infrastructures than rural areas. The calculated amount of heat absorbed and stored in metropolitan areas is twice in comparison to the rural counterparts during daytime.

2.5.1. Solar Reflectance Index (SRI) and Solar Reflectivity (R) of Surface Color

``Solar reflectivity or reflectance is the ability of a material to reflect solar energy from its surface back into the atmosphere. The SR value is a number from 0 to 1.0. A value of 0 indicates that the material absorbs all solar energy and a value of 1.0 indicates total reflectance. According to 'Energy Star' requirements an initial SR value of 0.25 or higher for steep slope which is bigger than 1/6 of roofs and 0.15 or greater after three years. Low slope roofs require an initial SR value of 0.65 or higher and 0.50 or greater after three years.

The Solar Reflectance Index is used for compliance with LEED requirements and is calculated according to ASTM E 1980 using values for reflectance and emissivity. Emissivity is a material's ability to release absorbed energy. To meet LEED requirements a roofing material must have a SRI of 29 or higher for steep slope (>2:12) roofing and a SRI value of 78 or higher for low slope roofing.``(www.deansteelbuildings.com).

Table 5. Solar Reflectance Index (SRI) by Color (http://energy.lbl.gov/coolroof/)

Material	*Albedo (%)*	*Emittance (%)*	*SRI*
White asphalt shingles	21	91	21
Black asphalt shingles	5	91	1
White granular-surface bitumen	26	92	28
Red clay tile	33	90	36
Red concrete tile	18	91	17
Unpainted concrete tile	25	90	25
White concrete tile	73	90	90
Galvanized steel (unpainted)	61	4	37
Aluminum	61	25	50
Siliconized white polyester over metal	59	85	69
Polyvinylidene fluoride (PVDF) white over metal	67	85	80
Black EPDM	6	86	-1
Gray EPDM	23	87	21
White EPDM	69	87	84
T-EPDM	81	92	102
Chlorosulfonated polyethylene (CSPE) synthetic rubber	76	91	95

Chapter 3

ANALYSES OF THE CASE STUDIES IN FAMAGUSTA CITY

3.1 Introduction

This chapter includes the case studies of the thesis with the aim of evaluating the solar energy in urban streets of Famagusta. The first part explores the potential of solar irradiance in Famagusta using Ladybug for Grasshopper in Rhino software program. The second part presents a comparative analysis of case studies following research problems of the thesis.

3.2 Methodology and Analysis

The understanding of the analysis method is very significant and will be presented in this chapter to have an overview. Firstly, climatic and geographic data of Famagusta is analyzed to estimate albedo rate. Secondly, the solar potential is estimated for Famagusta using Ladybug for Grasshopper in Rhino and Microsoft Excel software programs. The aim of the software analysis is providing a reliable solar scale/pattern for Famagusta. The solar pattern makes it possible to compare/criticize different case studies from the city. Thirdly, urban issues are analyzed about the Konak street in Sakarya district and the Cahit Sıtkı street in Gülseren district. Two different methods are used to analyze the case studies. Site plans are downloaded from google-maps, site photos have been taken by field survey. On the other hand, the collected data is analyzed by comparative method.

Finally, the analysis of three solar issues that affect streets and blocks qualities are regarded. These are orientation, height/width ratio, landscaping (greenery, shading, furniture, albedo).

Table 6 shows the summary of techniques and the tools used for collecting data and analysis which includes the elements and tools effecting the street spaces from solar point of view.

Table 6. Methodology of the Case Study Analysis

Elements		**Technique**	**Tool**
Solar Issues	Climate	Temperature, Humidity	Meteorological data, Energy Plus
	Radiation	Azimuth, Attitude, Sky clearness, Street, Façade, Cosine Method	Ladybug for Grasshopper in Rhino, Energy Plus, Python, MS Excel, Google Maps
	Geography	Latitude, See level, Land cover	GIS, Google Maps
Street Issues	Orientation	Observation, Street, Façade	Photographs, Google Maps

	H/W Ratio	Observation	Measurement, Photographs
	Landscape	Observation, Furniture, Greenery, Albedo, Shading, Paving	Photographs

3.3 Selection of Case Study Area

In order to consummate the thesis, it is essential to select case studies to compare the analyzed solar datas in street spaces. For that reason, two streets are selected: Konak street in Sakarya district and Cahit Sıtkı street in Gülseren district. The main reasons of case selections are:

- Famagusta is characterized by Mediterranean climate with its high rate of solar potential and needs for improving the value of shading elements on walkability.
- Climate conditions are main factor impacting urban outdoor activities like walking on street spaces.
- Selection of two streets with opposite orientation makes it possible to compare the solar street issues.

3.4 Definition of the Case-Studies

Cyprus is the 3rd largest island locating in the Eastern part of Mediterranean Sea. The island is located at 33 degrees east of Greenwich, and 35 degrees north of the equator.

On the other hand, Cyprus has a great potential for domesticating solar because of its geographical position and climatic benefits. Its climate includes of Mediterranean climate which has mild winters and hot dry summers (Michaelides & Votsi, 1991) .

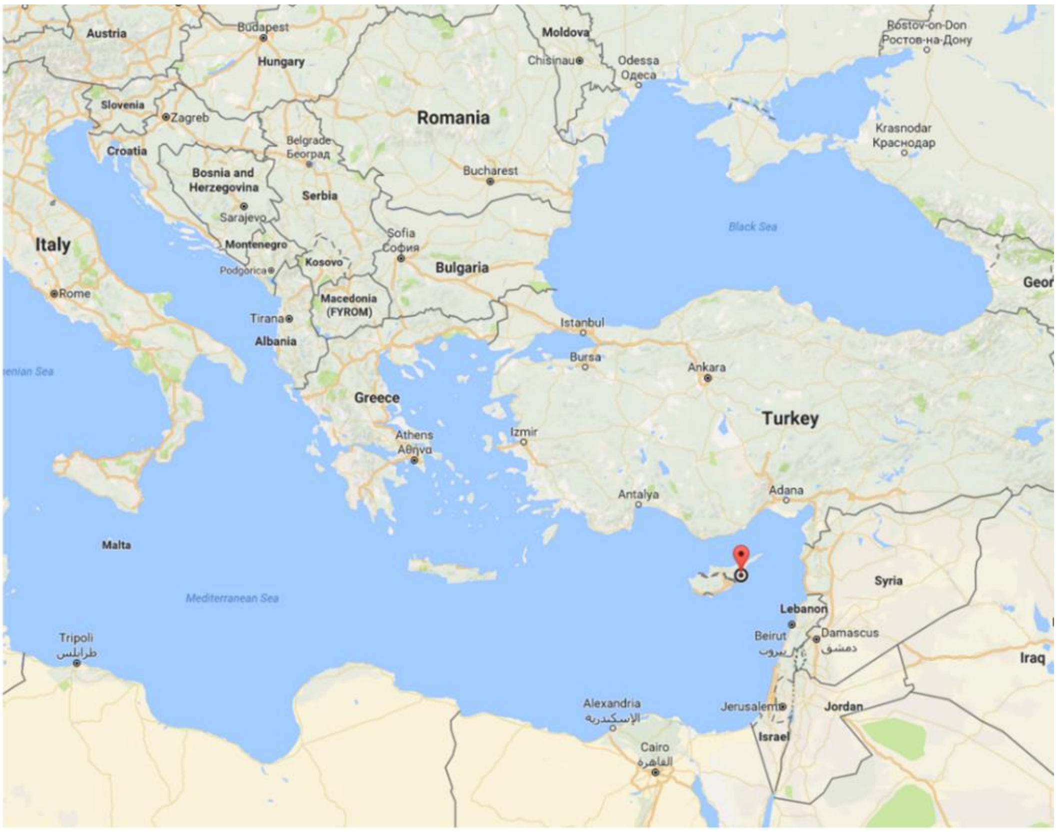


Figure 26. Location of Cyprus (https://www.google.com/maps 2017)

3.4.1 The City of Famagusta

Famagusta city is located in the eastern part of the island. Its population has been recorded 40920 persons in 2011. ``The history and urban development of Famagusta date back to the first century AD and the contemporary city has been developed over seven periods: the early period (648-1192 AD - the foundation period); the Lusignan period (1192- 1489); the Venetian period (1489-1571); the Ottoman period (1571-1878); the British period (1878-1960); the period between 1960-1974 (the Greek & the Turkish), and the period after 1974 (the Turkish)`` (Oktay, 2009).

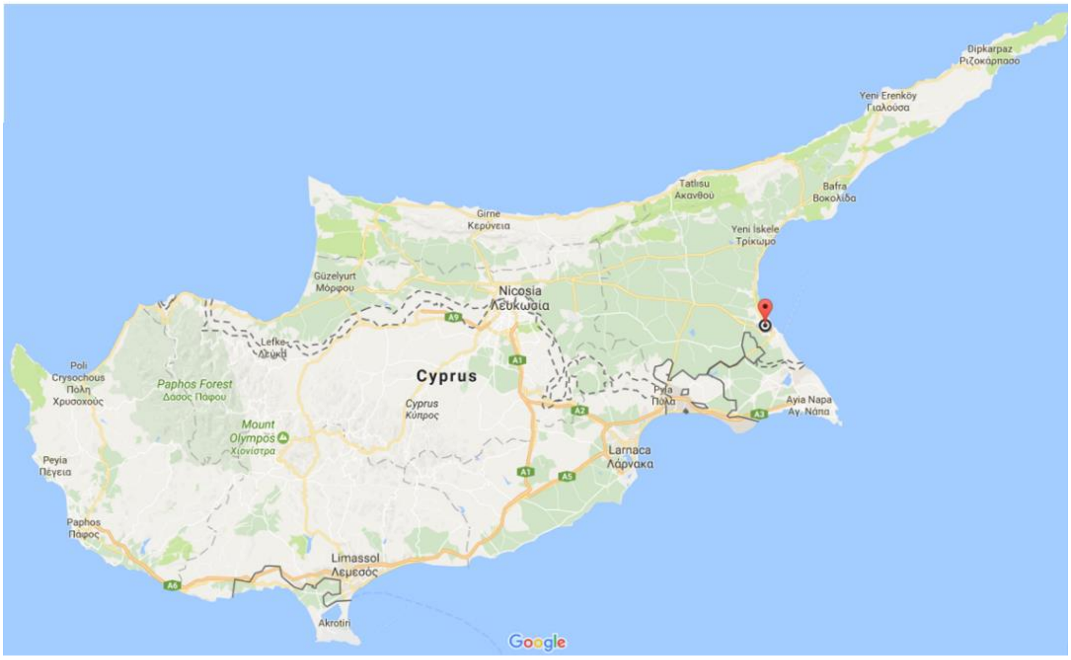


Figure 27. Location of Famagusta in Cyprus (Google-Maps 2017)

3.4.1.1 Climate and Geography of Famagusta

Famagusta is located at the eastern part of the island. Averagely, the city is 35 meters higher than sea level. The geographical location of stations is presented in table9.

Table 7. Geographical Location of Stations (Google Maps 2017)

Latitude (*φ*) (deg.)	Altitude / Sea Level (m)	Longitude (degree)
35.1° (N)	25 m	33.9°

Famagusta`s climate has a dry-summer subtropical or hot Mediterranean climate with mild/moderate seasons (Kottek, 2006). The rate of humid is noticeable in summers which cause to feel the heat of environment intolerable (Figure 28).

But it should not be forgotten that the rate of energy absorption is different than feeling heat caused by humidity.

The average monthly temperature is (22.0 °C) in Mediterranean climate. The differences between warmest and coldest month is (-3°C to +18°C) with at least 4 months above 10 °C.

