The Improvement of Housing Façade by Bioclimatic Design Means towards Sustainability: The Case of Duhok City, Iraq

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ABSTRACT

With the constant grow of world energy demand, and with nearly 80% of that energy coming from non-renewable energy such as fossil fuels, the non-renewable energy sources have seriously affected on the environment and caused issues like climate change, CO_2 emission, air pollution, etc. The residential building sector takes up around 23% of the world total energy consumption, and with building envelope being a vital element that effects on the total building energy consumption. Hence, this study pays attention to designing more environmental friendly houses and improving the existing ones, by taking the houses in Duhok city/ Iraq as case studies. The façades of the case study houses are improved by bioclimatic means, since the majority of the houses in the city has no considerations towards climate-adaptive design and are very much depending on non-renewable sources of energy.

By analyzing the case studies and their local climate, it became evident where the façades lacked consideration to the local climate. Therefore, the weaknesses in the case study houses' façades got improved by adopting the knowledge derived from the studies reviewed in literature on bioclimatic design, its principles and how to design the elements of façade according to climate and orientation. Lastly, recommendations based on bioclimatic principles are presented for different orientations (north, south, east and west) of housing façades to provide an energy efficient and sustainable house.

Keywords: sustainability, bioclimatic design, bioclimatic principles, façade design.

ÖZ

Dünyanın sürekli artan enerji gereksiniminin yaklaşık %80'i fosil yakıt gibi yenilenemeyen enerjiden gelmektedir ve çevreyi ciddi bir şekilde etkileyerek iklim değişikliği, karbondioksit emisyonu, hava kirliliği gibi sorunlara sebep olmaktadır. Konut sektörü dünyadaki toplam enerji tüketiminin yaklaşık %23'ünü kaplamaktadır ve yapı kabuğu da binanın toplam enerji tüketimini etkileyen en önemli unsuru oluşturmaktadır. Bu nedenle, bu çalışma Irak'ın Duhok şehrinde bulunan evleri örnek çalışma olarak ele alarak daha çevre dostu evler tasarlamayı ve mevcut yapıları geliştirmeyi dikkate almaktadır. Şehirdeki evlerin çoğunluğunun iklime uyumlu tasarımı göz önünde bulundurmaması ve çok fazla yenilenemeyen enerji kaynaklarına bağlı olması sebebiyle evlerinin cepheleri biyoiklimsel anlamda örnek çalışma olarak geliştirilmiştir.

Bu örnek yapılarda yerel iklimlerin analizini yaparak, cephelerin yerel iklimi dikkate almadıkları ortaya çıkmıştır. Bu sebeple, örnek yapıların cephelerinde bulunan eksiklikler, biyoiklimsel tasarım ve ilkeleri, iklim ve yöne göre cephe elemanları tasarlanması, kaynak taraması sonucu elde edilen bilgilere dayanarak geliştirilmiştir. Son olarak, enerji verimli ve sürdürülebilir evleri tasarlamak için, biyoiklimsel ilkelere bağlı olarak farklı yönlere (kuzey, güney, doğu ve batı) göre bina cepheleri için öneri tablosu sunulmuştur.

Anahtar kelimeler: sürdürülebilirlik, biyoiklimsel tasarım, biyoiklimsel ilkeler, cephe tasarımı

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BBCC	Building Bioclimatic Chart
CABS	Climate Adaptive Building Shells
CEC	California Energy Commission
Csa	Hot-Summer Mediterranean Climate
IAQ	Indoor Air Quality
ISIS	Islamic State of Iraq and Syria
KRG	Kurdistan Regional Government
Low-E	Low Emissivity
MRT	Mean Radiant Temperature
PV	Photovoltaic
PVC	Polymerizing Vinyl Chloride
SHGC	Solar Heat Gain Coefficient
VT	Visible Transmittance
WHO	World Health Organization
WWR	Window to Wall Ratio

Chapter 1

INTRODUCTION

1.1 Research Background

The world energy consumption is expected to grow at a rate of 1.3% per annum until 2050, and nearly 80% of that energy depends on fossil fuels as a source of energy, which will cause significant consequences that results in environmental issues such as greenhouse gas emissions, climate change, emission of CO_2, air pollution, global warming, etc. The building sector (residential and commercial) covers one third of the energy consumption worldwide as well as greenhouse gas emissions, and about 69% of that one third are residential buildings (IEEJ, 2018). Unlike cars and other means of transportation buildings do not have to meet fuel efficiency standards that cars have to, in addition buildings have a more direct impact on the environmental issues as well as world energy consumption amount, and that is due to buildings having a much longer life duration than any other means of transportation (Hong, Chiang, Shapiro & Clifford, 2007). So therefore, it is important to give more attention on designing more energy efficient buildings and improve the existing ones.

Maintenance and operations (cooling and heating) of the buildings take about 83% of the energy consumption in the building sector, the envelope of the building is very crucial to the comfort of the inner environment and has a significant impact on the amount of energy intake of the building (Loonen, Trčka, Cóstola & Hensen, 2013). Thus this study focuses on the improvement of the houses' façade, which will result in an improvement in the overall performance of the building and make it more sustainable, such improvement will be achieved by applying bioclimatic strategies on the façade to correspondence to the local climate better.

1.2 Problem Statement

The problem here is that majority of the houses in the city of Duhok, Iraq has no consideration towards climate-adaptive design which responds to the local climate condition, they are constructed at a lowest cost with no consideration to sustainable development. This leads to buildings with excessive heating and cooling loads, as the city has extreme temperature difference throughout the year. In addition, the only source of energy in those houses is non-renewable energy like fuel oil, which of course has an extremely damaging impact on the environment, because it is causing air pollution.

Many of the houses in Duhok city, Iraq are attached to each other from three sides and only have one façade. Therefore, that façade is crucial to the overall performance of the building. However, those street façades have issues in regards of being climate-adaptive, they all have the same openings regardless of the orientation, and they have no consideration towards shading and sun control, and many other issues that this study will try to improve.

1.3 Research Aim and Questions

Finding the balance between climate, and thermal comfort in architecture has always been a concern, and bioclimatic design can be an approach to balance between the two. Hence, this research will seek to understand bioclimatic architecture and its design principles, to ease that concern. Moreover, the study will also aim to analyze the houses' façades in the selected case studies and search for their weaknesses. The research will attempt to improve those weaknesses by setting up design recommendations for façades with different orientations. Furthermore, with lack of public's consideration towards sustainability and environmental issues this research will attempt to raise public awareness about a more sustainable design for the houses in the city of Duhok.

To be able to reach to the aims of the study as mentioned previously, the research will focus on the following questions:

- What is bioclimatic design and what are the principles of bioclimatic design?
- What are the weaknesses of the façade design of the houses in Duhok city?
- How can the façade design of the houses be improved based on bioclimatic design (thermal comfort, visual comfort, indoor air quality and reduce of energy usage) with accordance to Duhok city local climate?

1.4 Research Methodology

The methodology used in this study will consist of two parts. Applying a documentary research method in the first part, which is providing an overall literature review to define bioclimatic architecture and mention its principles, and collecting data on bioclimatic design strategies that are suitable for the local climate of Duhok city.

To apply bioclimatic design principles on housing façades, a case study approach has been used in the second part. Some attached houses in the city of Duhok have been selected as case studies. Most of the data on the case studies has been gained through a field visit, and own observation of the housing façades. As for the technical drawings of the case studies, they have been obtained from the architects of the houses.

With the obtained data on the case studies, the housing façades will be analyzed to know what their weak points are and where they do not correspond to local climate. Bioclimatic design principles will be applied to the façades to have a better respond to their climate, and to improve the missing part. Finally, the improvement will be provided through a table based on bioclimatic design recommendations for façades with different orientations.

1.5 Research Limitations

The study is limited to the façade development of a conventional type of houses in the city of Duhok in Iraq. Those houses are attached on three sides, therefore, the houses have one main façade. The research will attempt to cover the improvement of those façades facing to four main orientations, by applying bioclimatic design principles, especially in temperate climate. As the sub-climate of Duhok city is classified as a hot-summer Mediterranean climate (Csa) under the main temperate climate according to the Köppen-Geiger climate classification (Peel, Finlayson & McMahon, 2007). Finally, the research will develop a list of design recommendations for the façades facing to different orientations, based on the theoretical framework on bioclimatic design in the literature review.

Chapter 2

LITERATURE REVIEW

2.1 Definition of Sustainability

As the term *sustainability* itself improvise the two words *sustain* and *ability*, thus it suggests the ability to sustain a matter or a system (Campos Jr, 2019). Sustainability is an extensive discipline that covers many life aspects. In light of this, sustainability has been defined differently by various disciplines. However, they all seek one purpose, which is shown in the definition by Brundtland Commission (1987), it was defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland Commission, 1987). Sustainability is mainly about finding a stable state where the earth or some part of the earth can endure the growth of human population and economy without eventually causing any threat to the health of people, animals and plants. Thereby, the underlying base of sustainability is that the resources of earth cannot be used and exploited indefinitely (Portney, 2015).

The sustainable development mainly concerns with three main aspects in any system which are environmental, economic, and social aspects, they are the main three pillars that supports sustainability and they are sometimes informally referred to as planet, profits, and people (Hansmann, Mieg & Frischknecht, 2012). For a system to be sustainable it has to keep the balance between these three pillars if one of them is neglected in a system, then the system is no longer sustainable, see Figure 2.1.

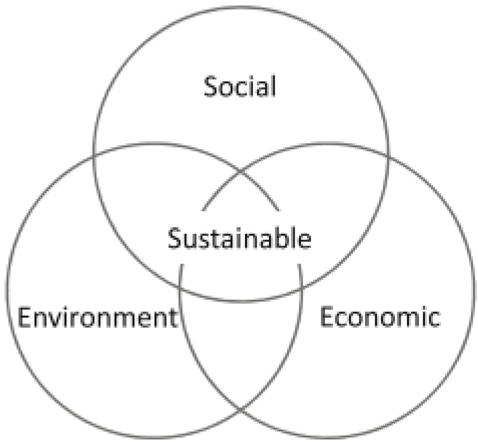


Figure 2.1: The Three Pillars of Sustainability (Purvis, Mao & Robinson, 2018)

2.1.1 Environmental Sustainability

Environmental sustainability is the most crucial pillar out of the three, as it highly influences the other two pillars, without the sustainability of the environment it will not be possible to maintain the sustainability of the other two pillars. The term “environmental sustainability” was introduced by Goodland (1995) in an article *“The Concept of Environmental Sustainability”*, it was defined as the improvement of the human wellbeing by preserving and protecting the earth’s raw materials that are used for the human needs, at the same time guaranteeing that the human waste does not exceed a limit that can cause harm to humans (Goodland, 1995).

After the introduction of the term “environmental sustainability”, throughout the years it become more established and started evolving and including more issues. According to one of the first scholarly journals concerned with environmental change and sustainability “*Current Opinion in Environmental Sustainability*”, it divides the environmental sustainability into six main disciplines, climate systems (concerned with climate change and risk management), human settlements (includes urbanization and transport), energy systems (concerned with energy usage, energy efficiency issues, and renewable energy), terrestrial systems (covering nature, ecosystems, and biodiversity), carbon and nitrogen cycles (concerned with feedback processes and links to other systems), and aquatic systems (includes marine, water ecosystems, and biodiversity) (Moldan, Janoušková & Hák, 2012). This shows that the concept of environmental sustainability is in constant grow and covers more issues for a better development.

Ultimately, environmental sustainability focuses on finding the right balance between the rate of natural resources harvest not exceeding the regeneration rate, and the rate of pollution not exceeding the capability of the environment intake.

2.1.2 Economic Sustainability

Like mentioned previously, environmental sustainability greatly effects other sustainability pillars, therefore the economic sustainability highly depends on environment. As Hamrin (1983) also states that the vital foundation of all economic activities is the natural resources and environment, and that the dependence of economy on environment is in constant increase, and is effected by sustained integrity of the resources and environment (Hamrin, 1983).

Unsustainable economic development is the main cause of financial and economic crisis in many countries, this reveals the importance of keeping a sustainable economy (Moldan et al., 2012). To keep such sustainable economy, it is a necessity to focus on the rate of the profit that can bear a specific level of production endlessly, and this is what most organizations and businesses strive for.

2.1.3 Social Sustainability

Social sustainability draws attention to the social wellbeing of the people in a system. The social wellbeing is a very indefinite scale for the social sustainability to depend on, and can drastically differ in different regions, societies and cultures, thus at many times making it the most overlooked pillar out of the three (Moldan et al., 2012).

Because of its vague nature it makes it hard to have one unified definition. Black (2004) defines it as to what degree a social system can preserve its social values, identities, relationships and traditions into the future (Black, 2004). Torjman (2000) thinks that social sustainability cannot be achieved if the people wellbeing is not sustained based on a healthy environment and a flourishing economy (Torjman, 2000). Despite of social sustainability being an unclear dimension of sustainability, there are still constant attempts on clearly defining its goals and elements.

2.1.4 Sustainability in Architecture

The building sector is a vital element in sustainability, it highly effects all three pillars of sustainability. Architecture is a massive actor in the sustainability of environment, without a thoughtful process of building design it can be a big cause of damage to the environment. In addition, the well development of architecture can flourish the economy of a country, therefore it is an effective contributor to the economic sustainability. And lastly because architecture shapes the lifestyle of the people, so it influences on the social sustainability of a system. With the high effect of architecture on sustainability it is crucial to implement sustainability in architecture.

As mentioned previously architecture in general plays a very effective role in sustainability, hence sustainable architecture tries to improve sustainability and minimize its negative impact on it especially environmentally, and this resulted in many strategies and concepts such as green architecture, ecological design, solar architecture, bioclimatic design, etc. All these approaches try to use methods that take the most advantage of the natural resources (water, sun, wind, climate, etc.), to use recycled materials, be compatible with its surrounding ecosystem and sufficient use of energy, all to minimize its footprint on the environment and to not have any negative consequences for future generations to meet their needs (Akadiri, Chinyio & Olomolaiye, 2012).

2.2 Bioclimatic Design as Sustainable Design Approach

The main purpose of the architecture has always been the protection of man from the exterior environment, and the concept of the bioclimatic architecture is highly related to that matter but without bringing environmental damage (Cruz, Torres & Silva, 2011). The first use of the term *bioclimatic* was in 1917, which is defined as “of or relating to the relations of climate and living matter” ("Bioclimatic", 2019). As for the concept of bioclimatic design in architecture its origin goes back to the traditional architecture style of each region. People obviously always tried to take maximum advantage of the local microclimate with the respect to the site topography, orientation, air, temperature, wind, humidity, etc., to achieve comfort in their buildings and that led to the vernacular architecture, which is very definite to its specific locality (Machaira, Labropoulos & Zentelis, 2012). Moreover, with the development of technology over time and the invention of more advanced strategies to benefit from the climate, the term *bioclimatic* was introduced for the first time in architecture in the book ‘*Design with Climate: Bioclimatic Approach to Architectural Regionalism’* by Victor Olgyay in 1963. The book guides a path with architectural techniques on how to design according to the regional climate with consideration to the air, temperature, humidity and wind to reach the human comfort and to save energy (Olgyay, 1963).

According to Victor Olgyay there are three main scientific disciplines that are necessary in architecture to achieve a bioclimatic building that adhere to its local climate, those disciplines are as follows (Suvorovs & Treija, 2011):

- Biology: it concerns with occupants of the building to reach its comfort based on the physiological matters of the human body;
- Meteorology: it concerns with examining the detailed conditions of the local climate;
- Engineering sciences: it concerns with technological strategies to provide a practical solution.

In the process of designing bioclimatic buildings, Victor Olgyay provides a guide with four consecutive stages in his book to achieve environmental control in relation to the local climate, those stages are (Suvorovs & Treija, 2011):

1. Obtaining and processing the local climate data, such as (temperature, humidity, wind, etc.);
2. Studying and evaluating the obtained climate data and specifying the comfort zone for the specific climate;
3. Offering technical solutions for the issues in the climate, with consideration to building orientation, shading conditions, building mass, wind movement;
4. Finally, all three previous stages should unify into architectural solutions.

Another architect that elaborated more on the topic is the architect Ken Yeang in his book '*The skyscraper bioclimatically considered'* in 1996, he describes that buildings are highly influenced by the climate conditions and site specifications (Yeang, 1996). Ken Yeang believes that the built environment has to interact with the site *Eco Infrastructures,* and maximize the benefit from the ecological systems. He divides the eco-infrastructures into four parts, which are Green, Gray, Blue and Red. The *Green* part is concerned with the ecological issues such as the surrounding ecosystems, plants, biodiversity, animals, etc. The second part *Gray* is related to engineering systems, energy saving technologies, sustainable buildings, zero CO_2 emission buildings etc. As for the third part *Blue* it is concerned with the management of water issues, like rainwater saving and grey water recycling technologies. Lastly the fourth part *Red* is concerned with people and their culture influence on buildings. (Widera, 2015). Furthermore, in Ken Yeang's works he reaches the optimal benefit from the *Eco Infrastructures* by using both passive strategies from the regional vernacular architecture and active strategies with cutting edge technologies.

In summary, the bioclimatic architecture aims to ensure the user comfort and at the same time to have maximum mutual interaction with its outdoor natural environment and ecosystems to maintain a sustainable built environment and promote energy saving (Bajcinovci & Jerliu, 2016).

2.2.1 Role of Bioclimatic Architecture in Sustainability

Bioclimatic design is a method of design to reach sustainability. Sustainable design approach looks at the impact of the buildings on local environment, and durability of buildings, and how efficient the buildings manage their resources such as water and energy. Meanwhile in bioclimatic design approach, the buildings' low environmental impact, long durability and its recourses efficiency are the outcomes of considering local climate characteristics in the design process for more comfortable conditions (Maciel, 2007). It can be said that bioclimatic design is an approach and sustainability is its result.

As an example on the role of bioclimatic design in sustainability are the houses in Ghadams, Libya which are 600 years old with new constructions. In summer when the outdoor temperature was about 44°C, it was found that inside the old houses the temperature was 26°C and in the new houses it was 38°C (Adwan & Abu Muhsen, 2016). A drastic difference of 12°C, that is because the traditional houses used climate-adaptive design strategies, unlike the new houses which did not have consideration to the local climate and strongly depending on active systems like air conditioning to achieve thermal comfort, without thinking of the negative consequences in future.

The importance and the role of bioclimatic design is very apparent in this example, because now bioclimatic design can learn from the vernacular building design methods to achieve indoor comfort, and also integrate advance technologies into the design, and significantly reduce negative impact on the environment.

2.2.2 Bioclimatic Chart

The purpose of designing architecture by bioclimatic means is to achieve bioclimatic comfort, which is the environment with optimum comfortable climatic conditions that can be achieved with passive design methods according to the local climate. In other words, it is the attainment of optimum thermal conditions with least amount of energy (Mahmoud, 2011). The required energy and thermal comfort have a contradictory relation, the greater the energy that is required the more uncomfortable the climate condition is felt to be. During the architectural design process, it is essential that the architect provides comfortable climatic conditions inside buildings, within a specified range to attain thermal comfort (Dalhat, 2014). This range of climatic conditions is called the comfort zone, which is an area on the bioclimatic chart with relevance to temperature and humidity that indicates where thermal comfort is obtained.

Bioclimatic chart is an initial analysis tool to help the architect to determine whether the indoor climate is within the comfort zone or not. Bioclimatic chart works as a feedback tool to test the effectiveness of passive design strategies during the design process, to know whether those strategies provide comfortable indoor climate or not. The very first architect Victor Olgyay who introduced the term “bioclimatic” into architecture also invented the “bioclimatic chart” in 1950s, based on the traditional psychrometric chart in 1905, see Figure 2.2. Olgyay’s chart is a more relative and advanced version than the psychrometric chart, what makes it different than the psychrometric chart is that it plots the relative humidity (measurement of water moisture relative to air temperature) rather than the absolute humidity (measurement of water vapor in air regardless of its temperature) that is used in psychrometric chart, this makes the bioclimatic chart more tangible to the human, as relative humidity is close to how we feel the temperature. The comfort zone in the chart is determined according to the air temperature, humidity solar radiation, wind speed, and evaporative cooling, in Figure 2.3 the chart also indicates primitive strategies outside the comfort zone to improve the thermal comfort and help the environment to reach within the comfort zone area (Steinfeld, Bhiwapurkar, Dyson & Vollen, 2010). The comfort zone in the chart for the relative humidity is between 30% and 60%, for the outdoor temperature between 21°C to 27.5°C and for the wind speeds up to 5 m/s (Katafygiotou & Serghides, 2014).

