SIMULTANEOUS OPTIMIZATION OF OFFICE BUILDING FACADES IN TERMS OF BOTH ENERGY CONSUMPTION AND TRANSPARENCY IN HOT ARID CLIMATES, ANALYSED ON THE EXAMPLE OF CAIRO

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Vorgelegt von

Tamer Awny Abd Elkader Mohamed
aus Kairo, Ägypten

Hauptberichter: Prof. Dipl.-Ing. José Luis Moro

Mitberichter: Prof. Dipl.-Ing. Jürgen Schreiber

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Institut für Entwerfen und Konstruieren (IEK)
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Abstract

Since the early days, buildings forms, types of construction, and development were closely responding to the local climatic conditions. However, the technical innovations during the last 150 years and the calls of modern architecture to transparency drove the building sector towards the extensive usage of glazed facades in commercial buildings and to the adoption of the international style buildings. Those building models can only function through the extensive intervention of technical equipment to guarantee the desired internal comfort conditions at any place of the world with the corresponding massive energy input, owing to the poor thermal performance of glazing and its selective property with respect to radiation permeability (greenhouse effect). Unfortunately, this situation is very apparent in Cairo. Contemporary commercial buildings are being increasingly designed and constructed based upon highly glazed building models originally conceived in, and for, countries with moderate climates. Such architecture is totally maladapted to the hot-arid climate, especially with the extensive solar radiation and the relatively high summer temperatures.

However, on the other hand, transparency provides crucial psychological values and benefits to the occupants. It affects their comfort, sense of well-being, and affords them view and natural light. View provides the occupants with visual amenity, access to environmental information, relief from claustrophobia and monotony, and recovery from daily stress. While natural lighting has a direct influence on mood and cognition, and influences the production of hormones, it also regulates motivation, and improves productivity in the workplace. In addition, the proper use of natural day-light decreases the energy used for lighting and improves the environmental quality indoors.

The research work aims to elaborate a scientific methodology in order to optimize the office facades configurations in hot-arid climates, analysed on the example of Cairo. The research methodology is based on investigating the adequate balance between two critical, and at the same time conflicting requirements or tasks, which are:

- **First:** To provide the required level of transparency that provides the occupants with their psychological sense of satisfaction and general well-being.
- **Second:** To reduce the total energy consumption of the building through an energy-efficient concept based on a proposed solar protection strategy.

Through a series of parametric analysis processes of the energetic performance of the selected solar protection variants (represented by their total annual energy consumption per square meter) with their corresponding visual quality (represented by their view index measures), the research provides an optimized definition for the configuration of office facades. The optimized façade designs achieved the required balancing ratio that gives the occupants psychological satisfaction and general well-being. The research proposes an Energy-Transparency Balancing Factor (ETBF) in order to compare and differentiate between the findings of these optimized configurations.

KURZBESCHREIBUNG

Seit jeher gehen Bauweise, Gebäudeform und die damit verbundene bauliche Umsetzung auf die lokalen klimatischen Bedingungen des Ortes ein. Die technischen Innovationen der vergangenen 150 Jahre und die Forderungen der modernen Architektur nach mehr Transparenz führten in allen Regionen der Welt bei Verwaltungsbauten zu einer starken Zunahme von verglasten Fassaden bei direkter Übernahme des so genannten "Internationalen Stils". Diese Gebäudetypen können aufgrund schlechter thermischer Konzepte und Leistung sowie ihrer materialspezifischen Eigenschaften von Verglasung in Bezug auf Strahlungsdurchlässigkeit (Treibhauseffekt) die gewünschten innenräumlichen Komfortbedingungen nur mit erheblichem Einsatz technischer Gebäudeausrüstung und einem entsprechenden massiven Energieeinsatz an jedem beliebigen Ort der Welt erfüllen. Bedauerlicherweise findet man die beschriebene Situation bis heute in Kairo vor. Zeitgenössische Verwaltungsbauten werden bis heute zunehmend als großflächig verglaste Gebäudemodelle entworfen und gebaut,- Konzepte des Verwaltungsbaus, die ursprünglich für Länder mit gemässigtem Klima entwickelt wurden. Eine solche Architektur ist keineswegs an das aride heiße Klima angepasst, insbesondere nicht für die starke Sonneneinstrahlung und die relativ hohen Temperaturen der Region.

Transparenz liefert natürlich entscheidene psychologische Vorteile für die Gebäudenutzer. Sie beeinflusst den Komfort, das Wohlbefinden, schafft Ausblicke und natürliche Belichtung. So beschert die freie Sicht nach außen den Nutzern visuelle Annehmlichkeiten, Zugang zum Umweltgeschehen, eine Aufhebung von Abgeschlossheit und Monotonie sowie Erholung vom Alltagsstress. Während natürliche Belichtung einen direkten Einfluss auf Stimmung, Konzentrationsfähigkeit und die menschliche Hormonproduktion aufweist, steuert sie damit ebenfalls die Motovation und verbessert die Produktivität am Arbeitsplatz. Des Weiteren verringert die richtige Nutzung von Tageslicht die ansonsten für die Beleuchtung verwendete Energie und verbessert die Qualität in Innenräumen.

Die Forschungsarbeit zielt darauf ab, eine wissenschaftliche Methodik zur Optimierung der Bürofassadengestaltung in trockenen heißen Klimazonen, analysiert am Beispiel von Kairo, zu erarbeiten. Die angewandte Forschungsmethodik basiert dabei auf der Untersuchung eines angemessenen Gleichgewichtszustands zwischen zwei kritischen und im Widerspruch befindlichen Anforderungen und Aufgaben, welche wie folgt beschrieben werden:

- **Erstens:** Die Gewährleistung der erforderlichen Transparenz, um den Nutzern ein psychologisches Gefühl von Zufriedenheit und allgemeinem Wohlbefindens zu geben.
- **Zweitens:** Den Gesamtgebäudeverbrauch an Energie durch ein effizietes Konzept basierend auf einer vorgeschlagenen Strategie für den Sonnenschutz zu reduzieren.

Durch eine Reihe parametrischer Analyseprozesse der energetischen Leistung ausgewählter Sonnenschutzvarianten (dargestellt anhand des gesamten jährlichen Energieverbrauchs pro m^2) mit ihrer entsprechenden visuellen Qualität (bewertet durch eine Kennzahl für den jeweiligen Ausblick), bietet die Forschung eine optimierte Anleitung zur Gestaltung von Bürofassaden. Die dadurch verbesserte Fassadenkonstruktion erzielt das erforderliche Gleichgewicht, das den Bewohnern psychologische Befriedigung und allgemeines Wohlbefinden garantiert. Die Forschung schlägt dabei einen Energietransparenz-Ausgleichsfaktor (ETBF) vor, um zwischen den Ergebnissen dieser optimierten Fassadenkonfigurationen zu vergleichen und zu unterscheiden.

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PART I: THE CONCEPTUAL STUDY

Chapter I

Research Introduction

1. Research Introduction:

1.1. Research Background:

Particularly in the last few decades, after the industrialization era, and as far as the design and construction of the built environment are concerned, the idea of mastering almost everything technically emerged. Architects and engineers considered themselves capable of erecting magnificent buildings; they believed to know how to create new building materials and to use them without any constraints. Heating, cooling, and lighting of buildings were achieved mainly by mechanical equipment (Lechner, 2015). Energy conservation was regarded as a marginal issue, since it was seemingly available in unlimited quantities and at reasonable prices. (Herzog, 1996).

This situation was first reconsidered after the 1973 energy crisis; a considerable progress has been made in reducing energy consumption since then. However, the non-stop thirst for energy has continued, and the dependence on fossil fuel and other non-renewable resources remains a fundamental requirement. Hegger, et al. (2008) attributed the wide increase in energy demand to the exponential growth of the world's population by an average of 1% per annum, primarily in the developing and newly industrialized countries, in addition to the changes that took place in the world since industrialization era towards a better quality in living conditions and increased demand for high standards of comfort, which is reflected in increasing the rates of urbanization. Currently, the world is changing into an age in which more people are living in cities than in rural areas. According to estimations, the current world energy supplies based on the fossil energy have reached 80% of the total energy consumed. This increase in demand goes side by side with the world limited fossil energy resources, which are gradually diminishing. The ability to obtain and burn oil exceeds its supplies; this shortage will, in turn, lead to an increase in its prices as a result of the market laws.

The environmental consequences of the high dependence on non-renewable energy resources were discussed in the Intergovernmental Panel on Climate Change (IPCC), fifth assessment report. The report demonstrated that the environmental consequences and the climate changes resulted from the combustion of fossil fuels have reached a very critical situation in the human history. The global problem is now common and requires an international cooperation on many crucial matters in tandem with local, national, and regional policies. The increasing emissions of carbon dioxide (CO_2) and the other greenhouse gasses (GHG) which resulted from fossil fuels combustion have risen rapidly from 2000 to 2010 with an average growth rate of 2.2% per year, compared to 1.3% per year over the whole period from 1970 to 2000. The continued emissions of GHG cause a further warming of the earth atmosphere. The last three decades have been successively warmer at the earth surface than any other preceding decade since 1850. The global averaged surface temperature data indicate a warming of 0.85°C over the period from 1880 to 2012 (IPCC, 2014). This caused diminishing and melting of snow, polar ice-caps and glacier. Oceans are now warming up and becoming more acidic, sea levels are rising, and extreme weather conditions are repetitive in shorter intervals. In the meantime, global warming has become a local threat and has placed mankind in an unprecedented situation. In order to avert the uncontrolled effect of climate changes, we all have no choice but to learn how to get along with each other and drastically change our consumption rates and our economic behavior over the next 10 to 20 years towards a more sustained and efficient use of the earth resources, and to achieve substantial reductions in the energy consumption rates (Hegger, et al., 2008).

Globally, the use of energy in the building sector accounts for a large share of the total end-use of energy. According to the International Energy Agency (IEA) estimations, buildings and their associated functions are responsible for 40% of the world end use of energy consumption (IEA, 2008). This consumed energy goes mainly for controlling the buildings' internal climate, lighting, installed equipment, appliances, and other services. Given the many possibilities and potentials to the substantial reduction in the energy requirements of the buildings, the scale of energy efficiency in the buildings sector is large enough to contribute to energy security policy and climate preservation on both national and global scales. In many developing countries, new constructions account for the larger share of the building's fabric. Savings by energy efficiency in new buildings will have a larger impact on the economy of these countries and result in larger savings than in other OECD nations (IEA, 2008).

Recent advances in several areas of research show a growing recognition of benefits related to the improvement of both human related as well as energy-performance aspects of buildings. It is widely accepted that the success of any building depends on achieving a comfortable indoor environment; including indoor air quality, visual comfort, and thermal comfort which is one of the biggest challenges with respect to energy use. For this reason, some energy-conscious ideas and concepts such as energy efficiency, low-energy buildings, passive design, Passivhaus and net zero energy buildings, as well as some standard rating systems as LEED (Leadership in Environment and Energy Design), BREAM (Building Research Establishment's Environmental Assessment Method), and DGNB (German Sustainable Building System) and energy conscious organizations as USGBC (U.S. Green Building Council) and ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) among many other national building codes, were developed for improving the buildings' energy efficiency at the design phase. This can help to realize the large potential of energy savings in new buildings while taking into consideration the domestic climate and human needs (Bessoudo, 2008).

The outer shell of the building is a key parameter in manipulating its total energy consumption. It has been traditionally regarded as a barrier that provides secured shelter and space, separating the interior from the outdoor environmental conditions; the architect provides an insulated internal environment, while engineers equipped it with energy-consuming devices to provide comfortable conditions for the occupants that live, work and interact within. The growing awareness of conserving energy consumptions in buildings have led to more attention on the building's envelope. Its role has been re-evaluated and taken on more complex to an energy mediator that can influence every other component of the building; in which it interacts with both the external ambient environmental forces and the required internal comfortable conditions for the occupants, and aims for regulating the energy flows between the outside and the inside. The architect priorities now are to guarantee providing the efficient thermal and visual internal conditions according to the prevailing environmental and the bioclimatic context by using the envelope itself. While, any other remaining needs could be satisfied by the electromechanical systems (Bradshaw, 2006).

The glazed transparent component plays the most crucial role in any building's envelope, basically in its facades. Glass gives the facade its distinctiveness, dynamic nature, and is considered a vital part of the architectural aesthetics of any building. The idea of transparency has always captured the imagination of humankind, which has sought to reach it through a long history of technical developments. Improving the quality of glazing from translucency to full transparency, boosted with the 20th century technical developments, enabled the occupants inside the building to enjoy an unobstructed view to the outside (ElKadi, 2006).

Transparency adds psychological values and benefits to the occupants; it provides them with view and natural lighting that enhance their comfort and gives them the sense of well-being. Views afford the occupants visual amenity, access to environmental information, access to sensory change, relief from claustrophobia and monotony, a feeling of connection to the world outside, and recovery from daily stress (Heerwagen, 1990). While natural lighting affects their mood and cognition; it influences the production of hormones and regulates motivation. It also improves productivity in the workplace and helps in maintaining a healthy environment. However, the most significant roles in this respect, are the aspects of visual comfort and the spontaneous glimpse of the sun (Herzog, 1996).

However, the extensive use of glass in the post-World War II architecture, and the increasing aspire for large glass expanses, pushed modern architecture towards the fully glazed facades and the adoption of the universal style of buildings. This movement does not consider the importance of local climatic conditions. Architects were liberated and disconnected themselves from the environmental issues. Hence, they lost their skill in optimizing energy use and comfort conditions in the building. Meanwhile, buildings have become increasingly a sicken factor; indoor air quality has worsened; there has been a tremendous increase in overall energy consumption rates needed to guarantee the occupant's comfort (Santamouris, 2007). Large transparent components and surfaces of the building envelope, on average, usually exhibit a poorer thermal performance in hot-arid climates and do not allow efficient solar and thermal control (Carmody, et al., 2004). This is attributed to the selective property of glazing with respect to solar radiation permeability. Where, Solar radiation is a form of energy that when absorbed is converted into heat. Most of the short-wave and visible solar radiation can pass through the glazing layers, whereas the long-wave heat radiation is reflected, the short-wave radiation that reaches the interior is absorbed by the surfaces in its direct path and converted into long-wave radiation which in turn cannot transmit from the glazed surface and starts to heat up the interior, or what is known as "the greenhouse effect" (Schittich, et al., 2007).

Unfortunately, contemporary buildings in Cairo as in the whole MENA region are often based upon imported international building models. Un-optimized glazed facades are being increasingly designed and constructed. Such architecture is entirely unsuited to hot-arid climates; it disregards all means of protection against the intensive solar radiation and hot weathering conditions. That's the universal style glazed office building (El Hamoly, 2003). St. Clair (2009) added that these building models could only function in such hot-arid climates through the extensive intervention of mechanical air-conditioning to maintain the required thermal comfort conditions, leading to exorbitant usage of oil and natural gas reserves, and with consequently high levels of carbon emissions.

Figure 1 - 1: BLOM Bank building in the fifth settlement, Cairo. The Southern façade of the building is constructed with highly tinted glass. However, this did not prevent the users from pulling down their internal curtains as a protective action towards the excessive solar radiation, thus, losing the attained value from the transparent façade (By researcher).

While ironically, Lechner (2015) noted that, these glazed building models must have their electric lights on during the day when daylight was abundant outside since they are not optimized for quality daylighting. Butera (2005) further explained that the extreme external daylight levels in hot-arid climates frequently lead to excessive penetration of solar radiation to the interior. The benefit of the natural light flood is entirely canceled by the effect of glare and solar heat gain. The occupants reacted to restore visual and thermal comfort by obscuring the solar radiation with internal curtains, Venetian blinds or whatever was available. The internal curtains, even if white, absorb the transmitted solar energy and gain thermal heat, while electric lights are always on, adding another source of heat. St. Clair (2009) added that the adequate use of daylighting could provide remarkable potential in reducing the lighting energy costs. Internationally, lighting accounts for nearly 50 percent of energy requirements in commercial buildings. The proper use of daylighting with high-performance artificial lighting and the correct glazing selections can provide from 30 to 50 percent reductions in lighting energy consumption. Figures from 1 - 1 to 1 - 7 describe this situation in Cairo's office buildings.

Figure 1 - 2: HSBC Bank, in Maadi district, Cairo. The fully glazed façade is facing the west orientation overlooking the Nile river. Disregarding the pleasant Nile view, the occupants pulled their internal opaque curtains, and turned electric lights on as a response for protection against the solar radiation (By researcher).

Figure 1 - 3: Unoccupied office building in the fifth settlement, Cairo. The building constructed in 2013 in the Elteseeiny road, with fully and clear glazed facades, exposed to the solar radiation all day without any external solar-protection (By researcher).

Figure 1 - 4: HC Office building in smart village, near Cairo - Alexandria road. The picture was taken in February with a partially cloudy sky conditions. However, the occupants also pulled down their internal shading for solar protection and ignoring the external green view (By researcher).

Figure 1 - 5: Address Office building in the 5th settlement, Cairo. The building is constructed in 2012, in the Elteseeiny road. The solar protection louvers are insufficient to protect the façade against solar radiation. Almost all internal curtains are pulled down to protect the unsatisfied users from the un-optimized glazed façade (By researcher).

Figure 1 - 6: Office building in El-Mokattam district, Cairo. The street façade of the building is fully glazed with tinted and reflective glazing, but with no external shading devices (By researcher).

Figure 1 - 7: HSBC Bank, in the 5th settlement, Cairo. The building is a low-rise office building with highly glazed façade. The design exhibits the poor environmental and climatic considerations for hot-arid climates (By researcher).

Herzog (1996) calls for a rapid and fundamental reorientation in our thinking. Particularly, on the part that involve architects and planners in the process of the envelope planning and construction. They must exert far more decisive influences during the conceptual design on the use of materials and the use of energy than they did in the past. The form of our future built environment should be based on a responsible approach to our environment and its limited resources. However, this objective should not be achieved on the expenses of the required physical and psychological needs of the occupants for external view and daylighting conditions.

1.2. Problem Definition:

Seeking for the values of transparency to satisfy the occupants psychological needs and supported with the calls of modern architecture for transparency, has driven the world towards a very extensive construction of glazed building models. These buildings are characterized by their heavy reliance on technical solutions to guarantee maintaining the required internal comfortable conditions, and typically with the corresponding massive energy input. The planning of energy-efficient building envelopes presumes an accurate understanding and analysis of the specific climatic condition as a prerequisite for its design. Building envelopes optimized for energy-efficient aspects have maximized passive potentials; and hence this should represent the foundation for viable energy concepts, besides the savings that had to be made on its technical systems to reduce the overall energy demand for human comfort that forms the focus of attention (Hegger, et al., 2008).

However, the design of the building's envelope should not be left to the efficient energy planning alone, Daryanani (1984, p. 112), ironically stated that:

> "If energy conservation was the only criterion for success of a commercial building, a windowless underground building would be the ultimate energy-conscious design."

Therefore, the transparent component of the facade plays a critical double role in both the buildings' energetic performance and its visual requirements. It should have high thermal insulation, high light transmittance, and low solar heat gain values to reduce the building's cooling/heating and lighting loads. While at the same time, it is responsible for the provision of the required visual transparency and daylighting conditions needed for the occupants' psychological sense of well-being and visual comfort. The matter that calls for a special care during its planning process.

Problem Statement: Generally, the psychological quest for high levels of office space transparency in hot-arid climates with its intensive solar radiation subsequently conflict with the accompanying high rates of energy consumption. Therefore, in these climates, the appropriate conceptual design of office building with a high degree of transparency should take into consideration the adequate balance between two critical and at the same time conflicting requirements or tasks:

- **First:** Affording the required level of transparency that provides the occupants with their psychological sense of satisfaction and general well-being. Basically, the need for the visual contact to the external environment and the admission of daylight.

- **Second:** Reducing the total energy consumption of the building, through protecting the interior from the excessive solar radiation and temperature, based on energy efficient concepts such as external shading devices and glazed solar control.

1.3. Research Objectives:

The main objective of the research is to provide the needed information to optimize the configuration of office building facades with a high degree of transparency in hot-arid climates though a defined systematic methodology. The research methodology is based on elaborating solar protection variables as an energy efficient strategy for glazed office facades to balance between the reduction of the total annual energy consumption and the provision of transparency that gives the occupants their psychological satisfaction and general well-being. The main objective of the research is accomplished through four specific objectives as followed:

- To study the context of Cairo through analyzing its hot-arid climatic condition, investigating its passive potentials, reviewing the energy stats of the country, and investigating the configuration and energy consumption rates of some office building patterns in Cairo.
- To survey the psychological values of transparency and its importance to the office space occupants in Cairo, in order to specify the occupant's preference to transparency, their interaction with it, their preferred design criteria to transparency, and the balancing ratio of transparency to energy efficiency that provide them with the required psychological sense of satisfaction and general well-being.
- To computationally measure the energetic performance of the psychologically accepted solar protection parameters (window to wall ratios, external shading devices, and glazed solar control concepts) that are modeled on a conceptual office space base-case and simulated in the context of Cairo. Basically, the lighting, the cooling, and the total energy consumption measures.
- To optimize the office facades through balancing both the research visual and energetic measures of the solar protection parameters based on the occupants' preference ratio that is investigated in the research survey.

1.4. Research Motivation:

Currently, Egypt is facing a severe energetic crisis, the shortage in fuel supply, specifically natural gas and Diesel has forced the government to reduce the loads on electric power supply grids, leading to frequent electricity blackouts across all Egyptian governorates. This problem started in August 2008 and has been mostly limited to summer times. However, nowadays, the crisis has dramatically worsened since the turmoil of 2011. Power cuts have become more frequent; and even started to occur in winter, specifically, in December 2012. Cairo neighborhoods have witnessed daily blackouts that would last for an hour or two, leaving streets dark and forcing businesses to shut down. In 2013, the Egyptian Government set a campaign to save 20% of the electrical energy demand through the efficient consumption (Ahramonline, 2014).

On the other hand, especially in Greater Cairo Region (CGR), there is an increasing trend of designing and constructing highly glazed office buildings that disregard any climatic and environmental considerations. The reason for this situation varies from functionality in providing the interior with the required level of daylighting conditions and the visual contact with the outside that gives the occupants their psychological satisfaction and wellbeing to the expression of the social aspiration to the glazed office building model (Figure 1 - 8). This issue dramatically increases the total electrical energy consumptions in the country. According to the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EEUCPRA), the building sector in Egypt is the largest electrical energy consuming sector. In 2013, it consumed nearly 58.48% of the total national generated electricity, and the previous figure is constantly growing in the short term (EEUCPRA, 2014). This increase in the energy supply will make it prohibitively expensive or will become less secure in its supply, and particularly during days with extreme weathering condition.

Figure 1 - 8: The general union of the Egyptian commerce chamber building in New Cairo, the building is an administrative governmental office building, constructed in 2013 with highly glazed façade. The southern facade shows no installations of external shading devices to protect it from the extensive solar radiations in Cairo's Hot-arid climate (By researcher).

The research targets to create a methodology that allows for the design and construction of office buildings with highly transparent facades in hot-arid climates through an energy efficient and passive concept. In other words, it is an attempt to achieve the appropriate balance between the willingness of possessing office buildings with transparent facades in hot climates with energy-efficient design considerations.

1.5. Scope of Research:

The research work was applied on office spaces in Cairo Region, where the psychological preference to transparency was surveyed, the survey targeted white collar office employees from different specialties; however, all are employed in Cairo. The research energy efficient strategy was also modeled and simulated on Cairo's climatic conditions.

Based on the climatic analysis of Cairo, solar protection was introduced as the research energy efficient strategy, where it is applied on a base-case model representing an imaginary office space with an area of 17.28 m^2. The dimensions of the base-case model are 3.60 m in width, 4.80 m in depth, and 3.00 m in height. Through using building information modeling and simulation software (DesignBuilder V 5.0.1.0.24), the solar protection parameters were modeled and simulated on the research base-case to investigate their energetic performance; precisely, the annual measures of cooling, lighting, and total energy consumption.

For optimizing the office space transparency in Cairo, the research targets to balance between the criteria of the energetic performance of the office space in Cairo and the psychological preference of the office occupants to transparency. Based on the energetic modeling and simulation findings, the total annual energy consumption measured in KWh per square meter represented the energetic performance of the office space, while the psychological preference to transparency was indicated by the view index as the measure to the ratio of the accessible visual contact to the outside.

1.6. Research Significance:

The research pins up the significant role of transparency in office spaces and its crucial role in providing the occupants with the required psychological satisfaction and general well-being. However, through Investigating this issue in Cairo's office spaces, it was found that the unoptimized glazed office buildings in Cairo's context leads to the intensive transmittance of solar radiation into the office spaces where the occupants interact to restore their visual and thermal comfort by closing internal shadings. This action deprives them of the required transparency and increases the total energy consumption, especially the energy required for cooling and lighting. The research provides a scientific methodology that gives the required information to optimize the office façade configurations in Cairo. The optimized configuration balance between a satisfactory level of office transparency and the efficient use of energy based on the occupants' psychological preference ratio that is investigated in the research survey.

In addition, the research proposes the energy-transparency balancing factor (ETBF). ETBF will assist the architect to measure the degree of preference of the optimized office façade configuration that gives the required balance between transparency and energy efficiency. Moreover, ETBF values can be used to compare and differentiate between several optimized façade alternatives.

1.7. Research Structure:

The thesis is divided into three main parts or studies that consists of twelve chapters as follows:

1.7.1. Part I: The Conceptual Study:

The conceptual study is covered through this chapter of the research (Chapter - I). It gives a brief introduction to the research and underpins the conceptual model upon which the research map is based. The conceptual study is mainly based on explaining the rationale behind considering the need to balance between the energy efficient use of highly transparent office facades in Cairo with the related psychological considerations. It discusses the research background and then presents a brief definition of the research problem, objectives, motivation, scope, and significance. The chapter ends by giving a complete overview of the research structure.

1.7.2. Part II: The Theoretical Study:

The theoretical study provides the required literature review and definitions. Data has been collected from books, articles, scientific periodicals, and reports. After data collection, it was analyzed in order to pins up the main aspects, topics, definitions, and tools that are relevant to the research. This part is covered from chapter II to chapter VII as followed:

- Chapter II: Worldwide Energy Predicaments: This chapter demonstrates the related manifestations of the worldwide energetic problem and its environmental consequences. It also addresses the types of energy consumption in buildings, and presents a brief description to the worldwide end use of energy in buildings.
- Chapter III: Review on Glazing in Architecture: The conceptual evolution of glazed application in architecture is discussed in this chapter according to the provided function.
- Chapter IV: Psychological Values of Transparency: This chapter studies the psychological values of transparency and its impact on the occupant's satisfaction and general wellbeing based on three main functions, which are: the external view, the natural daylighting, and the perception of the glazed office building.
- Chapter V: Solar - Thermal Performance of Glazing: First, the fundamentals of heat and solar radiation in buildings is introduced in this chapter. Then, the solar and thermal properties of glazing, as well as its different heat transfer mechanisms are explained.
- Chapter VI: Thermal and Visual Physical Comfort Modes: This chapter discusses the main principals of the physical human thermal and visual comfort conditions as one of the research

targets. It presents a brief overview on the thermal and the visual comfort definitions, determinants, variables and, their measuring standards.

- Chapter VII: Solar Protection: This chapter presents a literature review on the solar control concepts for glazed building facades as the research protective strategy. It presents with analysis the solar geometry fundamentals and the prominence of solar protection in buildings. In addition, it gives a review on two solar control tools, which are the external shading devices and the glazing solar control concepts. The chapter ends with a comparative analysis to the appropriate criteria of selection. These tools will be used for the research energy efficient strategy.

1.7.3. Part III: The Operational Study:

The research operational study is the main work of the research methodology; it is based on four main studies which represent the main pillars of the research. Each study meets one of the research specific objectives and is discussed in a separate chapter; from chapter VIII to chapter XI. Different research methods were applied for each operational study; however, the findings of each study were used as inputs for the following ones in a sequence as follows:

- Chapter VIII: Cairo, Contextual Study: In order to have a complete overview to the research issue, it is convenient to study the context of Cairo. First the study presents a general introduction to Cairo's geographical location, then the following three points were studied:
  - Cairo's Climate Profile: Based on literature review and meteorological software Climate Consultant V6.0 and Metronome V7.0, the complete climatic profile of Cairo is demonstrated and the Building Bio-Climatic Chart (BBCC) for Cairo is analyzed. The results indicate that solar protection is the most influential passive potential in the climatic conditions of Cairo since it provides the maximum possible increases in the internal comfort hours. Therefore, it is proposed by the research as its main energy efficient strategy that will be used through the upcoming sections.
  - The Building Sector Energy predicaments in Egypt: From literature and energetic reports from both official domestic and international firms, the energy stats of Egypt are reviewed. The findings showed the enormous increase in energy consumptions rates and the declination of energy production in the country. In addition, the study showed that the building sector is one of the major energy-consuming sectors in the country. This matter requires an urgent and efficient action to encounter these predicaments.
  - Office Buildings Energy Consumptions Modes in Cairo: Through the relevant data from literatures and extended meetings with office building managers in Cairo, the configuration and energy consumption rates of six office buildings in Cairo are demonstrated and analyzed.

