Energy Efficient Glazed Façade Design Strategies for High-Rise Office Buildings in Erbil City

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ABSTRACT

Sustainability and energy efficiency is increasingly a worldwide necessity due to a rise in the rate at which natural resources are being depleted through their use in cities and their buildings, especially energy in both its primary and secondary (electrical) forms. As the largest energy consumers in modern societies, buildings are also the best way through which environmental protection and conservation can be achieved; facades are the primary contributors to the building's comfort parameters as well as its energy budget. Due to their large scale, high-rise building facades are more exposed and thus susceptible to the impact of the external environment. As such, their sustainability and energy efficiency through ecologically-sensitive design is more paramount relative to that of regular buildings.

Erbil city has experienced fast none-legitimately controlled urban development and growth in the past few decades. The majority of the newly-developed high-rise buildings adopt the concept of a highly glazed façade. Until recently, the construction industry in Erbil city was the creator of non-energy efficient record-breaking high-rise towers.

The current study aimed to prepare and identify design strategies for achieving energy efficient glazed façade systems in Erbil city's high-rise office buildings, and accordingly evaluate the current high-rise office building glazed façades to discover the main problems and optimize existing building performance. The current research is designed as a qualitative and quantitative study. In order to accomplish the research objective, major methods used were a literature survey, personal observation, and computer simulation. For data collection, a literature survey conducted in order to outline the related documents concerning energy efficient glazed façade systems in literature. Secondly, a number of high-rise buildings in Erbil city were surveyed and analyzed through personal observation. For data analysis, The data analysis of observations was descriptive qualitative, while the computer simulations were quantitative, observational data was analyzed by identifying the observed high-rise office buildings and eventually, in order to precisely uncover the necessary data and gain a better understanding of the problems, one building was analyzed through a computer simulation (Autodesk Ecotect 2011, WINDOW 7.5) by running Erbil Weather file.

The study prepared numerous design strategies for achieving energy efficient glazed facades in high-rise office buildings in Erbil city and the existing glazed facades in high rise office buildings were evaluated within the context of energy efficiency by comparing the existing buildings with the recommended energy efficient design strategies; it was evident that the current glazed façade systems in high-rise office buildings are not energy efficient and they need optimization. implementation the recommended energy efficient design strategies in the case of existing glazed facades has a great impact on energy conservation and positively affects the (thermal, visual) comfort of interior spaces.

Keywords: Sustainability, Energy Efficiency, Glazed Façade System, Design Strategy, High-Rise Buildings, Erbil City.

ÖZ

Şeheırlerde ve bınalarda özellıkle enerjının bırıncıl ve ıkıncıl (elektrık) şeklı olmadızere dösal kaynaklarn tüketım oranının artmayl nedenıyle, Sürdürülebilirlik Enerji verimliliği dûnya genelinde giderek artam bir gereklilik haline gelmektedir. Toplumumuzdaki en büyük enerji kullanıcısı olan binalar, enerji tasarrufu ve çevrenin korunması için doğru değerlendirildiğinde en büyük fırsatımızdır. Binalarda cephe, enerji bütçesine ve binanın konfor parametrelerine en önemli katkıda bulunan unsurlardan biridir. Bina cepheleri, dış çevre koşullarının tam etkisine karşı diğer yapı türlerine göre daha fazla maruz kalma oranına sahiptir; bu nedenle, ozellikle yüksek binaların ekolojik tasarımı ve sürdürülebilirliği, olağan binalarınkilerden daha önemlidir.

Erbil şehrinde, geçtiğimiz son on yılda hiçbir şekilde yasal olarak kontrol edilemeyen kentsel gelişim ve büyümeyi hız kazandı. Yeni gelsin yüksek binaların çoğunda yüksek cam cephe kavramı benimsendi. Son zamanlarda, Erbil şehrindeki inşaat endüstrisi Enerji verimliliği açisindan dünya rekoru kıran yüksek katlı kulelerin yaratıcısı konumuna geldi.

Bu çalışmada, Erbil şehrindeki yüksek katlı ofis binalarındaki sürdürülebilir cam cephe sistemlerine ulaşmaya yönelik tasarım stratejileri hazırlanıp belirlenmeye çalışılmış ve bu tasarım stratejilerine göre mevcut yüksek katlı ofis binalarının cam kaplanmiş cepheleri değerlendirilerek ana problemlerin bulunması amaçlanmış ve mevcut binanın performans optimizasyonu hedeflenmiştir. Mevcut araştırma nitel ve nicel yöntemler kullanılarak yapılmıştır. Bu araştırmada amacı gerçekleştirmeye yönelik kullanılan temel yöntemler literatür araştırması, kişisel gözlem ve bilgisayar simülasyonudur. Gözlemlerin veri analizi kısmı nitel özellikteyken bilgisayar simülasyonları kısmı nicel özelliktedir. İlk olarak veri toplama amacıyla enerji verimli cam cephe sistemleriyle ilgili belge ve bilgilere ulaşmak için literatür araştırması yapıldı. İkinci olarak, Erbil kentinde kişisel gözlem yoluyla bir dizi yüksek katlı bina araştırıldı ve analiz edildi. Veri analizi için, gözlemsel veriler gözlemlenen yüksek katlı ofis binalarını tanımlayarak analiz edildi ve sonuçta verileri tam olarak bulmak ve sorunları daha iyi anlamak için bir bina bilgisayar simülasyonunda (Autodesk Ecotect 2011, WINDOW 7.5) Erbil Hava dosyası çalıştırılarak analiz edildi.

Çalışmada, Erbildeki yüksek katlı ofis binalarında enerji verimli cam cephe kaplamalari elde etmek için çok sayıda tasarım stratejisi hazırlandı ve mevcut binaları önerilen sürdürülebilir tasarım stratejileri ile karşılaştırarak Enerji verimliliği bağlamında mevcut cepheler değerlendirildi; Yüksek katlı ofis binalarındaki mevcut cam cephe sistemlerinin enerji verimli olmadığı, optimizasyona ihtiyaç duyduğu açıktı. Sonuç olarak önerilen enerji verimli tasarım stratejilerinin mevcut cepheler üzerine uygulanması, enerji tasarrufu ve iç mekan (termal, görsel) konforu açisindan olumlu yönde sonuc veren büyük bir etkiye sahiptir.

Anahtar kelimeler: Sürdürülebilirlik, Enerji Verimliliği, Cam Cephe Kaplama Sistemleri, Tasarım Stratejisi, Yüksek Katli Binalar, Erbil Şehri.

DEDICATION

I dedicated this humble effort:

-To my beloved mother and father, whose kindness, and endless love has kept me.

-To my lovely uncles, aunts, sisters, brothers, and others who inhabit my heart.

-To the guide of my way, my dear supervisor.

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LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BOI	Board of Investment
EBN	Environmental Building News
GCWS	Glass Curtain Wall System
GDP	Gross Domestic Product
GFS	Glass Façade System
HSA	Horizontal Shading Angle
HVAC	Heating, Ventilating, and Air Conditioning
IECC	International Energy Conservation Code
KRG	Kurdistan Regional Government
KRI	Kurdistan Region of Iraq
LCCA	Life Cycle Cost Analysis
LSG	Light To Solar Gain Ratio
MERI	Middle East Research Institute
MW	Megawatt
NPV	Net Present Value
SHGC	Solar Heat Gain Coefficient
SSBGS	Structural Silicone-Bonded Glazing System
USD	United States Dollar
VSA	Vertical Shading Angle
VT	Visual Transmittance
WWR	Window to Wall Ratio

Chapter 1

INTRODUCTION

1.1 Background

Energy issue is becoming more and more important in today's world because of a possible energy shortage in the future and also global warming (Yılmaz, 2007). Modern office buildings have high energy savings potential. During the nineties many office buildings with single and double skin glass facades were built. Highly glazed single skin office buildings are designed by architects to be airy, light and transparent with more access to daylight but their energy efficiency has become more and more questioned, as there is risk of a high cooling and heating demand (Poirazis et al, 2008).

Definition of sustainability is changeable according to the context in which it is used or proposed. One of the common definitions of sustainability is meeting the needs of the present without compromising the ability of future generations to meet their own needs. (Brundtland, 1987).Sustainability is known to be one of the foremost concerns in design concepts in the construction sector in the past two decades, particularly in large scale buildings. Buildings tend to be one of the most harmful aspects of society and the environment in regards to sustainability. In addition to consuming large amounts of energy and thus costing the users large amounts of money, they also release harmful gasses into the atmosphere (Graber and Dailey, 2003). Building façade systems, particularly GF systems, remain a significantly important issue that emerge during design, construction, and manufacturing when considering sustainability principles in the construction sector (pakishan, 2011).

As society's largest users of energy, buildings, particularly high-rise buildings, offer the best opportunity for us to both conserve energy and protect the environment. The rapidly increasing levels of global energy consumption have raised concerns over our irreversible depletion of natural resources and its impact on the environment, especially as such behavior is predicted to continually trend upwards (aksamija, 2013).

Facades are one of any building's most important energy budget and comfort contributors. The depletion of natural resources, including energy resources, has made clear the necessity of developing new technologies and strategies for modern façade designs that allow us to continue to be satisfied with our interior environment while simultaneously using fewer resources. Energy efficient facades need to be able to repel the adverse effects that result from external environmental pressures and retain internal comfort while consuming a minimum amount of energy. It is for this reason that location and climate are crucial for an appropriate energy efficient façade design strategy (Aksamija, 2013).

The use of glass in buildings has increased in the past two decades as a result of the innovation of curtain wall cladding techniques and steel framing systems in large scale buildings (vertical and horizontal) and has since been used as a central component in building envelopes (Pakishan, 2011). Some changes have however – in regards to energy performance, technological approaches, and the facades' aesthetic and appearance – been implemented in glazed facade systems and the construction materials and systems used. Glazed facade systems have been increasingly used for large-scale office buildings and building construction as a result of these developments (Patterson et al., 2008).

The problem with these buildings is the unwanted heat retained and the heat lost in the winter as a result of glass being transparent and a heat conductor. Consequently, contemporary glazed facade systems have tried to improve their functionality and allow designers the leeway to develop high performance remedies, including energy efficiency, reducing the heat lost during winter and the heat gained during summer, natural ventilation, and maximum use of natural daylighting, amongst others. (Pakishan, 2011).

1.2 The Problem Statement

Since the 1960s, the development of high-rise buildings, which had remained energy efficient and environmentally conscious, has not progressed. Although efforts to reinvigorate progress resumed following the 1973 energy crisis, the majority of architects have little interest in minimizing energy consumption even as energy efficiency remains an important issue (Lotfabadi, 2014).

There is a recent global trend towards the use of large-scale glazed facades in high-rise office buildings and Erbil city is no exception. It was observed that glazing facades have become increasingly popular in Erbil city as designers and architects are beginning to design and construct transparent buildings even as Erbil remains one of the region’s hottest cities. Glass Curtain wall systems are the most commonly used type of glass facade system used in high-rise office buildings. The main problem with buildings using these systems, is the high level of energy consumption that results from the lack of sustainability and energy efficiency considerations in early design stages of such glazed façade systems.

Many factors need to be taken into consideration when designing energy efficiency facades in early design stages, such as environmental conditions, the properties of the materials and façade components uses, fenestration design, and building orientation. One major contributor to the amount of energy used by a building is the physical behavior of the façade. The process of designing high-performance energy efficient facades begins with the identification of the environmental and climatic conditions that will affect the façade orientation, building envelope, and building orientation. Subsequently, on the basis of the orientation, program requirements, client requirements, spatial requirements, spatial organization, and the aesthetic requirements, a suitable facade type is identified. Designers must consider the particular characteristics of each intended component of the façade, such as their optical and thermal properties, and the amount of energy that might be expelled during construction. Energy efficient building designs take all of these factors into consideration and ensures that the negative effects of the building on the environment are limited (Aksamija, 2013).

Several studies have been conducted in areas related to sustainable and energy efficient glazed façade systems in high-rise office and commercial buildings. Instances of such studies are “Energy efficient design strategies in the hot dry area of Turkey” (Manioğlu et al, 2008), “Sustainable Facades, Design Methods for High-Performance Building Envelopes (aksamija, 2013)”. Evaluating the Appropriateness of Double Skin Glass Facade System, within the Context of Sustainability, for North Cyprus (pakishan, 2011). “Building skin and energy efficiency in a hot climate with particular reference to Dubai, UAE (Haggag, 2007)". "Building envelope regulations on thermal comfort in glass facade buildings and energy-saving potential for PMV-based comfort control (Hwang &Shu, 2011) ", "Control strategies for intelligent glazed façade and their influence on energy and comfort performance of office buildings in Denmark (Mingzhe et al, 2015)" and etc.

While these studies have discussed the issue of energy efficient glazed facades, none has directly engaged the energy efficient issues of high-rise office building glazed façade systems in Erbil city. Where similar studies have been conducted, they have used countries such as Turkey, Northern Cyprus, China, Denmark, etc. as their case studies. Consequently, there is a gap in the literature that this study hopes to fill by exploring the possibility of energy efficiency in high-rise office building glazed façade systems in Erbil city.

1.3 Research Aim and Questions

The study's main aim is to prepare and identify design strategies for achieving energy efficient glazed façade systems for Erbil city's high rise office buildings, and accordingly evaluate the current high rise office building glazed façades to find out the main problems and optimizing the existing building performance by implementing several recommended design strategies in existing buildings.

To accomplish this aim, the study looks to provide answers to the following questions:

- What are the characteristics of energy efficient glazed facade system?
- What are the conditions of Erbil city?
- What types of GF systems are already used for high rise office buildings in Erbil city?

1.4 The Research Methodology

It is nearly impossible to exaggerate how much the outcome of a research is affected by the chosen methodology. The chosen methodology must be suited to the particular objectives of the research so as to ensure that said objectives can be realised and the results of the research are valid (Fellows and Liu, 2015).

The current research is designed as a qualitative and quantitative method. In this research in order to accomplish the aim major methods used were literature survey, personal observation, and computer simulation.

For data collection, the literature survey conducted in order to find the related documents about energy efficient glazed façade system in literature. Secondly, 11 buildings have been surveyed and analysed through personal observation, which are presented via photos and summarized tables.

For data analysis, the analysis of the data gotten from observations was descriptive qualitative, and computer simulations were quantitative. The data gotten from the observations of high-rise buildings in Erbil was analyzed by outlining building names, height and floor number, glazed façade orientation, aspect ratio, arrangement of building mass, kind of façade system, kind and size of glass, shading device (if any), GF m2, and the cost of construction of each m2 of the GF. Finally, a computer simulation (Autodesk Ecotect 2011, WINDOW 7) used to find and define the problems statistically.

1.5 Scope and Limitations

This research is limited to glazed façade systems in high rise office buildings in Erbil city with a minimum of 10 floors. This study only takes into consideration glass curtain wall systems that are mechanically ventilated thus excluding other types of glass facade systems from the scope of the research.

1.6 The Study Significance

This study aims to aid the design of Energy efficient GF systems in Erbil city and determine the conditions under which they should be built. It also aims to serve as a go-to document for architects, stakeholder, and decision-makers looking to implement such systems in Erbil city.

1.7 The Research Design

This thesis is divided into six different chapters:

- Chapter one provides the introduction of the thesis. It provides a background to the study, its aim, research questions, scope, limitation and its methodology.
- Chapter two is a background of the glass façade system and categorizing glass materials types, GFS and emerging technologies in glazed façade designs.
- Chapter three provide an outline about energy efficiency and energy efficient glazed façade systems.
- Chapter four provides an overview about country conditions.
- Chapter five include design strategies for high rise office building glazed facades, observation, evaluation of existing high rise office building glazed facades and optimization.
- Chapter six contains conclusions and recommendations for future research.

Chapter 2

GFS IN HIGH RISE BUILDINGS

2.1 Glass Façade System

GF systems are transparent walls that covering the exteriors of buildings. The principal elements of GF systems include a glass pane and the other structural components that provide support as well as attach the cladding (framing system, glass panes, amongst others) to the building itself (Pakishan, 2011).The proceeding part of this thesis provides a brief history of GF systems and a categorization of the various types of glass used in these systems. GCW systems, their various kinds, emerging technologies in glazed façade designs are also explained and categorized in this chapter.

Glazing – which involves the process of combining various, primarily glass and framing, materials that fill the exterior walls of buildings – might serve a number of other functions in addition to providing a nice view for building inhabitants with a nice view.

2.1.1 Gf Systems Historical Background

Wigginton (1996) stated in his book "Glass in Architecture", that glass, remarkable as it is, presents a real challenge when it comes to designing buildings (Wiggington, 1996). Glass is mainly used as a transparent cladding material in building facades. Because the primary constitutive element of glass (base glass) is sand, it is considered a partially natural material and the fact that sand often comes with impurities, most frequently carbon dioxide, often results in the glass having tints (Compagno, 1999).

Wigginton (1996) argues that the foremost examples of true glass architecture could be found in the Gothic style of Northern Europe (Wigginton, 1996). The Chartres Cathedral illustrates the aforementioned Gothic Style found in Northern Europe.

Glass only began to be used as a primary building material in the late 16th and early 17th century. Flat glass sheets were the main types of glass used at that time; cast and rolled plate glass, two types of flat glass, were initially used in France between 1688 and 1702 for building windows. Subsequent developments in regards to the manufacturing of flat glass occurred in the eighteenth century when it was frequently used in mirrors, windows, and glazed doors. One illustration of this is Joseph Paxton's Crystal Palace; constructed in 1851, it exemplifies the use of glass as a material in architecture (W-Harvey, 2008).

2.1.2 Glass Types of GF Systems

Various kinds of glass and glass systems help realize advantages in GF systems. These include regulating the transmission of solar radiation, minimizing heat transmission, diverting solar radiation etc. The primary kinds of such glass are described and classified below in table 1.

Annealed Glass: This is a pane of glass that has been deprived of heat treatment. It is fragile in terms of its resistance to thermal pressures and is consequently vulnerable to failure due to thermal stress as a result of its only partial shading. Used primarily in glass fins, it is not intended to come in contact with direct sunlight (Chan, 2006).

Tempered glass: Tempered glass is the result of heat treatment on a glass pane. It is so resistant to tension and breakage that if will not shatter and hurt people even when broken. To make tempered glass, the glass is first cut into the necessary shapes, after which it is consistently heated to 621ºC in an oven. The heated glass is promptly cooled while the glass' outer surfaces remain compressed and its inner segments remain under tension, making the cooling process faster. The compression zone is typically roughly 0.2 of the aggregate thickness while that of the inner tension zone is approximately 0.6 (Chan, 2006). Tempered glass is approximately four times more resistant to bending that annealed glass (without heat treatment) and is significantly more resistant to thermal stress in addition to being more expensive. It is used mostly in facades expected to encounter extreme temperatures or heavy wind (Allen and Iano, 1938).

Tinted and Coated Glass : While fixed shading devices are undoubtedly the most effective way to bock unwanted sunlight in facades with a large glass area, tinted glass and reflected coated glass are also two types of glass designed specifically to decrease the glare and heat gained from the sun. The former (tinted glass) is the product of colorant being added to regular glass. The colorant is poured into molten glass and come in a number of tones including gray, bronze, blue, green, and gold. Depending on the color and thickness particular to the glass being used, the light transmittance of tinted glass ranges between 14% (for extremely dark gray) and 75% (in lighter tints) while the transmittance of clear glass is 85% (Allen and Iano, 1938). Tinted glass is often made using glass that has been heat-strengthened (and is made through a process similar to tempered glass with the exception of the reduced compressive stress) (Chan, 2006). On the other hand, coated glass results from inserting numerous coating layers on the surface of the glass. There are two primary kinds of coated glass: reflective coated glass (regulates solar radiation) and low emissivity (low-e) glass (has the capacity to decrease the glass' surface emissivity to e ~ 0.04 from e ~ 0.87, consequently decreasing infrared radiation by 20% while keeping light transmittance above 0.77 (Chan, 2006; and Compagno, 1999).

Insulating Glass: The insulating glass pane provides isolation from heat and sound transmittance. It is produced using at least two glass panes with air in the gap between them, thus providing insulation. The resulting gap may also be packed with hexafluoride, also an exemplary insulator. The insulating glass may be created using either reflective or low-e glass and is typically used in conjunction with a spacer made from metals, such as roll-formed aluminum, coated, stainless, or galvanized steel, wrapped with materials such as hot-melt butyl, polyurethane, polysulfide, amongst others (Chan, 2006).

Laminated Glass: Laminated glass is the result of an interlayer (e.g. resin or polyvinyl butyral (PVB)) being used to bond at least two glass layers. The thickness of the interlayer is typically in multiples of 0.38mm (Chan, 2006). Because the soft interlayer prevents broken glass from scattering, thereby reducing their risk to people if the glass breaks, laminated glass is one of the more frequently used glass types in LSGFB. Regardless, it is still weak relative to annealed glass (Allen and Iano, 1938), despite it being the next best sound barrier after insulating glass. The interlayer of laminated glass may be used to create a large variety of visual affects through the combination of various patterns and colors (Allen and Iano, 1938).

Table 1: Type of Glass used in GFS.

Types Of Glass	Properties	Production Process
▪ Annealed Glass	▪ Low resistance to heat	▪ Glass pane that hasn’t been heat-treated
▪ Tempered glass	▪ Very resistant to breakage and tension ▪ It has four times the resistance of non-heat-treated annealed glass against bending and costs significantly more	▪ It is a glass pane that has been heat-treated

	as it is more resistant to thermal stress.	
▪ Tinted & Coated Glass	▪ Minimizes solar heat gain and glare ▪ Comes in two forms: reflective coated glass, controls solar radiation, and low-emissivity glass (low-E), decreases glass surface emissivity.	▪ Tinted glass or heat-absorbing glass is produced through the addition of a colorant to regular glass. ▪ Coated glass is the result of coatings being added to the surface of the glass.
▪ Insulating Glass	▪ Provides proper insulation from heat and sound	▪ Results when at least to panes of glass are combined with an air-gap between them.
▪ Laminated Glass	▪ Next best sound barrier after insulating glass ▪ Weaker than annealed glass ▪ The soft interlayer keeps glass shards from dispersing when the glass shatters and minimizes the likelihood of injury.	▪ Results when an interlayer is used to bond two or more glass layers

Thickness of the Glass: Although differing between particular manufacturers, glass is usually produced in thicknesses starting from approximately 2.5mm, known as single-strength, 3mm, known as double-strength, up to a maximum of 25.4mm in large-scale buildings where the increased wind velocity at higher altitudes demands the use of thicker glass (Allen and Iano, 1938). Solar radiation transmittance, as well as the base glass' total transmittance, are significantly impacted by the thickness of the glass (Compagno, 1999).

From the existing literature, it is evident that the most frequently used types of glass are low-e glass, laminated glass, and tempered glass. Units of insulating glass (double glazing units) appear to be utilized mostly the inner skins of double skin glass facades systems, and GCW systems, which tend to have one (inner) low-e glass layer so as to redirect excessive heat and keep heat radiation away from the building's interior. Coated solar control glass has also been used for the outer glass layer so as to redirect unwanted sun rays (Tenhunen et al, 2002).

2.1.3 GF System Types

GCW, used in the production of highly glazed facades, and the various GCW types, are explained in this section.

Glass Curtain Wall Systems (GCW systems): As described by Saldano L. M. (1998),

> "Curtain wall systems are attached to the structural frame with angles or sub-framing. The most prevalent curtain wall systems are metal or metal and glass walls. These systems are used on many of today's skyscrapers. Curtain wall systems may also be constructed of natural stone, precast concrete, or either combinations of materials. Today, the curtain wall option is selected most often in enclosure systems" (Saldano, 1998).

GCW systems are resistant to wind and seismic forces exerted on the building, as well as water and air infiltration, and the GCW's own weight. They only recently became the more frequently used kind of curtain wall and primarily comprise an aluminum framing (previously, steel curtain walls were common), transoms, and mullions. The panes of glass are fitted to the aluminum frames using pressure plates and screws. The process of conceiving a GCW system involves analysis, designing the glass panels along with their respective framing systems, and connecting the panels, first to the frames and then to the actual building so as to provide resistance from out-of-plane wind pressures and contain the in-plane deflections that result from wind-induced drifts, thermal movement, earthquake loads, and long-term floor deflections (Sivanerupan, et al, 2008).

GCW systems have enjoyed common use in modern buildings since the mid-19th century due to their essential specifics, which include aesthetic and appearance, sustainability issues, and the increase of natural daylight usage. Depending on the particular design concepts and principles employed, different materials may be used for glazing and framing, such as aluminium, steel, wood, etc. Also, glazing systems may also differ and include point fixing system, suspended glazing system, structural silicone-bonded system, amongst others (Sivanerupan et al, 2008).

GCW systems are categorized as either frame GCW or frameless GCW. The two categories of GCW systems are discussed below:

2.1.3.1 Framed GCW Systems

In-fitted by glass panels, framed GCW systems are the preferred type used as a support structural element in facades. While earlier frames used in framed GCW systems tended to be steel, modern frames are usually produced using protruding aluminum frames, the interiors of which are filled with glass. The extruded aluminum frames of the glass panes result in the building's façade having a remarkable aesthetic and appearance and allows natural daylight to infiltrate building. Due to their significant performance advantages, including resistance to thermal expansion and contraction, water diversion, and the building's general movement, framed GCW systems are often used in covering various floors. They are also efficient thermally in that they allow the building to be heated, cooled, and lit economically (Sivanerupan et al, 2008).

There are four kinds of framed GCW systems in common use: stick system, unitized system, and semi-unitized system.

2.1.3.1.1 Stick Wall System

Stick: A stick system is composed of vertical and horizontal framing members with infill of glass, aluminum, stone, or other materials. Framing members are usually extruded aluminum, but can be other architectural-quality metals, shop fabricated to size with shop-applied finishes and assembled on-site to the designed framing configuration. Infill materials, infill attachments, system anchorages, sealants, and gaskets are installed at the project site (figure 1) (Boswell, 2013).

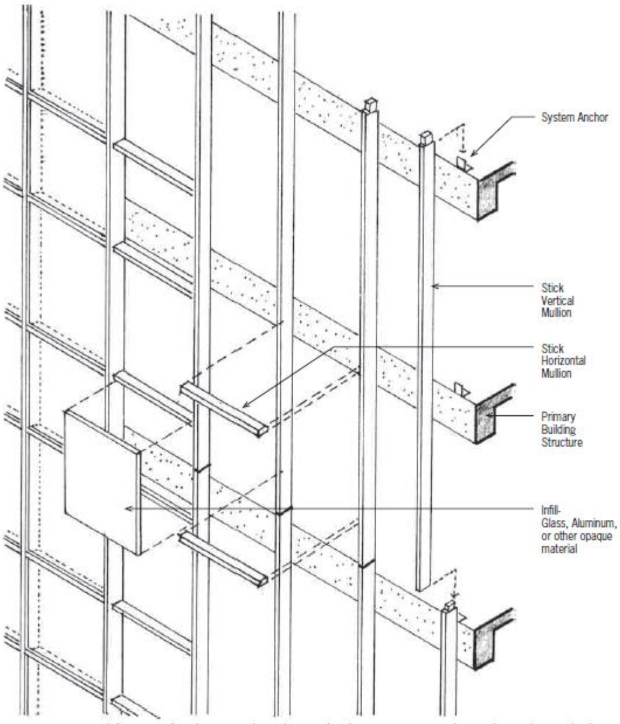


Figure 1: Metal framing referred to as "sticks." Along with other components such as sealants, glass, and other infill, these components are shop-fabricated and field-installed in a stick system. Sticks can be one or multiple floors tall. Source: (Boswell, 2013).

2.1.3.1.2 Unitized Curtain Wall System

Unitized: A unitized system is composed of shop-fabricated and assembled frames with glass or other infill materials. The shop- fabricated "unit" assemblies are shipped to the project site and installed on system anchors preset onto the structure or substructure. Units mate together with adjacent units along the jamb (vertical), head (top), and sill (bottom) edges. Shop fabrication for unitized assemblies typically allows for higher quality because the fabrication and assembly occur in a controlled shop or factory environment, in lieu of the construction site (figure 2) (Boswell, 2013).

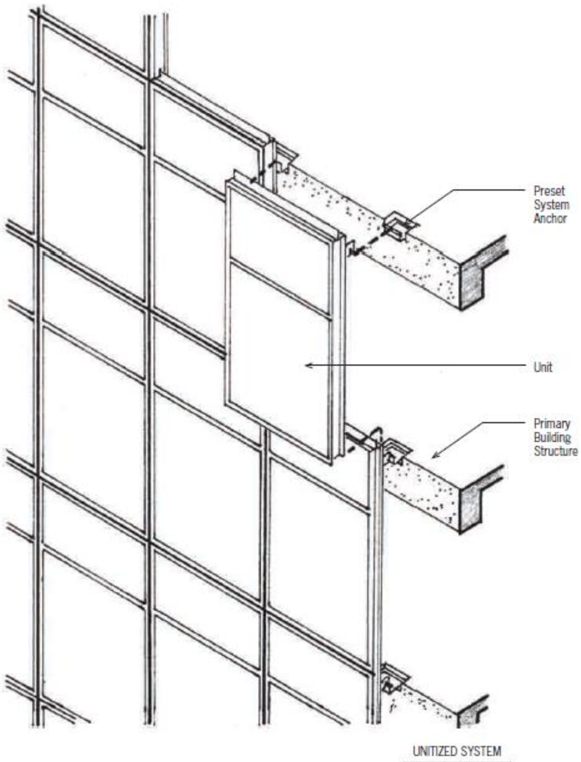


Figure 2: Unitized systems are shop-fabricated and shop-assembled as completed units, with infill materials such as glass, aluminum, and other infill materials. Units are typically one floor tall and field-installed on preset system anchors. Source: (Boswell, 2013).

2.1.3.1.3 Unitized on a stick

A unit on a stick system is composed of vertical or horizontal framing members—the sticks—of either aluminum or steel. Sticks are attached to the building structure or substructure with preset anchors. Units are shop-assembled. Sticks are erected and attached to the building structure, and units are installed on system anchors on the sticks at the project site. The primary difference between this and a unitized system is the addition of a more robust “stick” to accommodate higher lateral loading, taller floor-to-floor areas, or multiple unit frames within a floor-to-floor area (figure 3) (Boswell, 2013).

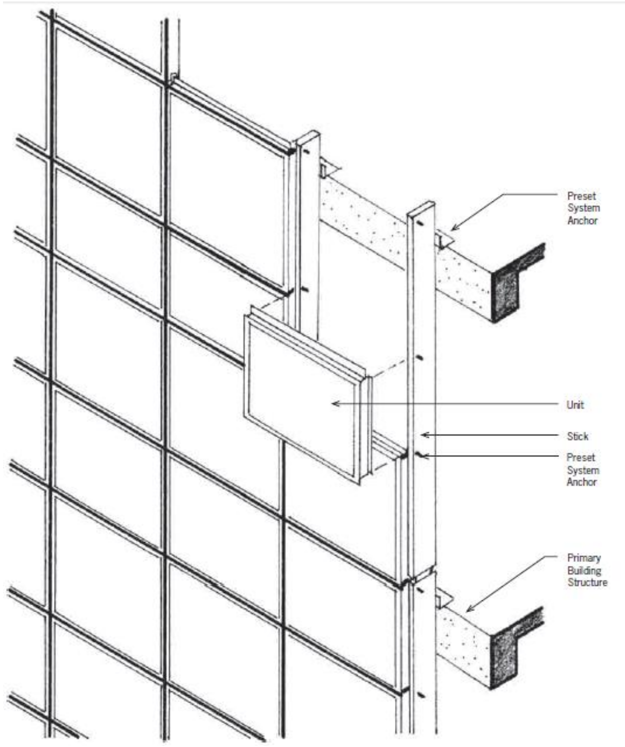


Figure 3: in a unit on a stick system, stick framing is shop-fabricated and anchored to preset system anchors. Shop fabricated and shop-assembled “units” are installed on the sticks at the project site. Source: (Boswell, 2013).

2.1.3.1.4 Column cover/spandrel panel

A column cover/ spandrel panel system is composed of panelized column covers and/or panelized spandrels. Infill areas between column covers and spandrels consist of stick or unitized framing with glass or other infill materials. Systems with only spandrels and continuous lengths of metal-framed and glass infill are often referred to as “ribbon windows.” (Figure 4) (Boswell, 2013).

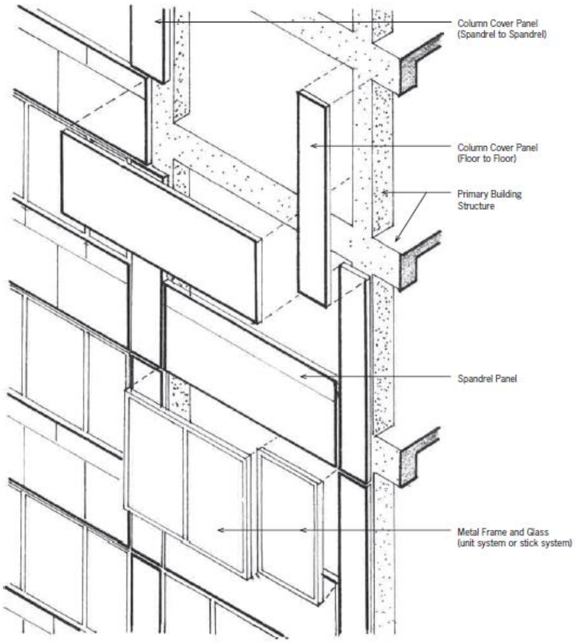


Figure 4: Column cover panels and/or spandrel panels are shop-fabricated and -assembled and installed on the primary building structure. The openings created by the column cover and spandrel panels are stick-built or unitized framing and glass or other infill. Source:(Boswell, 2013).

2.1.3.2 Frameless GCW Systems

Despite their merits, many architects and engineers have indicated a preference for frameless GCW systems as opposed to framed alternatives. This is so because despite being unconventional, these glass wall systems can aid the building's energy efficiency, when designed properly, by allowing for the fullest use of natural daylight as a result of less supporting structural elements (including mullions, transoms, and aluminum/metal profiles). There a various types of frameless GCW systems, all of which share the same goal of attaining as much transparency as possible by avoiding supporting structures (Sivanerupan e al., 2008). The various kinds of frameless glazed systems usable in GFs include:

2.1.3.2.1 Point Fixed Glass Supported by Steelwork

Point fixing (also known as bolted glazing) systems use the glass as a bearing component in order to provide support for the beams and mullions. Neither mullions nor frames are used in the structures that provide support in these systems, which are instead comprised of simple posts, fins, and trusses (Vyzantiadou and Avdelas, 2004). When the elevation of the glazed wall exceeds 4.0m, different forms of steel trussed posts are utilized for the glazing wall with support (Sivanerupan et al., 2008).

2.1.3.2.2 Point Fixed Glass Supported by Cable Systems

Tension elements, such as rods or wires, may be used almost entirely in producing support structures as the result is a lighter structure with fewer visual barriers. Both ends of the cables that hold them are used to transfer the load to boundary support structures while either the suspension of each panel from the panel above it or a tie rod hanger system is used to support the weight of the vertical glazing (Vyzantiadou, and Avdelas, 2004).

2.1.3.2.3 Glass Fin Support System

The glass walls for fin supported glazing are supported using fins or glass beams on their edges. The glazing is fixed to the fins either through a soft silicone sealant, or disjointedly by means of bolted connections. This system is inappropriate for tall buildings using the GF systems (Sivanerupan et al., 2008).

Glass fins may be used so as to attain the highest level of transparency possible. Design principles, as well as those concerning installation, should be considered when structuralizing the glazing system. The thickness, size, and safety of the glass should also be considered in glass fin supported systems. Furthermore, bolted joins are often used when devising glass fin supported systems. A number of fittings intended to absorb the forces acting on the glass are applied. These fittings offer a secure bond between the support structure and the glass fins. The glass fin supported systems also allow for better visibility and a higher Natural Daylight level in the interior (pakishan, 2011).

2.1.3.2.4 Suspended Glazing Support System

One possible solution to the problem of the deflection of glass on the façade is to suspend the glass panels from the top of the building as opposed to simply incorporating them into the body of the building itself. These types of systems do not use mullions and transoms; additionally, frames do not hold the glass panes. Instead, glass panes are hung from the constituting structure and generate a medium whereby the façade’s large openings provide the building with a nice view and maximum transparency. The suspended glazing support system was created to meet the needs of buildings with larger glazed portions. It is used primarily for tall glass panes vulnerable to buckling and bending as a result of their length (Compagno, 1999; Garg, 2009).

2.1.4 Emergıng Technologıes in Glazed Facade Desıgns

From the mid-19th century onwards, advances in the fields of materials, technology, and science, have driven innovation in building form and function. Advancements in building materials in particular have led to the increased capacity for innovative architectural design and implicitly, innovation. exterior curtail wall is now considered an economic, yet effecting, cladding method due to an increasing desire in the field to combine high performance and low construction costs. Three trends can be seen in modern developments in façade technology: a desire to enhance micro-level façade performance; an increase in large-scale innovations like the double-skin façade; and increased use of building skins integrated with energy-generation components. All three trends share the same functional performance goals: minimize the negative effects of the external environment, providing a border between both environments, and using as little energy as possible to ensure the comfort of the building’s occupants (aksamija, 2013). This chapter covers a few of the recent technological advancements in the field:

2.1.4.1 Emerging technologies and materials

Advanced Facade Materials: Aerogels are essentially air-based synthetic solids. Due to their incredibly low density compared to other solids, they are especially useful for the provision of thermal insulation as they have a correspondingly low thermal conductivity. A number of glazing products that use aerogel are commercially available. The aerogel is usually either use to fill the spaces between insulating units' glass lites (Figure 5) and channel glass cavities in a granular form, or is used to create a transparent cladding material by integrating it with polycarbonate sheets. Aerogel is an acoustically sound, non-combustible hydrophobic (water resistant) material. An aerogel-filled glazing, with a U-value somewhere around (0.57 W/m2-°W) and (1.00 W/m2-°W), is more thermally resistant than a regular unit, the U-values of which hardly ever go below (1.43 W/m2-°W). Because it is translucent, silica aerogel may be used permit diffused daylight into the building, although this quality does not make it compatible with vision glass (aksamija, 2013).