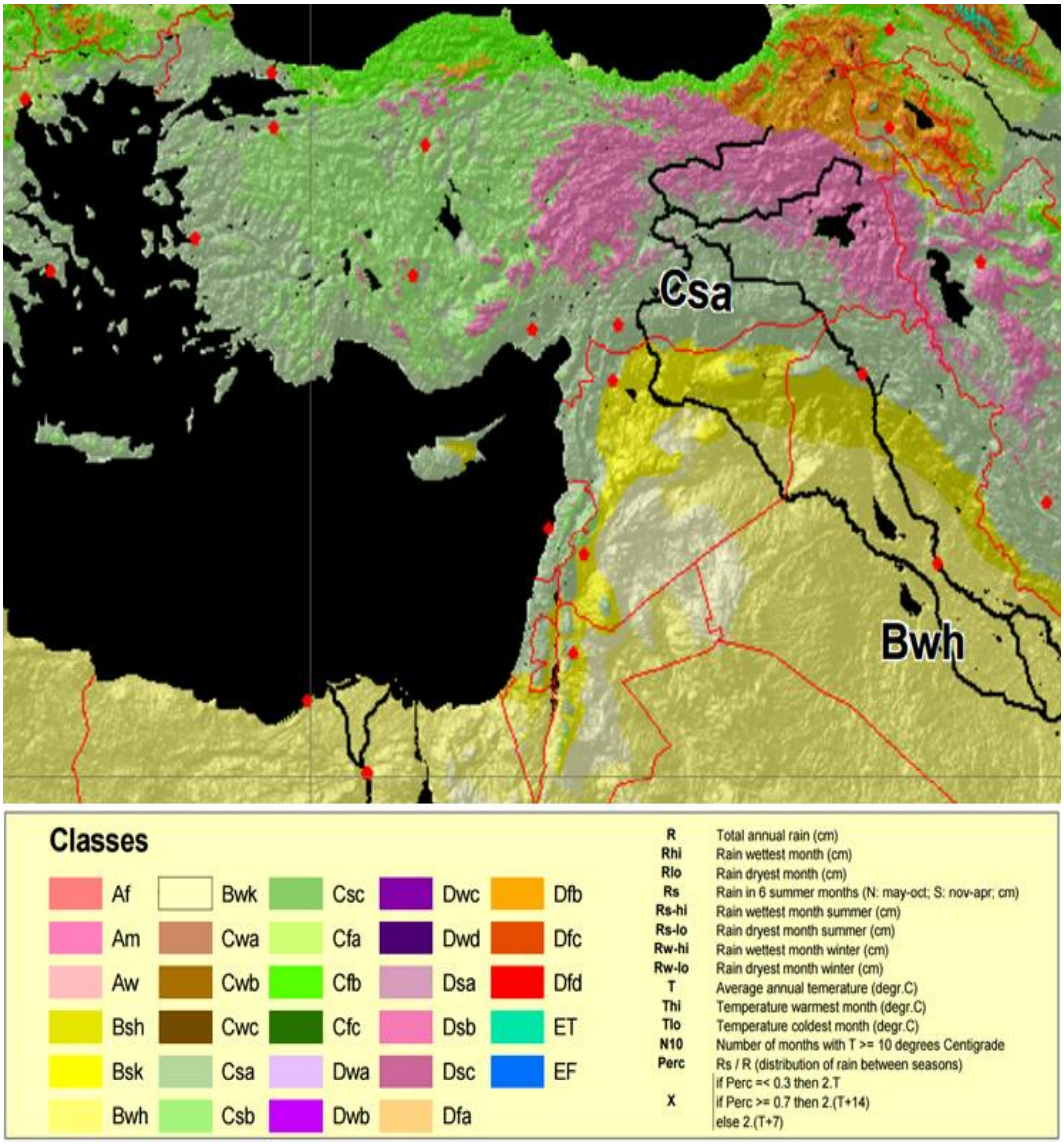


Figure 28. Classification of Climate in Köppen-Geiger System
(ftp://ftp.itc.nl/pub/debie/Koppen-Geiger%20Map2.pdf 2017)

In Famagusta, total rainfall is (403.5 mm) annually or (33.6 mm) monthly. July with an average of (0.5 mm) is the driest month. On the other hand, December with an average of (106 mm) is the wettest month.

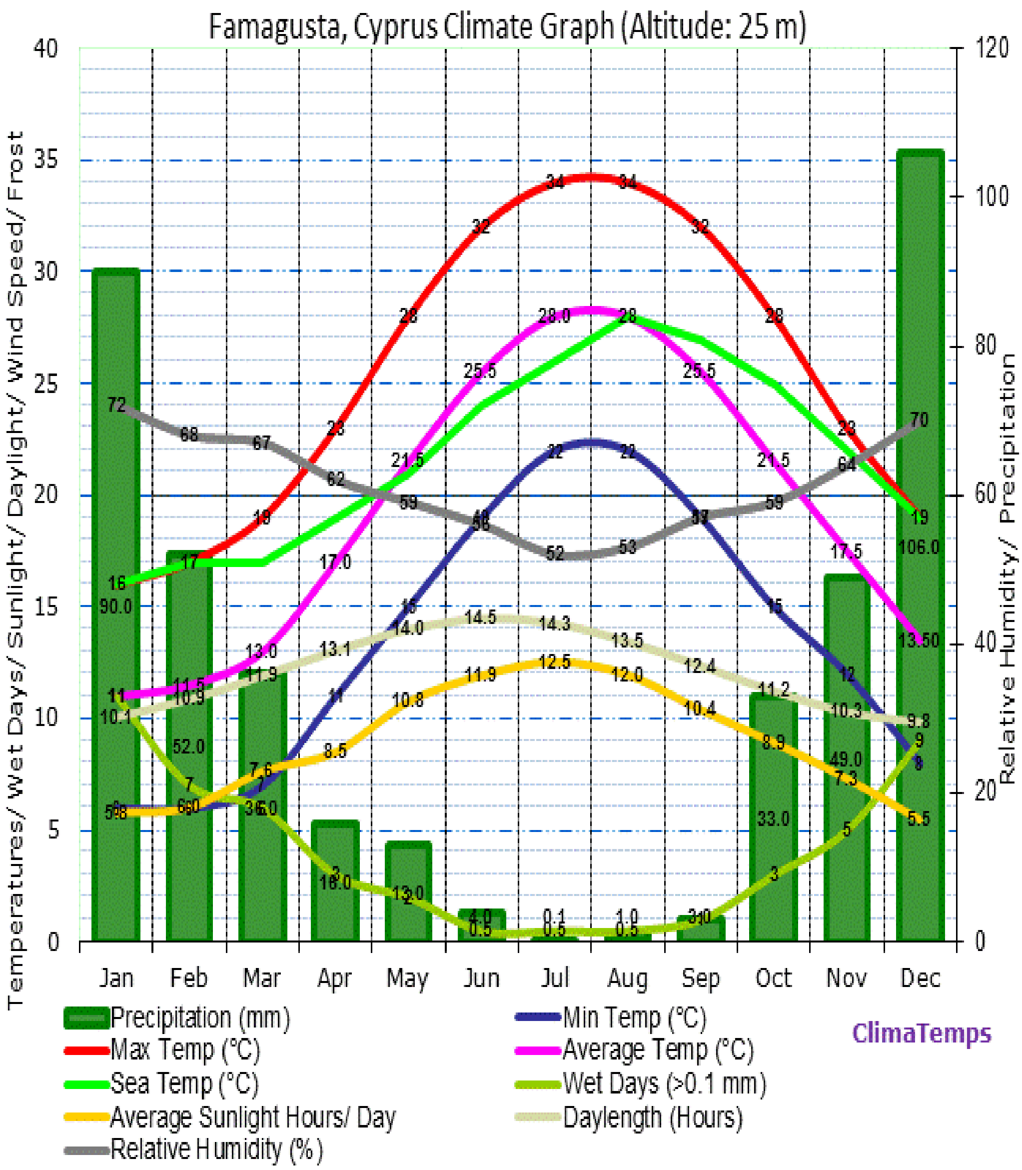


Figure 29. Famagusta Climate & Temperature (http://www.famagusta.climatemps.com/)

In December, duration of sunlight hours is 9:37 averagely, while is rise till 14:22 in July. The difference between the shortest and longest days is 4:44 hours. Potentially, Famagusta has 4383 sunlight hours but 24% of this amount wastes during cloudy, hazy and foggy days. There is just 3331 sunny hours. The solar altitude averagely is 55.2° in 21st of March at noon while it decreases until 32° in 21st of December, and rise at 72° in 21st of June.

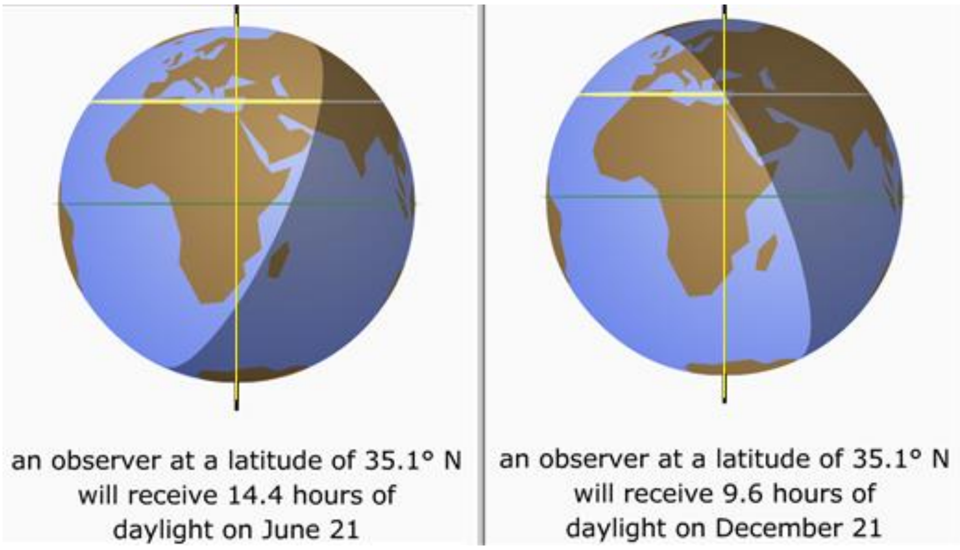


Figure 30. Daylight in Famagusta (http://astro.unl.edu n.d n.d.)

3.5 Analysis of GIS Data in Famagusta

The importance of land cover in the reflection rate of solar energy requires a consistent analysis on the land cover types and portions taking place on urban islands. Therefore, the distribution of the land use/cover within Famagusta region is analyzed. Then, the albedo constant in Famagusta is computed according to the GIS data and proportion of different materials and colors used in urban land cover.

3.5.1 Land Cover Analyses of Famagusta Region by GIS Data

Land cover is important factor in analysis of solar urban process. It is a main feature of urbanization. Institutional and demographic decisions may cause its quality. Urbanization is the most crucial process that impacts whole land area. Its sequences get more highlighted especially in places with limited physical extends (Bahrain, 2003). To analyze solar energy in an area, its cover and type of uses are necessary because they have different reaction against solar radiation. The land cover distribution of Famagusta region is presented as follows:

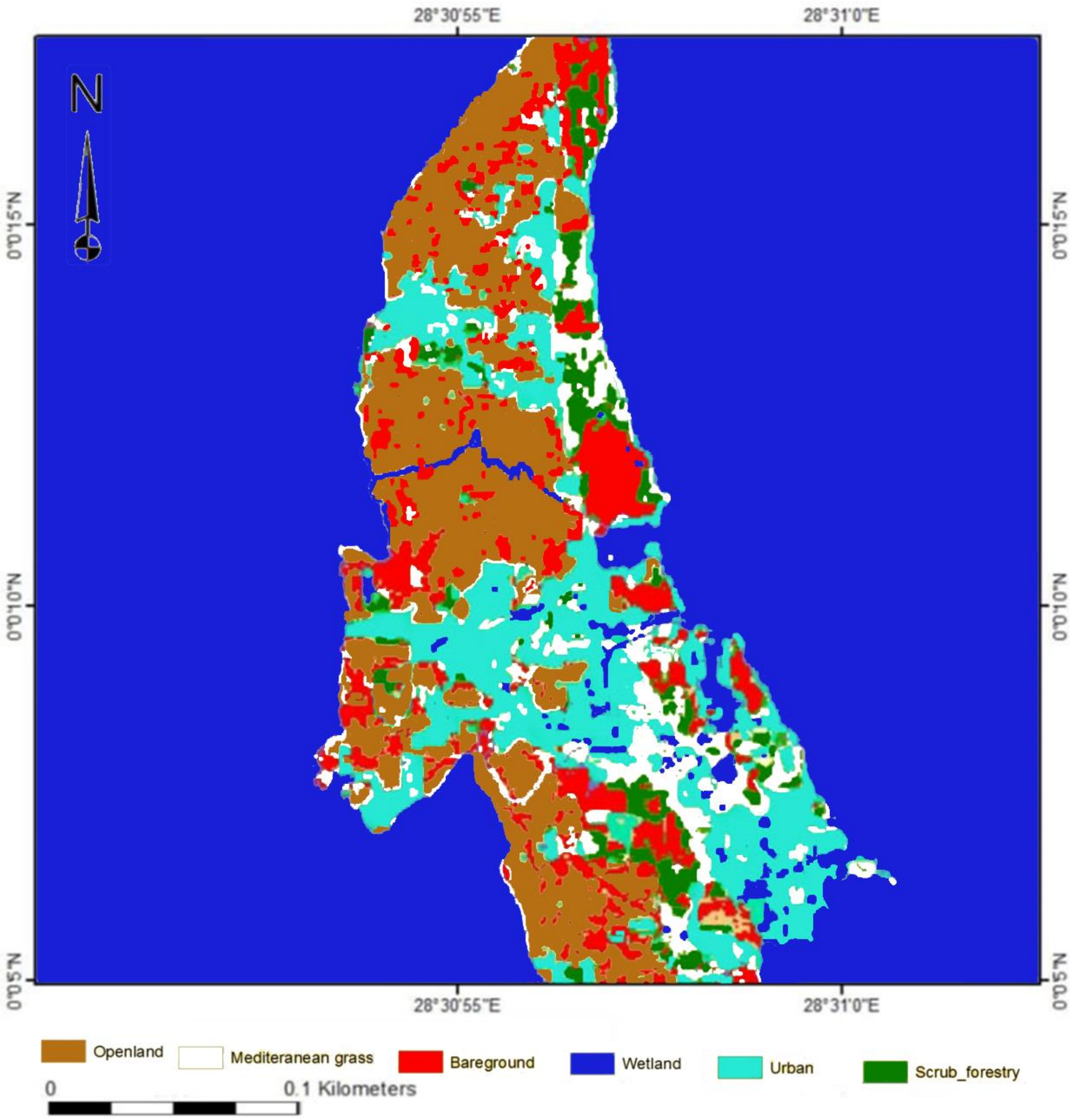


Figure 31. Land Use- Cover State of Famagusta Region after 2012 (Yetunde 2014), (Developed by author 2017)

According to the above-mentioned data, the rate of urban areas in Famagusta region is 661.7474 hectares. It includes of 11.5% of the total lands. The forest areas are 1193.447 ha which are 22% of the total areas.