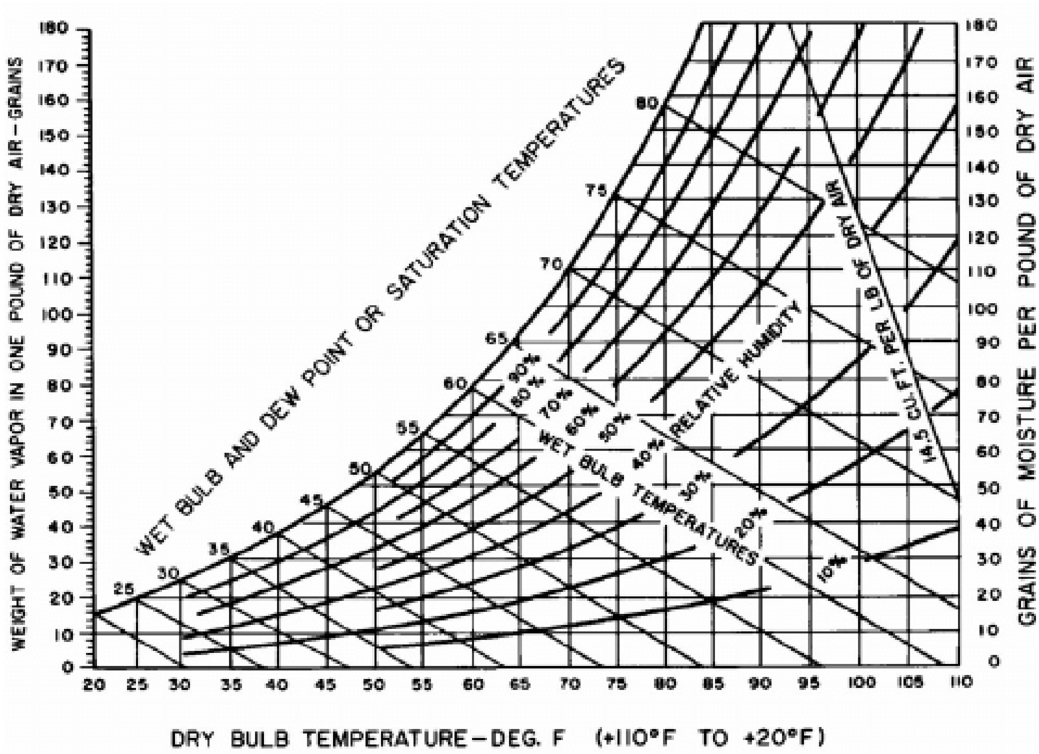


Figure 2.2: The Psychrometric Chart (Parsons & Boman, 2003)

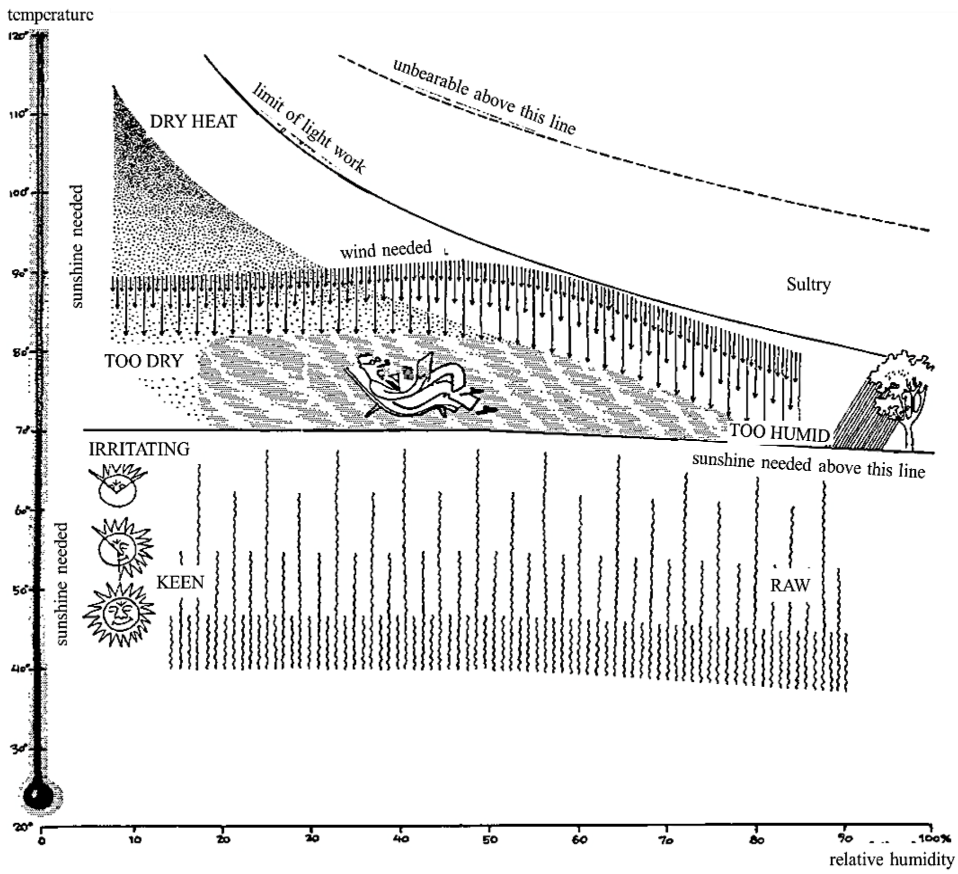


Figure 2.3: The Bioclimatic Chart (Olgyay, 1963)

The most notable and widely used chart after Olgyay's bioclimatic chart is Baruch Givoni's chart, he first extended Olgyay's chart in his book "*Man, Climate, and Architecture*" in (1969), and later develops a chart in (1992) and names it as "*Building Bioclimatic Chart (BBCC)*", see Figure 2.4 (Givoni, 1992).

What lacked with Olgyay's chart is that it only addressed the outdoor conditions without considerations towards the effect of thermal energy from building materials and other building elements on the comfort zone. Building bioclimatic chart is more close to architecture, it takes into consideration the building impact on the thermal comfort and it also plots different passive and active design strategies for the improvement of the thermal conditions in the building (Steinfeld et al., 2010).

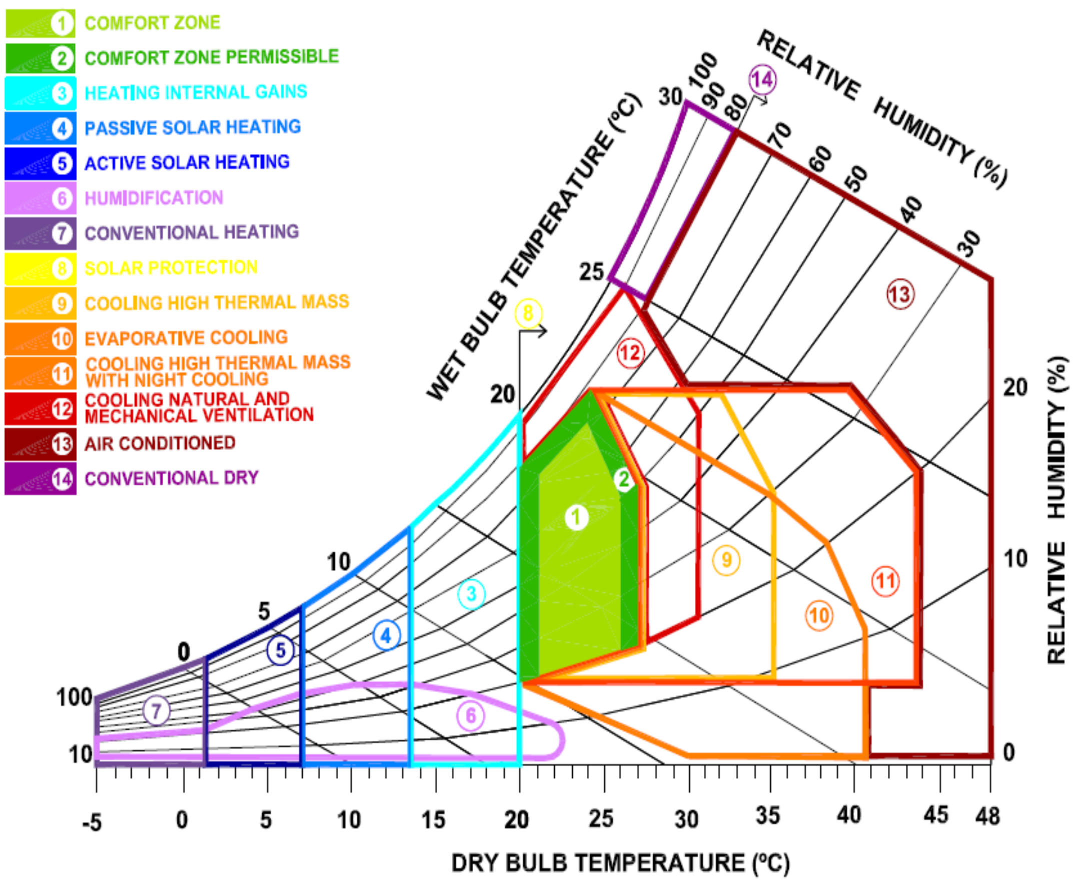


Figure 2.4: Example of Building Bioclimatic Chart (BBCC) (Manzano-Agugliaro, Montoya, Sabio-Ortega & García-Cruz, 2015)

2.2.3 Principles of Bioclimatic Architecture

The principles of bioclimatic architecture are the objectives of designing by bioclimatic means, which are used by architects in the design process as guidelines for designing with climate in mind, as well as helping them to translate theory into practice (Hyde, 2008). The application of these strategies differ according to the climate, region, building type and scale, due to this reason the principles of bioclimatic architecture are different from a source to another. For instance, in a paper by Axarli and Teli (2008) the principles of bioclimatic design in an urban scale and a coastal region is presented, and they are as follows (Axarli & Teli, 2008):

- achievement of thermal comfort;
- improvement of visual comfort;
- creation of acoustic comfort;
- improvement of air quality;
- improvement of building's energy behavior.

Furthermore, in another research by Dalhat (2014), “a new set of principles is proposed comparing the various sources”, that set of principles are (Dalhat, 2014):

- exploitation of solar energy;
- natural lighting;
- thermal protection;
- passive cooling systems and techniques;
- renewable energy sources (RES) installations;
- acoustic protection.

In a smaller scale building such as housing, another set of principles have been examined in a book called *Bioclimatic Housing* by Hyde (2008), they are defined as:

- creating user health and well-being;
- using passive systems;
- restoring ecological value;
- utilizing renewable energy;
- utilizing sustainable materials;
- applying life-cycle thinking, assessment and costing.

The difference between these sets of principles shows the intense challenge of having a universal set of principles or solutions for all kinds of buildings, due to the nature of the problem being climate, building type and scale specific (Yeang, 1999). Yet, the main goal of the principles is the same, which is to combine them and come up with the best design solution possible for the directed climate (Hyde, 2008). In light of this, in Table 2.1 a set of principles have been proposed based on previous principles, along with the design strategies and climate factors that are used in each principle. Since, the issue with some of the previously mentioned principles is they are more like strategies than principles. In Dalhat (2014) principles, "*natural lighting*" is a strategy to improve visual comfort, or in Hyde (2008) principles, "*utilizing renewable energy*" is a strategy to reduce non-renewable energy usage.

Table 2.1: Proposed Set of Bioclimatic Design Principles (by author)

Bioclimatic Design Principles	**Possible Design Strategies**	**Climate Factors**
- Improvement of Visual Comfort	- Lighting	- Daylight
- Improvement of Thermal Comfort	- Passive Cooling and Heating Techniques	- Solar Radiation - Wind
- Improvement of Indoor Air Quality	- Natural Ventilation	- Wind
- Reducing Energy Usage	- Renewable Energy Sources - Passive Design Systems	- Sky Conditions - Wind - Solar Insolation

2.2.3.1 Improvement of Visual Comfort

There are two main approaches to define visual comfort, the first approach is based on the statement that “comfort is not discomfort”, or in other words is the “non-annoyance approach”. This approach focuses on eliminating any symptoms that may cause a visual discomfort in the occupants, those symptoms are well identified and can be subjectively evaluated such as trouble in doing a visual task, stress, glare, annoyance, and also some other physical symptoms for instance headache, watering eyes, itchy eyes, and sore. The second approach is the “well-being approach”, it is based on the evaluation of the positive effects induced by well-being and satisfaction. By comparing these two approaches, the “non-annoyance approach” is more common, because it is easier to quantitatively and qualitatively evaluate the visual discomfort indicators rather than the comfort indicators that do not have a clear definition (Iacomussi, Radis, Rossi & Rossi, 2015).

One of the main strategies to improve the visual comfort by bioclimatic means is daylighting. The proper use of natural lighting will drastically improve the visual comfort and also minimize the energy usage on artificial lighting and on cooling loads on spaces that can be overheated by electric lighting appliances. In addition, natural lighting has significant influence on the well-being of the occupants’ both mentally and physically. Many factors and elements effects the daylighting design, and most of those factors have to be incorporated into the building in early design stages. Such factors are the building location, the shading from the surrounding buildings and trees, intense reflection from the surrounding glazing surfaces, form, space planning, however the factor that effects the most on the daylighting is the building orientation.

For the building orientation, the south orientation is the best one for daylighting in the northern hemisphere, and especially in winter where heat is desirable, as it gets the most amount of sunlight throughout the day. Another appropriate orientation is the north orientation, due to it receiving lower amount of sunlight compared to the south orientation, but at times it can be more preferable than the south orientation depending on the function of the space. The east and west orientation are the least desirable orientations for daylighting, not only do they get sunlight for only half of the day, the sunlight they receive is at maximum in summer rather than in winter, and makes them cause overheating in summer (Lechner, 2015). In Figure 2.5 shows the different strategies to let sunlight enter inside the building and be well distributed especially when the sunlight access is not direct.

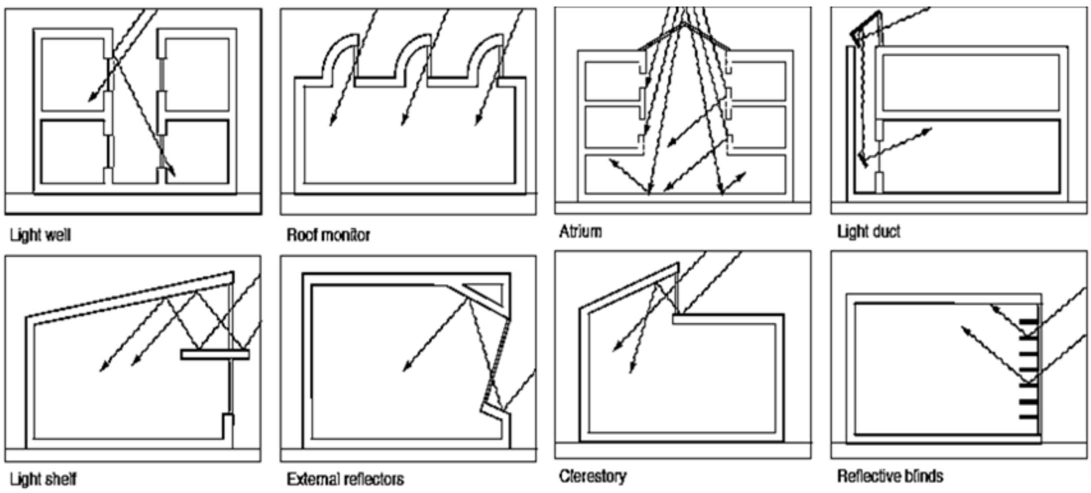


Figure 2.5: Daylighting Techniques (Goulding & Lewis, 1997)

Another key point in daylighting to provide a comfortable visual conditions is the avoidance of glare. Glare is an intense light source inside the visual field, that causes annoyance and visual discomfort, and it usually happens with the sunlight rather than the electric lamps as they are designed with proper enclosures, optics, and shielding. To avoid such discomfort, the position of visual tasks and workstations should be properly positioned in relation to windows to avoid direct glare and extreme contrast between surfaces illuminance. The proper use of shading prevents glare as well as by the use tinted windows and dark colors (Smith, 2005).

2.2.3.2 Improvement of Thermal Comfort

The human body is a biological machine that constantly produce heat by burning food as a fuel, to keep this metabolic process at equilibrium between the generated heat and the heat loss, the body needs to be at an internal temperature of 37°C, hence, it is essential to provide a comfortable environment where the body can preserve such temperature. Therefore, thermal comfort is the state where the occupants are satisfied with the thermal environment, and there is no urge to accurate the thermal environment by behavior. This state of satisfaction with thermal comfort makes it a state of mind rather than a state of condition, which leaves the definition of thermal comfort to be very open as to what is exactly the measurement of mind condition of satisfaction, since the sensations of people are different with the thermal environment even in being in the same environment. The different preferences of people on thermal comfort being in the same spaces, having the same culture, and climate is due to the combination of various factors effecting on the people perception on thermal comfort (Djongyang, Tchinda & Njomo, 2010). Such factors can be categorized into three main categories, environmental, personal and other contributing factors that are listed in more details in Table 2.2.

Table 2.2: The Factors that Affect the Thermal Comfort (Khalfan & Sharples, 2016)

Environmental	Personal	Contributing Factors
Air temperature	Metabolic Rate	Food and drink
Air movement	Clothing	Body shape
Humidity	State of health	Subcutaneous fat
Radiation	Acclimatization	Age and gender

It is important to provide thermal comfort inside the buildings throughout the year not only for human satisfaction, but also for reducing energy use as well as improving indoor air quality (Khalfan & Sharples, 2016). As mentioned before, in Table 2.2 there are three main categories of factors that effect on thermal comfort, and the category that the bioclimatic design is most concerned about is the environmental one, including air temperature, air movement, humidity and radiation. Firstly, the *air temperature* indicates how much heat is lost to the air, though convection. However, if the air temperature is above 37°C the body starts to gain heat from the air. Consequently, the comfortable range of air temperature for the majority of people (about 80%), where the heat loss and gain balance is 25°C for summer and 20°C for winter. Secondly, *air movement* highly influences on the heat-loss rate through both evaporation and convection, and it is a good asset in summer but a burden in winter. The comfort range of indoor air movement is between 0.1 to 0.3 m/s; the air becomes noticeable once between 0.3 to 1 m/s but still acceptable, above 1 m/s the air motion starts to disturbing and unpleasant. In Table 2.3 shows the effect of air velocity on comfort in more details.

Table 2.3: Effect of Air Movement on Thermal Comfort (Lechner, 2015)

Air Velocity		
m/s	***kph***	**Effect on Comfort**
0.05	0.2	Stagnant air, slightly uncomfortable
0.2	0.8	Barely noticeable but comfortable
0.25	1.0	Design velocity for air outlets that are near occupants
0.4	1.6	Noticeable and comfortable
0.8	3.2	Very noticeable but acceptable in certain high-activity areas if air is warm
1.0	3.7	Upper limit for air-conditioned spaces Good air velocity for natural ventilation in hot and dry climates
2.0	7.2	Good air velocity for comfort ventilation in hot and humid climates
4.5	16	Considered a gentle breeze when felt outdoors

Thirdly, the *relative humidity* determines the evaporation rate of the body, air with low levels of humidity absorbs the moisture from the skin, and this process cools the body. In contrast, when the humidity is 100%, where the air cannot hold any more water, it causes the process of cooling by evaporation to stop. To provide a comfortable indoor environment, the relative humidity should approximately range between 20% to 60% in summer and between 20% to 80% in winter. Finally, the *radiation* or *mean radiant temperature (MRT)* it has to be taken into account when it has a great difference with the air temperature. Such difference between air temperature and MRT is experienced when someone sits in front of large window on a sunny day in winter, that person will start to feel warm although the air temperature is comfortable (24°C). This is due to the sun radiation raising the MRT to a point that is too high for thermal comfort. Therefore, to maintain the thermal comfort MRT has to be close to the air temperature (Lechner, 2015). In summary, the thermal comfort occurs when the temperature is held within the comfort range, skin moisture is low, the body's effort is minimized in regulating its temperature (Djongyang, et al., 2010).

Improvement of thermal comfort can be accomplished, through taking advantage of climate factors such as solar radiation and wind, by using passive cooling and heating techniques. Passive cooling which is used in overheating seasons, controls the amount of heat gain from solar radiation and internal heat sources such as artificial lighting, by proper use of openings, daylighting, shading devices and natural ventilation in Figure 2.6 (Dalhat, 2014).

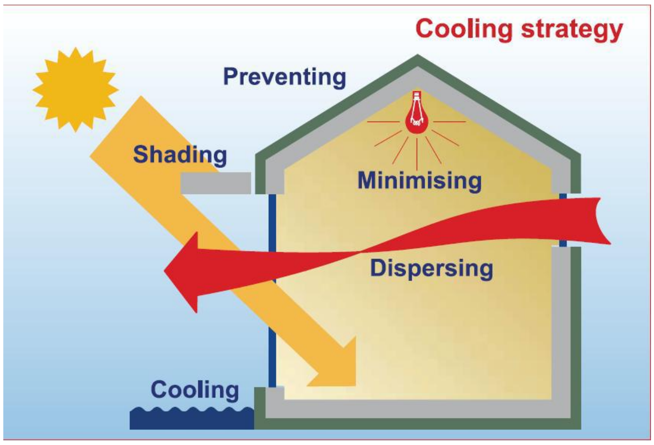


Figure 2.6: Passive Cooling Techniques (Dalhat, 2014)

Passive solar heating gains the heat from solar energy directly and indirectly, which majorly contributes to the heating requirements of a building. The heat from the solar energy is gained by four main techniques, which are solar collection (solar energy is collected and converted into heat), heat storage (the heat collected during the day is within the building for future use), heat distribution (collected/stored heat is redirected to spaces which require heat), and heat conservation (the heat is preserved in the building for as long as possible) in Figure 2.7. Lastly, installing an appropriate thermal insulation in the building to prevent heat loss, is a crucial element in passive solar heating (Goulding & Lewis, 1997).

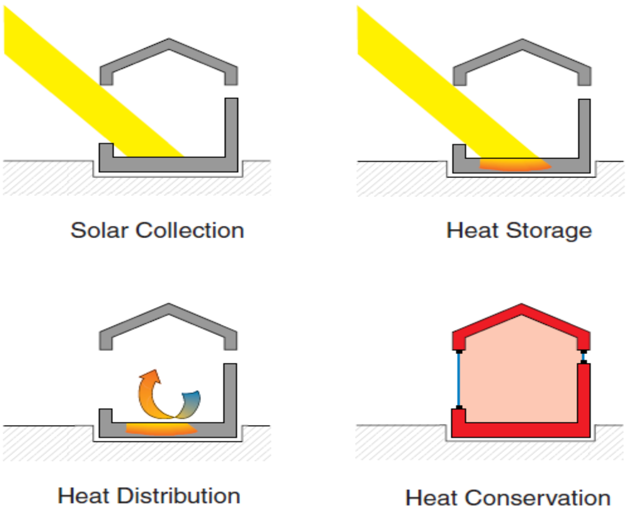


Figure 2.7: Passive Heating Techniques (Goulding & Lewis, 1997)

2.2.3.3 Improvement of Indoor Air Quality

Indoor air quality (IAQ) focuses on providing a healthy air inside buildings for the occupants' comfort and well-being, and ensuring there is no substance of pollutants or containments that could be a harm to the human health. This harm from air pollutants may be experienced shortly after exposure to it or perhaps years later. The health effects that show up soon after exposure to air with pollutants are mostly treatable such as coughing, headaches, exhaustion, dizziness, and itching throat and eyes. These kind of short-term reactions towards air pollutant differs from a person to the other, according to their age, sensitivity or in case of having a certain medical condition such as asthma (Seguel, Merrill, Seguel & Campagna, 2016).