For each building, the envelope configuration, cooling and lighting mechanisms, and the monthly energy consumption for a complete year are presented. The average energy consumption for the studied cases are used to represent the average energy consumption rate of office buildings in Cairo through the upcoming studies.

- Chapter IX: Surveying the Psychological Preference of Transparency: This part is the second pillar of the research; it quantitatively surveys the psychological values of transparency according to the office occupants' preference in Cairo. The research survey investigated the following topics:
  - The importance of transparency and its preference to the occupants.
  - The occupants' behavior and their interaction towards the transparent component (window) in their working places with regard to their visual and thermal comfortable conditions.
  - The office occupants preferred design criteria to transparency that gives them their psychological sense of satisfaction and general well-being.

The survey targets the white-collar office workers from different fields and specialties that are employed in Greater Cairo region (CGR). Both the self-administrated questionnaire and the E-Link questionnaire were used in the data gathering process. The results were then analyzed and used as a threshold value/margin for the inputs data profiles in the energetic modeling and simulation study of the research (chapter - X).

- Chapter X: Energetic Modeling and Simulation: This study represents the third pillar of the research work; the energetic performance of the research protective strategy is investigated through a series of modeling and simulation processes. First, solar protection parameter is set according to the psychologically accepted design criteria. Then, they are applied on an imaginary computer office model. DesignBuilder software V 5.0.1.0.24 © 2000-2016 is the used as the research building information modeling and simulation (BIMS) software. The modeling and simulation operations in this section could be defined in the following two phases:
  - Operations Phase I: Through this part, two office profile configurations are modeled and simulated on the research office space model. Profile - A represents a typical Egyptian office profile, while Profile - B is based on the ASHRAE standards for medium office buildings. First, the simulation findings of profile - A are compared with the actual energy consumption rates of Cairo's office buildings to test the validity and reliability of the research modeling and simulation tool. Then, they are compared with the findings of profile-B to choose from them the more energy efficient profile to be applied through the main modeling and simulation processes in operations (phase II).

- **Operations Phase II:** These operations are the main modeling and simulation processes of the research. where the most energy efficient profile configuration is applied to the base case model. Then, the research solar protection strategy parameters were modelled and simulated to investigate their energetic performance; basically, the cooling, the lighting and the total energy consumption measures.

- **Chapter XI: Optimizing Energy Consumption with Transparency:** This is the fourth and last pillar of the research; the optimization process of the office façade is elaborated based on balancing the energetic performance of the office space with its transparency measure according to the occupant's preference ratio. The total annual energy measures from the modeling and simulation findings are used to define the energetic performance of the office space. While the level of transparency is indicated by the view index to measure the fraction of area available as view.

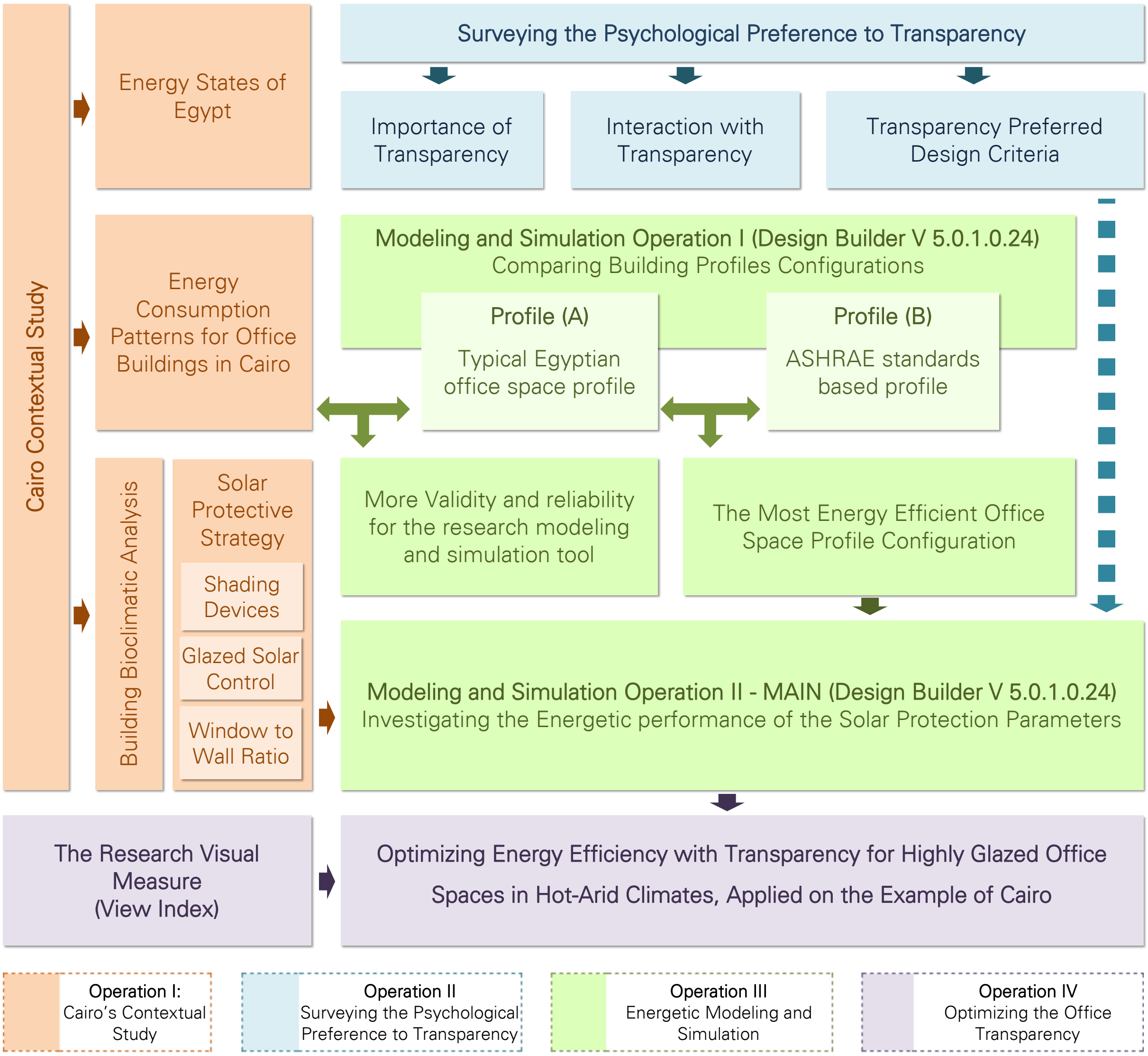

Figure 1 - 9: The research operational study

- **Chapter XII: Conclusion and Future Studies:** In this chapter, a summary of the research operational study findings and the relevant conclusion of the research are presented. Then, the research proposes future scientific studies.

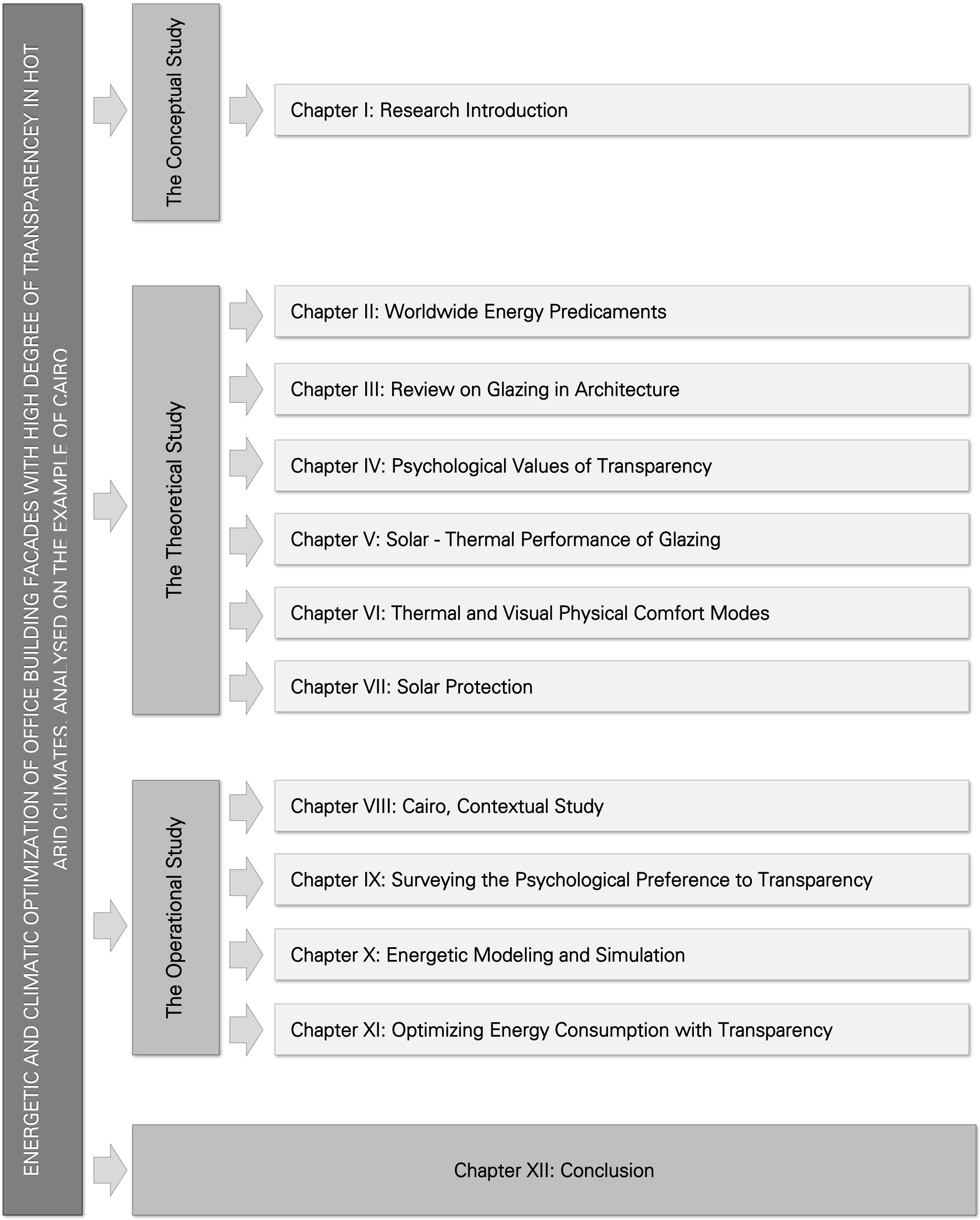

Figure 1 - 10: The research structure

PART II: THE THEORETICAL STUDY

Chapter II

Worldwide Energy Predicaments

2. Worldwide Energy Predicaments:

Nowadays, energy consumption became a fundamental requirement of our societies. It forms the basis of almost every activity we perform (Hegger, et al., 2008). Historically, the beginning of the nineteenth century witnesses the beginnings of the coal industry. By the mid of the twentieth century, oil and natural gas together have taken the lead. Currently, they have formed even shares of the market, while coal use is declining. In addition, since the 1950s, nuclear energy had entered the fuel mix (Bradshaw, 2006). Overtime, the thirst for energy increased, preserving its consumption was considered as a trivial concern, since it was available with unlimited quantities and with reasonable prices (Herzog, 1996).

This situation was first recognized after the 1973 energy crisis when oil prices raised rapidly in response to the geopolitical forces (Bradshaw, 2006). A considerable progress has been made in reducing energy consumption. However, this did not stop its increasing rates of consumption, and the high dependence on the energy-giving raw materials. Currently, almost 86% of the world's primary energy supplies are based on fossil fuels and other nonrenewable resources (Hegger, et al., 2008).

Bradshaw (2006) Noted that the exact amount of the non-renewable fuel reserves is not precisely known, however two issues are certainly known:

- First: There is a certain nongrowing limit to the nonrenewable fuel reserves.
- Second: We are using these reserves up at an ever-increasing rate.

In addition, despite of how much is still left under earth, it will become, by time, increasingly valuable and expensive according to the laws of market. Moreover, in some cases, it is expected to be environmentally prohibited to extract some other remaining amounts. In the following points the world-wide manifestations of energy predicaments and the energy consumptions in buildings will be demonstrated (In Chapter VIII of the research, the energy predicaments and the office building energy consumption for the case of Cairo / Egypt will be studied).

2.1. Manifestations of Energy Predicaments:

Our way of living has improved rapidly since the birth of the industrial revolution. The standard of living we have reached today, in addition to the ongoing economic growth, technical and social developments are highly dependent on the consumption of nonrenewable fuels. The first oil crisis of the 1970s clarified this situation. The urgent need for action is undeniable; a vital solution to the energy problem is needed if we are seeking to achieve a viable global development for our society. Fossil fuels (basically oil and gas) exhaustion is on the horizon, making energy prices steep upwards. In addition, the environmental consequences resulting from the extensive use of the non-renewable fuels that have been known for a long time triggered a long-term climate change. All these factors now call for an efficient and speedy action (Hegger, et al., 2008).

von Weizsacker (2014, p. 137) demonstrated in figure 2 - 1 the essential results of the first major report to the club of Rome (1972) "The limits to growth". It shows that the global civilization became aware of its outer limits that were ignored previously. Population and industry output growth is highly dependent on the environmental and natural resources constrains, and their ability to eliminate any further investments of the capital sector. However, nowadays, the physical state of the environment has already deteriorated largely. The current trends of growth have continued to exist, and have brought us much closer to the maximum limits. Even with the stabilization of consumption rates, the problem is not going to be solved; many analysts argue that "it is not about scarce resources but rather the absorptive capacity of the earth for all the pollutants that are limiting any further growth of resource consumption. However, the decline is not inevitable, and to avoid it, two changes are necessary: First, comprehensive revision of policies and practices that perpetuate growth in material consumption and in population. Second, rapid increase in efficiency with which materials and energy are used."

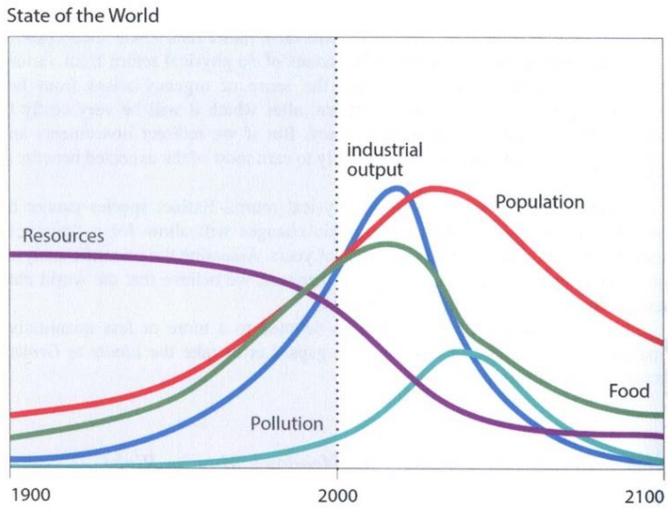

Figure 2 - 1: The report to the club of Rome, "the limits to growth", into the future of the world economy with trends towards crises after 2020 (von Weizsacker, 2014)

The main manifestations of the worldwide energy predicaments can be demonstrated in the following:

2.1.1. Increasing Dependence on Non-renewable Fuel Sources:

Currently, nonrenewable fossil energy sources account for the generality of the total primary energy consumption worldwide. Fossil fuel raw materials has been consumed in relatively shorter periods; since the end of the World War II, the consumed fossil energy is more than what is consumed in the entire prior history (Hegger, et al., 2008).

According to the BP stats (2014), in 2013, the global primary energy consumption rate is increased by 2.3%; it has reached 12730.4 million ton oil equivalent. Oil remains the world's dominant fuel resource with 4185.1 Million tons oil equivalent, representing 32.9% of the world's total primary energy consumption. Fossil hydrocarbon fuels with nuclear fuels (non-renewables) are currently representing

91.1% of the global primary energy consumption, while, hydroelectric power and other renewables energy resources in power generation both reached record shares of 6.7% and 2.2%, respectively.

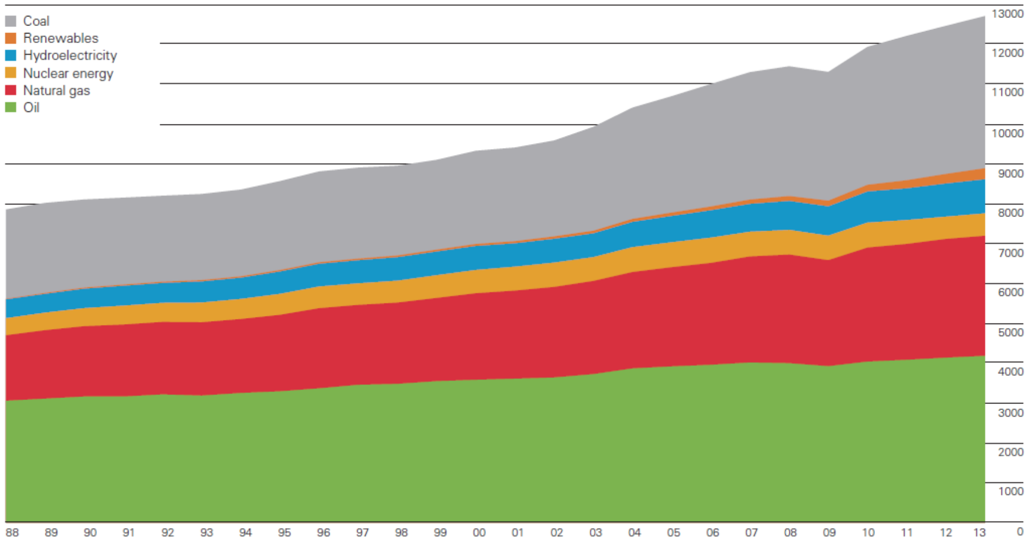

Figure 2 - 2: The world primary energy consumption (in million tons oil equivalent) from year 1988 to year 2013 (BP stats, 2014)

This increase in primary energy consumptions could be attributed to the following factors:

2.1.1.1. Population Increase:

The world population increased from 2.5 billion in 1950 to 6.1 billion in 2000, with an average annual growth rate of 1.76 percent. According to the United Nations, Department of Economic and Social Affairs, Population Division projections, the world population is estimated to reach 8.9 billion in 2050 (in the medium scenario), with an increase of 47% more than that of the year 2000. The annual increase in the world population will nearly reach 57 million per year till 2050, mainly in the developing and newly industrialized countries (UN Population Division, 2004).

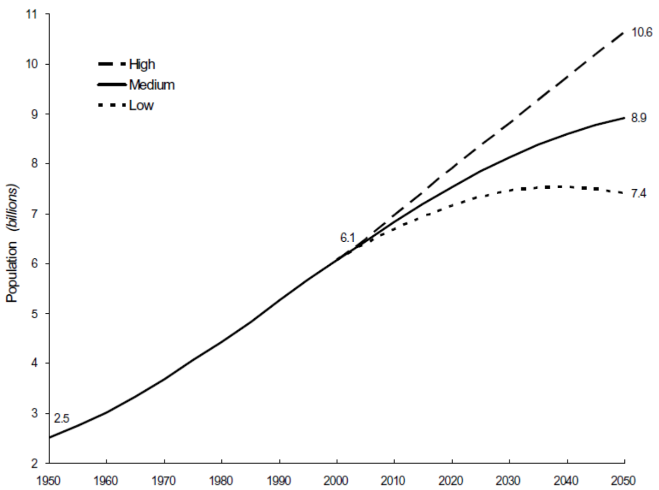

Figure 2 - 3: World population from 1950 to 2000, and estimated three projections from 2000 to 2050 (UN Population Division, 2004)

2.1.1.2. High Rate of Urbanization

Currently, we are changing worldwide into an age in which more people tend to live in cities rather than in rural areas. The urban populations of the world are increasing with a rate of 180 000 individuals per day. The highest rates of urban expansion mainly occur in developing countries. It is estimated that by 2020, the rate of urbanization will have increased by 50%, and by 2030, nearly 60 percent of the world's population are expected to live in urbanized cities. This over development is diminishing the planet's fertile land, meanwhile, it also encourages to the expansion in consumption of the earth nonrenewable raw materials (Hegger, et al., 2008).

2.1.1.3. Increasing Standards of Living:

The paradigm changes that have taken place in the world's societies since industrialization towards more quality in life has led to an increase in demand for high levels of energy consumption. The increasing numbers of vehicles, air-travel, air-conditioning, electrical appliances, electric lighting …etc., are all manifestations for the increasing living standards of humanity today. However, the impact of these changes should not be underestimated. According to the international monetary fund (IMF), research has shown a direct correlation between the economic developments and the access to electrical energy. Figure 2 - 4 shows the energy consumption per head for some countries in relation to their gross domestic product (GPD) in the period from 1970 to 1997. It is evident that through industrialization, the agricultural economy changes drastically into a consumer society, meanwhile, it maintains an increasing rate of energy consumption (Hegger, et al., 2008) and (Lechner, 2015).

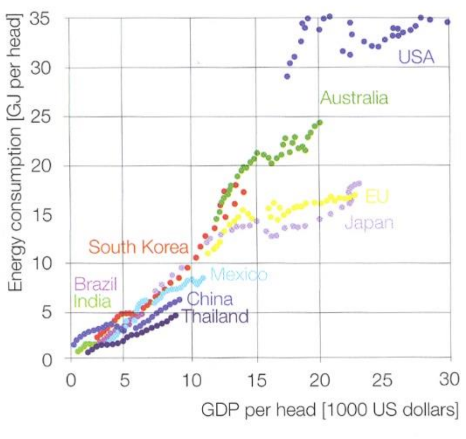

Figure 2 - 4: "Prosperity ladder": the relation-ship between energy consumption and domestic product of various countries in the period from 1970 to 1997 (Hegger, et al., 2008)

2.1.2. Running Out of Non-Renewable Fuel Reserves:

Regarding the developments of the world's energy resources, it is clear that the consumption of energy sources and types have taken place in certain cycles. The structural composition of the 20th century energy resources is characterized by broad mix. However, non-renewable fossil resources are still the primary source of energy; it accounts for nearly 86% of the worldwide energy consumption. The recent rapid increase of energy prices reveals the near end of fossil fuel resources. In addition, the gap between the supply and the consumption is beginning to widen. According to some statistical estimations, the fossil fuel reserves will last 41 years for crude oil, 62 years for natural gas, and 200 years for coal (Hegger, et al., 2008).

2.1.3. Environmental Consequences:

"A hundred years after we are gone and forgotten those who have never heard of us will have to live with the consequences of our actions" Oliver Wendell Holmes, cited from Hegger, et al. (2008, p. 13)

The environmental consequences of the high dependence on non-renewable energy resources were discussed in the Intergovernmental Panel on Climate Change (IPCC), fifth assessment report. The report demonstrated that the environmental consequences and the climate changes that resulted from the combustion of fossil fuels are growing rapidly, and have reached a very critical situation in human history. The global problem is now common; it has gone beyond individuality and requires an international cooperation on many crucial matters in tandem with local, national, and regional policies. The increasing emissions of carbon dioxide (CO_2) and the other greenhouse gasses (GHG) which resulted from fossil fuels combustion have risen rapidly from 2000 to 2010 more than that in the last three decades. In 2010, it has reached 49 (±4.5) $GtCO_2eq$/year with an average growth rate of 2.2% per year, while comparatively, this rate was 1.3% per year over the whole period from 1970 to 2000. The global emissions were temporarily reduced during global economic crisis in year 2007/2008, however, the longer-term trend did not change (IPCC, 2014).

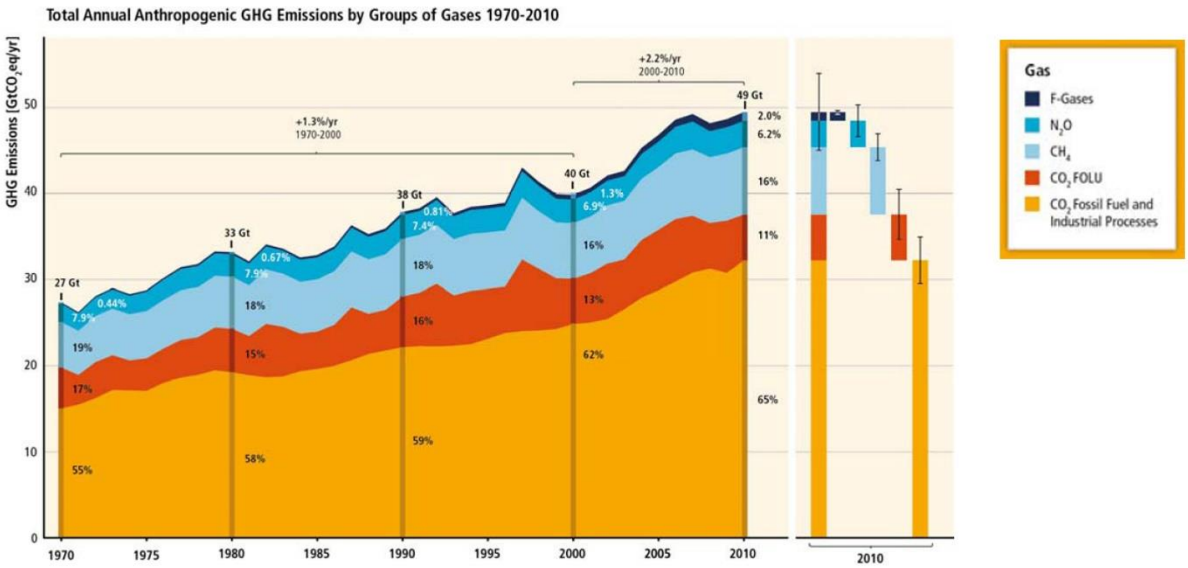

Figure 2 - 5: Total annual anthropogenic GHG emissions (GtCO2eq/year) by groups of gases 1970-2010: CO2 from fossil fuel combustion and industrial processes, CO2 from Forestry and Other Land-Use (FOLU), methane (CH4), nitrous oxide (N2O) and fluorinated gases (IPCC, 2014)

The increased emissions of the GHG has caused a further warming of the earth's atmosphere, in addition to further changes in all components of our climate system. During the last three decades, the earth surface has been warmer than that of any previous decade since 1850. The averaged surface temperature data of the earth shows a warming of 0.85 °C over the period from 1880 to 2012 as represented in figure 2 – 6 (IPCC, 2013). This change has caused diminishing the amount of snow and polar ice caps, oceans are getting warmer and more acidic, sea levels are rising up, and the extreme weathering conditions are repetitive in shorter intervals. Currently, global warming has become a real threat; it places the humankind in an unprecedented situation. In order to avert the uncontrolled effect of climate changes, we all have no choice but to learn how to get along with each other and change drastically our consumption and economic behavior over the next 10 to 20 years towards a more sustained use of planet earth resources, and substantial reductions to the energy consumptions and GHG emissions (Hegger, et al., 2008).