The bare land is 901.1273 ha or 16 %, wetland area is 880.41 ha means around 16%. Accountancy of Mediterranean grass shows 20.69% (1298.751ha) of total areas.

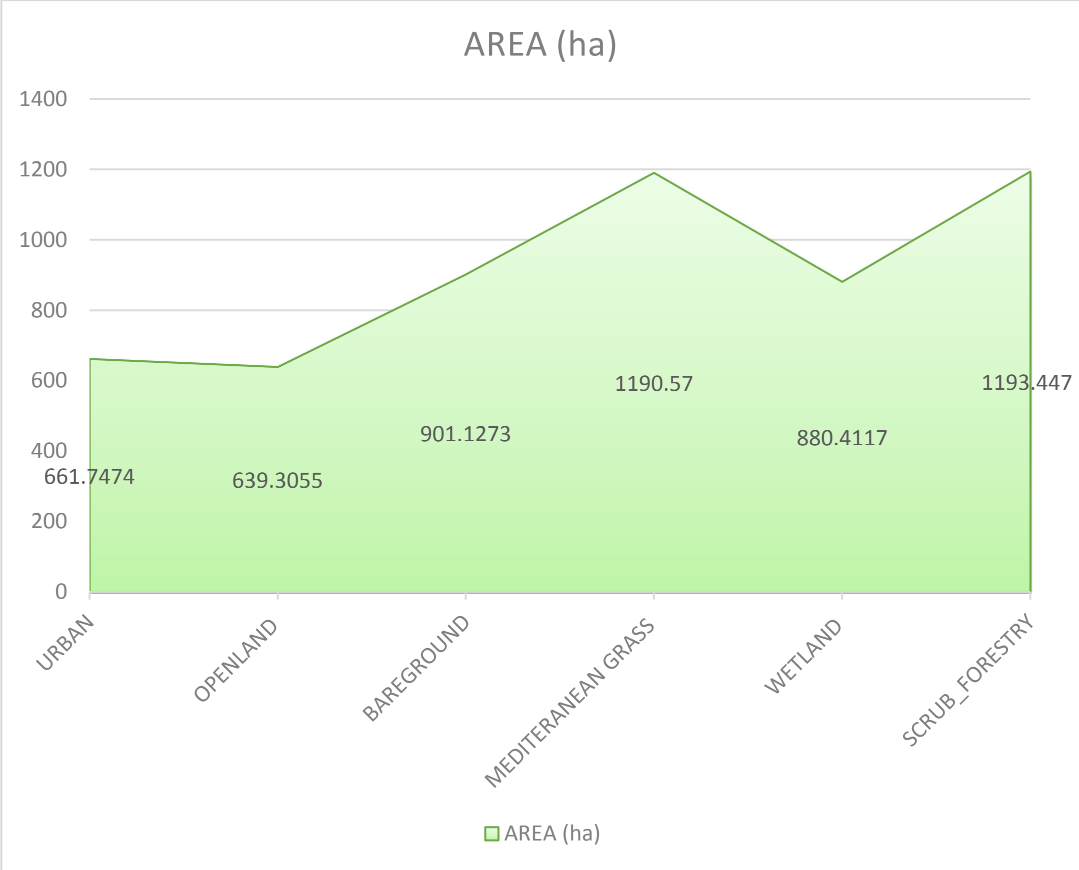


Figure 32. Different Areas of Land Use- Cover State of Famagusta after 2012

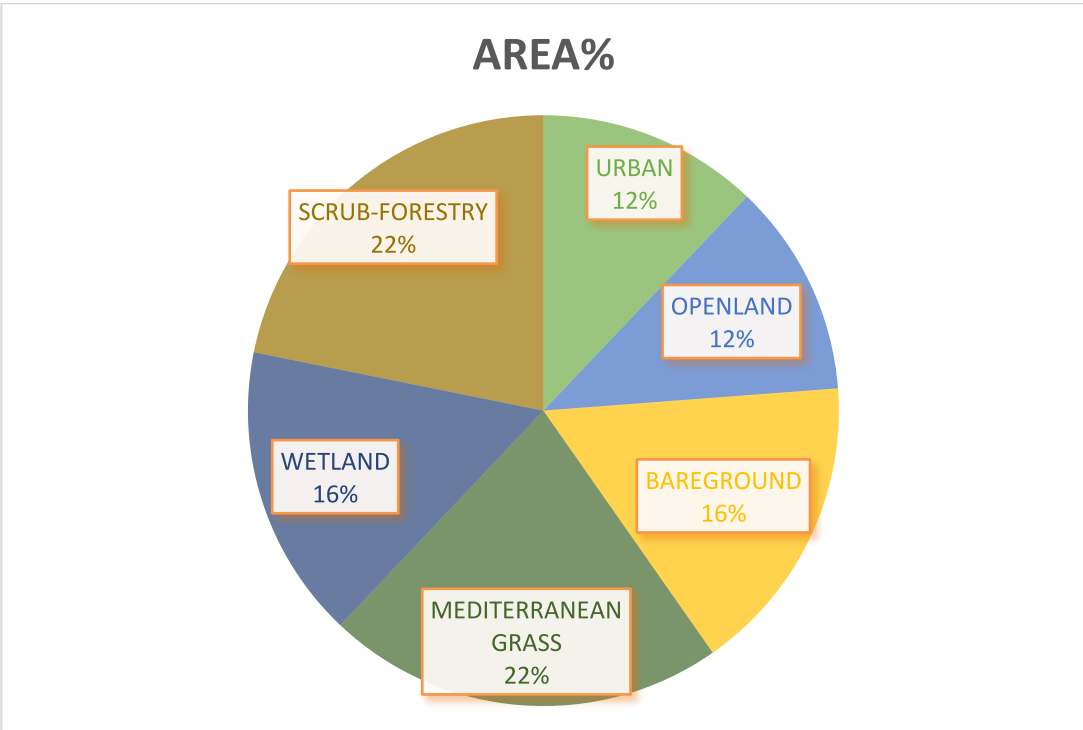


Figure 33. The Land Cover Portions of Famagusta after 2012 (by author 2017)

3.5.2 The Rate of Albedo in Famagusta

Albedo or reflectivity of different surfaces depends of the rate surface area and value. The amount of different land areas is estimated using GIS data for Famagusta region. However, the reflectivity of different surfaces is according to (Oke, 1973) and (Ahrens, 2006) as follows:

Table 8. Average Albedo Value of Land Covers in Famagusta Region (by author 2017)

Cover Types	Albedo Coefficient	Covered Area	Albedo Portion
Mediterranean Greenery	0.26	22%	5.7%
Open Land (Light Soil and Grass)	0.45	12%	5.4%
Bare Ground (light and wet)	0.22	16%	3.5%
Wetland (in average temperature of (23◦c)	0.1	16%	1.6%
Scrub forest	0.2	22%	4.4%
Urban (stone and metals with light color and low density)	0.15	12%	1.8%
Average Constant for Famagusta	-	100%	**22.4%**

It should be noted, the above portion of albedo (0.22) is estimated for urban scale of Famagusta by measuring of the area of the cover types and their special coefficients.

Therefore, it will be needed to focus on micro scale of environmental factors for each building. The rate of albedo in different districts of the city is different. Subsequently, the portion of each type of covers is presented in the same table.

Whereas, the rate of reflectivity varies between 0.2 and 0.5, the lower rate of albedo in Famagusta (0.22) helps citizens to feel the urban spaces more comfortable.

3.6 Solar Energy in Famagusta

3.6.1 Solar Geometry through Sky of Famagusta

To know the position of sun, it is enough to show the azimuth angle (Z) and attitude/ radiation angle (β) depends on observer (Famagusta in this thesis).

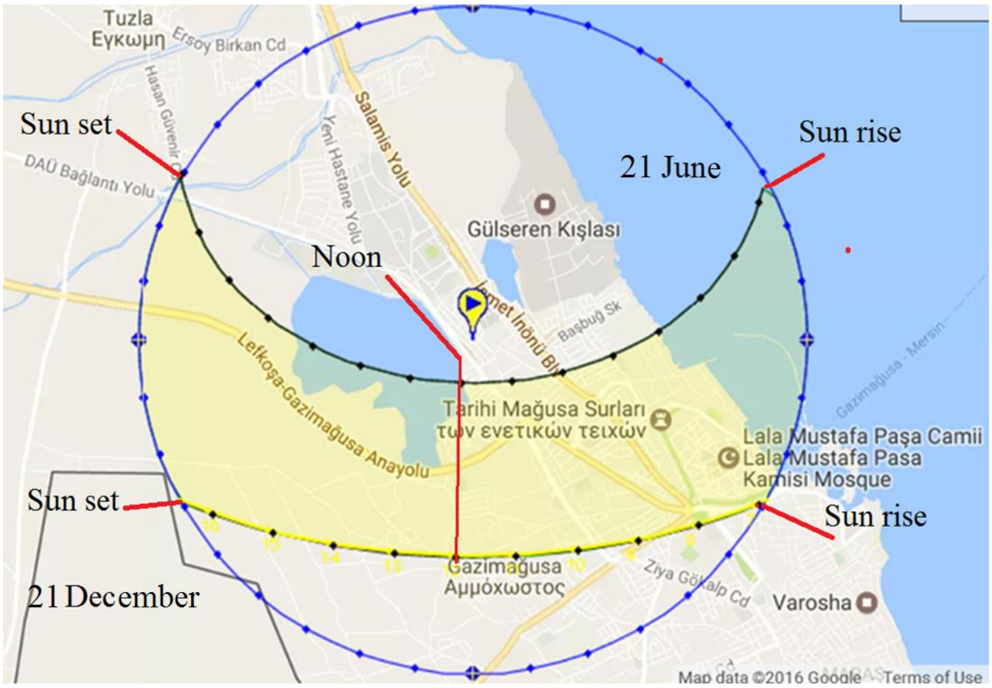


Figure 34. Solar Geometry through Sky of Famagusta (by author 2017)

The altitude and azimuth angles of Famagusta are presented in figure 35, and figure 36, respectively. The data are computed for March 21-22 (spring equinox), December 21-22 (winter solstice), September 22-23 (Autumn equinox) and June 21-22 (summer solstice) as follows:

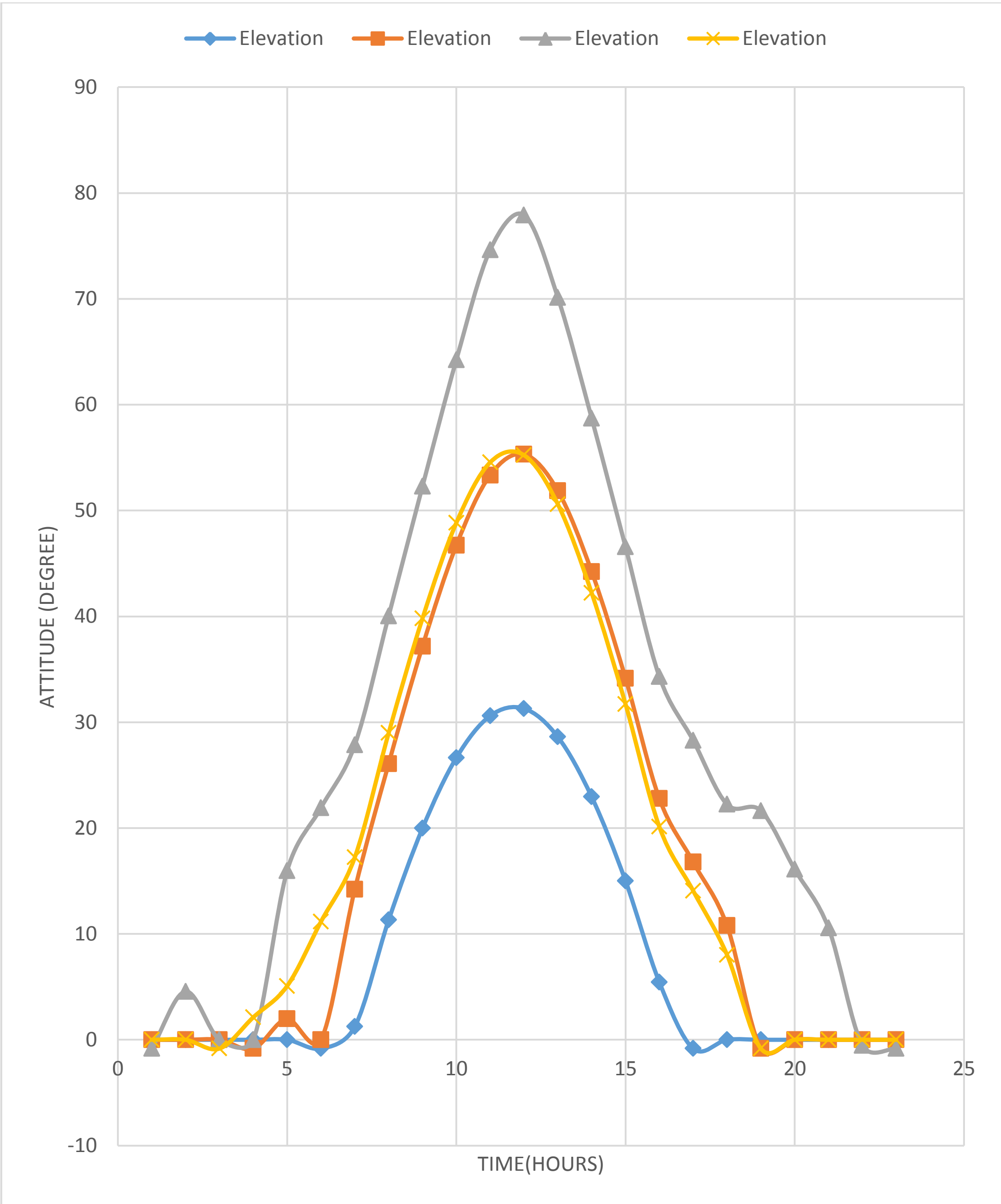


Figure 35. Solar Altitude through Sky of Famagusta (by author 2017)

The solar altitude averagely is 55.2º in March 21 at noon while it decreases until 32º in December 21, and rise at 72º in June 21. Also, the solar azimuth angle at sunrise is 90º in March 21 at 6:00 while it decreases until 61º in June 21, and rise at 129º in December 21.