The more serious health effects are the ones that appears years later after long or many repeated exposures, that can cause heart diseases, lungs diseases and even cancer. Thus, it is a necessity to provide a good indoor air quality even if the effects are not noticeable, since we spent 90% of our time inside the buildings. In Table 2.4 shows how the air pollutants effects on human health with the value that the pollutants should not exceed according to the World Health Organization (WHO) guidelines for indoor air quality (Li, 2013).

The IAQ can be improved with bioclimatic means by the suitable selection of vegetation around and inside building with the right wind direction, since vegetation works as natural air filters, by absorbing CO_2 and decreasing air pollutants. Taking advantage of the wind and its directions by providing natural ventilation inside buildings will drastically improve air quality, as it lets the access of fresh air inside the building, so it removes air pollutants from indoor sources, and also prevent the occurrence of any dampness or molds that may arise from high humidity and no air change or movement (Axarli & Teli, 2008).

Table 2.4: Effect of Air Pollutants on Human Health Exceed, According to the World Health Organization (WHO) Guidelines for Indoor Air Quality (Li, 2013)

Pollutants	**Adverse Effect**	**Recommended Value**
Benzene	Acute myeloid leukemia	No safe level exposure is recommended
Carbon monoxide	Ischemic heart disease	10 mg/m3 for 8 hours 30 mg/m3 for 1 hour 60 mg/m3 for 0.5 hour 100 mg/m3 for 0.25 hour
Formaldehyde	Sensory irritation	0.25 mg/m3 for 0.5 hour
Naphthalene	Respiratory tract lesion in animal studies	0.25 mg/m3 (annual average)
Nitrogen dioxide	Respiratory infection	200 μg/m3 for one hour 40 μg/m3 (annual average)
Polycyclic aromatic hydrocarbons (PAHs)	Lung cancer	8.7 × 10–5 per ng/m3
Radon	Lung cancer and possible leukemia cancer and extrathoracic airways cancers	100 Bq/m3
Trichloroethylene	Liver, kidney, blue duct and non-Hodgkin's lymphoma cancers	No safe level exposure is recommended
Tetrachloroethylene	Renal disease	0.25 mg/m3 for yearlong exposure
Dampness and mold	Hypersensitivity pneumonitis, allergy etc.	No safe level is recommended

2.2.3.4 Reducing Energy Usage

All the principles mentioned above promote the reduction of energy consumption, by reducing the dependence on mechanical systems and relying on the appropriate passive design systems with accordance to the microclimate. To fully take advantage of the climate factors, they can be used as a source of renewable energy. For instance, wind can be used as major source of energy, by installing wind turbines and converting the kinetic energy of wind into electricity. However, the wind energy systems are usually large scale systems that are installed in vast open fields, because in most cases the installation of small wind system in a house or a small building is not feasible, due to high cost of installation, not enough wind power and city regulations (Hossain, 2015).

Sun is a main climate factor the can be used as a source of energy by active design systems as solar panels that are either solar collectors used for heating or PV panels that convert sun insolation into electricity. Unlike the wind power the small scale solar energy systems are more feasible, as sufficient amount of sun radiation is available in most areas (Khanmohammadi, Zanjani & Veysi, 2019).

2.2.4 Bioclimatic Design for Temperate Climate Zone

In this section the focus of bioclimatic design will be in temperate climates, since the location of the selected case studies (Duhok city) are in the temperate climate zone (Csa) according to the Köppen-Geiger climate classification (Peel, Finlayson & McMahon, 2007).

In most cases human cannot dwell in natural climate conditions, therefore, the building elements have to be used in a way that mild the extreme climate conditions (storm, severe sun radiation, wind, rain, etc.) towards the human favor. The heating and cooling demands can reduce significantly, through the right utilization of the building elements that are able to correspond to its local climate. The strategies for the building elements that respond to its climate vary with the variation of climates.

Temperate climates extent from 23.5° to 66.5° latitude from the north and south of equator, they have broad range of temperature throughout the year between summer the warmest season and winter the coldest, as well as a wider seasonal change compared to other climates making it have four defined seasons with almost equal duration (Peel et al., 2007). Due to the wide seasonal variation, buildings in temperate climates demand equally cooling and heating loads.

Buildings in this climate region, need to have the right balance between the cooling and heating strategies applied to the building, and a key point in designing for temperate climates is to maximize the flexibility in the applied strategies, in order to modify the envelope according to the wide seasonal change throughout the year. Cautious design of the building elements with accordance of the solar angles is crucial, so that it can provide shade in overheating months and provide heating in under heating months (Boake & Williams, 2017).

For an appropriate design of openings in temperate climate buildings the overuse of glazing should be avoided especially in west orientation to avoid heat gain in warm months. Taking the most advantage from the south orientation with passive solar strategies, as it is the most effective orientation in heating and cooling of the space. It is essential to use wide shading on the east and west facing openings, since the sunlight can be very low in the morning and the afternoon which causes undesirable solar heat gain and glare. Finally, a vital design consideration in temperate climates is accurate insulation of walls and roof and sealed air in all spaces to avoid heat loss in cold months and heat gain in overheated months (Biket, 2006).

2.3 The Impact of Bioclimatic Design On Façade

The primitive function of façade has always been the protection of buildings' users from the exterior environment, and since vernacular architecture, passive design strategies were used in façades to correspond to its surrounding context to provide a more comfortable indoor environment. With the implement of advanced technology into the façade, it has helped in optimizing the comfort of indoor environment, by using least amount of energy possible. These comfortable indoor conditions that the façade provide such as thermal comfort, visual comfort, indoor air quality, wellbeing and safety of the building occupants, all help with the social sustainability of the building. The façade can improve the environmental sustainability of the building by the use of renewable energy, recyclable materials, and vegetation in the façade design, as well as optimization of the energy usage and reduction of the façade footprint and its negative impact on environment (Eren & Erturan, 2013).

As façade is the separation element between the indoor and outdoor environment, and bioclimatic design is the design of the building with accordance to its outdoor climate, so therefore, façade is the most crucial building element in bioclimatic design as it is the separation between the inner and outer space that the bioclimatic design can be applied on, to corresponds with its local climate.

With the advancement of technology and integration of sustainability into the façade, it resulted in many types of facades. Nevertheless, the façade that implements bioclimatic design principles and responds to its local climate is referred to as "*Climate Adaptive Building Shells (CABS)*", and it is defined as follows:

> Climate adaptive building shell has the ability to repeatedly and reversibly change some of its functions, features or behavior overtime in response to changing performance requirements and variable boundary conditions, and does this with the aim of improving overall building performance (Loonen et al., 2013, p. 485).

CABS are classified by the relation between four main physical domains (thermal, optical, air-flow, electrical), see Figure 2.8. The thermal domain is when changes occur in the energy inside the building through conduction, convection, radiation and thermal storage of energy. Optical domain is when there is change in the occupants' visual perception, due to the adaptive behavior of the transparent surfaces of the building façade. Air-flow domain is when adaptation causes an air-flow pass through the façade of the building via changes in the wind's speed and direction. Lastly, the electrical domain is when the façade generates energy or consumes electricity through its adaptive behavior performance (Loonen et al., 2013).

It can be noticed that the four main domain are much related to the principles of the bioclimatic design. The thermal domain is related to the improvement of thermal comfort, it provides comfortable thermal conditions by letting in the right amount of solar radiation and wind inside the building. The optical domain influences the improvement of visual comfort by having the suitable kind of openings and shading devices for daylight access. Air-flow domain improves the indoor air quality by letting wind cross through the façade and providing ventilation. The electric domain in CABS classification is related to reducing energy usage by designing a façade that may generate energy or uses the least amount of energy possible.

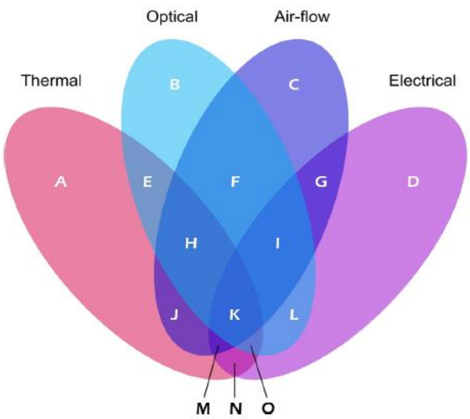


Figure 2.8: Classification of Climate Adaptive Building Shells (CABS) (Loonen et al., 2013)

2.3.1 The Historical Development of Façade Design

The origin of the word façade is from the Vulgar Latin "*facia*" literary meaning "*face*", in the mid-17th century, it passed its way through both French, as "*façade*", and Italian, as "*faccia*" ("Meaning of Facade", 2019). The first use of the word *"façade"* in

English was in refer to the face or frontage of a building; usually the one with the main entrance ("Facade", 2019).

Providing an enclosure to moderate the outer environment, and protection from extreme climatic conditions, natural disasters are primary incentive of the façade. Apart from that, due to the façade being the frontage of the building, it has received a lot of attention in the aesthetics, details, decoration and ornamentation throughout the history, and varying in appearance depending on the architectural style (Cikis, 2007). Therefore, the historical façade started acting as a blind wall, by covering the building and creating the face and the character of the building through different designs of entrances, materials, and fenestration. As it can be seen in Figure 2.9, the façade with its massive repetitive columns is working as a blind wall and forming the image and the identity to the building (Foster, Abel & Jenkins, 2002).

Figure 2.9: British Museum, London, UK, 1823 (Foster, Abel & Jenkins, 2002)

In addition of the façade being the frontage of the building, it is also a structural element transferring loads in load-bearing wall systems, although not much in contemporary buildings, since most of them are supported by framework systems and the façade is only an attachment to it. Hence, in the early 20th century with the structural framework system, it resulted in the free façade or the curtain wall, that does not transfer any structural loads from the building except from its own load. This freedom in the façade design leads to bigger openings and fully glazed façade, especially in high-rise buildings. Hallidie Building in California, USA was the first building to use the pure application of fully glazed curtain wall, in the year 1918, see Figure 2.10 (Cikis, 2007). Four decades after that, architects were much more concerned with façade aesthetics and views rather than on how façades can improve the energy performance of the building, until the oil shortages of the 1970s (Aksamija, 2013).

Figure 2.10: Hallidie Building in California, USA, 1918 (Cikis, 2007)

The curtain wall was a significant development in façade, aesthetically and structurally, however, the oil shortage of the 1970s and the advancement of digital technology influenced on the development of façade and resulted in intelligent façade and media façade. Intelligent façade is a dynamic façade, changing its parameters by the use of environmental control systems according to the outer changing conditions to optimize the overall performance of the building (Ahmed, Abel-Rahman & Ali, 2015). Media façade is another form of intelligent façade, where it uses light or animation to display a mood or specific information, for a means of communication and interaction between the building and its urban environment with the observer in the city (Kalčić, 2013). Kunsthaus Graz Museum in Figure 2.11 is an example of the media façade, it consists of 930 lamps that can be controlled individually to present films and images, which makes the façade a "communicative display skin" ("Kunsthaus Graz", 2012).

Figure 2.11: Kunsthaus Graz Museum, Graz, Austria, 2003 ("Kunsthaus Graz", 2012)

The constant development of technology in the building façade, is constantly making the role and responsibilities of façade bigger. The design of façade becoming a much more interdisciplinary and complicated work, with the integration of smart technologies, advance materials, aesthetics, new construction methods, energy efficiency, and most importantly sustainability. The development in façade has made it to have a major contribution to the overall sustainability of the building, from the social, economics, and environmental aspect.

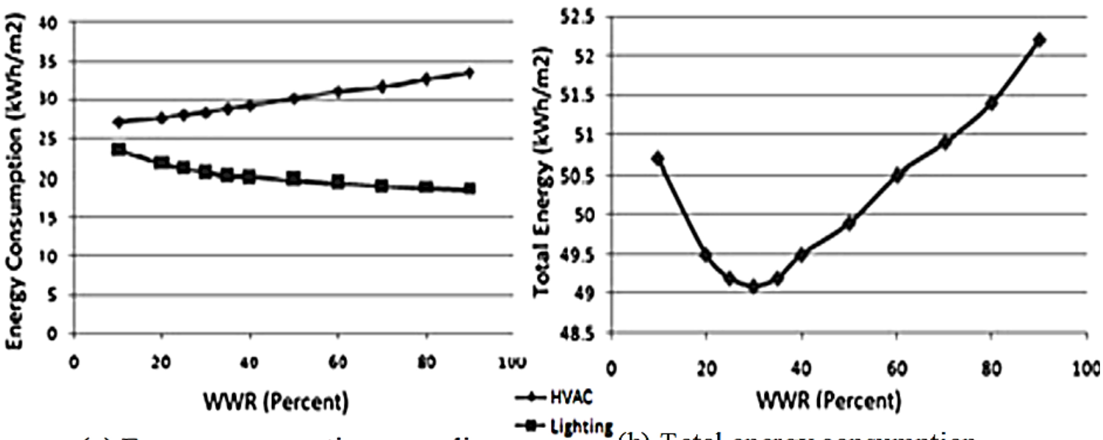
2.3.2 Sustainable Façade Design Based on Bioclimatic Principles

To design a façade by bioclimatic strategies and fulfill the bioclimatic principles, it is important to carefully go through the elements of façade design (window-to-wall ratio, window shape, window position, window glazing material, etc.), and understand what their performance depend on, and what is appropriate for each orientation, with accordance to the climate. By choosing façade elements with accordance to the orientation and climate, it fulfils the bioclimatic principles (improvement of visual comfort, improvement of thermal comfort, etc.) in the façade and overall building.

2.3.2.1 Window-to-Wall Ratio

Windows can become a major reason of the high energy consumption in a building, if it is not carefully designed, because oversize windows can deliver a significant amount of sunlight as well as a good view, but at the same time they may cause undesirable heat gains or losses that makes the building consume even more energy to make up for that, hence, it is important to know what size of the window can provide sufficient amount of daylight without causing overheating of the interior. The factor that determines the amount of sun radiation to transfer into the building is the Window-to-Wall Ratio (WWR). So therefore, WWR is a percentage that indicates the ratio of the window area to the building's exterior envelope (Tiew, 2012).

In a building simulation done by Didwania et al. (2011), where it examines the relation between Window-to-Wall Ratio (WWR) and energy consumption of the building. In the study it suggests by increasing WWR of a building the need for artificial lighting decreases, however, on the other hand it causes the energy on air conditioning to increase as well, as shown in Figure 2.12(a). Thus, the general effect of WWR on total energy consumption is shown in Figure 2.12(b), the graph has a U-shaped curve with the minimum energy consumption lying at approximately 30% WWR. The minimum energy consumption differs with different types of buildings and orientations (Didwania, Garg & Mathur, 2011). Therefore, when determining the WWR it should not only be looked at in relation to daylighting, but in general with the whole heat loss and gain and energy consumption.



(a) Energy consumption according to the HAVC and lighting

(b) Total energy consumption according to both HAVC and lighting

Figure 2.12: The Effect of Window to Wall Ratio (WWR) On Energy Consumption (Didwania, Garg & Mathur, 2011)

The optimum WWR with minimum energy consumption varies with accordance to the building location, orientation and type. The ASHRAE 90.2 (2018) energy standards suggests that window-to-wall ratio should not exceed 40% of the total envelope for all building types and climate zones in USA, and the window area be distributed equally in all four orientations (ASHRAE, 2018). In California Energy Commission (CEC) (2013) standards it suggests a maximum of 30% window-to-wall ratio for residential buildings in all climate zones in the state of California (CEC, 2013).

For a more detailed window-to-wall ratio on each orientation, a simulation study done by Yang et al. (2015), where the effect of WWR on thermal performance of residential buildings is simulated with all of its four orientations (north, south, east, west), in three locations having temperate climates (hot summer and cold winter). In Figure 2.13 the proposed ranges of WWR is shown with its effect on energy saving in four different orientations by using a Low-E glass window (Low-E glass is a type of glass with low-emissivity that reduces the emission of infrared and ultraviolet radiation, without effecting on the amount of visible light to pass through), in three different locations (Yang et al., 2015). It can be noticed from Figure 2.13 that the range and value of WWR for the north and south orientations is much wider and higher compared to the west and east orientations. As mentioned previously, the north and south orientations are more desirable in daylighting, and east and west orientations less desirable due to the excessive heat gain and sunlight during sunrise and sunset. Hence, the recommended ranges of WWR for temperate climate (hot summer and cold winter) in residential buildings for different orientations are 10% to 30% for east and west orientations, 30% to 60% for south orientation and 30% to 50% for north orientation.

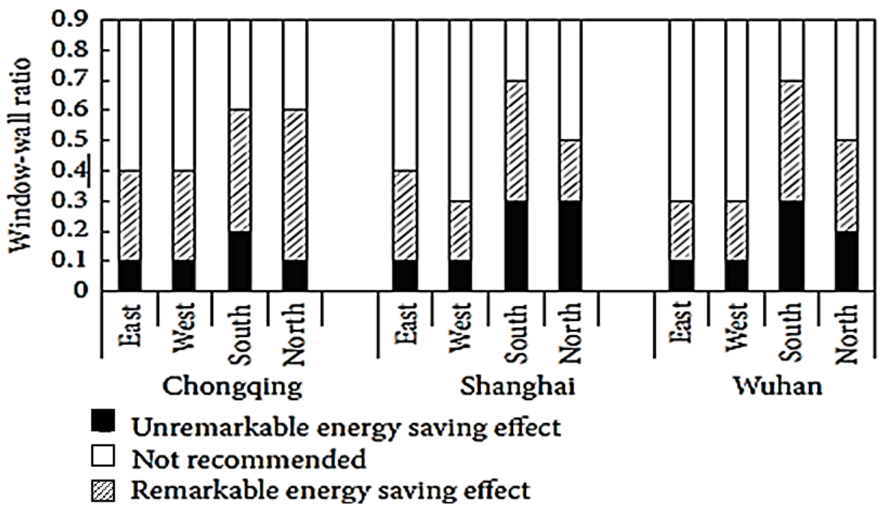


Figure 2.13: Proposed Range of Window-to-Wall Ratio with Accordance to Energy Saving and Orientations in Three Locations in China (Yang et al., 2015)

2.3.2.2 Window Shape and Position

The shape of the window and its position on the façade are one of the design criteria of window design. In a study by Acosta et al. (2016), the effect of window design on visual comfort and energy consumption examined through different window models having different geometries (square, horizontal, and vertical), positions (centered and upper), locations (Madrid, Munich, Stockholm and London) in residential buildings. It was concluded that all window shapes result in similar daylight values, and that the building energy consumption does not depend on it. Nevertheless, horizontal windows were slightly better in daylight values, distribution of illumination and energy saving than other shapes. It was also concluded that the upper position of widows is more preferable, as it provides a better daylight performance in the middle and back of the room, in addition, it saves energy in electric lighting by 10% in the middle of the room and 30% at the rear of the room (Acosta, Campano & Molina, 2016).

In another study by Bokel (2007), the window position (upper, centered and lower) having different sizes is analyzed in an office room in Groningen city in Netherland. The study resulted that the lower position of windows is disadvantageous when considering the totals energy demand (heating, cooling and lighting), in addition, it will probably not provide a pleasant view either. Moreover, the centered and higher position of window had similar effect on the total energy demand, but still the higher position of window is better than centered for lighting the areas far from the window (Bokel, 2007).

De Luca et al. (2016) did a research on whether vertical or horizontal windows perform better in energy saving. A model was simulated in three different locations (Tallinn, Milan and Cairo), and for sixteen different orientations of the window. The research conducted that the horizontal shape of window was the most preferable selection on the south quadrant orientations, and then on the east and west quadrant orientations for all three climates, although in most cases the differences in performances are negligible. However, for the orientations towards north the vertical window was more preferable (De Luca, Voll & Thalfeldt, 2016). In addition, guidelines for window design are presented in the book *Heating, Cooling, Lighting* by Lechner (2015). It is suggested in the guidelines that an upper position of the window is more desirable as it reaches the area that is far from the window, furthermore, it is also suggested to use a horizontal layout of window, and better spread out than concentrated, so that it provides a wide and uniform distribution of daylight.

In a study experimenting how much thermal performance indicators rely on building geometry by Rodrigues et al. (2015), six geometry-based building indices where analyzed (window shape and position being one of them) in eight different climates in residential buildings. The study concluded that none of geometry-based indices had a strong correlation to thermal performance in all eight locations. Especially, by the use of high insulation walls and high performance windows, the unwanted heat loss and gain through the building envelope is significantly reduced, hence, giving the architect more freedom in exploring building form. (Rodrigues, Amaral, Gaspar & Gomes, 2015).

It can be summarized from all these studies that the shape and position of the window on the façade does not have a significant influence on the visual comfort and building energy saving, but still the horizontal shape and upper position of the window are to some extent more preferable for a bioclimatic window design. However, the window position has an effect on the ventilation and air circulation within the room. For windows that are positioned on the same wall it is better to distribute them asymmetrically on the wall than symmetrically, because the asymmetrical positioning of windows on the wall causes differences in pressure on the windward wall, which results in ventilation unlike the symmetrical destitution where there is no pressure difference, see Figure 2.14 (Lechner, 2015). Nevertheless, even if the windows are symmetrically positioned on the same wall, adding fins to the side of windows to create pressure difference, results in a better air circulation within the room, as shown in Figure 2.15, (Brown & DeKay, 2001).