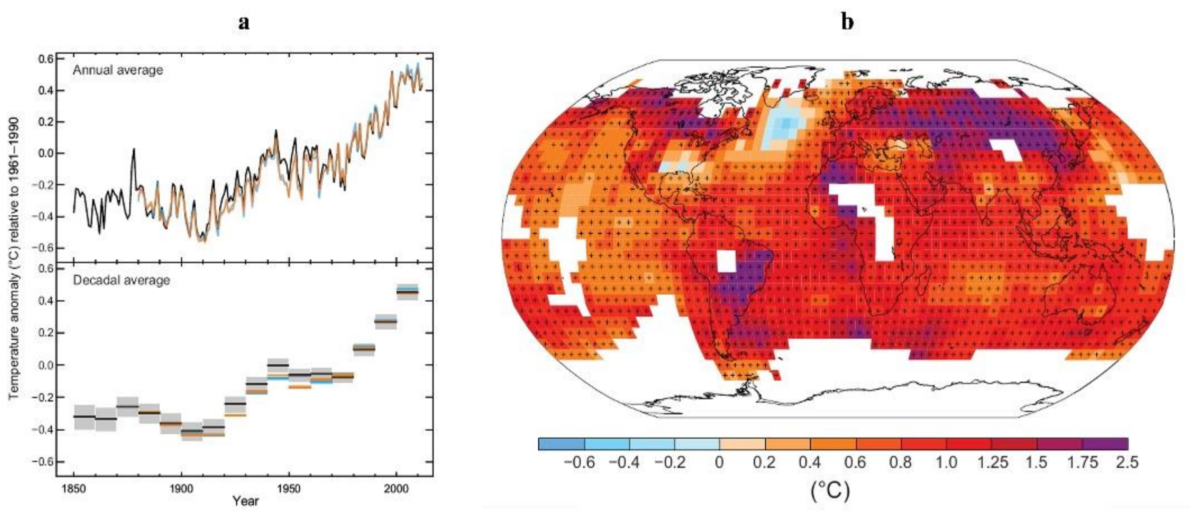

Figure 2 - 6: a) Observed globally averaged combined land and ocean surface temperature anomaly from 1850 to 2012, b) Observed change in surface temperature 1901–2012 (IPCC, 2013)

2.2. Energy in Buildings:

Hamza (2004) noted that energy in buildings is consumed into two categories, which are:

- **Embodied Energy (Grey Energy):** Energy which is consumed during the process of producing the raw materials (locally or imported), transporting it from their different sources to the manufacturing facilities then to site, storing it, transforming the raw or recycled materials into finished products, and in operating the construction equipment.
- **Operational Energy:** It is the principal category of the consumed energy in buildings. It indicates the required energy to operate the building's various systems. Operational energy is consumed mainly to attain internal comfort (mainly thermal and visual), safety, and healthy conditions for

the building's occupants. It depends largely on the building components, systems, site, and the prevailing climatic and environmental conditions.

According to the International Energy Agency, the use of energy in buildings and their associate activities accounts for nearly 50% of the total end-use of the worldwide energy consumptions. Energy used for regulating and operating the internal climate in buildings (operational energy) account for almost 40% (2589 million ton oil equivalent) of the final global energy use in 2004 - 2005, besides some 10% of the end use of global energy is consumed in the process of production of the materials, construction and transport (embodied energy) (IEA, 2008). In addition, nearly 40% of the worldwide greenhouse gases have resulted from the construction and the use of buildings. Moreover, about 50% of all the material that are extracted from earth is consumed in the building sector, and 60% of all the produced waste of the planet comes from buildings and other civil work (Hegger, et al., 2008).

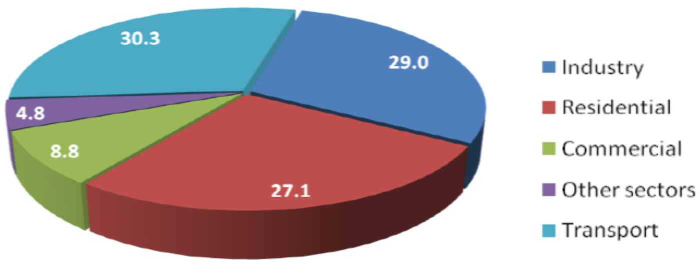

Figure 2 - 7: Share of final end-use of energy consumption in different sectors for the year 2004 – 2005 (IEA, 2008)

Bradshaw (2006) noted that traditionally, limitations to the building design have been imposed by the local site characteristics, prevailing topography, orientation, climatic conditions, its specific budget, preference of the owner, the applied building codes, and the specific regulations of the zone. However, nowadays, energy efficiency should be added as another crucial objective that influences the design process; where careful considerations should be given to the selection of the building components and its operating systems with regards to their energetic performance and the prevailing climatic conditions. The undeniable consequence of our design decisions is that the current buildings within the next 50-year of their functional life and 100-year of their structural life might outlast fossil fuel supplies. Thus, the designers should consider the following challenges:

- Use the minimum amount of energy that can be rationalized by the current economic conditions
- Design buildings that could be weaned away from the heavy dependence on nonrenewable fuels
- Use some shares of renewable energy sources

Altogether, architects, planners, engineers and everyone involved in the construction industry should expect to spend increasing efforts and time in considering the required strategies to reduce energy consumption in their projects. It is advantageous to everyone to construct buildings that consume energy with high rates of efficiency.

Generally, the current situation in the worldwide calls for a reversal of the only emphasis on the technological progress. The efficient use of our resources should be the main feature of the technological advances in our days. This call for a new emerging wave of green technologies that could be considered as the beginning of a new Kondraiev cycle that can offer a following optimistic picture for our future, and might be the biggest hope for the world (figure 2 - 8). The new wave should come up with unfolding suggestion of a new industrial revolution; where energy and resource efficiency, sustainability, and resource productivity should be at its core (von Weizsacker, 2014).

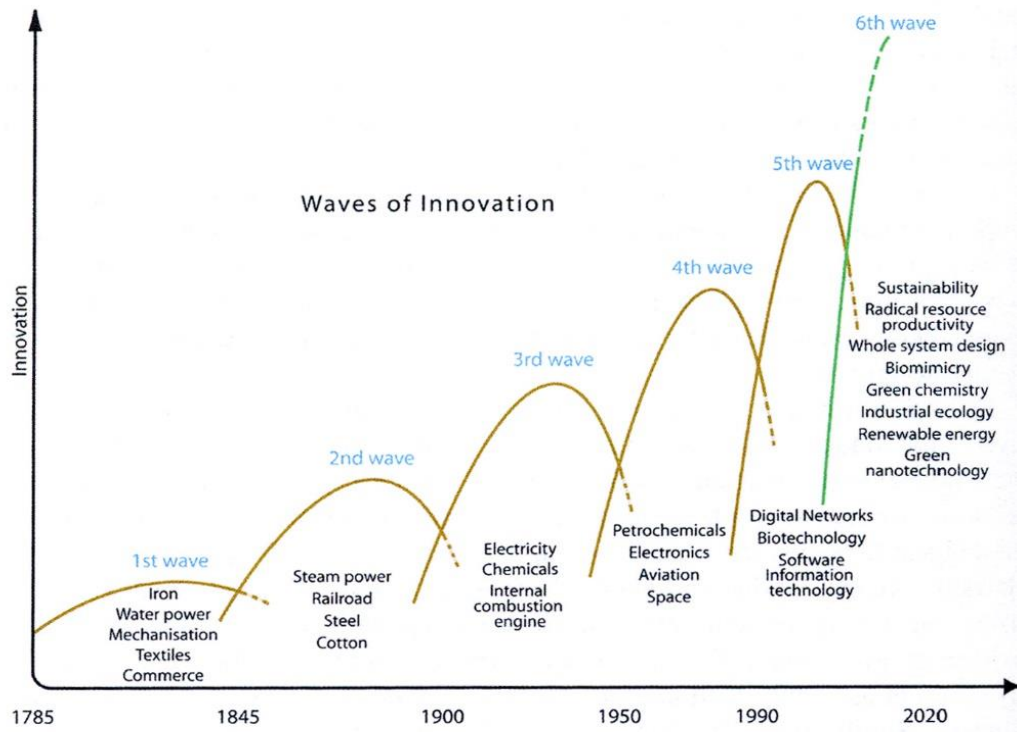

Figure 2 - 8: The five classical "Kondratiev Cycles" may be followed with a 6th green cycle, characterized by sustainability technologies, including notably increased resource productivity (von Weizsacker, 2014)

Chapter III

Review on Glazing in Architecture

3. Review on Glazing in Architecture:

Thousands of years ago, since mankind has learned how to build and he has been in a continuous search for developing new requirements and functions for his buildings. His first priority was to create an enclosure to provide him with privacy and protection. Then, when he searched for a way to transmit light into his enclosure and to provide it with view, he was successful to found glass. Since its discovery, glass has become one of the most remarkable ancient materials that were known and used by the human endeavor. Throughout 4000 years of its known history, glass use has spread across the whole world with its multi-dimensional characters; as it provides a material that is transparent, rock hard, and chemically inert (Wigginton, 1996).

Button, et al. (1993) noted that the transparency of glazing materials is its exclusive function and is considered the most significant property for its use in buildings; it gives us the chance to open our building, alters the correlation between interior and exterior, and between human, space, light, and nature. That's why any other material can hardly match the current popularity of glass as an architectural feature and material among architects.

The evolution of glass applications in architecture was influenced largely by the improvements of glass making technology, including the way of processing material, and techniques. This could be witnessed through the functions or the dimensions that were added by glass to architecture through time which can be classified into four main dimensions: (1) the provision of light, (2) the provision of external view, (3) the provision of a principal architectural element, and (4) the provision of an environmental control. In this chapter, the historical role of glazing in architecture according to the function that it provides will be discussed (Figure 3 - 1).

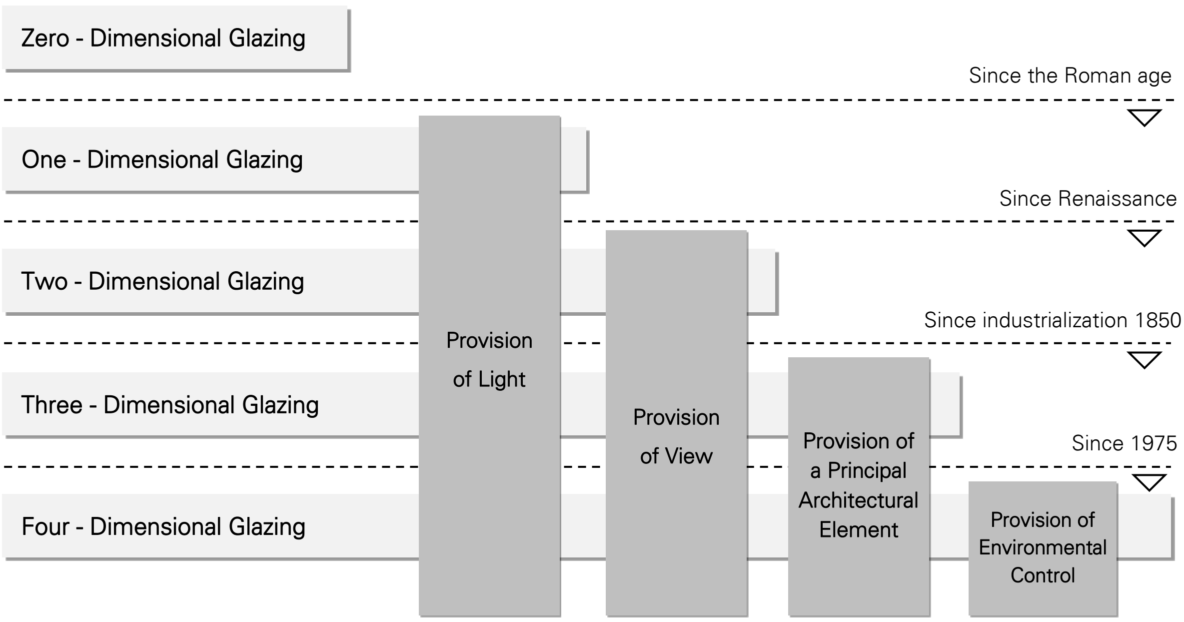

Figure 3 - 1: Review on glazing in architecture

3.1. Zero - Dimensional Glazing:

- *No-Glazing Window*

According to the definition of the Webster dictionary of English language, the word "window" is originally derived from the Icelandic word "vindauga", which means the wind eye. This seems logical, since from ancient times till Renaissance, most of the openings of buildings were not provided with glass (Butera, 2005). Doors are essential for the occupants' access, but windows were considered as a luxury refinement or an amenity that makes the internal space more livable. This explains why they have been subjected to a continuous evolution over history. A smoke hole could be considered as one of the earliest form of window; it allowed for some ventilation, air exchange, enhanced the indoor air quality, and provided a daylight shaft that enlightened the dark interior. However, it also allowed for some undesired heat loss/gain. The shuttered openings came next; it is considered the very first architectural use of windows that found its origin in the need to allow both daylight and air to penetrate into the interior. It was a small hole located on the external wall and limited by the load bearing capacity of the used stone. The hole is usually covered with wooden or an opaque cover that could be opened to afford light and air, or closed for security and protection from intruders, rain, insects and dust. (Carmody, et al., 2007).

Figure 3 - 2: Different forms of no-glazing building openings from the historical El-Kasr village, El-Kharga Oasis, Egypt (By researcher)

The addition of translucent materials to close the opening varies from region to another according to the available materials; such as thick papers, animal skin or bladders, wooden mesh, and canvas, similar materials were additionally oiled or greased to make them more wind proof and water repellent. For more controlled effect, the window closing materials were framed within the opening. The shutter itself might be installed fixed or to a hinged or sliding frames, thereby creating an early sort of operable window (Schitich, et al., 2007).

3.2. One - Dimensional Glazing:

- *Provision of Light*

The one - dimensional glass is the earliest form of glass panes that is used in architecture. It allows for the transmittance of daylight to the interior while affording some protection against the external weathering conditions such as rain and heat. The early glass making techniques placed limitations on the size, quality, and typically the application of glazed panes. Through such techniques, glazed panes were made with very small size and poor light transmission qualities; since its surface were not smooth and the material had air bubbles and many impurities. Therefore, the glass quality in that period was translucent, and couldn't allow for seeing through (Rice & Dutton, 1995)

The Romans were the first to introduce glass in buildings. The early architectural window panes were mounted during the Augustan age in wooden or metal frames. They were excavated in the baths and residential villas of Herculaneum and Pompeii. However, with the turmoil that faced the Roman Empire in the third century AD that led to its declination, glass panes became a very precious product that was only used for religious buildings. In the fourth century, glass applications in architecture had flourished once again in the Byzantine age, as the Glassmakers were confined to monasteries which encouraged them to produce colored stained glass for the windows, a good example is the Constantine church of St. Paul and Hagia Sophia in Istanbul AD 337 (ElKadi, 2006).

Figure 3 - 3: Inside view from Hagia-Sophia, Istanbul (El-Hamoly, 2003)

By the 13th century, the advent of the Gothic architecture liberated the external walls from supporting the loads of the structure. This new development gave an early way to the structural skeleton system with linear beams and columns. Loads of the vault were carried diagonally into ribs, then carried by shafts, piers, and flying buttresses. The vertical wall was evolved into a multi-tiered structure of piers and arches. The unloaded wall spaces were filled with large and colored glazed windows forming narrators of biblical and local cultures. The colored stained glass of the windows opened-up the interior to light and transformed it into something sacred and beautiful showing the glories, and providing an awe-inspiring atmosphere. The glass window of the Gothic architecture acted as a filter between the exterior and the interior; it transformed the sun rays into a mystical medium (Schitich, et al., 2007).

Figure 3 - 4: Notre Dame church, Paris, typical Gothic cathedral (Wigginton, 1996)

The stained-glass windows of the medieval churches became one of the most significant architectural features for this era (El-Hamoly, 2003). Artists and glass makers of that period developed the stained colored glass techniques by adding a thin layer of color over a thick layer of glass. This technique was used to demonstrate the biblical and local cultural stories on the large windows (ElKadi, 2006).

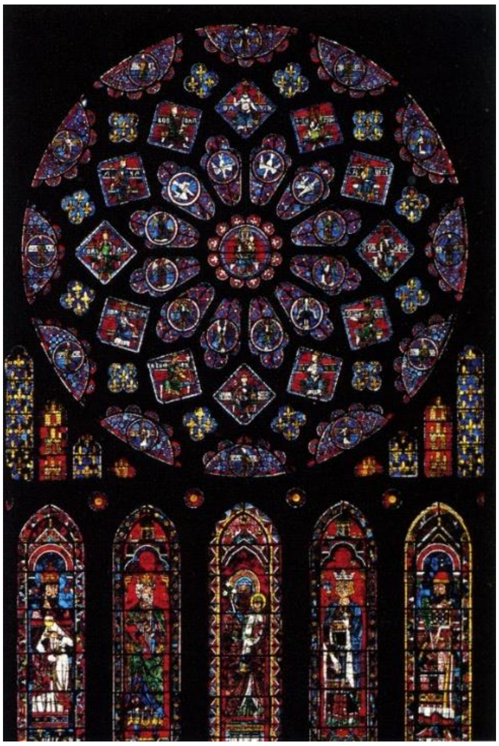

Figure 3 - 5: Rose window in north transept, Chartres Cathedral, 1240 A.D. (Schitich, et al., 2007)

3.3. Two - Dimensional Glazing:

- *Provision of Light*
- *Provision of View*

In the sixteenth century, with the continuous progressive developments in glass-making, glass centers in Europe (Venice, Germany, France and England) succeeded to develop the properties of flat glass panes; making it larger, stronger and finally reached high level of transparency, thus adding view as new function and dimension to glass. The achieved level of glass transparency merely enabled the architects to consider the view out in their designs, and gave them, for the first time, the chance to create the long-desired communications between the inside and the outside. The external environment was therefore allowed to be an important component in the composition of the internal spaces. However, the clarity of the perceived image from the other side was depended on three factors: (1) the smoothness and the quality of the glazed surface, (2) the size of the glass pane, and (3) the purity of the material and the absence of discoloration, air bubbles or other impurities. This led to the widespread of the flat architectural glass panes to meet the increasing demand for transparency, and for the first time in history it became more available and an affordable material for most residential buildings and not just restricted for the monasteries and religious buildings (Rice & Dutton, 1995).

The seventeenth century was marked by the wide spread of glass usage in Europe. The general political and the philosophical atmosphere during that time led to the desertion of the traditional stained glass and the more demand and usage of clear glass. The age of enlightenment and rationalism showed preference to the introduction of clarity and quality of natural light into architecture rather than the aura of mysticism presented by the stained glass; nevertheless, some wealthy and bourgeois societies in Europe remained to value the latter. In addition, the architecture of this era was characterized with its rich decorations and ornamentations in the interior spaces, which typically requires the maximum quality of daylight through clear glass to characterize it (ElKadi, 2006).

The palace and gardens of Versailles by Jules Hardouin-Mansart and Charles Le Brun (1678-84) are such a good example for the architecture of that era. The façade of the transverse wing that overlooks the gardens consists of a long series of repetitive arched windows which almost vanish the external wall, and altering it into an open frame. The composition of these arched openings reappeared again on the opposite internal wall, however, as mirrors. The stream of light that passed through the large openings and strengthened by the reflections of the mirrors made the internal space seem as almost melting away completely (Schitich, et al., 2007).

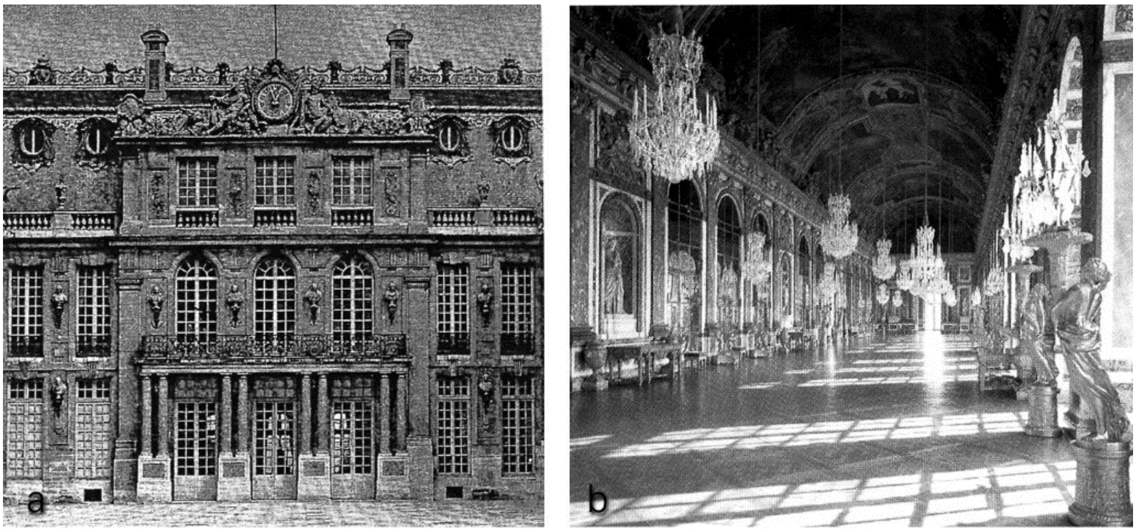

Figure 3 - 6: the palace of Versailles; (a) External view from the marble court (Rice & Dutton, 1995), (b) Internal view from the Galarie des Glaces, in the Palace of Versailles (Schitich, et al., 2007)

However, the main difficulty that faced architects at that time was to break through the heavy loaded stone walls and create large openings; since they were the main structural element that carries the building loads. This was totally changed by the intervention of timber-frame construction where the distinction between the load bearing and non-load bearing members was clearly expressed. The area between the grid of horizontal and vertical wooden members, made it possible to create a series of narrow longitudinal windows separated by timber posts, forming an early style of strip window. The relatively large glazed windows were installed in wooden frames mounted on hinges, and the glass was secured into the frame by a bead of mastic (Schitich, et al., 2007).

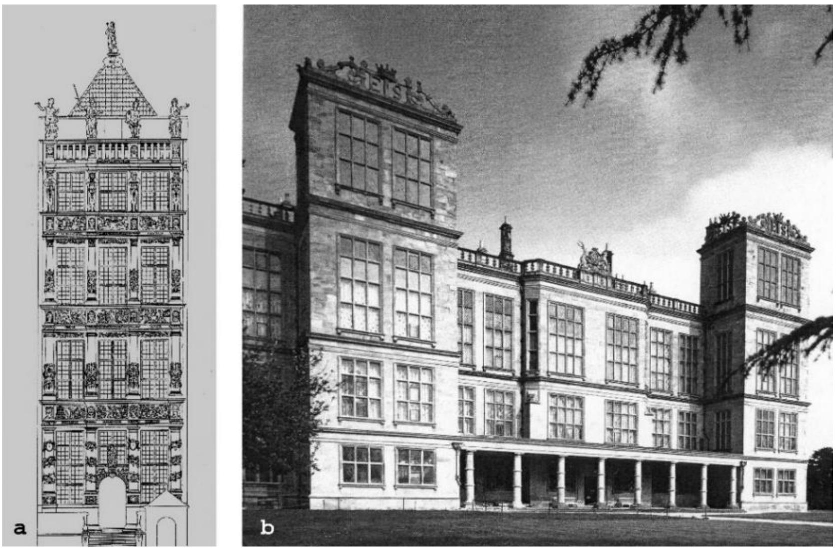

Figure 3 - 7: (a) Town house, Gdansk, 1609-17 (Schitich, et al., 2007), (b) Hardwick hall, Derbyshire, 1590-7 (Wigginton, 1996)

3.4. Three - Dimensional Glazing:

- *Provision of Light*
- *Provision of View*
- *Provision of a Principal Architectural Element*

The next and the most significant dimension was added to glass at the end of the nineteenth century when glass-making technology was completely switched from handmade to the mechanical process. Thus, affording new developments to the physical qualities of the glass panes making it larger and with better transparent qualities. Since then, glass design became not only a functional quest for lighting or searching for view, but also turned into a principal element in architecture giving the building new aesthetic qualities and forming its image (Button, et al., 1993). That time could be set as the evolution period of glass in the architectural design process; this can be showed through tracing some ideas which have enabled it to become less as a building material and more as a principal architectural element across the globe, these ideas are demonstrated in the following points:

3.4.1. The Progress in Building Construction:

Throughout history, dense wall-like load bearing structures have been the principal methods of construction. However, its massive nature severely limits the area of the window. This could not stop the willingness of the designers and architects to achieve larger window openings and to enhance the visual quality of the interior by providing daylight and external views. At the end of the 18th century, in the quest for new building materials, iron emerged as a construction material. The industrial revolution, boosted by technical improvements of the steam engines, improved the ability to produce cast iron, then wrought iron, and later steel and reinforced concrete with higher load bearing capacity. This opened entirely new horizons for building construction and architectural design (Schitich, et al., 2007) and (Button, et al., 1993).

Moreover, through this period, and in correspondence to the society edge trends and demands, new building prototypes and architectural tasks aroused such as; market halls, railway stations, departmental stores, office buildings and palm glass houses. The principal concepts in these new building typologies was to achieve maximum space, offering light, and seeking transparency. The materialistic elements in these buildings were diminished to its minimum freely from any stylistic requirements. The pioneering achievement that could express these ideas was the crystal palace that was built in 1851 by Sir Joseph Paxton. This iconic building became one of the first industrial achievements of mass production. The crystal palace was featured with its economical construction, production organization, supply, assembly, and the extremely short construction period where the 270000 glass sheets were constructed in only 9 months compared to its huge scale. The glass panels were an infilling that were fixed on a lightweight material frames (Schitich, et al., 2007).

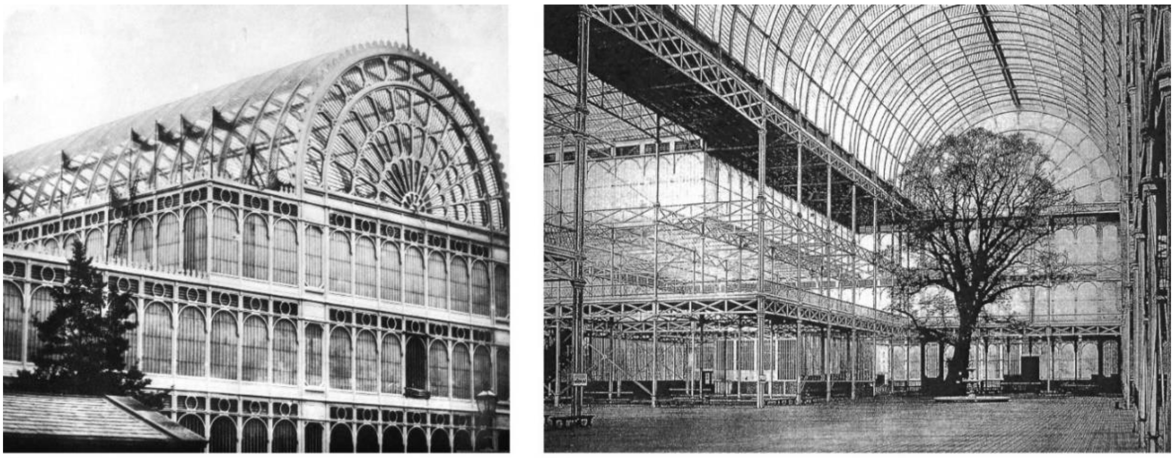

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Figure 3 - 8: The Crystal Palace 1851, (a) external view showing the industrial achievement of mass production (Wigginton, 1996), (b) internal view presents the idea of spatial transparency (Schitich, et al., 2007).

In addition, with the continuous progress in building structures, the heavy load bearing structures were gradually replaced by skeleton structures of column and beams. The interior spaces could then be built larger without the obstructing massive walls; giving them the possibility to be used in various ways. Furthermore, external walls were liberated from any load bearing roles, in which they were transformed from a wall to skin that could be totally erected from steel and transparent glass for admitting natural light and providing external views (Schitich, et al., 2007). Walter Gropius who was one of the pioneering modern architects designed in 1911 the Fagus factory in Germany. It was one of the first examples that were constructed with complete glazed facade supported by a thin steel frame. Followed by his Bauhaus building in Dessau in 1925, Gropius conceptualized the modern ideas that the designers have always strived for; he made it possible for the integration of the inside with the outside through a complete transparent skin. This façade skin itself was flat, continuous, and free from any load bearing function (Button, et al., 1993).