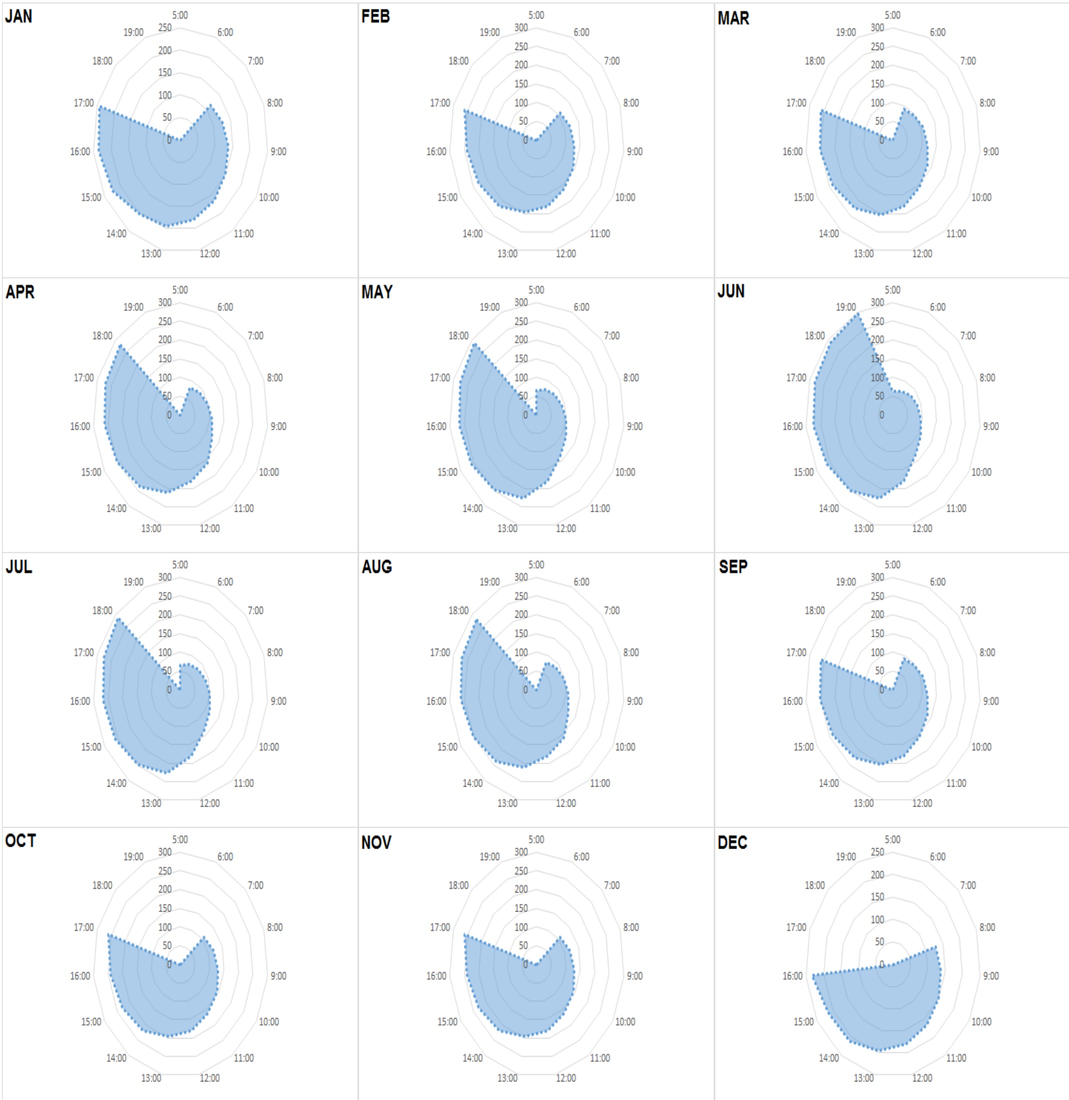


Figure 36. Solar Azimuth Angles of Famagusta (by author 2017)

3.6.2 Irradiation

There are a lot of methods to consider solar irradiation. In this thesis, Ladybug for Grasshopper in Rhino software program will be used for sun path analysis for simulating solar irradiation for Famagusta. On the other hand, Stephenson's cousin method is implemented to model vertical surfaces including façades using Microsoft Excel (Sen, 2008).

3.6.2.1 Sun Path Analysis in Ladybug

Ladybug for Grasshopper in Rhino is an application to analysis sun-path based on Python programming. It considers solar vectors to analyze shading and sun light hours.

The diagram shows changes in direct normal radiation rates in Famagusta locating on 35.1 degrees between sun rise and sun set, for all days of the year.

Direct normal radiation is the amount of solar radiation received per unit area by a surface that is always held perpendicular (or normal) to the rays that come in a straight line from the direction of the sun at its current position in the sky.

Diffused sky radiation is the amount of radiation received per unit area by a surface that does not arrive on a direct path from the sun, but has been scattered by molecules and particles in the atmosphere.

Global horizontal radiation is the total amount of shortwave radiation received from above by a surface horizontal to the ground. It includes both direct normal radiation and diffused horizontal radiation.

Regarding to the details, the most shining time of the day is around noon. In Famagusta where is located on 35.1 degrees in northern hemisphere, high rate of solar energy radiates between 150 degrees and 210 degrees. The rate of radiation differs depending on each month. The hourly direct normal radiation picks up to the highest rate 919 Wh/m^2 when the diffused horizontal radiation arrives 532 Wh/m^2. Also, the maximum hourly global horizontal radiation is 996 Wh/m^2 (Figure 37, 38, 39). Overall, the sun path diagram illustrates that the rate of diffusion is noticeable in cold times, and in the early morning and early evening periods.

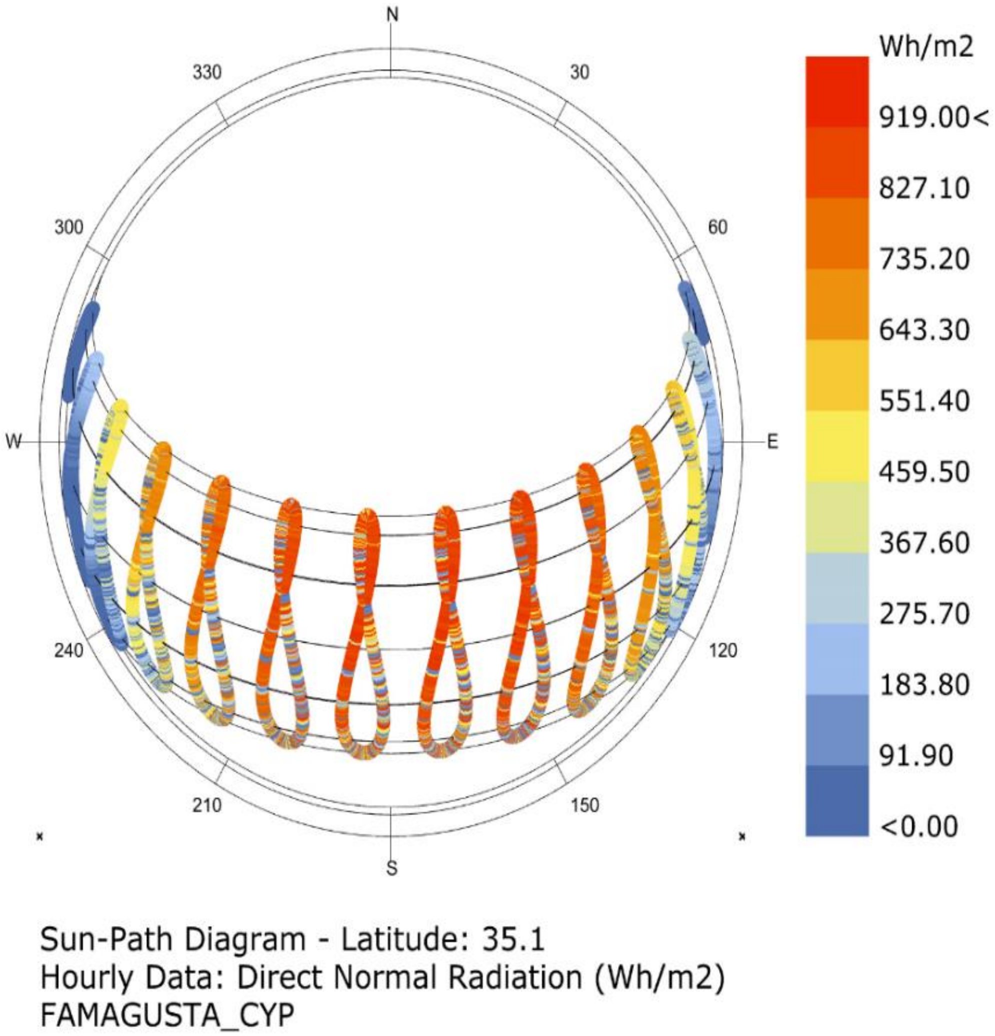


Figure 37. Hourly Direct Normal Radiation (by author using Rhino program 2017)

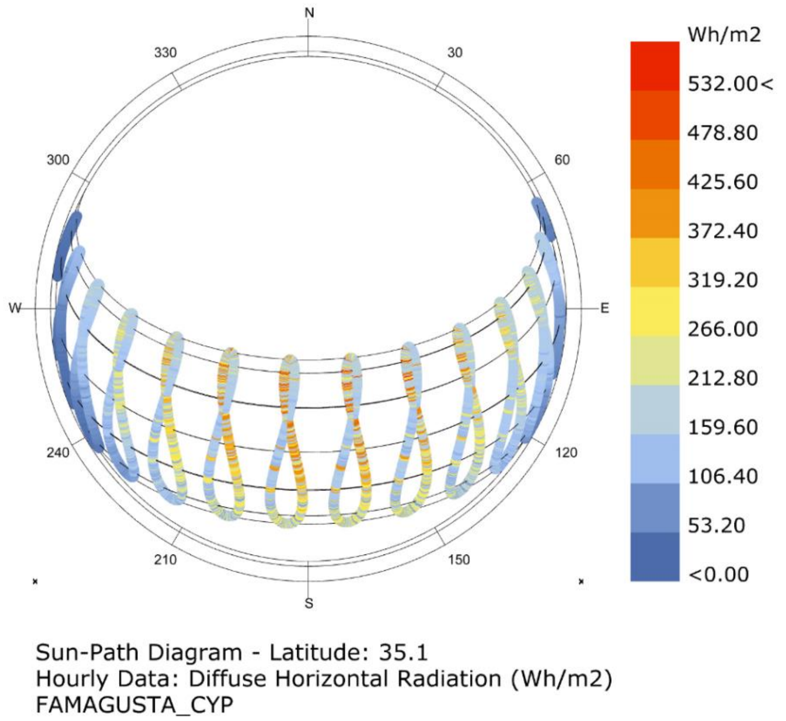


Figure 38. Hourly Diffused Horizontal Radiation (by author using Rhino program 2017)

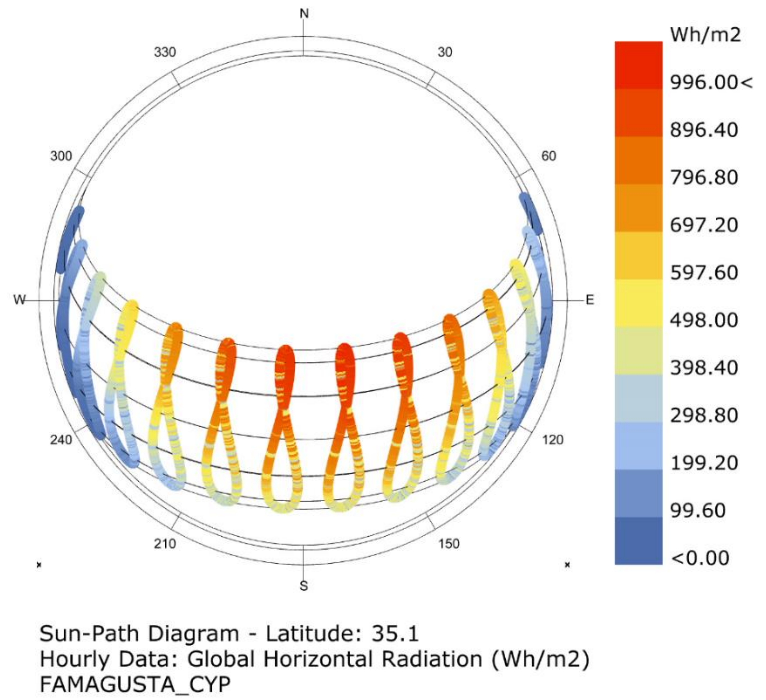


Figure 39. Hourly Global Horizontal Radiation (by author using Rhino program 2017)

On the other hand, solar tracking in Ladybug made it possible to estimate annual radiation for Famagusta. Also, the solar potential of different aspects exposing on sun beam directs are estimated using Ladybug in Rhino. The unit of energy is estimated in kwh/m^2 from 1 Jan 01:00 to 31 Dec 24:00.