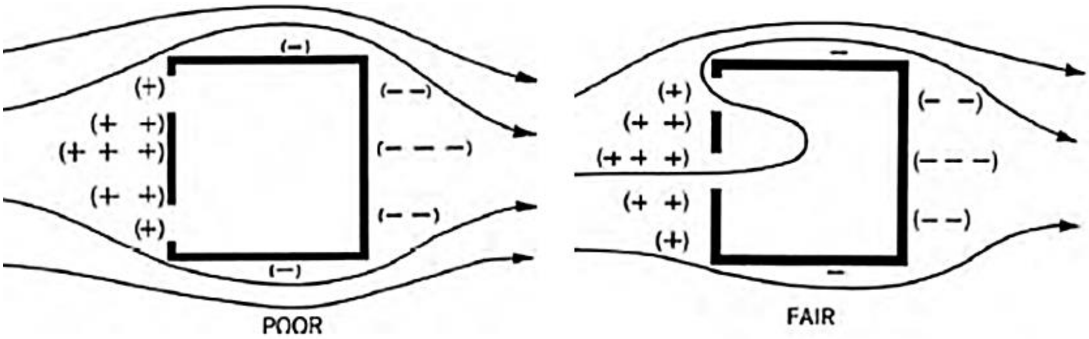


Figure 2.14: Window Positions on the Same Wall for Ventilation (Lechner, 2015)

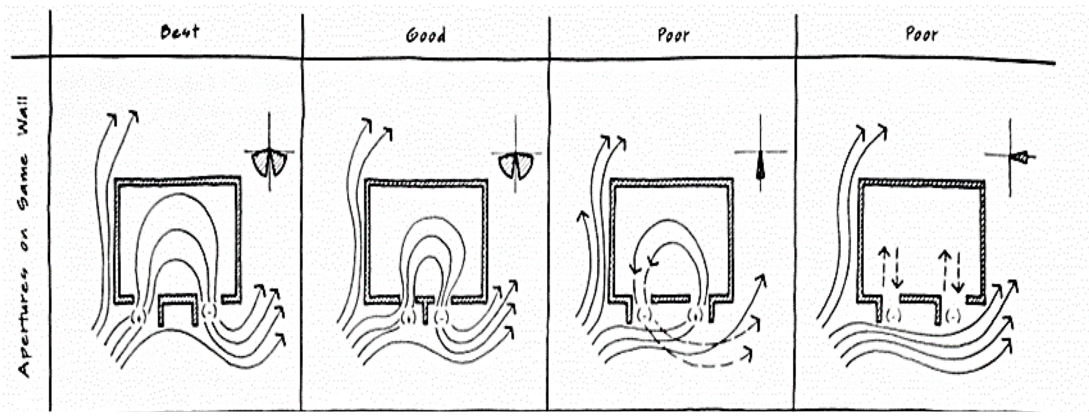


Figure 2.15: Window Fins for Increasing Ventilation Positioned on the Same Wall (Brown & DeKay, 2001)

2.3.2.3 Window Glazing and Framing Material

Windows is a primary element of the façade, the advancement of technology made a wide variation of glazing material that correspond to different environmental conditions like light and heat. Consequently, it is important to decide the right type of glazing so that the façade can be adaptive to its surrounding environment. The main criteria that makes these windows different from one and another is their U-value, solar heat gain coefficient and visible transmittance (Smith, 2005).

U-value in glazing is the measure of heat conductivity; it measures how much heat escapes through the window, and it is measured in (W/m^2 K), The lower the U-value, the better the window insulation and the lesser the heat loss. Secondly, the *solar heat gain coefficient (SHGC)* indicates the amount of solar heat (infrared radiation) gained in the interior through the window. A SHGC of 1 indicates that the window allows full transmission of the solar heat radiation, whereas a SHGC of 0 indicates no solar heat radiation passes through the window. Lastly, the visible transmittance (VT) is a measure of how much visible light is transmitted in via glazed area. A low VT indicates that a window lets through a low percentage of visible light into the interior Figure 2.16 (Omara, 2018). Table 2.5 shows the U-value, SHGC and VT of various types of glazing, and Table 2.6 shows the impact of orientation on the windows' U-values with solar heat gain.

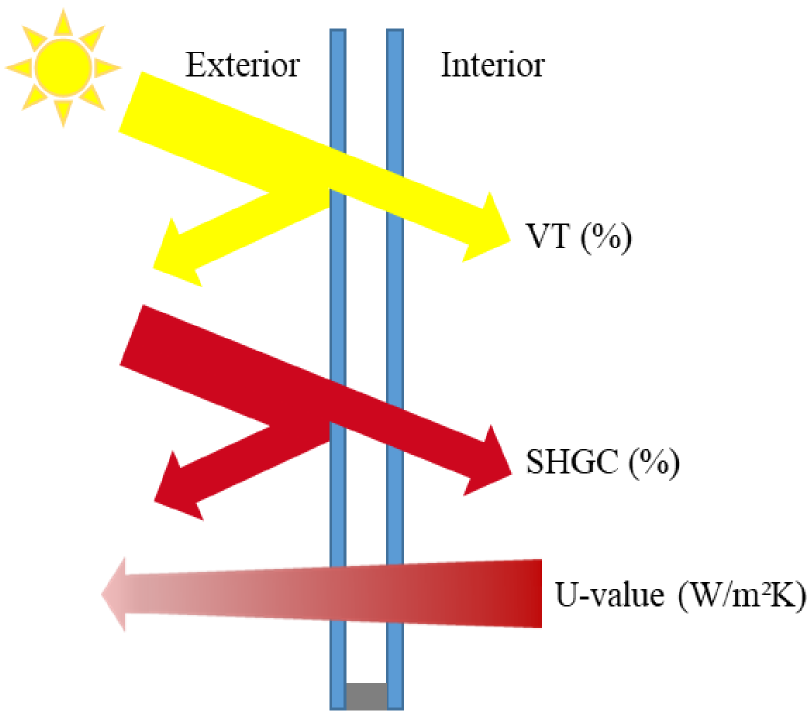


Figure 2.16: U-value, Solar Heat Gain Coefficient (SHGC) and Visible Transmittance (VT) (by author)

Table 2.5: Various Types of Glazing Performance Parameters (Cuce & Riffat, 2015)

Window	Glazing type	*U*-value (W/m^2 K)	SHGC	VT
A	Single, clear	0.84	0.64	0.65
B	Single, tint	0.84	0.54	0.49
C	Double, clear	0.49	0.56	0.59
D	Double, tint	0.49	0.47	0.44
E	Double, high performance tint	0.49	0.39	0.50
F	Double, high solar gain, low-e	0.37	0.53	0.54
G	Double, moderate solar gain, low-e	0.35	0.44	0.56
H	Double, low solar gain, low-e	0.34	0.30	0.51
I	Triple, moderate solar gain, low-e	0.29	0.38	0.47
J	Triple, low solar gain, low-e	0.28	0.25	0.40

Table 2.6: U-value with Solar Heat Gain in Different Orientations (Smith, 2005)

Glazing	U-value (W/m^2K) with solar gain		
	South	East/west	North
Single glazing	2.8–3.7	3.7–4.6	4.6–5.6
Double glazing	0.7–1.4	1.4–2.2	2.2–3.0
Triple glazing	0.0–0.6	0.6–1.1	1.1–2.4
Double with Low E	0.1–0.8	0.8–1.2	1.2–2.4
Triple with Low E	−0.5–0.3	0.3–0.9	0.9–1.6

Different types of windows have different visual and thermal performance, thus, serving different purposes. When cool daylight is required, which is when light but no extra heat is desired, then spectrally selective glazing should be used as a glazing material. As shown in Figure 2.17 in curve 3, it has a high performance in the visible light range but little to no transmittance in the infrared and ultraviolet range. However, when heat is required with daylighting, then a low-e glazing is recommended, as it has a high transmittance in both visible light and infrared, like shown in Figure 2.17 curve 2. In view windows, when neither heat nor light is required, then a low visible transmittance with low-e coating should be used, since it blocks some visible light and majority of the infrared radiation, as illustrated in curve 4 in Figure 2.17. Orientation of the window is also an important factor in determining the appropriate glazing material, as the window receives different amount of sunlight at different angles. A south-facing window receives an efficient amount of sunlight in both winter and summer. Moreover, if heat is required in the winter, then a high solar heat gain and clear glazing is preferred, if not then a high light-to-solar-gain with low-e coating glazing should be used. Glazing should be minimized in east and west orientation, due to intense sunlight that causes glare. Lastly, glazing with high visible transmittance is recommended for north orientated windows, since it does not receive sufficient sunlight (Lechner, 2015).

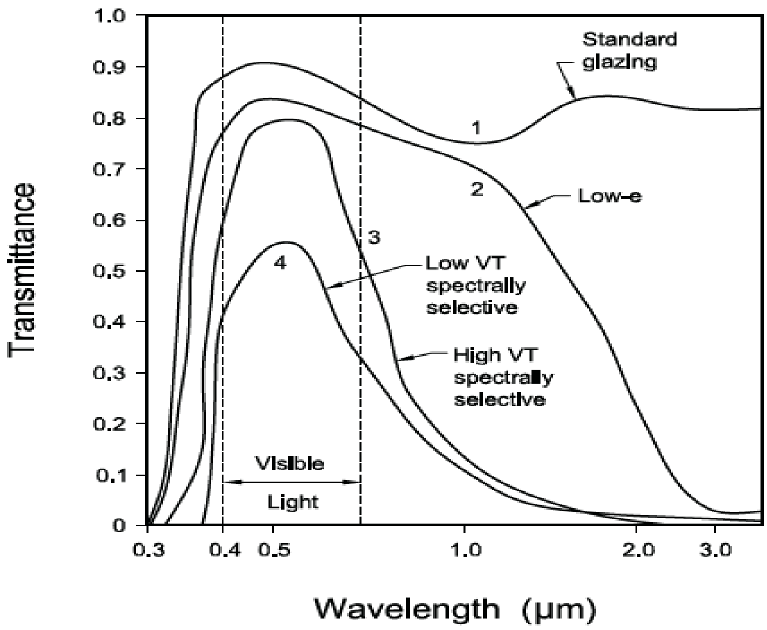


Figure 2.17: Selective Transmittance of Various Glazing Material (Carmody, Arasteh, Selkowitz & Heschong, 2007)

The window framing can be the weak point of the window design; without a proper frame installation it becomes a source of air leakage causing reduction in the thermal performance of the building. The thermal performance of window frames depends on the same factors as glazing material, the framing material has to have a low thermal conductivity and a low percentage of solar heat gain coefficient. The most common types of window frame materials are timber, aluminum, fiberglass and vinyl, their thermal performance is shown in Table 2.7 with a double window glazing type in residential buildings. Each of them perform differently and have their pros and cons, timber is a natural raw material with a low thermal conductivity but it has high maintenance, and it has a limited durability due to the influence of weather on it. Aluminum on the other hand has a high thermal conductivity, but it is durable. Vinyl is not a raw natural material and has a thermal performance similar to timber, but has low maintenance. As for fiberglass, again it is not a raw natural material, but it has the best thermal performance among them (Mempouo, Cooper & Riffat, 2010).

Table 2.7: Thermal Performance of Common Window Frame Materials (Mempouo, Cooper & Riffat, 2010)

Frame Material	U-value ($W/m^2 K$)	SHGC (ratio)	VT (ratio)
Aluminum	0.59	0.37	0.59
Timber	0.34	0.30	0.51
Vinyl	0.34	0.30	0.51
Fiberglass	0.26	0.39	0.44

2.3.2.4 Shading Devices as Sun Control

Shading is an effective strategy of reducing undesired solar heat gain in daytime in overheated periods of the year, as well as preventing the direct sunlight to cause glare. So therefore, shading devices are important elements in the design of façade, that need to be carefully designed with accordance to the location of the building, façade's orientation and to different seasons.

There are three main solar radiation components that need to be considered when shading a building, which are direct radiation, diffused radiation and reflected radiation, see Figure 2.18. The most vital radiation to shade is the direct radiation, since it has the most solar load, and it can be effectively controlled by exterior shading devices. Shading for diffused sky radiation should be considered in hot areas with high humidity having polluted and dusty air, as these particles in the air diffuse the solar radiation and can cause significant heat gain. The diffused sky radiation can be at times the hardest to shade as it has vast exposure angle, so it is shaded by additional interior shading elements. The reflected radiation can cause unwanted heat gain in the building, if the building is surrounded with high-reflected surfaces, which is usually the case in dense urban areas, having concrete paving, light colored walls, and wide glazing surfaces, all of them can reflect intense solar radiation into the building. There are some cases in which the north orientation receives more solar loads than the south orientation due to having high-reflective surfaces around the north orientation (Liébard & Herde, 2016). Such intense reflected radiations can be easily avoided and shaded by vegetation and plants.

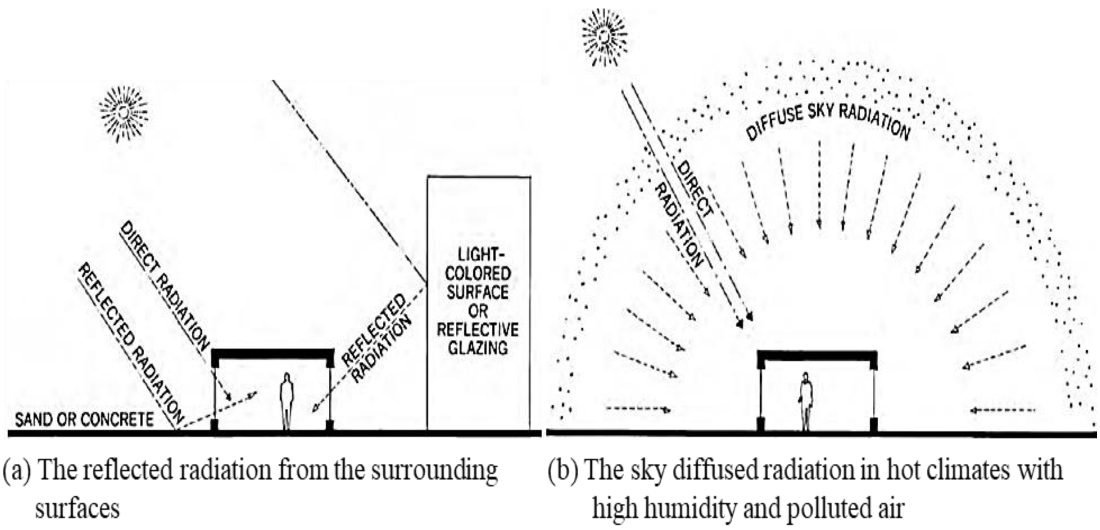


Figure 2.18: The Three Main Components (Direct, Diffuse, Reflected) of Solar Radiation (Lechner, 2015)

There are many strategies of shading, however, the exterior shading is much more effective than both interior shading and glazing materials that have the feature of shading. In general, there are three main types of exterior shading devices which are horizontal overhangs, vertical fins and a combination of both, and orientation is a dominant factor to determine the selection of the shading devices type. Horizontal overhangs and its variations are most effective in south orientated façades, since it blocks the high located sun to penetrate in summer but not the view, at the same time it allows the access of sun rays in winter due to the sun low angle. The horizontal overhangs are also effective in south-east, south-west, east, and west facing windows, although not as effective as it is in south-facing windows since the sun angle is low during sunrise and sunset, in addition, horizontal overhangs are not effective in north-facing windows (Rungta & Singh, 2011). When designing horizontal overhang for a window, the overhang has to extend on both sides of the window or using vertical fins on both sides of the window see Figure 2.19.

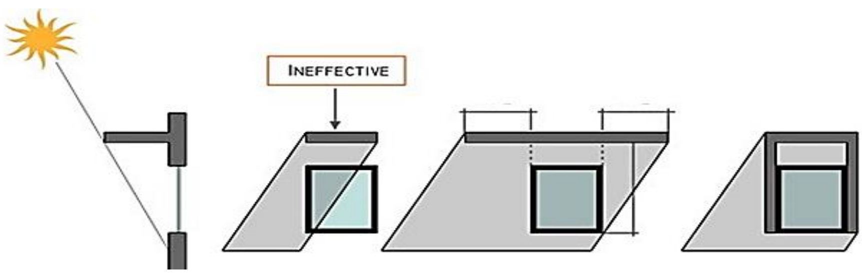


Figure 2.19: Extension of the Horizontal Overhang On Both Sides of the Window or Use of Vertical Fins (Munshi, 2015)

Vertical fins are most efficient for north-facing windows, especially for locations that have a long overheated period, however they can restrict the view. The vertical fins are ineffective for east and west orientated windows, as the spacing between the fins has to be very narrow to fully shade the low angle of the sun in sunrise and sunset, and this narrow spacing of fins almost blocks the view. However, slanted vertical fins are far more effective for east and west-facing windows, especially as there is a control over the direction of view. By using the slanted vertical fins in response to the daily movement of the sun, the view does not get obstructed and at the same time the necessary sunlight gets blocked (Rungta & Singh, 2011). For determining the dimensions of the horizontal overhangs and fins the following equation is used:

For overhangs:

$H = D \times \tan(A) / \cos(Z - N)$

For fins:

$W = D \times \tan(Z - N)$

Where height (H) is the length of the horizontal overhang's shadow on the window, width (W) is the length of the side fin's shadow on the window, and depth (D) stands for the width of the shading device. As for (A) it is the angle of shadow between the sun ray and surface perpendicular to the window, this angle of the shadow should be taken on the summer solstice, the longest day of the year. Moreover, (N) is the window azimuth angle and (Z) is the solar azimuth. The geometry and elements of vertical fins and horizontal overhangs are illustrated in Figure 2.20 (Zahiri & Altan, 2016).

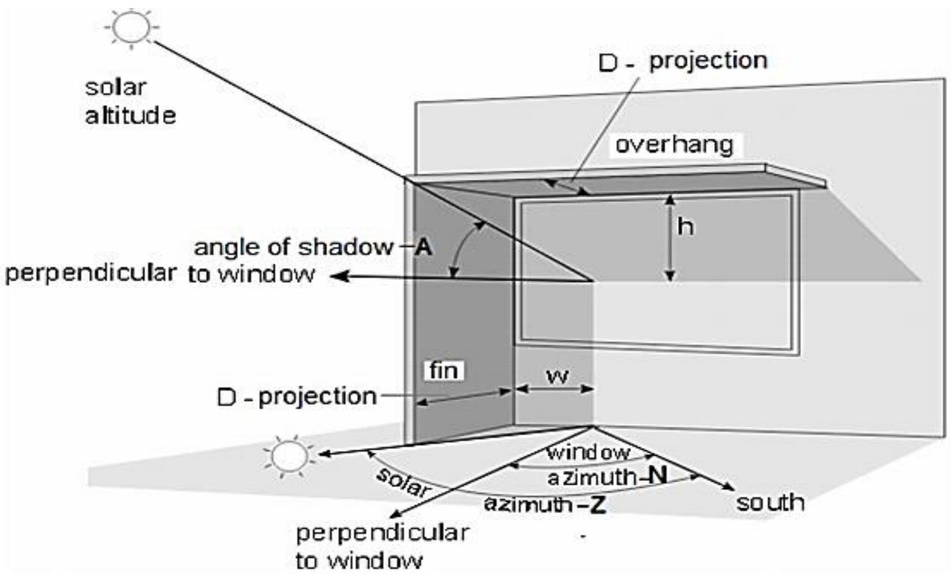
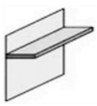
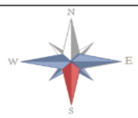
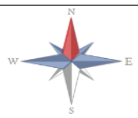
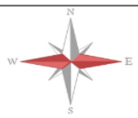
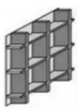
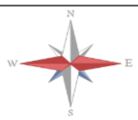


Figure 2.20: Geometry of Fins and Overhangs (Zahiri & Altan, 2016)

Another shading device that is a combination of horizontal overhangs and vertical fins is the egg-crate. This shading device is most effective for east and west orientated windows, and as well as southeast and southwest in very hot climates due to their high shading ratio. By having both horizontal and vertical elements, it can control the penetration of sun by both of its altitude and azimuth angle, and produce effective shading for windows. However, the view for such shading device is very obstructed, therefore, this type of shading device is not recommended if view or light is required (Munshi, 2015). In Table 2.8 different types of shading devices are listed with the most suitable orientation for it, with its relation to the view.

Table 2.8: Summery of Different Types of External Shading Devices (Rungta & Singh, 2011) (Munshi, 2015) (Lechner, 2015) (summarized by author)

Type of Shading Device		Best Orientation Secondary Orientation	Obstructed View	Comments
	Horizontal Overhangs			- Can be loaded by snow in cold climates - Can be designed slanted
	Vertical Fins			- Can highly restrict the view if used on east and west orientation, as the spacing between them is narrow
	Slanted Vertical Fins			- The fins slant toward north in hot climates and south in cold climates - Can have a wider spacing between them
	Egg-Crate			- It is used in hot climates, can be used in southeast and southwest orientations in very hot climates. - Traps hot air

2.3.2.5 Façade Materials

The material of the façade is an important element in façade design as it highly effects on the overall thermal performance of the building. The bioclimatic feature of materials differs from one and another in different climate zones. Vernacular architecture is an example on how it uses materials that are adaptive to its local climate, as it designs and constructs by solely using locally available resources based on its environment. By the use of climate adaptive materials, it can drastically improve the thermal comfort of the building, in addition, passive solar heating and cooling strategies cannot be effective if the suitable material with high insulation is not used. Not only locally available materials provide more comfortable thermal environment and decrease the overall energy consumption of the building, they also have a low embodied energy which is the amount of energy required in all of the associated process in producing a product ("Embodied Energy", 2019). The energy required to produce local material is less compared to conventional contemporary building materials that have high embodied energy from the operational energy in transportation, construction and maintenance (Chandel, Sharma & Marwah, 2016).

Materials that correspond to its local climate and having a high storage capacity and high effectiveness of thermal mass, they have the essential characteristic of conserving and absorbing heat, reserving and reducing heat loss, and later distributing the heat attained from solar energy. Materials effectiveness as thermal mass depend on some factors which are as follows:

Specific heat capacity: it is the amount of heat energy required to raise the temperature of every kilogram of material by 1°C. It is measured in J/kg.K ("Specific Heat Capacity", 2019).

Density: it is the mass of a material per unit volume, and is measured in units of kg/m^3 ("Density", 2019).

Thermal conductivity: it refers to the rate at which the heat passes through a material, and it is measured in W/m.K (Al-Homoud, 2005).

Emissivity: it the ratio between a material's surface ability to emit or absorb radiation compared to a black body under the same conditions. ("Emissivity", 2019).

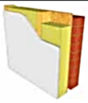
Materials that are effective thermal mass usually have a high thermal storage capacity, a high density, a moderate conductivity and a high emissivity. Materials such as masonry products are suitable for thermal mass as they have a high thermal storage, a moderate conductivity that allows the material to conduct heat and later distribute it in an appropriate period of time similar to the solar daily cycle, and high emissivity that promote absorption of heat rather than reflection of heat. In Table 2.9 is the thermal properties of common construction materials at room temperature.