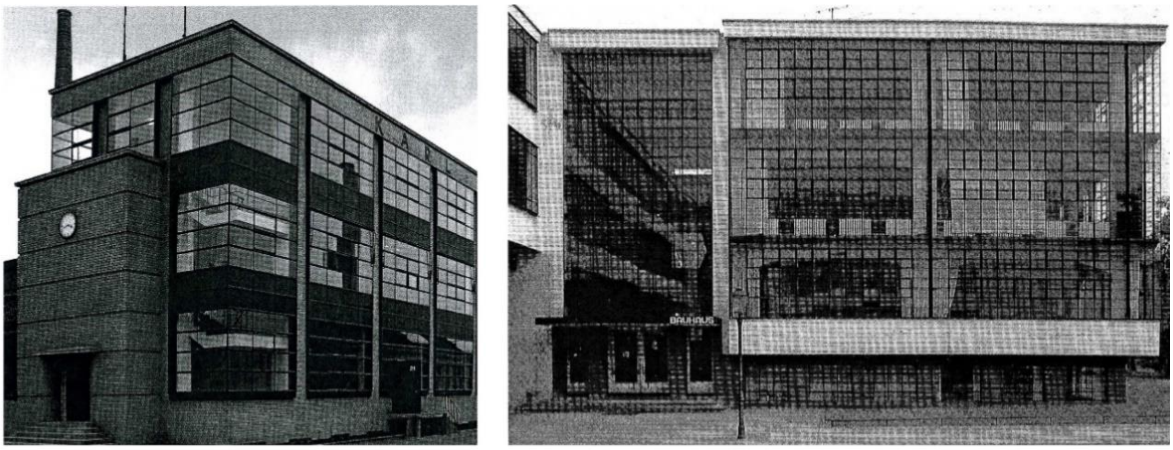

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Figure 3 - 9: (a) Fagus Factory, Germany, Gropius and Meyer, 1911 (Wigginton, 1996), (b) Bauhaus, Dessau, Germany, Walter Gropius, 1925 (Rice & Dutton, 1995)

3.4.2. The Call for Using Glass Architecture:

At the beginning of the 20th century, the idea of glass architecture and the existence of a full transparent façade were in the minds of many theorists and architects; this idea presented an image of what a new era might be. Introducing light to the inner dark spaces was a symbolic act of enlightenment; light was the spirit of the new architecture. One of those theorists was the visionary German writer Paul Scheerbart, who described his dream of a world revivified by glass architecture in 1914 as follows:

"If we want our culture to rise to a high level, we are obliged for better or for worse, to change our architecture. And this only becomes possible if we take away the closed character from the rooms in which we live. We can only do that by introducing glass architecture, which lets in the light of the sun, the moon and the stars, not merely through few windows, but through every possible wall, which will be made entirely of glass" Paul Scheerbart, cited from (Button, et al., 1993, p. 1)

Scheerbart book “Glasarchitektur” (Glass Architecture), expressed his dream to the new movement in architecture. His ideas were very inspiring to the emergent of the modern architecture at a time when mechanical glass production was evolving (Button, et al., 1993).

The above ideas were put into the ground by Bruno Taut; a German architect who was actually the most responsible for adopting and keeping Scheerbart vision of glass architecture. At the end of 1919, Taut initiated a correspondence with a group of 14 architects and called themselves “The Glass Chain” (Die Glaserne Kette), which has been described as the most significant exchange of theoretical ideas of architecture through this century. Despite its short life, the glass chain displayed the need for a new culture of higher levels of thinking with the introduction of glass in architecture and the expansion of its the role for the future. Of course, glass for them was the iconic building material for the modern age due to its capacity to hold and scatter light (Whyte, 1985)

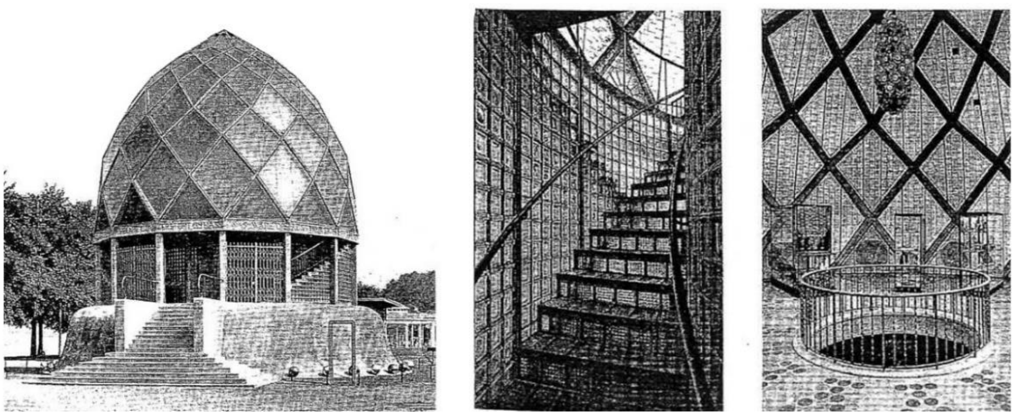

Figure 3 - 10: The Glass Pavilion by Bruno Taut (Rice & Dutton, 1995)

Taut revealed his ideas in his glass pavilion for the Werkbund Exhibition in Cologne in 1914. The pavilion was an educational representation of glass as an available material for almost everything: walls, floor, dome, and staircase, in which all were made of either translucent or transparent glass. However, the significant achievement of the pavilion lied in the intention to place the visitor inside all-glass made space to realize the modulations of the outer skin by means of daylight (Rice & Dutton, 1995).

Taut's pavilion had a significant influence on his contemporary architects. The idea of mastering the usage of glass as an extraordinary material in its own found a continuous inducement in later pioneering architectural works. Glass became no longer a functional material that only admits daylight and view; it acquired new embodied aesthetic and symbolic roles. These ideas had continued through to our present days. The glass skyscraper model by Mies Van der Rohe in 1922, was a further attempt to create a high-rise model with full glazed curtain wall. He intended to express the internal structure of the building, while at the same time illustrate the reflective qualities of glass. Mies curtain wall manifested both the leading innovations of structural design and the fulfillment of Scheerbart futuristic visions (Button, et al., 1993).

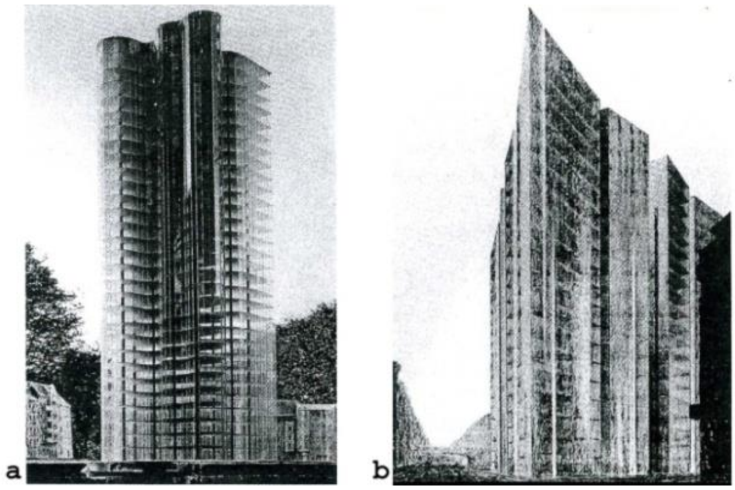

Figure 3 - 11: (a) Skyscraper model project, Mies Van der Rohe, 1922, (b) Friesdrichstrasse Office building Proposal, Mies Van der Rohe, 1919 (Wigginton, 1996)

3.4.3. Modern Architecture Movement:

At the beginning of the 20th century, a new architectural movement emerged from a group of architects like Le Corbusier, Walter Gropius, Frank Lloyd Wright, Mies van der Rohe and many others. Each one of these architects tried separately and in different ways, however, they all shared a common goal. They aimed to create a new architecture; an architecture with new social settings, new ideas, new ideals, free from the excessive ornamentation, and liberated from the traditional building constrains. An architecture that can express itself through the edge achievements of the industry, technology, and new materials. An open architecture that provides the occupants with sunlight, air, and, offers a closer contact with nature. Significantly, glass became one of the most iconic motors of the emerging modern architecture, and a key element which revealed the new concepts such as liberation, external views, natural light, transparency, health, and social well-being. This was clearly apparent in the work of the pioneering modern architects (Schitich, et al., 2007).

Le Corbusier (1907-60) defines the unique and important quality of architectural glass in its ability to transmit light.

> "I use light abundantly, as you may have suspected; light for me is the fundamental basis of architecture. I compose with light" Le Corbusier, Oeuvre Complete, Cited from (Button, et al., 1993, p. vii).

In 1926, he drew up his five concepts of the new modern architecture (Cinq points d'une architecture nouvelle); the 4th among is the long horizontal sliding window. In his famous Villa Savoye (1931), he applied all his concepts and contributed to further development to the external wall through extending the width of the openings and arranging them according to his will freely from any load bearing roles.

Frank Lloyd Wright (1890-1957) work presented a shift towards a new objective in the perception of space; he expressed the idea of the dissolution of the old traditional solid cube-like building. In his architecture, he tried to break-up the barriers between the interior and the exterior that were set by load bearing structures. The defined edge between the inside and the outside was vanished by glass, and transformed into one flowing space. His main principal was to perform "continuity with nature" through blending into the landscape, extending over an open plan, and opening-up the interior to nature (Schitich, et al., 2007).

The work of Ludwig Mies Van der Rohe expressed the idea of the free-flowing space. He tried to develop an architecture of planes with various materials and structures. An architecture that is "evolving from the inside" through the rational methods by reducing the masses of the buildings to individual elements; making the columns bear the roof and the walls were freed from any load bearing functions to act as a partition that define the internal spaces and were made of glass or other precious materials such as thin natural stones. Mies put his modern architecture ideas in pure form for the German Pavilion for world exhibition in Barcelona in 1929; the Pavilion consisted of plates of different materials and structures. Mies used glass to obtain a continuous flow of space as well as to provide an enclosure with little interruption from framing as much as possible (Schitich, et al., 2007).

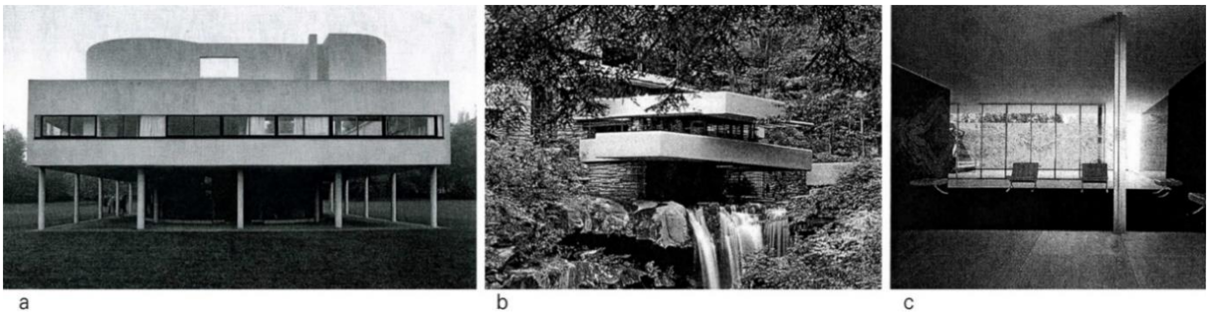

Figure 3 - 12: (a) Villa Savoye, Paris, 1931, Le Corbusier, (b) House of Edgar J. Kaufmann, "Falling water" Pennsylvania, 1935/36, Frank Lloyd Wright, (c) German Pavilion for the 1929 world exposition in Barcelona, Ludwig Mies Van der Rohe (Schitich, et al., 2007)

3.5. Four - Dimensional Glazing:

- *Provision of Light*
- *Provision of View*
- *Provision of a Principal Architectural Element*
- *Provision of Environmental Control*

Since glass became a symbol of the modern architecture, the architect's ambitions to create fully glazed buildings led to its extensive use. The Farnsworth glass house by Mies Van der Rohe was an example of the spreading of such glazed applications of buildings that reflected the radical and concise realization of the architectural ideas of space and aesthetics while giving some justifications to the occupant's needs. However, it also reveals the limited considerations of the modern architecture to the prevailing climatic and environmental issues (Schitich, et al., 2007).

Figure 3 - 13: Farnsworth House, Plano, Illinois, Mies Van der Rohe, 1951 (Schitich, et al., 2007)

In addition, after the 50s, the interaction of the economic, technological and stylistic factors led to the rapid spreading of glazed high-rise buildings. Glazed office towers became a status icon for confident headquarters. Even the skyline silhouette of glazed office towers became a symbol to the prosperous and powerful cities (Schitich, et al., 2007).

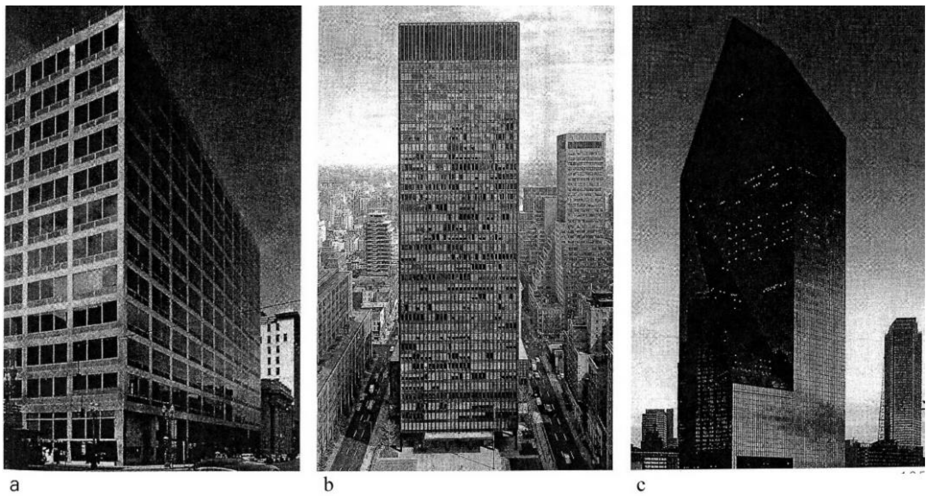

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Figure 3 - 14: (a) Equitable life assurance building, Portland, Oregon, Pietro Belluschi, (b) Seagram Building, New York, Ludwig Mies Van der Rohe, 1956-59, (c) Allied Bank Tower, Dallas, Texas, Leoh Ming Pei, 1983-86 (Schitich, et al., 2007)

However, such entirely glazed building models were only possible to be inhabited through the intervention of active HVAC systems. Architects themselves felt liberated from any environmental constraint. Even more critical, they ceased to consider the basic physical principles in their designs. Thus, producing undesired complications regarding comfort and energy. One of the most significant models that represent these cases is the Cité de Refuge by Le Corbusier. Based on Le Corbusier's ideas of de-materializing the building skin and the call to use glass, the southwest façade of the building was constructed entirely glazed. However, during the summer season, the building was documented as the first case of overheating problems that had serious health consequences on its occupants. Later, Le Corbusier introduced the brise-soleil (which is an external shading based on vertical and horizontal structures) as solar protection retrofit on the southwest façade (Butera, 2005)

Figure 3 - 15: La Cite de Refuge, Paris, Le Corbusier, before and after adding solar protection (Butera, 2005)

However, considering the environmental issues in buildings was rather slow, since architects found an early solution in the development of mechanical air conditioning systems introduced by Willis Carrier and others. They began to take these emerging technologies on-board, which to some extent obscured the solar overheating problems (Button, et al., 1993).

In conjunction with the worldwide energy crisis in 1973, major changes have occurred in the building sector regarding energy efficiency. In addition, in the 1990s, the rise of the global warming issues and the need to reduce carbon dioxide emissions stimulate a new wave of technical and scientific activities. These proceedings accelerated the evaluation of the intensive usage of our natural resources, and particularly energy resources. In the construction industry, new green theories and sustainable concepts were introduced, and hence new ideologies in the façade design was emerged (ElKadi, 2006).

In 1981, Davis and Rogers described what was perceived then as a radical new proposal for the way to design building façades: "We need to develop a new integrated window wall, where all these elements are one, where multiple performance is integrated in one single element. What is needed is an environmental diode, a progressive thermal and spectral switching device, a dynamic interactive multi-capability processor acting as a building skin … This environmental diode, a polyvalent wall as the envelope of a building, will remove the distinction between solid and transparent, as it will be capable of replacing both conditions and will dynamically regulate energy flow in either direction depending upon external and internal conditions, monitor and control light levels and constant ratios as necessary at all points in the envelope. The wall would be capable of energy transfer along its surface adding to or removing energy from building zones which are too hot or cold, trading energy surplus for energy need" (ElKadi, 2006, p. 23).

The concept of environmental control (4th Dimension) and energy efficiency became more apparent and a keyword in the whole role of glass in buildings. In addition, with the sophistication of the building service, and the increased demands of comfort levels, the façade function was re-evaluated as an environmental modifier to the external conditions. Architects switched to seek for an environmentally responsive glazing concepts to regulate the thermal performance of the façade. Glass products were developed in a direction creating a new series of energy-efficient and intelligent glazing concepts with enhanced environmental performance. Thus, significant glazing materials and innovations have been introduced. Glass manufacturers began to develop new high and medium performance coatings that enabled them to achieve some control in terms of visible light transmittance, solar reflectance and solar heat gain such as low emissivity solar coatings, switchable glazing for solar gain attenuation, as well as multiple glazed panes with inert gas infill for better thermal insulation (ElKadi, 2006).

Chapter IV

PSYCHOLOGICAL VALUES OF TRANSPARENCY

4. Psychological Values of Transparency:

According to The American Heritage Dictionary of the English Language, the word “psychology” is defined as “The science that deals with mental processes and behavior”. In other words, it is the summary of human emotional and behavioral characteristics including how humans think, need, feel or behave (American Heritage Dictionaries Editors, 2011, p. 5846).

Leather, et al. (2010), Evans, et al. (1994), Vischer (2007a), and Thayer, et al. (2010) investigated the effects of the physical environmental design of office spaces on the occupant’s psychology, perceived comfort, level of satisfaction, and general well-being. They all accentuate that any feature of the physical environment works directly and/or interactively with either (a) the psychological work environment or (b) other physical elements. These features profoundly impact the occupant’s behavior, arousal level, physiological health, occupational physical stress, productivity, job satisfaction, and their overall working performance. Cooper, et al. (2009) added that the lighting level, view from the window, air quality, and noise level are cited as the most physical properties that likely to positively or negatively influence the office workers’ general wellbeing depending on some demographic characteristics, such as gender, and other office design issues (e.g. open-plan versus segmented office layout).

Vischer (2007b) added that the concept of workplace environmental comfort links the psychological aspects of the workers’ behavior and their level of satisfaction with physical features of the working environment. This is revealed in concrete outcome measures such as task performance, strain and employee health. Vischer proposed an environmental comfort model for working spaces that comprises three hierarchically related comfort types:

- Physical comfort: Covers the basic human needs that are necessary for the habitability of any building. These needs are assured by the responsible building design and operation, as well as by meeting standards of health and safety for the work environment.
- Functional comfort: Defined in terms of providing the required comfortable conditions for users to perform their work-related tasks and activities. It calls for the need to invest more in good workspace design and quality management in order to add more value to the performed work.
- Psychological comfort: Determined from linking the environmental design and management of the workplace with the occupant’s feelings of satisfaction, belonging, ownership, privacy and control over the workplace.

Each type of comfort could be assessed separately. However, their interaction together determines the occupants’ moral satisfaction and general well-being as well as the effectiveness of task performance, as shown in (Figure 4 - 1).

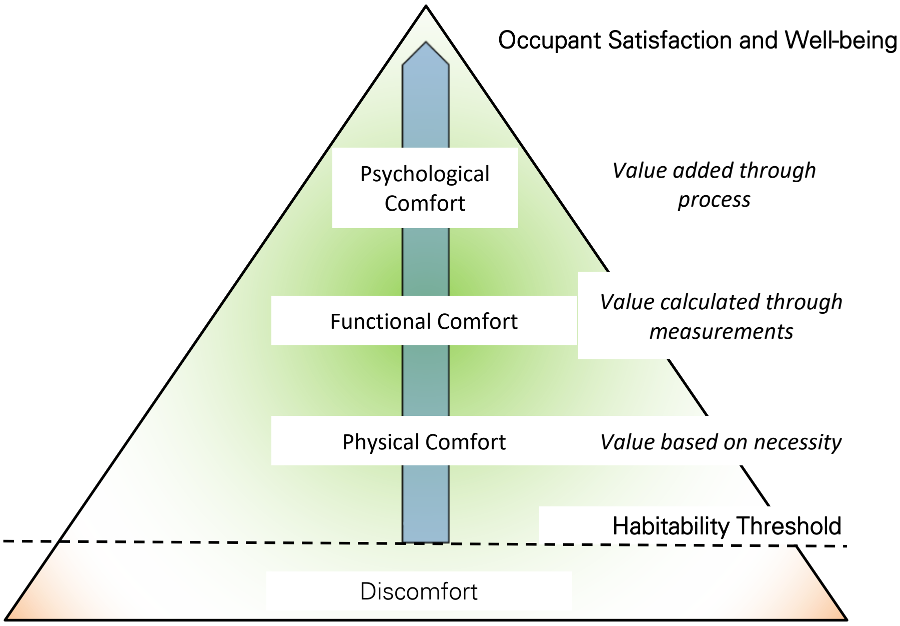


Figure 4 - 1: Ranges of environmental comfort, from basic habitability to optimal well-being (Vischer, 2007b)

The glazed component of the building's façade is one of the most crucial and valuable elements that influence its internal working environment. Throughout the long history of progress in glass manufacture, its roles came into more complex. It involves introducing daylight, providing opportunities for visual surveillance to the outside world, affording ventilation for mass cooling and air quality, providing heating from the solar radiation, giving some privacy, and acting as a climate moderator, noise barrier, and protector from glare. In addition, it also had an important impact on the total energetic performance of the building (CIBSE, 1999). These roles could be classified for the building occupants into two main categories: first, quantitative physical categories that affect the human physical comfort including lighting level, heating, cooling, ventilation and energy consumption, and second, qualitative and subjective category, which have a psychological impact on the occupant's sense of satisfaction and general well-being which includes access to daylight and visual contact to the outside. The designer should be always able to reconcile the conflicting demands of these roles (Tabet Aoul, 2004).

Literature review shows that the importance and the psychological benefits of windows are, in fact, not only a function of personal preference, but also have remarkable effects on the worker's health and general well-being. Workplaces with windows overlooking the external environment have been found to afford beneficial and restorative effects for the workers. Moreover, workers with better access to windows report, on average, better comfort conditions and increased job satisfaction. Different surveys on employees demonstrate the reasons of their preference for windows in their workplaces; it includes access to monitor the weather conditions and seasonal changes, provides information to the outside world, visual relief and generally, it enhances their mood (Soliman, 2000).

In an extensive study attempting to describe the psychological interaction between transparency and the building occupant's satisfaction, Markus (1967a) surveyed 400 workers on nine floors of a 12-story open-plan office building; he found that 95% of the occupants preferred daylight to electric lighting. In addition, workers sitting closer to windows showed more satisfaction than those sitting farther, particularly on the lower floors. He attributed these results to the fact that workers psychologically value the external view or to the availability of natural sunlight which they perceive.

In the same context, Yildirim, et al. (2007) study provides further evidence to demonstrate the role of windows in characterizing the physical working environment. The study explored the effects of windows proximity on the occupant's perceptions in open-plan offices through three environmental measures are: the general planning, privacy, and lighting since open-plan office occupants are usually subjected to a lack of both visual and acoustic privacy through some increased amount of unwanted distractions and interruptions. The result of the study indicates that having access to windows in the workplace, with the required daylight and outside view conditions is usually beneficial to the occupants' perceptions; it affects their sense of satisfaction with their workspace environment. Moreover, the proximity to windows was also found to be a significant positive predictor of the occupants' satisfaction; it somehow buffers the mentioned negative aspects of open-plan offices. Whereas workers who sit away from a window show negative satisfaction toward their working place planning and privacy; they were found to complain more of being disturbed by their nearby colleagues.

Through studies on scaled models under artificial sky conditions to investigate the criteria of the interior space spaciousness, Inui & Miyata (1973) found that the concept of spaciousness is not just related to the room size, shape, internal level of illuminance, or its color. One of the basic functions of the window is to provide the occupants with the required level of satisfaction and spaciousness by providing the adequate visual link between the interior and the exterior. In addition, the level of spaciousness was mostly correlated to window size; in which rooms with a larger window size provide the occupants with greater satisfaction and better effect on the perceived spaciousness. They also found that spaciousness is less affected by the building orientation and the closeness to other buildings than are other criteria such as view, sky illuminance, and the sunshine. These results are consistent with the studies of Ozdemir (2010) in the same context.

Leather, et al. (1998) investigated both the direct and indirect effects of windows in the workplace in relation to three outcome measures are: the worker's well-being, job satisfaction, and intention to quit the organization through examining the impact of three specific influencing mechanisms are: the general illumination level, penetration of natural sunlight, and the accessibility to visual content. The study also investigated the extent to which these three environmental features might modulate the negative consequences which result from job stresses. The study was surveyed on a sample of 100 employees in a wine-producing company in South Europe at the Mediterranean region. The results report showed considerable support for the crucial importance of windows in the workplace. Moreover, the willingness for windows is more than a matter of simple preference; it is a fundamental requirement to the emotional and psychological general well-being. The study also showed the significant and direct positive effect of sunshine penetration on the research three outcome measures (worker's well-being, job satisfaction, and intention to quit the organization). While, there is no effect was found for the general level of illumination. The view of natural elements or rural views such as trees, vegetation, and plants was found to provide the employees with relief from the negative impact of job stress and buffer the intention to quit; it was also found to have a considerable effect on their general well-being.

Laurentin, et al. (2000) argued that the perceived visual comfort condition in any building is not only a quest for applying the appropriate illuminance levels, illuminance ratios, or color temperature, but also requires a much more complex interaction between several parameters. The main parameter is most likely to be the presence of windows in order to provide the occupants with the preferred conditions of daylight and view to the outside followed by other physical environmental conditions such as thermal conditions (temperature) or illuminance levels.

Previous research work that addressed windows preference confirmed that the presence of windows is generally preferred by the building occupants', in addition, larger windows are even the most preferred. However, no theoretical model of window preference factors has been proposed before. Butler & Biner (1989) examined the window preference in 14 common spaces in terms of size, number, and degree of transparency to determine the factors that may govern these preferences from a list of 18 potential factors. The results of the study showed that window preference factors vary more widely than was indicated in the previous research work. For office spaces, five major factors which influence the occupants' preference to windows were reported. According to their scores, they are respectively ranked as follows: (1) provides view to the outside for temporal information 80%, (2) improves task performance 76%, (3) enhances mood 73%, (4) provide sunlight 70%, and (5) allow view to the outside to see others 64%. The research also demonstrates that the required windows in any space can be reliably predicted by knowing the degree of importance of these specific factors to the occupants.

On the other hand, research on windowless space indicates that people generally prefer to be in windowed office environments. While occupants that are working in environments which lack windows show decreased productivity and working inefficiency besides signs of depression and negative job satisfaction (Abdou, 1997). In their research on windowless environments, Wayon & Nilsson (1980) found that windowless conditions for people whose jobs are sedentary or routine may be particularly bothersome; they feel static, restricted and missing sense of stimulation due to their routine jobs more than those who work in active jobs that allow them to move around their workplace. Heerwagen & Orians (1986) added that studies in windowless offices have found that workers tend to have some adverse psychological consequences; they feel tense, depressed, and restricted. Moreover, they show less positive feelings about their jobs and their physical working conditions.

In a questionnaire survey study, Nagy, et al. (1995) investigated the psychological reaction of the Japanese office workers to underground and aboveground offices with regard to the perceived importance of windows and the perceived lighting and visual conditions. The results of the study showed that windows are highly desired in office spaces, especially by employees who are disadvantaged from having windows. They also reported dissatisfaction from their lighting conditions. In addition, the study concluded that the workers' need for windows and their perception of the lighting conditions are highly influenced by the psychological awareness of being windowless. Furthermore, it suggests that the occupants' reactions towards windowless spaces are widespread, and not influenced substantially by cultural or climatic conditions. It is, therefore, argued that windowless spaces for office use should be avoided. However, if their utilization is necessary, the occupants' psychological interaction should be considered to a greater extent during the design process.

Heerwagen & Orians (1986) research investigated the use of visual material to decorate both the windowed and the windowless office spaces. The results showed that occupants of the windowless spaces use almost twice visual materials to decorate their offices than did the occupants of windowed spaces (195 versus 82). Furthermore, the materials used in windowless offices were more dominated by contents of natural themes and landscapes with fewer cityscapes.

The absence of windows and the poor physical working environment had a crucial impact on the workers' health and their physiological measures. Thayer, et al. (2010) investigated this hypothesis; the results of the study presented an important evidence that the physical work environment altered physiological measures associated with some negative health effects of the increased work stress, even without the subjects are being consciously aware. The study found that persons working in office spaces characterized by poorer subjective features such as less daylight and less access to window views, have a decreased diurnal variation in heart rate variability (HRV), including less HRV at night, as well as a higher morning rise in cortisol. These are the same physiological responses identified as intermediate mechanisms for the relationship between the work stress and coronary heart disease (CHD). Woo & Postolache (2008) added that the poor factors of the occupational working environment could drive the occupants to depressive mood disorders and even suicide.

The psychological interaction between the transparent component of the building and the occupants in providing their sense of satisfaction, and how it can promote associated psychological outcomes will be discussed in this part of the research through the provision of three main functions are: external view, natural daylighting, and the perception of the glazed office building (figure 4 - 2). However, in most of the studied literature, the word "transparency" as the supreme function of windows was rarely found, most of them generally mean it in "window".