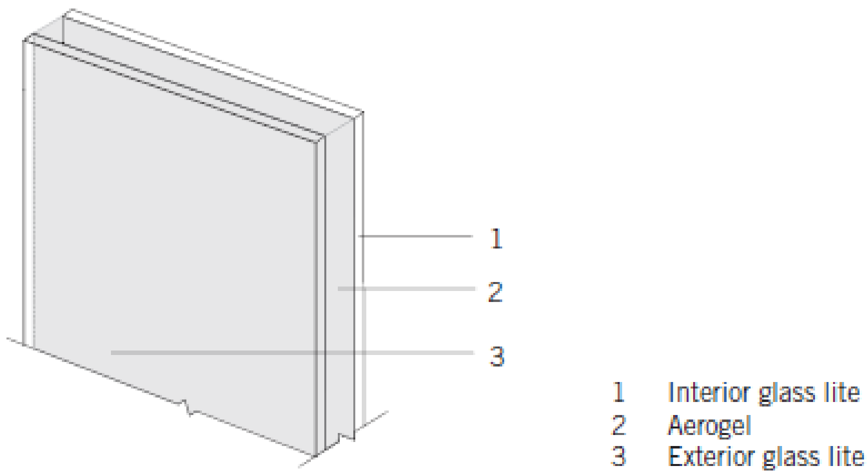


Figure 5: Diagram of glazing unit with integrated aerogel insulation (aksamija, 2013)

The thermal resistance afforded by vacuum-insulated glazing units is superior to that of units filled with either regular air or gas. Such units bolster the thermal resistance of the assembly by creating a vacuum between the two glass lites. As such, virtually no heat is conducted between the lites as gas, which usually acts as the heat transfer medium, is no longer present. The radiation of heat through the glass could be further reduced by applying a low-e coating to the #2 or #3 glass surfaces. Through the combination of all these measure, the U-value of the glazing units could even be extended below 0.10 Btu/hr-ft2-°F (0.57 W/m2-°W), The two glass lites are pulled together by the negative pressure created by the vacuum between them thus necessitating the placement of a grid of spacers between them .Said spacers are created using low-conductivity materials and are positioned a couple of inches from each other in either direction. The thickness of vacuum-insulted glazing units is usually between quarter or half an inch, making them perfect for existing frames where supplementary high-performance glazing is required, which is common place for retrofit projects (aksamija,2013).

A budding kind of insulating material is vacuum-insulated panels (VIPs). These panels are comprised of a central insulating material (typically glass fiber or silica) within a vacuum-sealed, airtight fil envelope. The thermal conductivity of VIPs is $1/7^{th}$ that o regular insulating materials (Wang et al., 2007). As unfinished materials, VIPs need to be used behind curtain wall spandrels or within non-transparent façade elements. Lastly, VIPs are capable of minimizing the thickness of an exterior wall while keeping its thermal performance intact due to the quality of their insulating capacity.

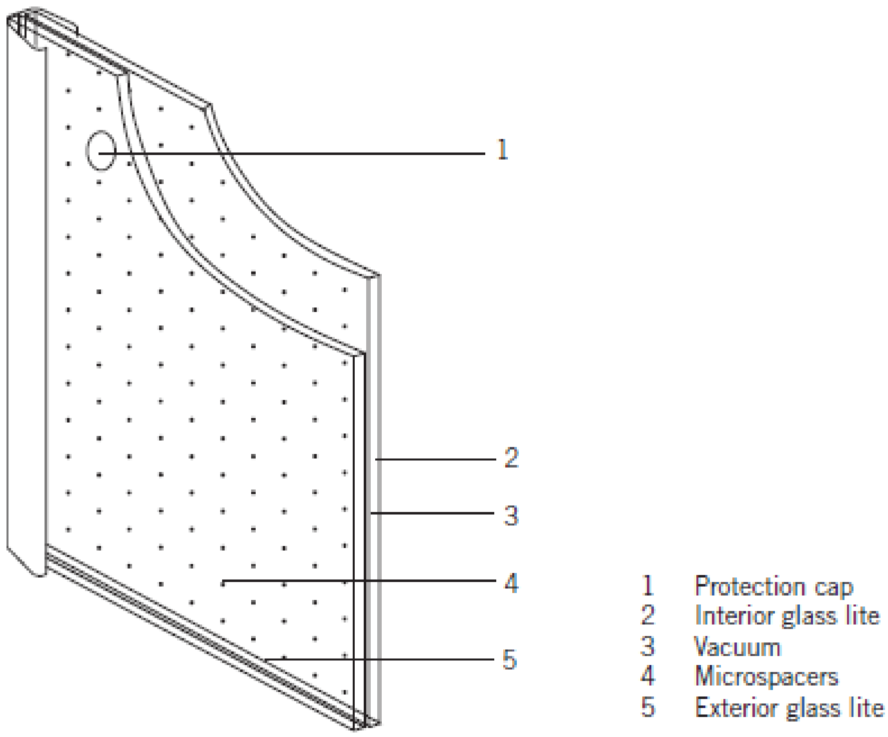


Figure 6: Diagram of vacuum-insulted glazing unit. Source :(Aksamija, 2013).

Smart Materials: Living organisms are capable of adapting themselves to the prevailing environmental conditions facing them. This ability has been transposed into the realm of smart materials through advances in both physical and materials sciences. Modern smart materials are able to physically respond to their particular lighting, environmental, and acoustic conditions (Spillman et al., 1996).

Electrochromic glass is one such smart material and encompasses a film capable of changing its opacity based on the application of electric voltage and so clear electrochromic glass may become dark, and remain that way without any supplementary electricity and vice versa (Figure 27). To return the glass to its original state, another round of voltage is applied the voltage-consequent darkening and lighting begins at the edges of the glass and progresses towards the centre until the whole glass is affected in a process that may can extend up to several minutes. The use of electrochromic glass can be used to provide the building with dynamic shading control and the visual transmittance ranges from 4% in its tinted state to 60% in its clear state, while its SHGC is 0.09 ad 0.48 in its tinted and clear states respectively. This type of glass can be used to change the tint of glass without any additional energy requirements.

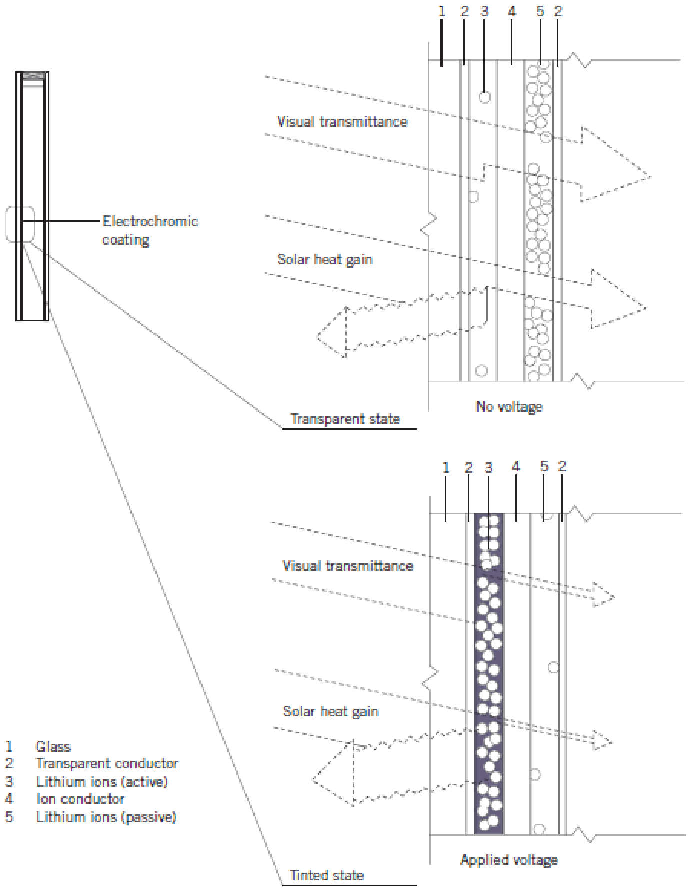


Figure 7:Electrochromic glass diagram. Source:(aksamija, 2013)

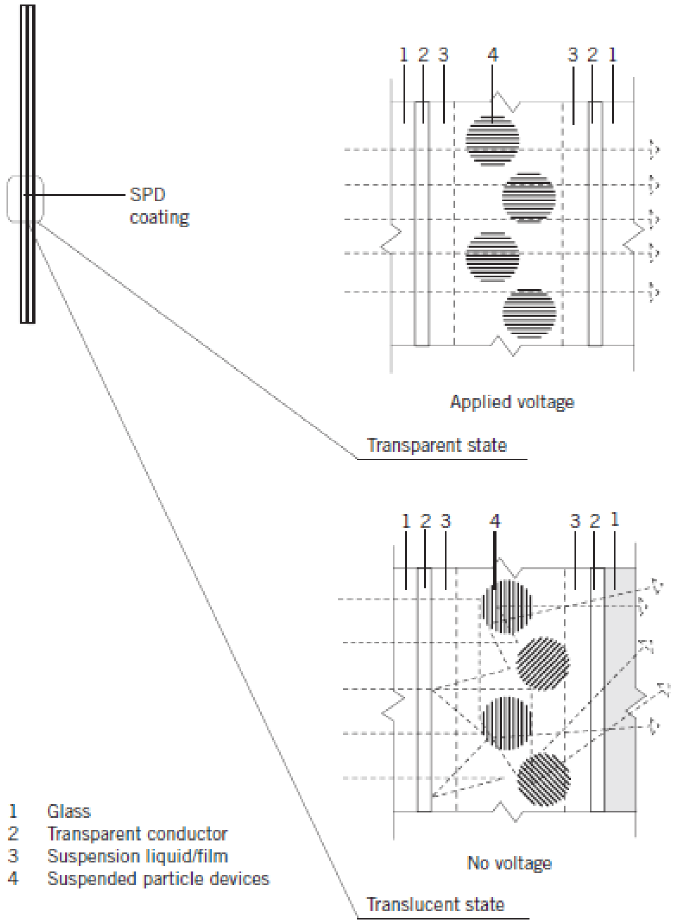


Figure 8: SPD glass diagram (aksamija, 2013)

Suspended particle device (SPD) glass is made up of two layers of glass with a thin liquid crystal film suspended in a transparent conductive material. The translucency of the glass is regulated through the application of voltage to it. The crystals that comprise SPD are arranged randomly when it is in its unaltered non-electrified state and a translucent appearance is provided by scattering light through the crystals. The application of the voltage to the glass causes the hitherto random crystals to take form and permit light to pass through the glass, thus making it transparent (Figure 8). SPD glass is often used in the provision of privacy for interior spaces and switching between states is virtually immediate. The downside is that the glass has very little impact for energy conservation and is not recommended for exterior envelopes (aksamija, 2013).

Self-cleaning glass includes a thin titanium dioxide film, applied as a photocatalytic coating, on the exterior surface. A photocatalyst is a compound that enables a chemical reaction using sunlight's UV bands. Exposing the glass to sunlight results in an oxidation process triggered by the titanium oxide, whereby harmful inorganic and organic substances alike are converted to harmless compounds. The process is comprised of two phases (Figure 9). In the first, the photo catalytic stage, exposing the glass to sunlight causes organic dirt to be broken down, and in the hydrophilic stage, the loosened particles are run off by rain water, thus keeping the clean without any additional energy costs. In locations with lesser amounts of rainfall however, the hydrophilic stage might need to be manually prompted. It has been discovered that air pollution in dense urban areas can be somewhat mitigated using self-cleaning glass (Chabasa et al., 2008).

The self-cleaning is not exclusive to glass as titanium dioxide can be added to many other materials to allow them become self-cleaning. For example, photocatalytic cement can be used for the production of self-cleaning concrete panels capable of minimizing air pollution, although, this has little effect on how strong the concrete will be (Cassar, 2004).

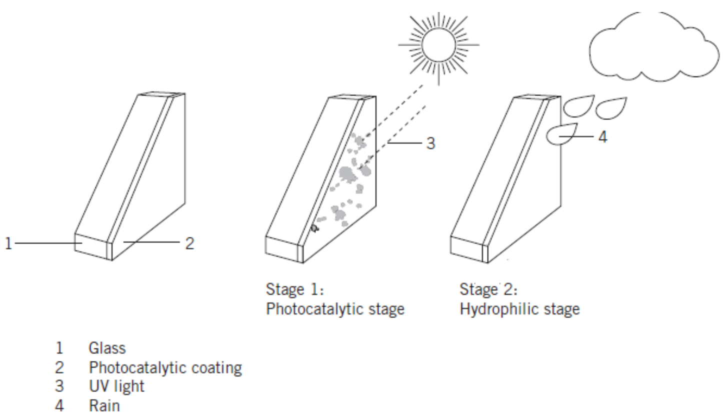


Figure 9: Diagram showing the two steps in the self-cleaning process for glass with photocatalytic coating (aksamija, 2013).

When phase-change materials – organic or inorganic materials that absorb and store heat in the process of changing form from solid to liquid following an increase in temperature – are integrated into the building envelope, they dissipate heat absorbed during the day into the interior at night. A wide variety of PCM-integrated products are available on the market; one such product is the triple-insulated glazing unit (IGU) integrated with PCM (Figure 10). The interior gap is filled with polycarbonate PCM-incorporated containers while the two exterior gaps are filled with inert gas, and outermost gap of the IGU comprises a prismatic pane. IGUs of this kind act as a source of passive heat in winter as the prismatic pane permits the PCM to be heated and subsequently liquefied through the penetration of low-angle sunlight, which is then disseminated to the interior for heating. In the summer, the prismatic pane allows the PCM to remain in its solid form by reflecting high-angle solar rays. Glazing units of this kind have relatively high U-values of around 0.08 Btu/hr-ft2-°F (0.48 W/m2-°K). The visual transmittance and SHGC of solid and liquid-state PCM's lie between 0%-28% and 0.17-0.98, and 4%-45% and 0.17-0.48 respectively. Glazing units with PCM are translucent regardless of its state and consequently unsuitable for situations requiring outside views (aksamija, 2013).

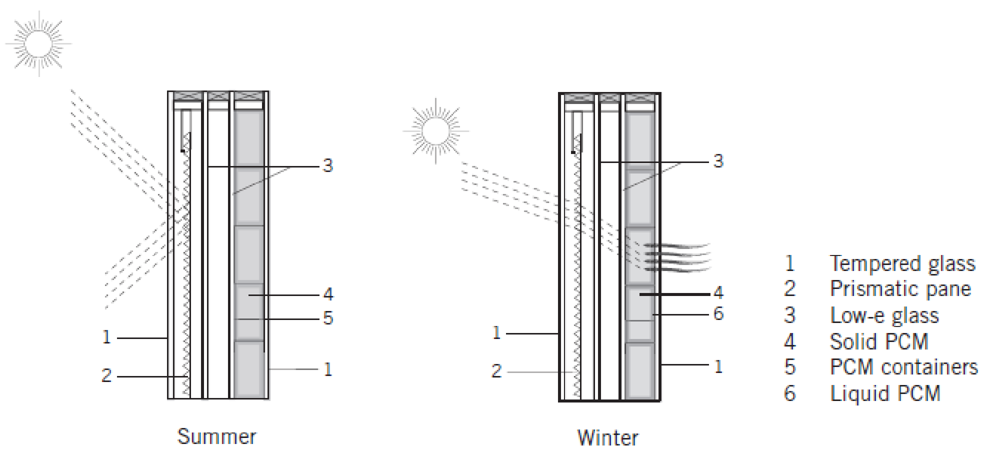


Figure 10: Diagram of triple-insulted glazing unit with integrated PCM (aksamija, 2013)

Photovoltaic (PV) glass results from the integration of amorphous thin films or crystalline solar cells capable of producing light-generated energy. This kind of glass is usually incorporated in to double-glazed or laminated units and comes in either opaque or semi-transparent form (Figure 11) (aksamija, 2013).

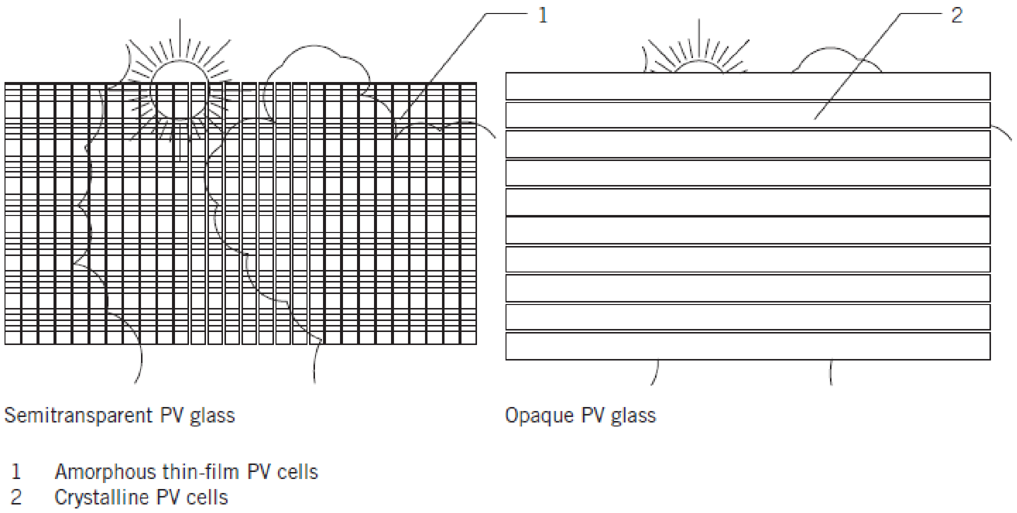


Figure 11: semitransparent and opaque PV glass (aksamija, 2013)

Semi-transparent PV glass is functionally similar to patterned ceramic frit in that it allows only a certain amount of light into the interior while simultaneously allowing the occupants to have an outside view. The opaque variation on the other hand, is only suitable for no division façade areas, such as spandrels, because it uses solid PVs. The use of PVs for energy generation and its performance is covered in a later section. A comparative look at the properties of the materials discussed above and conventional high-performance glazing materials is provided in Table 2 (Aksamija, 2013).

Table 2: comparision of commercially available emergin g facde glazing materials with standard high-performance products. (Aksamija, 2013)

Material	Solar Control	Insulation	Daylight	Glare Control	Maintenance	View to exterior	Lifetime
Aerogel insulation within insulated glazing unit	0	+	+	+	0	–	0
Vacuum-insulated glazing unit	0	+	0	0	0	0	–
Electrochromic glass	+	0	0	+	0	0	0
SPD glass	0	0	0	+	0	–	0
Translucent state	0	0	0	+	0	0	0
Transparent state							
Self-cleaning glass	0	0	0	0	+	+	0
PCM in insulated glazing unit	+	+	0	+	0	–	+
PV glass (semitransparent)	+	0	0	+	0	–	0

Legend: + Improved performance 0 Similar performance — Lower performance

A current string of research is aimed at the discovery of novel self-healing materials, such as metal composites, polymer composites, and reinforced self-healing concrete, for commercial use (Asanuma, 2000; Kuang et al., 2008). Such materials comprise healing agents or embedded shape-memory alloy wires capable to reacting to and repairing material cracks. They do this by releasing polymer healing agents from microcapsules in the polymer when a crack develops. The crack is bonded by the solidification of the polymer, which occurs when catalysts within the material come in contact with the polymer itself. This process is similar to that that occurs between self-healing concrete and metal composites. These advancements would drastically change the field of building facades as it will enable materials repair themselves unilaterally (aksamija, 2013).

2.1.4.2 Facades as energy generators

Buildings are more frequently being equipped with non-conventional sources of energy, such as wind and solar power. Solar energy falls in either of two categories: active and passive. Active solar energy results from a process whereby electricity is generated or fluids are heated by devices like photovoltaic (PV) panels and solar collectors. On the other hand, passive solar energy is either radiation or heat that results directly from the exterior materials of the building coming in contact with sunlight. For example, heat collected by highly thermal materials can be released into the interior at night. Either form of solar energy may be used in facade design. This section focuses on energy generated by the sun because other sources of energy are not as common for facades. Two examples of emerging passive solar energy systems are solar dynamic buffer zone (SDBZ) curtain walls and solar air heating systems. (Aksamija, 2013).

For facades, photovoltaics are one of the more widely used active energy-generation systems. Façade-integrated PV modules come in one of two variants: solid cells and thin films. Thin films, usually located between panes of glass and comprised of interconnected solar cells, convert visible light to electricity. Thin films may be incorporated into a variety of façade surfaces including vision glass, spandrels, and shading devices. Similarly, shading devices and spandrels may also be integrated with solar cell modules. The overall performance and aesthetic appearance of PVs is determined by the size, kind, and relative position to the sun (Aksamija, 2013).

The most common conventional cell type for PV modules, monocrystalline silicon cells typically have a consistent structure and colour. Even in the best of conditions, their efficiency (how much electric energy they are able to convert from solar energy) does not exceed 20%. Even with the lack of variation in their silicone structure, the surface structure and colour of polycrystalline silicon cells is inconsistent and they are usually cheaper, thus less efficient than monocrystalline cells. Thin films typically use amorphous silicon cells as they are compatible with both flexible and rigid substrates.

These cells are made up of hydrogenated amorphous silicon, which are highly absorbent to incident light. They are incredibly cheap to manufacture and as such have a correspondingly low efficiency that is usually less than 7%. They are, however, advantageous in that they function consistently in either sunlight or shade. (Aksamija, 2013).

The maximum efficiency of monocrystalline and polycrystalline cells is only achievable through direct sunlight as the use of shading significantly reduces their capacity to produce energy, as does sand, snow, or dust covering, and a sunlight-reducing orientation. PVs typically generate more energy when they are oriented in such a way that the sun's rays are perpendicular to their plane. The most effective positioning for a PV may be determined by taking into consideration the angle of inclination and plan orientation. The ideal orientations are northward in the south and southward in the north. Failure to adhere to these, by using either an eastward or westward orientation, will have an adverse effect on the production of energy. Similarly, the ideal inclination is towards the sun at an angle to be determined by its altitude, which is itself determined by the building's latitudinal position. The conventional practice is to angle the PV panels equal to the latitude. (Aksamija, 2013).

The energy production of a south-facing PV system, consisting of a 10,000 square-feet of extremely efficient polycrystalline silicon panels, with a 42°N latitude, is outlined in Figure 1 and the lowest level of energy production results from a vertical 90° angle, and designers should take this into consideration when deciding the angle of inclination. To counter this, the PVs may be integrated within vertical shading elements that are capable of rotating and 'tracking' the sun's movements. Or out rightly affixed to shading elements with a more suitable angle of inclination. Figure

13 provides a comparison of the energy output of PV panels attached to moveable vertical shading devices and similar, but stationary, shading devices. While the use of adjustable shading devices has a positive effect on the amount of energy generated, the degree is considerably less than when the PVs arike inclined. (Aksamija, 2013).

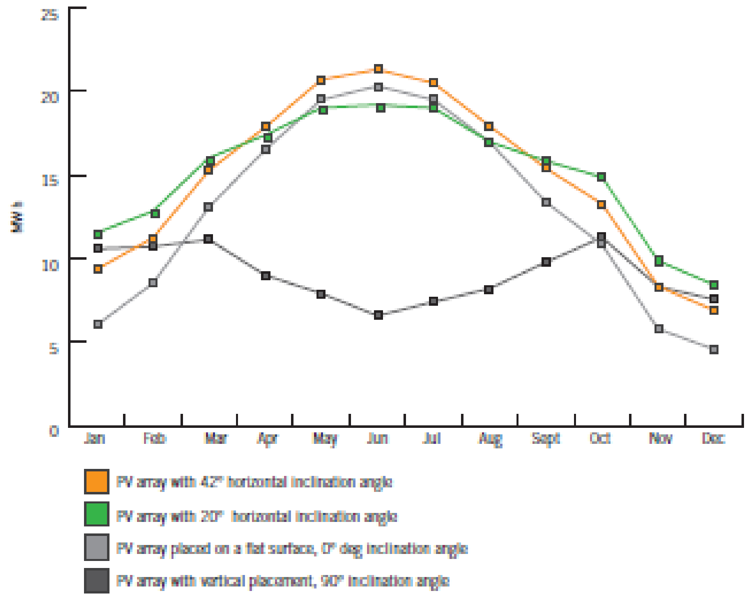


Figure 12:Annual energy output for PV panels with different inclination angles. (aksamija,2013).

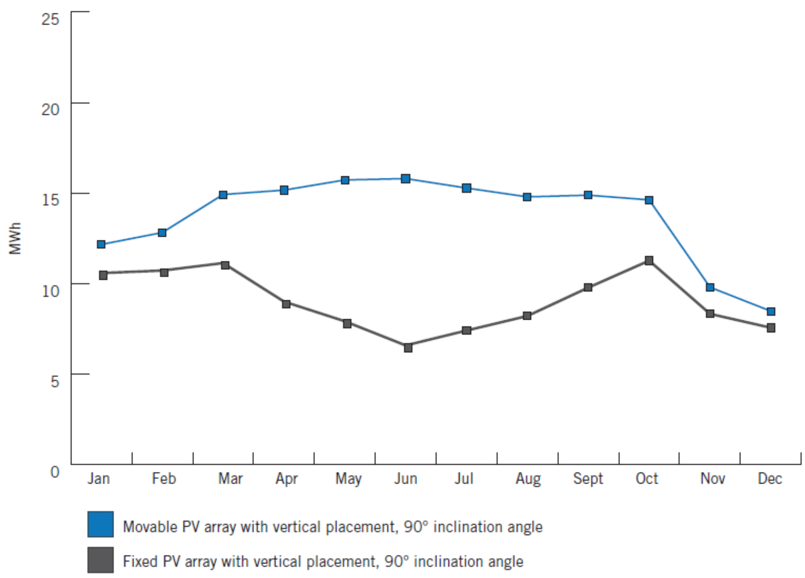


Figure 13: Annual energy output for facade-integrated pv panel (aksamija,2013).

2.1.4.3 Control systems for facades

The facades of the future would be capable of intelligently responding to environmental changes. Dynamically controlled, interactive facades, will encompass systems that will adjust their performance in response to changes in both interior and exterior conditions, while also allowing the occupants to make changes as necessary. The components of these facades will be able to adjust their ventilation, daylighting, heat loss, and solar gain, in response to exterior environmental changes. Furthermore, the integration of building automation systems, smart building controls, and occupant-operated controls would lead to significant increases in energy conservation while providing mechanisms for individual control over interior environmental conditions will also ensure the comfort of each individual occupant (aksamija,2013).

These 'intelligent' facades should be receptive to a variety of wired and wireless inputs from building sensors to ensure occupant comfort and satisfy energy requirements. Presently, façade components can be controlled using internet communication protocols and low-cost sensors. Facades themselves are usually split into function-based zones, such as those responsible for controlling shading devices. Each building orientation for example, could have a unique zone and specific control mechanisms for the respective zones, such as the ability to lower eastward blinds in the early hours of the day. In cases where the shape of the building could result in different sun and wind conditions, the same façade may be adapted for several zones by way of specific control mechanisms and sensors. Façade control systems include natural ventilation, thermal storage, the control of internal shades and other shading devices, and integrated lighting and façade systems. Façade technologies of the future will allow for building automation systems that will be able to detect faults and repair them automatically where applicable by tracking importance performance metrics and comparing them to historical data. Façade control systems would be capable of tracking humidity, temperature, wind, cloud cover, solar position, and other environmental conditions in real-time. Such systems would also be able to predict short-term environmental changes using algorithms intended for that purpose. Additionally, natural ventilation, thermal storage, and lighting and façade integration systems are pivotal for the creation of energy conservation opportunities. Fully integrated 'intelligent' systems will be capable of sensing occupancy patterns, adjusting shading devices, HVAC systems, and lighting, to conserve energy (aksamija, 2013).

The emergence of adaptive construction processes and advancements in production technology allow for the built environment to be considerably revolutionised in terms of performance, thermal behaviour, aesthetics, and energy usage. They will significantly alter how we design and operate our buildings and the use of sustainable-energy efficient facades, and intelligent building operations and materials, will positively affect the human experience. (Aksamija, 2013).

2.1.5 High-Rise Buildings

In different periods of the history of architecture, man has incessantly challenged heights in construction, being limited only by its technological capacity. Naturally, what could be called as a tall building has changed dramatically over the years. Verticality has always been a symbol of superiority and power (Sayigh, 2016).

A high-rise building has been defined by the Council of Tall Buildings and Urban Habitat, CTBUH (2015) as "A building whose height creates different conditions in the design, construction, and use than those that exist in common buildings of a certain region and period". Nonetheless, CTBUH stated that there is no absolute definition of what constitutes a “tall building”. It is a building that exhibits some element of “tallness” in one or more of three categories: (a) Height Relative to Context, (b) Proportion, and (c) Tall Building Technologies (figure 14).(CTBUH , 2015).

According to Oral Buyukozturk, high-rise buildings have been demanded as a result of economic growth and increased demand for office space worldwide (Buyukozturk, 2004).The United States is considered the birthplace of high-rise buildings in our contemporary society. According to the Council on Tall Buildings and Urban Habitat (Gerometta, M., CTBUH), the first tall building was the ‘Home Insurance Building’. In addition, The American cities of New York and Chicago began competing for the world’s tallest building. Buildings in Chicago like the Tribune Tower (1925) at 141 m were promptly beaten by buildings in New York such as the Chrysler Building (1930) at 319 m and the Empire State Building (1932) at 381 m high (Sayigh, 2016).

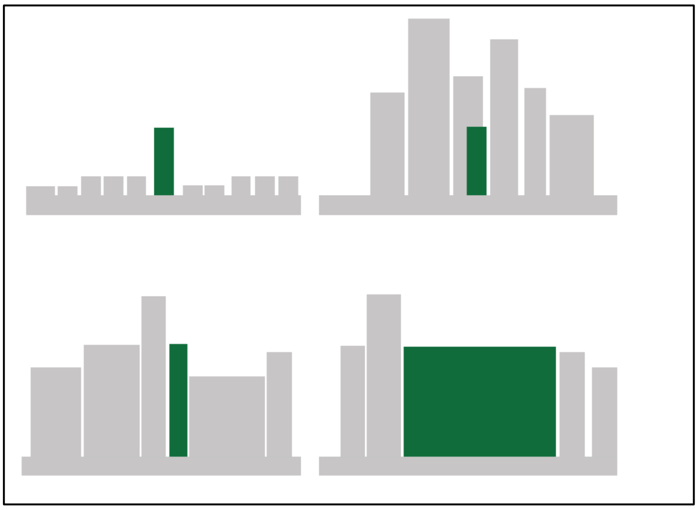


Figure 14: Proportion and Context of tall buildings [online]. Source :(URL1).

2.1.6 Office Buildings

The primary purpose of an office building is to provide a workplace and working environment primarily for administrative and managerial workers. Literature differentiates two types of office activity related requirements, namely physical and psychological (Raymond and Cunliffe, 1997).

- Physically every activity needs space, working facilities and other technical requirements such as for lighting, indoor climate, ventilation, and acoustics in the environment.
- Psychologically, activity needs certain requirements such as environment condition that supports users' psychological comfort.

Raymond and Cunliffe (1997) indicated four physical requirements regarding office activities namely: space, light, indoor climate condition and sound. Some researchers showed that these four physical environment aspects significantly influence the occupants' health, mood, satisfaction and then their productivity (Boyce et al., 2003; Sundstrom, 1986).

Chapter 3

ENERGY EFFICIENT GLAZED FACADE SYSTEMS

This chapter particularly provide an outline about energy efficiency in high rise office buildings and characteristics of energy efficient glazed façade systems:

3.1 Highly Glazed Façade Issues in High-Rise Buildings

Highly glazed facades have been in use ever since the 1851 construction of the Crystal palace. Global curtain wall use however, did not begin up until post-war economic prosperity and building technology allowed for it in the early 1950s. Following their popularity, the vast majority of designers tended to be more concerned with the aesthetic appearance of facades as opposed to their capacity to improve buildings' energy performance. The 1970s oil crises however, changed this as they forced architects to begin to pay attention to issues pertaining to energy conservation, climate change, and the design of high-performance facades and energy-efficient buildings (Aksamija, 2013).

The thermal performance and ability of highly glazed office buildings to use energy efficiently is often a point of contention. Regardless, there is a recent trend towards the increased use of glazed buildings as

> "There is a growing tendency on the part of architects to use large proportions of glass that lead to higher transparency; Users (who do not take into account the risk of visual and thermal discomfort that can occur due to this construction type) often also like the idea of increased glass area, relating it to better view and more pleasant indoor environment; Companies who want to create a distinctive image for themselves (e.g. transparency or openness) often like the idea of being located in a glazed office building" (Poirazis, 2005).

Criticism of the increased energy usage used by fully GF buildings began in the 1950s (Compagno, 1999). Examples of such buildings, such as those where the curtain wall was used as a high-rise cladding system, include Mies van der Roe's Seagram Building in New York, 1954-8 and 860 Lake Shore Drive, Chicago, 1948-51 and the Lever House by Skidmore Owings and Merrill, also in New York, 1951-2 (Patterson, 2008).

The oil crisis of 1973/74 resulted in pressure to find an urgent means of reducing the energy consumed by GF buildings thus forcing architects and engineers to look for additional means of employing GF with an eye to reducing the Energy Efficiency performance of the building (Compagno, 1999). The façade used in the Willis Faber & Dumas building is a suitable example as its GF focused more on reflection as opposed to transparency, at least during the daytime. Bronze solar-control coated glass was used, thus resulting in a single solid reflective surface, and the weather scale through which the glass panes were attached was delivered by a small field applied silicone joint (Patterson, 2008).

Developments in GF, and glass architecture in general, increased monumentally and became even more significant when pressures for ecologically and environmentally friendly design were at their peak in the 1980s.

Facades remain one serious issue frequently encountered in the building construction sector in regards to construction, design, and manufacturing. They are one of the chief distinguishing aesthetical features of any building, thus differentiating it from other buildings (Winxie, 2007). Besides the façade, no other building system occupies such an important position for Aesthetic and Appearance and building performance (Patterson et al, 2008). Because they are the foremost building systems, facades perform the very important functions of allowing users interact with the exterior surrounding area and providing sufficient levels of Natural Daylight and Natural Ventilation for an improved quality Indoor Environment (Sivanerupan et al, 2008).

Problems, such as the loss of heat and the amount of energy used in cooling, lighting, and ventilating, plague buildings with large scale GF. However, the effective use of Natural Daylight and Natural Ventilation can substantially reduce the energy consumed for such facilities. Buildings with GF have become a feature of contemporary architecture in the past 20 years. This phenomenon has been accompanied with a simultaneous increase in the number of buildings with GF-related disadvantages (overheating and heat loss) (Comoagno, 1999).

Consequently, facade-related advancements have been more functional and have allowed designers the flexibility to invent more internal and external high performance solutions. Huge advancements in the area of façade technology have afforded engineers and architects alike the chance to modify the Aesthetic and Appearance of the building's envelope and design an integrated grid system using concepts like ventilation elements, large glass panes, windows, aluminium features, amongst others (Winxie, 2007).

3.2 Energy Efficiency in High Rise Office Buildings

Presently, "Buildings are the main destination for the nation's power supplies and hence the main sources of carbon dioxide emissions" (Pank, and Girardet, 2002) and high-rise structures are an unavoidable building form in society. Additionally, the increasing necessity of skyscrapers due to their maximal use of a finite land supply (Yeang, 1999) is making them a permanent feature of many societies. In fact, the energy efficiency and ecological design of such buildings is arguably more pertinent than that of regular buildings. This is so because tall buildings are uniquely able to maintain and recycle resources, even as the process of designing them requires more experience as it is markedly more complicated (Lotfabadi, 2014). As such, the energy efficient design of such buildings warrants particular attention. Some of the advantages afforded by these high-rise buildings are as follows:

- They allow for the saving of materials due to the repetition of plans.
- The use of efficient contractors in purchasing large quantities of san leads to lower costs.
- Using sustainable materials for their elevations allows for a reduction in energy usage and material waste.
- Less land is needed for tall buildings.
- Daylight are better used.
- Horizontal access is better for its residents (Yeang, 1997).

Many high-rise buildings are intrinsically non-energy efficient as they follow predetermined forms with little regard for particular context and environmental relationship to their specific locales. This issue relates directly to the impact of their high-energy operation on other infrastructure and the environment. Tall buildings with larger glazing have been known to retain excess heat in the summer and suffer from heat loss in the winter.in addition It is noteworthy that designing environmentally per formative high-rise buildings requires in-depth knowledge of potential constraints and climatic context. The popularity of such buildings began to increase from the year 1990 onwards. Moreover the plethora of environmental concerns where high-rise buildings are concerned necessitates the consideration of contextual, engineering, and architectural issues for energy efficient high-rises as they relate to building and environmental performance. As per performance, the primary strategy is the reduction of energy demands based on the building context (Siyag, 2016).

There is little question that the energy consumption of high-rise buildings can be considerably reduced through the use of appropriate sustainable, energy efficient and vernacular strategies. The lessons gleaned from vernacular architecture however, such as increasing thermal mass, daylighting, and natural ventilation, while easily adapted for use in small-scale buildings, are not as compatible with larger buildings. For example, the increased wind velocity at higher altitudes makes opening windows for natural ventilation impractical (Sayigh, 2016).