Table 2.9: Thermal Properties of Common Materials at Temperature of 24 C° (CIBSE, 2006) (Tuohy, McElroy & Johnstone, 2005) (Walker & Pavía, 2015)

Material	Specific heat capacity (J/kg.K)	Thermal conductivity (W/m.K)	Density (kg/m^3)	Emissivity (ratio)	Thermal Mass Effectiveness
Brick	800	0.62	1700	0.85–0.95	High
Synthetic Carpet	2500	0.06	160	-	Low
Cellulosic Fiber	1380	0.042	43	-	Low
Concrete	1000	1.13	2000	0.85–0.95	High
Clay Bricks	1000	0.21	750	0.85–0.95	High
Dense Concrete Block	840	1.31	2240	0.94	High
Gypsum Plaster	960	0.51	1120	0.91-0.93	High
Mineral Fiber Insulation	710	0.036	100	-	Low
Steel	480	45	7800	0.074–0.097	Low
Stone	720	1.8	2200	0.90–0.93	High
Timber	1200	0.14	650	0.82–0.94	Low
Water	4200	0.6	1000	0.96	High
Ceramic	840	1.4	2500	0.90 - 0.94	Low

Material with very low thermal conductivity and low density such as mineral or cellulosic fiber are great insulator but have low thermal mass, therefore, to design a building with high insulation and thermal mass a combination of different material layers is used in the building envelope having different thicknesses, shapes, and surfaces. This helps the façade to save heat gain or reduce heat loss and reduce the building's dependence on mechanical systems for heating and cooling loads. In Table 2.10 different types of wall construction are illustrated with their admittance value, k-value and decrement factor. Admittance value is the ability of materials to exchange heat with a space when it is exposed to cyclic differences in temperature, the value shows the effectiveness of the material in practice as it takes into account the amount of time needed to get heat in and out of material typically in 24-hour period, as well as the resistance of the material surface to the heat flow, along with heat capacity, conductivity and material density. The higher the admittance value of a material the more desirable for thermal mass. Moreover, k-value which is measured in (kJ/m^2 K), indicates the heat capacity of a material per square meter, and the higher the k-value, the more the heat can be stored in the material, which makes it have a greater potential for thermal mass. Finally, the decrement factor, is the ratio between the different cyclic temperature on the inner surface compared to the outer. For instance, a wall having a decrement factor of 0.5 that experiences 10-degree daily variation on the outer surface of the wall, it will experience a 5-degree variation on the inner surface. Therefore, a wall with low decrement factor will guarantee a greater stability of the inner surface temperature, as well as helping reduce the risk of overheating (Saulles, 2012).

Table 2.10: Admittance Value, k-Value and Decrement Factor of Different Types of Wall Construction (Saulles, 2012)

	External Wall Material	Internal Finish Material	Admittance value 24 hours cycle (W/m².K)	k-value (kJ/m².K)	Decrement Factor (ratio)
	Brick and Timber Frame	Plasterboard	1.0	9	0.56
	Masonry cavity wall (100mm aircrete block)	Plasterboard	1.85	52	0.26
		Wet plaster	2.65	65	0.33
	Masonry cavity wall (100mm lightweight aggregate block)	Plasterboard	2.38	114	0.16
		Wet plaster	4.05	141	0.25
	Masonry cavity wall (100mm dense aggregate block)	Plasterboard	2.65	154	0.13
		Wet plaster	5.04	190	0.23
	Solid masonry (215mm aircrete block)	Plasterboard	1.74	52	0.12
		Wet plaster	2.45	65	0.15

2.3.2.6 Color and Texture of Exterior Building Surface

The color of the exterior surface has a significant effect on the thermal performance of the building, according to ASHRAE 90.1 (2019) the heat gain by a black wall is 33% more of the heat gain by a white wall (ASHRAE, 2019). Each color and material have different solar reflectivity or sometimes referred to as *albedo*, which is a percentage that measures the reflection of solar radiation from a surface. The closer the albedo to 0 the lesser the reflection of radiation, and vice versa. Figure 2.21 shows the albedo value of various surfaces. The effect of the façade's color on a building's thermal performance depends on the thermal mass of the façade material and the global solar radiation. The lower the level of a material thermal mass on one hand, and the higher the level of solar radiation on the other, the more the effect of façade's color on the building's thermal performance. In an experiment done by Cheng et al. (2005), where a room with no-window and ventilation had an air temperature 10 degree higher when it was colored dark than when it was colored white (Cheng, Ng & Givoni, 2005).

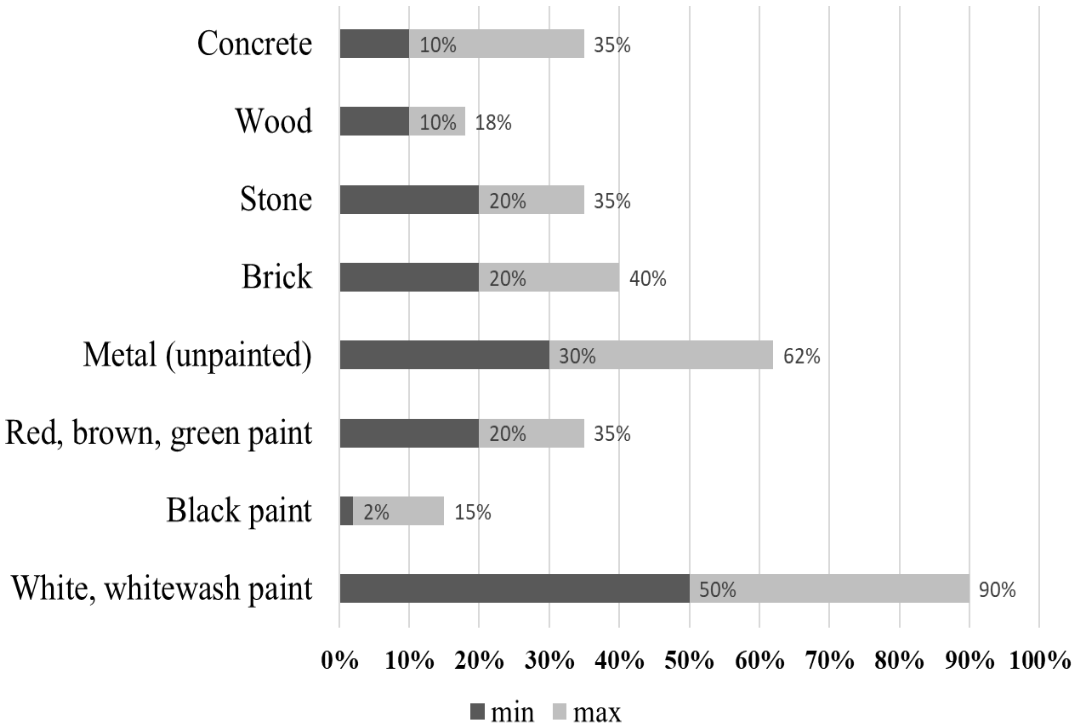


Figure 2.21: Albedo Values of Common Building Surfaces (Oke, 1987)

The color white in hot climates, and particularly on east and west orientations significantly reduces the amount of energy required for cooling buildings, since it fully reflects the heat gained from solar radiation. For a white surface to reflect light even more a rough textured surface of any scale is recommended as it reflects light in all directions unlike a smooth white surface, as shown in Figure 2.22 (Lechner, 2015). The color white is even recommended in cold climates. Theoretically, dark-colored surfaces absorb the heat from solar radiation, thus reduces heating loads in cold climates, however, practically that is not the case, due to the asymmetry of solar geometry. For instance, in a location having a latitude of 40° N, the daytime period is 15 hours on 21st of June, and on 21st of December it is only 8 hours, the sun will heat the building for 7 hours less daily in winter.

Moreover, the low altitude angle of sun in winter only partially lights the building surface, whereas in summer the high altitude angle of sun almost fully covers the building surfaces. In addition, dark-colored surfaces lose most of the gained heat from the cold wind in winter, as the wind is usually stronger in winter compared to summer (Bansal, Garg & Kothari, 1992). As a result, the application of light-colored surfaces is actually the simplest, highly effective, and economical way to improve the thermal performance of building in almost all climates.

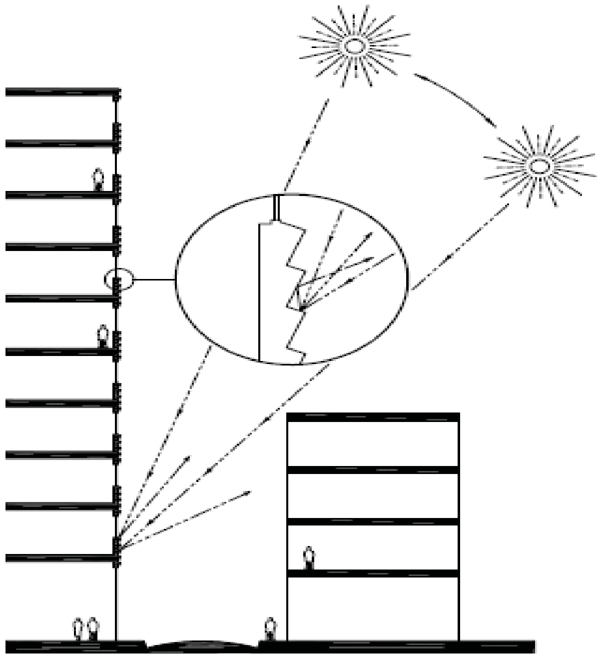


Figure 2.22: Increase of Solar Reflectivity by The Use of Jagged Surfaces (Lechner, 2015)

Chapter 3

EVALUATION OF HOUSING FACADES IN DUHOK CITY/IRAQ ACCORDING TO BIOCLIMATIC DESIGN APPROACH

3.1 Background on the City of Duhok

Duhok is the capital city of the governorate of Duhok, that is the northernmost governorate of Iraq having borders with Turkey. The city is the 3rd largest city of the autonomous Kurdish Region of Iraq, having approximately an area of 107 km^2. Duhok city is a mountainous area located 120 km away from the northwest of Erbil capital city of autonomous Kurdish Region and 470 km away from the north of Baghdad capital city of Iraq, with a latitude between 36º50′00″ and 36º54′40″ N of the equator and a longitude between 42º52′00″ and 43º04′44″ E and its about 430-450 m above the sea level (Mustafa, Ali, & Saleh, 2012). The governorate of Duhok has a population of 1,133,627, with the dominant ethnic group being Kurds and other minority groups being Arabs and Turkmen (KRSO, 2018). Administratively, the governorate is divided into seven districts which are Duhok, Simele, Zakho, Amadya, Shekhan, Aqrah and Bardarash (Omer, 2015). The city has liner rout organization as it is surrounded by two chains of mountains on both sides, Zawa in the southwest and Bekhair to the north and northwest of the city, and it has a small river that passes through the city called Duhok river Figure 3.1 (Mustafa et al., 2012).

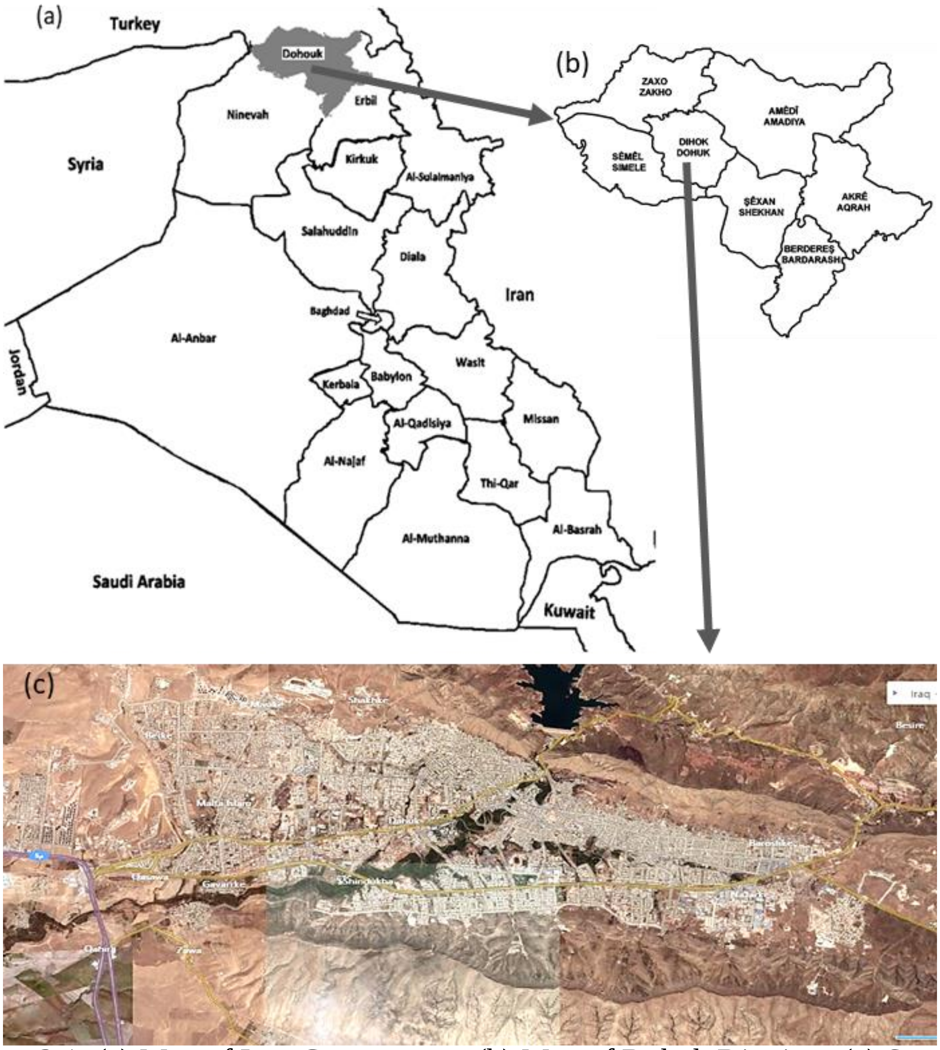


Figure 3.1: (a) Map of Iraq Governorate, (b) Map of Duhok Districts, (c) Satellite Image of Duhok City ("Bing Maps", 2019) (Omer, 2015)

3.2 Climate Data of Duhok City

The city of Duhok has a warm and temperate climate, according to Köppen-Geiger climate classification, Duhok city has a subtype climate of hot-summer Mediterranean climate (Csa) Figure 3.2. The (Csa) subtype climate is the most common type of the Mediterranean climate. Areas having this subtype of climate usually experience high temperatures during summers with no precipitation similar to the dry summers in arid climate, all areas in (Csa) climate receive high precipitation falls in winter with mild temperatures. Though, there are areas that have very cold winters with snowfall occasionally Figure 3.2 (Beck et al., 2018).

Duhok has an 810 mm of precipitation falls yearly and an average temperature of 18.5°C. the driest months with no precipitation of the year are June, July and August. Nevertheless, the warmest month with the highest temperature is July with an average temperature of 33°C. The month with the most precipitation falls is February, having an average of 156 mm. Duhok experience its coldest period and lowest average temperature in January, an average temperature of 5°C, see Figure 3.3. Moreover, there is a difference of 156 mm in precipitation between the driest and the wettest month and an average temperatures difference of 27°C between January and July.

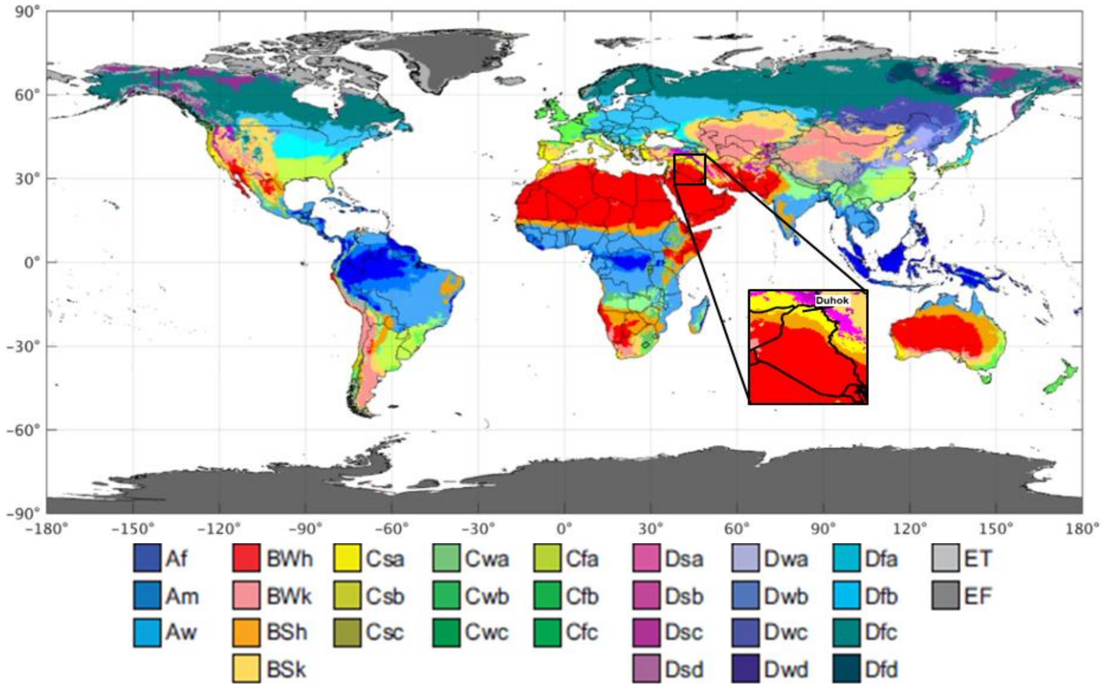
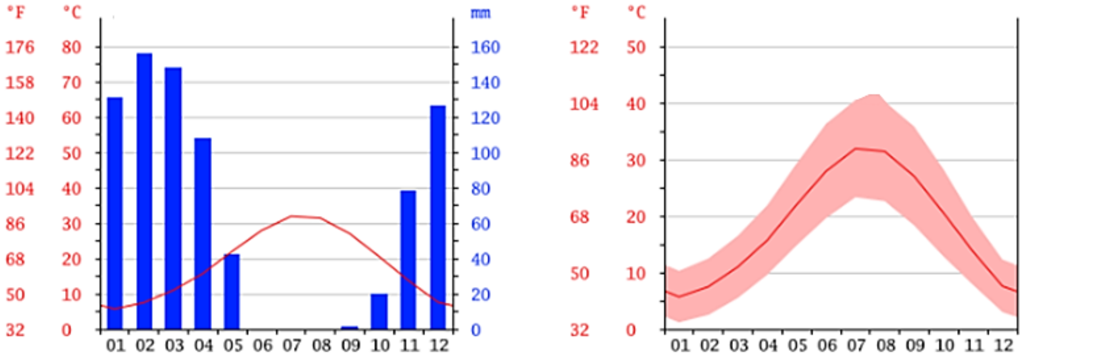


Figure 3.2: Present-Day Map of Köppen-Geiger Classifications (Beck et al., 2018)

The high percentage of humidity in Duhok are in winter, with December having the highest percentage of 62%, and summer having a low percentage with August having the lowest percentage of 18%, see Figure 3.4. Moreover, the highest monthly total of sun hours is in August with a total of almost 400hr, and December has a monthly total of 200hr which is the least amount, see Figure 3.5 ("Duhok Monthly Climate Averages", 2019). The sun path diagram of Duhok city is illustrated in Figure 3.6, on

21st June at 12pm the sun has a high altitude angle of 76°, on 21st of December it has an angle of 29° at 12pm, and on 21st of March and September it has an angle of 52° at 12pm ("Gaisma", 2019).