From the sun path diagram, which tracked in Famagusta using Ladybug, there is no radiation on northwest-northeast aspect between 300 degrees and 60 degrees. Northeast-southeast aspects (between 60 degrees and 120 degrees) and southwest-northwest ones (between 240 degrees and 300 degrees) obtain a range of total radiation from 560.86 kwh/m^2 to 897.38 kwh/m^2. Southeast-southwest (between 120 degrees and 240 degrees) absorb a range of radiational energy from 1009.55 up to 1121.72 kwh/m^2. The annual diffusion varies between 347.52 kwh/m^2 and 417.02 kwh/m^2.

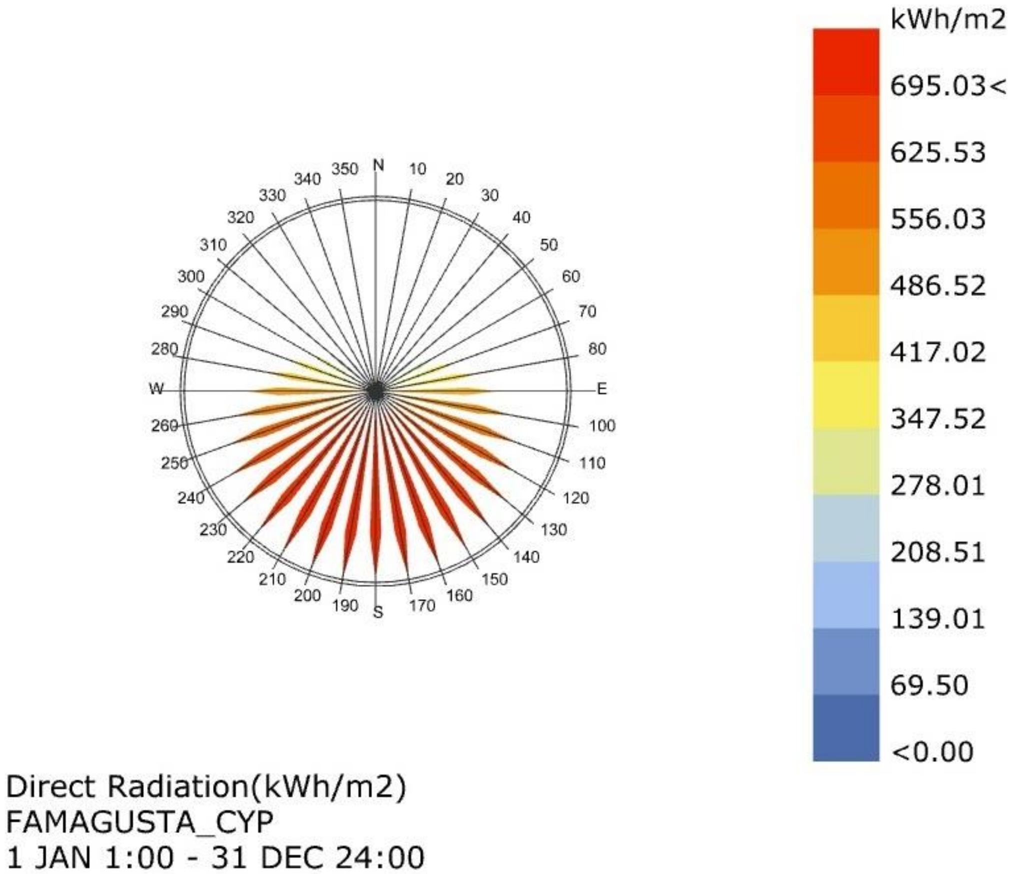


Figure 40. Direct Radiation (by author using Rhino program 2017)

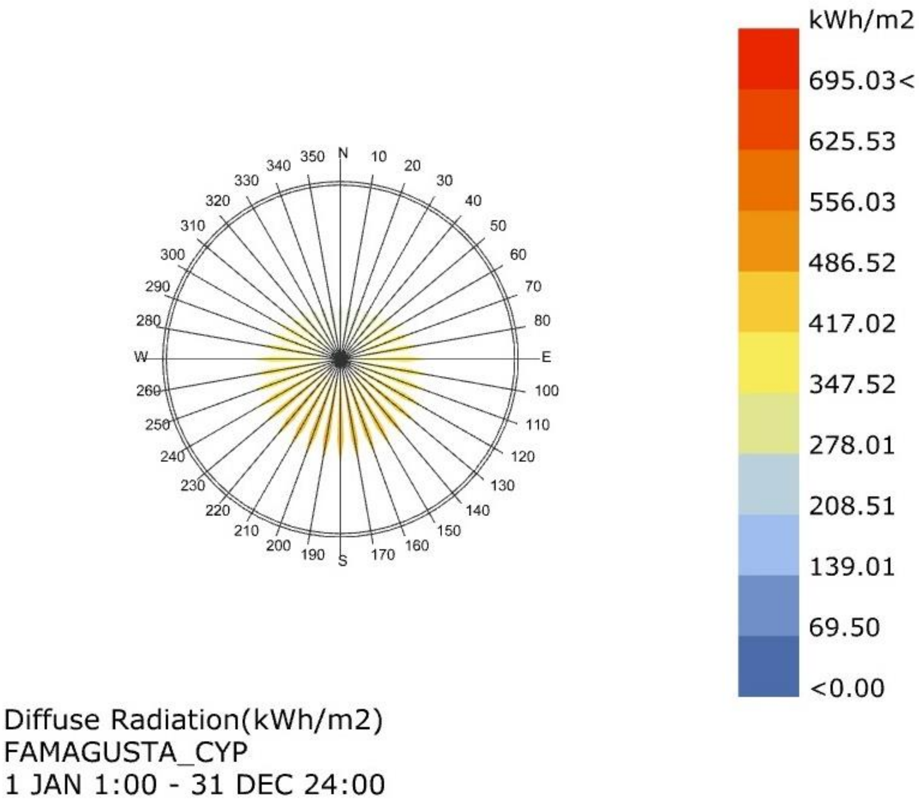


Figure 41. Diffuse Radiation (by author using Rhino Program 2017)

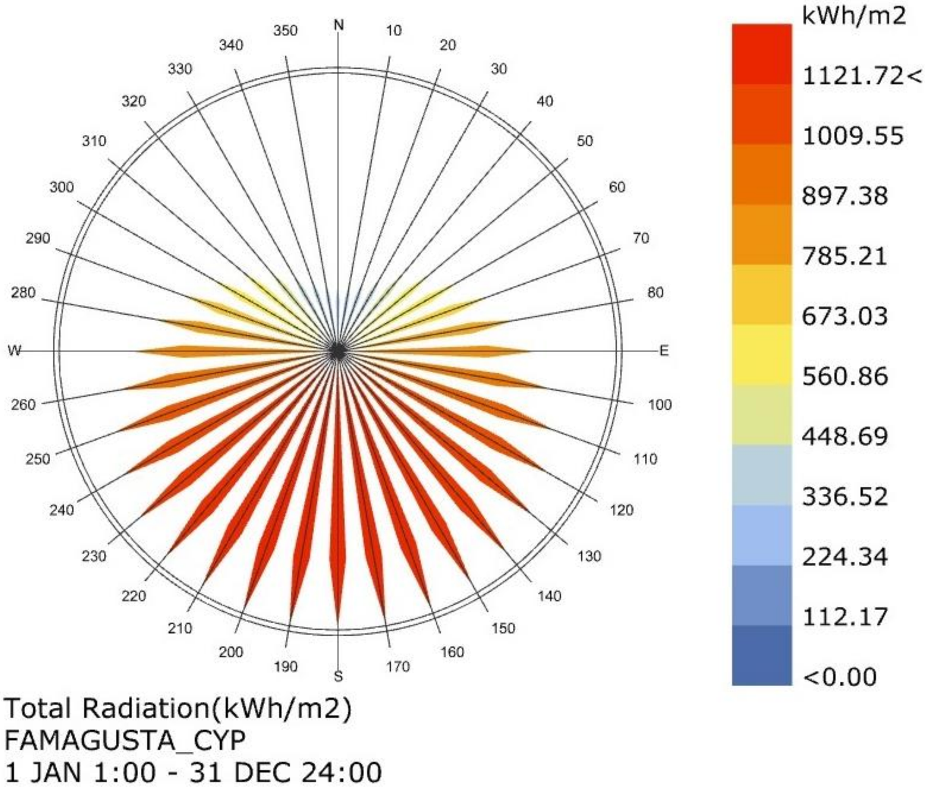


Figure 42. Total Radiation (by author using Rhino Program 2017)

3.6.2.2 Stephenson's Cousin Method in Vertical Surfaces

Stephenson cousin method is used to consider solar energy of vertical surfaces. The most important factor is crosses angle (θ) between the intensity of the direct beam and façades as follows:

$$I_{vs} = I_h . \text{Cos}\,\theta$$

$$\text{Cos}\,\theta = \text{Cos}\beta . \text{Cos}(\text{Z} - Z^{`})$$

$$\beta = \sin^{-1}(\sin(\varphi). \sin(\delta) + \cos(\varphi). \cos(\delta). \cos(\omega))$$

The azimuth angle of the Sun (Z) is different than ($Z^{`}$). The azimuth of the façades is presented by ($Z^{`}$). The azimuth angle of façades is based on degree that the north equals with zero (0 degree). (β) is the attitude/radiation angle of the Sun that varies according to latitude (φ), declination angle (δ) and solar time angle (ω).

The solar energy of vertical surfaces is computed for winter solstices (21 December), summer solstice (21 June), without any orientation (vertical walls). In this process, all the climatic and geographic factors such as altitude, latitude, sky clearness have been considered. Figures 43, 44, 45 present the solar energy on different surfaces in Famagusta per hour as follows:

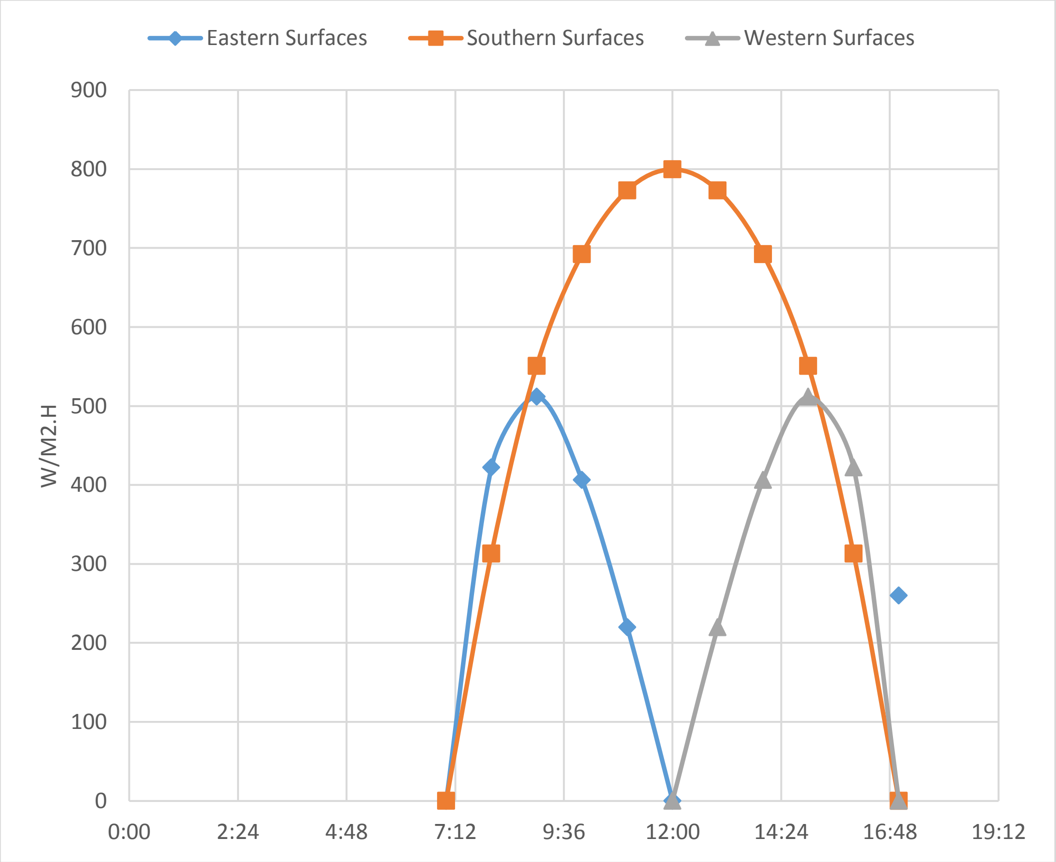


Figure 43. Solar Irradiation on Vertical Surfaces in Famagusta in 21 December (W/m2h) (by author 2017)