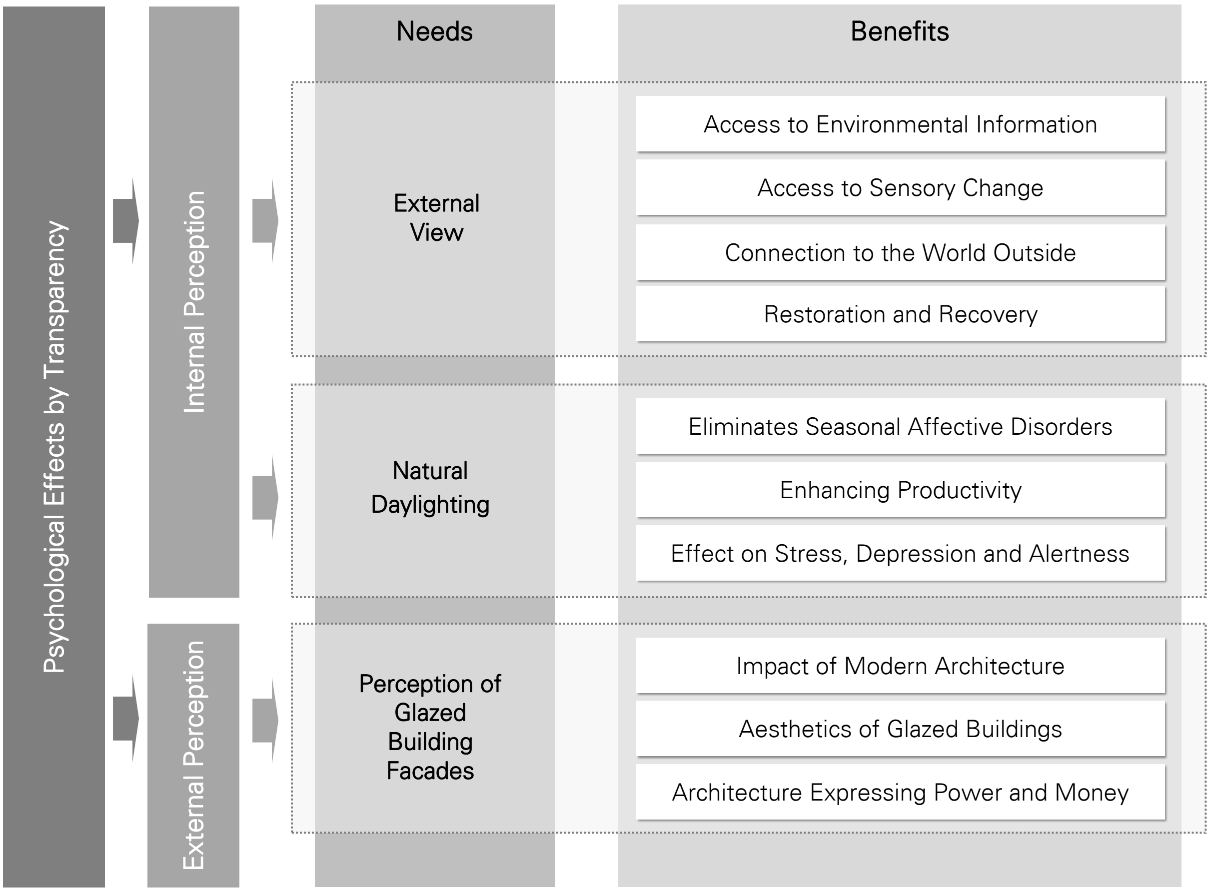


Figure 4 - 2: Diagram of the psychological preferences to windows (by researcher)

4.1. External View:

The visual surveillance to the outside is significantly important; view through windows adds a psychological value to the building occupants'. It affords a dynamic experience to the users that are associated with changes in skylight, sunlight, and season. At its lowest level, a view to the outside satisfies the physiological need of the eye for a change of focus and provides some awareness of the external environment beyond the closed building (CIBSE, 1999).

In working places, views from windows are mostly accompanied by positive impacts on the employee's wellbeing. Most employees agree that office spaces with windows overlooking pleasant view, especially natural content, are more preferred than ones with blocked concrete walls in the basement (Cooper, et al., 2009). Previous research findings in office buildings indicate a direct relationship between higher satisfaction about the office space view and the increased working productivity. On the other hand, occupants of office spaces that lack a visual content to the outside feel more claustrophobic, depressed, isolated, restricted and tensioned. In addition, they begin to lack a clear sense of orientation and less revitalization of the spirit which occurs when they miss the opportunity to witness the outdoor activities (Kim & Wineman, 2005).

Figure 4 - 3: Pleasant view from the researcher window at IEK institute, Stuttgart University (by researcher)

In a study to investigate the critical minimum size of window, and if it could be assessed according to subjective psychological approach, Ne'eman & Hopkinson (1970) found out that when working spaces are provided by the required permanent artificial lighting supplementary, the functions of the window are re-modulated; they became first, the provision of an external view, and second, the provision of some modeling light to enhance the appearance of internal objects. It was also found that the main criterion that identifies the critical minimum size of office windows was more influenced by visual content provided by the outside view rather than by the amount of daylight nor by sunlight penetration.

Wotton & Barkow (1983) research survey interviewed 235 employees in six high-rise office buildings with window to wall ratio that varies from 11% to 68%. The results showed that for the majority of the employees with 56% it is very important for them to be visually linked to the outside world. Furthermore, most of the subjects preferred to have windows located near to their work stations.

Through an extensive field study conducted in the Netherlands, Aries, et al. (2010) used path analysis to investigate the interrelationship between different factors and the occupants physical and psychological discomfort. The studied factors were (1) personal factors (gender and seasonality of mood shifts), (2) building factors (view type, view quality, window distance, and social density), and (3) the perceived environmental factors (light quality, and office impression). The results of the study showed that the view from windows, especially views which are rated as being more attractive, are very beneficial to building occupants' in respect of reducing the sense of physical and psychological discomfort. In addition, the reduced sense of psychological discomfort at workplaces relieves from stress and improves sleep quality, indicating that the physical conditions at work can completely influence the human life and the general well-being of the individuals.

In order to understand more fully the relationship between people and view through windows, Heerwagen (1990) demonstrated in the following points four kinds of psychological benefits of view through windows that vary in the degree to which we are consciously aware of them:

4.1.1. Access to Environmental Information:

In our past days, the usual environmental data such as time of day, seasonal changes, weather conditions, and other forms of such data were likely to have had an evident influence on the human survival and health. Thus, it typically made sense that our ancestors paid attention to changes in daylight to provide them with time cues, or monitor cloud formations for information about future weathering conditions. Therefore, it is not surprising that since then, weather and seasonal environmental changes were crucial factors, and formed a fundamental human instinct that mankind needed to accommodate with his nature. This function is frequently cited as the primary benefit of windows.

4.1.2. Access to Sensory Change:

The change in the weather conditions whether slow or rapid is a fundamental feature of the natural world. In the previous benefit of view, the change was only necessary for the data that it provides. However, Sensory change provides a pleasurable quality independent of the information it affords. It is a fundamental need to the human perception and essential for the efficient functioning of the brain. Preferred types and levels of sensory change are likely to be influenced by many factors such as personality, mood differences or the context. Static indoor environments are usually devoid of any sensory change; they are kept at constant temperatures, ventilation rates, and lighting levels. In addition, the furnishings and colors remain almost steady over time. Windows provide the occupants with the only way to have some access to change their levels of sensation.

4.1.3. Connection to the World Outside:

The psychological need for the connections with the outside world is not trivial, people working in windowless office environments are often feel enclosed, depressed and shut off from the larger world outside. Even in large scale or well-designed windowless office spaces, the occupants still miss the feel of connection with the outdoors. Windows give the building users the chance to access to the events and monitor the situations in the world beyond our walled boundaries.

4.1.4. Restoration and Recovery:

Medical research and their relevant commentary have long argued that one of the main benefits of windows is the provision of a kind of psychological relief. Previous research that defined the benefits of windows strongly confirmed that views with rural or green nature contents, especially trees, have more restorative and relieving effects on the occupants than windows with views overlooking cityscape or those without nature scenery. Furthermore, the benefits of restoration and recovery could also include milder feelings of pleasure and satisfaction.

In addition to the provided psychological benefits, Osterhaus (2005) demonstrated that research has found that the presence of a pleasant view from the window tolerate discomfort glare which results from the presence of excessive daylight to a much higher degree than that predicted by available assessment methods. Moreover, views to the outside are also extremely beneficial in the reduction of the eye muscle strain by allowing it to shift the eye's focal length from the near field surrounding of the task area towards distant objects and thereby relaxes the ocular muscles; Whereas, various screen-based tasks require frequent eye movement up to 30,000 times per day between display, keyboard, and paperwork with limited change of focus, which can determine in the longer-term eye strain, fatigue, possible headaches and thus causes decreased productivity. Muscular pain may be added to these problems when users try to shift their position to get access to external view or avoid visual discomfort.

The quality of the view is clearly important; some views have exceptional beauty and provide pleasure in themselves. However, any attempt to explore the outside world that would extend our experience of space beyond the window is needed (CIBSE, 1999). Visual content with the natural environmental settings has always been associated with more beneficial effects on the human physiological health and the general psychological well-being. In workplaces, employees who have view from their workstations to natural elements, such as trees, mountains and flowers, have reported less levels of job stress, and higher job satisfaction than their other colleagues who either had no chance to the outside view or could see only the external build environment from the window (Leather, et al., 1998).

Proximity and availability of windows viewing natural environmental contents can boost many desired outcomes and might buffer some negative consequences of job stress and fatigue, even if the employee does not spend a much time in front of it. This provides a low-cost, high-gain approach in the office context that would improve the employee's well-being and their task effectiveness (Kaplan, 1993). Tuaycharoen (2011) added that view with natural environmental settings have some specific preference factors such as mystery, coherence, legibility, and visual complexity. These factors could significantly effect and reduce the undesired symptoms of discomfort glare.

Ulrich (1981) evaluates the effects of visual exposure to some presented scenes, which include both natural and urban scenes, on the alpha amplitude, heart rate, and emotional states. The results indicate that natural views especially water and to a lesser extent vegetation views had more positive influences on the subjects' psycho-physiological and emotional states than that of the urban scenes. Alpha rates were significantly higher during the scenes of natural contents as compared to urban ones. These findings give evidence that the significance of visual contacts with nature extends goes beyond the aesthetic benefits; it encompasses a wide range of psychological and physiological values and benefits.

Markus (1967b) mentioned that the quality of the external view could be analyzed in terms of its informational content in three visual layers, each has its deeper and unconscious significance:

- **Upward layer (the sky):** being the sky and its boundary and the sun, providing us with information about seasonal change, time of the day and the weather conditions.
- **Middle layer (horizontal view):** being the natural or man-made scenes, such as views of the city and landscape which gives us information about the static environment.
- **Downward layer (Close):** being the ground scape activities forming the foreground of the view, it gives visual cues about the distance and hence the scale, this layer comprises the basic human and social portion of the view

Views including all three layers are considered the most satisfactory ones. However, within the city-urban context, the provision of this type of view has become difficult. Horizontal wide windows can guarantee a better view of the external landscape (Altomonte, 2008). Heerwagen (1990) added that there are times, for instance, when occupants of the space may prefer to experience some calming effects, cognitive and emotional tranquility. Distant views with some apparent depth of the visual field, especially natural scenes overlooking to the horizon such as mountains, sunset, and ocean would be then required. These scenes effortlessly capture attention and provide the opportunity of being away, thus relieving the viewer from the negative effects which occur because of being focused for long periods, such as mental fatigue, muscle tension, production of stress hormones, increased blood pressure, and elevated heart rates. In addition, such views give visual stimuli and produce different arousal outcomes. As evidence, in Sclaich bergermann und partner office, Stuttgart, upper rooms with the best horizon view in the building were chosen for mental thinking and brainstorming process, and so they were called in the office "think tank rooms," figure 4 - 4 (Stockhusen, 2015).

Figure 4 - 4: External and internal view showing the "think tank" rooms at the top corner of the building, Sclaich bergermann und partner office, Stuttgart, Germany (by researcher).

Regarding the importance of the psychological role that windows play in providing occupants with visual amenity, it is not possible to quantify the perceived value of a view in physical terms. However, in the field of real estate, a quality view has a returning monetary value. Buildings which overlook a good view normally acquires more rent or purchasing prices. Even if the orientation of the view is undesirable regarding solar heat gain or discomfort glare, and will cost more to offset these effects, it is usually the case that the monetary value of the view exceeds these costs (Hamza, 2004). In their research to quantify the relationship of the building views with its economic value, Kim & Wineman (2005) analyzed the 2002 BOMA (Building Owner and Manager Association) Experience Exchange Report quantitatively. It was found that buildings with more quality views (as defined by high-rise or access to better skyline and cityscape views) have generated higher rental income and assigned more property value measured in dollars per square foot, especially in residential and office building types. These results confirm the idea that quality views have an economic value, and people do consider the psychological as well as the interpersonal benefits of the external view more highly when assigning price or making a choice about their properties.

However, in some specific presetting, large glazed ratios could be associated with several physical liabilities such as solar heat gains, heat loss at night or in wintertime, and discomfort glare that can cause kind of visual disability. In addition, it could create spaces with no enclosure; these issues could have some significant psychological costs that should be better understood (Kim & Wineman, 2005). Heerwagen (1990) added that, although windows provide the occupants with the visual amenity and access to the outside, they also create possibilities for visual exposure. The key to control this effect is to define precisely whether the visual exposure is desired or not. This requires better understanding to the internal context (e.g., the kind of behavior typically performed in the space) as well as the external context (e.g., the character of the surrounding external environment). Levels of visual access to the outside and visual exposure can be expressed in the following four types:

- The golden bowel: can see and be seen
- The ideal: can see without being seen
- The interrogation room: cannot see but can be seen
- The cave: cannot see and cannot be seen

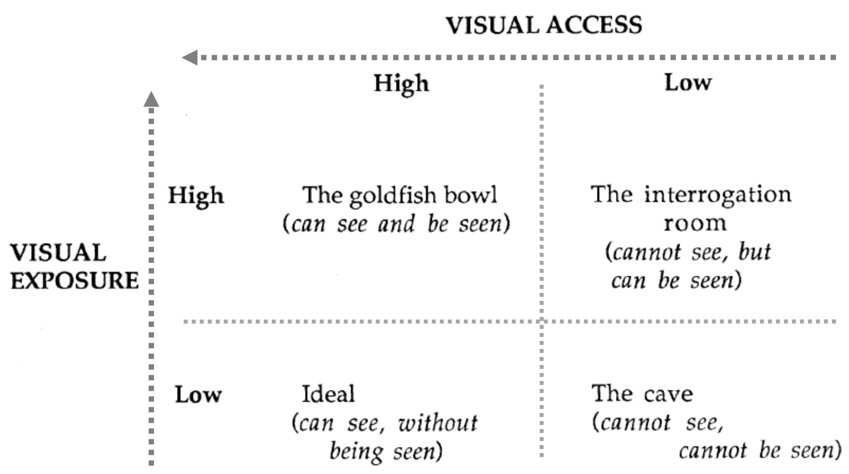


Figure 4 - 5: Visual access and visual exposure matrix (Heerwagen, 1990)

Successful window design should provide the adequate balance between the visual access to the outside and the appropriate visual exposure for the context as well as for the personal preference of the occupants. Heerwagen (1990) indicated that the degree of visual access or exposure could be easily controlled through the manipulation of some physical properties including the following:

- **Features of the window itself**: such as the opening size, placement, the used materials, its opaqueness, the presence of shading elements, and light balance between inside and outside.
- **Nature of the interior space:** such as the area and the dimensions of the space, location in the space in relation to the opening, the presence of any features that obstructs the view-in while allowing visual access out.

4.2. Natural Day-lighting:

"We were born of light. The seasons are felt through light. We only know the world as it is evoked by light…. To me natural light is the only light, because it has mood – It provides a ground of common agreement for man – it puts us in touch with the eternal. Natural light is the only light that makes architecture architecture". Louis I. Kahn quote, cited from (Lechner, 2015, p. 399)

Natural light is an energy that has a crucial biological and health consequences for the human beings; its benefits extends far beyond the ordinary question of the required level of illumination for visual activities. Data surveyed from some laboratory research clearly indicate that daylight is considered necessary for the working performance and general wellbeing, in addition, if the light is controlled properly, it can enhance the human physiology, mood, and behavior. In a survey held on 240 participants to regard their attitude toward sunlight in the workplace, it was found that 84% liked it, 9% dislike it, and the rest were neutral (Abdou, 1997).

From various research, comes the fact that office workers reveal a strong preference for daylight, this could be attributed to two main reasons. First, it is the main lighting source with which they would like to illuminate their work area. Second, for its psychological and physiological benefits that may become apparent only in the long term, however, they are nonetheless factual and should be taken into consideration (Boubekri, 2008).

From behavioral observation of office workers, research found out that those of higher status in an organization are commonly given offices closer to windows or with more windows (Boyce, 2003). Office occupants usually rank natural lighting conditions as one of the most important factors that contribute to their environmental satisfaction in offices owing to its associated high positive value. Research also indicate that natural lighting preference by workers is independent of its contribution to task visibility or illuminance level; employees whose office location is closer to windows assess both the quality and quantity of lighting more highly and show more satisfaction than their colleagues located farther away from windows. Generally, full-spectrum lighting increases the occupant visual acuity, reduce their overall fatigue, and improve their working performance (Wineman, 1982). Besides, the dynamic nature of daylight and its varying characters in both intensity and color have a positive influence on the worker's mood, stimulation and his state of activity (van Bommel & van den Beld, 2004).

Physiologically, the human visual system response to light spectrum is determined by the spectral sensitivity of the three cone photoreceptors and the rod photoreceptor. Each of these photoreceptors has a specific response to a broad range of the spectrum (the covered wavelengths). This implies that the human visual system should use light consisting of many different wavelength combinations in order to be capable of functioning equally well. This issue was further supported by scientific measurements of visual acuity, contrast sensitivity, color discrimination, and other visual functions measured under different light sources with varying wavelength (Boyce, 2003). In addition, studies of the human visual performance also show that providing a daylighting system, even with a modest amount, supports the visual needs of the occupants to see even fine details (Veitch & Galasiu, 2012).

Lighting condition is one of the most important aspects of the office environment, both the quantity and the perceived quality of light impact the occupants' mood, well-being, task performance and work engagement. Some physical measures such as higher levels of illuminance at the work-plane, lighting uniformity, absence of glare, and light directionality are always associated with increasing the employees' satisfaction with the general lighting conditions. However, for the psychological aspects of visual comfort, environmental appearance, and the occupants' amenity, it is well known that daylight is more desirable than electric lighting only. Any access to daylighting generally enhances these functions and improves the general satisfaction of the lighting conditions. In the last decade, daylight was also found to regulate many physiological and non-visual functions in our bodies, such as the human biological clock that drives our 24-hour circadian rhythms of alertness, core body temperature, secretion of some hormones, and affect sleep duration. In addition, the exposure of office employees to bright polychromatic light during daytime increases their alertness, cognitive performance, mood, and vitality, while it also decreases their subjective level of discomfort glare (Borisuit, et al., 2015). In other words, the daily exposure to daylight provides occupants with the needed stimuli to regulate the normal rhythm of life and contributes to the feeling of being well and healthy (Altomonte, 2008)

The exposure to daylight can even eliminate the negative effects of thermal and visual discomfort. Laurentin, et al. (2000) examined the effect of thermal conditions and light-source type on the occupants' visual comfort appraisal. The experiment was performed on twenty subjects; where they were asked to evaluate their visual and thermal comfort conditions at two temperature setups of 20.5°C and 27°C, and under three lighting types are daylight, electric light, and combined lighting at a constant luminance level of 300 lx. The results demonstrated that the light-source types have a crucial effect on the subjects' visual comfort appraisal; it did not only affect their perception or preference of the visual environment but also their perception and preference of the general illumination on their working surfaces. Even the sky conditions were found to have an impact on their visual perception. The results also proposed that the occupants may prefer to work in higher levels of illuminance under daylight or mixed light rather than under electric light only, this is due to the state of luminance equilibrium in the space. In addition, in daylight only, the subjects considered air temperature, lighting level on the desk and the general lighting environment pleasing even if the lighting level on the desk is low and the temperature is more than the comfort margins. This is not the same case under electric lighting, even if the lighting level on the desk was neither low nor high, it was considered unpleasant.

From a series of research that surveyed office workers in England and New Zealand, it was found that working under daylight conditions is mostly preferred by the office workers. This is attributed to the fact that working by daylight results in less stress and less sense of discomfort than working by electric lighting. In addition, working with electrical lighting, particularly in the long term, is detrimental to the workers' health. These results were found to be similar to a survey held on 2950 members of the public attending New York state fair in 1991, where fluorescent lamps were found to be uncomfortable and had some negative effects on people. Table 4-1 shows the office occupants preference ratio to daylight than electric light through seven factors. It is clear that daylight is considered better than electric lighting (which presumably means fluorescent lighting), for all of the seven factors (Boyce, et al., 2003).

Factor	Daylight Better	Electric Light better	No Difference	No opinion
For psychological comfort	88	3	3	6
For office appearance and pleasantness	79	0	18	3
For general health	73	3	15	8
For visual health	73	9	9	9
For color appearance of people and furnishing	70	9	9	12
For work performance	49	21	27	3
For job requiring fine observation	46	30	18	6

Table 4 - 1: Office worker's preference to daylight (Boyce, et al., 2003)

Patterns of various research work confirmed the belief that the exposure to levels of direct sun or substantial daylighting conditions in interiors can have beneficial outcomes for the health and the general well-being (Veitch & Galasiu, 2012). Since ancient times, our ancestors had known the beneficial effects of daylight; for instance, it was used as a heliotherapy, or used as a treatment of some disease by exposing the body to the sun rays. However, Nowadays, many research scientifically explained how daylight mediates and regulates a large number of biochemical operations inside the human body; the most significant are the regulation of the human biological clock that controls the secretions of some crucial hormones through the regular light-dark (circadian) rhythms (van Bommel & van den Beld, 2004). In addition, the exposure to ultra-violet radiation which is a component of normal daylight radiation is essential for the required generation of Vitamin-D under the skin. Vitamin-D has very important functions in regulating cell growth and differentiation. However, our current daily lifestyle that involves long periods of staying indoors has deprived many of us of its required generation. Vitamin-D deficiency has crucial widespread effects on the human health; the most obvious are the bone softening diseases, and increased risk of death due to colon, breast, prostate and ovarian cancer, as well as developing diabetes and multiple sclerosis (Boyce, et al., 2003).

On investigating the effect of the indoor exposure to natural daylight on afternoon sleepiness, Kaida, et al. (2006) found out that the short-term exposure to natural bright light can enhance the levels of the afternoon physiologic arousal, and can wipe out the feeling of afternoon sleepiness. The study recommends that a brief indoor exposure to the natural bright light could be a practical method for office environments in order to regulate the worker's arousal level. Cheung, et al. (2013) further showed that there is a strong correlation between longer sleep durations at night and the quality of the office environment regarding daylight conditions. Office workers with access to daylight have longer sleep duration which counts almost 46 continuous minutes on average per night when compared to their colleagues who had no access to windows.

On the other hand, Abdou (1997) noted that, if the people are deprived of the required daylighting conditions, approximately one in every 20 people may suffer from serious symptoms. These symptoms include lethargy, weight gain, withdrawal, reduced alertness, and increased need for sleep. However, the most crucial effect is that they face difficulties in concentration. Undoubtedly, these symptoms had a severe effect on the working performance of individuals, especially among night-shift workers.

Natural daylight has some combined psychological and physiological effects on the building occupants. Boubekri (2008), Boyce, et al. (2003), Veitch & Galasiu (2012) and van Bommel & van den Beld (2004) addressed these effects and functions in the following points:

4.2.1. Eliminates Seasonal Affective Disorders (SAD):

Seasonal depression which is found mostly among people living in northern latitudes is typically referred to as Seasonal Affective Disorder (SAD). It is a commonly known phenomenon that results because of lacking natural lighting conditions that are related to the human endocrinal system. SAD is an emotional disorder; its symptoms ranged from drastic mood swings, lowered energy, to total depression. Nearly 10% of Finland's population and about 6% of the people living in the United States (especially residents of the northernmost parts, between 45° and 50° north latitude) suffer from these seasonal disorders.

Research found that the secretion of melatonin levels (melatonin: is brain hormone produced at night to help our bodies regulate our light-dark diurnal cycles. At low light levels, melatonin secretion increases, and drowsiness occurs) in people experiencing SAD are higher than normal during the day. Therefore, they sufferers from symptoms of sleepiness, fatigue, and other melatonin-induced effects such as insomnia, weight gain, and craving for carbohydrate. In addition, they are also subjected to symptoms of serotonin deficiency (serotonin: is brain hormone that suppresses the production of melatonin and fosters an alert state of mind) such as negative emotional states and low performance.

Natural daylight serves as a catalyst for the secretion of serotonin hormone. Various research works confirmed the direct relation between the vulnerability of SAD disorders and the exposure to daylight. Higher levels of melatonin secretions that are caused by fewer exposure hours to daylight contribute to this disorder, while higher exposure to daylight lowers this disorder. In addition, the sky conditions can also affect these disorders, where SAD patients reported that their depression is worsening under overcast sky conditions. Researchers now speculate that 80% of the SAD patients could be cured by using the natural daylight as an effective therapeutic agent.

4.2.2. Enhancing Productivity:

In the working environment, the advantages of daylight are not only expressed in terms of health and well-being; proper daylight conditions also lead to better working performance (speed), fewer errors, better safety and lower absenteeism. The overall effect of this is revealed in better productivity. Natural lighting conditions can influence the occupant's performance through three routes explained as follows

- **The visual system (Physical criteria):** The effect of lighting level or the illumination on vision is the most obvious function of light. The interaction between the task characteristics and the received lighting level, spectrum, and the general distribution of light determines to a great extent the level of the achieved performance. These factors give a superiority to daylighting.
- **The Circadian system (Psycho-Physiological criteria):** Basically, the state of the circadian system in humans is influenced by the light/dark or sleep/awake cycles. This variation affects many hormonal rhythms over a 24-hour interval; it accordingly influences the human performance in all tasks and not only visual tasks. Exposure to daylight causes two distinct effects: first, a shifting effect; where the circadian rhythm can be preceded, or delayed by the exposure to bright levels of light at certain times, and second, the effect of the suppression of the melatonin hormone, both effects can enhance the human performance and direct it in right circumstances.
- **The perceptual system (Psychological criteria):** The message delivered by the perceptional system from the retinal image is influenced by many factors, one of which is lighting. The perceptional system starts once the retinal image has been processed by the visual system. Its output affects the observer's mood, social behavior, and cognition. This, in turn, is reflected in

their prolonged working performance, especially when they are upbeat and in a good mood, they typically perform better, and vice versa. A moderate amount of sunlight penetration (between 25% and 40%, as a ratio between the size of the sun patches in space to the total floor area was found optimal for providing the office workers mood with a feeling of excitement and cheerfulness. However, the perceived perceptional image is also interactively affected by the context and the occupants own culture, preference, and expectations.

As evidence, Lockheed Corporation moved 2700 employees to a new facility where its design strongly emphasizes the use of daylighting. After this moving, the employees' productivity increased by 15% and their absence rate decreased by 15% less than that recorder previously. The savings resulted from the increase in productivity paid for the extra costs of adding daylighting features after only one year. In another evidence from Los Angeles, the VeriFone Company reports showed that after just one and half years from moving the company employees to new distribution center that was constructed with extreme care to daylighting usage, their productivity is increased by 5%, and the total product output is increased by 25%. The report also shows that the absence rate declined to 6.8 hours per person/year.

4.2.3. Effect on Stress, Mood and Alertness:

Cortisol, which is also known as the stress hormone, is a corticosteroid hormone that is produced by the adrenal cortex. Cortisol secretion follows the circadian rhythm; it is secreted around waking when activity levels rise and decreases later at night as activity slows. Cortisol hormone is involved in regulating the proper glucose metabolism, blood pressure, insulin production for maintaining blood sugar level, and a healthy functioning of the human immune system. Increasing or decreasing the cortisol level has been implicated in various illnesses. The human body needs cortisol, but only in the right time with the right amount. Awakening in the morning synchronized with the exposure to bright daylight is a strong stimulus to cortisol secretion, which in turn, influences the subjective states of alertness, enhances activity, increases blood sugar to give the body energy and improves its immunity.