(a) Monthly average precipitation fall and temperature (b) Monthly maximum, minimum and average temperature

Figure 3.3: Monthly Precipitation and Temperature of Duhok City ("Dahuk Climate", 2019)

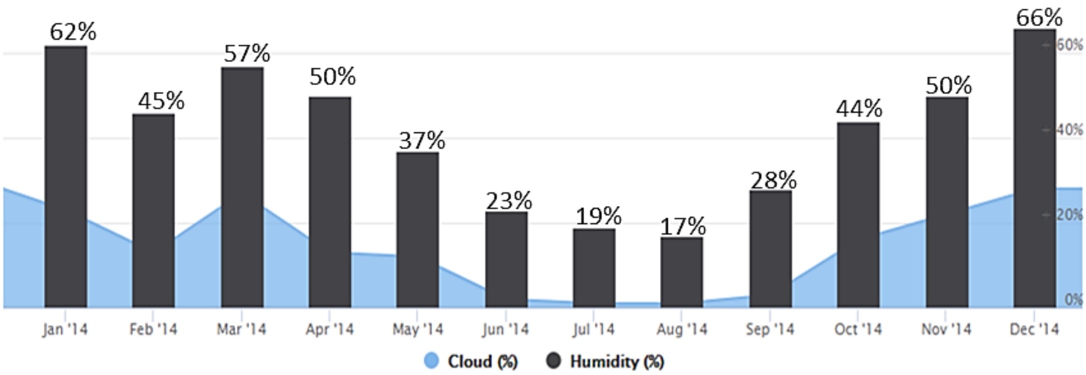


Figure 3.4: Average Cloud and Humidity of Duhok ("Duhok Monthly Climate Averages", 2019)

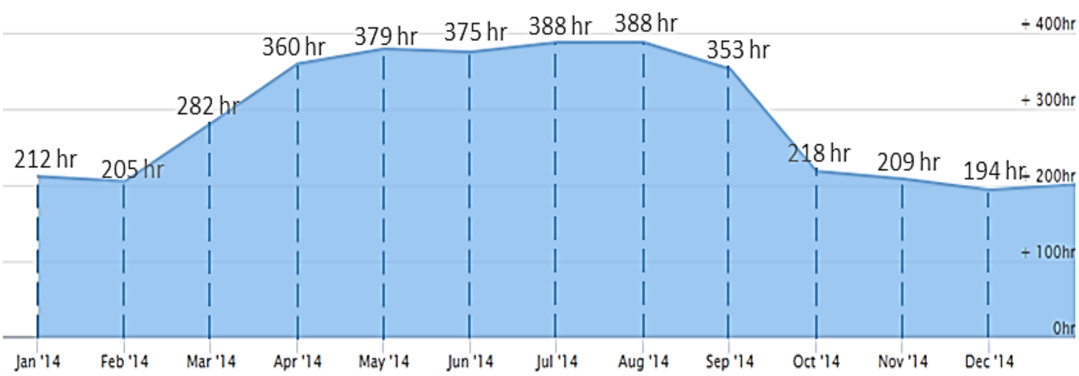


Figure 3.5: Duhok City Monthly Total of Sun Hours ("Duhok Monthly Climate Averages", 2019)

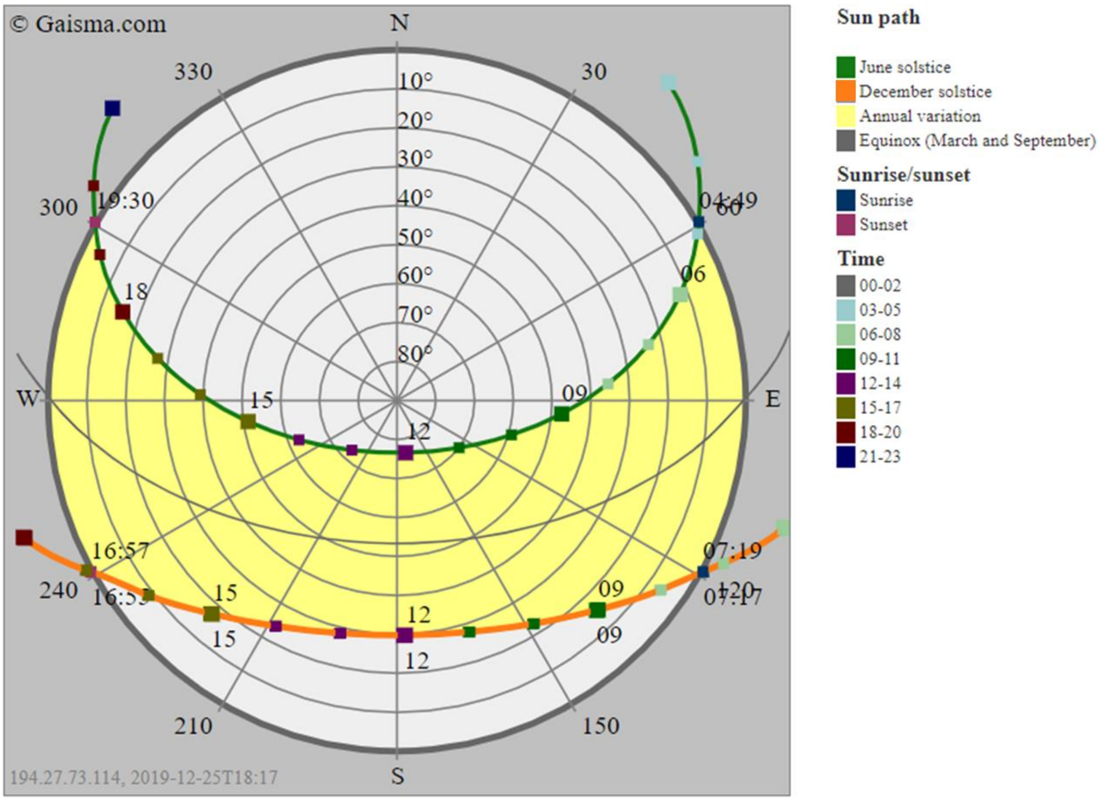


Figure 3.6: Duhok City Sun Path Diagram ("Gaisma", 2019)

3.3 Psychometric Chart of Duhok City

Since Duhok city has a hot-summer Mediterranean climate (Csa) (Beck et al., 2018), it experiences hot and dry summer where the temperatures go above 40°C and humidity goes below 17%, the city has cold and wet winters where the temperature goes down to 0°C and humidity goes up to 66%. Therefore, it can be seen in Figure 3.7 that the buildings in this climate needs various strategies to reach the comfort zone.

In Figure 3.7 the month of May, October and a small part of April are within the comfort zone. The months June, July, August, and September are within the cooling zone and a small part of the months July and August need night ventilation as well. But the majority of the year needs heating, where the months January, February, March, April, November, December and half of October are within the heating zone.

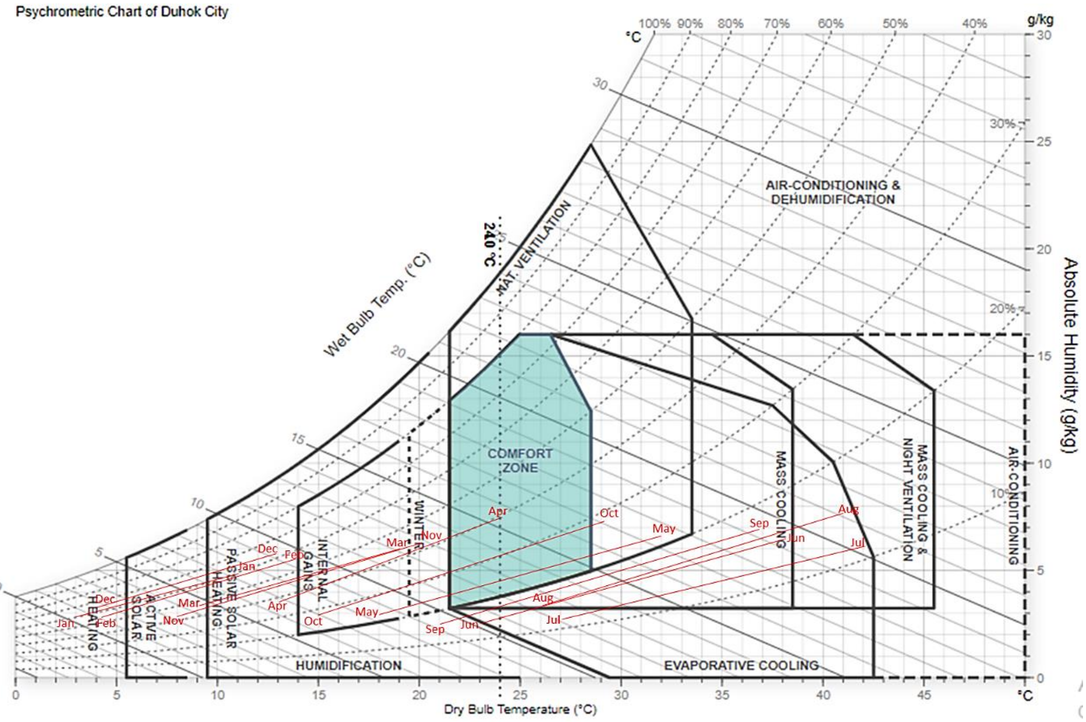


Figure 3.7: Psychometric Chart of Duhok City with Givoni Comfort Standards (Environment Directorate of Duhok Governorate, 2017)

3.4 The Social and Housing Development in Duhok City

Duhok city has been through six main different phases of urban growth transformations since 1947, those urban growth phases can be seen in Figure 3.10, and the land utilization in Figure 3.11. In phase one up to 1947, Duhok was not a city, it was only a small town settlement that had a population of 5,621, see Figure 3.8. During phase two (1947-1977), in year 1969 Iraqi Revolutionary Command Council decided to create the Governorate of Duhok that consisted of four districts. When Duhok city became the center district of the governorate, people started moving from villages to the city, and it has experienced its highest housing shortage of 36.7%, see Figure 3.9. Moreover, in the third phase (1977-1990) the urban growth continued in the city and the population increased drastically from 40,191 to 114,322. Throughout the fourth (1990-2003) and the fifth (2003-2008) phase, the city went through many internal wars and political changes, during the national uprising of Kurds in 1991 and the fall of

Iraqi Central Government in 2003. These internal wars caused a significant amount of internally displaced persons from south of Iraq into the city, which resulted in rapid population growth (from 114,322 to 212,469) and high housing shortage of 32.65%. During the sixth phase (2008-2014), the population growth was more steady and the housing shortage decreased to 10.12% (Omer, 2015). However, the exact data of population statistics and surveys are not available after 2014; after the invasion of Islamic State of Iraq and Syria (ISIS) into Iraq. Yet, according to the Coordinator for International Advocacy of the Kurdistan Regional Government (KRG) the city received a number of 490,000 internally displaced persons and refugees (Shilani, 2019). Therefore, it is evident that the city has went through a lot of unexpected crises of overpopulation and housing demand. The data on the housing shortage in 2014 is at 14.5%, but evidently the shortage is more than that now, as the city has received a number of refugees that is larger than its own population.

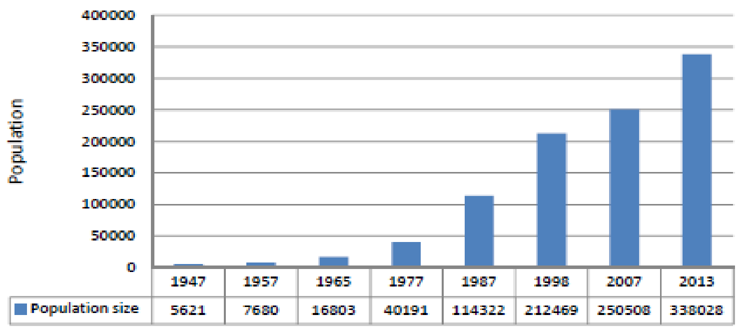


Figure 3.8: Population of Duhok City Since 1947 to 2013 (Omer, 2015)

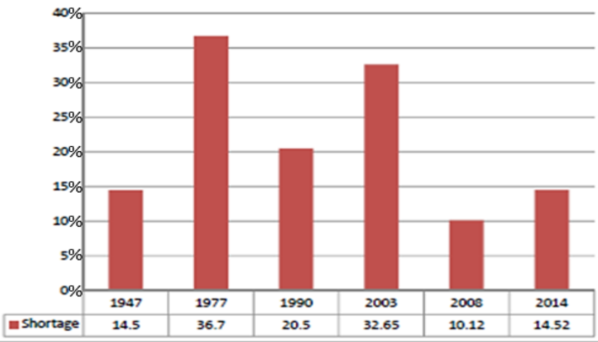


Figure 3.9: Housing Shortage of Duhok City since 1947 to 2014 (Omer, 2015)

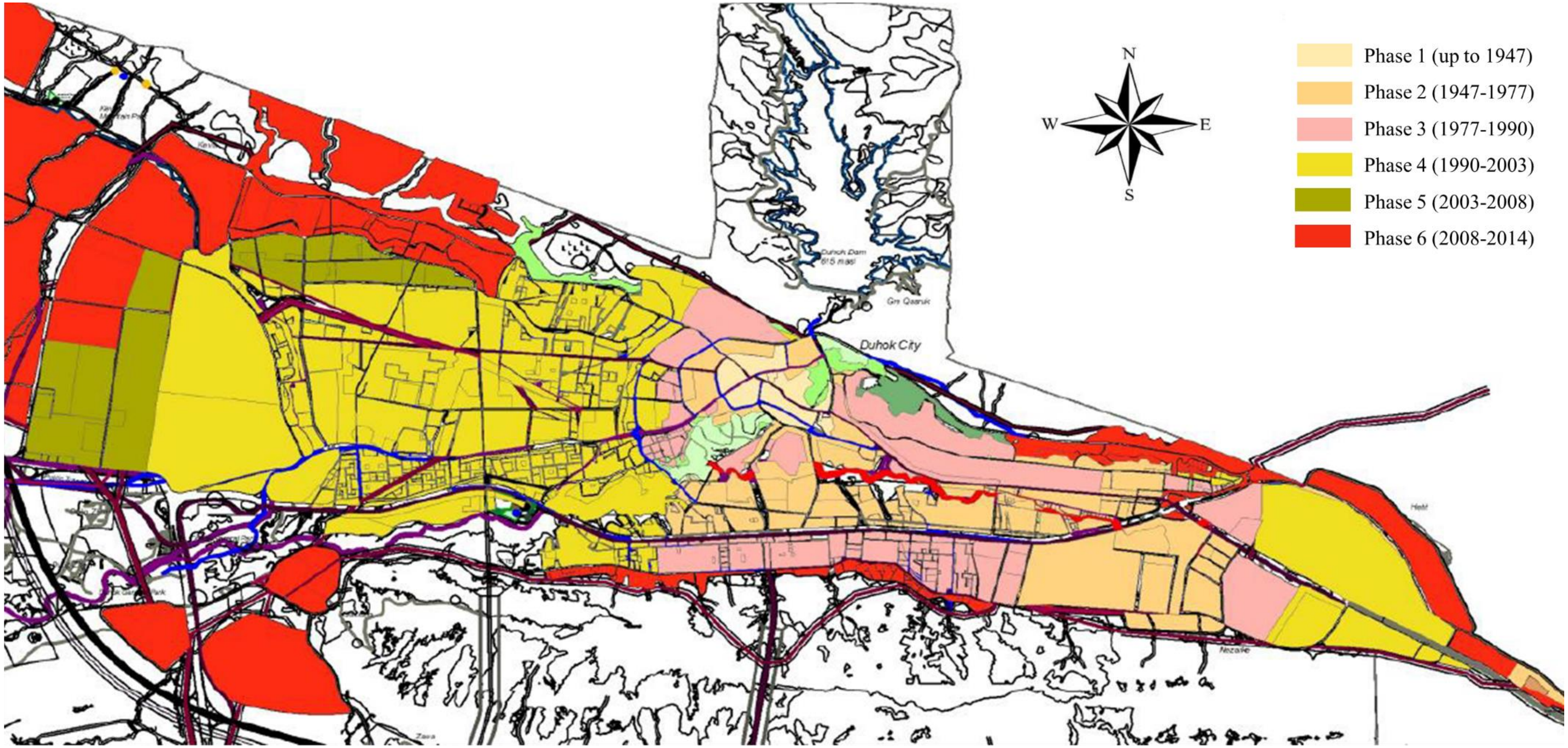


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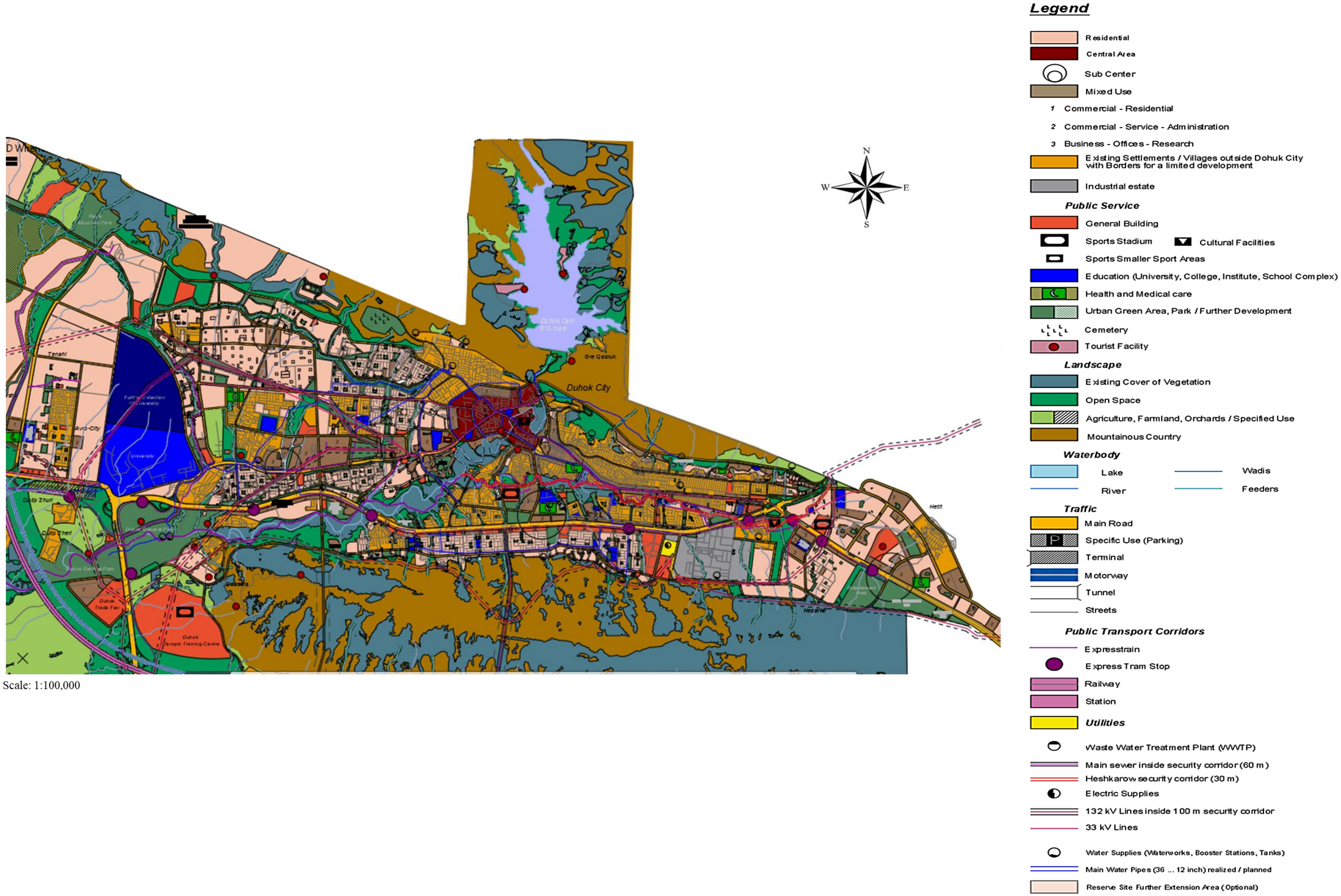
Figure 3.10: Duhok City Urban Growth Since 1947 (Urban Planning Directorate of Duhok Governorate, 2007)



Scale: 1:100,000

Figure 3.11: Land Utilization of Duhok City (Urban Planning Directorate of Duhok Governorate, 2007)

3.5 Different Housing Typologies as Case Studies

During the end of phase 4 (1990-2003) and the beginning of phase 5 (2003-2008) of Duhok urban growth, where there was a significant percentage of housing shortage (32.65%), a conventional type of houses emerged in that period, the concerned area of such houses is highlighted in Figure 3.12. The plots distributed during that phase had an area of 200m^2 (10m×20m), the design of those houses attempt to make the most use out of the plot area. Almost all of those houses are fully attached to its neighboring houses from three of its sides. Those houses share the same design characteristics in spatial distribution and in façade design as well, despite having different locations and orientations. Nonetheless, the houses either have 1,2 or 3- storeys, which makes the houses have different surface and façade area. Therefore, three houses each having a different number of storeys will be taken as case studies.

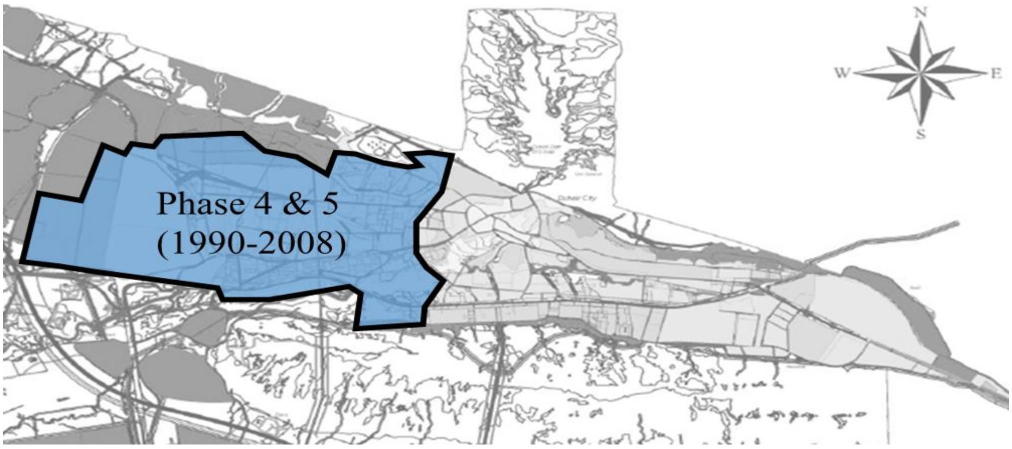
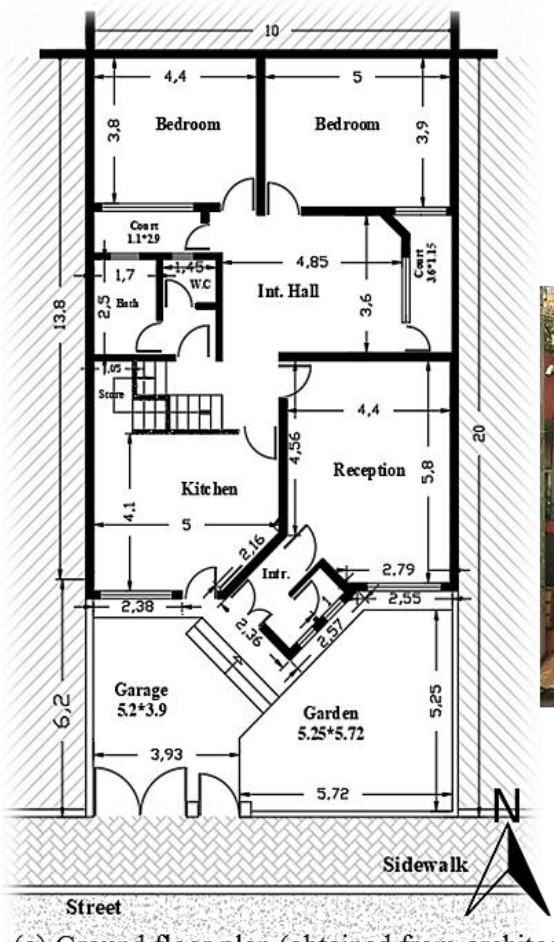


Figure 3.12: The Area of the Case Study Houses

3.5.1 Case Study 1: Attached One-Storey Dwelling (Type I)

This house type consists of one floor, like shown in Figure 3.13 there are two bedrooms at the back of the house that have windows to a small court (light shaft), and on the front part of the house there is the kitchen, reception and a small bathroom, as well as a small garden and garage at the front of the house, which are surrounded by a 2m high wall. In addition, the house has a flat roof that extends half a meter over the façade. The selected house of this type is located in Shreen Street as shown in Figure 3.14, and the sun path diagram of the location is illustrated in Figure 3.15 where the sun angles on 21st of June at noon is highlighted. The improvement of this house façade will be attempted from four orientations, so that it can be a reference to all of the other houses that share the same design but have different orientations.