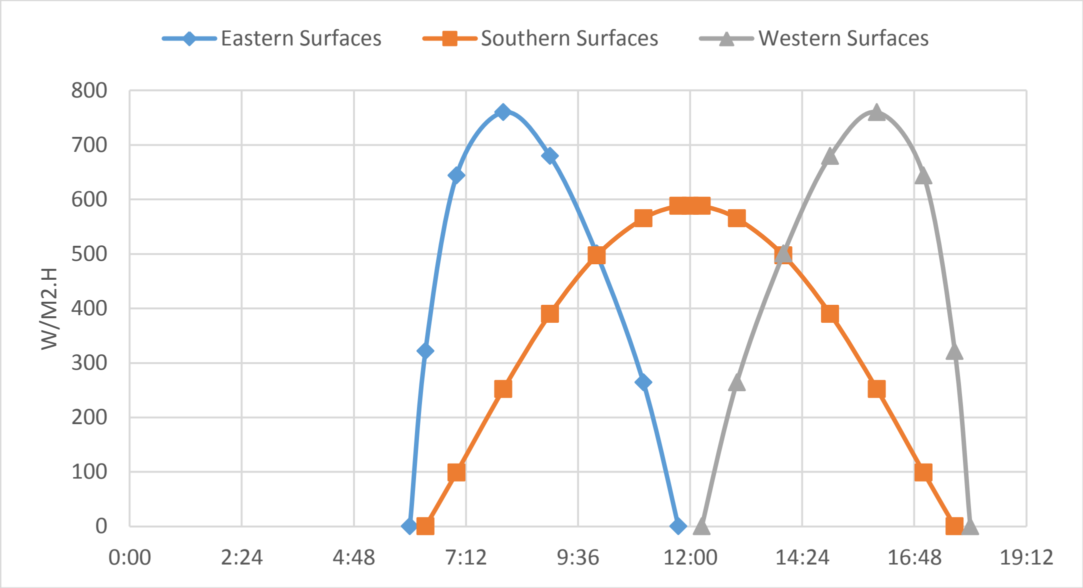


Figure 44. Solar Irradiation on Vertical Surfaces in Famagusta in 21 March (W/m2h)

(by author 2017)

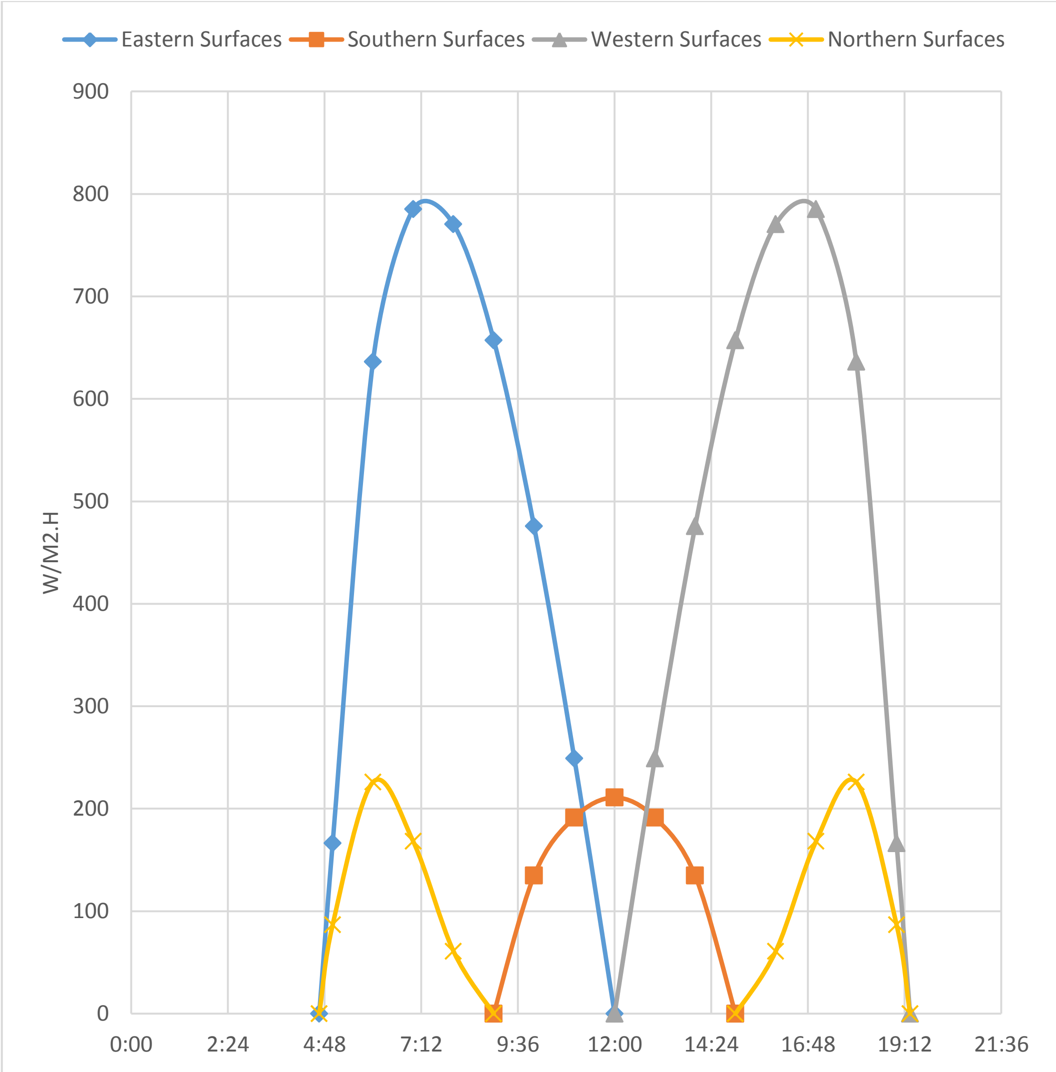


Figure 45. Irradiation of Solar Energy on Vertical Surfaces in Famagusta in 21 June (W/m2h) (by author 2017)

3.7 Street Space Analysis of the Case Studies in Famagusta

As it is clear, the quality of street spaces effects human actives. Therefore, an analysis has been carried out on two streets in Famagusta. The selection reason of these streets is their opposite orientation which represent majority of streets locating in Famagusta.

One example is the Konak street of social housing complex that located beside Eastern Mediterranean University in Sakarya district along to the Gazi Mustafa

Kemal Boulevard. Another example is Cahit street in Gülseren street perpendicular to the İsmet İnönü Boulevard (Figure 49).

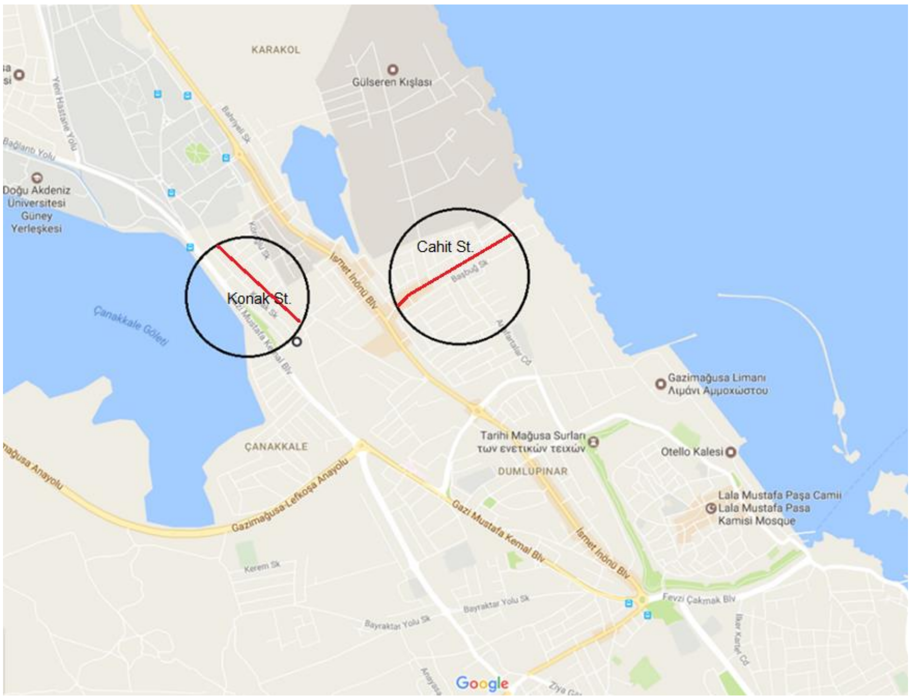


Figure 46. Location of Case Studies in Famagusta (Google maps 2017)

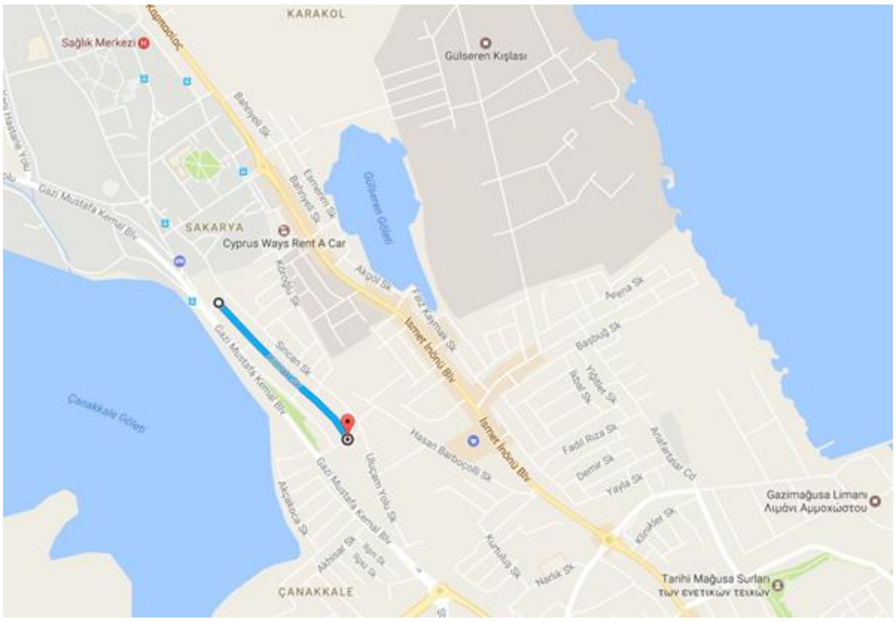


Figure 47. Location of Konak Street in Social Housing Complex in Famagusta (Google maps 2017)

Figure 48. Konak Street in Sakarya District (A. Anarjani 2013)

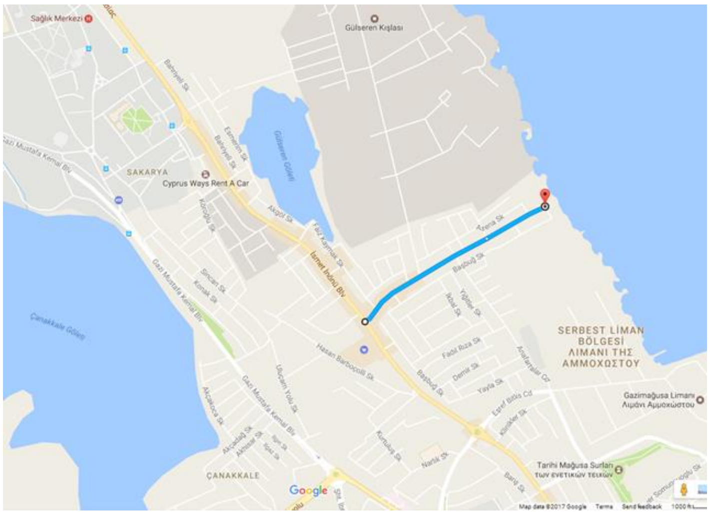


Figure 49. Location of Cahit Street in Gülseren District - Famagusta (Google maps 2017)

Figure 50. Cahit Street in Gülseren District - Famagusta (by author 2017)

3.7.1 Orientation Analysis

The orientation rose of the district such as Konak street implies to southeast-northwest direct which expose southwest-northeast façade orientation (figure 51). In this part, the street and blocks have been considered according to orientation angle to evaluate their solar performance and street space discomfort.

The accordance or variance of the block`s angle is checked with street angle (Figure 51). The street is oriented by 47 degrees from the southern direct (Figure 52).