The majority of building energy consumption is accounted for by service, office, and retail buildings due to their popularity and the fact that they often exist in clusters. In the United States, such buildings collectively account for 41% of all commercial building energy consumtion (EIA-CBEC, 2003). In fact, office buildings alone, as the second most common building type, account for 19% of all commercial (high-rise) energy consumtion – the highest percentage for a single building type. (Sayigh, 2016).

3.3 Energy Efficiency GFS in High Rise Office Buildings

Understood to be outside enclosures that use as little energy as possible in maintaining a comfortable interior setting, thus promoting the productivity and health of building occupants, high-performance energy efficient facades are more than mere barriers separating the exterior environment from the interior. By remaining responsive to the external environment, these building systems create comfortable settings, in addition to their capacity to reduce any building’s energy consumption and contribute immensely to its energy consumption and comfort parameters. One major goal of modern façade designs is maintaining satisfaction levels while simultaneously developing strategies and technologies that allow us to consume fewer of out fast depleting energy and other natural resources (Aksamija, 2013).

An immense amount of energy can be saved through a well-designed building envelope. Adaptable permeability (to heat, air, and light) and visual transparency should be used to ensure that the building can be modified as needed to meet ever changing climatic conditions. As such, an environmentally-responsive envelope is ideal. Hermetically-sealed skins are not compatible with the green approach. The building skin should serve the following functions: providing adequate ventilation, an acoustic barrier, aesthetic improvement, maximal use of daylight, and external shading to reduce heat gain (aksamija, 2016; Aksamija, 2013).

During the process of designing the façade, controlling environmental factors (light, and heat) must be taken into consideration, as should be various strategies that could aid the design in improving the comfort of potential occupants (thermal, visual, and air quality).

The central concern here is the elucidation of technical and strategic guidelines for the design of environmentally-sensitive, energy-efficient facades on the basis of select scientific principles.

3.3.1 Climate-Based Design Approach for Facades

This section explores the various ways climates can be classified, as well as the particular features of the different climatic zones. It also provides a discussion centred on the various factors taken into consideration in designing high-performance energy efficient facades on the basis of the characteristics of particular climatic environments.

High performance -Energy efficient facade designers should use the characteristics of the particular building's climatic locale, in conjunction with its site constraints and program requirements, to create high-performance building enveloped capable to minimizing said building's energy usage. Designers must also take into consideration climate-specific guidelines as strategies intended for humid climates differ from those intended for arid climates (Aksamija, 2013).

3.3.1.1 Climate Classifications and Types

The term Climate refers to the aggregate humidity, temperature, wind, atmospheric temperature, atmospheric particles, rainfall, and a host of other meteorogical specificities of a particular area over an extended time-period. A location's particular climate is affected, in different degrees, by its terrain, latitude, altitude, and the presence of water bodies and/or mountain ranges.

One of the first attempts at categorizing climates, the Koppen Climate Classification System is comprised of five climatic groups, each of which is subdivided into at least one subgroup (Aksamija, 2013).

Designers can easily use the climate classification developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for the United States together with the International Energy Conservation Code (IECC). The classification splits the United States into 8 temperature-determined climatic zones (labelled numbers 1 through 8), and 3 humidity-based subzones (labelled A, B, and C)."The climatic zones are as follows:

Zone 1: very hot, Zone 2: hot, Zone 3: warm, Zone 4: mixed, Zone 5: cool, Zone 6: cold, Zone 7: very cold and Zone 8: subarctic. The 3 subcategories are – A: humid, B: dry and C: marine" (Aksamija, 2013).

Modelling the energy performance of buildings is usually done using historical weather data collected over the course of a specific time period e.g. 30 years. To enable stakeholders predict the future climatic conditions of a location, predictive climate models are currently being developed (Lawrence and Chase, 2010). These models consider the impact of extant and prospective greenhouse emission, temperature, and climate changes. A such, the resulting predicted weather data can be used to model a building's energy consumption as opposed to using historical data. In so doing, it is possible to prepare for how future changes could possibly affect building energy consumption (Aksamija, 2013).

3.3.1.2 Climate-Specific Design Guidelines for Facades

Environmental Considerations and Design Criteria: Designers need to take into consideration the space dimensions, external environment, occupants' comfort expectations, and the building orientation. Table 3 provides an illustration of how solar radiation, air temperature, wind velocity, humidity, ground reflectivity, noise, and the location and dimensions of external objects (such as topography, buildings, and plantings) come to exert an influence on acoustic, visual, and thermal comfort. Design decisions are affected by the relative importance of these criteria, such as the characteristics of transparent and opaque materials (reflectivity, thickness, amongst others) (Aksamija, 2013).

Table 3: Façade-element characteristics and environmental conditions that affect visual, and thermal comfort. Source: (Aksamija, 2013).

Environmental Conditions	Thermal comfort	Visual comfort
Outdoor design criteria	▪ Sun and wind obstructions ▪ Building dimensions ▪ Air temperature range ▪ Relative humidity range	▪ View and daylight obstructions ▪ Building dimensions ▪ Latitude and location ▪ Time of day

	▪ Wind velocity ▪ Solar radiation	▪ External horizontal illuminance ▪ Ground reflectivity
Indoor design Criteria	▪ Space dimensions ▪ User's activity level ▪ User's clothing insulation	▪ Space dimensions ▪ Colors of surfaces ▪ Working plane location
Indoor comfort criteria	▪ Air temperature ▪ Relative humidity ▪ Air velocity ▪ Mean radiant temperature	▪ Illuminance level and distribution ▪ Glare index
Opaque facades	▪ Material properties of cladding ▪ Amount of insulation ▪ Effective heat resistance properties ▪ (R-value)	▪ Window-to-wall ratio
Glazing	▪ Orientation ▪ Number of glass layers ▪ Layer thicknesses ▪ Heat transfer coefficient ▪ (U-value) ▪ Visual transmittance ▪ Solar heat gain coefficient (SHGC)	▪ Orientation ▪ Window properties, size, location, ▪ and shape ▪ Glass thickness and color ▪ Visual transmittance ▪ Reflectance
Frames and supporting structure for glazed facades	▪ Thermal properties of the frames	

Design Strategies and Climate: Considering climate design principles are useful to keep in mind user comfort and energy use reduction. They are specific for each location and define the interactions between building and outer environment (Capeluto, & Ochoa, 2016).

Strategies can be derived from examination of the biophysical effects of the environment inside a building (Givoni 1998). They show how changes in the climate affect temperature levels, thermal comfort, air velocity, relative humidity and solar radiation absorption. With these factors in mind, climate strategies can be grouped in following groups:

1. Heat management, collection and storage
2. Ventilation for comfort and air quality
3. Daylight (and sunlight) admission and control (Capeluto, & Ochoa, 2016).

Aksamija (2013) opined that different climates necessitate the use of equally different design strategies. The design of high-performance building facades is carried out using the following basic methods:

- Using the position of the sun to determine the orientation, development, and massing of the building.
- Controlling cooling loads and improving thermal comfort through the provision of solar shading.
- Enhancing air quality and reducing cooling loads through natural ventilation.
- Reducing the amount of energy used to provide mechanical cooling artificial lighting and heating by optimizing exterior wall insulation and the use of daylighting.

When deciding between different design strategies, the designer needs to account for local climatic conditions so as to reduce the potential impact of said conditions and minimize energy consumption. Table 4 offers a delineation of how climate comes to affect the choice of design strategies (Aksamija, 2010).

Cooler climatic zones (5 through 8) require passive heating, heat retention, the collection of solar radiation, maximal daylighting to reduce the need for artificial lighting, and insulation to reduce the need for supplementary heat sources. Conversely, hotter climates (1 to 3) require solar protection and minimal heat retention (Aksamija, 2013; Capetulo & Ochoa, 2016).

Mixed climates (zone 4) however, require a combination of strategies able to balance daylight permeation and solar exposure simultaneously. As a final point, designers need to take care to pay particular attention to the specific conditions of the building site as localized conditions have been known to differ from the general conditions of the constituting climatic zone (Aksamija 2013).

Table 4: Facade design strategies for different climate zones (Aksamija, 2013).

Climate type	Design strategies for energy efficient facades
Heating-dominated climates Zones 5, 6, 7, 8	▪ Solar collection and passive heating: collection of solar heat through the building envelope ▪ Heat storage: storage of heat in the mass of the walls ▪ Heat conservation: preservation of heat within the building through ▪ improved insulation ▪ Daylight: use of natural light sources and increased glazed areas of the facade, use of high-performance glass, and use of light shelves to redirect light into interior spaces
Cooling-dominated climates Zones 1, 2, 3	▪ Solar control: protection of the facade from direct solar radiation through self-shading methods (building form) or shading devices ▪ Reduction of external heat gains: protection from solar heat gain by infiltration (by using well-insulated opaque facade elements) or conduction (by using shading devices)

	▪ Cooling: use of natural ventilation where environmental characteristics and building function permit ▪ Daylight: use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves
Mixed climates Zone 4	▪ Solar control: protection of facade from direct solar radiation (shading) during warm seasons ▪ Solar collection and passive heating: solar collection during cold seasons ▪ Daylight: use of natural light sources and increased glazed areas of the facade with shading devices

Many energy codes reference ASHRAE 90.1, Energy Standard for Buildings except Low-Rise Residential Buildings, which provides recommendations for building envelopes (ASHRAE, 2010). ASHRAE 90.1 is periodically updated based on increasing expectations of building performance. These recommendations are based on building location and climate zone, using the IECC climate classification system of eight zones and three subzones .If ASHRAE 90.1 has been adopted as part of the state energy or building code, then the ASHRAE recommendations become the required metrics of building performance. ASHRAE's requirements are categorized based on the basic building function and occupancy, including:

(1) Nonresidential conditioned space (daytime use, higher internal loads).

(2) Residential conditioned space (24-hour occupancy, building envelope-dominated due to lower internal loads), and (3) nonresidential and residential semi heated space (Aksamija, 2013). ASHRAE requirements are recommended for all climatic zones in 3 ways:

- Least permissible thermal resistance (R-value) for the exterior walls

- The façade assembly’s highest permissible heat transfer coefficient (U-value) (with framing members’ thermal bridging effects also included)
- The façade assembly’s highest permissible solar heat gain coefficient (SHGC) for its glazed portions.

R-values are most appropriate for determining the thermal performance of wall systems that consist of multiple layers of materials, each with its own R-value. The heat transfer coefficient (U-value) of glazed facades represents its particular thermal properties. As the reverse of R-values, U-values decrease relative to increases in the thermal performance of a glazed wall area (NFRC, 2010).

Figure 15 shows ASHRAE’s maximum recommended U-values for different nonresidential buildings’ facade assemblies; it is based on metal framing (curtain wall and store front) and all climate zones. In colder climates require lower overall U-values. In contrast, required higher U-values in hot climates (ASHRAE 90.1-2010).

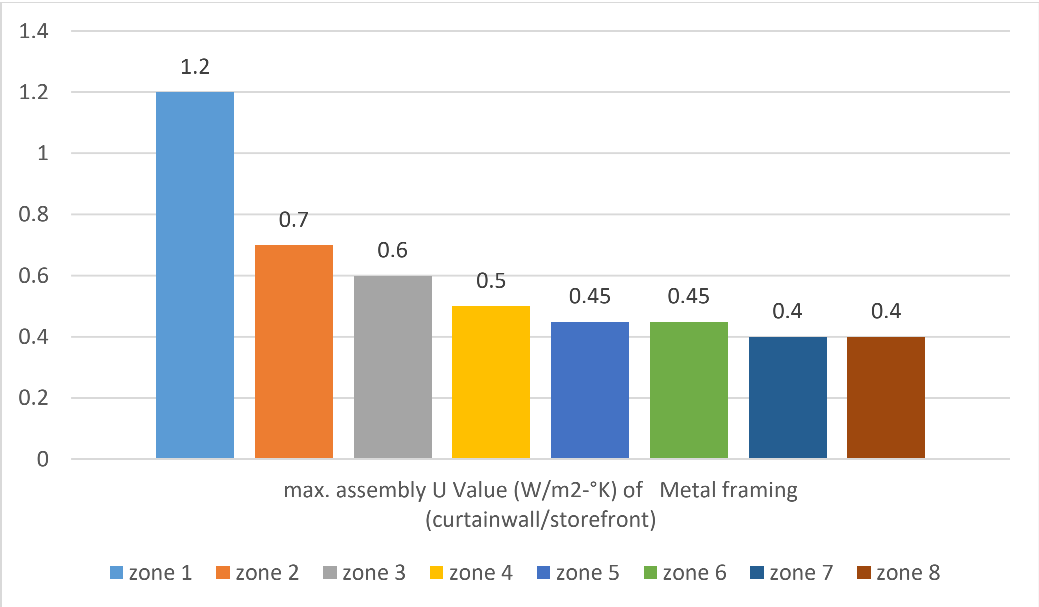


Figure 15: Max recommended U-values for exterior walls for metal framing (storefront /curtain wall) for all climate zones. Source: (ASHRAE 90.1-2010)

Figure 16 contains the highest SHGC recommended by ASHRAE for glazed façade areas. An SHGC value below 25% is preferred for warmer climates where the reflection of excess solar radiation is key. However, while higher SHGCs are preferred for colder climes, they should still remain below 45% (ASHRAE 90.1-2010).

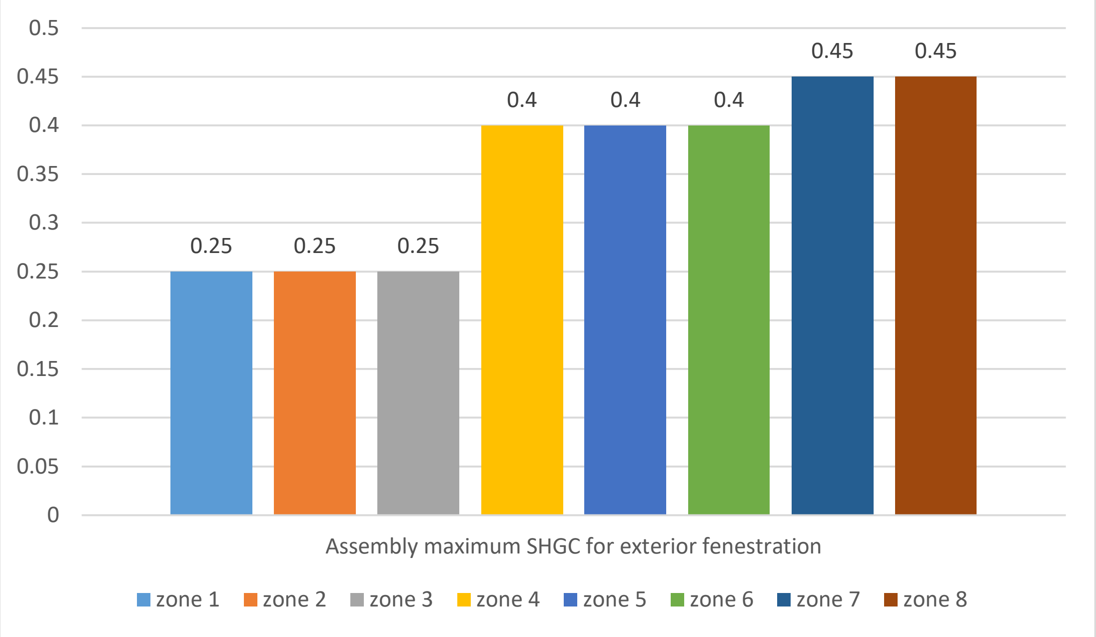


Figure 16: Max. Recommended SHGCs for fenestration for all types of façade and climatic zones. Source: (ASHRAE 90.1-2010)

3.3.2 Characteristics of Energy Efficient Facades

Four mechanisms play a deterministic role for the overall effect of the façade on the amount of energy used by a building. These mechanisms are: solar heat gain, lighting load, air leakage, and thermal heat transfer. A number of different tools and strategies are available to designers to help them bolster façade performance. Solar heat gain can be mitigated by means of high-performance glazing and solar shading; lighting load can be reduced through the proper use of daylight to lower the reliance on artificial lighting; and air leakage can be minimized through efficient window systems and uninterrupted air barriers. The proceeding section covers high-performance facades' properties and the various factors influencing their attendant design processes (Aksamija, 2013).

3.3.2.1 Energy Efficiency

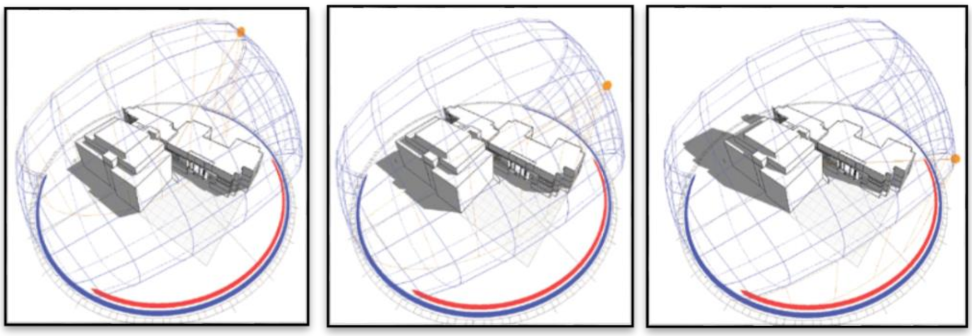
The following are the characteristics of energy-efficient building facades:

- Permitting for the admission of sunlight into the building
- Providing insulation from undesirable solar heat
- Amassing heat in the wall mass
- Using insulation to prevent heat transfers
- Preventing moisture or air from permeating the facade
- Allowing the interior of the building to be cooled naturally.

Each of these characteristics depends to a large extent on the particular climate, orientation, equipment load, and occupancy pattern in question (Aksamija, 2016; Aksamija, 2013). According to Aksamija (2013), the design of any energy-efficient façade is characterised by two elements: orientation, aspect ratio, arranging building masses and fenestration.

3.3.2.1.1 Orientation, Aspect Ratio (Floor Plate Design) Arranging of Building Masses

The level of sunlight a building is exposed to is determined by its particular orientation. The amount of solar radiation the façade is exposed to vary a great deal due to the Earth's changing angle relative to the sun and the Sun's East-West movement during the day. For simplicity's sake, solar exposure is calculated using the March 21st and September 21st equinoxes, and the June 21st (sun's highest point) and December 21st (lowest point) solstices, as shown in in Figure 17 (Aksamija, 2013).



21 June	21 March/September	21 December

Figure 17: Different solar positions and building orientations at various times of the year. Source: (aksamija, 2013)

The particular strategy to be used in regulating the solar heat gain depends to a large extent on the orientation of the building. As has been mentioned earlier, while buildings in warmer climes need to be shielded from sunlight for the majority of the year, solar heat gain is beneficial to buildings in colder climates. The ideal building orientation, where solar heat gain is concerned, strikes a balance between the provision of shade during the summer and heat retention in the winter (Aksamija, 2013).

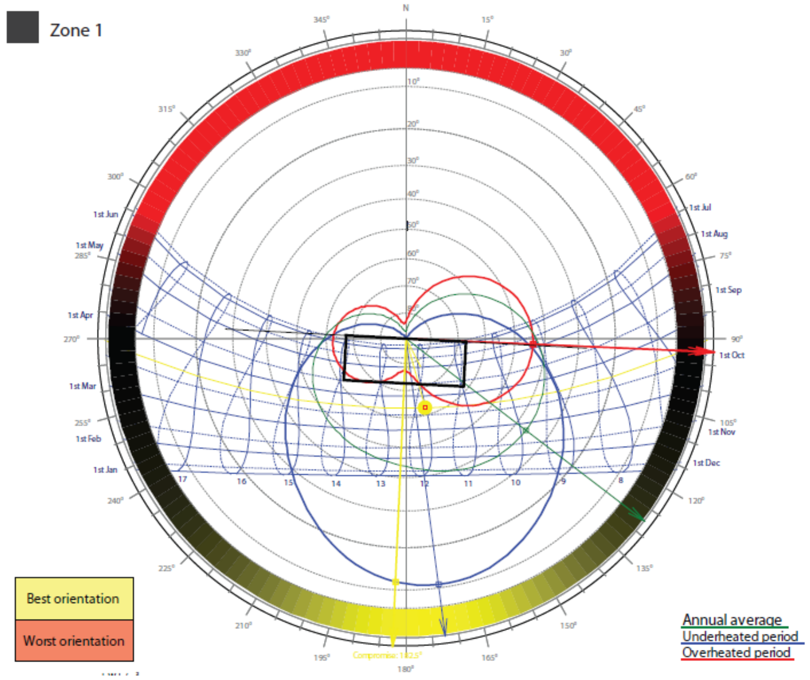


Figure 18: Ideal building orientation for very hot climate (zone 1). Based on yearly solar radiation Source: (aksamija, 2013)

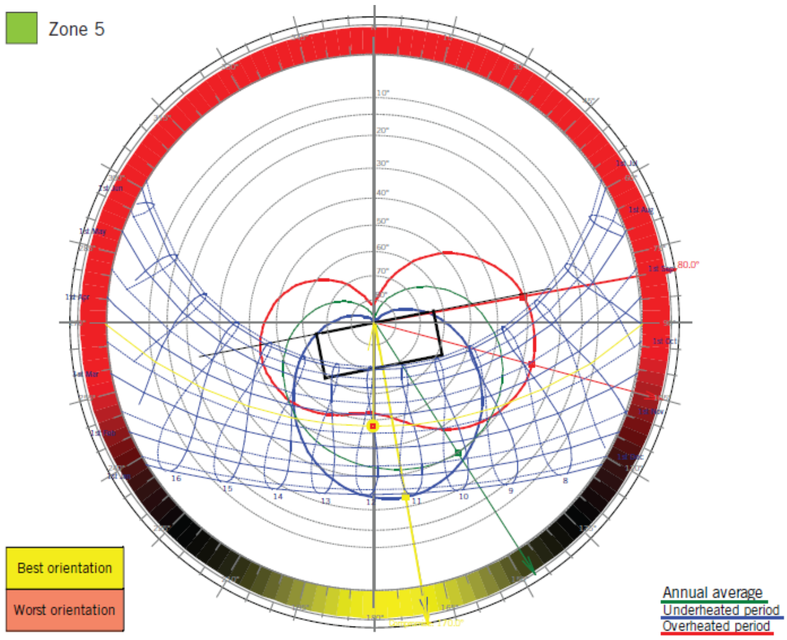


Figure 19: Ideal building orientation for cool climate (zone 5) based on yearly solar radiation. Source: (aksamija, 2013).

Using the usual latitudes of the respective climatic zones, Figures 18 and 19 contain the solar diagrams and optimal orientations for hot and cool climates respectively. Figure 18 shows that solar heat gain should be kept at a bare minimum year round, particularly during the summer in very hot climates (zone 1), while cool climates (zone 5) require a more balance exposure all year round but require a tad more exposure during winter (Figure 19) (Aksamija, 2013).

Managing solar heat gain is hardest for East and West facades as the sun's low angle in the mornings and evenings lends itself to little control by horizontal shading and they need complex shading device designs. Southward facades in the Northern hemisphere are able to permit desirable lighting levels even when there are externally-projected shading systems. The majority of this light would otherwise have been reflected and the amount of heat reduced. Northward lighting is not as string and is more evenly distributed (Napier, 2015). Furthermore, both northern and southern exposures are good for lighting during the day – in the north because the light is not direct, and in the south because the sun's height allows the shading of direct sunlight. Conversely, the low altitude of the sun in the east and west means that the façade in these exposures should be as minimal as possible to mitigate the prevalence of unnecessary radiation. If designers are forced to orient the building either eastward or westward as a result of site constraints, they can block out the majority of the low morning and afternoon sunlight using deep vertical fins (Aksamija, 2013; Sayigh, 2016; Kibert, 2016).

Professor Kibert, in his book (sustainable construction, 2016) stated that the traditional passive design approach to building orientation was to situate the longer side on a true east-west axis so as to keep the solar load on both surfaces at a minimum level, especially in summer (kibert,2016).

Aspect ratio refers to the ratio of the width of a building to its length, and is indicative of the building's shape. According to the rules of passive design, buildings in colder climates should ideally have an aspect ratio either close or equal to 1.0 i.e. they should be square-like. Buildings in warmer climates however, should have higher aspect ratios and thus be narrower and longer. The reason behind this shift in aspect ratio is that the volume of a square building would be larger relative to its surface area, which is necessary in colder climates where heat transmission (facilitated by the smaller surface area) is a major concern. Temperature differentials for heating are generally much greater than those for cooling, and so the building's total skin area is more important in heating situations (Kibert, 2016).

The orientation of the building is sometimes out of the control of the designer and may come to be determined by zoning requirements, site orientation and configuration, amongst other similar considerations. Façade orientation should be taken into consideration early because the effects of solar orientation are quite significant (Aksamija, 2013).

Due to the fact that the position of the building masses could either increase or reduce heat gain, their arrangement should be take n into consideration in bioclimatic design. In hot climates such as in Erbil, the building's service cores should be on its eastern and western sides in order to ensure that adequate shade is provided against low-angle sunlight for the most part of the day. Research has revealed that a double-core arrangement in which the openings of the windows run northward and southward with cores in the east and west will result in considerable energy saving where air-conditioning is concerned. The benefit of this arrangement is that in addition to providing a buffer zone for the hotter sides in the interior, it also minimizes solar heat gain and improves heat loss from the necessary spaces (Sayigh, 2016).

3.3.2.2 Fenestration

Components of Fenestration (curtain walls, skylights, clerestories windows) are both performance and aesthetically important for the design of the envelope. This is so because they are responsible for allowing natural light into the building's interior, this, in addition to fact that they also conduct the transfer of heat between the interior and the exterior. These elements affect the overall energy consumption of the building and the comfort, well-being, and productivity of its occupants. While deciding between alternative fenestration materials, the designed needs to take the particular properties of the glass – visual transmittance, U-values, SHGC – into consideration. Also of significant importance is the actual design of the framing system used for the fenestration as a poor design could result in noise, glare, condensation, drafts, and heat gain/loss, eventually leading to increases in energy consumption and occupant discomfort levels (aksamija, 2013).

Modern fenestration products, by means of recent advances in the field of building technology, are used in the manufacture of transparent, energy-efficient facades. The glazing units may be insulated with two or more glass layers, the space between which can be filled with aerogel or inert gases to lower the unit's U-value. The glass' ability to transmit solar heat gain can be reduced further by applying ceramic frit, low-e, or reflective coatings, or simply colour tinting the glass itself. Shade can also be provided by placing interlayer films inside the laminated glass and the U-value of the unit can be boosted even further by thermally improving or thermal breaking the aluminium frames. Overall, various types of glass are constantly being introduced to the market to meet a variety of aesthetic, functional, and security requirements (Aksamija, 2013).

The window-to-wall ratio (WWR) is an important façade measurement. WWR represents the ratio of the glazed and opaque façade areas. The ratio contributes significantly to the façade's energy consumption and solar heat gain. Generally, lower WWRs lead to lower energy consumption levels as the thermal resistance of an opaque façade is usually higher than of a glazed façade (Aksamija, 2013).

WWR (Window to Wall Ratio): The WWR is measured on a scale from 0% to 100% or from factor 0–1 for no windows to full windows, respectively. These two extremes usually result in negative effects in terms of energy, daylighting and visibility. Figure 20 illustrates the different WWRs in relation to their daylighting and visibility (Sustainable Window Design - Green Garage Detroit, 2017).A common rule of thumb states that to enhance a building's energy performance, the optimal WWR for hot and cold climates should be around 40% or less, and ASHRE recommended the optimal WWR for hot and cold climates should be around 40% or less, A higher WWR up to 90% can be accepted in cold climates, but only if the windows are well insulated, and in hot climates, only if they are well shaded (Walker, 2015). The formula to calculate the window wall ratio is given by Equation (1):

WWR = NGA/GWA (1) Where, NGA is the net glazing area and GWA is the gross wall area (Aperture Placement & Area | Sustainability Workshop, 2017).

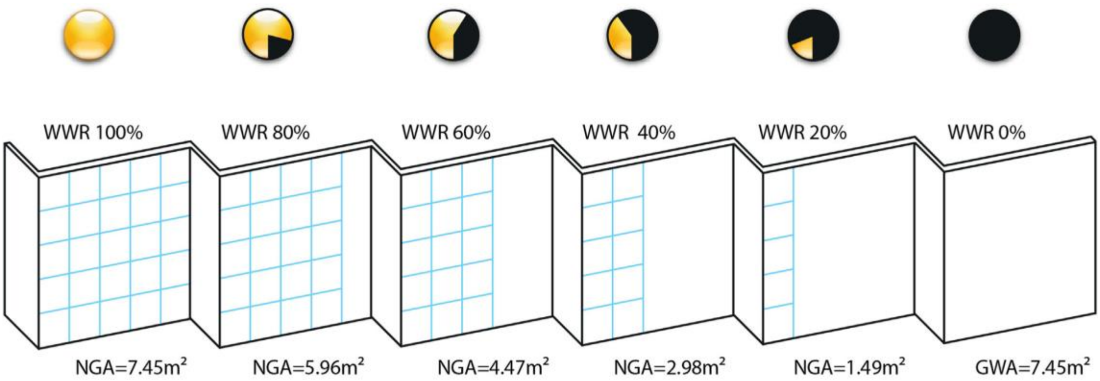


Figure 20: Schematic 3D view of WWRs in relation to their daylighting and visibility Source: (Sustainable Window Design, 2017).

Materials and its properties

Facade Materials Properties and Components: The process of selecting materials is central to the design of energy efficient facades. Every material has particular physical characteristics, such as thermal resistance, density, permeability, and thermal conductivity. While permeability is used as the basis for choosing between vapour barriers, thermal resistance is the primary criteria for insulating materials (Aksamija, 2016).The optical and thermal characteristics of glazing units have to be taken into consideration for glazed facades, such as the visual transmittance (VT), solar heat gain coefficient (SHGC), light-to-solar-gain (LSG) ratio, and shading coefficient (SC) (Aksamija, 2013).

The SHGC represents the level of solar radiation allowed through the window and becomes heat. Denoted by a value between 0 and 1, it is comprised of the solar radiation that is both absorbed and directly transmitted. The higher the SHGC, the more solar heat is transmitted to the interior through the glazing and the lower its ability to provide shade (Aksamija, 2013; Kibert, 2016).

Generally speaking, the southern window(s) of a building designed specifically to provide passive solar heating should have a high SHGC to allow useful heat in the winter. The east and west facing windows, on the other hand, should have lower a SHGC as they are exposed to higher levels of solar energy in the mornings and afternoons. Low-e coatings cause the amount of solar radiation allowed into the interior to be considerably reduced and can also minimize the SHGCs of insulated glazing units. In whichever case, thermal resistance is diminished by thermal bridging (Kibert, 2016).

The heat transfer coefficient, or U-value, of glazed facades represents their particular thermal properties. As the converse of R-values, U-values decrease relative to increases in the thermal performance of glazed wall area. Glazed assemblies' U-values are computed by means of an area-weighted approach whereby 3 distinct U-values – 2.5 inches from the frame, at the glass perimeter, and at the glass' centre – are taken into consideration. The values are usually high at the metal frames and considerably low at the glass centre, presumably because the metal frames are more conductive. The National Fenestration Rating Council (NFRC) determines the techniques to be used in calculating the overall U-values (NFRC, 2010).

The overall U-value can be reduced by designing the framing systems such that they are geared towards reducing heat transfer or by using glass that is deliberately high-performance. Similarly, the addition of more Glass panes and using inert gases, such as krypton or argon between glass lites instead of air, improves the insulating capacity of the glazing units. The thermal transmittance of the glazed facades may also be reduced by way of thermally-broken aluminium frames or structural glazing whereby a silicone layer separates the metal frame and outside glass (Aksamija, 2013).

Low-emissivity (low-E) and reflective coatings, usually consisting of a several-molecule-thick metal layer are used to regulate the amount of light penetrating the glass in the glazing. The level of solar heat gain in the interior space is directly correlated to the reflectivity and thickness of the coating, and the location of the coated glass itself. There have been considerable advances in the area of coating technology. Low-E2 (2 silver coatings) and low-E3 (three silver coatings) windows, capable of improving glass performance immensely, are now available in the market. The SHGC of the low-E3 windows has an outstandingly low maximum value of 0.30. By reducing heat transfer five to ten-fold, low-E coatings provide practically the same effects as the addition of an extra glass pane (Kibert, 2016).

As a measurement of how much heat is transmitted through the glazing, the emissivity value of a material should be preferably low as this means that said material reduces external heat transfers. The majority of low-E coatings simultaneously limit the amount of light allowed through the glass, even if just a little. Below is a listing of the emissivity values for select glass types.

- Uncoated clear glass: 0.84
- Single hard-coat low-E glass: 0.15
- Single soft-coat low-E2 glass: 0.10

An attempt at maximizing daylight penetration by increasing the window areas also means that less thermally-resistant glass is used to replace the highly resistant wall. In so doing, heating infrared rays are permitted to penetrate the envelope and the window frame. When deciding between optimizing the thermal envelope and maximizing daylight, an important consideration is the control of the solar heat gain via the windows. Modern developments in window glazing and film technologies have mitigate the experiences of the previous era whereby up to 85% of the infrared was allows through single or double-paned glass (Kibert, 2016).

EBN suggests the approach to window selection depicted in Table 5. EBN also provides these additional suggestions:

- Optimize the fenestration system of the building by way of modeling software, like RESFEN and WINDOW.
- For the majority of climate zones, always use at least double-glazed, argon-filled, low-E windows.
- In colder climes, use higher-performance low-E2 coated, gas-filled, triple-glazed windows. In fact, windows with triple-glazing are compulsory in Germany,
- Windows should be adapted to the particular climate and orientation. For example, low-SHGC windows are preferable for east and west orientations where minimizing heat gain is key.
- While SHGC is of little concern for north-side windows in most climes where the more thermal resistance the better, high-SHGC windows may be used on the south side to provide passive solar heating.

The ratio between a reference pane of clear glass and the SSHGC of a glazing system is known as the shading coefficient (SC). Rather than measuring the radiant temperature effects resulting from the glass coming in contact with solar rays, the SC only measures the direct solar radiation.A value between 0 and 1, VT denotes the amount of the visible spectrum (380-720 nanometers) permitted through the glazing. A high-VT glazing is preferable when maximizing the amount of daylight is the aim. On the other hand, when reducing the amount of interior glare is desirable, such as in an office building, lower-VT glazing should be used. An ordinary single-pane windows allows 90% of visible light with a VT of 0.90. Such a high VT translates into a high SHGC and so it is necessary for the designer to strike a balance between solar radiation and lighting (Aksamija, 2013; Kibert, 2016).

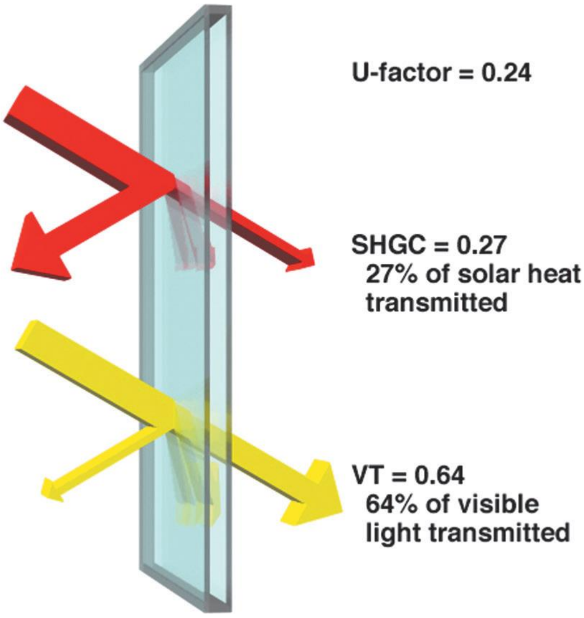


Figure 21: Properties of a standard double-glazed low SHGC window with low-E glass, filled with argon gas. (Illustration courtesy of Efficient Windows Collaborative).

The light-to-solar-gain (LSG) ratio, is the ratio of VT to SHGC and provides a measure of the efficiency of the glass in simultaneously transmitting daylight and minimizing heat gains. Higher LSG ratios mean more light is admitted without excess heat see fig .17, while higher light to solar gain ratios are suitable for warmer zone facades, colder climates require lower light to solar gain ratios because solar heat is necessary for passive heating. Warmer climates require glazing that is spectrally selective with an LSG ratio of at least 1.25 for an energy efficient façade (Aksamija, 2013; Kibert, 2016).

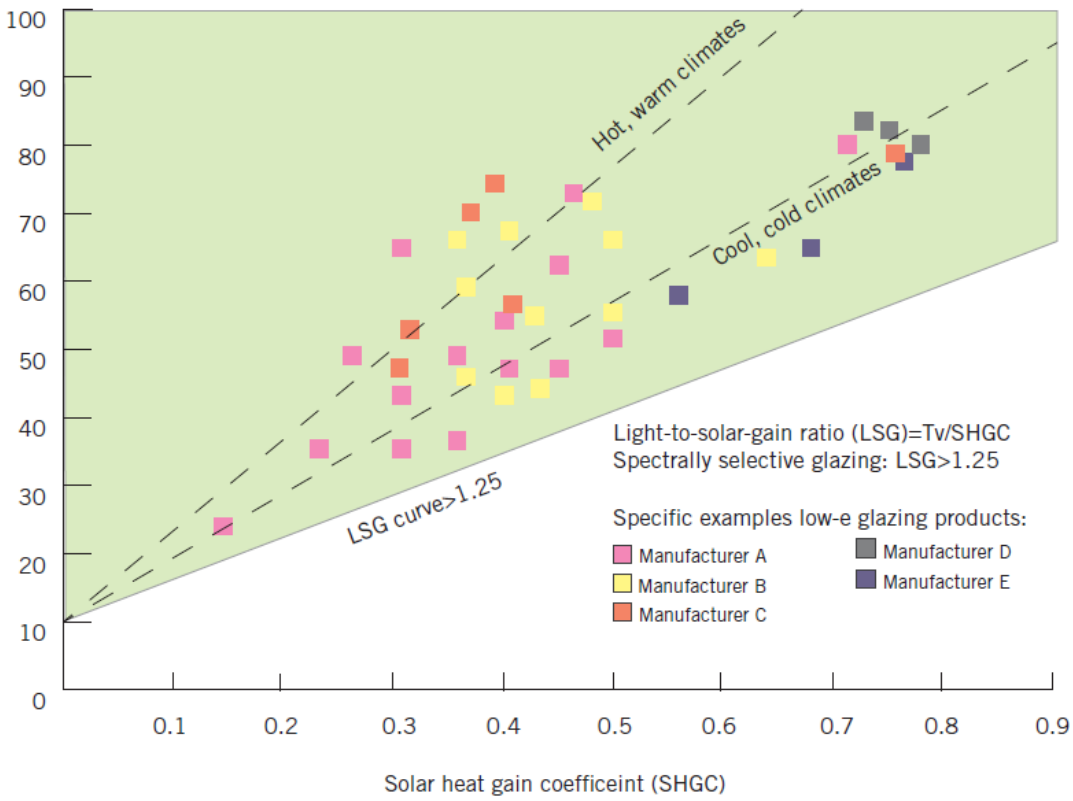


Figure 22: LSG Ratio as a Balance Indicator between VT and SHGC (Aksamija, 2013).