Office employees whose workstations are near to windows were found to have higher levels of morning cortisol during summer than in winter due to the frequent exposure to daylight, which, in turn, suppresses the production of melatonin and stimulates the secretion of cortisol, making the employees to feel more alert and vital. In addition, high values of morning cortisol engender a state of more sociability and activeness. Moreover, daylight intensities found in the morning produce the optimal levels of serotonin hormone, which is always associated with a high state of alertness but not stress.

On the other hand, Low levels of serotonin hormone or the day hormone in conjunction with low levels of norepinephrine is the main reason that causes depression. Lack of serotonin secretion may also account for the emotional, appetite, and sleep disturbances associated with the feeling of depression.

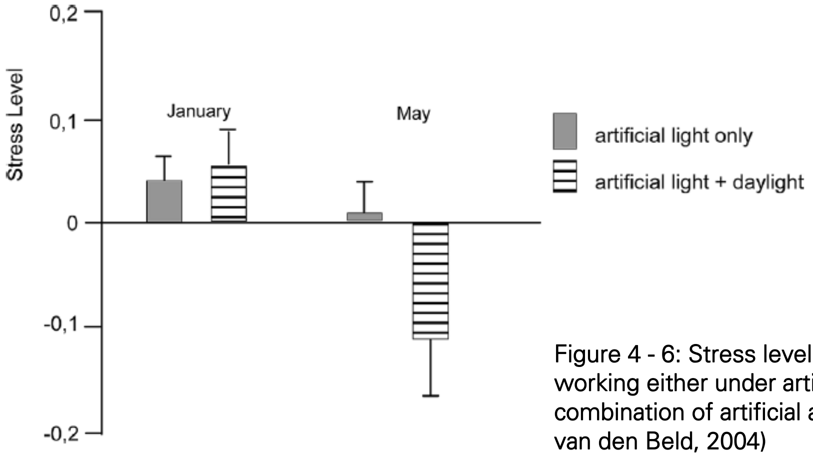


Figure 4 - 6: Stress levels in a group of workers working either under artificial light only or under a combination of artificial and daylight (van Bommel & van den Beld, 2004)

Generally, mounting evidence from studies and research verified that the exposure to daylight has positive outcomes on mood, alertness, social behaviors, and cognitive task performance. This could be explained by many physiological processes involving the circadian rhythms that are regulated by the daily cycle of light/dark periods. Obviously, daylight provides the required intensity, spectrum and timing to regulate the human circadian system; these daily acts stimulate the production of three crucial hormones are cortisol, serotonin, and melatonin. These hormones affect our biological clock and subsequently affect our mood, among many other effects. It is important to keep these hormones in a proper balancing state. These findings, give evidence that because of its various positive contributions, daylight is considered one of the most efficient and available antidepressant agents. In addition, the variability nature of daylighting has also the potential for the generation of a good mood as it always introduces the unexpected directly into the space.

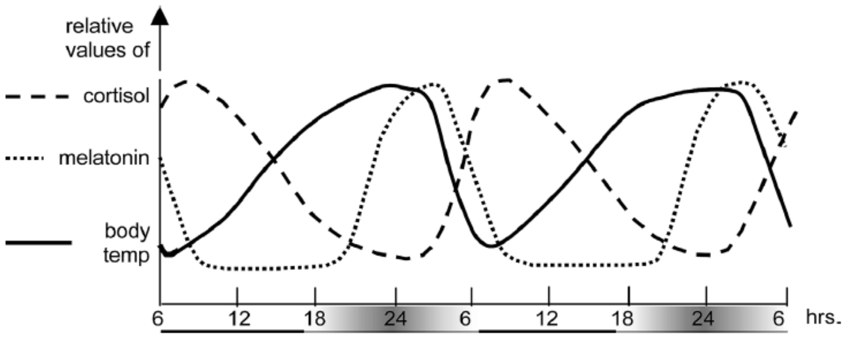


Figure 4 - 7: Double plot (2x24 h) of typical daily rhythms, between relative values of body temperature, melatonin and cortisol in humans (van Bommel & van den Beld, 2004)

However, it is not always an advantage to seek high levels of daylighting; building occupants who are exposed to high daylight factors reports undesired and annoying physiological effects such as excessive glare and overheating problems. According to Heerwagen, et al. (1985) cited from Hamza (2004), the building occupants' anticipation in terms of illuminance could be linked to the thermal conditions and to the prevailing environmental conditions due to some combined psychological effects. For example, it was noted that in summer times, office occupants who work under high temperatures deliberately lowered their daylighting levels, even less than the recommended levels (for instance with blinds closed) without turning on electric lights, as if the light dimness is a symbol of coolness.

The previous assumptions were examined by Yamazaki, et al. (1998). They investigated the interaction of the typical environmental factors for the office space such as heat, light, and sound with the way that these factors affect the occupants' workability through factorial analysis of subjective responses received from the occupants. The results showed that when illumination was low, the sensitivity of the occupants to temperature variations is low, while with increasing luminance their sensitivity to temperature increases. Hamza (2004) argued that these findings could be related to the reactions of the office occupants in hot-arid climates; where they usually close the windows, shut off views and the dim light behind wooden shutters during peak temperature hours in summer. These actions were noticed through a field study to some office buildings in Cairo; the psychological effects of these actions might impact the occupants' general satisfaction

4.3. Perception of Glazed Building Facades:

The building skin plays a crucial and important role as a transition between the internal space of the building and the external urban space; its primary function is to provide protection and enclosure. However, its aesthetic as well as its cultural function is just as important. The building skin and especially its façade is considered as its calling card, no wonder that it always captures more attention than any other component of the building (Schittich, 2006).

External skin or walls of the buildings are usually referred to as "facades". In contrast to its fundamental functions of protection from the external conditions, the perception of the building takes the center stage by way of being its "face." The French word "façade" is derived in a roundabout way from the Latin word "facies" (Herzog, et al., 2008). The Facade dominates the external appearance of any building, it enters a dialogue with its adjacent ones to formulate the urban context. The history of the building envelopes is therefore dominated by features that govern its appearance, proportions, choice of materials, in addition to the prevailing cultural, social and climatic aspects (Hegger, et al., 2008).

(Markus, 1967b) Argued that the preference to the highly-glazed buildings is one of the main criteria that the building designer should consider during window design process. This psychological preference could be attributed to the following reasons:

4.3.1. Impact of Modern Architecture:

Throughout a long history, architects have always aimed to generate alternatives in order to create hierarchical levels of interaction with nature. Evidently, this is witnessed from the work of Vitruvius to the neo-modernist; all have pushed the continued flow of internal and external space to new horizons. Typically, these principals lead to the extensive use of glass in architecture. Currently, Neo-modernists are still continuing on the same path but with rather more considerations for the building environmental performance. Furthermore, some contemporary architects argued that through applying the controlled aesthetics of modernism and its emphasis on indoor–outdoor connections, architecture can give more value to outside space (ElKadi, 2006).

Traditionally, the local circumstances in any region; such as the type of society, the historic aspects, the ethnography, the ideology, the local environment, and the availability of local materials have all played a key role in the formalization of the building envelopes in that region (Herzog, et al., 2008). However, the impact of the modern architecture principals and the call for glazed architecture driven by "the glass chain" at the beginning of the twentieth century (as previously discussed in chapter III) ceased the buildings' cultural and regional identity and led it towards the globalization of heritage. With the advent of the international style, glazed towers had spread throughout the world. The glazed office tower turns into a fundamental assignment in the building industry, and the grid of glazed curtain walls became its icon. Glass architecture was then established on an international scale. The emergence of the uniform glazed curtain walls was boosted by the advances of the conceptual evolution of architecture, the economical investments, in addition, to the technical innovations (Schittich, 2007).

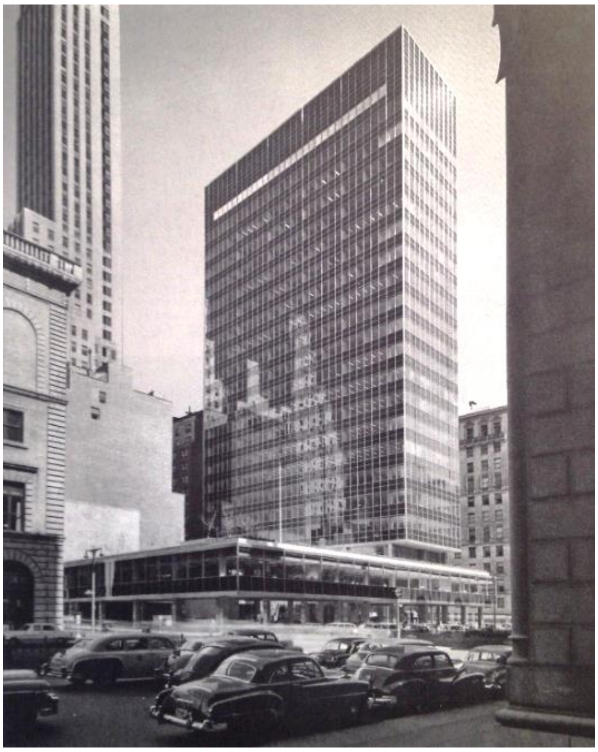


Figure 4 - 8: The principal of the pure glass and metal at Lever building (1951-2), Park Avenue, New- York, by Skidmore, Owings & Merrill (SOM) (Schittich, 2007)

Currently, in many cultures around the world, the construction of highly glazed façades is strongly linked with the concepts of modernization (ElKadi, 2006). Asfour (2007) further explained that the rising in competition towards modernity and the calls for glazed buildings is a strong cultural mechanism that leads to the "social aspiration" of the society toward modern architecture and adopting the western model of architecture. This is clear in the prevailing practice in many parts of the world and especially the Middle East; where architects have evidently accepted the social aspirations of their clients toward modernity and the prestigious and distinguished images. These contemporary buildings failed to cope in line with the traditional urban fabric or even create its own identity. Only a few cities in the Middle East realized this and searched for their own identity in a way that satisfies the social aspirations. They re-defined the terms of the traditional architecture but with rather high-tech imaging of both classical and modern architecture. However, it still seems that one of the easiest ways to practice the alternative approach is to construct a fully glazed high-rise building to show the signs of modernity and to be easily identifiable from all over the city like Al-Mamlakah tower in Riyadh.

Figure 4 - 9: Al-Mamlakah Tower in Riyadh, an example of modern high-tech architecture imaging (Asfour, 2007)

4.3.2. Aesthetics of Glazed Buildings:

In ancient times, Aristotle regarded a building façade as an integral part of the natural order. Beauty during that time was considered as the alignment with the natural order. In the Renaissance era, these understanding of the early the Greek philosophers were enhanced and continued. However, with the advent of the enlightenment era in the seventeenth century, nature was halted to be the role model of cultural production; the definition beauty was disengaged from the study of morals and divine orders to a separate discipline known as the "subject of aesthetics". This disengagement has liberated arts and provided more exciting varieties that re-explored the meanings and qualities of beauty. Later, Neo-classicism, empiricism, and rationalism have replaced the Renaissance principals of emphasizing on the imagination to invention, experimentation, and mysticism; they introduced beauty in terms of geometry, good taste, and proportion. With the innovations in the glass industry, clear glass replaced the stained colored glass to fulfill the need of daylighting and to elaborate the interior decorations rather than being a beautiful material itself. The sequential developments in glass applications and the need for more interaction with nature rather than just observing it built up confidence in its usage for conservatories and glasshouses, and for the first time, the efforts to modify and control climatic conditions was possible by using large panes of glass (ElKadi, 2006).

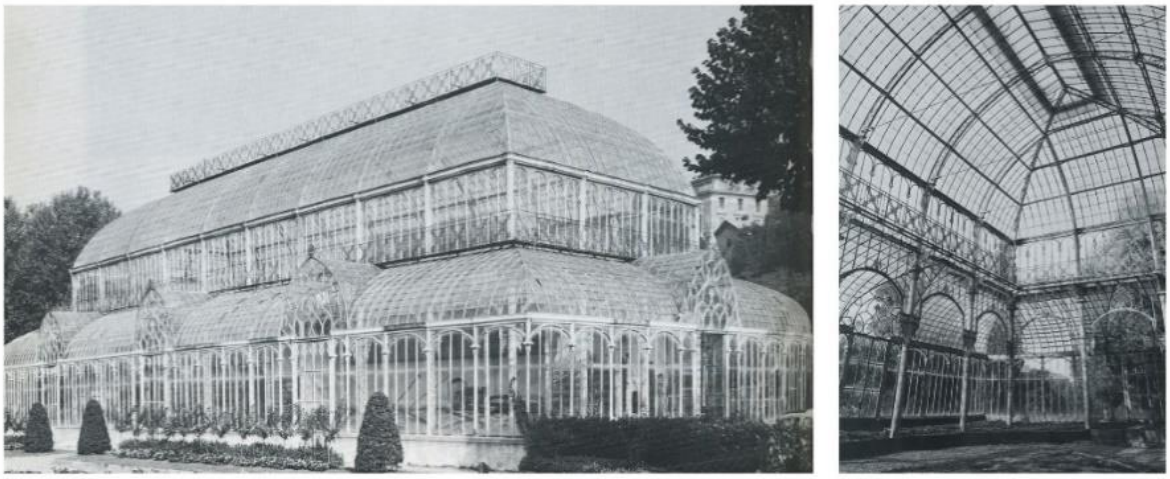


Figure 4 - 10: Giacomo Roster & Orto Botanico palm house, Florence, Italy, 1874
(Kohlmaier & von Sartory, 1988)

With the rise of the industrial revolution in the nineteenth century, the extensive usage of glazed façades had emerged in many buildings types such as exhibitions, office buildings, and many other types; this provoked the discussion on the role of aesthetics in architecture and whether beauty is essential or is an excess requirement. Traditionalists totally rejected the wide use of glass, while modernists viewed glass as one of the new-generation materials that would develop a suitable future for the architectural skin and would provide a more modern discipline. Modernists showed their intention to separate the people from their old culture through the preference of the faceless and culturally independent glazed facades and relate it more to nature. The German philosopher Baumgarten reintroduced the term "aesthetic" as "a reaction to the rational philosophy of Descartes and the mechanistic science of Newton. Baumgarten added that it is a mistake to exclude sensations and perceptions from knowledge and that these sensations and perceptions provide a conception of reality equally valid as Cartesian logic" (ElKadi, 2006, p. 20).

At the beginning of the twentieth century, the glass architecture flourished. New glass technologies transferred glazing from a simple window to solid plain wall and made it possible for the see through and light permeable outer skin. The transparency and the materiality of glass allowed the glazed skin to become alive. The aesthetic accomplishments formed the main focal point. The role of the façade shifted from being a protector from the natural forces to being a manipulator of those forces. Thus, it became has such a high priority as an architectural medium and a vital ingredient of the aesthetics of the buildings (Schittich, 2007). Today, glazed facades have become an established feature of the of the built environment. Glass gave the facades its distinctive appearance and added a new aesthetical value to architecture (Button, et al., 1993)

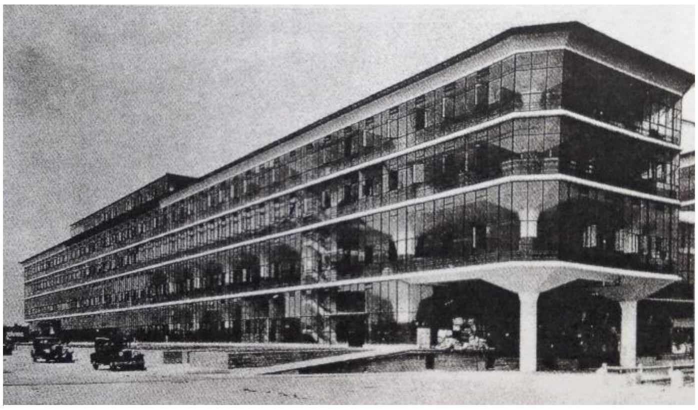


Figure 4 - 11: Boots pharmaceutical factory, Nottingham, 1930-32, designed by Owen Williams (Wigginton, 1996)

However, there is no doubt that glazed buildings give a significant visual character to a building and this, in turn, allows the building to influence the urban characteristics of a place. Glass is one of the most valuable invented materials that formulated the architectural façades; its sensitive use created elegant buildings that manifested the harmony of their beauty with the its surroundings (ElKadi, 2006).

Figure 4 - 12: Art Gallery, Hascher Jehle, 2004 (by researcher)

4.3.3. Architecture Expressing Power and Money:

At the end of the nineteenth century, glass architects continued to challenge the environmental aspects and the specific characteristics of a place. The European mega-structures introduced iconic buildings (such as the crystal palace) through using excessive amounts of glass. Both the form and the materials of these buildings express the cultural power and the economic wealth rather than serving to reflect the functionality and the identities of the users. However, despite their powerful presence, the dominance of these buildings was only temporary. At the end of the twentieth century, and in advance to the progress in the façade technology, most glazed office buildings continued to compete in demonstrating their symbolic power through their heights and forms. The continuous emphasis on these qualities has ended up that many office towers are just looking the same (ElKadi, 2006).

Nowadays, the interaction of the economic, technological, and stylistic factors drives to the wide use of glass in buildings. High-rise glazed office buildings became more fashionable as corporate headquarters, meanwhile, a growing number of multinational groups were emerging boomed with the economical advances. However, regarding their associated negative environmental impact, glazed towers could be seen as an extreme use of architecture that cannot be justified on the functional level, they became rather a status symbol of confident companies, the silhouette line of glazed towers in the city turn into a sign of prosperity and power (Schittich, 2007).

Figure 4 - 13: high rise glazed office towers shapes Frankfurt business center (by researcher)

The contemporary skyscrapers movement in the East reveals a completely different cultural concept from the West; it rather symbolizes the transfer of the economical evolution from the West to the rising East. The unbelievable race to build the world's highest tower is currently taking place among competitors from Malaysia, China, Emirates and Saudi Arabia. The appearance of glazed high-rise buildings in the skyline of many cities reveals a sign to the change in the identity of the urban landscape beyond their traditional boundaries. Contemporary, skyscrapers with their highly glazed façades are considered as iconic symbol for the economic and the political power rather than social power. However, they do not provide themselves any particular identity and bond with the places where they are constructed (ElKadi, 2006).

Figure 4 - 14: Glazed towers in the business center, Brussels (by researcher)

The city of Dubai is a significant model that demonstrate such economic and political symbolic power. Dubai is a relatively new urban settlement, which illustrates the contemporary evolution of the United Emirates, and the way that a centralized and hyper-entrepreneurial approach has characterized the city attempt to ascend in the urban hierarchy and establish itself as one of the 21st century global cities. An analysis of this attempt through the city's contemporary urban evolution reveals the problematic social effects of Dubai's quest for the symbolic power, and the method of applying it to its urban order. Such technique of world-making is influenced by mediating the people's understandings and perceptions to the direction of development (Acuto, 2010).

Figure 4 - 15: A Strip of burgeoning glazed towers that constitute the spine of Dubai (Acuto, 2010)

Chapter V

Solar – Thermal Performance of Glazing

5. Solar - Thermal Performance of Glazing:

In our outer environment, nothing is fixed or can be taken as constant, everything is in a continuous change with its variables; the sun, pressure, wind movement, temperature, humidity, cloud cover, all are among other factors interact altogether mutually. This matter poses a challenge to the architect who strives to place his fixed and rigid structure intending to provide a comfortable internal living condition for his occupants among that wide range of variables (Fathy, 1986).

"A design can succeed in uniting the particular and permanent with the universal and continuously changing. Yet another design, by failing to sense the forces at work or to create a harmonious union, can isolate and alienate human life." (Fathy, 1986, p. 11).

Fathy (1986) describes the discipline of the architect that typically relies on the knowledge of the basic physical principals which explains the interaction of his conceptual design and choice of materials with the prevailing environmental factors. Understanding these principles allows the architect to conceptualize his choices for enhancing the building's energetic performance, and gives him better passive control over the internal environment for its occupant's comfort from the start.

When considering the design with glass as an envelope material, its physical properties should be regarded first. Glass excludes some climatic parameters from entering the building such as wind and rain, while unlike any other building material, it permits the introduction of solar radiation into the interior. The matter that needs a brief understanding to its basic physical properties as a prerequisite to can estimate its role in controlling the energetic performance of any building (Schitich, et al., 2007).

Therefore, it is convenient for the research work to study in this chapter the fundamentals of solar and thermal heat transfer in buildings, the key properties of glazing that affect its energetic performance, and the commonly used heat transfer measuring mechanisms of glazing.

5.1. Fundamentals of Heat and Solar Radiation in Buildings:

5.1.1. Heat Fundamentals:

According to Sonntag & Borgnakke (2003, p. 100), heat is defined as "A form of energy transferred across a boundary of a system at a given temperature to another system (or surroundings) at a lower temperature by virtue of temperature deference between the two systems". Thomas & Fordham (1999) and Bradshaw (2006) noted that, there are two forms of heat in concern:

- **Sensible heat**: A form of heat energy that can be sensed or felt. It is expressed in the degree of molecular excitation (motion) of any given material. An object whose molecular motion is larger is said to be hotter, and to contain more heat.

- **Latent heat**: Is the amount of heat energy taken or released to change the state of a matter. It has two forms, either latent heat of fusion (heat needed to melt the solid state to liquid) or the latent heat of vaporization (heat required to change liquid to a gas). When any gas condensates to liquid or when any liquid solidifies, it releases its latent heat.

The previous definition of heat indicates that it is an energy that is transferred from a material of the higher temperature to another one with lower temperature, and it occurs only because of the temperature difference. Another aspect of this definition is that any object never contains heat; heat can be identified when it crosses boundaries, as a transit phenomenon. The point at which no temperature difference exists between two boundaries is called the thermal equilibrium state, where heat transfer no longer occurs (Sonntag & Borgnakke, 2003). Fathy (1986), Thomas & Fordham (1999) and Sonntag & Borgnakke (2003) demonstrated the normal modes of heat energy transfer as follows:

- **Conduction heat transfer:** Conduction is a process of heat transfer through one material, or from a material to another adjacent one in direct contact due to temperature deference between the two sides. The molecules of the hotter end of the material increase the energy of their vibrations with the rise of temperature, causing collision and sharing energy with the neighboring ones, thereby they become hotter and allow heat to pass through. Or more technically, through the transfer of the internal kinetic energy of the material.

- **Convection heat transfer:** Convection is the thermal energy (heat) transfer through the flow of fluids (liquid or gas). Natural or free convection takes place through the actual motion of the heated fluids; the fluid in contact with any hot surface is heated up by means of conduction, thus becomes less dense and rises upward, meanwhile, the cold fluid replaces the ones at the bottom causing a natural circulation in the fluid current. While convection that results from any process other than variation in densities due to deference in temperature is known as forced convection, such as the movement of air caused by a fan, bump, or by the wind.

- **Radiation heat transfer:** In radiative heat transfer, the matter exchanges heat with the surroundings by emitting an electromagnetic wave generated by the thermal motion of its molecules within a direct line of site. The intensity and the wavelength distribution of this radiation depend on the nature and the temperature of the material. When the temperature of the radiating object increases, the amount of heat emitted from its surface increases, the wavelength of maximum radiation intensity becomes shorter, and the electromagnetic distribution changes so that a greater portion of the energy is radiated at a shorter wavelength.

  When the emitted radiation strikes any surface, it is either absorbed and reconverted its energy into heat, reflected to the surroundings, or transmitted through the material. However, this happens with specific portions depending on the properties of the material, its surface conditions, and the wavelength of the incoming radiations. A perfectly opaque material that absorbs all the radiation falling on its surface is termed a black body, in which it emits radiations at the maximum possible rate for any given temperature. The black body is taken as a convenient reference to evaluate the emissivity, absorptivity, and reflectivity properties of any given material.

5.1.2. Solar Radiation Fundamentals:

The electromagnetic spectrum (radiation) is a directional energy that travels in straight lines at the speed of light in the form of waves, generated by oscillating magnetic and electrical fields. All known matters, which are warmer than zero (0 k or -273 °C) produce a range of spectrum of radiation; these emitted radiation covers a spectrum of wavelengths which varies according to the temperature of the material, its nature, and the conditions of its surface (Thomas & Fordham, 1999). The total spectrum of electromagnetic radiation is divided into bands, each with a specific wavelength. There is no distinction between these radiation ranges other than their wavelength (Duffie & Beckman, 2006).

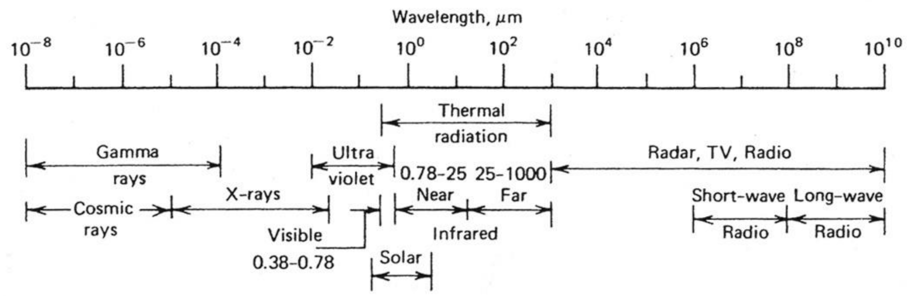


Figure 5 - 1: The spectrum of the electromagnetic radiation (Duffie & Beckman, 2006)

The spectrum of the sun is equivalent to that of a blackbody at a temperature of 6000°C. It produces a wide range of radiation (Thomas & Fordham, 1999). Figure 5 - 2 shows the spectral distribution or the solar radiation wavelength distribution at the earth's surface.

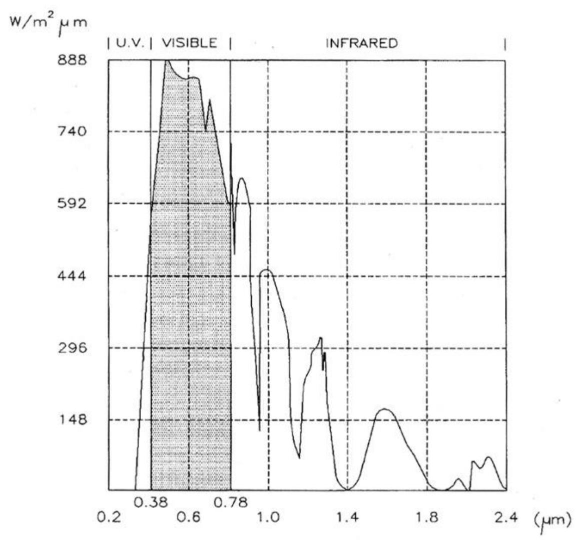


Figure 5 - 2: The spectrum of solar radiation at the Earth's surface (Gallo, et al., 1998)

Schitich, et al. (2007), Thomas & Fordham (1999) and Button, et al. (1993) clarified that the solar radiation received at the earth's surface is divided into three wavelength groups: (1) ultraviolet radiation, (2) visible light radiation and (3) infrared radiation, as follows:

- **Ultra violet radiation:** A small fraction representing nearly 7% of the sun's radiated energy that ranges between 280 – 380 nm. This small fraction is very crucial, as it is responsible for the fading of fabrics, deterioration of paints and polymers, skin burn, and in some cases skin cancer.
- **Visible light radiation**: Is the portion of the electromagnetic spectrum to which our eyes are sensitive, its wavelengths range from about 380 nm to 780 nm. This band forms mainly 47% of the total solar radiation. visible light wavelengths are associated with colors, Figure 5 - 3 shows roughly the average human eye response to the visible portion of the spectrum, where it is most sensitive to the green light at about 550 nm.

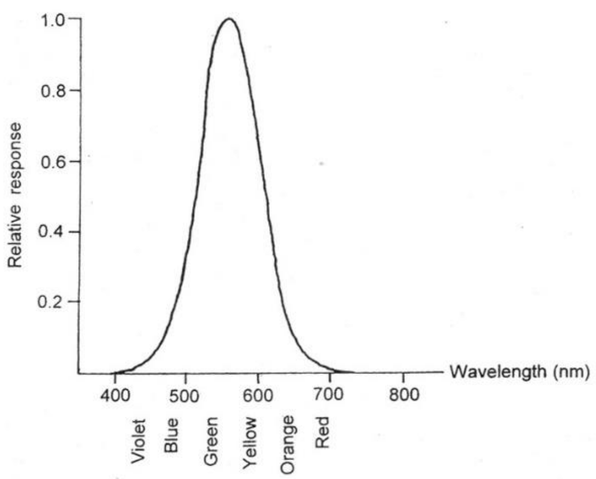


Figure 5 - 3: The spectral response of the average human eye to the electromagnetic spectrum (Thomas & Fordham, 1999)

- **Infrared Radiation:** It is also called heat radiations; it is responsible for providing heat to the earth. Infrared radiation is divided into near and far-infrared radiation. The near infrared radiation ranges from 780 to 2800 nm which consists the remaining 46% of the solar radiation. This portion is invisible to the human eye; however, it can be detected by electronic and thermal means.