Figure 51. Orientation of Konak Street in Social Housing Complex in Famagusta (by author using google maps 2017)

Figure 52. Orientation of Konak Street in Social Housing Complex in Famagusta
(by author using google-maps)

A circular distribution (0 to 360 degree) which shows distribution of variable values of street angles, presented for Konak street using Ladybug for Grasshopper in Rhino and Google map as follows:

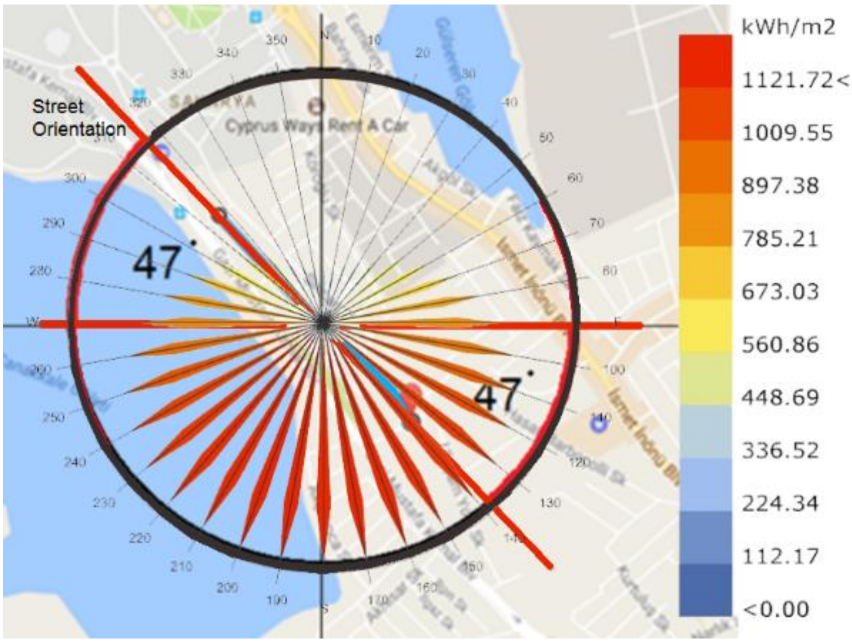


Figure 53. Total Radiation and Direct Radiation of Konak Street
(by author using Rhino Program and google maps 2017)

On the other hand, Cahit street is orientated in northeast-southwest direct (figure 54). The street and blocks have been considered according to orientation angle to evaluate their solar performance and street space discomfort. The street is oriented by 27 degrees from the southern direct toward east (Figure 55).


Figure 54. Orientation of Cahit Street in Famagusta (by author using google maps 2017

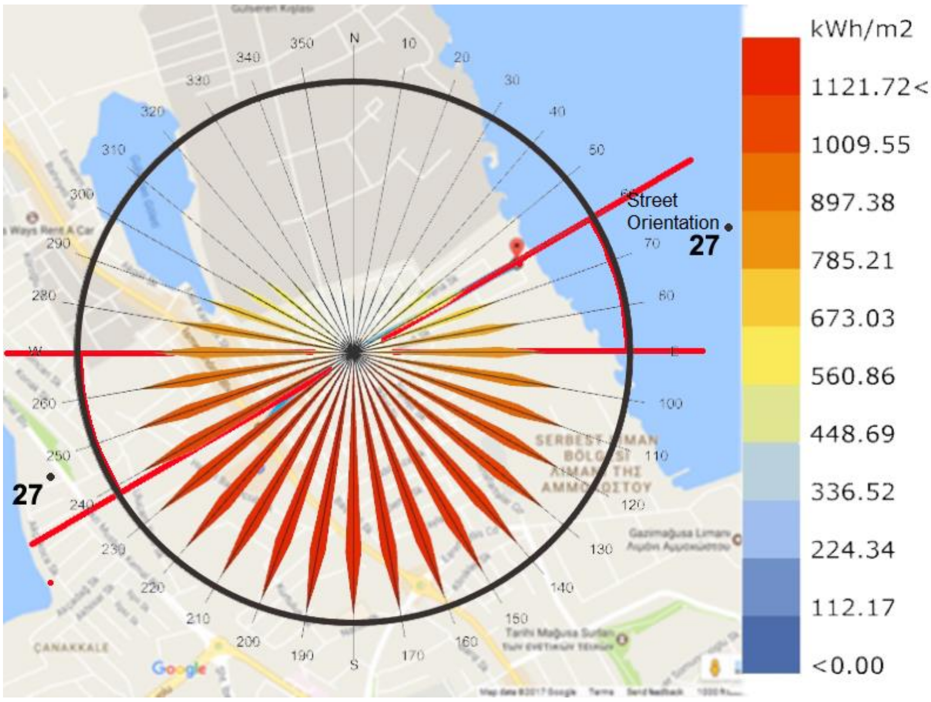


Figure 55. Total Radiation and Direct Radiation of Cahit Street (by author using Rhino Program and google maps 2017)

3.7.2 Height per Width Ratio

Heat island effect is increasing in cities in the recent years. Therefore, the micro climate should be regarded in micro urban scale. Because, it has a direct relation with human health. There are some effective parameters that have an important influence on the human energy and energy balance like H/W ratio. On the other hand, H/W ratio should provide enough daylight for neighbors.

In this part, the role of block juxtaposition in front of/beside each other has been analyzed. The juxtaposition of the blocks beside each other and azimuth of blocks caused passive solar energy loss from the facades that are important to domesticate of solar energy. Also, it is the main problem of daylight in neighborhoods. On the other hand, H/W ratio effects air circulation. So, it is effective on street thermal comfort/discomfort.

In Konak street in Sakarya district, the width of the street is 14 meters. The height of buildings is 9 meters. So, the height/width ratio in Konak street is 9/14 meters which equals with 0.64 as shown in figure 57.

On the other hand, in Cahit street, the height of buildings is around 10 meters, and the street width is 14 meters. Therefore, the height/width ratio in Cahit street is 10/14 meters which equals with 0.71 (Figure 59).


Figure 56. Konak Street in Sakarya (Baytin 2005)

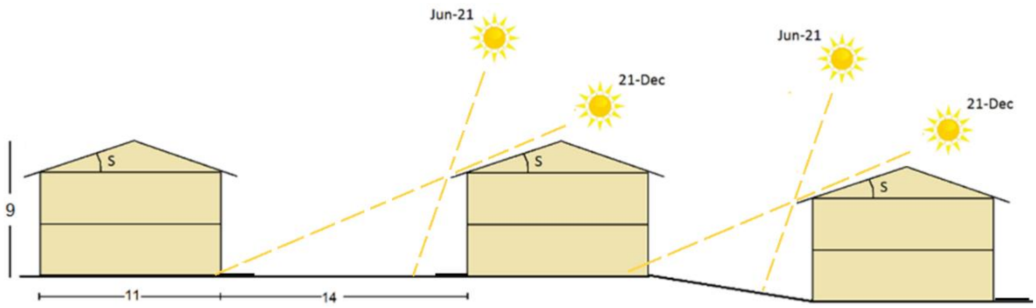


Figure 57. The Height/Width Ratio in Konak Street (by author 2017)

Figure 58. Cahit Street in Gülseren (by author 2017)

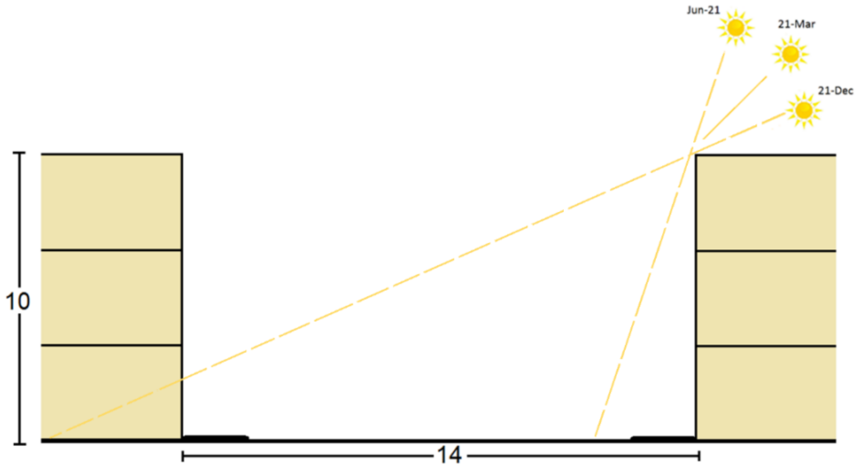


Figure 59. The Height/Width Ratio in Cahit Street (by author 2017)

3.7.3 Landscape Analysis of Selected Streets in Famagusta

In this part, landscape (the quality of plantings and pavements) will be analyzed using field survey and photos.

3.7.3.1 Greenery Analysis of Selected Streets in Famagusta

Figure 60 and 61, show the greenery situation of Konak street and Cahit street. As it can be seen in the figures, trees are planted in private spaces rather than on street space.

They effect the street quality visually, but they don’t work as natural solar shading element in street space as well. Also, furniture is not applied as well (Figure 60 and 61).

On the other hand, the type and quality of materials are important factors effecting the landscape. Materials with high rate of reflectance should be chosen in side walk (Takebayashi, 2015). Because, the reflectance is directly impacting the heat storage capacity of materials and the human health.

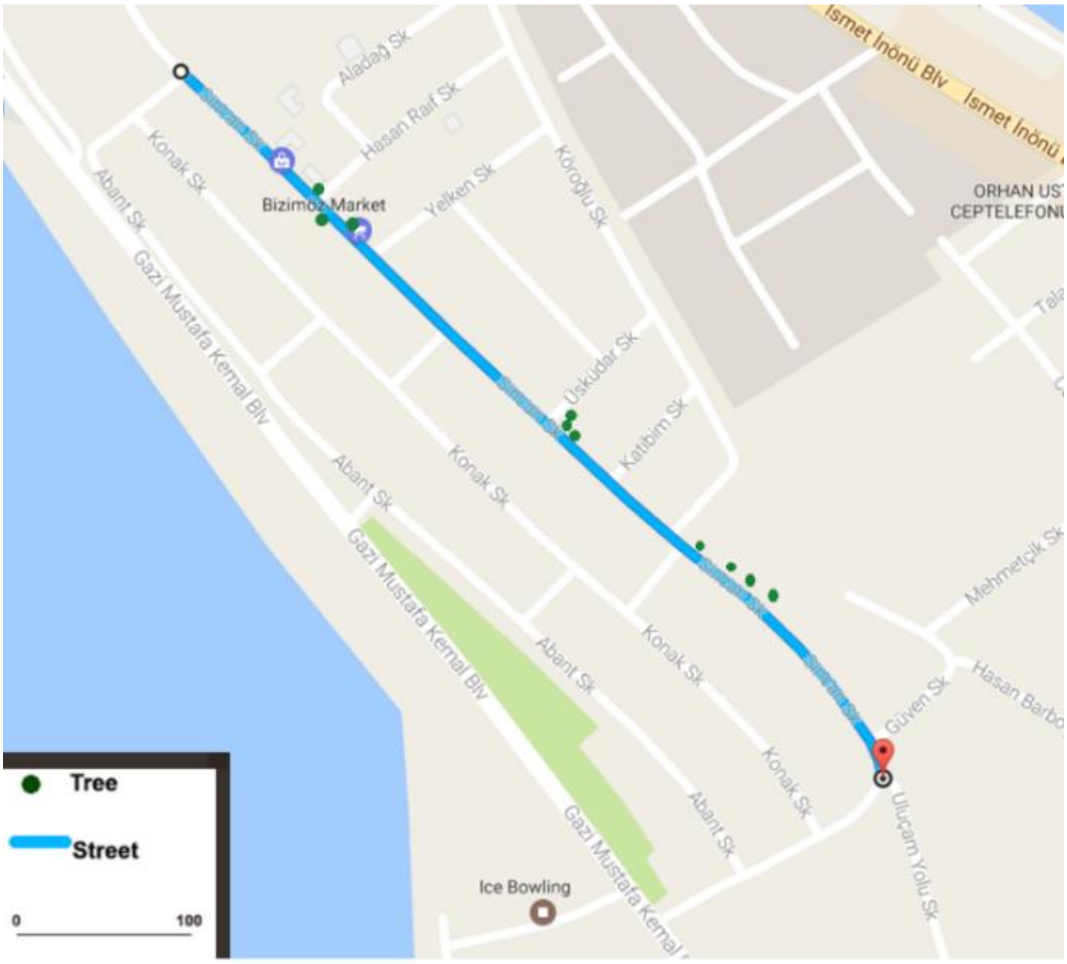


Figure 60. Landscape of Konak Street (by author 2017)

Figure 61. Konak Street (by author 2017)

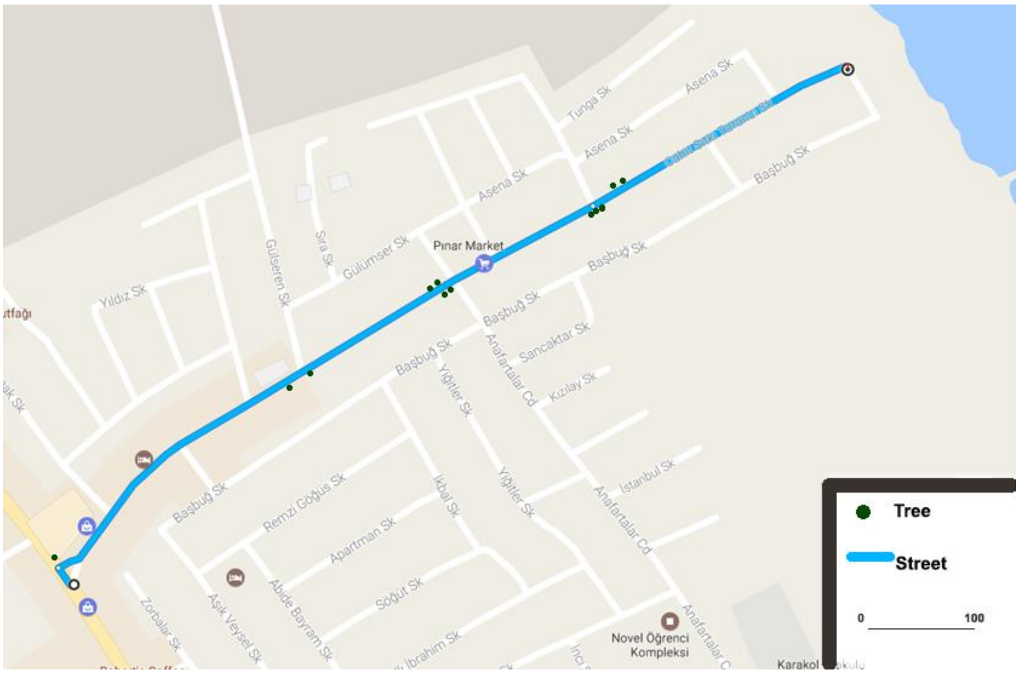


Figure 62. Lanscape of Cahit Street (by author 2017)

Figure 63. Cahit Street (by author 2017)

3.7.4 Shading Analysis of Selected Streets in Famagusta

Shading is another important factor in solar street space. Shadow impacts the walking period especially in hot climates (Almeida , 2006). Despite of inappropriate landscape, there is a shading problem in both Konak street and Cahit street. There is not any element to provide shadow in the street (Figure 62). Plants, trees and greeneries are used for buildings where the street spaces are very poor. In Cahit street, trees are planted randomly that blocks the sidewalks (Figure 63).