Table 5: Typical Values of SHGC, VT, and LSG for Total Window (Center of Glass) for Different Types of Window (Kibert, 2016)

Window Type	Glazing	SHGC	VT	LSG
Single-glazed	Clear	0.79 (0.86)	0.69 (0.90)	0.97 (1.04)
Double-glazed	Clear	0.58 (0.86)	0.57 (0.81)	0.98 (1.07)
Double-glazed	Bronze	0.48 (0.62)	0.43 (0.61)	0.89 (0.98)
Double-glazed	Spectrally selective	0.31 (0.41)	0.51 (0.72	1.65 (1.75)
Triple-glazed	Low-E	0.37 (0.49)	0.48 (0.68)	1.29 (1.39)

Clear glass is often the preferred choice because it allows for a maximum amount of natural light to penetrate the building's interior space. Tinted glass is an insufficient substitute for sun shading as it only reduces the amount of heat transmitted by about

20%, which is insufficient for hotter zones. Furthermore, in addition to significantly reducing daylight, it transmits heat to the building's interior after absorbing it.

Alternatively, solar-reflective glass may be used to minimize solar penetration while preserving the view. The problem however, is that it mitigates the transmission of both short (heat) and long (light) waves, inadvertently reducing the amount of potentially useful heat in the winter and natural light. As such, it is primarily useful for climatic zones where heat gain is not a major consideration. Low-emissivity glass minimizes the amount of direct heat gained by absorbing less heat than light. Also, because it visually resembles clear glass, it is particularly useful for maximizing daylight while simultaneously minimizing heat. It permits the designer to admit daylight using larger glazing area without having to pay for it in terms of energy consumption. A number of novel glazing systems have been developed, such as phase-change materials, photo-chromatics, holographic, and electrically responsive glass. The use of low emissivity glass or clear glass is encouraged in the green approach (Kibert, 2016).

Shading devices: Shading devices, as practical and low maintenance elements, are increasingly used to block insolation impacts. The target of shading devices is to enlarge the shading ratio, especially on windows, to keep spaces conditioned, lower energy demands and reduce glare levels near windows. Proper designs prevent overheating during sum mer whilst allowing maximum daylight to enter during winter (Rungta & Singh, 2011). In general, external Shading devices have a higher performance than internal ones (Atzeri, et al, 2014). And fixed shading devises are economical solutions, as they do not require manual adjustments (Freewan, 2014). Shading devices must be adapted to seasonal solar variations occurring at different locations. To design effective shading devises, the sun's position with respect to the surface normal of a vertical plane needs to be known (Lechner, 2001).

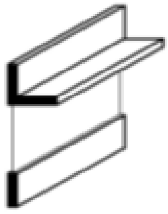
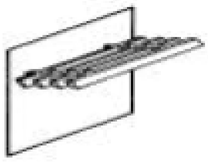
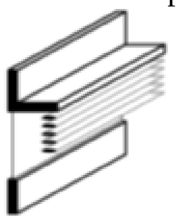
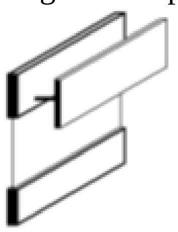
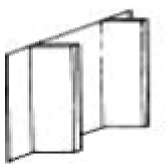
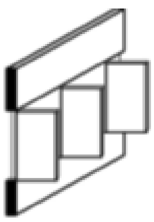
Incorporating shading elements into the curtain wall and the use of ceramic frit glass coatings can provide additional protection from solar heat and minimize the building's energy consumption. A properly designed shading device can be instrumental in the reduction of the peak heat gain of the building and thus, in the extra cooling effort while simultaneously providing quality natural interior lighting. For maximum impact however, shading devices should be chosen to fit the particular orientation of the façade. For east and west exposures, vertical shading devices, such as vertical fins or louvers, are the preferred choice. On the other hand, south facades are better served by horizontal shading devices like overhangs. Intermediate orientations require a combination of both vertical and horizontal shading devices (aksamija, 2013).

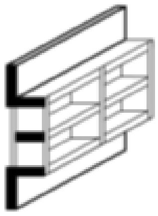
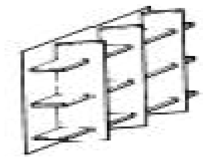
Type of Shading Devices

1) Fixed Shading Devices

Fixed shading devices are usually used for the external glazing as they reduce the amount of direct radiation that reaches the interior by reflecting said radiation. Table 6 provides an illustration of some of the more popular kinds of fixed external shading devices, all of which are either variations of the horizontal overhang, the vertical fin, or the egg crate (which itself combines both horizontal and vertical). The louvers and fins may be angled so as to provide supplementary solar control (Tzempelikos, et al, 2007).

Table 6: Examples of fixed shading devices (Tzempelikos, et al, 2007).

Descriptive name	Best orientation	Comments
Overhang horizontal panel 	South ,east, west	Traps hot air can be loaded by snow and wind
Over hang horizontal louvers in horizontal plane 	South ,east, west	Free air movement snow or wind load is small small scale
Over hang horizontal louvers in vertical plane 	South ,east, west	Reduces length of overhang View restricted Also available with miniature louvers
Overhang vertical panel 	South ,east, west	Free air movement No snow load View restricted
Vertical fin 	east, west, north	View restricted For north facades in hot climates only
Vertical fin slanted 	East, west	Slant toward north Restricts view significantly

Egg crate 	East and west	For very hot climates View very restricted
Egg crate with slanted fines 	East and west	Slant towards north View very restricted For very hot climates

2) Operable shading devices

While operable shading devices are better at providing shade than fixed devices, because they can be adjusted to match the sun's particular position, they require continuous maintenance to ensure solar control. For this reason, ceramic frit coatings, while less effective, might be used as a low-cost alternative to shading devices. The frit reflects most of the sunlight while permitting the absorption of solar energy, albeit to a limited degree, unlike shading devices which simply prevent the glass from coming in direct contact with sunlight (Aksamija, 2013).

3) Façade Self-shading

Façade Self-shading is an aesthetic and functional skin of a building. The target of is Façade Self-shading to lower the insolation on the opaque and glazing elements of the building during a required period. Decreased heat gains on the building envelope can lower the energy demands (Nikpour et al, 2012) .There are simple designs which are effective in blocking insolation during noon time and other more complex designs that are able to protect from severe insolation between early morning and late afternoon. The formula to ensure that a certain point on the facade is under the shade of the roof contour during a required period is given by Equation: h = d/ tan ˆZ, Where, h is the height from the certain point in the facade to be under shade perpendicular to a point in the roof mesh, d is the distance from a point in the roof mesh towards the roof's contour and ˆZ is a wall angle between the zenith and the sun's altitude (Capeluto, 2003).

Affects Shading Device on SHGC: Projection factor (PF) is the ratio of the horizontal depth (distance between outside edge of shading to the outside surface of the glass) of the external shading projection (Item A) divided by the sum of the height of the fenestration plus the distance from the top of the fenestration to the bottom of the farthest point of the external shading projection (Item B), in consistent units. Refer to Figure 23 below.

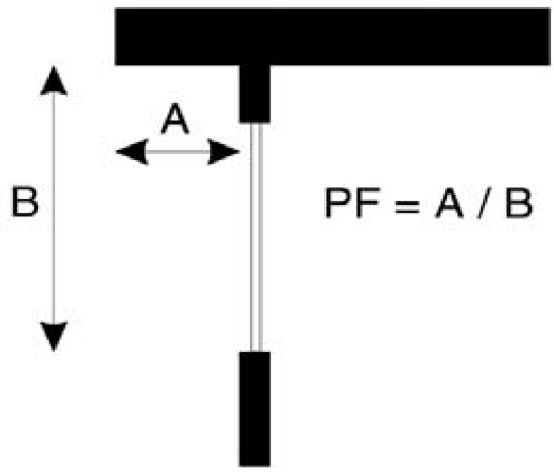


Figure 23: projection factor. Source :(NEEC, 2011).

To take this exception, the projection factor for the shading device is calculated and this number is then matched with the corresponding multiplier. Refer to SHGC Multiplier Table 7 below. This multiplier is then applied to the rated SHGC of the glazing component that is being installed with a permanent shading device. If this resulting value is equal to or lower than the specified maximum SHGC, then this value may be used to demonstrate prescriptive compliance. Glazing components with permanent shading devices may be area-weighted with other glazing components. Area-weighting limitations for north-facing glazing still apply (NEEC, 2011).

Table 7: SHGC multiplier. Source:(ASHRAE 90.1, 2010).

Projection factor	SHGC multiplier (all orientation except north orientation)	SHGC multiplier (north oriented)
0-0.1	1.00	1.00
< 0.1-0.2	0.91	0.95
< 0.2-0.3	0.82	0.91
< 0.3-0.4	0.74	0.87
< 0.4-0.5	0.67	0.84
< 0.5-0.6	0.61	0.81
< 0.6-0.7	0.56	0.78
< 0.7-0.8	0.51	0.76
< 0.8-0.9	0.47	0.75
< 0.9-1.00	0.44	0.73

Embodied Energy of Materials: Embodied energy, the total amount of energy used in acquiring and processing raw materials, is another factor designers need to take into consideration when deciding between the materials to be used for an energy efficient façade. The lower the embodied energy of the material, the smaller its impact on the environment as a result of the greenhouse gases and emissions resulting from energy consumption. Regardless, a better measure of the environmental impact is provided by using the material’s length of use to divide its embodied energy; less durable materials have a higher embodied energy per time in use. To illustrate how these terms are related, aluminum, despite its high embodied energy, could have a lower embodied energy per time in use because it is very durable. Furthermore, the embodied energy of certain products can be reduced by recycling them. Recycled steel and aluminum have only 20% and 10% of the embodied energies of those made from their respective ores (Aksamija, 2013; Kibert, 2016).

Table 8: Building Material's Embodied Energy (Hilmarsson, 2008).

Material	**Embodied energy Mj/kg**	**Material**	**Embodied energy Mj/kg**
Plywood	10.4	Polystyrene insulation	117.0
Mineral wool insulation	14.6	Aluminum	227.0
Aluminum (recycled)	8.1	Paint	93.3
Steel (recycled)	8.9	Linoleum	116.0
Brick	2.5	PVC	70.0
Cellulose insulation	3.3	Copper	70.6
Concrete	1.3	Steel	32.0
Concrete precast	2.0	Zinc	51.0
Aggregate	0.10	Glass	15.9
Stone (local)	0.79	Fiberglass insulation	30.30

The primary component of a GF, glass, has been the subject of much criticism by researchers due to its high embodied energy. The embodied energy of various building materials is shown in Table 8 (Hilmarsson, 2008).

3.3.2.2.1 Thermal Behaviour and Moisture Resistance

Control of Heat Transfer, and Air and Moisture Movement: The process of facade heat transfer adheres to a basic physics principle: heat moves from hotter temperatures to colder temperatures. This heat transfer occurs via one of these processes:

- Conduction (heat is exchanged between contacting facade materials).
- Convection (air currents inside the façade transport the heat).
- Radiation (heat moves in the form of electromagnetic energy over the materials and air spaces inside the facade).
- Air leakage (air transiting the façade transports the heat).

The rate at which heat is transferred through the skin of the building is largely dependent on the difference between the exterior and interior temperatures and how easily the façade is able to control the flow of heat. Air leakage control, thermal resistance, and the properties of the materials all affect the flow of heat inside the façade. The flow of heat within the façade can be controlled using the following design strategies: avoiding thermal bridging, preventing conduction by filling the gaps between the materials, preventing air leakage and heat loss through a continuous air barrier, and using a continuous insulation layer (aksamija, 2013; aksamija, 2016).

Air leakage, which allows undesired warm air into the building or the escape of arm air, thereby increasing the cooling or heating loads respectively, affects the overall energy consumption of a building. Furthermore, outside air has the potential to cause material damage, condensation, or even mold as it carries moisture into both the building and its envelope as vapour. Unfortunately, even as air leakage is undesirable, it can never be fully averted (aksamija, 2013; aksamija, 2016)

Another important consideration for energy efficient building envelopes concerns the infiltration of vapour and moisture through the façade. It is impossible to prevent vapour from penetrating the exterior wall as it is transmitted by air. The issue therefore, is that when the air carrying the vapour comes into a cooler temperature, it is less able to carry the vapour, which is eventually condensed to water. This water can damage building materials, especially when the condensation occurs within the walls. It can also adversely affect the health of the occupants as it encourages mold. Energy efficient facades make it such that the vapour condenses in such a manner that the resulting water runs off to the exterior of the building. (Aksamija, 2013; aksamija, 2016).

Heat Transfer Analysis for Glazed Building Facades: Heat transfer analysis and thermal properties of glazed building facades are computed using a different approach. As was alluded to in the section on "Properties of Façade Materials and Components", calculating the U-value of a glazed façade requires the computation of the individual U-values at the frame, edge, and centre of the glass. 2D finite-element heat transfer models are used to analyse the transfer of heat in such facades. A computer software, THERM, created by the Lawrence Berkley National Laboratory (LBNL) can be used to analyse how heat is transferred through curtain walls and window frames (metal) (LBNL, 2011).

Another software developed by LBNL, WINDOW, is used to compute the properties of glazing. Both WINDOW and THERM can be used conterminously as the former computes the visual transmittance (VT), shading coefficient (SC), solar heat gain coefficient (SHGC), and lazing units' summer and winter U-values. WINDOW calculates the properties of a glazing using its components, number of glass layers, and kind of glass between said layers. (Aksamija, 2013).

3.3.2.3 Building Performance Analysis Procedures

As a means of investigating design options and assessing the potential energy and environmental impact of the design, building performance simulations are central to the design of high-performance energy-efficient buildings (Aksamija, 2009; Aksamija, 2010).The predictions made during the various design stages are useful for the establishment of metrics that quantify the improvements provided by alternative strategies. The design process should include a number of analysis cycles so as to appraise and enhance building performance (Punjabi & Miranda, 2005).

The basic types of performance analysis as they relate to various project stages, with specific emphasis on the envelope design of the building, are shown in Figure 24, the top part of which outlines how decisions actually affct building performance and how they relate to the diffeent project stages. Analysis during the programming phase should concentrate on issues of context, such as orientation, building massing, and climate information, while analysis at the schmatic and conceptual phases involves the entirety of the poposed façade sun shading method as it concerns the overshadowing of neighbouring buildings. In general, different sun shade options should be analyzed in conjuction with dayligh studies. Decisions taken in this regard are monumentally significant for the overall design as affect the level of comfort of the users, the exterior appearance of the building, and the potential energy use. Such analyses usually occur during the design process as opposed to the actual construction phase.(aksamija ,2016)

It is increasingly important for designers to carry out an evaluation of the building energy performance in the initial stages of the project, prior to the production of a detailed energy model. In so doing, the occurrence of future energy-related changes is mitigated. Building performance assessment is a protracted process and is usually carried out through two methods. The first concerns energy analysis and is comprised of two stages. These are:

A. Understanding energy target goals: the goal here is the early establishment of certain energy-performance targets to aid the assessment of alternative design schemes. These targets guide decision-making in regards to early design characteristics, such as: solar exposure and directionality, building site and orientation, climatic conditions, and other location-based passive strategies.
B. B. Design solutions and optimization: these are relevant during the design development phase of the project. The building envelope, for example, is subjected to a series of performance analyses based on different configurations of the exterior skin. Here, various design alternatives are tested using an exact 3D replica using the following analyses: shadow analysis, façade solar exposure analysis, an itemization of energy gains (internal, exterior wall, and direct solar gains), and daylight simulations. (Aksamija, 2016).

The second model is energy modelling and involves the use of a "whole building" approach to guide the selection of mechanical equipment and predict year-round energy consumption. Both performance analysis and simulation tools may be categorized as BIM-based or non-BIM programs. The different simulation programs and tools have varying modelling abilities; a comparative study of the abilities twenty performance simulation programs' – IDA ICE, Ecotect, BLAST, Power Domus, TRYNSYS, TAS, Sunrel, DOE-2.1E, Ener-Win, BSim, HEED, TRACE, DeSTm, IES VE, Energy-10, ESP-r, Energy Plus, BLAST, e Quest, HAP – was conducted by Crawley et al. (2006).

An overview of the simulation programs suitable for the design of high-performance, energy efficient facades is provided in Figure 25. Several simulation programs must be combined in the design of these facades as no single software is able to singularly account for all potential design questions and aspects relating to the behaviour and properties of the façade systems. To illustrate, the figure 25 shows which simulation programs are applicable for heat transfer analysis, thermal comfort analysis, energy analysis and modelling, heat and moisture analysis, and daylight analysis, all of which are critical to the design of high-performance facades (aksamija, 2016).

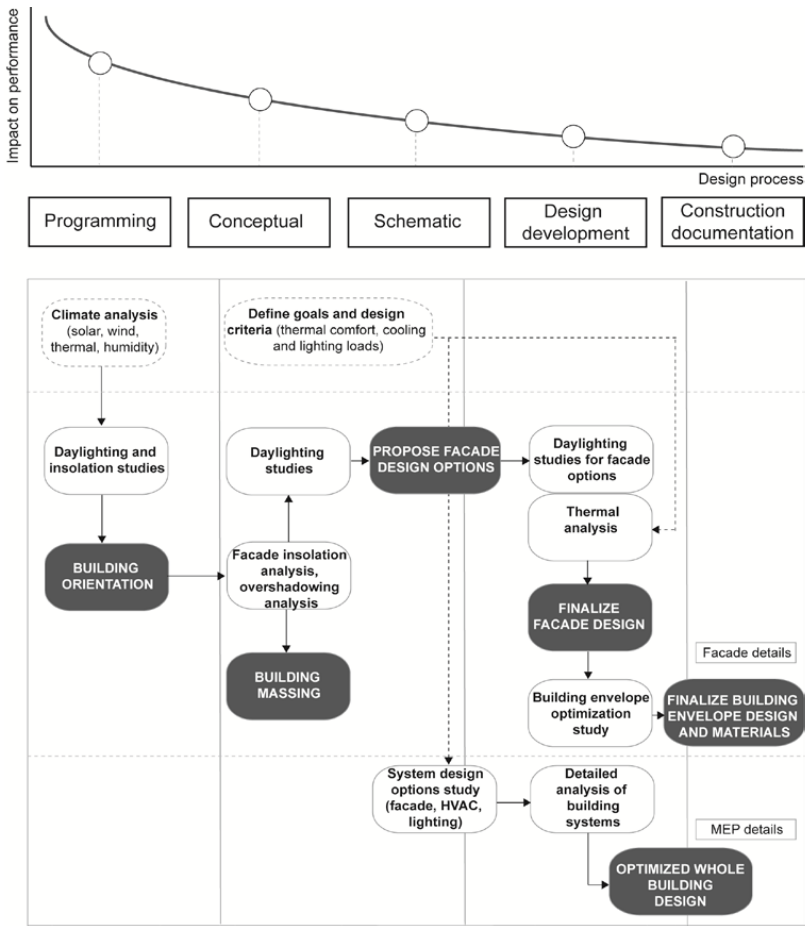


Figure 24: Framework for incorporating building performance analysis procedures with design of high-performance building envelopes. Source :(aksamija, 2016).

Simulation tool	Energy analysis	Energy modeling	Heat transfer analysis	Combined heat and moisture analysis	Daylight analysis	Thermal comfort analysis	BIM-compatible
Ecotect	+				+		Yes
Radiance					+		
COMFEN/ EnergyPlus	+	+					
eQuest	+	+					
Green Building Studio	+	+					Yes
CBE Thermal Comfort Model						+	
WINDOW			+				
THERM			+				
WUFI				+			

Figure 25: Building performance simulation software programs and their applicability for facade design. (Aksamija, 2016)

3.3.2.4 Designing for Comfort

What are the characteristics of a “high performance-energy efficient” façade? While all facades should provide occupants with a thermally, and visually comfortable interior environment well separated from the exterior, high performance-energy efficient facades go a step further to provide such a comfortable environment using a minimal amount of energy (Aksamija, 2013).

3.3.2.4.1 Thermal Comfort

Thermal comfort refers to “that condition of mind which expresses satisfaction with the thermal environment” (ASHRAE, 2004). As a mental condition, it is determined primarily by the perception and experience of the individual, which vary both psychologically and physiologically per individual (Arens et al., 2006). Thermal comfort is determined primarily by six variables: mean radiant temperature, air temperature, occupants’ clothing, air movement, air temperature, and the occupants’ metabolic rate (Huizenga et al., 2006). The human body’s response to each of these is holistic, even as they are each measured separately.

Methods of Measurement: Thermal comfort is a subjective experience as it is a perceived sensation. Regardless, a number of different methods have been proposed for the purpose of providing an objective measurement of how satisfied occupants are with the interior environment. The number of individual expected to be dissatisfied with particular comfort conditions can be predicted by way of ASHRAE's Predicted Percentage of Dissatisfied (PPD) and Predicted Mean Vote (PMV). The PMV index works using a hot-cold 7-point thermal sensation scale based on responses of scores of people exposes to a particular environment. The scale extends from -3 (cold) to +3 (hot) with 0 (neutral) value in-between. The PPD index used the data from the PMV index to predict the percentage of thermally dissatisfied people. The relationship between both indexes is shown in Figure 26. The PPD takes those who vote +3, +2, -2, and -3 (hot, warm, cool, and cold respectively) to be thermally dissatisfied in an inverse bell-shaped distribution with a 0 center value (aksmaija,2013).

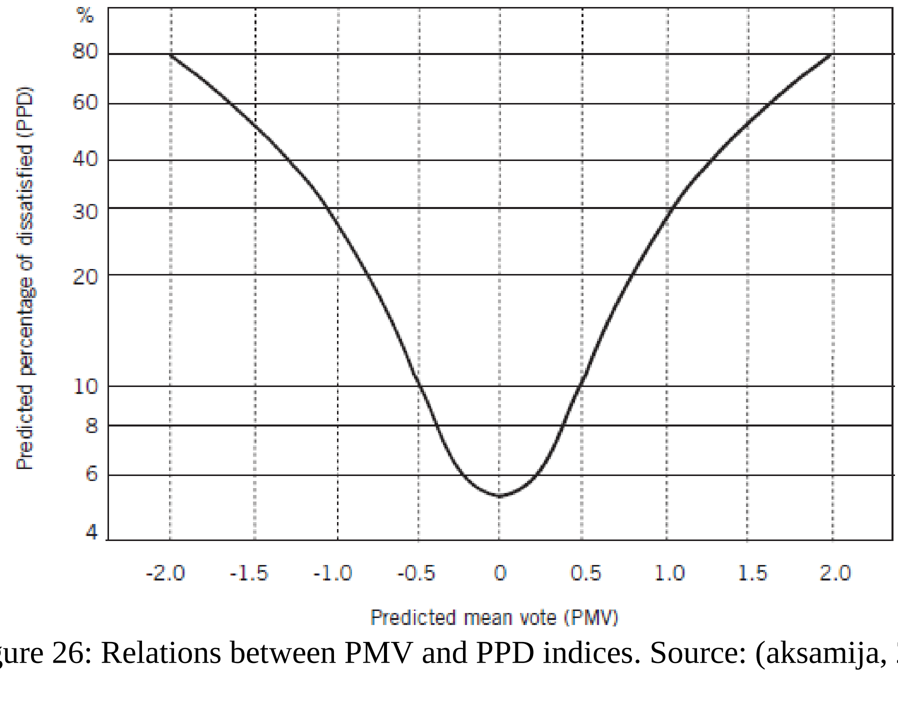


Figure 26: Relations between PMV and PPD indices. Source: (aksamija, 2013).

The PPD curves consists of numbers with no particular unit of measurement that represent the percentage is thermally dissatisfied people. The recommendation of ASHRAE Standard 55-2004 is that the PMV values lie between -0.5 and +0.5 for general conditions, corresponding to a PPD equal to 10 (10% dissatisfied occupants). The standard also suggests a method for determining thermally acceptable conditions for naturally ventilated spaces where the occupants are able to excessive some environmental control. Depending on the mean monthly outdoor temperature, indoor temperatures may be adjusted upward or downward, while maintaining comfort conditions. Figure 27 illustrates this by providing a range of operating temperatures for thermal comfort in naturally-ventilated buildings. The higher the mean monthly temperature for the climate, the higher the acceptable operating temperature as this significantly minimizes energy consumption, thus allowing only 10% each of occupants to experience partial and whole-body discomfort. To illustrate, if the mean monthly outdoor temperature is 35°C, an indoor operating temperature between 24°C and 30.5°C is still passable as it should keep 80% of the occupants within their comfort level. Similarly, if the mean monthly outdoor temperature is 10°C, the indoor temperature can lie somewhere between 17.5°C and 25°C. (aksmaija,2013)

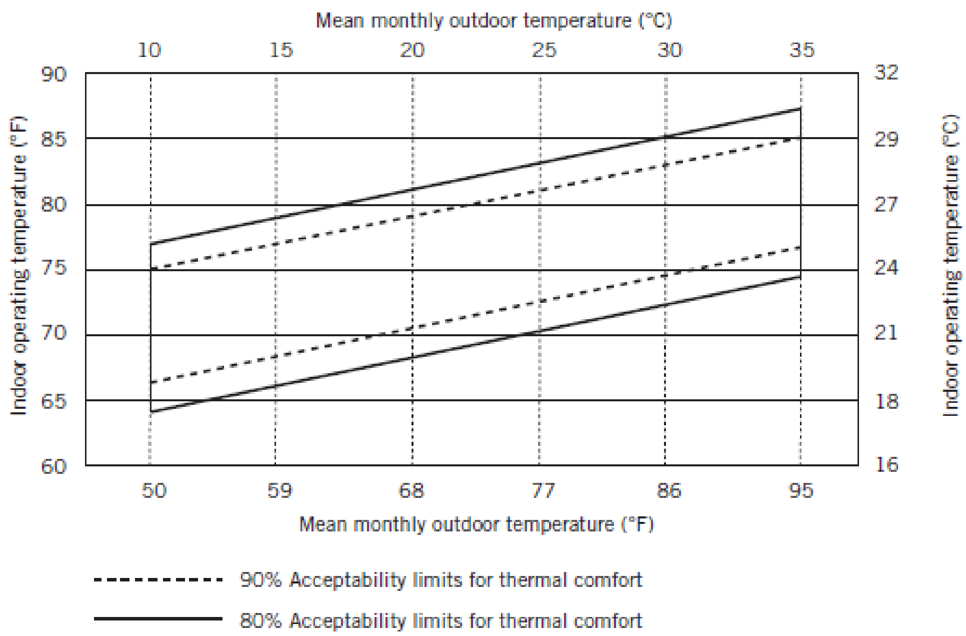


Figure 27: Acceptable operating temperatures for naturally conditions spaces, according to ASHRAE Standard 55-2004. (Aksamija, 2013).

Facade Design and Thermal Comfort: Windows have the largest thermal fluctuations of all façade elements and are usually the warmest and coldest elements depending on the weather. The use of thermally broken frames and high-performance glazing does little to mitigate this. Consequently, the higher the WWR of the façade, the more likely it is that the occupants' comfort would be affected, with variations depending on their level of activity and proximity to the window. The optimal WWR depends on the occupants' position(s), the particular floor plan, and the nature of activities occurring in the interior environment. Larger WWRs are preferable for spaces where the occupants are not expected to be close to the windows (Aksamija, 2013).

The thermal comfort of the occupants is also affected by the type of façade glazing materials used (Huizenga et al., 2006) and varies depending on the season. In summer, thermal comfort is determined primarily by the amount of solar radiation transmitted through the glass and its interior temperature, while in the winter, it is determined by the surface temperature of the window which is typically lower than that of the room. These are in turn determined by how effective the shading elements are, how the glazing units were constructed, and what type of materials were used for the glass. For climates with high levels of solar radiation, spectrally selective low-e, double-glazed, air-insulated glazing units should be used as they a light-to-solar-gain ratio of at least 1.25, meaning that they provide adequate protection from solar heat while simultaneously permitting daylight penetration (Aksamija, 2013).

Changes in the temperature of the window surface and how this affects the comfort of the occupants can be mitigated by altering the temperature of the interior air. The internal air temperature can be altered to compensate for the cooling and heating of the glass. The air temperature of the interior spaces relative to the temperature of the glass, specifically how the comfort of an occupant close to the window is affected (Aksamija, 2013).

Air movement can also have an effect on thermal comfort. Facades can cause two forms of undesirable air movement: induced air motion caused by cold interior window surfaces, and infiltration of outside air through gaps in the exterior enclosure. In general, the drafts affect thermal comfort. In the exceptional cases—for example, very tall windows with low-performance glass—a heater under the window sill may mitigate the effects of the draft (Aksamija, 2013).

A truly interior comfort strategy should be designed in such a manner that it precludes air induction as comfort is more significantly impacted by air infiltration. While an entirely airtight façade is a practical impossibility, an air barrier can be used to minimize the amount of air permitted into the interior space. Air leakage is particularly problematic when there is a significant discrepancy between the interior and exterior air pressures. Such differences in air pressure can be caused by differences in the air pressure of tall buildings in what is known as the stack effect, or the HVAC system itself. Furthermore, the pressure difference can force either conditioned air to the exterior or the outside air to the interior through perforations in the barrier. The diffusion necessitates the use of more internal air to maintain comfort levels. (Aksamija, 2013).

Overall, designers can improve a building's thermal comfort using the following strategies:

- Using the optimal window-to-wall ratio (WWR). Depending on the particular situation, more or less windows, for more daylight or better insulation respectively, could be preferable. The optimal WWR provides occupants with the best possible comfort level by providing a balance between thermal comfort and other factors.
- Selecting materials with the best U-values, SHGC, and other performance characteristics.
- Designing the shading elements specifically to provide passive heating in cold seasons through direct sunlight and reduce solar heat gain in hotter seasons.
- Using an airtight assembly strategy for the façade to limit the unfettered movement of air through the façade, thus keeping the conditioned air on the inside and exterior air outside (aksamija, 2013).

3.3.2.4.2 Daylight and Glare

Daylighting Strategies: A useful strategy for the improvement of the energy efficiency of a building involves the use of natural light as this minimizes the amount of artificial lighting required. Daylighting also has a role to play in minimizing the cooling load as heat is generated by even the most efficient light fixtures (Aksamija, 2013).

It has been proven that daylight is beneficial beyond aiding the conservation of energy and includes the psychological and physiological well-being of the occupants. Natural light is known to improve the circadian rhythms of an individual, resulting in higher productivity and internal environment satisfaction (Edwards and Torcellini, 2002). Overall, while the effects of light on the human body differ depending on the spectral distribution and wavelength, natural light is fully beneficial as it encompasses a full wavelength spectral distribution. This is why people generally, even if purely on a subconscious level, prefer daylight to artificial lighting (Liberman, 1991). Studies have shown that daylight improves productivity, savings, health, and minimizes absenteeism (Edwards and Torcellini, 2002).

While the benefits of daylight surpass any potential costs, as with all things, direct exposure to sunlight has both good and bad effects. To illustrate, overexposure to solar radiation can cause skin damage but the right amount encourages vitamin D production. The glass in windows usually prevents most sun rays fom reaching the interior spaces. When designing naturally lit spaces, the vriable and fixed conditions as well as the design goals and criteria should be taken into consideration. These include objective qualities like daylight intensity and energy consumption, and subjective qualities like privacy. Daylight distribution, degree of illumination, and sunlight/glare protection should be considerd to imorove visual comfort. Integrating the building systems is equally important as facades, shading elements, building controles, lighting, and HVAC systems must work in using so as to maximally improve building performance. For example the cooling load of the HVAC suystem can be reduces by using natural daylighting in conjuction with dimmers and photo sensors for light fixtures (aksamija,2013).

Fixed conditions, such as climate, topography, and location, are beyond the control of the designer. The designer can, however, control variable conditions like the façade design, geometry of the building, window orientation and size, window shading, and the properties of materials. The proper adaptation of variable conditions coupled with an understanding of the fixed conditions would be instrumental to the enhancement of the visual comfort of the occupants. Examples of variable and fixed conditions are shown in Table 9 (Aksamija, 2013).

Table 9: Daylight design considerations.(aksamija,2013)

Design goals and criteria	Fixed and variable conditions
Visual comfort	Climate (fixed)
Illuminance	Daylight availability
Daylight distribution	Temperature
Exposure to direct sunlight	Site and location (fixed)
Glare	Latitude
Visual characteristics	Local daylight availability
Views to the outside	Exterior obstructions and surrounding buildings
Daylight quality: color, brightness	Ground reflectance
Privacy	
Building energy use/costs	Room and fenestration properties (variable)
Codes and standards	Geometry
Systems and products	Material properties and reflectance
Integration of systems: facade, lighting, shading, HVAC, and controls	Fenestration size and orientation
	Shading system
	Lighting system (variable)
	Light fixture properties
	Ambient and task lighting
	Controls
	Occupants' activities (fixed)

The provision of an optimum amount of light (artificial or natural) to enable them perform their set tasks directly relates to people's visual comfort. Light intensity on a surface is measured by Illuminance, the unit of which is lux in the metric system and foot-candles (fc) in the imperial system (1fc=10.764lux). The recommended illumance levels for various tasks and spaces are outlined in the IESNA Lighting handbook (IESNA, 2011) published by the Illuminating Engineering Society. The recommended level for a task-intensive work area, for example, is between 10-20fc (100-200 lux). (Aksamija, 2013).

The new European standard sets unified glare ratio (UGR) = 19 as the maximum permissible value for offices, which is equivalent to the luminance limiting curve for 500 lux (Zomtobel, 2017). The daylight hand book recommended illuminance and UGR for different activities in office space as follow:

Table 10: Recommended illuminance and glare in office spaces (Zomtobel, 2017).

Office activity or task	Illuminance (Lux)	Glare (UGR)
Filling ,coping , etc.	300	19
Writing, typing , reading, data processing	500	19

The amount of natural light allowed into an interior space is influenced by the building's orientation and the process of designing high-performance energy efficient facades should include an analysis of the seasonal daylight availability. A daylight system's principal energy-related design goal is the provision of a maximum level of usable daylight in the interior of the building, followed by the conservation of energy. It is common knowledge that the depth of a room's interior lighting zone should be double the window's height and an energy efficient strategy for the improvement of natural light should do just that without causing increases in the glazing (aksamija,2013).

Daylighting zones have been successfully extended using light shelves, which are horizontal fins affixed to the interior of the window frame a minimum of 80 inches above floor level. When the sun is low during the winter, the sunlight warms the interior space as it is allowed to pass over the light shelf, which also serves as a block preventing direct sunlight from said space in the summer. The blocked sunlight however, is reflected onto the ceiling and then deep into the interior space as shown in Figure 28, thus providing supplementary daylighting via indirect sunlight. The shelf could either be complicated or as simple as a light-colour painted surface. Reflexivity may be enhanced by covering the top surface with prismatic aluminized films. The light shelf could either be made specifically for particular solar altitudes or be seasonally adjusted for optimal protection. Sloped ceilings may be used additionally to increase the amount of bounced indirect light (aksamija, 2013).

Uniform, filtered, glare-free daylight can be provided by way of translucent materials for the glazing. Daylighting can also be enhanced further thought the combination of eye-level transparent vision glass supplemented at the top and bottom with translucent glass The success of a daylighting strategy is determined by the amount of daylight permitted into the building envelope and such strategies differ depending on the prevalent climatic conditions (aksamija, 2013).

Table 11: Applicability of different daylight facade strategies. Source: (Ruck et al., 2000).

				Design selection criteria					
Type	Strategy	Climate	Location of system	View to the outside	Light redirection into interior	Uniform illumination	Energy saving potential	Glare	Need for solar tracking
System for locations with predominately diffuse light	Light shelf	Temperate climates with cloudy skies	Windows above eye level	+	+	0	0	0	No
	Anidolic integrated systems	Temperate climates	Windows	+	+	+	+	–	No
System for locations with predominately direct sunlight	Light guiding shade	Hot and sunny	Windows above eye level	+	+	0	0	+	No
	Louvers and blinds	All climates	Windows	0	+	+	+	+	No
	Light shelf for redirecting light	All climates	Windows at eye level	+	+	+	+	0	No
	Glazing with reflecting profiles	Temperate climates	Windows	0	0	0	0	0	No
	Lamellas	Temperate climates	Windows	0	0	0	0	0	Yes

Legend: + Excellent 0 Average – Poor

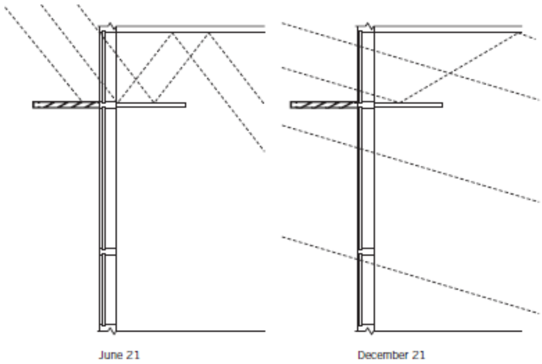


Figure 28: Diagram of light shelf performance in summer and winter.source: (aksamija, 2013).