The Earth envelope and its atmosphere filter out most of the sun ultraviolet radiation and much of the infrared radiation. Ultraviolet radiation is removed by the ozone in the upper atmosphere layers. While water vapor, carbon dioxide, and the atmosphere absorb varied portions of infrared radiation, either the direct radiation from the sun or the reflected radiation from the earth's surface, and transform it into heat which insulates the planet Earth and keeps it warm. The Earth on average is in a state of thermal equilibrium; it loses the same amount of heat to the universe as it gains from the sun (Thomas & Fordham, 1999).

5.1.3. Thermal Loads in Buildings:

A major portion of the energy used in buildings is disbursed in thermal exchange; either lost or gained to establish the required thermal comfort conditions for the occupants. However, the responsible and efficient design can cooperate in reducing, to some extent, such energy figures. Thomas & Fordham (1999) and Bradshaw (2006) Pointed out that thermal heat exchange affects any building and its inhabitants in two ways, either externally or internally:

- External loads: When there exists a temperature difference between the interior and the exterior, the building envelope acts as a moderator for heat transfer. However, it is not a perfect seal; it allows some sensible heat transmission through it that encompasses the three modes of heat transfer (conduction, convection, and radiation). Opaque envelope materials gain heat either through surface convection, where heat transfer between the outer surfaces and the adjacent air gaps, or by absorbing the incoming solar radiation and transferring them into heat. Once heat became inside the mass material of the wall, it continues passing through by conduction. If there are air gaps within the wall, heat will flow either by convection or by radiation. When heat reaches the inner surface, another convection and radiation processes occur between the surface and the interior. While for transparent or translucent components of the envelope's (such as windows and skylights) heat is gained moreover to the previously mentioned ways through the direct transmission of solar radiation to the interior, thus, heating the internal air, surfaces, and objects. In addition to the heat gain through ventilation or infiltration that results when the outside warm air flew into the building through the openings, replacing cooler air of the inside, which can also transfer some latent loads as humidity. On the other hand, losing heat from buildings occurs through the same process of its gaining, but in the opposite direction.
- Internal loads: Heat is gained internally (sensible and latent) mainly from two sources, either from the building occupants' according to their density and level of space activity, or from their running electrical equipment, appliances or devices including lighting, computers, cooking machines and many others, since some portions of the energy supplied to any device ends up as heat, even when there is a useful intermediate stage such as light or a moving fan.

(Bradshaw, 2006) presented the building's heat balance can in the following equation:

$$\pm M = I + S \pm T \pm O$$

Where: (M) = mechanical heating (-) or cooling (+), (I) = internal gains, from people and any other energy using appliances or equipment, (S) = solar radiation heat gains, (T) = transmission of heat through the building envelope, loss (-) or gain (+), (O) = outside air load (ventilation) loss (-) or gain (+).

From the previous equation, when I + S do not equal ± T ± O, extra heat should be gained or removed by M in order to maintain the required temperature and humidity level for the occupant's comfort (Bradshaw, 2006). Basically, the design should contribute to create buildings that achieve the required passive balance between all these contradictory factors if anyone is given too much emphasize (Thomas & Fordham, 1999).

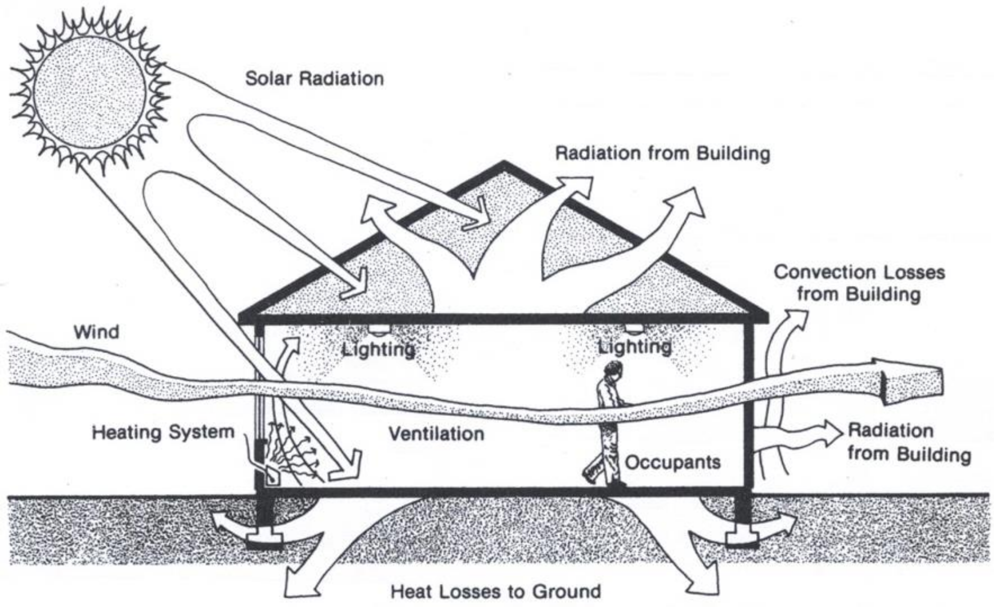


Figure 5 - 4: Heat gains and losses in buildings (Bradshaw, 2006)

5.2. Solar Properties of Glazing:

Carmody, et al. (2007) Noted that, solar radiation received by buildings envelopes is a mixture of direct sunlight, diffused skylight, and reflected radiation from the ground and other buildings or surfaces; when this radiation strikes any glazed surface, it is either absorbed by the glass, reflected to the outside or transmitted into the building with different and relative portions. Yellott (1979) Further explained that when the beam of solar radiation strikes any glazed surface at an incident angle θ, which is the incident angle with respect to a line perpendicular to the glass surface, a fraction of the incident radiation is reflected back with an angle equal to the incident one, while the remainder of the radiation is refracted towards the normal and enters through the glass pane. The angles of incidences and refraction are specified by the reflective index of the glazed material composition. The refracted beam proceeds through the glass pane losing some of its radiative energy by absorption within the pane till it reaches the inner second surface, where it is either transmitted to the inside space with another refraction to resume a parallel path to the original direction but slightly displaced, or another reflection will take place at the angle of refraction, and it will undergo both absorption within the glass and reflection at the next glass - air interface but with different portions. Thus, the solar ray undergoes a series of multiple reflections and absorptions until no energy is left (Figure 5 – 5).

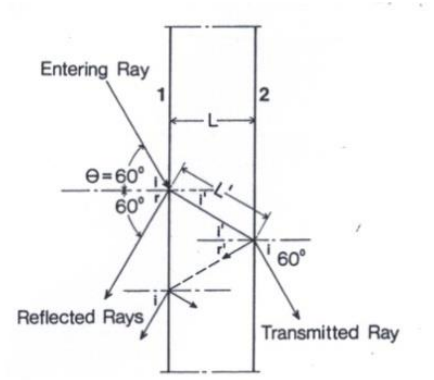


Figure 5 - 5: the path of solar rays through glass (Yellott, 1979)

Transmittance, reflectance, and absorptance are the three key properties of glass that determine the energy performance of any glazed envelope. They depend mainly upon the composition of the glazed material, its thickness, the number of layers, size, the quality of its surface, the wavelength of the incident radiation, glazed surface treatments, and the angle of incidence (θ) between the line normal to the surface with the incoming solar rays (Yellott, 1979). Manipulating the proportions of these properties are experienced in the development of many glass types that vary in performance and use. In addition, they represent the source of many recent innovations in glazed energy performance (Carmody, et al., 2007).

Since no energy can be lost from the total system, Button, et al. (1993) demonstrated the relation between the glazed solar-optical properties in a mathematical equation describing the equilibrium of the incident solar energy radiation that strikes the building as:

Transmittance (T) + Reflectance (R) + Absorbtance (A) = 1.00

For the direct or incident portion of solar radiation, its directional angle can be determined according to the time of the day, time of the year, and the specific orientation. Considering this angular property, the incident solar intensity can be calculated sufficiently using the laws of physical optics to quantify the direct solar energy transmitted through the glazing (Yellott, 1979).

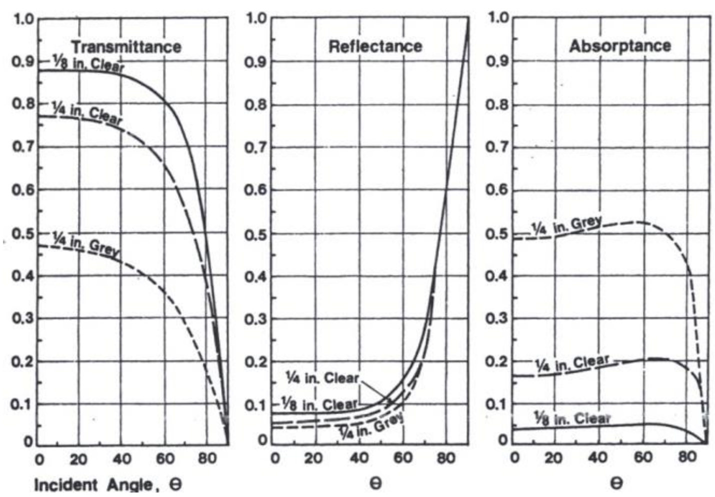


Figure 5 - 6: variation with incident angle of solar-optical properties for clear glass (Yellott, 1979)

Figure 5 - 6 shows the variation of solar properties with respect to the incidence angle (θ) for three types of glass. However, they all show the same behavior; with the increase in the incident angle, the reflected portion is increased with a significant rise after it passes 35 degrees. When θ reaches 90 degrees, nearly all the incident radiation is reflected, therefore no transmittance or absorbance occurs. The figure also indicates that the absorption within the glass is raised with the increase in the incident angle until it reaches about 50 degrees. At higher values of θ, the increase in reflectance will led to the rapid reduction of both the transmitted and absorbed radiation to zero (Yellott, 1979).

5.2.1. Transmittance:

Lechner (2015) defined the transmittance of glazed materials as the factor that describes the percentage of solar radiation that transmits through any glazing material as compared to the incident ones. In other words, transmittance is that part of the incident light remaining after reflection and absorption. The property of transmitting light is the feature that provides glass with its uniqueness among any other building materials. However, Schitich, et al. (2007), Carmody, et al. (2007), ElKadi (2006), Carmody, et al. (2004), and Yellott (1979) noted that this is only a part of the whole picture, since the interaction of transmitted solar radiation with the glazed surface is always accompanied with the permeability of solar radiation components as visible light, near-infrared heat energy, and ultraviolet radiation; each component describes a different characteristic of the glazing transmission property, the matter, which is the core of understanding the energy performance to this material.

- **Ultraviolet transmittance (τ_{UV}):** Clear glass partially blocks the UV radiation and especially with panes of thickness more than 5 mm. However, the reduction of ultraviolet transmittance is generally considered a benefit, since even small proportions of UV light can fade the fabrics, deteriorate the paints, polymers, burn skin, and in some cases, can cause skin cancer. This property is important in museum buildings, for instance, when objects are sensitive to ultraviolet radiation, they had to be exhibited under electric light conditions. On the other hand, plants behind glazed surfaces requires sufficient amount of the ultraviolet radiation.

- **Visible light transmittance:** Visible light transmittance (VLT), or what's we call daylight is the measure of the visible portion of the incident solar radiation that penetrates through the glazed material with wavelengths relating to the human eye sensitivity from 380 to 780 nm. VLT determines the effectiveness of the glazed pane in providing daylight and clear view through the window, it ranges from nearly 90% for the water-white 4 mm clear glass, to less than 10% for the applied reflective solar coatings on tinted glass.

  There is a direct relationship between visible light transmittance and thermal transmittance. When visible light transmittance increases, the thermal transmittance is also expected to increase, as visible light is a form of energy that when transmitted, it is absorbed and converted into heat. Since VLT plays an important role in illuminating the space, its value should be carefully chosen to comply with the building's function and its required internal environment, for example, glass with a high visible transmittance factor can introduce discomfort glare, where the window and its adjacent area can be by far brighter than the surrounding areas.

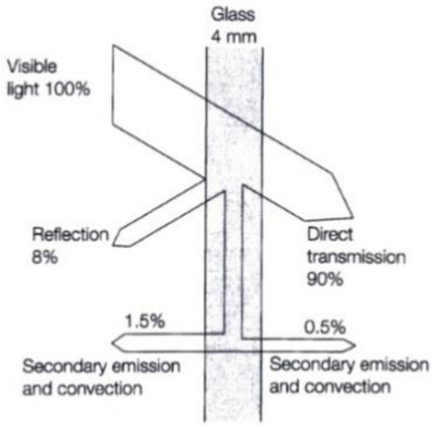


Figure 5 - 7: Visible light balance for a 4mm glass pane (Schitich, et al., 2007)

- **Infrared transmittance:** White clear glass is nearly transparent for the near-infrared portion of the spectrum between 780 and 2800 nm, which contains the remaining 46% of the received solar energy. Near infrared radiation is invisible to the human eye, however, when it is transmitted to the interior, it is absorbed by its components and transferred into heat. While, beyond wavelength of 3000 nm or the far-infrared radiation, glass transmittance falls to a virtually zero.

One of the most crucial consequence of the spectral transmittance property of glass is the greenhouse effect. Schitich, et al. (2007) explained that this effect happens due to the transmission of high levels of short-wave solar radiation through glass to the interior. Once the radiation is inside, it is either partly absorbed by the interior surfaces or partly reflected to be absorbed by other surfaces. Some portions of the radiation are reflected back and transmitted to the outside through the glass as short-wave radiation. The absorbed radiation is directly transferred into heat energy at the surface of the object exposed to it. The heated object reacts to this rise in temperature by emitting its own long-wave heat radiation; some this emitted radiation strikes the glass surface where it is either reflected back or absorbed, but none is re-transmitted to the outside since glass is impervious to this portion of radiation. This explains why it is possible for highly glazed spaces to experience an overheat effect despite a low outside temperature. Carmody, et al. (2007) added that the recent innovations in the glazing technology enables new glazed products to control the transmittance of different areas of the solar spectrum. The basic properties of the material components can be altered, and coatings can be applied to its surface. For solar control glass, its selectivity figure indicates the success for the desirable combination of high light transmittance and low total energy transmittance, especially in the infrared spectrum. A high selectivity figure expresses a favorable relationship, where plenty of light and less heat gain.

5.2.2. Reflectance

Reflectance is the measure of the total fraction of reflected solar radiation by glass to the incident ones that results from multiple reflections which occur at each separate surface of the glazed panes integral over all wavelengths of the spectral radiation (Button, et al., 1993). The reflectance factor does not indicate how the light will be reflected; it only defines how much reflections take place (Lechner, 2015). Carmody, et al. (2004) added that the reflectivity of any glazed surface is dependent on the quality of the glazed surface, type of the glazing material, type of coatings, the angle of incidence of light, and the wavelength of the radiation. However, nowadays, virtually all glass manufactures of float glass have a very similar quality with respect to reflectance. (Button, et al., 1993) Demonstrated that the reflected radiation may be diffuse, specular or a mixture of both (spread) as demonstrated in the following points:

- Specular reflection: Specular reflection takes place when the surface of the glazed materials is microscopically smooth and flat; where the light ray is reflected with the same angle of the incident ray with a normal to the reflecting surface.
- Diffuse reflection: Diffuse reflection occurs on rough surfaced or unsmooth materials; in which each light ray falling on any particle will obey the basic law of reflection; and since these particles are randomly distributed, the reflected rays will be randomly oriented. In practice, a perfectly diffusing surface would reflect light equally in all directions, giving a perfect matt finish. Patterned glass or etched glazed surfaces gives special diffuse reflections.
- Spread reflections: Occurs when an incident light beam is reflected with a mixture of both diffuse and specular reflections. It is also termed as semi-diffuse reflections. The incident ray of light is partly reflected randomly (diffusely), while the other portion is reflected with the same incident angle (specular reflection). Corrugated, dimpled, and etched glazed surfaces produce this kind of spread reflections.

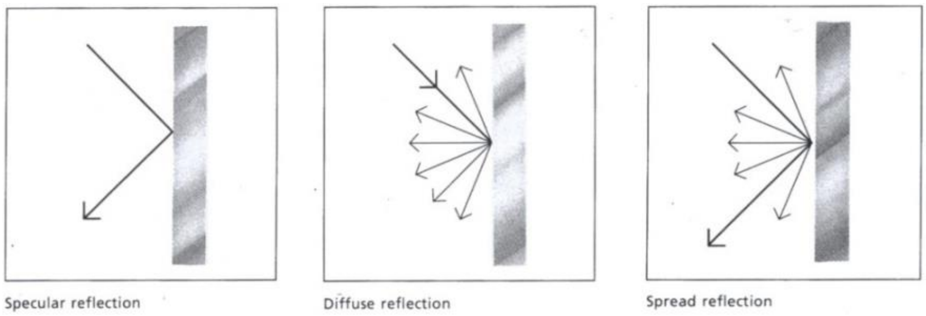


Figure 5 - 8: Specular, Diffuse and Spread reflections (Button, et al., 1993)

The reflective property of glazing becomes especially apparent during the presence of a big difference in lighting conditions between the two sides of the window. The surface on the brighter side will act as a mirror since the amount of visible light transmitting through the window from the darker side is less than the amount of light being reflected from the lighter side. This effect is very obvious when looking from the outside during the daytime and from the inside during the night. Most of the commonly used coatings reflect in all areas of the spectrum. However, in the last 20 years, a great development has occurred in research dealing with glass coatings that can be applied to reflect only a selected wavelength portion of the incident radiation. Varying the reflectance property of the far and near infrared radiation has formed the main basis of developing the high performance or the low-E solar protection coatings (Carmody, et al., 2004).

5.2.3. Absorbtance:

Absorbtance is the fraction of the incident solar radiation that is absorbed by the glass and not transmitted through or reflected from its surface. In other words, it is the solar energy which is lost in the glass after several reflection and transmission operations. This portion of solar radiation is responsible for raising the temperature of the glass (Button, et al., 1993).

Clear white glass absorbs very little portions of solar energy, while dark tinted or heat-absorbing glass absorbs more portions of the solar radiation. The absorbed radiation is transformed into heat inside the glass pane making it warmer, thus when they are left in the sun, tinted glazing felt much warmer than clear glass. Glass tinting colors are usually grey, bronze, or blue-green, they are primarily used to reduce the solar heat gain and to control the glare effect, since they obstruct a considerable amount of the solar energy and consequently reduce the solar cooling loads of the building (Carmody, et al., 2004).

Since all absorbed solar radiation produces heat, which always flows from higher temperatures to lower ones, therefore the absorbed heat raises the temperature of the material beneath the surface, where it is then either convected away by the moving air or re-radiated from the glazed surface (Button, et al., 1993). This property of a material to re-radiated heat energy is called its emissivity. Glass as well as other materials, emit or re-radiate heat energy in form of long-wave of far infrared radiation. Therefore, it is called the transmitted long wave component of the solar radiation. The wavelength of the emitted far-infrared energy depends on the temperature of the glazed surface. This re-emission of radiant heat is one of the main heat transfer pathways of the glazed envelope to the interior. Thus, controlling the emission property of windows can generally improve its insulating values (Carmody, et al., 2004).

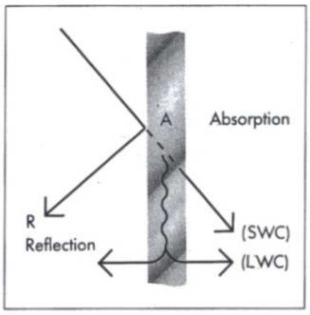


Figure 5 - 9: short wave and long wave components of total solar radiation (Button, et al., 1993)

5.3. Energy Performance Measuring Mechanisms of Glazing:

Glazing is a crucial component of the buildings envelope. As mentioned before, heat flows through it from the warmer side to the colder one by the following three ordinary mechanisms of heat transfer: conduction, convection and radiation. However, when these basic heat transfer mechanisms are applied to the glazed envelopes, they interact mutually in complex ways. Therefore, they cannot be evaluated or measured separately. Instead, three energy performance mechanisms of glazing are used to describe how energy is transferred through, and are considered the base tools for quantifying the energetic performance of any glazing assembly (Carmody, et al., 2007). These measuring mechanisms are discussed in the following points:

5.3.1. Thermal Transmittance (U-value):

The thermal transmittance or the insulating value (U-value) is the standard measurement unit for heat transfer through any building component. The capacity of the glazing's assembly to resist heat transfer is referred to as its insulating value (Carmody, et al., 2004). According to ElKadi (2006, p. 60), the thermal transmittance or the U-value of any material can be defined as "the time rate of heat flow per unit area (1m^2) under steady conditions from a fluid on the warm side of the barrier to the fluid on the cold side, per unit temperature difference between the two fluids (Kelvin or degree Celsius)". Reducing the U-values (in W/m^2.K) of the any component of the envelope is considered a benefit. Button, et al. (1993) added that the thermal transmittance could also be quantified in terms of the thermal resistance or the R-value, which is the inverse of the U-value: R = 1/U m^{2}K/W.

For the glazed component of the building envelopes, their thermal insulation property is based like any other opaque component; since it separates between the inside and outside climatic conditions. Depending on the thermal properties of the complete glazed assembly and the prevailing weather conditions, heat is transferred through glazing whenever there exists a temperature difference between the two sides by combined mechanisms of conduction, convection, and radiation (Carmody, et al., 2007). Button, et al. (1993) and Carmody, et al. (2007) mentioned that there are three stages of thermal transmission through glazing which can be explained in the following points:

- **First: Heat transfer to the external glazed surface:** Heat is transferred to or from the external surface of the glass, in two ways; either by the exchange of long-wave (heat) radiation between the glazed surface and the external or by convection/conduction from the adjacent layer of air which moves over the glazed surface.

  The rate of heat transfer at the outer surface varies considerably and is climate dominated. The long-wave radiation exchange depends on the external temperature and the sky conditions. While the rate of heat transfer by convection/conduction is usually influenced by the air film adjacent to the glazed surface; when the wind blows, this film is replaced by another one, which contributes to a higher rate of surface heat exchange.

- **Second: Heat transfer through the glass pane/s:** Heat is transferred through a single glass pane by the ordinary means of conduction; where, there is a relatively little resistance to heat transfer because glass conducts heat efficiently and is, therefore, a poor insulator.

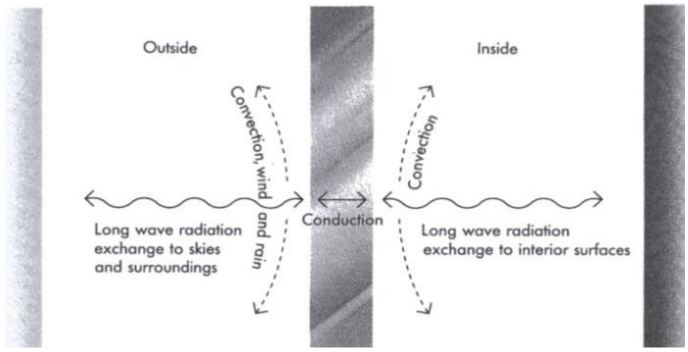


Figure 5 - 10: heat transfer through single glazing pane (Button, et al., 1993)

However, to increase the thermal resistance, or decrease the thermal transmittance (U-Value) of the glazed envelope, a second pane of glass separated from the first by an air space could be added, in which heat is transferred through this air gap by both means of convection and long-wave radiation exchange. The second glass pane provides an extra thermal resistance to the heat exchange by conduction, while the layer of enclosed air provides some additional thermal resistance in advance of the low thermal conductivity of the air.

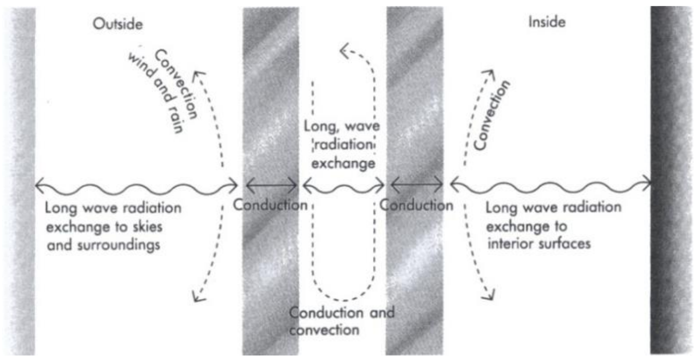


Figure 5 - 11: heat transfer through double glazing pane (Button, et al., 1993)

- **Third: Heat transfer from the inner glass surface:** The final stage of heat transfer between the inner glazed surface with the interior. Similar to the outer glass surface, two modes of heat transfer take place: the long-wave radiation exchange and the conduction/convection exchange. If the difference in temperatures between the inner surface and the interior is rather big, an internal convection current could start nearby the inner surface of the glazed assembly.

However, it could be misleading to compare the U-value of the glass panes only; therefore, the concept of the total U-value for the whole glazed assembly is more convenient instead. It expresses the total heat transfer coefficient of the complete glazed assembly taking into account the mutual interaction of the insulating values of the glass itself, the edge effects, the frame, and the sash insulations. The overall U-factor of the glazed assembly unit is determined through specific procedures of engineering assumptions and calculations that are measured at the center of the assembly. In most cases, the total U-value is higher than the U-value for the glass pane by itself, since the glass remains superior to the frame in the insulating value. The total U-value of a glazing unit is typically described in a vertical position, any change in the mounting angle can affect its U-value (Carmody, et al., 2007).

ElKadi (2006) Noted that more recently, a series of new strategies and technological advances have led to substantial improvements in the insulating value of the entire window assembly, while maintaining high visible light transmittance, these improvements include the following:

- The existence of a number of air gaps between the glass panes (Multi-layered glazing)
- Using insulating gas infills in the air gaps
- Using special surface treatments
- Improving the insulating properties and/or treatments of the glazing material, edge spacers, sashes and frames

5.3.2. Solar Radiation Control Mechanisms:

The second major energy performance mechanism of the glazed envelopes is its ability to gain heat from the solar radiation through its transparent property, regardless the outside temperature (Carmody, et al., 2007). Bradshaw (2006) noted that the origin of the solar radiation heat gain by any surface are mainly conducted through the following means:

- Unshaded direct solar radiation
- Unobstructed diffused or indirect solar radiation from the sky
- Reflected solar radiation from adjacent buildings or other surfaces, basically the ground

Part of the impinging solar radiation is directly transmitted through the glazing to the interior, while some other portions are first absorbed by the glazed panes and then transferred to the interior by means of radiation/convection. Generally, solar heat gain through glazing are considered the most influential factor in determining the cooling loads of any buildings; it exceeds by far the heat gain from other sources, such as external air temperature or humidity, which makes reducing and eliminating its effects a benefit during hot summer seasons. While on the other hand, maximizing solar heat gain can be very efficient in winter or cold climatic conditions (Carmody, et al., 2007).

The ability to measure the amount of solar radiation heat gain through glazed envelopes is described by the following terms:

5.3.2.1. Shading Coefficient (SC):

The shading coefficient (SC) or solar coefficient was the primary term that has been used to characterize the solar efficiency of any glazed windows. According to the American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE), shading coefficient is defined as "the ratio of the total solar heat gain through fenestration, with or without integral shading devices, at normal incidence, to the solar heat gain that occurs through unshaded 1/8 inch (3mm) thick clear double strength glass". Which have a solar heat transmittance of 0.87 (ElKadi, 2006, p. 61).

The shading coefficient value is expressed as a dimensionless figure from zero to one; higher shading coefficient value signifies higher solar heat gain and the vice versa. The SC value of the glazed assembly is strongly dependent on the type of the selected glass, in addition, to the presence of any integral part of the glazing system that can diminish the flow of solar heat, such as additional glazing layers, reflective coatings, or blinds between layers of glass (Carmody, et al., 2007).

Schitich, et al. (2007) noted that since October 1994, the shading coefficient specifies the ratio of the solar heat gain of a specific glazing to the gain of a standard double-glazing unit. Which is taken to be constant at 80%. This new reference replaced the old 3mm single glazing standard (0.87).

5.3.2.2. Solar Heat Gain Coefficient (SHGC):

The solar heat gain coefficient (SHGC) or the g-value gradually replaces the shading coefficient (SC) as the key solar gain measure in most references and literature. It defines how much solar energy is blocked by the glazed assembly (ElKadi, 2006). The SHGC can be defined as the total fraction of the solar energy transmitted to the interior in the range of wavelengths from 300 to 2500 nm. SHGC is also a dimensionless value, expressed as a ratio from 0 to 1. SHGC consists mainly of two components, first: the direct transmitted solar radiation, and second, the long-wave (heat) emission that are absorbed by the glass then radiated or convected towards the inside (Schitich, et al., 2007). The SHGC or the g-value is a very crucial measure for HVAC calculations, it is affected by the same factors as the shading coefficient. However, it is also influenced by the shading of the frame and the ratio of the glazing to the frame for the complete assembly (Carmody, et al., 2004).