Figure 64. Lack of Elements to Provide Shadow in Konak Street (by author 2017)


Figure 65. Lack of Elements to Provide Shadow in Cahit Street (by author 2017)

Chapter 4

RESULTS OF ANALYSIS

4.1 Results of Orientation Analysis

Whereas, the main façade of blocks is usually perpendicular to the street direct, therefore, the street orientation impacts solar performance of the blocks. Then, a part of absorbed solar energy radiates from the blocks toward street spaces that causes the increase of street temperature and thermal discomfort.

In Konak street, main aspects of the blocks are orientated 47 degree toward southwest which cause the increase of solar absorption at afternoon. The street gets exposed on the sun between 137 degree and 313 degree. Subsequently, street temperature is high at afternoons. On the other hand, Cahit street is orientated 27 degree toward northeast which cause rising temperature in the mornings. From thermal comfort point of view, the Konak street has discomfort in summer afternoons, and Cahit street is not comfortable at mornings. The street gets exposed on the sun between 63 degree and 153 degree. In contrast, the street orientation provides a comfort space for public activities for Konak street in winter afternoons, and for Cahit street in winter mornings.

Table 9. Orientation Issues of Konak Street (by author 2017)

Orientation Direct	**Street Maximum Radiation**	**Façade Maximum Radiation**	**Exposed Range (Degree)**	**Discomfort Time**	**Comfort Time**
Southeast-Northwest -47 degree	1121 Wh/m^2 From 180 degree at noon	750 Wh/m^2 From Southwest (14:00-17:00)	137 - 313 degree	Summer-afternoon	Winter-afternoon

Table 10. Orientation Issues of Cahit Street (by author 2017)

Orientation Direct	**Street Maximum Radiation**	**Façade Maximum Radiation**	**Exposed Range (Degree)**	**Discomfort Time**	**Comfort Time**
Northeast-Southwest 27 degree	1121 Wh/m^2 from180 degree at noon	800 Wh/m^2 From Northeast (09:00-11:00)	63-153 degree	Summer-morning	Winter-morning

4.2 Results of Height per Width Ratio Analysis

The (H/W)/ aspect ratio is effective on the microclimate. Block height and their juxtaposition in front of/beside each other define the H/W ratio. Horizontal surfaces like streets and roofs are more exposed on the solar radiation than vertical surfaces. Therefore, the street surface exposure depends on (H/W) ratio or canyon's depth (Ali-Toudert, 2006).

The radiation quantity that receives via the canyon surfaces influences the ambient temperature. The impact rate of these surfaces is up to on the thermal performance of the materials like reflectance (albedo). Urban surfaces transmit a part of their absorbed energy into atmosphere. Sensible heat flux is a clear example of transmitted energy through urban surfaces. Regular urban canopy provides healthy daylight in Famagusta city. The H/W ratio analysis in Famagusta streets shows a regular category of canopy as follows:

Table 10. H/W Ratio Analysis of Konak Street (by author 2017)

Block Height (H)	**Street Width (W)**	**Canopy Ratio**	**Category**
9 m	14 m	0.64	Regular

Table 11. H/W Ratio Analysis of Cahit Street (by author 2017)

Block Height (H)	**Street Width (W)**	**Canopy Ratio**	**Category**
10 m	14 m	0.71	Regular

4.3 Results of Landscape Analysis

Inappropriate planting made its landscape poor. Because of its poor landscape, there is not enough elements for shading. Therefore, it is difficult for pedestrians to pave paths especially during summer.

The materials used in pavements are made of concrete and stone. They are effective in mitigation of the urban heat island which impact on reduction of the sensible heat flux that released to the atmosphere by the paving surfaces. High rate of reflection coefficient of concrete and stone with light color is resistant to heat accumulation on roads

On the other hand, the use of existing asphalt with high rate of heat absorption caused the increase of urban heat island. Using permeable paving is effective on reducing the temperature of pavements.

4.3.1 Results of Greenery Analysis

Greenery analysis of Famagusta streets displays a very poor condition. Both of the Konak street and Cahit street have inefficient greenery. Analysis of green area using Google Map shows less than 20% of total green areas for Konak street while the Cahit street includes less than 3% as follows:

Table 12. Greenery Analysis of Konak Street (by author 2017)

Greenery Type	Greenery Area
Mediterranean Greenery/Trees	<20%

Table 13. Greenery Analysis of Cahit Street (by author 2017)

Greenery Type	**Greenery Area**
Mediterranean Greenery/Trees	<3%

4.4 Results of Shading Analysis

Shading analysis of Famagusta streets shows that there is no efficient element to provide shadow. The number of trees is very low. On the other hand, existing trees are planted in inappropriate places. Also, the tall and softwood type of existing trees are not able to provide shadow. It is suggesting to plant short and hardwood trees that concords with climatic conditions of Famagusta city.

4.5 Results of Albedo Value Analysis

According to data given in table 8, the rate of albedo (0.22) is estimated for urban scale of Famagusta by measuring the area of the cover types and their special coefficients. But the rate of albedo varies in both Konak street and Cahit street because their land cover is different. Konak street includes urban materials (asphalt, concrete and stone) with albedo rate of 0.26, and a few of Mediterranean greeneries with albedo rate of 0.15. On the other hand, the greenery/planting rate of Cahit street is very poor. The Cahit street consists of only urban materials. Table 15 and 16 show albedo rate of above mentioned streets in Famagusta City.

Table 14. Albedo Rate of Land Covers in Konak Street (by author 2017)

Cover Types	Albedo Coefficient	Covered Area	Albedo Portion
Mediterranean Greenery/Trees	0.26	<20%	0.052
Urban	0.15	>80%	0.12
Average Constant for Famagusta	-	100%	**17.2%**

Table 15. Albedo Rate of Land Covers in Cahit Street (by author 2017)

Cover Types	Albedo Coefficient	Covered Area	Albedo Portion
Mediterranean Greenery/Trees	0.26	<3%	0.0078
Urban	0.15	>97%	0.1455
Average Constant for Famagusta	-	100%	**0.1533**

4.6 Summary of the Chapter and Compression of Findings

The results of this chapter are subsequences of the solar assessment of the street elements and issues considered in previous chapters. Solar issues and street elements were similar in both of the streets, but differed in orientation; therefore, the periods of the thermal discomfort vary. These analyzed elements and the results are presented in a summarized form in a table for each street. Therefore, it will help to establish a conclusion, according to the research questions of the thesis.

Table 16. Summary of Findings for Solar Street Issues of Konak Street in Famagusta (by author 2017)

Issues effecting the street spaces	**Good**	**Poor**	**Comments**
Orientation	■		Well exposed facades
H/W Ratio	■		Enough width of streets to provide daylight, low-raised buildings, regular category, providing healthy daylight
Landscape		■	Poor solar furniture, lack of solar equipment, ruined sidewalks, good materials
Greenery	■		Inappropriate location of plants in private sides but effective in solar street.
Street Shading		■	Lack of trees in the streets, lack of any element to provide shadow, inappropriate type of tall trees with low rate of shadow range.
Albedo		■	High rate of urban surfaces, surfaces with low rate of reflectance.

Table 17. Summary of Findings for Solar Street Issues of Cahit Street in Famagusta (by author 2017)

Issues effecting the street spaces	**Good**	**Poor**	**Comments**
Orientation	■		Well exposed facades
H/W Ratio	■		Enough width of streets to provide daylight, low-raised buildings, regular category, providing healthy daylight
Landscape		■	Poor solar furniture, lack of solar equipment, ruined sidewalks, good materials
Greenery		■	Lack of sufficient green areas, inappropriate location of existing plants.
Street Shading		■	Lack of trees in the streets, lack of any element to provide shadow, inappropriate type of tall trees with low rate of shadow range.
Albedo		■	High rate of urban surfaces, surfaces with low rate of reflectance.

Table 18. A Comparative Evaluation of the Solar Street Space of Konak Street and Cahit Street (by author 2014)

Issues effecting the street spaces	Konak Street	Comparison	Cahit Street
Orientation	47 toward Southeast-Northwest, critical time is the afternoon time.	Konak Street is suitable for public activities in afternoons but, Cahit Street is suitable for mornings	27 degree toward Northeast-Southwest, critical time is the morning time.
H/W Ratio	Canopy Ratio is 0.64, regular category, providing healthy daylight	Both of the streets are regular.	Canopy Ratio is 0.71, regular category, providing healthy daylight
Landscape	Poor furniture, lack of solar equipment	Both of the streets have very poor landscape.	Poor solar furniture, lack of solar equipment, ruined sidewalks, good materials
Greenery	Inappropriate location of plants	Greenery situation of Konak street is a	Lack of sufficient green areas,

	in private sites but effective in solar street.	little better than Cahit street.	inappropriate location of existing plants.
Street Shading	Lack of trees in the streets, lack of any element to provide shadow, inappropriate type of tall trees with low rate of shadow range.	Both of the streets are very poor in providing shadow.	Lack of trees in the streets, lack of any element to provide shadow, inappropriate type of tall trees with low rate of shadow range.
Albedo	High rate of urban surfaces, surfaces with low rate of reflectance.	The albedo rate of the both of the streets are less than normal value of the city.	High rate of urban surfaces, surfaces with low rate of reflectance.

Chapter 5

CONCLUSION AND RECOMMENDATIONS

Climatic and geographic features of urban spaces effect the rate of solar energy, but the quality of street spaces related to solar energy is not depending just on these factors; urban characteristics of street such as orientation, H/W ratio and landscape have also decisive role on the quality of street spaces.

Sky clearness factor impacts diffused solar radiation while appropriate/inappropriate street orientation increases/declines absorption rate of direct solar radiation. Therefore, total solar radiation on street spaces influences both, the sky clearness and street orientation. Also, street orientation limits the period of public activities on the solar street. Whereas, sky clearness in Konak street is equal as Cahit street, therefore, orientation angle of each street provides different thermal quality in different periods. Konak Street is suitable for public activities at afternoons but, Cahit Street is comfortable at morning times.

Urban canopy or H/W ratio is related to the urban micro climate and human health. Regular urban canopy provides healthy daylight in both Konak street (0.64) and Cahit street (0.71) which supports the right for daylight in Famagusta.

Landscape analysis shows poor and inappropriate greenery and solar tools. The street spaces in Famagusta have shading problem. Existing trees cannot provide sufficient shadow. Short trees and solar tools are required to solve the shading problem.

Albedo value in both Konak street and Cahit street is less than total value of Famagusta influencing the poor landscape.

According to the energy modeling for Famagusta using Ladybug for Grasshopper in Rhino program, direct radiation is 695.03 Wh/m^2, diffused horizontal radiation is 426.72 Wh/m^2, and global horizontal radiation is 1121.75 Wh/m^2. On the other hand, Stephenson cousin method for vertical surfaces modeling for Famagusta using Microsoft Excel program shows radiation rate for Cahit street around 800 Wh/m^2 from northeast in summer (09:00-11:00) which is the most discomfort period for public activities on the street. The model shows, a radiation rate for Konak street around 750 Wh/m^2 from southwest in summer (14:00-17:00) which is the most discomfort period for public activities in Konak street.

For this reason, it is recommended that the orientation concept of streets and blocks according to the solar potential on its latitude should be considered as one possible sustainable concept in a very early stage of macro planning level.

Moreover, avoiding inappropriate street orientation which is aimed to optimize the performance of different streets, façades and thermal discomfort is one of the aims of sustainable urban design, but can restrain the design process, for which this research is conducted. Orientation concept for different climatic conditions needs different requirements for the purpose of any street spaces related to solar energy, but such a purpose cannot be reached without regarding the aspects such as diagonal orientation of roads, exposure of façades and the axis. For achieving sustainable development and solar energy efficiency of cities in macro planning stage, these aspects should achieve a significant enhancement in landscape by onsite solar energy potential and urban form.

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