(a) Ground floor plan (obtained from architect)
Scale 1:200

(b) Main façade (photo taken by author)

Figure 3.13: Plan and Façade of Case Study 1

Figure 3.14: Location of the Case Study 1 ("Bing Maps", 2019)

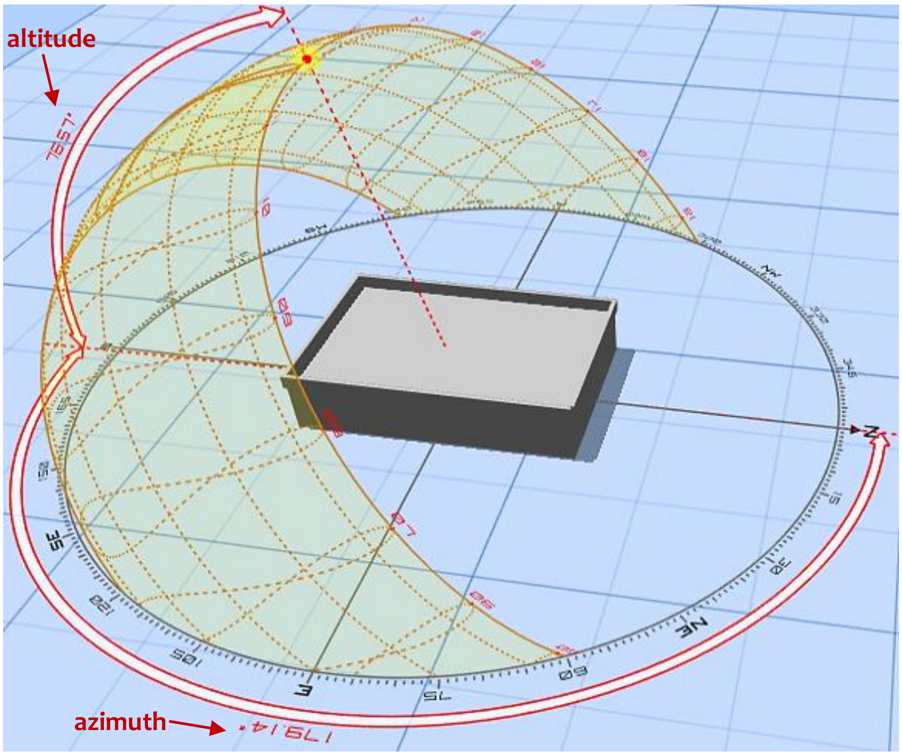


Figure 3.15: Sun Path Diagram of Case Study 1

3.5.2 Case Study 2: Attached Two-Storey Dwelling (Type II)

This type of the house shares a ground floor similar to the previous case, nonetheless, on the first floor there is one bedroom and one bathroom at the back of the house that have windows to a court (light shaft), as for the front part there are two bedrooms with balconies and a bathroom, see Figure 3.16. Like the one-storey houses it has a garage and garden at the front of the house, and again the flat roof is extended over the front façade, see Figure 3.17. The selected house of this type is located in Gazok Street like shown in Figure 3.18 and it will be taken as a reference to all the other houses that share similar design. The sun path diagram of the house is illustrated in Figure 3.19 and the sun angles of 21st of June at 12pm are noted.

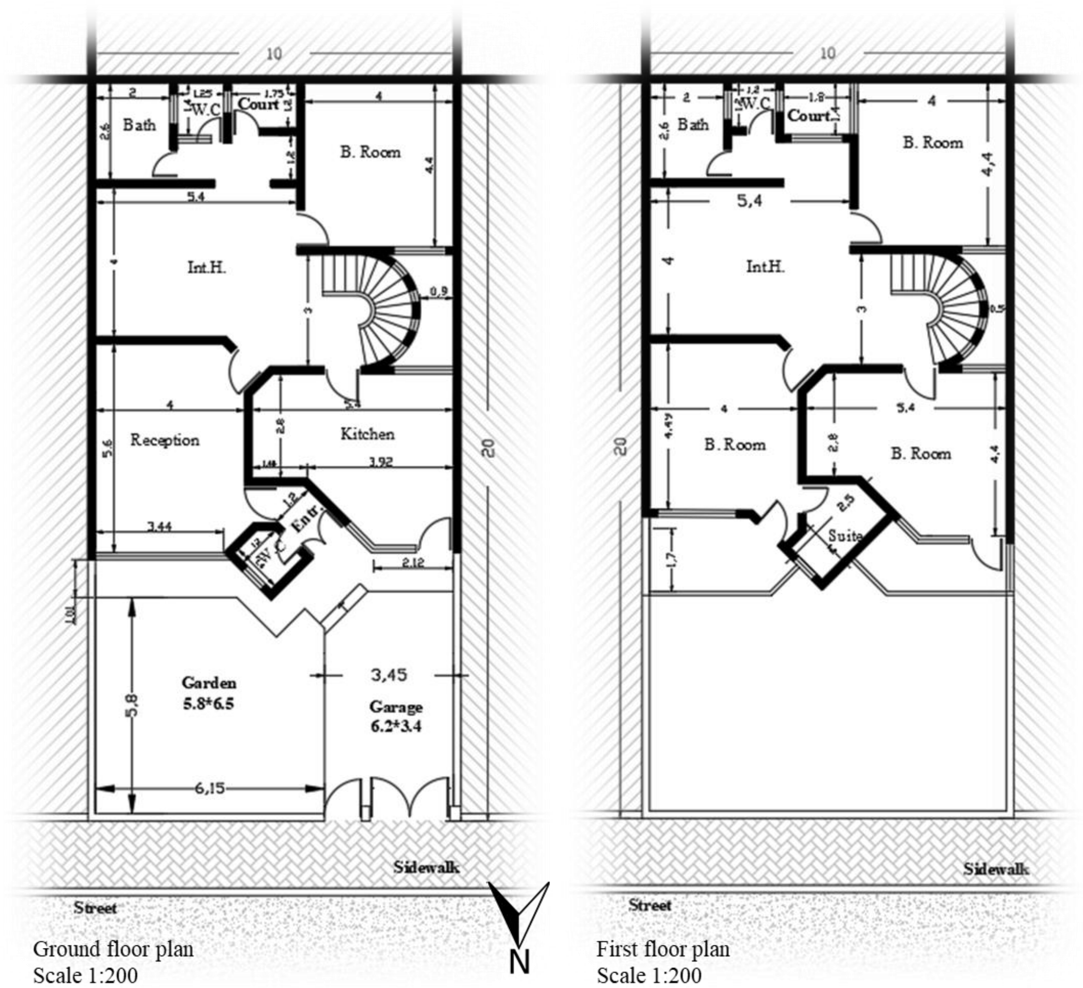


Figure 3.16: Plans of Case Study 2 (obtained from the architect)

Figure 3.17: The Façade of the Case Study 2 (taken by the author)

Figure 3.18: Location of the Case Study 2 ("Bing Maps", 2019)

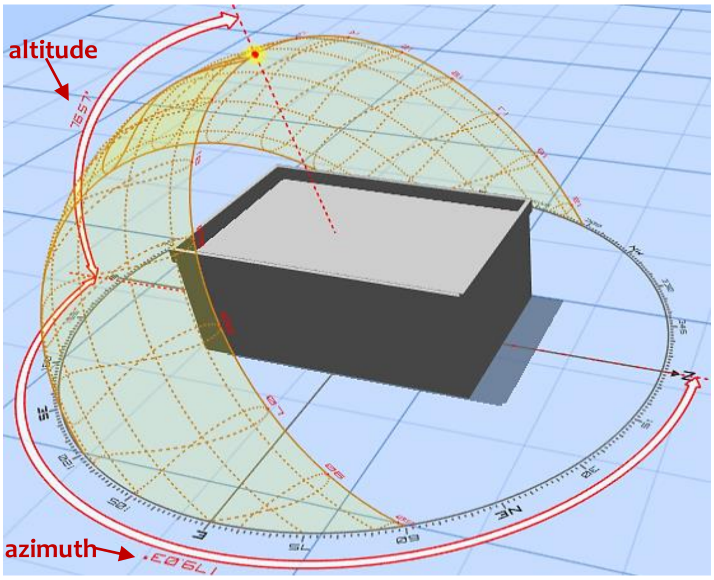


Figure 3.19: Sun Path Diagram of Case Study 2

3.5.3 Case Study 3: Attached Three -Storey Dwelling (Type III)

This type of the house is basically like the previous case only that it has the whole ground floor as a garage. Then on the first floor there is the kitchen and reception like the ground floor of the two-storey house, and bedrooms on the second floor like the first floor of the two-storey house, like shown in Figure 3.20. In this house type the garage is bigger since it is on the ground floor, and the garden is on the first floor at the front of the house, Figure 3.21. The house selected as a case study is located on Awat Street where there are six houses with exact same design, see Figure 3.22. In Figure 3.23 the sun path diagram is shown for the case study with the angles of summer solstice at 12pm. The house will be a reference to all the other houses that share the same design characteristics.

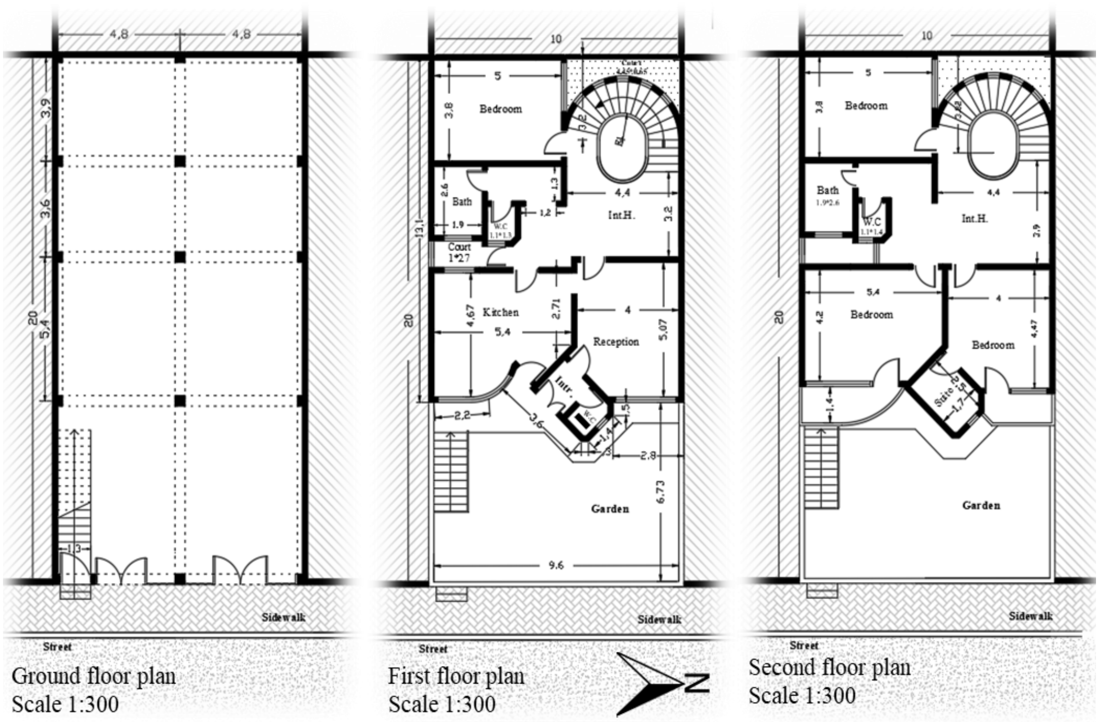


Figure 3.20: Plans of Case Study 3 (obtained from the architect)

Figure 3.21: The Façade of the Case Study 3 (taken by the author)

Figure 3.22: Location and Street Façade of the Case Study 3 ("Bing Maps", 2019)

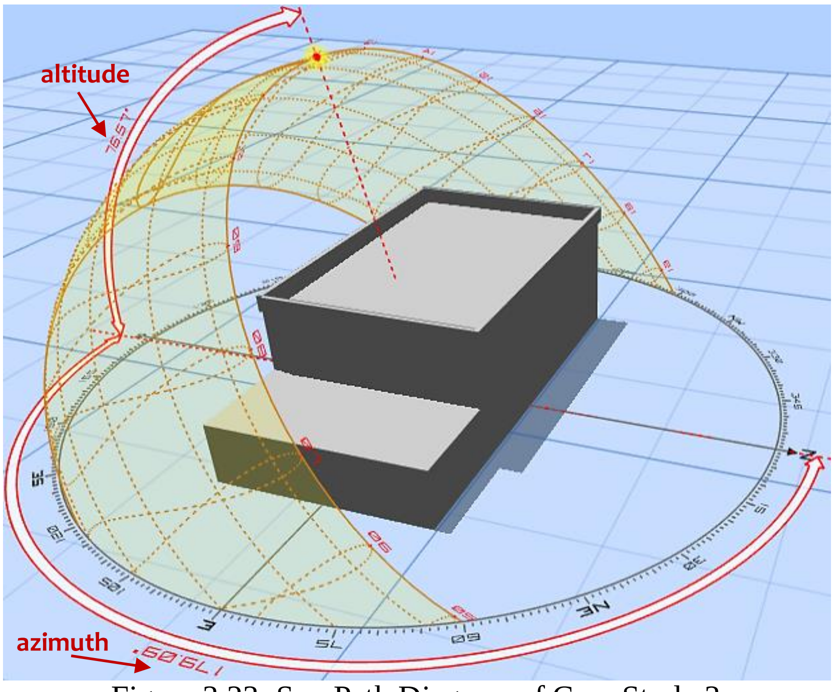


Figure 3.23: Sun Path Diagram of Case Study 3

3.6 Analysis of Housing Facades Elements

In this section the façade design of the case studies will be analyzed by going through the elements of façade design (window-to-wall ratio, façade material, window position, window glazing material, etc.), to know where they lack consideration towards their climate and what the weaknesses are. Knowing the weaknesses will help to know how the façades can be improved to fulfill the bioclimatic principles (improvement of visual comfort, improvement of thermal comfort, etc.).

3.6.1 Window-to-Wall Ratio

Type I of the houses has a surface area of 290m^2, while type II has 424m^2, and type III 672m^2. But more importantly, the main façade of type I has an area of 36m^2 with a south orientation, and a window-to wall ratio of 21%. Type II has a north-facing façade with an area of 68m^2, and having a window-to-wall ratio of 29%. Lastly, type III has an area of 100m^2 on its east-facing façade, and a window-to-wall ratio of 22%.

3.6.2 Façade Material and Color

The main building material are concrete blocks in all three types. As for the finishing material, both type I and type II has a smooth cement plaster and there are some ceramic tiles on type 1 house, but type III house has a rough cement plaster with some rough stone tiles. In regards to the finishing color, type I house is mainly red with lesser white, type II has a light green color, and type III house has a light beige color.

3.6.3 Window Glazing and Framing Material

Type I house has a single layer and clear glazing windows; type II house has double layer glazing with no tint, and type III also has a double layer windows but with tinted glazing. As for the window framing material, both type I and type III have a PVC window framing, but type II has an aluminum window framing.

3.6.4 Window Shape and Position on the Façade

The windows are positioned on the center of the wall for all rooms in all three cases. As for the shape of the windows, all of the three houses have square shaped windows for all rooms on the façade, except for the kitchen window as it has a horizontal window shape.

3.6.5 Sun Control and Glare Prevention

In type I, the roof shades the windows as it extends 0.5m over the façade and it is 0.5m above the window. In type II and III the windows shading is similar, there is no specifically designed shading devices for the windows, the two balconies on the upper floor extend over the reception and the kitchen windows, and the roof extends over the two bedrooms' windows on the upper floor and they are also placed 0.5m above the windows. The balconies and the extension of the roof are the only means of sun control and glare prevention in all of the three case studies. Lastly, in Table 3.1 the façade analysis of all three cases are summarized.

Table 3.1: Summary of Three Case Studies' Façade Analysis

	Type I	Type II	Type III
Orientation	South	North	East
Envelope Area (m^2)	290	424	672
Façade Area (m^2)	36	68	100
Window-to-Wall ratio (%)	21	29	22
Façade Material	Concrete Block	Concrete Block	Concrete Block
Finishing Material	Smooth Cement Plaster and Ceramic Tiles	Smooth Cement Plaster	Rough Cement Plaster and Stone Tiles
Exterior Surface Color	Red and White	Light Green	Light Beige
Exterior Surface Texture	Smooth	Smooth	Coarse
Window Glazing Material	Single and Clear	Double and Clear	Double and Tint
Window Framing Material	PVC	Aluminum	PVC
Window Position	Centered	Centered	Centered
Window Shape	Square and Horizontal	Square and Horizontal	Square and Horizontal
Window Shading	0.5m Horizontal Overhang, Placed 0.5m above Window	Ground Floor: 1m Horizontal Overhang, Placed 0.5m above Window First Floor: 2m Horizontal Overhang, Placed 0.5m above Window	First Floor: 1m Horizontal Overhang, Placed 0.5m above Window Second Floor: 1.5m Horizontal Overhang, Placed 0.5m above Window

Chapter 4

DISCUSSION AND RECOMMENDATIONS

4.1 Results of Analysis

This section will discuss the results of case studies analysis, to know how their weaknesses can be improved by bioclimatic means towards a more sustainable house and lastly summarized into a table of recommendations.

It can be seen from the analysis in chapter 3, that the problem in the houses' façade design starts at a much smaller scale; it starts from an urban scale. Due to the high housing shortage during that period the distributed plots where narrow (10m×20m), and there were no building regulations by the authorities where there has to be a set back from the plot. Therefore, the house owners build the houses attached to the plot from three side, and having only a set back from the street side.

This attachment between the houses caused many daylighting and ventilation issues in the spaces at the back of the house, where their only source of daylighting and ventilation is from a small light shaft. Because it is not rational to rebuild all these houses that take up most of the city, as well as, the full attachment between the houses, makes the main and the only façade of the house play a big role to the comfort of the interior. So, it is crucial that these façades can be designed according to their climate and orientation.

In the forthcoming parts, the improvements for the façade design will be proposed based on bioclimatic principles for all three case studies, but including four main orientations (north, south, east and west) instead of the three orientations of the case studies.

4.1.1 Thermal Comfort

The window-to-wall ratio (WWR) of the façade effects on the thermal and visual performance of the building. The ASHRAE 90.2 (2018) energy standards recommends that the WWR should not exceed 40% to avoid overheating from excessive sunlight inside the building and excessive energy consumption. However, the California Energy Commission (CEC) (2013) standards recommends that the WWR should not exceed 30% for residential buildings in State of California. The state of California shares the same temperate climate of Duhok (Beck et al., 2018), as well as the same latitude, where Duhok has a latitude of 36.833° N and California has a latitude of 36.7947° N ("GPS Coordinates", 2019).

The effect of WWR on thermal performance of residential buildings done by Yang et al. (2015) in temperate climate which is the same climate of Duhok, suggests 10% to 30% for west and east orientations, 30% to 50% for north orientation and 30% to 60% for south orientation. Therefore, anywhere between 10% to 30% is sufficient for the thermal comfort of the case studies with east or west orientations, at the same time this percentage is not exceeding the California Energy Commission (CEC) standards. Hence, east and west oriented houses of type I should have a glazing area between $3.6m^2$ to $10.8m^2$, type II house would have a window area within $6.8m^2$ to $20.4m^2$, and type III houses would have glazing area of $10m^2$ to $30m^2$. As for north oriented façades Yang et al. (2015) recommends 30% to 50% and 30% to 60% for south-facing façades, but this percentage range exceeds both 30% of California Energy Commission and

40% of ASHRAE 90.2 standards, so 30% of WWR is suitable for the case study houses that are oriented to north and south. Which will make type I house have a glazing area of 10.8m^2, type II house will have an area of 20.4m^2, and type III house will have a window area of 30m^2.

Another façade element that effects on the thermal comfort of the building is the window glazing and framing material. The type I house had a clear and single layered glazing, which is almost never recommended as it has a high percentage of solar heat gain coefficient (SHGC) (64%) and a high U-value (0.84 W/m^2. K) and it causes unwanted heat gain. Type II and type III house double layered glazing which has efficient percentage of SHGC (47%) and U-value (0.49 W/m^2. K) (Cuce & Riffat, 2015). Furthermore, the recommended window material for north and south-facing windows in the three case studies is glazing with high solar heat gain, since heat is required in the cold winters of Duhok city. However, high solar heat gain is not recommended in east and west oriented windows due to intense sunlight that causes overheating, a glazing with low-e coating is required (Lechner, 2015). As for the framing material type I and type III house has PVC window frame and type II house has aluminum framing. PVC is sufficient material for window framing as it has longevity and performs well thermally as it has a low U-value (0.34 W/m^2. K) and SHGC (30%). But the aluminum framing in type II house have a poor thermal performance, as it has a high U-value (0.56 W/m^2. K) and SHGC (37%) (Mempouo, Cooper & Riffat, 2010).

External shading devices of windows control the amount of sunlight that enters the building, which effects in the heat gain and the thermal comfort inside the building. From the analysis of the case studies in chapter 3, it was evident that the shading devices in all case studies were the same although they had different orientations, the shading was not specifically designed, they were only an extension of the upper floor or the roof over the windows. Moreover, for south-facing windows horizontal overhangs are effective as it blocks the high altitude angle of sun in summer to penetrate the building but not the view. On the other hand, the sunlight in winter can penetrate the window due to the low altitude angle of sun (Rungta & Singh, 2011). The depth of horizontal overhangs can be calculated for the case study houses with the help of the overhang equation that was clarified in chapter 2 [$H = D \times \tan(A) / \cos(Z - N)$], see Figure 2.20 for the equation acronym.