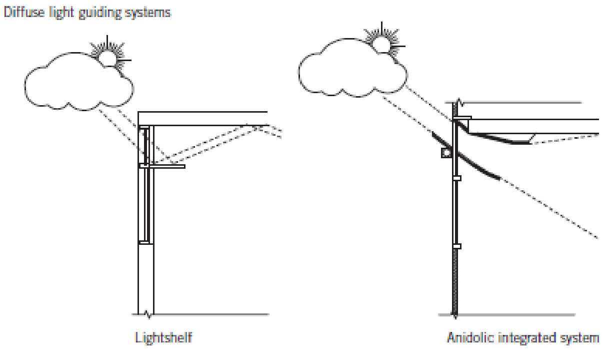


Figure 29: strategies of daylight facades for places with mostly cloudy sky conditions. Source :(aksamija, 2013).

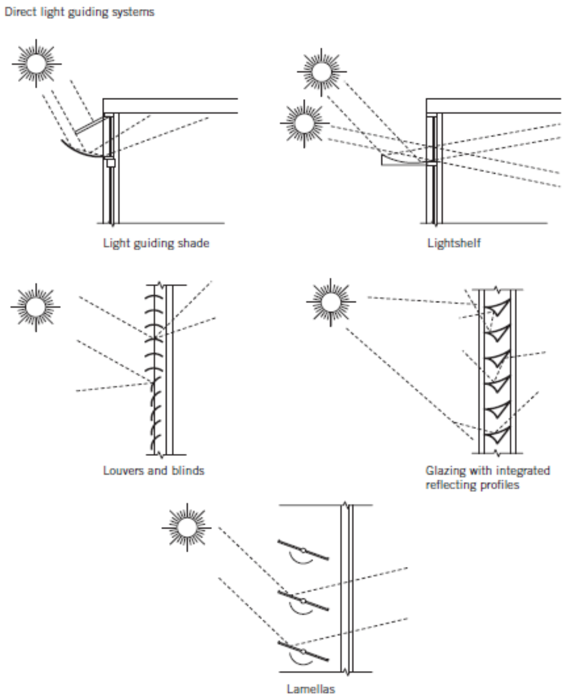


Figure 30: strategies of daylight facades for places with mostly sunny sky .Source :(aksamija, 2013

Large highly-place light shelf-equipped windows are preferable for predominantly cloudy climes (Figure 29), while smaller windows, shading elements, and better control of direct sunlight are preferable for clear-skied locations (Figure 30) A list of different sky conditions, climates, and criteria, and how their corresponding strategies if provided in Table 11.

Glare: When light is concentrated in certain areas relative to less lit areas in the field of view, the result is known as glare. Like thermal comfort, it is a subject response of a primarily physiological nature with the distinction being that it is able to cause the occupants visual discomfort. A successful daylight strategy should allow for sufficient lighting while simultaneously minimizing glare, which itself may be measured using either the Illuminating Society of North America's (ISNA) Visual Comfort Probability (VCP) or the Commission Internationale de L'Eclairage's (CIE) Unified Glare Rating (UGR). While both were intended for use in relation to artificial lighting, they may be used for glare analysis in computer simulations. (Aksamija, 2013).

UGR uses the angle of sight and position of the viewer, as well as the brightness and position of every potential source of glare in calculating the visual discomfort of the occupant. The following acceptable ranges are recommended by the CIE (CIE, 1995):
Comfort zone:

- "Imperceptible: < 10, Just perceptible: 13, Perceptible: 16, Just acceptable: 19

Discomfort zone:

- Unacceptable: 22, Just uncomfortable: 25, Uncomfortable: > 28." (Aksamija, 2013).

The new European standard sets unified glare ratio (UGR) = 19 as the maximum permissible value for offices, which is equivalent to the luminance limiting curve for 500 lux. (Zomtobel, 2017).

VCP estimates the percentile of occupants that would find a visual environment to be comfortable (IESNA, 2011). Using an empirically-based predictive assessment, it takes the number of lighting sources, room shape and size, background luminance, illumination levels, glare sensitivity differences between individuals, materials' surface reflectance, and individual glare sensitivity into consideration. Glare can be minimized through light-diffusing translucent glass and a host of other daylight redirecting methods.The goal is the reduction of artificial lighting by maximizing daylight use and reduced energy consumption to improve the quality of indoor spaces. A regular sized window could easily permit a sufficient amount of daylight to the deeper parts of the interior spaces by up to 4.6 (15ft), while advanced experimental methods, such as light pipes, holographic optical elements, and articulated light shelves, can increase this depth up to 9.1m (30ft). Such systems are advantageous in that a) they increase the amount of daylight in deeper levels without increasing the solar heat gain, and b) they allow the daylight to be more uniformly distributed regardless of season (Aksamija, 2013; aksamija, 2016).

A 'cheerfully daylight' room with a height-depth ratio of 1:2 and 20% exterior wall glazing, should allow an adequate amount of light to pass through. One potential problem however, concerns glare, the resolution of which necessitates a lighting strategy and could potentially impact energy performance (Sayigh, 2016).

3.4 Life cycle cost analysis

The National Institute of Standards and Technology (NIST) Handbook 135,1995edition(Fuller et al ,2008)defines life cycle cost (LCC) as “the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system” over a period of time. Life cycle cost analysis is an economic evaluation technique that determines the total cost of owning and operating a facility over a period of time (Mearig et al, 1999). Life cycle cost analysis can be performed on large and small buildings or on isolated building systems. Many building owners apply the principles of lifecycle cost analysis in decisions they make regarding construction or improvements to a facility. (Cabeza et al, 2014). LCC assessment of buildings aims to determine the overall costs of a building alternatives to ensures that the ownerships will take benefits by purchasing of a building.

The first step for LCCA is determining a proper life cycle for project. Subsequently, the costs, what the life cycle of project includes should be determined. The life cycle costs can be classified into initial costs, constructing costs and operation costs. Initial costs are the costs that should be invested at the beginning of the project. Land acquisition costs, primary studies cost, data collection costs, demolition costs and licenses and permits cost all are in this category. Construction costs are the costs that are imposed during construction of the project. Construction costs includes costs of design, materials preparation, labor costs, and machinery costs. Operation costs such as maintenance costs, replacement costs, and cost of energy are the costs that occurred during operating phase of project (Mahdi, 2015).

The estimation of life cycle cost is a highly technical and professional discipline. It is difficult to estimate the exact cost of a construction. An appropriate estimation should be able to consider the whole project to have a proper judgment about technical aspects and related costs. Providing a good estimation needs training, enough experience, and enough time to be aware about the project details. Considering all project details and aspects is not possible since it needs several researches and studies. (Mahdi, 2015).

With determining the life cycle costs of each variable and calculating the benefits, it turns to economic evaluation. May be at first it seems that, costs and benefits can be gathered with positive and negative amounts and make total life cycle cost but doing such a process is economically impossible (Mahdi, 2015).

As regards, the value of money is changing over time, present values cannot be gathered mathematically with future values that will be imposed to the project. Therefore, the costs and benefits should be adjusted into specific time to be compared. Discount Factors make it possible to adjust values into specific time. LCCA methods follow (Badea et al., 2014):

1. Present worth Method (PWM)
2. Annual Cost Method
3. Benefit-Cost Ratio Method
4. Internal Rate of Return (IRR)

In the first method, all costs and benefits will be adjusted to the present value then lifecycle costs can be calculated. Lower present value shows better economic alternative. In second method, the average annual life cycle costs are calculated. Third method evaluates the ratio of costs to benefits. In IRR method, the interest rate of project is calculated and will be compared with other interest rates. An affordable Project should offer same or higher IRR than other interest rates

Following discount rates are needed to adjust economic variables to present or future values:

1- F = P (1+*i)* n F

2- P = F (1+*i)*-n

Where in these equations,

'F' is the future value

'P' is the present value

'*i*' is an interest rate (or might be inflation rate)

'n' is the number of years

Chapter 4

COUNTRY CONDITION

This chapter provides an overview of the prevalent socio-economic and environmental conditions in Erbil city, and the influence of social and cultural factors on the architecture identity of facades in Erbil city:

4.1 Environmental Condition of Erbil city

Multi-factors in environmental scanning, which exert an influence on how construction and the GF are contextualised in sustainability, whether positive or negative, are clarified.

4.1.1 Location and Population of Erbil city

Erbil is the primary city in KRI and the capital of the KRI (Rasul et al ,2016).Erbil has Latitude 36.2° North and Longitude 44.02° in the Eastern Time zone from Greenwich, the city is situated 453m above sea level (Climate Consultant 6.0). The past two decades have witnessed the city's monumental growth in terms of its population and infrastructure. With an annual population growth rate of 2.9% (Dizayee, 2010), Erbil's population stood at 1,530,722 in 2015 (Erbil Governorate Profile, 2015).

Figure 31: Map of KRI. Source: (URL 2).

4.1.2 Climatic Condition

The climate of the location chosen for this study is a semi-arid, continental climate with a subtropical semi-arid (BSh) classification in the Koppen system (Rasul, Balzter et al, 2017; Baiz, 2016).

Overall, Erbil's climates have two different cases in which they are warm to hot with very low humidity; it can be said to be extremely dry in the summer period. During the winter season, the temperature decreases to cold and wet with rain. In general, it has a Semi-Arid Climate and that means the voids and the windows of the spaces need shading to block the sun from entering into spaces in the summer and allowing the sun into the interior in the cool season (Figure 32).

As has been mentioned before, Erbil has two main climatic conditions – hot and dry, and cool and wet. There is a quite big difference between the average maximum temperature and average minimum temperature during the months of the year. In the three summer months, the maximum average temperature reaches above 40° Celsius. While, in two months, Jan and Feb, the average minimum temperature plummets below zero. This means that the difference between the maximum and the minimum average temperatures is almost 45° Celsius (Figure 32). Overall, the average annual temperature is somewhere between about 5° Celsius and 34° Celsius.

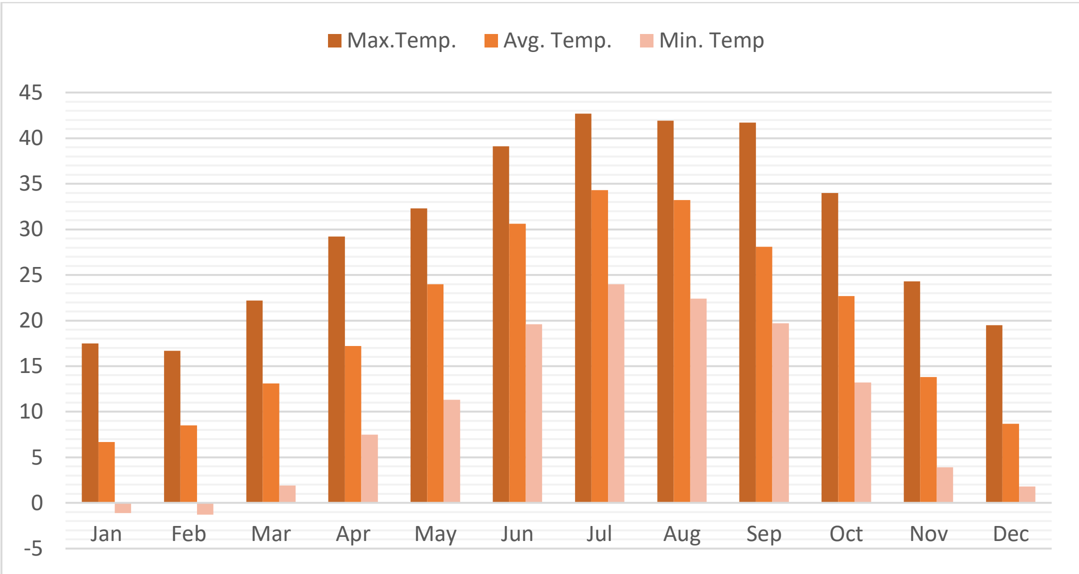


Figure 32: Maximum average, minimum average and average temperatures in Erbil City (weather file of Erbil).

Based on the psychometric chart and the comfort zone (Figure 33) on it that is related to average temperature and relative humidity, Erbil can be seen to have a low range of comfortable climate relative to the non-comfortable climate. The comfort zone on the psychometric chart covered less than quarter of the year. The months of May and October, in the spring and fall respectively, are a more comfortable period than the other months. In other words, only the comfortable periods do not need an air conditioner system/energy consumption for heating and cooling load, while the other periods need a cooling system or heating system depending on their situation.

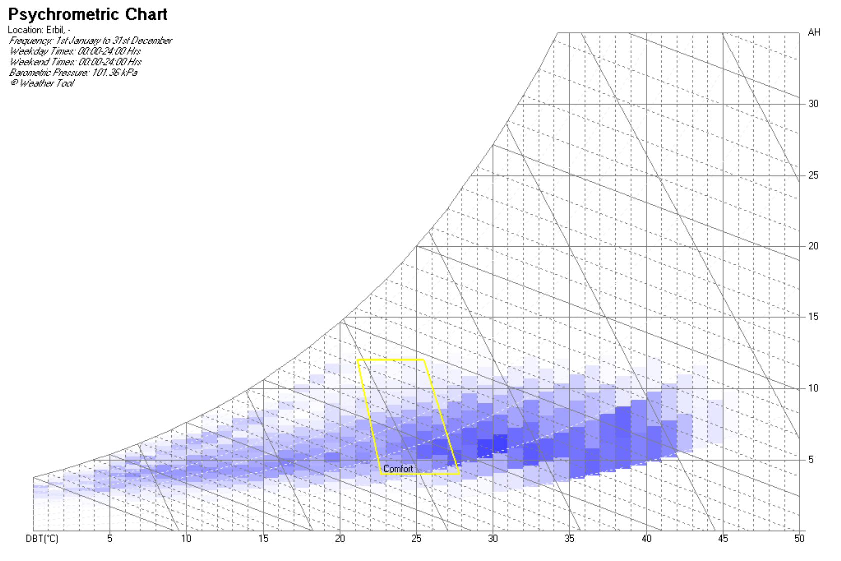


Figure 33:Psychometric chart and comfortable zone in Erbil city (weather file of Erbil).

4.1.2.1 Solar Radiation

The reasons for the hot summer and cool winter relate to the solar angle in the sky. It reaches its highest in July and it’s lowest in January. The high solar angle in the summer, which means the solar radiation will travel a shorter distance to reach the Earth's surfaces, results in the most direct solar radiation and minimum loss of it in the Earth's atmosphere. The longer period of the sunshine in the summer season is another reason for the hot summer days and the short period of sunshine in the winter months is shown in (Figure 34). The sun shines for nearly 15 hours in June and July with only a short period of daytime in January where it shines for about 10 hours (Baiz, 2016).

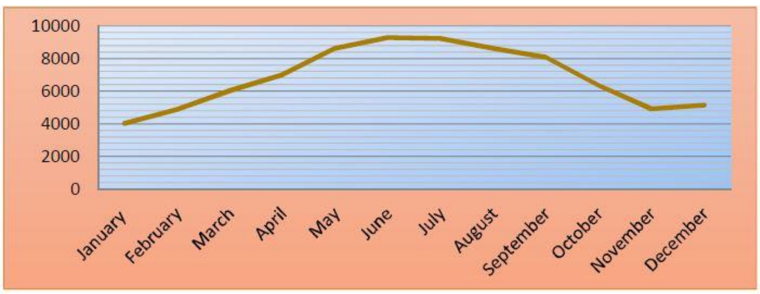


Figure 34: Solar radiation intensity in (Wh/m²) (Baiz, 2016).

4.1.2.2 Wind and Moisture

Knowledge about the statistics of wind speed and direction as well as its frequency distribution during the course of the day, month, and the year are very necessary in the analysis of wind both spatially and temporally. The wind power potentials of Iraq increase in value when moving from the northern region towards the southern region due to the increase of air temperature in this direction. It has already been concluded that the Weibull model is a successful and useful tool for wind power analysis and could be used to supply electricity to many parts of Iraq .In the city of Erbil, the group of places with high winds are Shaqlawa, Makhmur, and Koya, with monthly average wind speeds ranging from 2.55m/sec to 6.29m/sec, and from 4.66m/sec to 10.69m/sec, at 10m and 50m heights, respectively. At 50 meters, the largest value of mean wind speed was 10.69m/sec in the Shaqlawa district during the month of April, followed by 9.86m/sec in the same region during February (Saeed et al, 2014).A close look at Figure 35 shows the Annually prevailing winds in Erbil city.

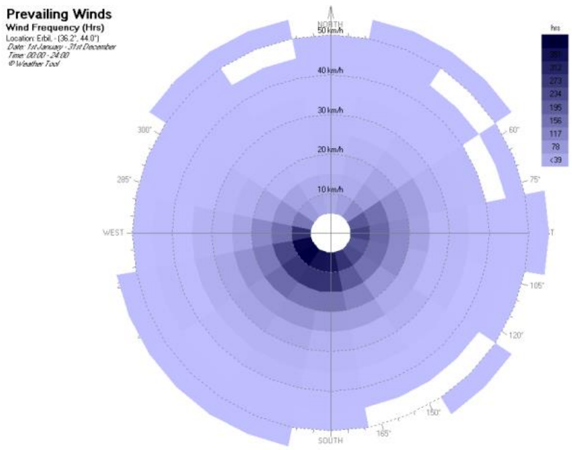


Figure 35: Annually prevailing winds in Erbil city. Source (Erbil weather tool 2011).

4.2 Socio-Economic Condition

The administrative and commercial capital of the Kurdistan region in Iraq is Erbil. The region was largely excluded from the sectarian violence that ensued following the US'

2003 invasion of the country, thus allowing Erbil to capitalize on the relative security and calm compared to other regions in Iraq (Erbil Governorate Profile, 2015).

Oil has been a substantial driver of economic development within the KRI. Public administration and construction sectors have the highest share in non-oil GDP. In 2014, the RAND Corporation and Ministry of Planning KRSO provided an estimate of the 2012 non-oil GDP based on the sectoral value added in all sectors on a consistent national income accounting framework basis (World Bank group, 2016).

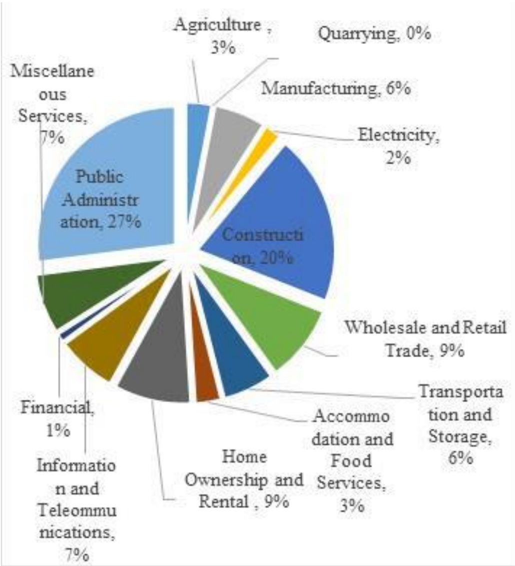


Figure 36: Share of Economic Sectors in GDP, 2014 (World Bank group, 2016).

Legislation designed to encourage private investment and economic diversification (the 2006 Kurdistan Investment Law) effectively lowered financial barriers to entry into KRI markets for both local and foreign investors and played a supporting role in overall economic growth (KRG Ministry of planning, 2012 ; MERI,2016 a). During the pre-2014 period, the growth performance was, to a large extent, underpinned by oil revenue transfers that reached about US$12 billion by 2013 from the central government due to increasing oil production and exports by Iraq.

In 2013, real GDP increased by 8 percent in KRI with oil production as the primary growth driver. The construction sector also expanded while both public and capital spending increased , The results show that public administration and construction sectors have the highest contribution to GDP while other non-oil sectors improve their contribution to growth only marginally in the last few years (figure 36).in addition Looking at past GDP data, the GDP of the Kurdistan region grew by an impressive 12% and 8% in 2012 and 2013 with the GDP in 2013, the most recent year for which the data is available, having been an estimated $26.5 billion. The increasing standard of living in the region also serves to prove just how economically buoyant the region is proving to be and even per capita income multiplied eight-fold from $800 in 2002 to $7,000 in 2013 (figure 37) (Invest In Group. 2016).

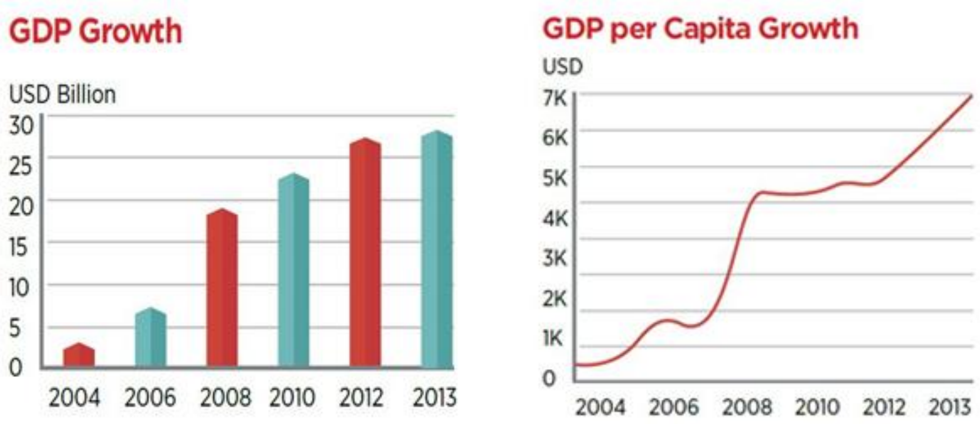


Figure 37: GDP Growth & GDP per Capita Growth from 2004-2013 in Northern Iraq

Following its buoyant growth during the 2011-2013 period, the KRG economy has mirrored the path of the overall Iraqi economy and experienced a significant downturn since 2014. The region remains highly dependent on oil, with most of the labor force employed by the public sector. In 2014, a combination of factors adversely affected the overall economy. Firstly, political gridlock prevented the region from receiving its $1billion per month ($12 billion annually) share of the federal budget. The Ministry of Finance and Economy reports that only US$1.1 billion was transferred for the entire year. Similarly, in 2015, there were no fiscal transfers at all. Second, the humanitarian response offered to the IDPs, who add up to more than five times the number of refugees from Syria has brought significant pressures on the KRG. Lastly, domestic economic activities have been disrupted, and international trade and investment adversely affected, by the plethora of issues directly linked to the activities of ISIS. Currently, over 4000 projects that were under implementation have equally been suspended (MERI, 2016-B). At present, the KRG's financial and macroeconomic condition is hardly anything but grim. In spite of its being able to fiscally consolidate 37 percent of its GDP between 2014 and the first quarter of 2016, there was a negative prediction in regards to the 2016 operational budget deficit (MERI, 2016 -A) The compression of government spending in 2016, which was expected to continue in 2017, has led to the cutting of government investment, further dragging down the economy, including the non-oil sector. Growth deceleration could extend into 2016 and 2017, driven by low oil revenues and fiscal adjustment. The economic growth is expected to remain sluggish in 2016-2018, with government spending, private consumption, exports, and investment to remain depressed by low oil prices and a tight government budget (MERI, 2016 b).

4.3 Construction Sector

Construction became a primary contributor the economic growth of the Kurdistan region starting in 1991. The region recorded dynamic, double-digit growth between 2003 and 2013 and was even highly ranked in FDI policy, macroeconomic investment, and market opportunities by the Economic Intelligence Unit. In fact, commendable progress was made in 2006 as foreign investors were now allowed to have majority shares in joint ventures and even become landowners (Philips, 2015). The construction sector did pretty well for itself with steady revenue increases from ID 46.8 billion to a whopping 15,394.17 billion between 2004 and 2007 (KRG-ministry of planning, 2012).

The period from 2007 to 2013 saw a boom in economic activity in the KRI and foreign investment flows, particularly in the construction sector. The Board of Investment (BOI) maintains data on licensed and approved non-energy sector investments financed by the private sector. Figure 38 below shows the increase in investment projects, followed by a drop off in 2014. The BOI estimates that between 2006 and 2012 the region received US$22 billion in investment, 21 percent of which was FDI or joint ventures. According to the BOI, licensed investment projects declined from $12.4 billion in 2013 to $4.4 in 2014. As a result of sharp decline in government capital spending, construction projects have been suspended and cement production plants are operating below full capacity. Property prices have fallen by about 50 percent by early 2016 from their peak reached in early 2014 (see figure 38). (World Bank group, 2016).

Construction and real estate, as the primary drivers of domestic and foreign investment alike in Kurdistan, have attracted a lot of resources with about $13.7 billion in housing projects licenced by the BOI since 2006 (excluding industrial and commercial spaces). They are, however, one of the region's most volatile sectors with fluctuations in construction quantity and quality, including the quality of the spaces required by foreign firms coming into the region, abound. 2014 marked the beginning of diverse changes within the sector (Invest In Group, 2015).

About 3,500 public-investment projects have been suspended for over a year due to economic crises. There is a prevalent lack of confidence in the private sector, particularly in the construction sector, due to the unstable nature of the economy (MERI, 2016 b).

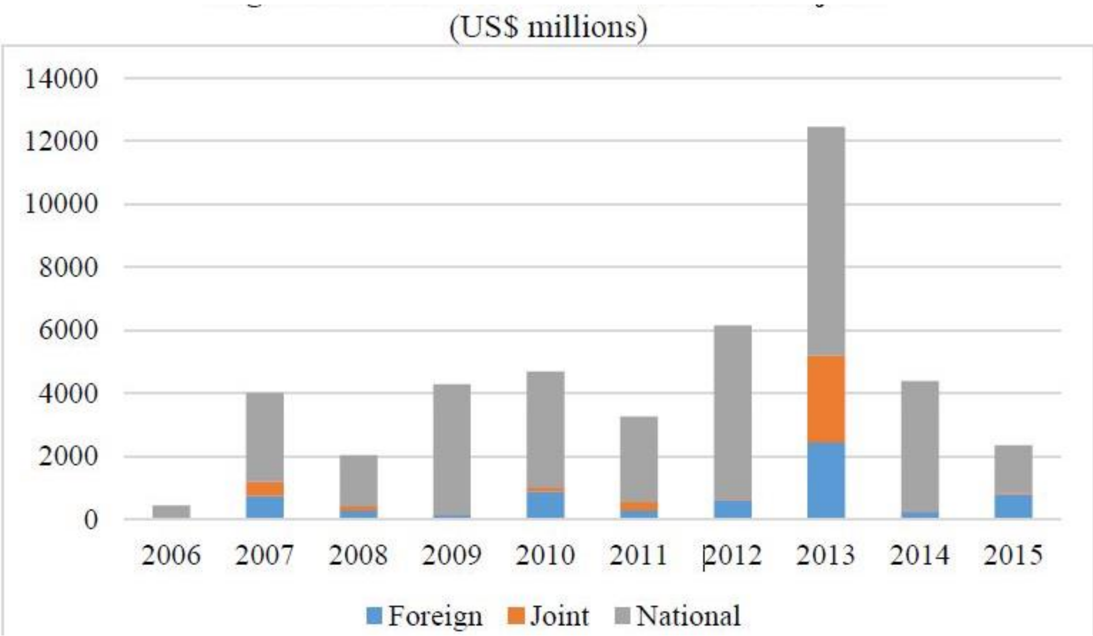


Figure 38: KRI: Licensed Investment Projects (USD Millions) source:(World Bank group, 2016).

Quantity-quality and Establishing standards: The primary goal of the construction industry has been to complete as many projects in as little time as possible, particularly due to its delayed development. With the increasing convergence between demand and supply, coupled with the arrival of many international firms to Erbil, the majority of which demand graded office spaces, the quality of construction projects has experienced significant increases. Furthermore, the quality is expected to only get better with time as more companies come to the region. Some experts, however, have said that some of the office spaces intended to be offered up on the marked fall short of international standards. Regardless, the quality of real estate in the region is on an upward trajectory and is driven primarily by an increasing demand for quality projects in the sector. Changes in the private sector would prove instrumental in stimulating progress the construction sector, which is important as numerous conditions necessary for the success of international businesses are applied irregularly. Increasing the level of supervision of the construction projects helps to ensure that development and construction firms continue to improve the quality of plans and building standards while simultaneously increasing the accountability project owners and designers alike. Even as the increased demand has caused a corresponding increase in quality, there is still much progress to be made especially as the regional government hardly enforces unified building standard, meaning that low-quality construction methods still exist. The sector itself will not police itself and there is a limit to how much market demand is able to cause developers to adhere to international standards. The top international firms in the region are pushing for a better regulated environment where regulations are strictly enforced, especially as they relate to safety and structural integrity. The enforcement of these standards are integral to the sector's progress (World Bank group, 2016).

4.4 Energy Sector

The energy sector (oil, natural gas and power) is the KRG's most significant economic sector. Oil accounts for more than half of GDP, whilst the gas and electricity sectors contribute significantly to economic growth, job creation and the quality of life for the Kurdish people. Securing the provision of reliable and efficient electricity supply in the long-run is key for increasing private sector productivity, job creation and sustained growth. The challenges the KRG faces in its energy sector are not only physical in nature and economic and financial; they are also legal and regulatory and, more significantly, policy and institutional—including the need to re-build and re-enforce institutions and their technical and management capacity. These challenges are hampering the effective strategic management of the sector as well as planning, development and operation of its physical infrastructure (MERI, 2016 b).

KRG's energy sector, including electricity, has suffered from decades of conflict and sanctions that have left its institutions weakened and have resulted in chronic under-investment and deterioration in infrastructure. This situation improved considerably between 2005 and 2013 as the KRG adopted proactive policies and encouraged the private sector to invest in oil and gas exploration and production (E&P), petroleum refining, and independent power generation projects (IPPs), all of which saw tremendous investment in these sectors. However, such successes were not followed up with sector reform and were, in any case, set back when the current financial crisis commenced in 2014 affecting KRG's ability to pay its suppliers, which slowed down private investment.

Energy subsidies are becoming unaffordable. Most of the Government subsidies for energy are used for the purchase of liquid fuel, as the domestic gas sector is still not producing enough gas to feed the power stations. It is now evident that improved electricity pricing policies, which reflect market prices, are essential. For example, the economic losses in the electricity sector are estimated around US$2.1 billion representing 80 percent of the economic subsidies in KRG. The subsidies have become unsustainable with the decrease on fiscal revenues, and increased defense spending (World Bank group, 2016).

Electricity: The power sector's developments in the last 10 years are a testament to its promising future. Only a marginal amount of the energy used in the region was locally generated before 2009 and it relied mostly on the national grip and imports from Turkey. Despite low demand and an underdeveloped distribution network, the region often fell short in power supply and even experienced relatively frequent blackouts. This however, changed from 2009 when the KRG began to develop its electricity infrastructure. Demand for electricity jumped from a mere 925MW in 2004 to 5,000MW in 2015. Since 2004, over $5billion has been invested in the generation of electricity by the private sector. The KRGs Ministry of Electricity estimates that over the next three years, electricity demand would experience an annual growth rate of 15% due to population growth, economic, and infrastructural development. Between 2009 and 2015, the number of active transformers and consumers went up from 20,000-28,000 and 705,000-1.1million respectively. The power industry in the Kurdistan region is dominated by the private sector and receives the bulk of its supply from gas-fired power stations in Khurmala and Khor Mor. Its overall generating capacity increased to 2,850MW in 2015 from about 482MW in 2007. This growth was the result of 3 new plants being constructed in Slemani, Duhok, and Erbil by Mass Group Holding, which is also responsible for their operation. These new power plants have a potential growth capacity of at least 3,500MW (World Bank group, 2016).

The Kurdistan Regional Government will also need to address the issue of unplanned power outages across Kurdistan. Sets of reforms are being implemented, signalling to investors that the government is committed to solving this issue, but the rising demand for electricity means that greater generation capacity is needed. The Kurdistan Region's current operating capacity is 3,886 MW. Kurdistan's current minimum power demand is in the range of 5,000 megawatts, in order to secure a stable supply (figure 39) (World Bank group, 2016).

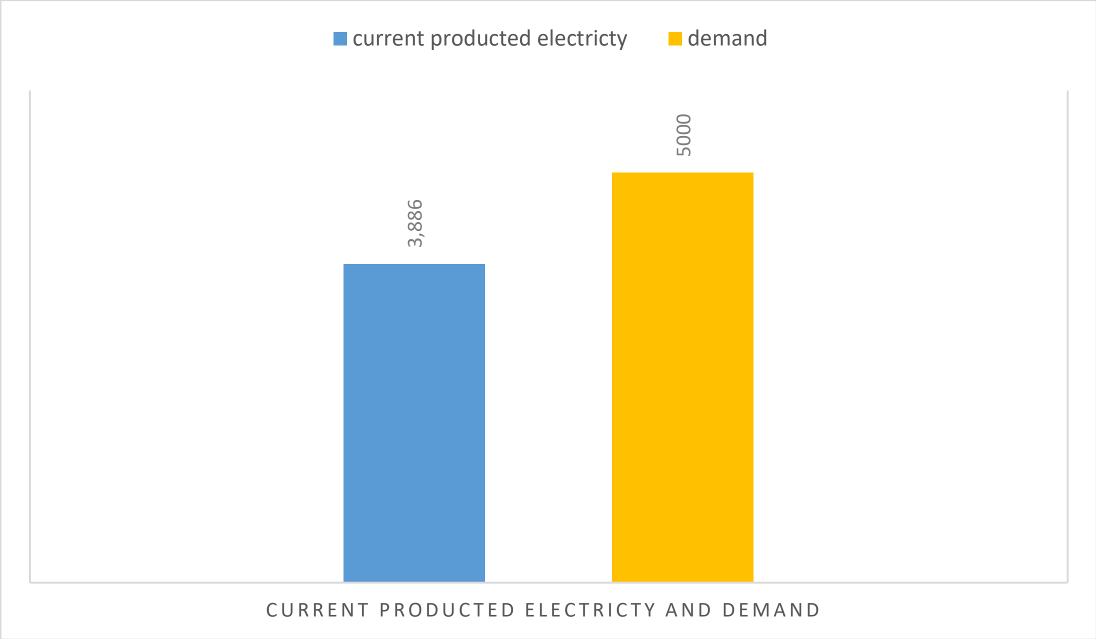


Figure 39: current produced electricity power and electricity demand in 2016 Source: (World Bank group, 2016).

Renewables: The KRG has conceded that renewable energy sources play a minimal role where the region's power demand is concerned as there is only a limited capacity for renewable sources at present. The government is working however, to improve this present condition as shown by their inclusion of alternative energy sources in the strategic energy outlook. The two hydroelectric power plants at Dukan and Darbandikhan have a maximum capacity of 300MW and plans to introduce wind power generation plants are underway. Solar projects in the private sector have a limited generation capacity of approximately 50MW. Overall, even though it is widely recognized that renewables are insufficient to unilaterally satisfy the region's energy demand, they do have a role to play if long-term energy generation goals are to be achieved. (World Bank group, 2016).

4.5 Socio-Cultural Factors Effect on Architectural Identity of Erbil City Facades

In light of the wide nest cast by the term ‘socio-cultural issues’, the focus of this study is on the socio-cultural factors surrounding building facades’ Architecture Identity and Aesthetic and Appearance , especially as they relate to the systems used in Erbil city. Series of interviews and observations have shown that while some buildings in Erbil city still have traditional façade designs, an increasing number of commercial (particularly office) buildings, hospitals, banks, and even some schools in the city may be described as modern due to the designs used for the GS systems.

4.5.1 Historical Background

In its 6,000 years as an urban settlement, the architectural tradition of Erbil has adhered to architectural principles that aim to draw parallels between nature and the built environment (Pavelka et al., 2007; HCECR, 2009). The Citadel Town of Erbil (Figures 40) is a continuously-inhabited elevated settlement known for its remarkable character. As one of the longest inhabited cities in the world, the Citadel is an integral part of Erbil’s history and was the city itself for much of history (McDermid, 2010). The Citadel has taken three forms thus far: as the city itself, as the city’s largest section and as a part of the city.

Despite the lack of reliable historical sources refer to the period of time that the citadel was the city, but it is possible to imagine that it returns to Ottomans authority from 1638 (Al-haidary, 1983). As the lifeblood of the city, the citadel shaped the city’s structure and its road network in particular. It has been instrumental for Erbil’s continued existence was described by UNESCO as "one of the most dramatic and visually exciting cultural sites not only in the Middle East but also in the world."

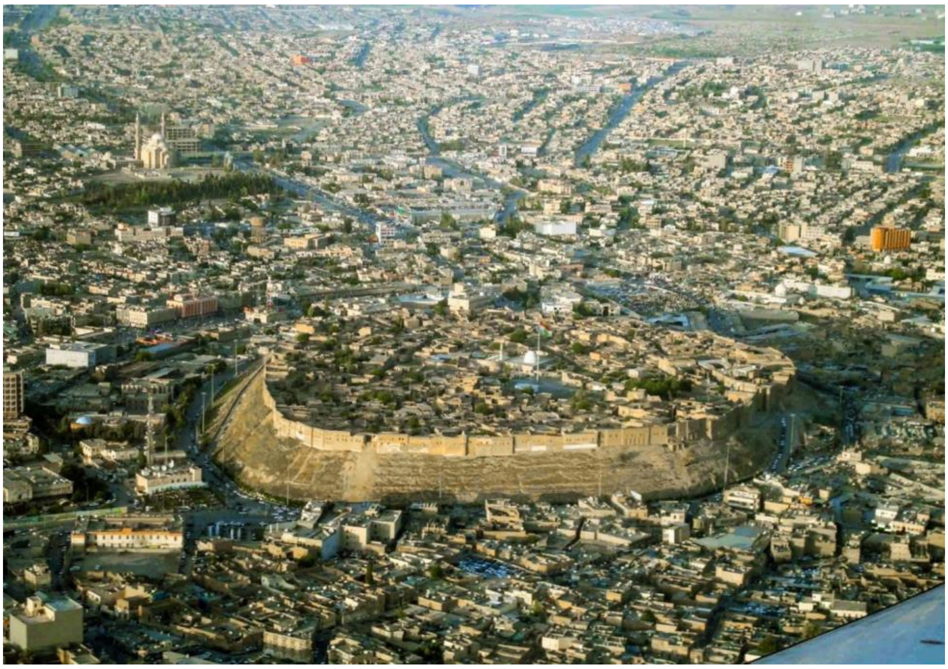


Figure 40: Erbil city center (Erbil citadel) (source: URL 3).