The data will be added to the equation from the sun path diagram of the case studies on 21st of June at noon, all three case studies share the same altitude angle with 0.11° difference in azimuth angle, which does not make any significant difference in the depth of the horizontal overhang. The calculation for the overhangs depth for all windows except the kitchen window (all of the windows have a height of 2m, but kitchen window has a height of 1m) is as follows:

$D = H \times \cos(Z - N) / \tan(A)$

$D = 2m \times \cos(0° - 0°) / \tan(76.57°)$

$D = 2 \times 1 / 4.19$

$D = 0.48 \simeq 0.5m$

The calculation for the overhang depth of the kitchen window is as follows:

$D = H \times \cos(Z - N) / \tan(A)$

$D = 1m \times \cos(0° - 0°) / \tan(76.57°)$

$D = 1 \times 1 / 4.19$

$D = 0.24m$

Therefore, the depth of the overhang for all three cases with the exception of the kitchen window should be 0.5m, and the depth for the kitchen window would be 0.24m, as illustrated in Figure 4.1. The overhang has to be directly placed over the windows so that it can shade the window completely in intense sunlight, unlike the case in the houses where the extended roof and balconies are about 0.5m above the window.

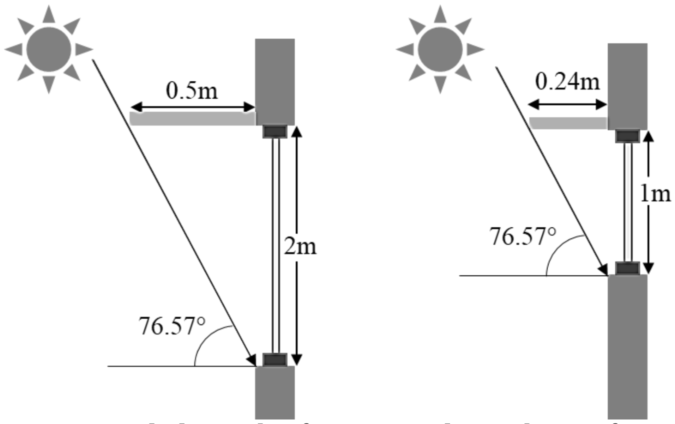


Figure 4.1: Recommended Depth of Horizontal Overhangs for South Oriented Windows a Section View (by author)

Slanted vertical fins and egg-crate are mostly appropriate for east and west oriented windows, as it has a high shading ratio and prevents the intense glare of east and west orientations (Munshi, 2015) (Rungta & Singh, 2011). But both of them almost completely blocks the view, and since the case studies only have one façade, therefore they are not suitable for the houses. Highly deep horizontal overhangs will be a better shading device for the case studies, as it will shade the window without blocking the view. To determine the depth of the overhangs in east and west windows the same equation will be used [$H = D \times \tan(A) / \cos(Z - N)$]. The data for the equation is collected on 21st of June in the morning when the sun azimuth angle is perpendicular on the window for east oriented windows, and it is calculated for 1m high windows as follows:

D= H × cos (Z - N) / tan (A)

D= 1m × cos (90° - 90°) / tan (41.31°)

D= 1 × 1 / 0.87

D= 1.15m

For west oriented windows, the data is collected on 21st of June in the afternoon when the sun's azimuth angle is perpendicular on the window, for 1m high windows is calculated as follows:

D= H × cos (Z - N) / tan (A)

D= 1m × cos [(-90°) - (-90°)] / tan (41.47°)

D= 1 × 1 / 0.88

D= 1.14m

Consequently, for east-facing windows the depth of the overhang for a 1m high window has to be a minimum of 1.2m, like shown in Figure 4.2. As for west-facing 1m high windows ought to have an overhang with a 1.1m depth, see Figure 4.3.

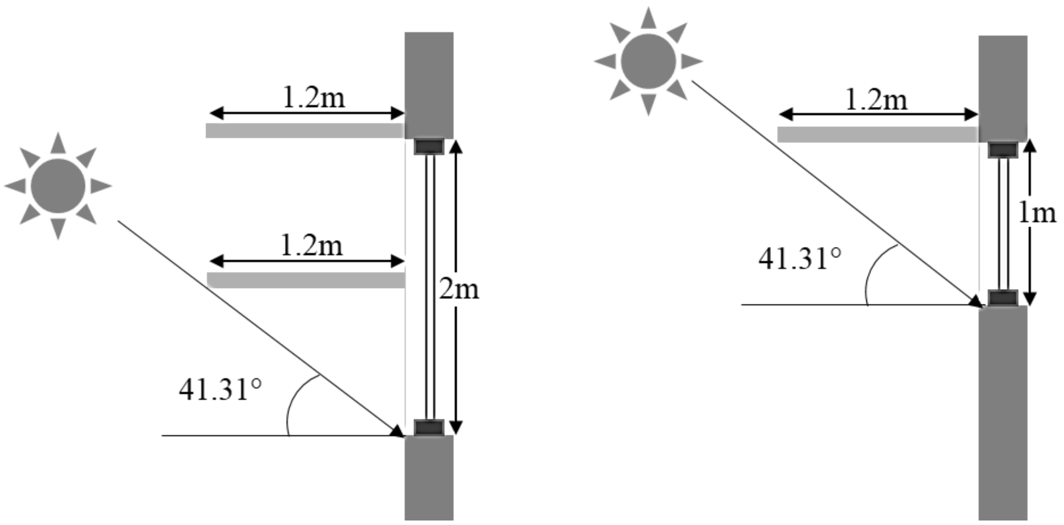


Figure 4.2: Recommended Depth of Horizontal Overhangs for East Oriented Windows a Section View (by author)

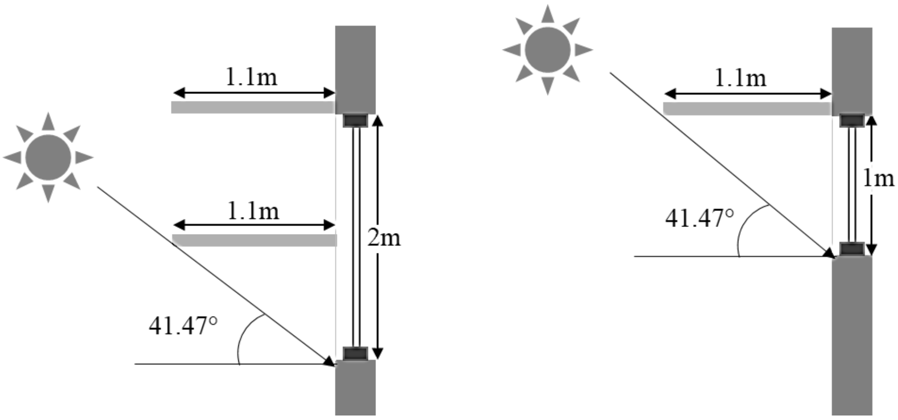


Figure 4.3: Recommended Depth of Horizontal Overhangs for West Oriented Windows a Section View (by author)

In regards to north-facing windows, vertical fins are suitable for it (Lechner, 2015) (Rungta & Singh, 2011). The vertical fins equation [W = D × tan (Z - N)] is used to calculate the depth of the vertical fins. By the use of the equation and the case studies sun path data on 21st of June at sunset and sunrise azimuth angle is calculated for every 1m width of north-facing window as follows:

$W = D \times \tan (Z - N)$

$D = W / \tan (Z - N)$

$D = 1m / \tan [(-120°) - (-180°)]$

$D = 1 / 1.73$

$D = 0.57 \simeq 0.60m$

Hence, for every 1m width of north oriented windows in the case study houses there needs to be 0.6m deep virtical fin, as illustrated in Figure 4.4.

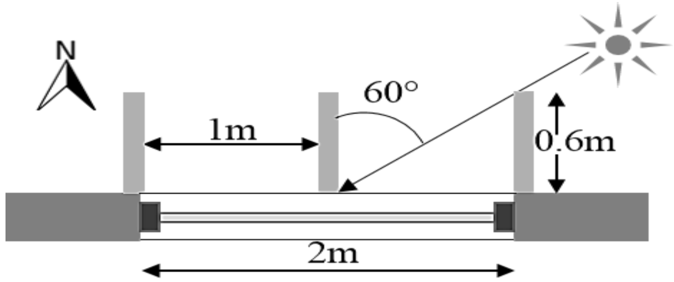


Figure 4.4: Recommended Depth of Vertical Fins for North Oriented Windows a Plan View (by author)

Another façade element that plays a crucial role in the thermal performance of the building are façade materials. The façade wall in the case studies consists of one layer of dense concrete block. Concrete blocks has a high thermal mass effectiveness but it is not an effective insulator (1.13 W/m.K) (CIBSE, 2006) (Walker & Pavía, 2015). A combination of both thermal mass and insulation is the best answer for thermal comfort and low energy demand. Cavity walls satisfy both basic rule of thermal mass as it is built from masonry and insulation is placed in the cavity.

A cavity wall made of bricks at the exterior wall and made of 10cm dense aggregated concrete block at the interior wall, having a finishing material of wet plaster, has a very well thermal performance as it has a high k-value (190 kJ/m^2. K), a high admittance value (5.04 W/m^2. K) and a low percentage of decrement factor (23%) (Saulles, 2012). The thermal comfort and energy efficiency can be significantly improved in the case study houses if the exterior walls are built as cavity walls, since one layer of concrete block without insulation does not perform well as an exterior wall as it has a high thermal conductivity (1.13 W/m.K) (CIBSE, 2006).

The color and texture of the exterior surface has an effect on the heat gain of the building. The exterior colors and textures of case studies vary; as the type I house has a smooth red and white surface color, type II has a smooth light green surface, and type III has a coarse light beige exterior surface. The thermal performance of the colors depends on their albedo percentage. A red color surface has a low albedo value (20% to 35%), but light colors and white have high values (50% to 90%) (Oke, 1987). It is preferable if the color of the façade in the case studies are white or whitewashed color, since in Duhok climate the temperatures in summer get excessive, and white color reflects most of the radiation and decreases the chances of overheating. To reduce overheating even more in summer, it is better to use coarse textured surface, because it reflects solar radiation in all directions, such surface can be attained by using rough finish plaster.

4.1.2 Visual Comfort

The window-to-wall ratio (WWR) effects on the visual comfort, the WWR standards that were explained in the previous section are the recommended standards for sufficient thermal and visual performance for efficient energy consumption, thus, the same ratios are recommended for the improvement of visual comfort in the case study houses. The same case goes for the external shading devices; it effects on the visual performance in the building, as it is one of the most effective strategies to prevent glare (Smith, 2005). The dimensions that were suggested for the shading devices in the thermal comfort section for the case study houses can also improve the visual comfort of the houses.

As windows play a vital role in façade design and effects the visual performance of buildings, its shapes and position on the wall needs to be taken into consideration. In all three case studies the shape of the windows are squares with the exception of the kitchen window; it is a horizontal rectangle window. In regards to the window position, the windows in the three cases are positioned in the center of the wall. According to the studies reviewed in literature review (Acosta et al., 2016) (Bokel, 2007) (De Luca et al., 2016) (Lechner, 2015) (Rodrigues et al., 2015), window shape and position do not have a noticeable effect on thermal and visual performance as well as energy saving. Yet, in most studies the upper position of the window and the horizontal shape of the window were more preferable than other shapes and positions (Acosta et al., 2016) (Bokel, 2007) (De Luca et al., 2016) (Lechner, 2015). However, in the study by

De Luca et al. (2016), the vertical shape of the window was more preferable for north-facing windows. Therefore, the square-shaped windows in the case studies will perform better if they are horizontal, and if they are placed in the upper position rather than center. Upper position of the window illuminates the parts far from the window, as it lets light to pass through deep into the room. The horizontal shape of the window provides a uniform distribution of light.

Window glazing material effects on the amount of sunlight that can pass through the window. In type I and type II house they had clear glazing windows, which is sufficient for north and south orientations, because south-facing windows receives sufficient sunlight both in winter and summer and north-facing windows do not receive enough sunlight, so it is better to let most amount of sunlight possible from north orientation pass through the window. Hence, glazing with high visible transmittance percentage is desirable for south and north-facing windows (Lechner, 2015). As for type III house it has a tinted glazing material, which is preferable in east and west oriented windows, since the sunlight is intense that it causes glare and discomfort to the human eye. The window framing materials have different visible transmittance ratios, and there is not significant difference in common framing material; the highest one aluminum has 59% and fiberglass has the lowest 44%. Moreover, window framing materials do not have a notable effect on the visual performance (Mempouo, Cooper & Riffat, 2010), so the PVC framing that been recommended for better thermal performance can be used in the case study houses.

4.1.3 Indoor Air Quality

The indoor air quality of the case studies can be improved by providing natural ventilation inside the houses, as it removes air pollutants and access fresh air. The position of the window effects on the air movement through the window. since the case study houses only have one façade so the ventilation inside the rooms have to be within windows on the same walls. It is better to position windows asymmetrically on the wall to create pressure difference thus a better air circulation, because there is pressure difference when they are symmetrically positioned. Yet, symmetrical positioning of windows can make pressure difference by adding fins to the side of the window (Brown & DeKay, 2001), this case can be applied on the houses with north orientations, since they need the fins on windows for shading as well. Ventilation is mostly needed in the case studies to improve the IAQ, and not so much for the improvement of thermal comfort, as shown in the psychrometric chart of Duhok city climate, natural ventilation is only needed in a short period of the month May, hence, the ventilation through the windows on one wall is sufficient. Lastly, the IAQ can be further improved by adding vegetation near windows, since vegetation works as natural air filters, by decreasing air pollutants that may be a threat to the human health.

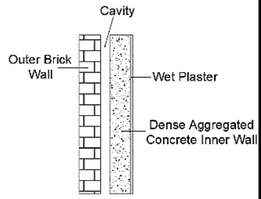
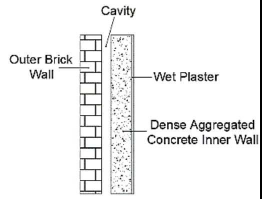
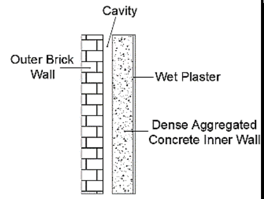
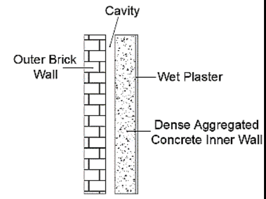
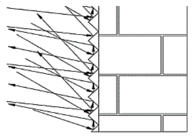
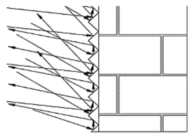
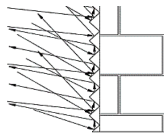
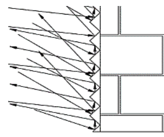
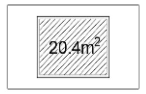
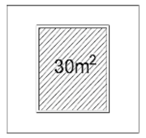
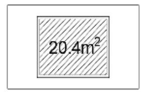
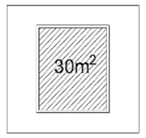
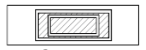
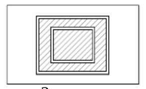
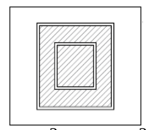
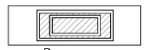
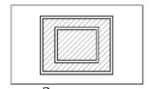
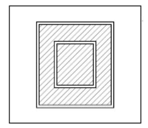
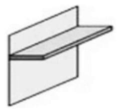
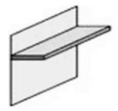
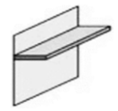
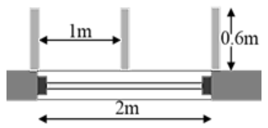
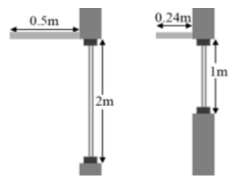
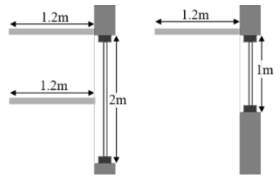
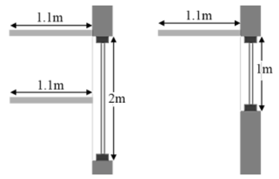
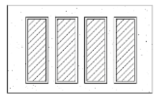
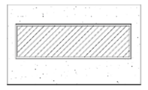
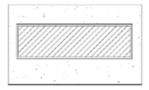
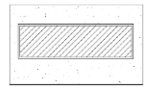
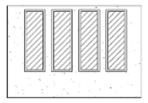
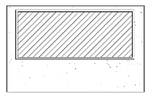
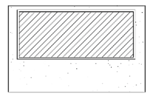
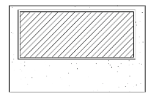
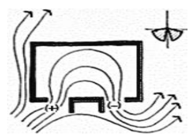
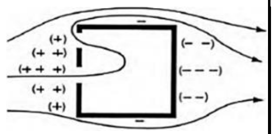
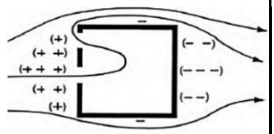
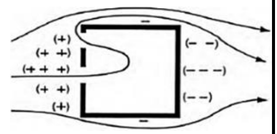
4.1.4 Reduce of Energy Usage

The fourth principle of bioclimatic design which is the reduce of energy usage; it is the result of the improvement of the thermal comfort, visual comfort, and indoor air quality. As implementing passive strategies in a house can save about 70 kWh/m^2 to 100 kWh/m^2 per year (Audenaert, De Cleyn & Vankerckhove, 2008) (Galvin, 2014) (Konášová & Freitas, 2014). With the high price of electricity 0.25$ kWh, the house owners can approximately save up to 2600$ to 3900$ a year by implementing passive design strategies that correspond to its local climate (Hasan, 2018).

4.2 Recommendations

In the following table the recommendations for improving façade design in the case studies based on bioclimatic principles has been summarize.

Table 4.1: Recommendations for Improving Thermal Comfort, Visual Comfort, and Indoor Air Quality (by author)

	North	South	East	West
Thermal Comfort				
Façade Material	Cavity wall (brick wall as an outer wall, dense aggregated concrete wall as the inner wall, and wet plaster as a finishing) 	Cavity wall (brick wall as an outer wall, dense aggregated concrete wall as the inner wall, and wet plaster as a finishing) 	Cavity wall (brick wall as an outer wall, dense aggregated concrete wall as the inner wall, and wet plaster as a finishing) 	Cavity wall (brick wall as an outer wall, dense aggregated concrete wall as the inner wall, and wet plaster as a finishing) 
Exterior Surface Color	White or whitewash color	White or whitewash color	White or whitewash color	White or whitewash color
Exterior Surface Texture	Coarse texture of exterior wall to increases sun reflection 	Coarse texture of exterior wall to increases sun reflection 	Coarse texture of exterior wall to increases sun reflection 	Coarse texture of exterior wall to increases sun reflection 
Thermal and Visual Comfort				
Window-to-Wall Ratio	30%	30%	10% to 30%	10% to 30%
Area of Window-to-Wall Ratio	type i:  type ii:  type iii: 	type i:  type ii:  type iii: 	type i:  $3.6m^2$ to $10.8m^2$ type ii:  $6.8m^2$ to $20.4m^2$ type iii:  $10m^2$ to $30m^2$	type i:  $3.6m^2$ to $10.8m^2$ type ii:  $6.8m^2$ to $20.4\ m^2$ type iii:  $10\ m^2$ to $30m^2$
Window Glazing Material	A double-layered clear glazing with high solar heat gain and visible transmittance value	A double-layered clear glazing with high solar heat gain and visible transmittance value	A double-layered tinted glazing with low-e coating and low visible transmittance value	A double-layered tinted glazing with low-e coating and low visible transmittance value
Window Framing Material	PVC	PVC	PVC	PVC
Shading Devices	Vertical fins 	Horizontal overhangs 	Horizontal overhangs 	Horizontal overhangs 
Shading Devices Dimension	0.6m deep fins for every 1m of window width 	0.24m deep overhangs for 1m of window height 0.5 deep overhangs for 2m of window height 	1.2m deep overhangs for every 1m of window height 	1.1m deep overhangs for every 1m of window height 
Visual Comfort				
Window Shape	Vertical 	Horizontal 	Horizontal 	Horizontal 
Window Position	Upper 	Upper 	Upper 	Upper 
Indoor Air Quality				
Window Position	Symmetrical positioning of windows on the same wall with vertical fins 	Asymmetrical positioning of windows on the same wall 	Asymmetrical positioning of windows on the same wall 	Asymmetrical positioning of windows on the same wall 

Chapter 5

CONCLUSION

The research aim was to understand bioclimatic design and its principles, to improve the case studies' performances (thermal comfort, visual comfort, indoor air quality, and reduce of energy usage) by applying bioclimatic design to their poorly designed façades with accordance to the local climate.

The first research question was to know what is bioclimatic design and its principles, through the studies reviewed in literature, it became that bioclimatic design is a way out for buildings that excessively depend on fossil fuels as a source of energy for heating, cooling, lighting, and ventilation into a more environmental-friendly building. Bioclimatic architecture follows with the local climatic conditions and natural environment through its design process, at the same time maximizing the comfort of the users (thermal comfort, visual comfort, indoor air quality). By reviewing and comparing various sources of bioclimatic principles in chapter 2, a set of principles for the research were proposed:

- Improvement of visual comfort
- Improvement of thermal comfort
- Improvement of indoor air quality
- Reducing energy usage

The second question of the study was to know the weaknesses of façade design in the case study houses, the weaknesses appeared through the discussion in chapter 4 by comparing the analysis in chapter 3 with the standards and recommendations in the literature. One of the weaknesses in the case studies were the shading devices as they all had the extension of balconies or roofs as the only from of shading without considering the orientation and different sun angles. Another weakness in the façade was the building material, as it was concrete blocks without any insulation, which results in excessive heating and cooling demand.

The last research question was how the housing façades can be improved based on bioclimatic design, this was answered through the recommendations that were proposed for different façade elements in chapter 4 to improve the weaknesses in the façade design to result in a better thermal comfort, visual comfort, and indoor air quality. For instance, all of the houses had square window shape, but based on literature horizontal window shape for south, east and west orientations and vertical window shape for north orientation result in better visual performance in the houses.

In general, there needs to be more considerations towards energy saving, renewable energy, and sustainable buildings, and bioclimatic design can be a convenient solution to the case study houses to reach that. Where house owners can reconsider their investment in façade ornaments and decorations and instead invest in a more sustainable and climate adaptive façade. While this study was limited to the passive strategies on the façade design, further studies can be conducted on the use and feasibility of active solar technology in the housing façade in Duhok city, to have even more sustainable buildings that can generate its own energy, and reduce dependence on non-renewable energy usage, especially since Duhok climate has the potential of it.

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