Cultural Heritage of Erbil City: The city of Erbil is characterized by traditional courtyard houses known as the Citadel, which is composed of about 350 medium sized houses, 500 courtyard houses, and palace-like structures numbering 30 in total (Novacek and Karel, 2008). The construction of Erbil City was mainly characterized by the usage of bricks and dominated by courtyard features. The buildings' roofs were made using timber joists as shown in figure 41. In addition, the plastering of houses in Erbil was also done using ‘’juss’’ and beautiful features and colours were also used to enhance the appearance of the houses. The most essential element in the traditional aesthetic of Erbil is that floral and bright colours were dominantly used for decorative purposes. The type of the roofs of Erbil houses were designed irrespective of the number of house floors though a significant number of houses has two floors as shown below in figure 41.

The layout of the houses was always structured in a manner that the entrance always leads to the courtyard (Akram, Ismail and Franco, 2016). On the other hand, differences were observed in terms of the distance between upper and lower floors from the courtyard. Such differences were made so as to make a space provision for putting windows. A distance of 1-1.5 separated the courtyard from both the upper and lower floors (Akram, Ismail and Franco, 2016).

Traditional aesthetic values were also observed in arcaded terraces, which were vast in number and were a common characteristic in most Erbil houses. The traditional element was further accompanied by materials supplied from Mosul, such as grey marble. Moreover, the building designs followed a certain design pattern. For instance, rectangular or shaped layouts were mainly used for the layout of courtyards but the geometrical structure was based on the structure of the courtyard. Traditional Erbil houses were also characterized by a lot of windows. Such windows were important for ventilation and allowing daylight into the house and this is shown below in Fig 41. Spatial planning responsibilities were thus thrusted into the hands of an ‘Usta’ also known as the master designer. Major limitations in traditional Erbil houses concerned space. This was underwritten by the fact that the shape of the plot on which the houses were built also played a main role in the structure design of the building. Regular shaped plots were not suitable for building structures that had asymmetrical plans. The most notable feature of traditional Erbil houses is that they were built with an emphasis on privacy. Doors were therefore placed in a manner that contributes to the privacy of the house (Hariry, 2017).

Figure 41: cultural heritage in Erbil city source: (Invest In Group, 2015).

4.5.2 Contemporary Arhitecture Identity of Facades in Erbil City

Modern Aesthetics in Erbil City: As time passed, the needs of people, buildings, cities, and even countries had to evolve with the invention of new materials. Similarly, designers, architects, design, and architecture alike have also been affected to a large extern by the modern movement. This is one of the reasons why numerous buildings from the previous eras have been replaced with those with a more modern inclination and the 'ground level' has only gotten higher. Conversely, social and technological changes engendered by the movement have proven to be much more of a challenge to architects as traditional values are applied less in the construction of modern buildings, which is done primarily using metal, concrete, and increasingly, glass (Oktay, 1996).

After the liberation of Iraq in 2003, architecture in Erbil City has gone through major changes and passed through rapid transformations due to economic developments, consequently, relative prosperity, peace, and democracy have been growing in the region (Gunter, 2004). This period can be considered as golden era of the city evolution. Many of development projects have been constructed and the urbanization process reached its climax. The speedy growth experienced in the construction and housing sectors has resulted in contradictory architectural forms with strange orientations beginning to replace tradition (Baper, Hassan, & Ismail, 2013).Erbil city faced a rapid, inadequately controlled urban growth and development during the last decades (Khayat, 2012). Today the landscape of Erbil is marked by inactive hollow high-rise buildings and construction cranes even as the construction sector remains integral to the regional economy due to its size and links to other sector (Phillips, 2015).

Even in light of the above mentioned changes, progress is being made in the sector an overall supply increase as high as 2017 is predicted to happen in 2017 according to IKG property. A string of high-profile projects (residential and commercial alike) have been completed. Numerous hotels, office spaces, and residences are expected in the near future. The top mixed-use development in Erbil, Empire World, has been rolling out spaces and numerous oil companies have moved to its office and residential spaces (Kurdistan review, 2015).

Chapter 5

PREPARING DESIGN STRATEGIES, EVALUATION AND OPTIMIZATION

In this chapter, in order to prepare design strategies for achieving energy efficient glazed façade in high-rise office buildings, the literature survey and computer simulation methods (Autodesk Ecotect software 2011, climate consultant 6, WINDOW 7.5) were used.

5.1.1 Computer Simulation

5.1.1.1 Autodesk Ecotect Software

Ecotect analysis software was designed primarily for use in the initial design stages of design and is utilized for a range of analyses, including: solar exposure studies, shading, shadow analysis, daylight studies, and lighting (Aksamija, 2016; Aksamija, 2016).

A tool for energy efficient building design, Ecotect is visually-responsive user-friendly computer program. It aids in addressing a number of environmental principles that need to be taken into consideration in the initial stages of the design process and provides both analytical and visual feedback for complex and even simple models. The tool is also useful for the purpose of designating the aggregate amount of energy used, Thermal performance, acoustics, carbon emissions, solar radiation, daylighting, water use, reflections, shadows, and cost (Sustainability Workshop, 2017).

A recent survey into how architectural practice addressed the use of building performance tools, principally with a comparative view to these simulation programs: HEED, Design Builder, Energy 10, ECOTECT, DOE-2, e-Quest, IES VE, Green Building Studio, EnergyPlus and the EnergyPlus Sketch Up plugin in Open Studio With the conclusions drawn from its 249 survey respondents, the researcher rated the use of said tools as well as investigated the means through which these applications could potentially be improved. The survey reveals that Ecotect is the most commonly utilized application (Attia, et al 2009).

5.1.1.2 Climate consultant

Climate Consultant is a freeware software use to provide a graphical illustration of weather data and carry out a simple analysis to suggest the suitable strategies for a particular climate. With its simple user-friendly interface, the software allows shading effectiveness for different orientations and depths to be quickly and easily determined. Effectiveness at various orientations and shading depths (Kjell Anderson, 2014).

5.1.1.3 WINDOW 7.5 software

The computer program WINDOW, which was developed by the Lawrence Berkeley National Laboratory is used to calculate glazing properties, including the shading coefficient (SC), solar heat gain coefficient (SHGC), summer and winter U-values for glazing units, and visual transmittance (TV) (Aksamija,2013)

Weather data of Erbil: The weather data for Erbil was used in Ecotect in conjunction with the international weather for energy calculation file. Using the weather tool and the solar tool, Erbil was discovered to be situated between latitude 36 °N Longitude 44 °E. In regards to its elevation, it is average 453m above sea level. The EPW (energy plus weather) was used in climate consultant 6.

5.1.2 Preparing The Model

In order to accurately prepare useful design strategies (orientation, fenestration, aspect ratio, material properties U value, SHGC, VT, amongst others), an office space model prepared to statistically achieve this goal.

The model office was a 25 m2 rectangular room with dimensions 3.55m by 7.05m and a 3m high, double glazed, clear glass window with a U value of 1.88 W/m2K. The opaque wall satisfies the minimum ASHRAE U value requirement. These specifications are only relevant for regular office hours (8am-5pm) during the week when the set temperature points were 20°C (heating) or 27°C (cooling) with humidity % 60 .

5.1.3 Erbil Climate Zone According to Koppen Classification and IECC

Erbil's climate is semi-arid continental and in the Koppen climate classification, is categorized as subtropical semi-arid (BSh) (Rasul et al., 2016; Rasul, Balzter, & Smith, 2017; Baiz, 2016).

In order to discover Erbil's climate zone according to the International Energy Conservation Code (IECC), Autodesk Ecotect was used by entering 18 degree heating and 10 degree cooling; the results from the Ecotect software show that Erbil has more than double the amount of cooling-degree days (4040 CDD) than heating-degree days (1306 HDD) in a year. Figure 42 shows the monthly cooling and heating degree days in Erbil.

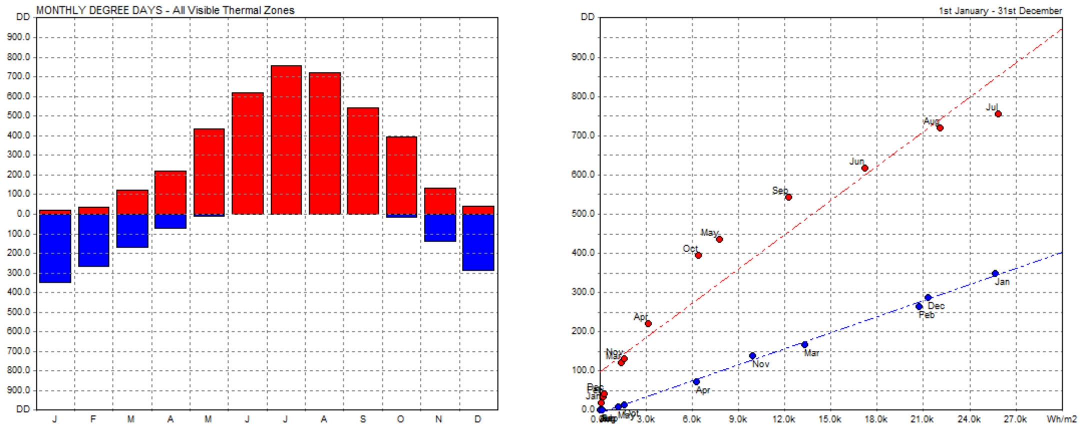


Figure 42: monthly degree days in Erbil city. Source :(Autodesk Ecotect based on Erbil weather tool).

By comparing the total heating and cooling degrees in Erbil city with the table12, it is possible to denote the city's climate zone according to the International Energy Conservation Code (IECC).

It was found that the total cooling degree days in Erbil city CDD = 4040, this amount is characteristic of locations in zone 2, which is considered a hot zone (Table 12). Therefore, summer conditions were the primary concern for the facade design. Zone 2 consists of the climates that have CDD between 3500 < CCD 10c < 5000.

Table 12: US climate zones defined by HHDs and CDDs. source: (Kibert, 2016).

	Thermal Criteria	
Zone Number	IP Units	SI Units
1	9000<CDD50F	5000<CDD10C
2	6300 CDD50F ≤ 9000	3500<CDD10C ≤ 5000
3A and 3B	4500 CDD50F ≤ 6300 and HDD65F ≤ 5400	2500<CDD10C ≤ 3500 and HDD18C ≤ 3000
4A and 4B	CDD50F ≤ 4500 and HDD65F ≤ 5400	CDD10C ≤ 2500 and HDD18C ≤ 3000
3C	HDD65F ≤ 3600	HDD18C ≤ 2000
4C	3600<HDD65F ≤ 5400	2000<HDD18C ≤ 3000
5	5400<HDD65F ≤ 7200	3000<HDD18C ≤ 4000
6	7200<HDD65F ≤ 9000	4000<HDD18C ≤ 5000
7	9000<HDD65F ≤ 12600	5000<HDD18C ≤ 7000
8	12600<HDD65F	7000<HDD18C

5.1.4 Preparing Design Strategies

5.1.4.1 Climate-Based Design Approach in Erbil City

According to the literature, the external environment, space dimensions, building orientation, and occupant comfort ought to be taken into consideration by designers. The acoustic, thermal, and visual comfort of a building's occupants are affected by wind velocity, humidity, air temperature, noise, solar radiation, humidity, ground reflectivity, and the size and placement of external objects (such as plantings, buildings, or topography). The surrounding buildings must be considered during the early design stages in Erbil city because Erbil has flat land and there is no topography. Plantings also do not significantly affect high rise buildings in the city due to their large scale.

Design Strategies and Climate: In literature it was observed that Cooling-dominated climates Zones 2 need the following strategies:

- Solar control: protection of the facade from direct solar radiation through self-shading methods (building form) or shading devices
- Reduction of external heat gains: protection from solar heat gain by infiltration (by using well-insulated opaque facade elements) or conduction (by using shading devices)
- Cooling: use of natural ventilation where environmental characteristics and building function permit
- Daylight: use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves.

An initial climate analysis can be made to delimit a series of possibilities for intelligent envelope elements. One type of initial examination would include finding the most appropriate design strategies, based on the psychrometric chart for bioclimatic design. Climate analysis using specialized software for the location is possible, given the existence of electronic yearly data.

The psychrometric analysis for Erbil city, executed using the Climate Consultant 6 software program, revealed a series of general strategies as illustrated in Fig.49. It shows that comfort levels are only achieved for a relatively reduced number of hours for that particular climate. Therefore, it is necessary to employ passive or active climate design strategies to extend comfort times.

In this case, in order to extend the comfort period as much as possible and reduce the use of mechanical measures, the following strategies are suggested by the analysis:

For the summer period:

- Sun shading of glazed area
- Supplemental mechanical cooling for extreme peaks.

For the winter period:

- Passive solar heat gain
- Supplemental artificial heating for extreme peaks.

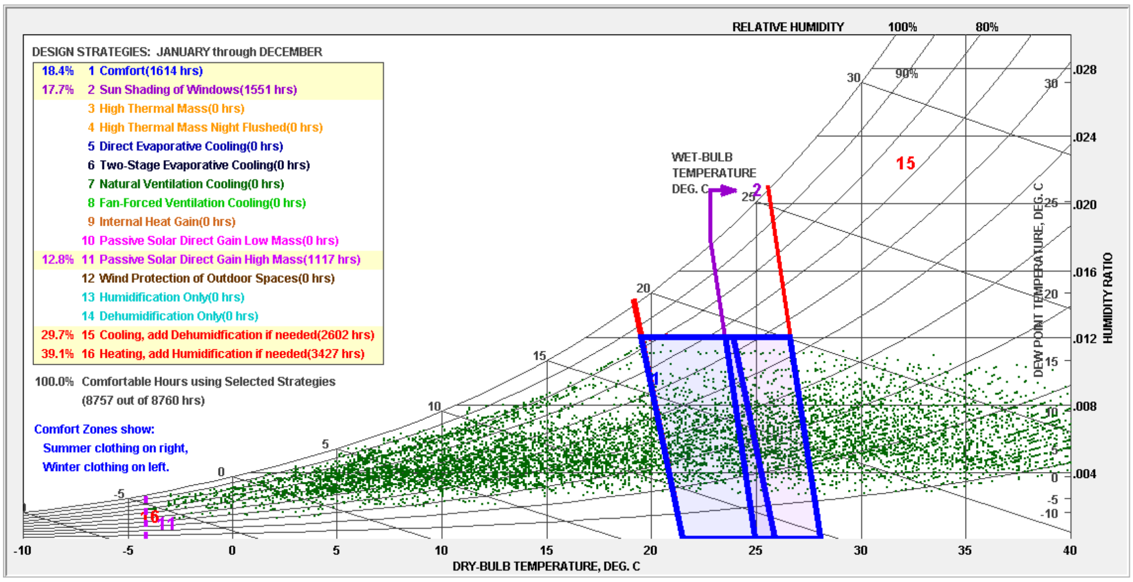


Figure 43: Psychometric analysis for Erbil city. Performed using Climate Consultant v 6.0

5.1.4.2 Orientation and floor plate design and arranging building mass

According to literature, in hot climates such as Erbil, the designer ought to make sure that the built form’s long axis has an east-west orientation such that the building’s long sides face the north and the south. The reason for this is that it minimizes solar heat gain as it situates most of the windows on the north and south walls.

In order to find the precise optimal building orientation in Erbil city, the weather tool was used. Three hot and cold months were inputted into the Erbil weather tool in Autodesk Ecotect 2011.

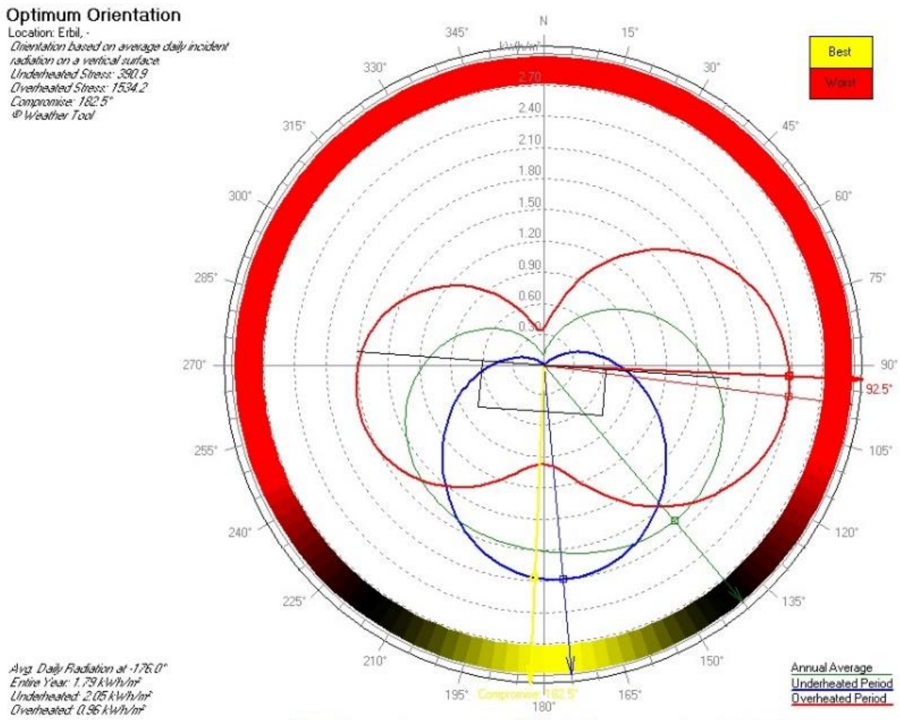


Figure 44: the Optimal building orientation in relation to solar heat gain in Erbil city source :(Autodesk Ecotect based on Erbil weather tool).

Figure 44 shows the stereographic diagram with the azimuth (AZM) angles found for Optimal building orientation for solar protection (OBOSP) and Optimal building orientation for solar collection (OBOSC) in Erbil city. The AZM angles show that for OBOSP and OBOSC in a rectangular building located in Erbil city, a shorter facade pointing to an AZM angle of 92.5º is optimal for the strategic placement of complex designs shading devise, which will provide maximum shading during summer. However, a larger facade pointing to an AZM angle of 182.5ºN is optimal for applying simple designs that will provide shading during summer but maximum daylighting during winter.

Floor-Plate Design (aspect ratio): The floor-plate strategy concerns the interplay between the shapes of the floor plate of the building, where it is situated on the site, its orientation relative to the path of the sun and the direction of the wind. The ideal shape for tropical and arid climates is a rectangle through which the length of the east and west sides could be kept at a minimum while simultaneously maximizing that of the north and south sides and minimizing solar insolation. The arrangement of the internal spaces should be in such a way that the solar gain of high-occupancy spaces is minimized and service spaces serve as solar buffers.

Generally speaking, the built form should have an optimal aspect ratio of 1:2-1:3 in climates closer to the equator and lower at higher altitudes. In order to find the optimum aspect ratio in Erbil city for high-rise office buildings, two distinct aspect ratios were compared in Autodesk Ecotect 2011. The first one is square in shape (1:1) and the second one rectangular in shape (1:2); with the same glazing (WWR) ratio, the results show that the rectangular model with an aspect ratio of 1:2, can save more than 17 %) (Table 13).

Table 13: annually Energy consumption in square (1:1) and rectangular (1:2) (Autodesk Ecotect 2011based on erbil weather file).

Aspect ratio	Heating(Kwh)	Cooling (Kwh)	Total(Kwh)
1:1 (square)	465.096	5487.417	5952.513
1:2 (rectangular)	370	4521	4891

Arrangement of the Building Masses: Due to the fact that the position of the building masses could either increase or reduce heat gain, their arrangement should be take n into consideration in bioclimatic design. In hot climates such as in Erbil, the building's service cores should be on its eastern and western sides in order to ensure that adequate shade is provided against low-angle sunlight for the most part of the day. Research has revealed that a double-core arrangement in which the openings of the windows run northward and southward with cores in the east and west will result in considerable energy saving where air-conditioning is concerned. The benefit of this arrangement is that in addition to providing a buffer zone for the hotter sides in the interior, it also minimizes solar heat gain and improves heat loss from the necessary spaces.

5.1.4.3 Fenestration

Window to wall ratio (WWR): As a common rule of thumb, ASHRAE and IECC code state that to enhance a building's energy performance, the optimal WWR for hot and cold climates should be approximately or less than 40%. A higher WWR of up to 90% can be accepted in cold climates, but only if the windows are well insulated, and in hot climates, only if they are well shaded.

5.1.4.4 Material Property and Components

U Value: For hot climates (Zone 2), such as Erbil city, ASHRE 90.1 2010 recommends a maximum U value of 0.7 for metal framing (curtain wall, store front).

The use of high-performance glass and framing system designs that minimize heat transfers are useful in the overall reduction of the U-values. The use of additional glass lites improves the glazing units' insulating values, as does using inert gases (krypton or argon) to file the spaces between the lites as opposed to air.

EBN provides these supplementary recommendations: optimizing the fenestration system of the building by way of modelling software, such as RESFEN and WINDOW and using low-e double-glazed, argon-filled windows as the minimum standard in most climate zones.

SHGC (Solar Heat Gain Coefficient): In hot climates (Zone 2) like Erbil city, ASHRE 90.1 2010 and IEEC code recommended a maximum SHGC of 0.25 for all facades except the north-facing façade because there it is not subject to direct solar radiation.

VT (Visual Transmittance) if daylight is desired in a space, the logical course of action would be to use a high-VT glazing. Conversely, low-VT glazing is preferable for spaces where interior glare needs to be kept to a minimum, such as in office buildings.

LSG (Light to Solar Gain Ratio) VT/SHGC: According to the reviewed literature, energy efficient facades in all climates require an LSG ratio of at least 1.25 and facades that are located in hot climates benefit from higher LSG ratios (>1.25).

In order to accurately find the proper (SHGC, VT, and LSG) ratio in Erbil city, three different LSG ratios (0.87, 1.25, 1.4 and 1.6) were tested on the all facades in Autodesk Ecotect 2011 by running the Erbil weather file for the previously suggested office model (see table 14).

Table 14: Simulation of (SHGC, VT, LSG) ratio in all directions (Autodesk Ecotect 2011 based on Erbil weather file).

Orientation	LSG	SHGC	VT	Total energy (Wh)
south	1.25	0.15	0.25	18264
	1.4	0.25	0.35	18419
	1.6	0.25	0.4	18463
	0.87	0.79	0.69	20192
East	1.25	0.15	0.25	18057
	1.4	0.25	0.35	18203
	1.6	0.25	0.4	18238
	0.87	0.79	0.69	19597
west	1.25	0.15	0.25	18156
	1.4	0.25	0.35	18413
	1.6	0.25	0.4	18477
	0.87	0.79	0.69	20832
north	1.25	0.15	0.25	18351
	1.4	0.25	0.35	18327
	1.6	0.25	0.4	18471
	0.87	0.79	0.69	19224

The results show that in the South, East and West exposures, lower SHGCs result in better performance, while North facades benefit from higher SHGCs because there is no direct solar radiation on this façade as can be seen in table14.

Shading Devices : For the purpose of finding the shading device depth (VSA,HSA) angle in all orientations, climate consultant 6.0 was used with a metric unit and small non-residential. The weather file for Erbil with epw extend was also used, as was the comfort model for simulating the weather in ASHRAE standard 55.

Findings and Analysis: The climate consultant program showed the number of hours during which shade and sun were needed.

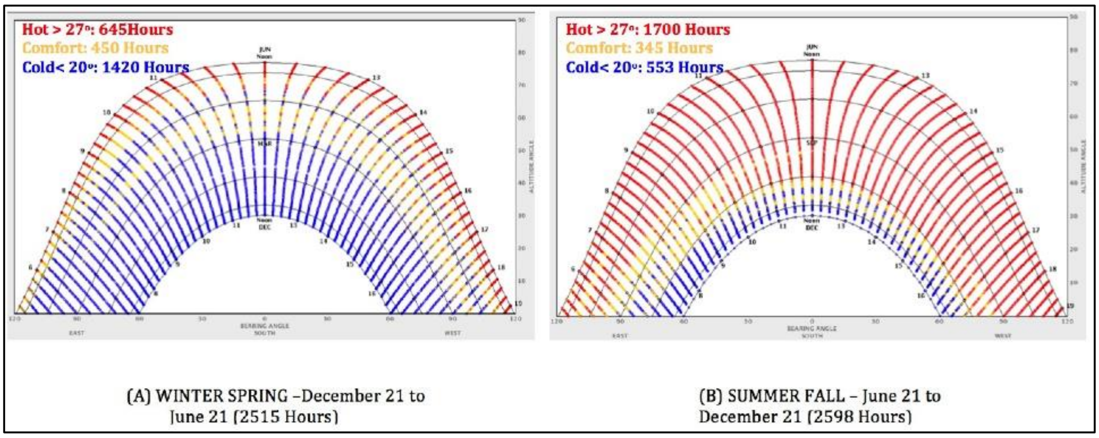


Figure 45: Sun shading chart with two different plots month period Source: (Climate consultant 6).

Figure 45 shows that in both periods (winter-spring and summer-fall), shading devices are necessary, albeit in different ways. Windows should be shaded for approximately 2345hours over the year with only 795 hours in the year of comfortable temperatures, and 1973 hours during which shading is to be avoided. This means that the shading devices at this location should prevent direct solar radiation from entering the buildings in the hot season to keep the interior cool and reduce cooling system requirements, and permit limited radiation in the cold seasons.

In this case, there are different types of shading devices that can be used; in general, they can be divided into horizontal lovers (side fins), cantilevers (overhangs), and the combination of both (overhangs and side fins)

A. South Orientation

By using the overhang at an angle of 50º, it is possible to get the fewer hours of exposure to the sun (Figure 46). Figure 46 illustrates that a space with a southward orientation should have windows with horizontal shading devices with the angle of 50º in two different plot months: winter spring and summer fall. It can be clearly seen that there is no hour during which exposed shade is needed in the hot and warm period between 21st December to 21st of June. Also, more than 1520 hours of shade are needed in high-temperature times in the summer-fall season. Overall, there are over 3150 hours of shade needed, while for about 400 hours, the window is shaded when it is cold and the sun needed.

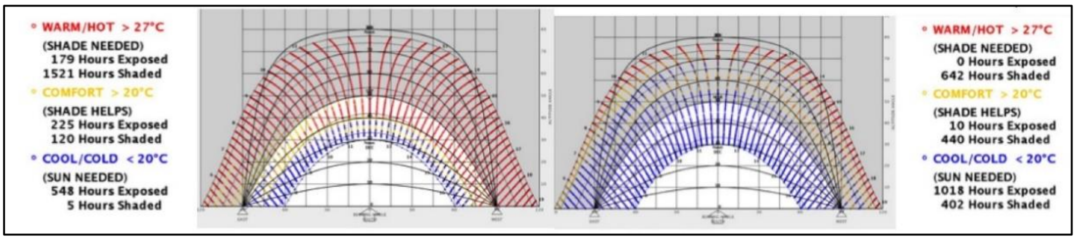


Figure 46: South orientation solar shading element 50o degree angle. Source: (climate consultant 6).

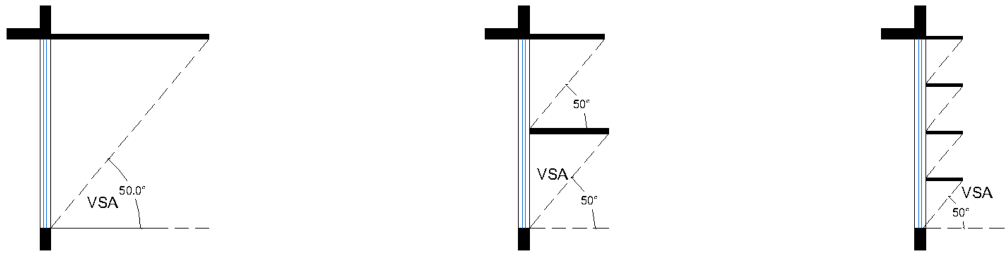


Figure 47: South orientation solar shading element 50o degree angle –Elevation. (Drawn by author).

B. East Orientation

By using an overhang with an angle of 50º and vertical fins with a 15º angle, it is possible to get fewer hours of direct exposure to the sun (Figure 48). Figure 48 illustrates a space with an eastward orientation and windows with horizontal shading device with the angle of 50º and vertical fins with an angle of 15º in two different plot months: winter spring and summer fall. It can be clearly seen that there are no hours where exposed shade is needed in the hot and warm period between 21st December to 21st of June. Also, more than 1350 hours are shaded and there are 230 hours of exposure in high-temperature times in the summer-fall season, and 549 hours of sun shading in the low temperature winter-spring time and about 892 hours that the window is shaded in the cold when the sun is needed. It is obvious from the shading chart that the east orientation is difficult to shade as compared to south façade. And it was studied in literature this exposure should be minimize and glazing ratio in this exposure should be decrease as well.

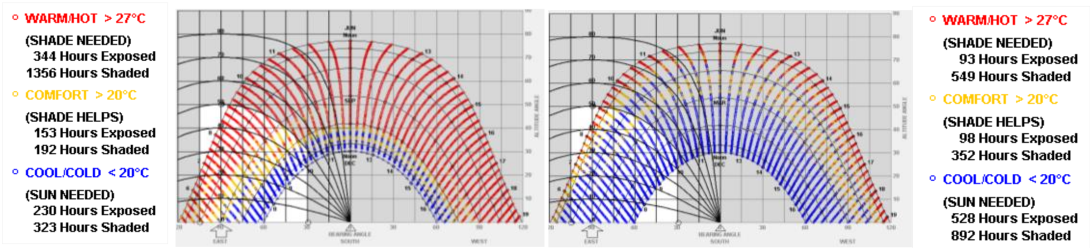


Figure 48: East orientation solar shading element 50º degree angle (VSA) for overhangs and 15 degree angle (HSA) for vertical fins. Source: (climate consultant 6)

Figure 49: East orientation solar shading element 50o degree angle (VSA) for overhangs and 15 degree angle (HSA) for vertical fins (Drawn by author).

C. West Orientation

Using an overhang with an angle of 50º and vertical fins with a 15º angle results in fewer hours of exposure to sunlight (Figure 50). Figure 50 illustrates a west-oriented space and its windows with horizontal shading devices at a 50º angle and vertical fins at a 15º angle in two different plot months: winter spring and summer fall. It is evident that there are 473 hours of shade needed in the hot and warm period between 21st December and the 21st of June. Also, more than 1220 hours of shading and 172 hours of exposure in the high-temperature time in the summer-fall season and almost 995 hours when the window is shaded and 425 hours during which it is exposed exposed in the cold when the sun is needed. It is clear from the shading chart that the west orientation is also difficult to shade in shade needed time, and it was studied in literature this exposure should be minimize and glazing ratio in this exposure should be decrease as well.

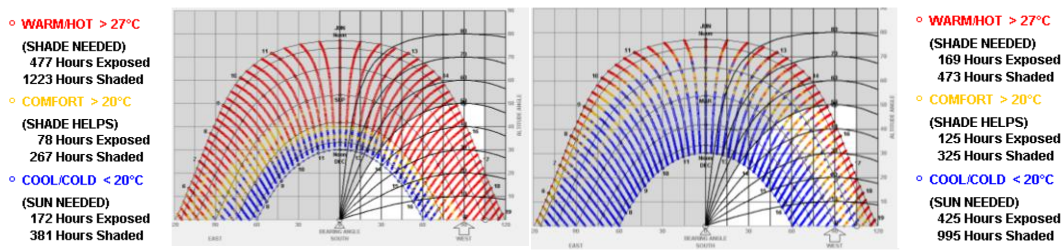


Figure 50: West orientation solar shading element 50o degree angle (VSA) for overhangs and 15 degree angle (HSA) for vertical fins. Source: (climate consultant 6).

Figure 51: West orientation solar shading element 50o degree angle (VSA) for overhangs and 15 degree angle (HSA) for vertical fins. (Drawn by author)

D. North Orientation

Using vertical fins at a 60° angle provides total early morning shade and protection from low-altitude sunlight in the afternoon (Figure 52). Figure 52 shows a space with a Northward orientation; its windows have vertical fin shading devices with an angle of 60° in two different plot months: winter-spring and summer-fall. It can be observed that there is no hour of exposed shade needed in the hot and warm period between the 21st December and the 21st of June. Also, 1700 hours of shade and no hours of exposure are experienced in the high-temperature times in the summer-fall season and 1420 hours during which the window is shaded and 425 hour when it is exposed when the sun is needed in the cold.

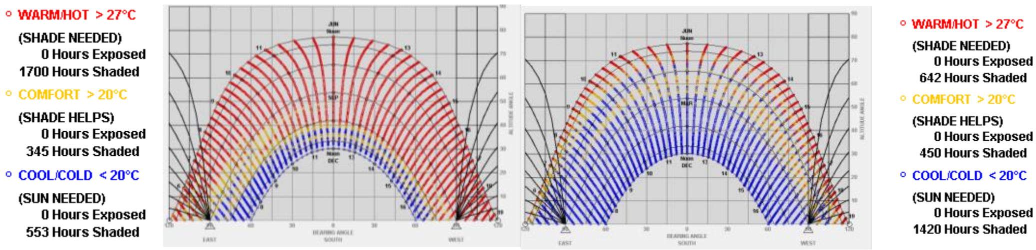


Figure 52: North orientation solar shading element 60o degree angle (HSA) for vertical fins. Source: (climate consultant 6)

Figure 53: North orientation solar shading element 60° degree angle (HSA) for vertical fins. (Drawn by author).

Shading Device and SHGC Relation: According to ASHRAE 90.1 2010 by using shading devices higher SHGC could be acceptable.in addition it was found by climate consultant 6. VSA angle of 50 (for overhangs) should be used for south, east and west facades. As an example if the window has the height of 3.4 m and the overhang depth should be 2.85 m with VSA 50.

Projection factor (PF) =2.85/3.4 , Pf =0.838.

According To ASHRAE 90.1 PF of 0.838 has SHGC multiplier of 0.47 for all orientations except north and North Orientation has PF of 0.75. Therefore, the effective SHGC is 0.47 x 0.55 = 0.25, which meets the code requirement.

5.2 Observation Analysis and Computer Simulation Analysis for Existing Glazing Façades in High Rise Office Buildings in Erbil City

5.2.1 Personal Observation

In order to reach the conclusions of this research 11 high rise office buildings were observed, 5 towers located the Empire world, 4 towers locate Media city, the Gulan park office tower and Justice Tower located in different place (figure 54).

Figure 54: The observed high rise office buildings location on Erbil city map .Source:(URL 4).

Empire World: Covering a 750,000m2 land area, Empire employs a mixed-use approach to land use and contains leisure, entertainment, residential, leisure, and service spaces, earning the development its designation as a city within a city.

Empire Business Towers (Office Buildings): The Empire Business Towers comprise 5 towers in the center of the Empire Project site (see table 15). The central tower, T1, is 27 floors high and covers a construction area of 24,000m2. T1 is enclosed by 4 other towers in the shape of a circle (T2 – T5). Each tower has a construction area of 21,000m2 and is a 23-floors high. The Central Business Tower, T1, is shared into:

- The basement and ground floors, reserved for offices and information services.
- The first floor, mezzanine floor and second floors include a conference hall, business centre and meeting rooms.
- 9 floors each with 4 offices an an average area of 215m2.

- 8 floors each with 2 offices and an average area of 520m2.
- 6 floors with just 1 office and an average area of 1,045m2.

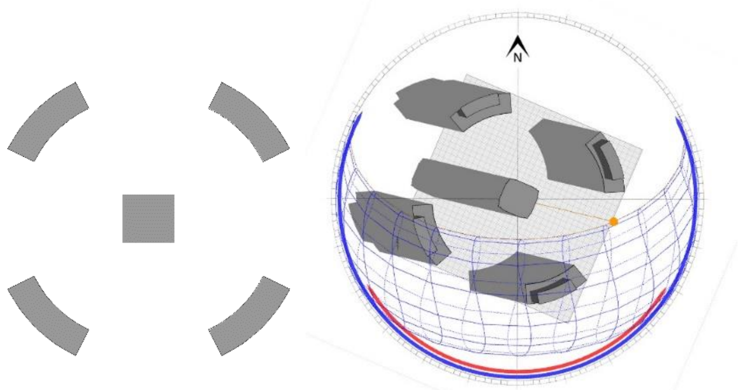
T2, T3, T4 and T5 buildings are divided as follows:

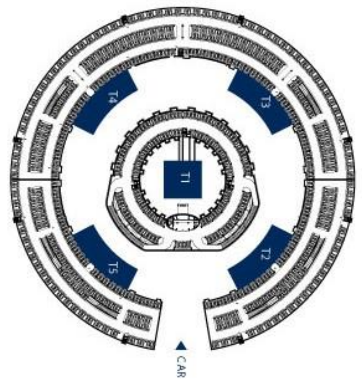
Each floor has an area of 911m2 subdivided into 7 offices:

- 5 offices at 123m2.
- 2 offices at 148m2.
- The offices can be easily merged to create a larger space or left as stand-alone units.

The T1, T2, T3, T4 and T5 office tower buildings (located in empire world), of which T1 has an almost 10000 m2 glass façade, and T2, T3, T4 and T5 each have an almost 12000m2 glass façade, have GCW systems employing a Low-e tempered clear inner side & a blue-green tempered, heat soaked outer side with sizes 165*100,100*100 cm using a double glazing system. T1's GF faces south, north, east, and west over a vertical span of 129m over 27 floors, while the T2, T3 T4, T5 buildings each have a height of 79m with 22 floors. The structure v of the buildings' glass facade is aluminium framing. The GF of the buildings' (T1, T2, T3, T4, and T5) are not equipped with any shading devices (table 15).

Table 15: Analysis of existing GFS of (T1,T2,T3,T4 and T5) Buildings-empire world

Empire world						
1-Height of the building and floors	T1 building	129 m2 , 27 Floors				
	T2, T3,T4,T5	79 m2, 22 floors				
2 Type of façade system and façade support system	Glass Curtain wall system ,aluminium frame system					
3- Built form configuration	A. Orientation					
	B. Aspect ratio					
	C. Arrangement of the building masses					
4 Fenestration (WWR)	Orientation	South	East	West	North	
	T1	High WWR	High WWR	High WWR	High WWR	
	T2,T3,T4,T5	High WWR	High WWR	High WWR	High WWR	
5 Shading devices	No shading devices used					
6 construction cost	$ 250					
7-Glazing properties	Building Name	Glazing type	Inner	Space	Outer	glass Size & m2
	T1	Double glazing-SSBGS	6 mm , Low –e tempered clear	12mm space	8 mm, blue green tempered heat soaked	90*90&120*90 ~10000 M2
	T2,T3,T4,T5	Double glazing-SSBGS	6 mm , Low –e tempered clear	12mm space	8 mm, blue green tempered heat soaked	165*100,100*100 & ~12000 m2 each building



Justice Tower (Erbil Business & Trade Centre Tower): This development is considered to be the tallest and largest tower in Erbil and its area is approximately 240.000m2 comprising 37 floors, 3 underground floors and a 120m high suspended bridge. The building is situated at Mosul Road, adjacent to the Sami Abdul Park, Iraq's largest park. The design is also modern and deserving of the famous World Trade Centers.It is split into two constituting units:

The front part contains a 5-star hotel and 336 luxury hotel rooms, as well as a host of other services and facilities.

The back part consists of office spaces with a modern design. These offices are in different size variants between 55m2 and 140m2 on the building's second to twenty-second floors. From the twenty-fourth floor and above, large commercial spaces are provided for use by big companies, such as banks, to provide upscale services.

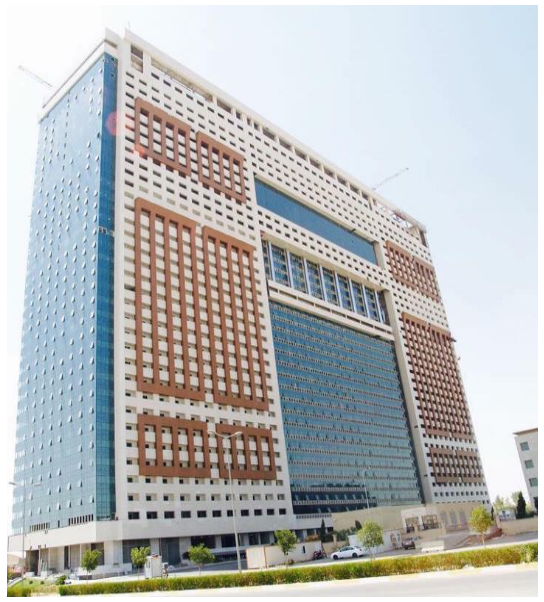
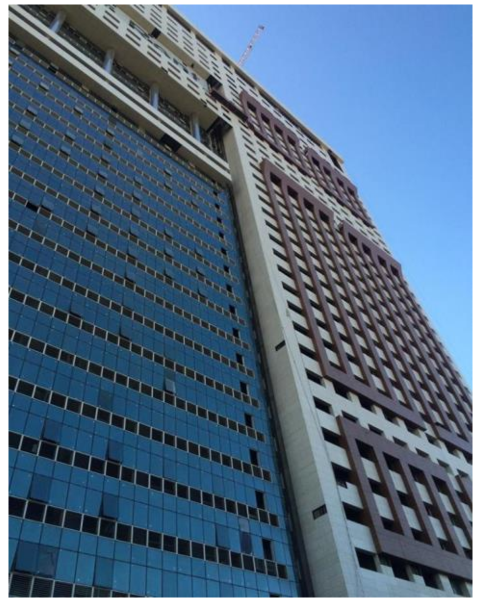
consists of a modern office designs with different sizes starting from 55 square meters to 140 square meters and these offices are located from floor 2 to floor 22 , and from the 24 floor to the top will be big commercial offices with large areas for banks and big companies with all the services of an upscale style .

Justice tower has the largest GF. The building, in total, has a nearly 20000m2 glazed facade 125m in height, spanning 38 floors including ground floors. The building has a GCW system with low-emissivity semi-reflective blue-green colored outside & clear tempered glass inside. The sizes of the glass panels are 80% 90*90m and others are 120*90m; the facade support structure is an aluminium framing system and double glazing was used for the glazing units. The cost of construction per m2 of the glazed facade is approximately 170$ (table 16).

Table 16: Analysis of existing GF justice tower buildings. (Erbil business & trade centre tower).

JUSTICE TOWER					
1-Height of the building and floors	125m, 36 +ground floors				
2 Type of façade system and façade support system	Glass Curtain wall system ,aluminium frame system				
3- Built form configuration: A. Orientation; B. Aspect ratio; C. Arrangement of the building masses					
4 Fenestration (WWR)	South	East	West	North	
	High	Medium	Medium	High	
5 Shading devices	No shading devices used				
6. Glazing properties	Glazing type	Inner	Space	Outer	glass Size & glass m2
	Double glazing - SSBGS	6 mm , tempered clear glass	12 mm	6 mm Low-e reflective blue green color6 mm outside	90*90&120*9 & ~20000 M2
7.Construction cost per m2	$170				



World Trade Centre –Gulan Park: The Park Gulan development consists of three buildings: Shopping Mall, Residential Tower, and an Office Tower (21 floors each). The development's total area is an estimated 182,490 sq. m. The facade area of Gulan office tower is about 10150m2, with a southward orientation, the building uses a glass cladding System reinforced by an aluminium framing system for its façade. The type of glass used in this facade is Low-e colored outside (6mm) & clear tempered glass inside (8 mm) with a space of 19.3mm between them, dimensions measuring 177*134 & 56*134cm with a double glazing system covering a height of 92m over 21 floors Each m2 of the facade costs an approximate $250 (table 17).

Media City :The primary feature of this city is a wide range of commercial office spaces (eight other office high-rises), The media city office towers, each of which has nearly 2500m2 of GCW systems covering almost a 60m height, comprise 11 floors. The façade of first tower faces South, East and West, while the façade of second tower is a mirror of the first tower's, facing North, East and West, and the façades of towers 3 and 4 are a total mirror of that of towers 1 and 2 .The glass facade is supported by an aluminium framing and uses glass lites that are clear tinted 6mm inside & low-e blue-green semi reflective 6 mm outside with a space 15-20 mm between them with the size of 120*120cm &120*240cm. The facade buildings have shading devices, but these are inappropriately placed.For instance, the west-facing façades of the buildings are equipped with horizontal shading devices instead of vertical shading devices for that as well as the eastward side, Estimated cost for per m2 of the glass facade is almost $250 (table18).

Table 17: Analysis of existing GFS of -gulan park (world trade center).

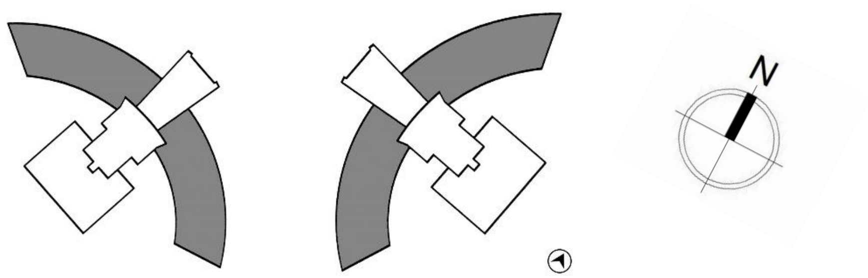
GULAN PARK						
1-Height of the building and floors		92 m ,21floors				
2 Type of façade system and façade support system		Glass Curtain wall system ,aluminum frame system				
3- Built form configuration	A. Orientation					
	B. Aspect ratio					
	C. Arrangement of the building masses					
4 Fenestration (WWR)		South	East	West	North	
		High	Medium	Medium	High	
5 Shading devices		No shading devices used				
6. Glazing properties		Glazing type	Inner	Space	Outer	glass Size
		Double glazing - SSBGS	8mm tempered clear glass	20 mm space	6mm , low-e – tempered reflective green	177*134 and 134*56 & ~10150 M2
7.Construction cost per m2		230 $				

Table 18: Analysis of existing GFS of –Media city .

MEDIA CITY						
1-Height of the building and floors		60 m ,10floors +ground				
2 Type of façade system and façade support system		Glass Curtain wall system ,aluminium frame system				
3- Built form configuration	A. Orientation					
	B. Aspect ratio					
	C. Arrangement of the building masses					
4 Fenestration (WWR)			South	East	West	North
		1	High	High	High	Mostly opaque
		2	Mostly opaque	High	High	High
		3	High	High	High	Mostly opaque
		4	High	High	High	Mostly opaque
5 Shading devices		Shading devices use				
6. Glazing properties		Glazing type	Inner	Space	Outer	glass Size
		Double glazing-SSBGS	6 mm, clear tinted	15-20 space	6 mm, low-e blue green semi reflective	120*240 &120*120 &~2500 M2 each tower
7.Construction cost per m2		250 $				

5.2.2 Computer Simulation Analysis of T1 Building –Empire World

T1 Buıldıng –Empire World: A business tower T1 high-rise office building located at Empire world was selected as the case study high-rise office building because it has more than 25 floors and the building facades are almost fully glazed with a high WWR as shown in table 21. This represents the modern facade design trend of office buildings in Erbil city. Furthermore, the fully glazed facades are suitable for use as a base case building model so that this building model can be duplicated and applied with various simulations.

T1 is 27 floors high and covers a construction area of 24,000m2. T1 is encircled by 4 other towers (T2 – T5). Each of the other towers has a construction area of 21,000m2 and is 23 floors high.

Tower, T1, is split into:

- The basement and ground floors, which are intended to be used in the provision of information and office services.
- The first floor, mezzanine floor, and second floor, all of which have a conference hall, business centre, and meeting rooms.
- 9 floors, each with 4 offices and an average area of 215m2.
- 8 floors, each with 2 offices and an average area of 520m2.
- 6 floors with just 1 office and an average area of 1054 m2.

Construction Materials of T1 Building-Empire World: The high-rise office building that is our present case was reconstructed in the Autodesk Ecotect software using actual building specifications and construction materials. A summary of the specifications for the building model is shown in Table 20. The case study building has almost fully glazed facades facing all 4 orientations. The building envelope comprises an aluminium frame curtain wall system. The curtain wall was constructed using double glazed low-e glass panels. The floor to floor height is 400cm.

In order to precisely find the properties of the glazing area (U value, SHGC, VT and LSG ratio), the WINDOW software was used by inputting the actual materials used for the windows into WINDOW software (see table 21).

Table 19: The actual T1 building glazing properties

Building Name	Glazing type	Inner	Air Space	Outer	glass Size & m2
T1	Double glazing-	6 mm , Low –e tempered clear	12mm space	8 mm, blue green tempered heat soaked	90*90&120*9 0 ~10000 M2

Table 20: The precise glazing properties found by WINDOW 7.5 software.

Glazing area properties	U value (w/m2-k)	SHGC	VT	LSG
T1	1.879	0.401	0.578	1.44

Simulation Findings and Analysis: The T1 has 4 main elevations and the main elevation entrance facing (NE) N 23º (figure 55).Figure 55 shows the position of the sun during the summer and winter months, the colour red colour outlines the sun's path during winter while the colour blue shows the sun's path in the summer months.

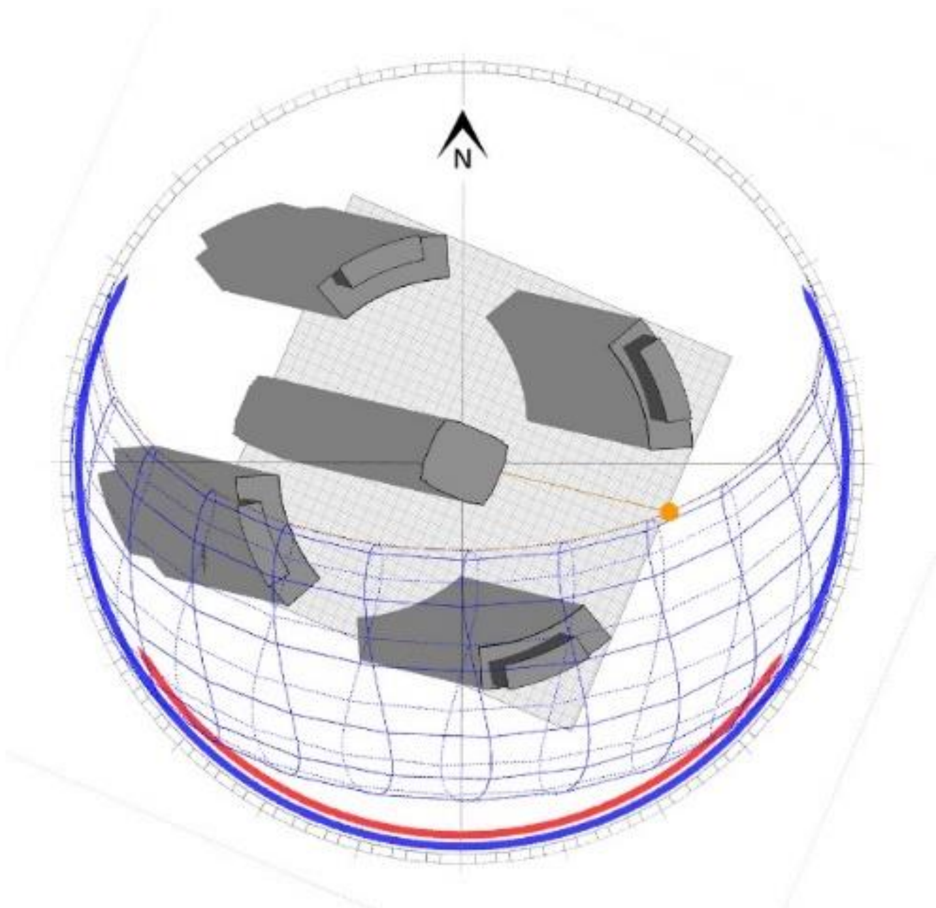


Figure 55: sun path during winter and summer months (autodesk ecotect 2011 based on erbil wetaher file).

In Table 21 shows solar radiation on the site and reveals that buildings T2-T5 and their surroundings receive the greatest amounts of solar radiation. The T1 building surroundings get a minimal amount of solar radiation from the close spacing of individual buildings; this provides shading for this area.

In table 21 shows solar radiation for the southern and eastern exposures, indicating that these exposures receive a high ratio of solar radiation with orange to red colour. However, it can be clearly seen in table 21 that the north exposure gets a minimum amount of solar radiation with blue colour.

The solar gain breakdown chart for the building envelope, as seen in table 22, floor 5 as an example shows from where heat gains and losses originate:

- Material conductivity is responsible for approximately 62.9 of the building's thermal loss during the winter season as a result of insufficient insulation, and is responsible for just 25.4 % of heat gain in the summer.
- Sol-air (brown color) is responsible for 8% of the heat gain due to the monocular heating of the building material.
- 29.8% of heat gain over the course the year is caused by direct solar radiation (yellow color) due to the absence of exterior shading and the transparency of the windows.
- Approximately 22% of the heat gain results from the internal spaces (blue color) while a minor amount of both heat gain and heat loss is accounted for by the inter-zonal indicator i.e. the distribution across different spaces. See table 23, 24 for above floor gains and losses.

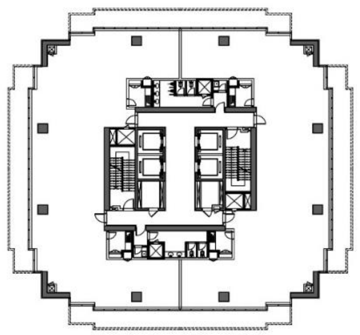
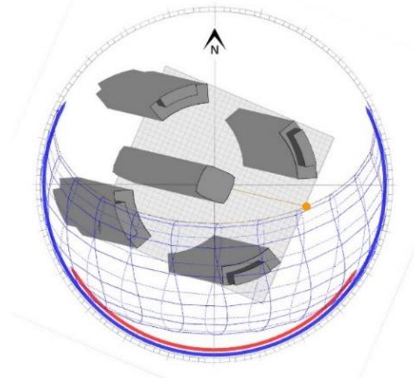
In terms of Energy consumption and the annual heating and cooling loads of Floor 5 (see table 22), it is readily observed that cooling loads require a greater amount of energy (33594Kwh) while the heating load has a less ratio (9750 Kwh); the total amount of heating and cooling loads on Floor 5, calculated with surrounding buildings equals 43344 Kwh, which changes to 43922Kwh when calculating the Floor 5 without surrounding buildings (Table 22).

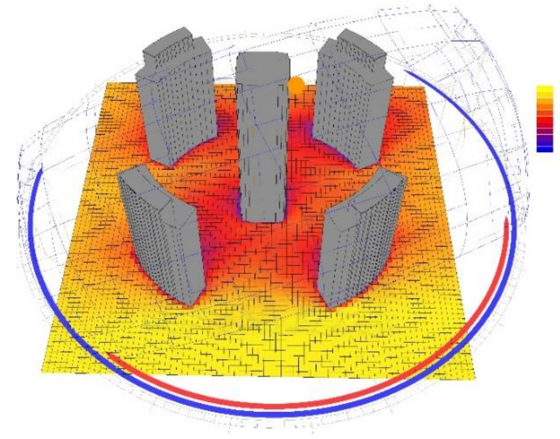
On Floor 13, the simulation results show that annually, energy consumption is about 40487 Kwh without surrounding buildings and when the same building floor is simulated with surrounding buildings, the energy consumption ratio decreases a little to 40018 Kwh because the surrounding buildings shade the T1 building. The simulation result of Floor 20 shows a high ratio of energy consumption as compared to lower floors due to lack of shade on these floors; annually, energy consumption is 54305Kwh (table 23,24).

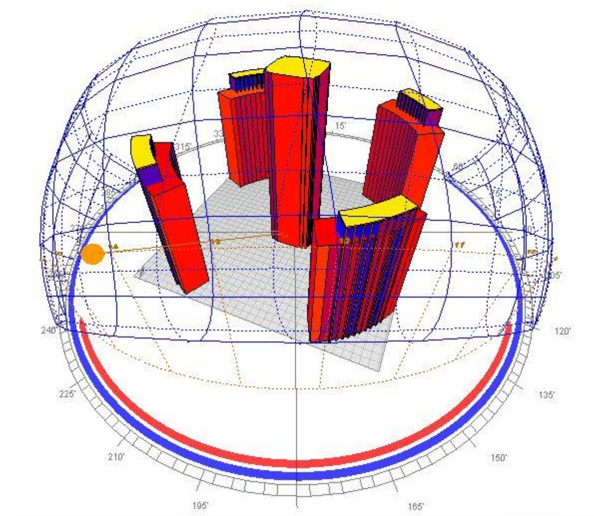
From a thermal comfort point of view, all floors have nearly the same range of thermal comfort. For instance, the simulation for Floor 5, on the 21st of December at 12 pm has a min. indoor average temp of 12.9ºC, and on the 21st of June at 12 pm, has the highest average indoor temp at 37.95ºC. On the 21st of March at 12 pm, it has a temperature of 16.43ºC and on the 21st of Sept. at 12 pm, has an average indoor temp. Of 30.38ºC.

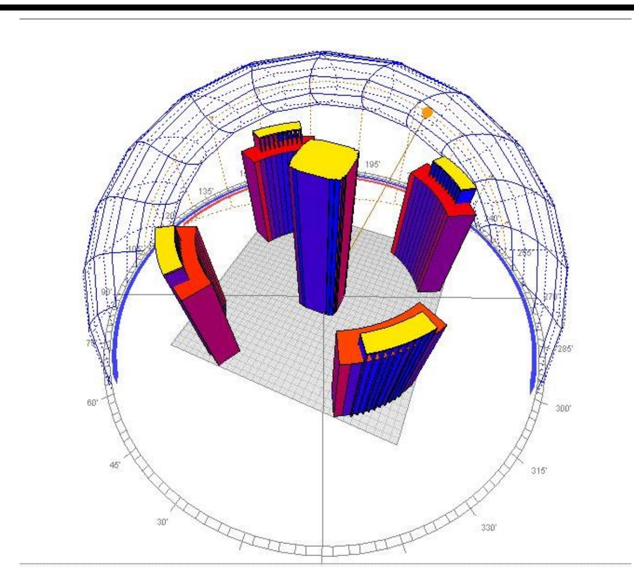
The analysis of daylighting has been conducted based on the sun's path during the year and the transmittance and sizes of the windows in all orientations. The results show that on Floor 5, the daylight illuminance is between 500-1000 (near the glazing area) in the interior spaces, the yellow colour range shows a high level above that required, and causes the overheating of the interior spaces. The daylighting analysis of Floor 13 shows the high illuminance ratio, which lies between 600 to more than 1000 lux in indoor spaces and the simulation analysis of Floor 20 shows a higher illuminance ratio in interior spaces (700 to +1000 lux) none of the surrounding buildings affect the lighting of this floor due to its height, and the fact that the interior spaces on this floor get higher daylight illuminance.

Table 21:simulation analaysis of T1 building –Empire world

<table>
<tr><th colspan="7">Empire business towers T1</th></tr>
<tr><td>1-Height of the building and floors</td><td colspan="6">129 m2 , 27 Floors
400 cm distance between floors</td></tr>
<tr><td>2-Type of façade system and façade support system</td><td colspan="6">Glass Curtain wall system ,aluminium frame system</td></tr>
<tr><td rowspan="2">3- Built form configuration</td><td>Floor plate design Aspect ratio</td><td colspan="3">Arrangement of the building masses</td><td colspan="2">Orientation</td></tr>
<tr><td>Square 1:1</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td rowspan="2">4-Fenestration (WWR)</td><td>Orientation</td><td>South</td><td>East</td><td colspan="2">West</td><td>North</td></tr>
<tr><td>WWR</td><td>0.8</td><td>0.8</td><td colspan="2">0.8</td><td>0.8</td></tr>
<tr><td>5- Shading devices</td><td colspan="6">No shading devices used</td></tr>
<tr><td rowspan="2">6 Glass property</td><td colspan="2">U value (W/M2.K)</td><td colspan="2">SHGC</td><td>VT</td><td>LSG</td></tr>
<tr><td colspan="2">1.879</td><td colspan="2">0.401</td><td>0.578</td><td>1.44</td></tr>
<tr><td rowspan="2">7. Glazing properties</td><td>Building Name</td><td>Glazing type</td><td>Inner</td><td>Space</td><td>Outer</td><td>glass Size & m2</td></tr>
<tr><td>T1</td><td>Double glazing</td><td>6 mm , Low –e tempered clear</td><td>12mm space</td><td>8 mm, blue green tempered heat soaked</td><td>90*90&120*90 ~10000 M2</td></tr>
</table>







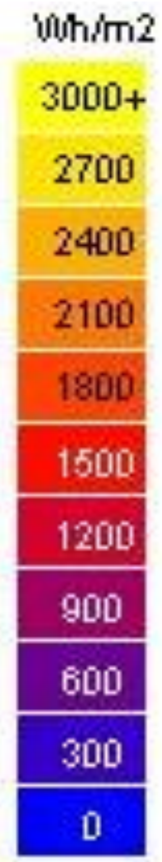
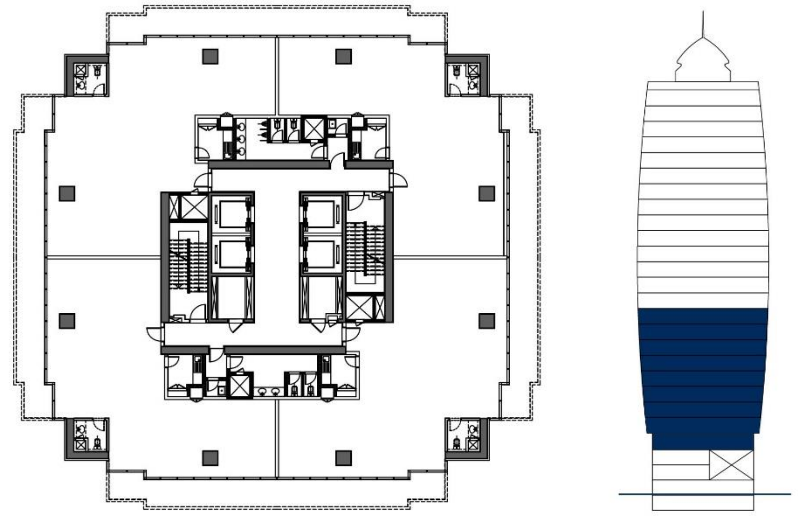
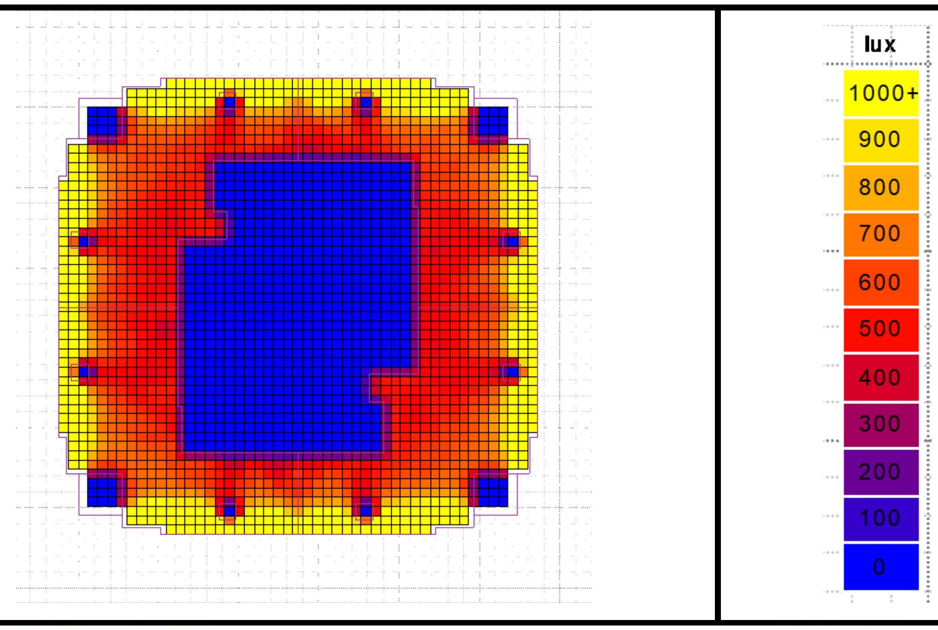


Table 22: simulation analaysis of T1 building –Empire world

Empire business tower T1 plan 5-11									
Energy consumption	Situation	Heating (Kwh)		Cooling (Kwh)		Total (Kwh)			
	With surrounding buildings	9750.258		33594.246		43344.504			
	Without surrounding buildings	9311.225		34611.141		43922.363			
Daylight	With surrounding buildings	Far from glazing area		Near glazing area					
		~ 500 lux		+1000 lux					
Thermal comfort	With surrounding buildings	21 Dec		21 march		21 June		21 Sep	
		Indoor (C)	Outdoor (C)	Indoor (C)	Outdoor (C)	Indoor (C)	Outdoor (C)	Indoor (C)	Outdo or (C)
		12.9	8.9	16.43	15.5	37.95	39.7	30.38	33.5
Yearly gains breakdown		material conductivity	Direct solar radiation	Ventilation	Solar air	Internal	Internal zonal		
	Gains (summer)	25.4%	29.8%	16.3%	8.0%	20.5%	0.0%		
	losses (winter)	62.9%	0.0%	37.1%	0.0%	0.0%	0.0%		





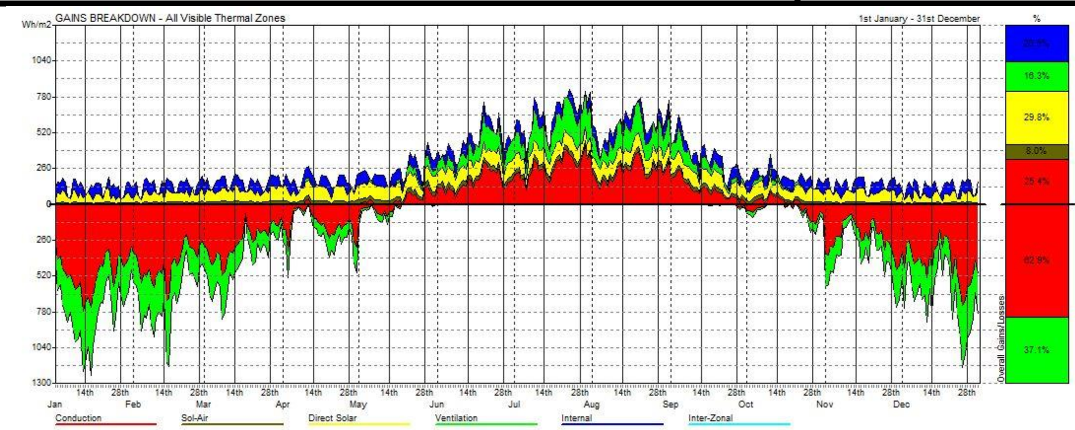
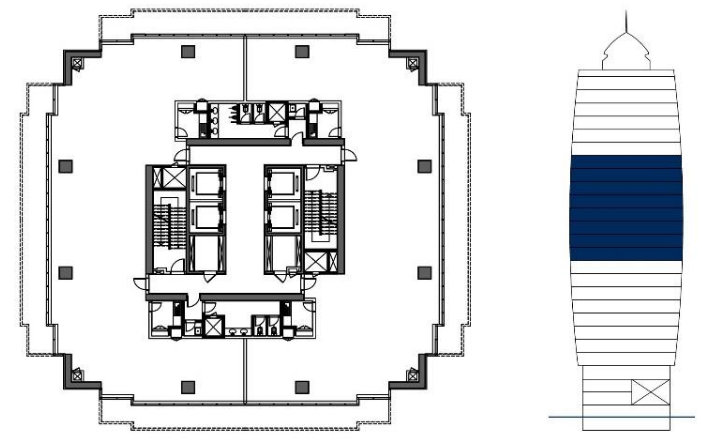


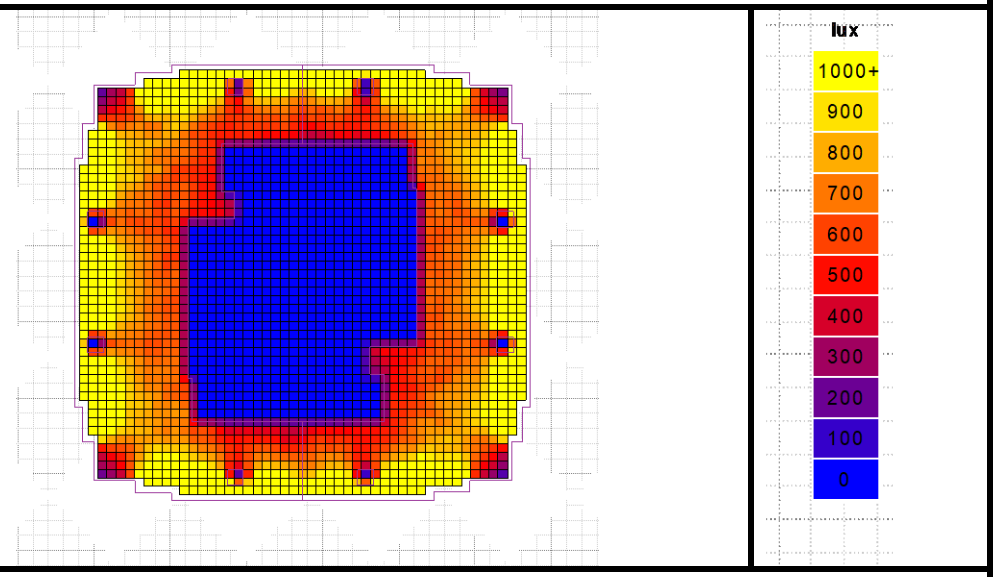
Table 23: simulation anaalysis of T1 building –Empire world

Empire business tower T1 plan 12-19



		Heating (Kwh)	Cooling (Kwh)	Total (Kwh)
Energy consumption	With surrounding buildings	3844.799	36173.617	40018.414
	Without surrounding buildings	3731.077	36756.719	40487.797

		Far from glazing area	Near glazing area
Daylight	With surrounding buildings	~ 600 lux	+1000 lux



		21 Dec. (12 Pm)		21 March (12 Pm)		21 June (12 Pm)		21 Sep. (12 Pm)	
		Indoor (C)	Outdoor (C)	Indoor (C)	Outdoor (C)	Indoor (C)	Outdoor (C)	Indoor (C)	Outdoor (C)
Thermal comfort	With surrounding buildings	12.37	8.9	16.2	15.5	38.04	39.7	30.65	33.5

Yearly gains breakdown	Summer	material conductivity	Direct solar radiation	Ventilation	Solar air	Internal	Internal zonal
	Gains (Summer)	24.3%	32.20%	15.6%	8.2%	20.5%	0.0%
	losses (Winter)	62.8%	0.0%	37.20%	0.0%	0.0%	0.0%

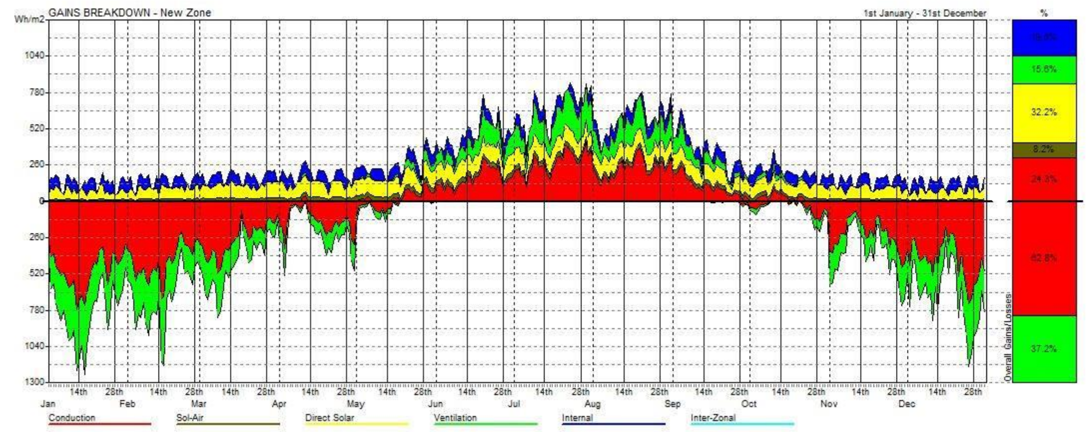
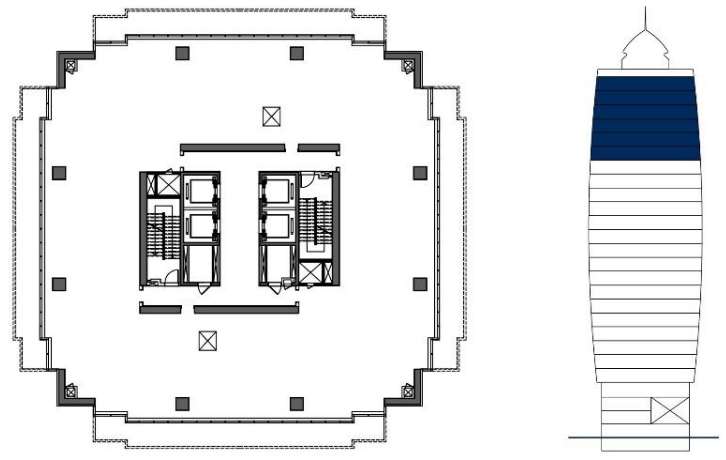


Table 24: simulation analaysis of T1 building –Empire world

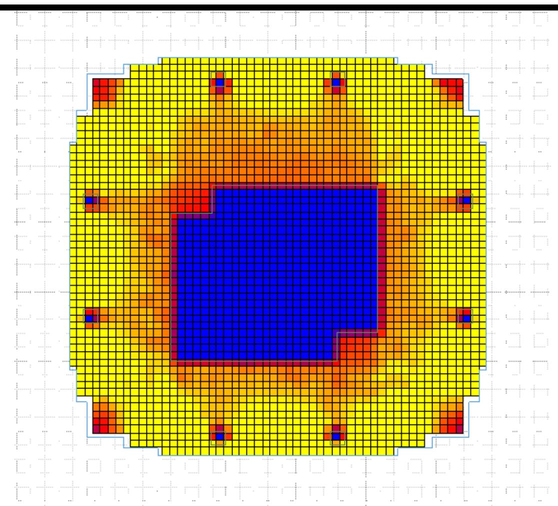
Empire business tower T1 plan 20-26

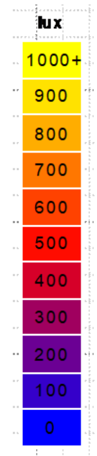
Energy consumption	Cases	Heating (Kwh)	Cooling (Kwh)	Total (Kwh)
	With surroundings	12167.056	42138.809	54305.863
	Without surroundings	12167.056	42138.809	54305.863



Daylight illuminance (lux)		Far from glazing area	Near glazing area
	With surrounding buildings	~ 700 lux	+1000 lux

Thermal comfort		21 Dec. (12 Pm)		21 March (12 Pm)		21 June (12 Pm)		21 Sep. (12 Pm)	
		Indoor (C)	Outdoor (C)	Indoor (C)	Outdoor (C)	Indoor (C)	Outdoor(C)	Indoor (C)	Outdoor (C)
	With surrounding buildings	13.7	8.9	17	15.5	38.64	39.7	31.7	33.5





Yearly gains breakdown		material conductivity	Direct solar radiation	Ventilation	Solar air	Internal	Internal zonal
	Summer	17.40%	19.70%	13.40%	2.30%	29.40%	17.80%
	Winter	46.50%	0.00%	33.30%	0.00%	0.00%	20.20%

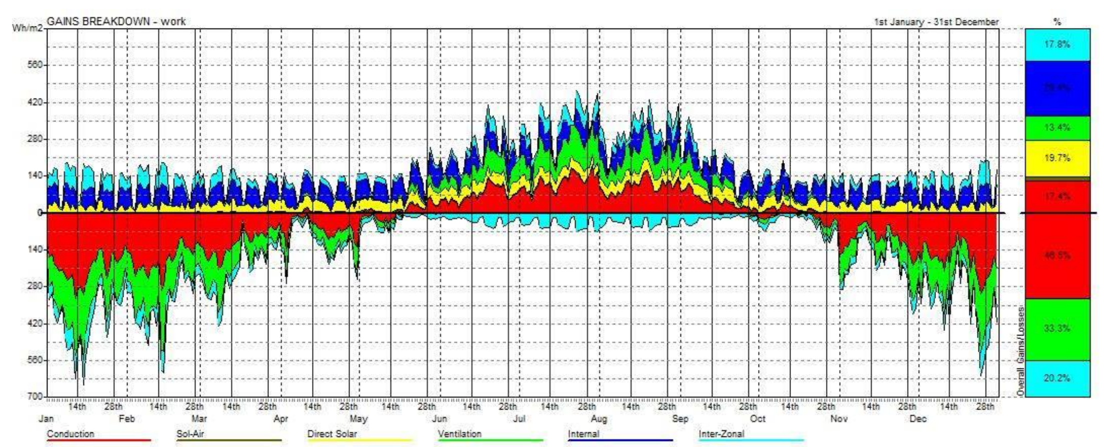


Table 25: Evaluation of observed facts of existing high-rise office buildings in Erbil city

<table>
<tr><th colspan="2">Main design strategies for achieving energy efficient glazed façade</th><th colspan="3">T1 Building -Empire World</th><th>Author Evaluation according to recommended strategies in Erbil city</th></tr>
<tr><td colspan="2">Orientation (main)</td><td colspan="3">N 23 –North East</td><td>▪ The buildings should oriented to east-west axis (182.5)</td></tr>
<tr><td colspan="2">aspect ratio (shape)</td><td colspan="3">1:1 Square in shape</td><td>▪ The aspect ratio should be more than 1:2 (rectangular in shape), with considering wind velocity in Erbil city.</td></tr>
<tr><td colspan="2">Placing Service cores in building</td><td colspan="3">Centre of the building</td><td>▪ Service cores should place in east and west exposures</td></tr>
<tr><td colspan="2">Fenestration , WWR</td><td colspan="3">0.8 including aluminium frames</td><td>▪ WWR should not more than % 40, high WWR is acceptable if well shaded.</td></tr>
<tr><td rowspan="6">Material property</td><td rowspan="2">Glazing type and properties</td><td>Inner</td><td>Space</td><td>outer</td><td rowspan="2">▪ Using double glazing Low E argon filled as min requirement</td></tr>
<tr><td>6 mm , Low –e tempered clear</td><td>12mm space-air</td><td>8 mm, blue green tempered heat soaked</td></tr>
<tr><td>U value (W/M2.K)</td><td colspan="3">1.879</td><td>▪ Use U value 0.7 as a MIN. requirement</td></tr>
<tr><td>SHGC</td><td colspan="3">0.401</td><td>▪ Use SHGC 0.25 as a max requirement for all directions except north orientation
▪ SHGC of 0.55 is acceptable with horizontal shading device VSA 50 in all directions except North.</td></tr>
<tr><td>VT</td><td colspan="3">0.578</td><td>▪ Lower VT is acceptable in office buildings</td></tr>
<tr><td>LSG</td><td colspan="3">1.44</td><td>▪ Using LSG ratio of 1.25 as minimum requirement the higher ratio is better</td></tr>
<tr><td colspan="2">Shading device</td><td colspan="3">No shading devices used</td><td>▪ Use horizontal overhang for south façade with VSA 50
▪ Use horizontal overhang with VSA 50 and vertical fins with HSA 15 on east and west sides
▪ Use the vertical fins with HSA 60in on North orientation</td></tr>
<tr><td colspan="2">Climatic based design approach , Surrounding building consideration</td><td colspan="3">NO</td><td>▪ Erbil climate need the strategies to protect the interior building from the sun in summer while allow Entering sun during winter</td></tr>
<tr><td colspan="2">Using Computer simulations during design stages</td><td colspan="3">NO</td><td>▪ Various simulations (Energy ,daylight and glare, thermal comfort , etc.) should be used in different design stages
▪ Outside obstacles (buildings) should consider in order to shade the building during shade needed times (summer).</td></tr>
<tr><td colspan="2">Daylight illuminance</td><td colspan="3">500 –more than 1000 lux</td><td>▪ Office space illuminance should have a ratio between 300-500 lux</td></tr>
</table>

5.3 Optimization Results and Discussion

Following an exploration of the factors that could be detrimental to building energy performance, and on the basis of optimizing passive design as explicated in the literature for hot climates (Zone 2) and designed strategies for achieving energy efficiency in high-rise office buildings glazed façade in Erbil city, the principal recommendations for optimization are summarized thus:

Existing Building: The first simulation of the existing building (T1 building) in empire world was modeled in order to contribute to a better facade design for the T1 building in Erbil city. As discussed earlier, the building is covered using GCW system employing low-e clear tempered glass in its inner side and blue-green heat soaked tempered on its outer side, with a 12 mm air space between them. It has double glazing system. The building is oriented 23ºN and it has an aspect ratio nearly 1:1, with a high glazed ratio.

Scenario 1: The second simulation used the current building in its present WWR and aspect ratio and changed the building orientation from 23ºN to 182.5ºN. Furthermore, some improvements were made in regards to the glass' U Value, SHGC by using double glazed clear low-e glass with argon filled gas as observed in the literature as a minimum glass property requirement in hot climates, and by the addition of shading devices as well. By adding these glass properties into the WINDOW software, the U Value, SHGC and VT were explicated (table 26).

Scenario2: The third simulation used the current building in its present WWR and aspect ratio, oriented 182.5ºN. Double glazed low-e green glass with argon filled gas was used without shading devices and a lower SHGC. By adding these glass properties into the WINDOW software, the U Value, SHGC and VT were found and are outlined in table 26, it can be clearly seen that the SHGC of Low-e green glass is less than low-e clear glass; it changed from 0.401 to 0.244.

Scenario 3: The fourth simulation used the current building with its respective aspect ratio and the building oriented 182.5ºN. The building's WWR was decreased to 40% and double glazed low-e green glass with argon filled gas was used with shading devices and the same U value & SHGC. By adding these glass properties into the WINDOW software, the U Value, SHGC and VT were established (table 26).

Scenario 4: The fifth simulation is the current building with its aspect ratio and the building oriented 182.5ºN. The building's WWR was decreased to 40% and double glazed low-e green glass with krypton filled gas was used without shading devices and the SHGC. By adding these glass properties into the WINDOW software, the U Value, SHGC and VT were found and are shown in table 26. It is evident that by changing the argon gas to krypton gas, the U value changes from 1.015 to 0.747 and thus, meets the ASHRAE min requirement for (Zone 2) hot climates.

Scenario 5: The sixth simulation is the current building with its aspect ratio and the building oriented 182.5ºN, the building's WWR was decreased to 40% and triple glazed low-e clear glass and an outer lite with low-e green glass with krypton filled gas were used without shading devices. By adding these glass properties into the WINDOW software, the U Value, SHGC and VT were found and are shown in table 26. It can be clearly seen that by changing the glass type from double glazed to triple glazed, the U value changes from 0.747 to 0.598 and the SHGC from 0.244 to 0.19.

Table 26: Existing building and 5 scenario properties, Energy consumption and daylight analysis

	Orientation	Aspect ratio	Shading device	Glazing system &property	Material property				WWR ratio	Heating (Kwh)	Cooling (Kwh)	Total (Kwh)	Daylight (lux) Inside to outside
					U value	SHGC	VT	LSG					
Existing building	**N 23**	**1:1**	**No**	**Double glazing low E**	**1.879**	**0.41**	**0.578**	**1.4**	**%100**	**7951.648**	**36542.730**	**44494.379**	**~500-1000**
Scenario 1	**S (182.5)**	**1:1**	**Yes**	**Double glazing low E on clear - argon filled**	**1.105**	**0.36**	**0.39**	**1.08**	**% 100**	**36913.680**	**36913.680**	**36913.680**	**~ 400-800**
Scenario 2	**S (182.5)**	**1:1**	**No**	**Double glazing low E on green- argon filled**	**1.105**	**0.244**	**0.38**	**1.47**	**%100**	**9091.441**	**28142.797**	**37234.234**	**~500-1200**
Scenario 3	**S (182.5)**	**1:1**	**yes**	**Double glazing low E on clear - argon filled**	**1.105**	**0.36**	**0.39**	**1.08**	**% 40**	**8404.148**	**25977.707**	**34381.855**	**~150-300**
Scenario 4	**S (182.5)**	**1:1**	**No**	**Double glazing low E on green- krypton filled**	**0.747**	**0.244**	**0.38**	**1.47**	**% 40**	**8100.767**	**25505.682**	**33606.449**	**~250-450**
Scenario 5	**S (182.5)**	**1:1**	**No**	**Triple glazing low E on green- krypton filled**	**0.598**	**0.194**	**0.38**	**1.23**	**% 40**	**8025.627**	**25185.842**	**33211.469**	**~250-450**

Table 27: Thermal comfort analysis of existing building (T1 building, Empire world) and 5 recommended scenarios

Situation	Thermal comfort measurement	21 Dec (12 PM)			21 march (12 PM)			21 June (12 PM)			21 Sep (12 PM)		
		Outdoor Temp.	Near window	Indoor	Outdoor Temp.	Near window	Indoor	Outdoor Temp.	Near window	Indoor	Outdoor Temp.	Near window	Indoor
Existing Building	**TEMP. C**	**8.9**	**14.02**	**13.62**	**15.5**	**17.32**	**16.92**	**39.7**	**38.71**	**38.43**	**33.5**	**31.85**	**31**
	PMV	--	-3.43	-3.47	--	-2.39	-2.42	--	4.76	4.73	--	2.18	2.1
Scenario 1	**TEMP. C**	**8.9**	**12.38**	**11.83**	**15.5**	**15.66**	**15.55**	**39.7**	**37.56**	**37.41**	**33.5**	**29.81**	**29.31**
	PMV	--	-3.91	-3.96	--	-2.83	-2.84	--	4.42	4.41	--	1.67	1.62
Scenario 2	**TEMP. C**	**8.9**	**11.94**	**11.74**	**15.5**	**15.72**	**15.65**	**39.7**	**37.56**	**37.5**	**33.5**	**29.63**	**29.47**
	PMV	--	-3.96	-3.89	--	-2.81	-2.81	--	4.45	4.44	--	1.67	1.65
Scenario 3	**TEMP. C**	**8.9**	**12.88**	**12.9**	**15.5**	**16.58**	**16.57**	**39.7**	**38.87**	**38.87**	**33.5**	**30.74**	**30.72**
	PMV	--	-3.62	-3.62	--	-2.53	-2.53	--	4.93	4.93	--	2.07	2.07
Scenario 4	**TEMP. C**	**8.9**	**12.05**	**12.05**	**15.5**	**15.73**	**15.73**	**39.7**	**37.59**	**37.61**	**33.5**	**29.48**	**29.49**
	PMV	--	-3.94	-394	--	-2.78	-2.78	--	4.49	4.49	--	1.67	1.67
Scenario 5	**TEMP. C**	**8.9**	**13.05**	**13.1**	**15.5**	**16.67**	**16.67**	**39.7**	**39**	**39**	**33.5**	**30.81**	**30.83**
	PMV	--	**-3.68**	-369	--	-2.49	-2.49	--	4.98	4.98	--	2.11	2.11

By comparing the existing building with the 5 recommended scenarios, it is evident that the building's energy consumption, thermal comfort, and daylight parameters could all be improved.

In the first scenario, it can be clearly seen that after adding shading devices to the existing building and optimizing its glazing properties (U value, SHGC, VT), the Energy consumption annually decreased from 44494 Kwh to 36913 Kwh and almost 17% energy can be conserved (figure 56 and table 26).

In terms of thermal comfort, the selected dates and times were the 21st of March, June September, and December at 12:00 pm. An aggregate look at the simulations reveals that the optimization of the glazing properties decreased the inside temperature from 8.43ºC to 37.43ºC on the 21st of June, 12 pm and it has its maximum indoor temperature at this time. It also reduces the temperature from 31ºC to 29.3ºC at 12 pm on the 21st of September while it decreases the temperature on both Dec. 21st and March 21st at 12 pm with a minimum temperature of 11.83ºC on the former date.
The predicted mean vote (PMV) results showed an improvement in thermal comfort in June and September, while it showed almost the same temperatures in March but decreased in Dec. (Table 27).

Daylight analysis showed that by applying these properties, the daylight luminance could be decreased from 500-1000 lux to 400-800 lux, but this daylight luminance is still high because it caused glare in the interior spaces, especially in office buildings, which require the luminance ratio 300-500lux (table 26).
In the second scenario simulation, the SHGC decreased from 0.39 to 0.244 and the shading devices were removed. It is evident that the annual energy consumption

decreased from 44494 Kwh annually to 37234 Kwh; so, about 16% energy can be saved (Table 26 figure 56).

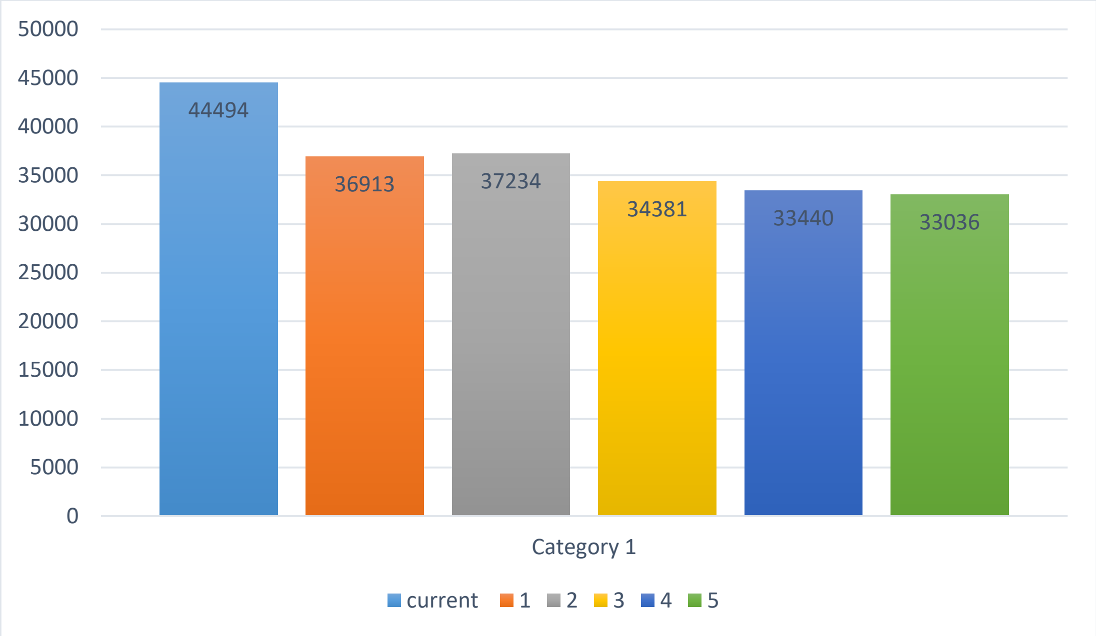


Figure 56: energy consumption of 5 scenarios

An overall look at the simulation of Scenario 2 reveals that (table 27) after decreasing the SHGC and removing shading devices, Scenario 2 has nearly the same inside temperature as Scenario 1. The 21st of June at 12 pm had the maximum inside temperature at 37.5ºC, while the 21st of Dec at 12 pm had the minimum inside temperature of 11.74ºC, both of which fall outside the comfort range, and on the 21st of March and 21st of Sept., they have temperature ranges near the comfort level. On March 21st, 12 pm, the inside temperature is 15.65ºC and on September 21st, 12 pm the indoor temperature is 29.47ºC. On the other hand, the PMV results showed the same truth.

The Scenario 2 daylight analysis showed that by decreasing the SHGC from 0.36 to 0.244 and removing shading devices, the daylight luminance could be increased from

400-800lux to 500-1000lux but this daylight luminance is very high due to the removed shading devices and a high WWR, thus causing glare in interior spaces, particularly in office buildings, which require a luminance ratio between 300-500lux. (Table 26).

In the third scenario, after decreasing the WWR ratio to 40% and adding shading devices, and the glazing has the same property of the scenario one (see table27) and the minimum required U value estimated for opaque walls according to the ASHRAE standard, it is obvious from the tables that the annual energy consumption could be decreased from 44494 Kwh to 34381 Kwh; almost 23% energy could be conserved.

In terms of thermal comfort, the third scenario has poor thermal comfort as compared to Scenarios 1 and 2. The 21st of June, 12 pm had the max. Inside temperature of 38.87ºC, which was nearest to the outdoor temperature. The 21st of Dec, 12 pm had the minimum inside temperature a 12.9ºC; both of them are out of comfort range. The 21st of March and 21st of September have temperatures within the range of the comfort level. On March 21st, 12 pm the inside temperature is 16.58ºC and on September 21st, 12 pm, the indoor temperature is 30.72ºC. PMV results also revealed similar (table 27).

The Scenario 3 daylight analysis showed that after decreasing the WWR ratio to 40% and adding shading devices with a glazing ratio having the same properties as the scenario, the daylight luminance could be decreased from 500-1000lux to 150-300lux, but this daylight luminance is low compared to the office building daylight illuminance. Requirement (300-500lux) (Table 26). In this case Unified glare ratio (UGR) is more than 19 which is maximum permissible.

In the fourth scenario, after removing shading devices and optimizing the glazing's U value by changing the argon gas to krypton gas and decreasing the SHGC from 0.36 to 0.244 by changing the outer glass lite from clear low-e glass to green low-e glass (table 26) and using the minimum required U value estimated for opaque walls according to the ASHRAE standard, it is apparent that the annual energy consumption could be decreased from 44494 Kwh to 33606 Kwh and almost 24.5% energy could be conserved.

In the thermal comfort perspective, the fourth scenario has a better thermal comfort as compared to Scenario 3. On the 21^{st} June, 12 pm it had the max inside temperature of 37.61ºC, on the 21^{st} Dec, 12 pm it had the min inside temperature of 12.05ºC, both outside the range of comfort. The 21^{st} March and 21^{st} Sep, have temperature ranges near the comfort level; on March 21^{st}, 12 pm the inside temperature is 15.73ºC, while on the 21^{st} of September, 12pm, the indoor temperature is 30.72ºC and the PMV results draw the same conclusion(table 27).

The scenario 4 daylight analysis showed that after removing shading devices and decreasing the U value and SHGC, the daylight illuminance could be improved from 150-300 lux to 250-450 lux and is within the acceptable range according to office building daylight illuminance requirements 300-500lux (Table 26).in this case the unified glare ratio (UGR) is about 19 and less and its acceptable ratio.

In the last scenario (5), the glazing system changed from double low-e to triple low-e and the glazing properties' U value and SHGC were decreased. It was revealed that this caused only a mere 1.17% reduction in energy consumption as compared to

Scenario 4 and annual energy consumption was reduced by 25.3% as compared with the existing building (44494 Kwh to 33211 Kwh) (figure 56 ,table 26).

From a thermal comfort point of view, Scenario 5 has the worst thermal comfort. On the 21st of June, 12 pm, it had the maximum inside temperature of 39ºC, which is similar to the outdoor temperature. On the 21st of Dec, 12 pm, it had the minimum inside temperature of 13.1ºC, both if which are out of the comfort range. On 21st March and 21st Sep, temperatures range nearer to the comfort level. In March at 12pm, the inside temperature is 16.67ºC and in September at 12 pm, the indoor temperature is 30.83ºC. The PMV results show the same facts (table 27).

The Scenario 5 daylight analysis illustrates that after changing the glazing system from double glazing low-e to triple low-e, the U value and SHGC ratio are automatically decreased, the daylight illuminance had the same ratio of 250-450 lux and is within the acceptable range according to office building daylight illuminance requirements (300-500lux) (Table 26).

From the simulated scenarios, it is evident that Scenario 4 is the best option in terms of energy conservation, thermal comfort and daylight analysis.

5.3.1 Life Cycle Cost Assessment Outcomes

In order to perform Life Cycle Cost Assessment, all obtained data including initial costs, operation and electricity saving have been calculated. Carried out results follow:

Net Present Value (NPV)

Net Present Value (NPV) is the most important result that can be carried out by assessment of life cycle cost. NPV is one of the best method that is helpful to determine the profitability of an investment. NPV represents the discounted amount of costs minus discounted amount of profits that are discounted by a specific rate of return to present value. Overall, positive NPV indicates that the rate of return on investment is higher than expected rate of return. Projects with higher NPV would be desirable (Mahdi, 2015).

According to the results, by implementing the design strategies in scenario 5 electricity supply systems accounts $ 383552 during 25 years. It simply means that, an owner by installation such a design strategies in a period of 25 years can take $ 383552 more benefit than depositing money on the bank accordance to current interest rate which is offered by banks. And by changing the aspect ratio from 1:1 (square) to 1:2 can take $ 129839 in a period of 25 years. Thus, implementation the previous design strategies as (orienting building to 182.5 degree south façade, decreasing glazing ratio to %40, using double low-E on green glass filling with inert gas and using aspect ratio 1:2) are feasible to use in high rise office buildings in Erbil city. Despite the fact that using shading devices annually can conserve great amount of energy, but according to LCCA results using shading devices economically is not feasible in high rise office buildings in Erbil city since the initial cost of aluminium shading panels is very high in Erbil city (APPX 1, 2.)

Chapter 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

In this study numerous design strategies have been prepared and categorized for achieving energy efficiency in glazed facades for high rise office buildings in Erbil city as the main aim, and in second step a number of high rise office building glazed facades have been evaluated within the context of energy efficiency, and finally the existing glazed facades in high rise buildings have been optimized by implementing various recommended strategies.

In order to accomplish the aim of the study, the following questions have been answered in this research:

- What are the characteristics of energy efficient glazed facade system?
- What are the conditions of Erbil city?
- What types of GF systems are already used for high-rise office buildings in Erbil city?

In order to fill the gap concerning the energy efficiency in glazed facades for high rise office buildings in the case of Erbil city, the above questions were asked and answered.

In first step by studding the literature in this area, and computer simulation, for achieving energy efficiency for high rise office building glazed facades in Erbil city, the analysis revealed the following specific design strategies in (energy conservation, thermal comfort, visual comfort) perspective:

Climatic Based Design Approach

In this case, in order to extend as much as possible the comfort period reducing the use of mechanical means, the following strategies are suggested by the analysis:

- Designers need to consider and study the external environment, building orientation, space dimensions, location of external obstacles and occupants ‘comfort expectations.
- Daylight: use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves.

For the summer period:

- Solar control: protection of the facade from direct solar radiation through self-shading methods (building form) or shading devices.
- Supplemental mechanical cooling for extreme peaks.

For the winter period:

- Passive solar heat gain by allowing solar into the interior spaces.
- Supplemental artificial heating for extreme peaks.

Orientation, Aspect Ratio and Arranging Building Masses

- The classic passive design approach to orienting a building on its site is to locate the long side on East–West axis (pointing to an AZM angle of 182.5◦) to minimize solar loads on the east and west surfaces.
- Increasing the aspect ratio, with the building becoming longer and narrower. (Rectangular rather than square), with considering wind velocity of Erbil city.

- Minimizing East and West exposures and maximizing the south and north exposures.
- Developing the building mass to respond solar radiation in specific site.
- Placing service cores on East and West facades.

Fenestration

- The total vertical fenestration area (WWR) shall be less than 40% of the gross wall area.
- Higher WWR facade are acceptable only if well shaded.
- Glazing units can be insulated using two, three, or more layers of glass.
- The spaces between the glass layers should be filled with inert gases or aerogel insulation.
- Ceramic frit coatings, or Low-e, reflective can be used to the glass to protect interiors from solar heat gain.
- Using tinted with a color glass. Laminated glass Interlayer films can provide shading as well.

Material properties

- Using Lower solar heat gain coefficient (SHGC) of glass, not exceeding 25% (0.25), and SHGC of 0.55 is acceptable with VSA 50 of horizontal shading devices.
- Visual transmittance (VT) should be consider.
- Using light-to-solar-gain (LSG) ratio (VT/ SHGC) of 1.25 or more for all directions for all directions except North directions.
- Using inert gases, like argon or krypton in spaces between the glass lites.

- U value of assembly glazed area should not be exceed 0.113 Btu/h-ft2-°F (0.7 W/m2-°K).
- Selecting double-glazed, low-E, argon-filled glazing as a minimum.
- Using structural glazing that puts a layer of silicone between the outside glass and the metal framing. Or using thermally broken aluminum frames.

Fixed Shading devices

- Using horizontal overhang with the VSA angle of 50 on south facades.
- Using vertical fins with HSA 60 on north orientations.
- Using horizontal overhang with the VSA angle of 50 and vertical fins with the Has 15 on east facades.
- Using horizontal overhang with the VSA angle of 50 and vertical fins with the Has 15 on west facades.

In second step the existing glazed facades in high rise office buildings were evaluated within the context of energy efficiency by comparing the existing buildings with the recommended energy efficient design strategies; it was evident that the current glazed façade systems in high-rise office buildings are not energy efficient and they need optimization. Implementing the recommended energy efficient design strategies in the case of existing glazed facades has a great impact on energy conservation and positively affects the (thermal, visual) comfort of interior spaces.

Eventually, it was evident according to the results of LCCA that, implementation the design strategies of scenario 4 as (orienting building to 182.5 degree south façade, decreasing glazing ratio to %40, using double low-E on green glass filling with inert gas) and using aspect ratio 1:2 are feasible to use in high rise office buildings in Erbil city, And By installation such a design strategies in a period of 25 years can take $ 513391 **$** benefit. However, according to results of LCCA, using shading devices economically is not feasible in high rise office buildings in Erbil city since the initial cost of aluminium shading panels is very high in the region.

6.2 Recommendations for Further Research

1) Evaluation of double skin glass façade system appropriateness with naturally and mechanically ventilation in Erbil city.

2) Evaluating the effectiveness of movable shading devices, self-shading and finding the required angle for both of them.

3) Life cycle cost analysis for emerging material and technologies such us (using PV panel as a shading device, PV between lite of glasses, etc.).

4) Energy efficient facades design strategies in high rise (commercial and residential) buildings in Erbil city.

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APPENDICES

Appendix A: Life Cycle Cost Analysis

Inputs

Life cycle cost	25 years	25 years considered as life cycle of the building.
Interest rate	10 %	World bank group
Current Electricity price	$ 0.104	Ministry of electricity ,KRG
Average Electricity price during 25 years	$ 0.125	It is predicted that the electricity price might increase 2% each year

1) Life cycle cost analysis for model building aspect ratio 1:1and 1:2

By changing aspect ratio of the building from 1:1 to 1:2 the surface area of the building will increase about % 5.5

Aspect Ratio	1:1	(1:2)
Surface area	10000 m2	10550 m2
Opaque area (%60)	6000 m2	6330 m2
Glazing area(%40)	4000 m2	4220 m2
Opaque cost	$ 175 per m2	$175 per m2
Glazing cost	$ 200 per m2	$ 200per m2
Energy consumption	(44494Kwh*27floor)	(36930 Kwh *27 floor)
Total initial cost	$1050000+$800000= $1850000	$1107750+$844000 =$1951750

Aspect ratio (1:1)

Energy consumption in 1:1= 44494Kwh*$ 0.125 *27 floor of T1 building

Energy consumption = $150167

(P/A*%10 *25) =9.077 APPX B

Aspect ratio (1:1) =$1850000 +$ 150167 (P/A*%10 *25)

Aspect ratio (1:1) =$1850000 +$150167 (9.077)

Aspect ratio (1:1) =$1850000 +$1363068

Aspect ratio (1:1) = **$ 3213068** cost of 25 years

Aspect ratio 1:2

Energy consumption in 1:1= 36930 Kwh*$ 0.125 *27 floor

Energy consumption =$124638

(P/A*%10 *25) =9.077 APPX B

Aspect ratio (1:2) = $1951750 +$124638 (P/A*%10 *25)

Aspect ratio 1:2 (1:2) =$1951750 +$124638 (9.077)

Aspect ratio (1:2) =$1951750 +$1131339

Aspect ratio 1 (1:2) = **$3083228** cost of 25 years

$3213068-$3083228= $129839

$ 129839 save money in 25 years by changing aspect ratio 1:1 to 1:2

2) Life cycle analysis for existing building and scenario 5

Type	Existing	Optimized (scenario 5)
Surface area	10 000 m2	10 000 m2
Opaque area	-----	6 000 m2
Glazing area	1 0000 m2	4 000 m2
Opaque cost	-----	$175
Glazing cost	$ 200 per m2	$ 220 per m2
Energy consumption	(44494Kwh*27floor)	(33606 Kwh *27 floor)
Average Electricity price during 25 years	$ 0.125 per (Kwh)	$ 0.125 per (Kwh)
Total initial cost	$ 2000 000	$ 1930000

LCCA of existing building

Energy consumption= 44494Kwh*$ 0.125 *27 floor

Energy consumption = $150167

Existing building LCCA =$200000 +$150167 (P/A*%10 *25)

(P/A*%10 *25) =9.077 APPX B

Existing LCCA =$ 2000000 +$150167 (9.077)

$2000 000 + $ 1363068= $ **3363068** LCCA of 25 years.

LCCA of Optimized building

Total cost of facade=$1930000

Energy consumption= 33606Kwh*$ 0.125 *27 floor

Energy consumption = $113420

Design cost= $20000

(P/A*%10 *25) =9.077 APPX B

Optimized building LCCA =$ 20000 + $1930000 + $113420 (P/A*%10 *25)

Optimized building LCCA = $20000 + $ 1930000 + $ 113420 (9.077)

Optimized building LCCA=$ 20000 +$ 1930000 +$1029515

Optimized building LCCA= **$ 2979515**

$3363068 -$2979515 **= $ 383552** money saving during 25 years.

3) Life cycle cost analysis after Adding shading devices for existing building with double glazing clear glass

South

Total horizontal shading device (VSA 50) m2 *price of aluminium panel $ per m2.

2092 m2 *$ 150 =$ 313800

East

Total horizontal (VSA 50) +vertical fins (HAS 15)*price of aluminium panel $ per m2.

East = (2092+4950) *$150

East= $ 1056300

West

Total horizontal (VSA 50) +vertical fins (HAS 15)*price of aluminium panel $ per m2.

West = (2092+4950) *$ 150

West =$ 1056300

North

Total vertical fins (HAS 60)*price of aluminium panel $ per m2.

North =1420*150=$ 213000

South (angle 50)	East	West	North	Total shading price
$ 313800	**$ 1056300**	**$ 1056300**	**$ 213000**	**$ 2639400**

LCCA of building without shading device -

Total cost of facade=$ 1900000

Glass cost $= $ 190

Energy consumption= 41966 Kwh*$ 0.125 $ *27 floor

Energy consumption =$ 141635

(P/A*%10 *25) =9.077 APPX B

Building LCCA = $ 1900000 + $ 141635 (P/A*%10 *25)

Building LCCA = $ 1900000 + $ 141635 (9.077)

Building LCCA=$ 1900000$ + $ 1285623

Building LCCA=$ **3185623** LCCA of 25 years

LCCA with shading device

Energy consumption= 38369 Kwh* $ 0.125 *27 floor

Energy consumption = $129495

(P/A*%10 *25) =9.077 APPX B

Building LCCA = $ 2639400+$ 1900000 +$ 129495 (P/A*%10 *25)

$ 2639400+$ 1900000 + 129495 $(9.077)

$ 2639400+$ 1900000+$ 1175426=$ 5714826

LCCA 25 years **= $ 5714826**

3185623-5714826= **$ -2529203** loss during 25 years.

Appendix B: Compound Interest Factors

10% Compound Interest Factors 10%

	Single Payment		Uniform Payment Series				Arithmetic Gradient		
n	Compound Amount Factor Find F Given P F/P	Present Worth Factor Find P Given F P/F	Sinking Fund Factor Find A Given F A/F	Capital Recovery Factor Find A Given P A/P	Compound Amount Factor Find F Given A F/A	Present Worth Factor Find P Given A P/A	Gradient Uniform Series Find A Given G A/G	Gradient Present Worth Find P Given G P/G	n
1	1.100	.9091	1.0000	1.1000	1.000	0.909	0	0	1
2	1.210	.8264	.4762	.5762	2.100	1.736	0.476	0.826	2
3	1.331	.7513	.3021	.4021	3.310	2.487	0.937	2.329	3
4	1.464	.6830	.2155	.3155	4.641	3.170	1.381	4.378	4
5	1.611	.6209	.1638	.2638	6.105	3.791	1.810	6.862	5
6	1.772	.5645	.1296	.2296	7.716	4.355	2.224	9.684	6
7	1.949	.5132	.1054	.2054	9.487	4.868	2.622	12.763	7
8	2.144	.4665	.0874	.1874	11.436	5.335	3.004	16.029	8
9	2.358	.4241	.0736	.1736	13.579	5.759	3.372	19.421	9
10	2.594	.3855	.0627	.1627	15.937	6.145	3.725	22.891	10
11	2.853	.3505	.0540	.1540	18.531	6.495	4.064	26.396	11
12	3.138	.3186	.0468	.1468	21.384	6.814	4.388	29.901	12
13	3.452	.2897	.0408	.1408	24.523	7.103	4.699	33.377	13
14	3.797	.2633	.0357	.1357	27.975	7.367	4.996	36.801	14
15	4.177	.2394	.0315	.1315	31.772	7.606	5.279	40.152	15
16	4.595	.2176	.0278	.1278	35.950	7.824	5.549	43.416	16
17	5.054	.1978	.0247	.1247	40.545	8.022	5.807	46.582	17
18	5.560	.1799	.0219	.1219	45.599	8.201	6.053	49.640	18
19	6.116	.1635	.0195	.1195	51.159	8.365	6.286	52.583	19
20	6.728	.1486	.0175	.1175	57.275	8.514	6.508	55.407	20
21	7.400	.1351	.0156	.1156	64.003	8.649	6.719	58.110	21
22	8.140	.1228	.0140	.1140	71.403	8.772	6.919	60.689	22
23	8.954	.1117	.0126	.1126	79.543	8.883	7.108	63.146	23
24	9.850	.1015	.0113	.1113	88.497	8.985	7.288	65.481	24
25	10.835	.0923	.0102	.1102	98.347	9.077	7.458	67.696	25
26	11.918	.0839	.00916	.1092	109.182	9.161	7.619	69.794	26
27	13.110	.0763	.00826	.1083	121.100	9.237	7.770	71.777	27
28	14.421	.0693	.00745	.1075	134.210	9.307	7.914	73.650	28
29	15.863	.0630	.00673	.1067	148.631	9.370	8.049	75.415	29
30	17.449	.0573	.00608	.1061	164.494	9.427	8.176	77.077	30
31	19.194	.0521	.00550	.1055	181.944	9.479	8.296	78.640	31
32	21.114	.0474	.00497	.1050	201.138	9.526	8.409	80.108	32
33	23.225	.0431	.00450	.1045	222.252	9.569	8.515	81.486	33
34	25.548	.0391	.00407	.1041	245.477	9.609	8.615	82.777	34
35	28.102	.0356	.00369	.1037	271.025	9.644	8.709	83.987	35
40	45.259	.0221	.00226	.1023	442.593	9.779	9.096	88.953	40
45	72.891	.0137	.00139	.1014	718.905	9.863	9.374	92.454	45
50	117.391	.00852	.00086	.1009	1 163.9	9.915	9.570	94.889	50
55	189.059	.00529	.00053	.1005	1 880.6	9.947	9.708	96.562	55
60	304.482	.00328	.00033	.1003	3 034.8	9.967	9.802	97.701	60
65	490.371	.00204	.00020	.1002	4 893.7	9.980	9.867	98.471	65
70	789.748	.00127	.00013	.1001	7 887.5	9.987	9.911	98.987	70
75	1 271.9	.00079	.00008	.1001	12 709.0	9.992	9.941	99.332	75
80	2 048.4	.00049	.00005	.1000	20 474.0	9.995	9.961	99.561	80
85	3 299.0	.00030	.00003	.1000	32 979.7	9.997	9.974	99.712	85
90	5 313.0	.00019	.00002	.1000	53 120.3	9.998	9.983	99.812	90
95	8 556.7	.00012	.00001	.1000	85 556.9	9.999	9.989	99.877	95
100	13 780.6	.00007	.00001	.1000	137 796.3	9.999	9.993	99.920	100