5.3.2.3. Coolness Index (Ke-Factor):

The Ke-factor or the coolness index is defined as "the ratio of visible light transmittance (VLT) to the shading coefficient (SC) of any glazed assembly" (ElKadi, 2006, p. 62).

$$Ke = VLT / SC$$

Ke factor is one of the significant measures that indicate the glazing performance. It is very beneficial in comparing between glazing products for different climates, especially in terms of those that prefer the transmission of more light than heat. Higher Ke values indicate better filtering of heat energy from the total solar radiation by the glazing assembly. Figure 5 - 12 shows the correlation of the shading coefficient with the visible transmittance for some glazing products. It is evident that the two measures had a defined linear relationship. In addition, the integration of glazing solar control concepts decreases the amount of the transmitted solar radiation through the glazing, however, the amount of visible light transmittance also decreases (ElKadi, 2006).

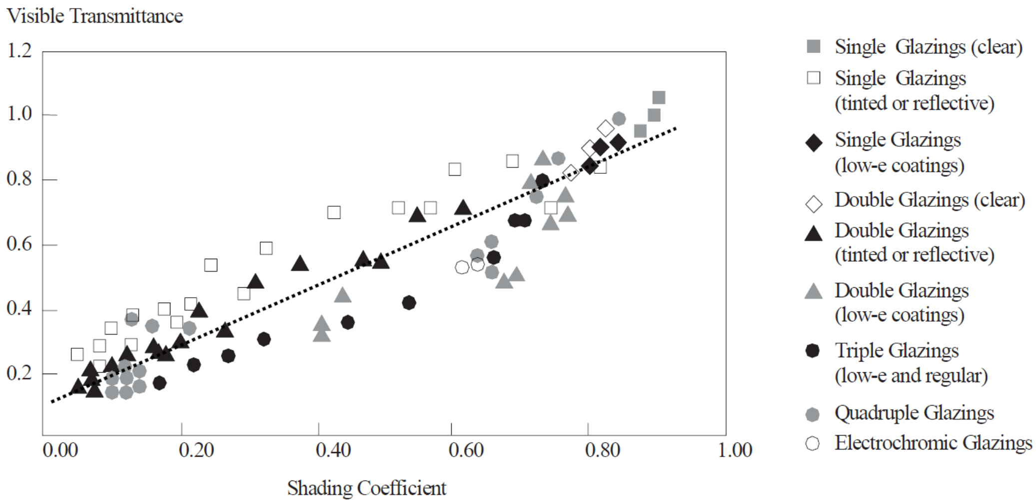


Figure 5 - 12: Shading coefficient and visible light transmittance correlation (ElKadi, 2006)

5.3.2.4. Light to Solar Gain (LSG):

The light to solar gain (LSG) is "the ratio between the visible light transmittance (VLT) to the total solar heat coefficient (SHGC) of the glazed assembly", it gives an indicator of the glazing performance, however, it does not refer to the actual energy use (Carmody, et al., 2004, p. 29).

$$LSG = VLT / SHGC$$

LSG factor is also referred to as the glass selectivity property or the light/heat ratio. Some glass manufactures use it as a descriptive code, where they quote the light transmission value followed by the total heat transmission value (Button, et al., 1993). Light to solar gain is a similar measure to the coolness index; however, since the SHGC = 0.87 x SC, therefore, LSG equals to 1.15 x Ke. Higher LSG values indicate the success of achieving the desirable combination of high light transmittance and low total solar heat gain. This is very advisable especially in building contexts that requires high levels of solar control; where maximum day lighting is needed with a minimal solar heat gain. Theoretically, the highest possible LSG value is 2.0, Clear white glazing has LSG value close to 1.0, while a spectrally selective high-performance glazing would have a value more than 1.7 (ElKadi, 2006).

Currently, many technical innovations are being increasingly introduced to manipulate the transmission, reflection and absorption properties of glazing such as body-tinted glass, reflective coated glass, single and double-glazed units incorporating blinds and louvers, low-E Coatings among many others. These innovations can regulate the total solar heat transmittance to some required levels, while taking into considerations the importance of the transmission of the visible portion of the solar spectrum. This can be revealed in the measures of their shading coefficient (SC), solar heat gain coefficient (SHGC) and light solar ratio (LSR) (Button, et al., 1993). (Table 5 – 1).

	Window					
	1	5	6	9	10	11
General glazing description	Single-glazed clear	Double-glazed clear	Double-glazed bronze	Double-glazed spectrally selective	Double-glazed spectrally selective	Triple-glazed low-E (2)
Center-of-glass						
SHGC	0.86	0.76	0.62	0.41	0.32	0.49
SC	1.00	0.89	0.72	0.47	0.38	0.57
VT	0.90	0.81	0.61	0.72	0.44	0.68
LSG	1.04	1.07	0.98	1.75	1.38	1.39
Total window						
SHGC	0.79	0.58	0.48	0.31	0.26	0.37
VT	0.69	0.57	0.43	0.51	0.31	0.48
LSG	0.87	0.98	0.89	1.65	1.19	1.29

SHGC: Solar heat gain coefficient

SC: Shading coefficient

VT: Visible transmittance

LSG: Light-solar heat gain or ratio

Table 5 - 1: Solar heat gain characteristics of typical windows (Carmody, et al., 2007)

5.3.3. Infiltration:

Whenever there exists a pressure difference between the interior and the exterior; either driven by temperature difference or by the wind, air will flow as a leakage between cracks of the components of the glazing assembly or between the whole assembly and the external wall. This leakage property contributes to the total air infiltration of the building, which leads to an increased building loads; either heating or cooling. In some climates, it can be also responsible for raising the internal level of humidity (Carmody, et al., 2004). Thus, infiltration could be defined as "ventilation that is not controlled and usually not wanted". The rate of infiltration can be measured in terms of the amount of air volume (in cubic meters per minutes) that passes through a unit area of glazed assembly (in meter square) under a given pressure conditions" (Carmody, et al., 2007, p. 38).

The rate of infiltration mainly depends on the prevailing wind conditions and the other microclimates that surrounds the building, and also on the presence of cracks and air spaces between the glazing unit and the building wall. Therefore, the effective insulation and sealing of these areas during construction or refurbishment can be very efficient strategy in controlling the infiltration rates. Infiltration can be critical issue in increasing heating loads during winter, especially in cold climates that had high temperatures differentials between the inside and the outside, and during windy weathering conditions (Carmody, et al., 2007).

Chapter VI

Thermal and Visual Physical Comfort Modes

6. Thermal and Visual Physical Comfort Modes:

The pursuit of comfort is a fundamental requirement for the human behavior that basically evolved for the purpose of survival. However, it is by far a more holistic experience that hide multitude of complexities in perceptions and actions that affects all the human senses (Baker & Steemers, 2000).

Bradshaw (2006, p. 4) defined the human physical comfort as "The absence of discomfort", where positive comfort conditions are those states which are not distracted by the unpleasant sensation of the surrounding environment based on a network of human sense organs. Vischer (2007a) added that the human comfortable conditions are not only a simple recognition of the occupants needs of being healthy and safe in the building they occupy; but it is rather the need for an environmental support to all the activities that they are required to perform, this environmental support is what meant by comfortable conditions.

Some of those comfortable conditions can be standardized through physically measurable criteria such as interior air temperature, lighting intensity, and noise level, others are individual physiological criteria such as age or gender, while some are intermediary changing criteria such as clothing and activity. However, comfort condition is not a specific factor that can be quantified precisely, but instead, it represent various empirical values at which the human being can evaluate his or her surrounding environment as being agreeable according to his sensible determinants (Hegger, et al., 2008).

Vischer (2007a) noted that the physical comfort conditions should be basic requirement for the habitability of any building. The effective design and operation processes can be assured through the integration of the appropriate comfort standards. Those standards are mostly address the extremes, such as too hot, cold or noise. They exist to ensure that the occupants are not placed under stress by having to adapt themselves to the extreme environmental conditions. Fathy (1986) added that the role of an architect should carefully consider two main parameters: first, the mutual interaction of the continuously changing external environmental variables with the buildings bearing capacity and second, the ability of the human body and its considerable margin of tolerance for the changing internal environmental conditions.

However, since the rise of science in the Renaissance, architects and environmental engineers has taken technology and pushed it to the limits of its capabilities in order to create reasonably comfortable conditions in any building under almost any environmental conditions. Since then, the engineering systems usually require high-grade of energy consumption to deal with the environmental problems in buildings (Thomas & Fordham, 1999). Therefore, Gallo, et al. (1998, p. 1) described the relation between energy consumption and architecture as "a form a natural marriage". But first, the internal comfort with respect to the prevailing environment should be considered; then, the role of energy in buildings came next in which it will typically vary from country to country and from climate to climate.

In this chapter, the thermal and the visual physical comfortable conditions will be discussed through demonstrating their main principals, determinants, and standards. It is essential to provide the research theoretical study with the relevant information for the physical comfortable standards that are typically affected by the transparent component of the façade, and its relevance with the buildings' total energy consumption. These comfort standards will be used as an input date for modeling the office-profiles through the upcoming modeling and simulation study (Chapter X).

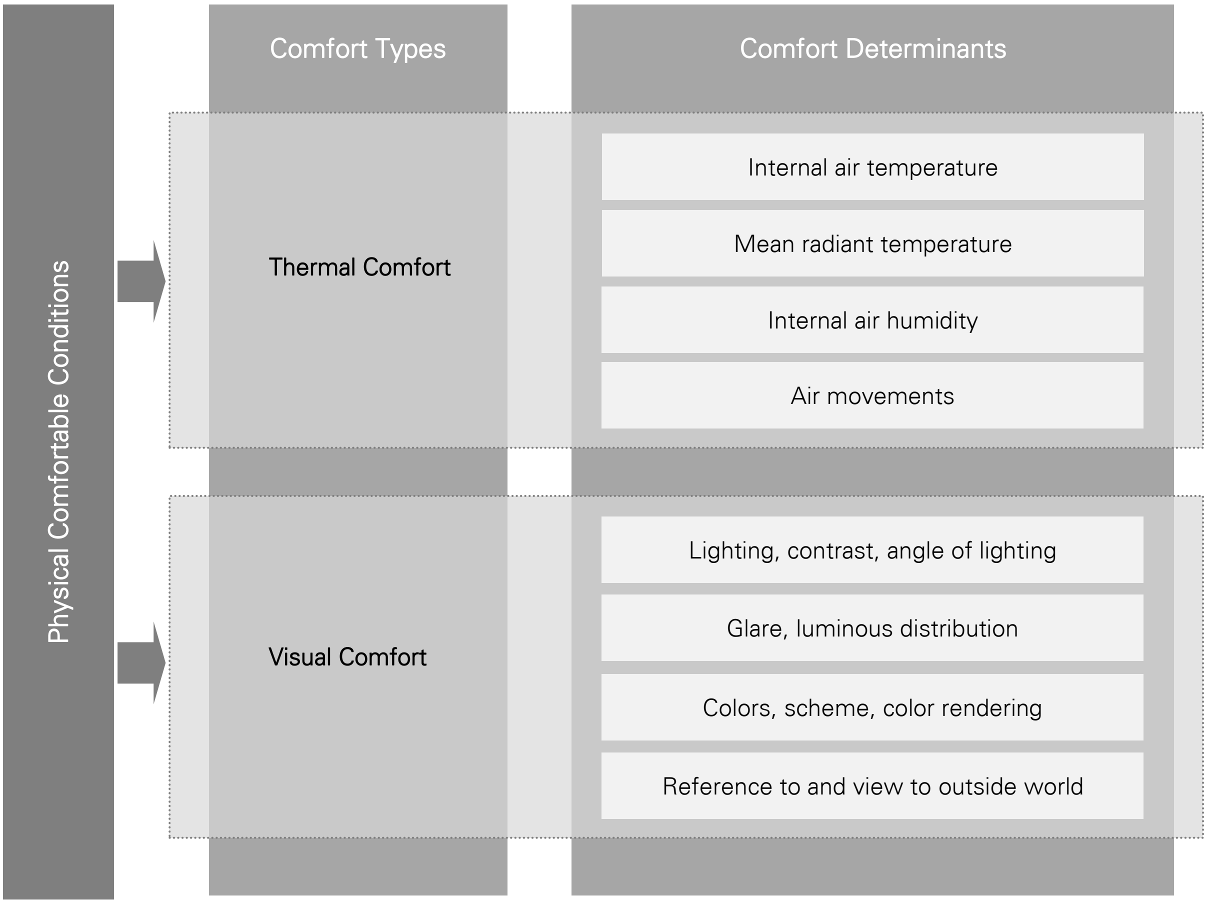


Figure 6 - 1: Physical thermal and visual comfort determinants (Hegger, et al., 2008)

6.1. Thermal Comfort:

6.1.1. Thermal Comfort Definition:

While the architect designs his buildings for protecting the occupants from the external environmental conditions, their thermal comfort should be a principal target in his decisions. He should not only compromise it, but also improve it passively with the minimum energy requirements. Thermal comfort is a rather complex concept that defines the optimum margins of the internal thermal conditions; in which the highest number of the occupants can feel comfortable, can optimize their productivity, and can fully utilize their human potentials (Santamouris & Asimakopoulos, 1996).

According to ASHRAE standard 55 - 2005, thermal comfort is defined as "That state of mind which expresses satisfaction with the thermal environment". Despite that the previous definition appears as a psychological definition (state of mind), however, it has been modeled in both terms of physiology and physics (Nicol & Roaf, 2007, p. 3). The condition of satisfaction mentioned in the definition only occurs when the human body is in the state of "thermal neutrality" (Goulding, et al., 1993, p. 59). Where he is kept in a narrow range of comfortable and acceptable environmental conditions inside the building in which the heat flow of the human thermal system is balanced. i.e. in state of absence of any sensation of thermal discomfort, either hot or cold (Givoni, 1998).

Hegger, et al. (2008) argued that recently, it has become more evidently that office spaces which are designed to provide the occupants with optimum internal thermal conditions, led to an improvement in their efficiency, sense of satisfaction, and general well-being. This is reflected in raising their rate of productivity and typically had uncontroverted economic benefits.

6.1.2. Human Thermal Comfort Determinants:

The human body can be considered as a biological engine or a thermodynamic system; it burns food as a fuel with oxygen to produce mechanical work and generates heat as a byproduct. However, the human system requires to remain in a thermal equilibrium state at constant internal temperature around 37 ± 0.5 ˚C to function in healthy conditions. To achieve this goal, the rate of heat generation of the human body must be balanced with its rate of heat loss. Within specific limits, the human body can acclimate itself to the thermal environmental change through the simple heat transfer mechanisms. But, such limits are not wide, especially when the change is vast or sudden (Lechner, 2015).

However, the human satisfaction with its thermal environment is rather complex issue, it is a subjective response to many interacting variables or determinants, in which the human perception of comfort can judge the quality of the perceived thermal environment. These determinants influence either the occupants' thermal equilibrium state (heat gain or heat loss), or their rate of internal heat generation (Abrams, 1986). They include physical environmental parameters, personal determinants, and organic determinants as will be demonstrated in the following points:

6.1.2.1. Environmental Determinants:

The external environment is the most crucial determinant that influence the human thermal comfort. Its major parameters are temperature, humidity, radiation, and air movement. These parameters interact mutually with each other and with the human's comfort as follows:

- **Temperature:** It is the most important determinant of thermal comfort; only a narrow range of comfortable temperatures can create thermal comfort. Temperature can be defined as "the measure of the degree of heat intensity". It is measured by the ordinary dry bulb thermometer that is shielded away from any radiant exchange (Bradshaw, 2006, p. 6). Dry-bulb temperature is an indicator to the rate of heat exchange between the human skin and the ambient air, which is mostly by convection (Lechner, 2015).

Temperature has crucial impact on the workers performance, figure 6 – 2 shows its effect on the accidents frequency of sedentary workers. The accidents frequency and the workers efficiency indicate that the range of thermal comfortable temperatures are not very wide. If the interior air temperature is out of comfort range, the risk of accidents increase, and the workers dexterity, productivity, and their mental skills rapidly decrease (Hegger, et al., 2008).

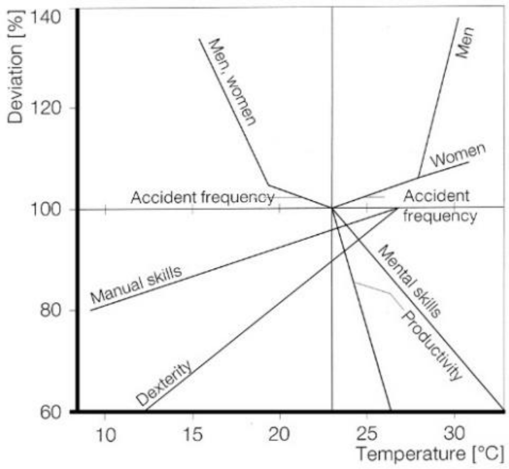


Figure 6 - 2: accidents frequency and productivity in relation to the interior air temperature for sedentary workers (Hegger, et al., 2008)

- **Humidity:** Humidity is "the amount of water vapor content in any given space" (Bradshaw, 2006, p. 18). Although humidity does not affect the thermal loads and the human tolerance to its variations is wide, but it determines the evaporative capacity of the air, where evaporation or respiration is one of the effective cooling mechanisms of the human body (Santamouris & Asimakopoulos, 1996). In addition, humidity is also a function of temperature; warmer air can hold more water content (Bradshaw, 2006). Humidity is expressed as follows:

  - **Dew-point temperature (t_{dp}):** "It is the temperature at which any given air water-vapour mixture is saturated with water vapour" (Santamouris & Asimakopoulos, 1996, p. 138), any further cooling beyond this temperature cause condensation (Lechner, 2015).

  - **Wet-bulb temperature (t_{wb}):** "It is the temperature for any state of moist air, at which liquid water may be evaporated into the air to bring it to saturation at exactly the same temperature and pressure". Wet-bulb temperature is useful measure to indicate severe heat stress when the human body is sweating and near its upper limits of temperature control (Santamouris & Asimakopoulos, 1996, p. 138).

  - **Relative humidity (rh):** "It is the ratio of the partial pressure of water vapour to the saturation pressure, for any temperature and barometric pressure". Relative humidity is expressed as a percentage or fraction. However, its value loses its meaning as an environmental index unless dry-bulb temperature is mentioned (Santamouris & Asimakopoulos, 1996, p. 138). Figure 6 - 3 shows the relation of the internal temperature with its relative humidity. It indicates that with internal ambient temperature range from 20 to 22 °C, the relative humidity could fluctuate between 35 and 70% in the agreeable comfort range (Hegger, et al., 2008).

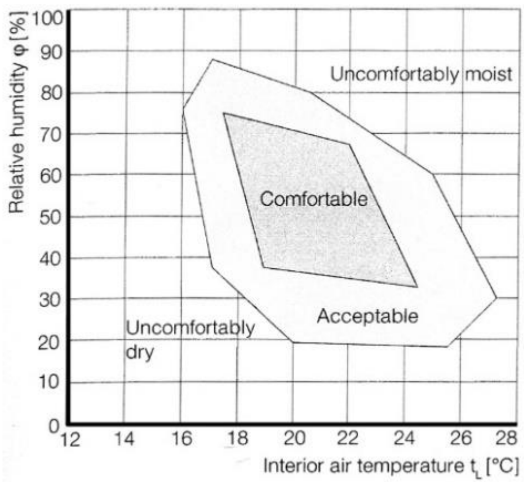


Figure 6 - 3: Thermal Comfort zone in relation to internal ambient temperature and relative humidity (Hegger, et al., 2008).

- **Air movement (V):** Air movement is a remarkable index in the in the human heat balance equations. It has a very pronounced effect on the convective heat transfer, as well as it determines the evaporative capacity to air. Convective heat transfer is directly proportional to air movement, where increasing the convection of air (natural or artificial) over the human body allows for the dissipation of its heat. While higher air speed increases the evaporative rate from the human skin which consequently enhance the sensation of cooling and diminish the negative effect of high humidity (Santamouris & Asimakopoulos, 1996). However, the exact limits of the acceptable air movement in any space are a function of its temperature, humidity and radiant temperature (Bradshaw, 2006).

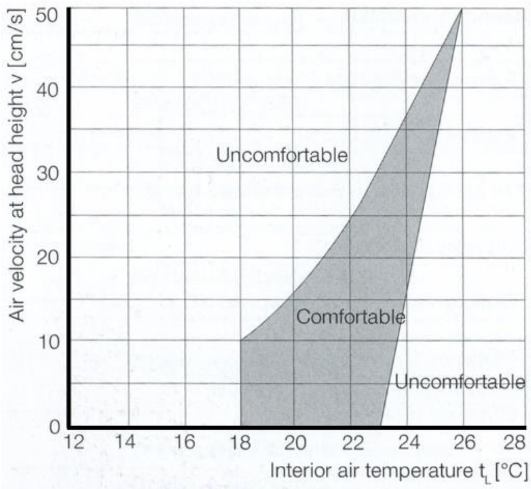
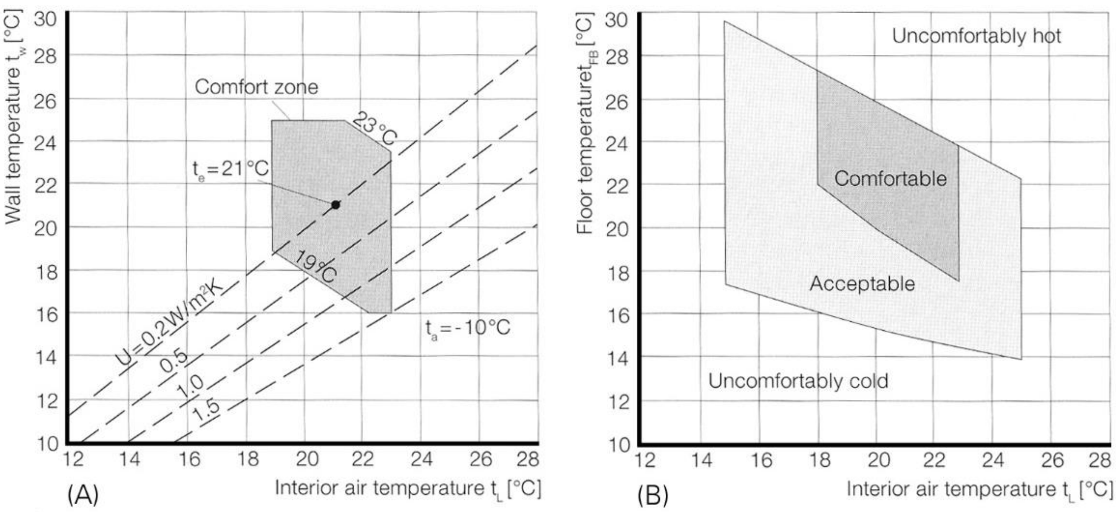


Figure 6 - 4: Thermal Comfort zone in relation to internal ambient temperature and air velocity (Hegger, et al., 2008).

- **Radiant temperature:** At any enclosed space, the temperatures of its surrounding surfaces in relation to the temperature of occupants at the same space indicate both the rate and the direction of the radiant heat exchange between them and their surrounding surfaces (Bradshaw, 2006). Diminishing the difference between those temperatures will give the occupants more comfortable conditions in their enclosure (Hegger, et al., 2008).

  The mean radiant temperature (t_{mrt}) at any space is defined as "the uniform surface temperature of an imaginary black enclosure with which a person exchanges the same heat by radiation as that in the actual real environment" (Santamouris & Asimakopoulos, 1996, p. 140). Or in other words, it is the average temperature of all surfaces surrounding the point of interest; including the incident solar radiation. MRT measure is usually determined by globe thermometer. Since the glazed surfaces in any space experience larger temperature fluctuations, the measure of the MRT close to these surfaces may be different (higher or lower) than in the rest of the space (Goulding, et al., 1993). Figure 6 - 5 show the human thermal comfort zone relation to the internal air temperature with the temperature of deferent surfaces of the interior space.



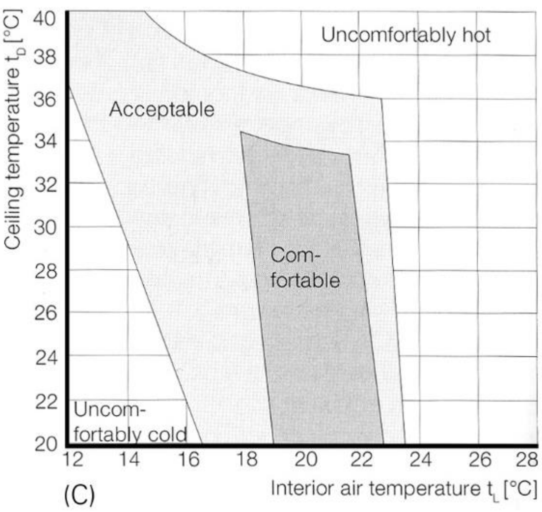


Figure 6 - 5: (A) Comfort in relation to internal air temperature, average enclosing surfaces and U-value of the envelope; (B) Comfort in relation to interior air temperature and floor temperature; (C) Comfort in relation to interior air temperature and ceiling temperature (Hegger, et al., 2008)

6.1.2.2. Personal Determinants:

Human thermal comfort is also affected by variant personal factors that can change either the rate of internal heat production or the rate of heat transfer of the human body. Those are the human activity level (metabolic rate) and the level of clothing as will be discussed in the following points:

- Metabolic rate: The metabolic rate is the amount of energy that are generated by a human body per unit area of its skin through the bio-chemical process of food (fuel) conversion during his normal activities (Bessoudo, 2008). The human metabolic rate mainly depends on the level of the performed activity in any given task. It is measured in met; where one met = 58.2 W/m^2, which is equal to the rate of energy/heat production from a seated person at rest for an average size man with surface area of about 1.8 m^2 (Goulding, et al., 1993). The metabolic rates in met for different activities are given in table 6-1:

Activity	Metabolic Rate in Met Unit
Seated, Writing	1.0
Seated, typing or talking	1.2 to 1.4
Seated, filing	1.2
Standing, talking	1.2
Drafting	1.1 to 1.3
Miscellaneous office work	1.1 to 1.3
Standing, filing	1.4

Table 6 - 1: Metabolic rate at various typical office activities (Bradshaw, 2006)

- Clothing level: Clothing gives an additional insulation property to the human body. According to the layers and the type of materials, clothing level directly influences the rate of heat exchange between the human body and its surrounding environment. It is considered as one of the easiest and adjustable passive controllers that can achieve the required thermal comfort in any given environmental conditions (Santamouris & Asimakopoulos, 1996). However, unfortunately controlling the level of clothing is out of the architects' reach; sometimes fashion, status, and tradition in clothing can work against this passive thermal controller (Lechner, 2015).

  The thermal insulation property of clothing has been quantified in a dimensionless unit called clo value; where clo measures the insulation of clothing from the human skin to the outer surface of the cloth and exclude any external surface resistance. One clo equals to 0.155 m2 °C/W (Gallo, et al., 1998). The total thermal insulation value of the clothing ensemble can be determined through summing up the individual garment of clo values (Bradshaw, 2006). Clo values for some common clothing ensembles are listed in table 6 - 2:

Clothing Ensembles	clo unit
Typical tropical clothing ensembles (briefs, shorts, open neck shirt with short sleeves, light socks and sandals)	0.3
Light summer clothing ensembles (briefs, long light-weight trousers, open neck shirt with short sleeves, light socks and shoes)	0.5
Light working ensembles (light underwear, cotton work shirt with long sleeves, work trousers, woolen socks and shoes)	0.7
Typical indoor winter clothing ensembles (underwear, shirt with long sleeves, work trousers, jacket or sweater with long sleeves, heavy socks and shoes)	1.0
Heavy traditional European business suit (cotton underwear with long legs and sleeves, shirt, suit including trousers, jacket and waistcoat, woolen socks and heavy shoes)	1.5

Table 6 - 2: Values of typical clothing ensembles (Gallo, et al., 1998)

Figure 6 - 6 demonstrate the relation of the necessary insulation value of the clothing with the required operative temperature for the human sensation of thermal neutrality for sedentary office occupants with a specified air speed and humidity level (operative temperature is a function of both air temperature and mean radiant temperature) (Bradshaw, 2006).

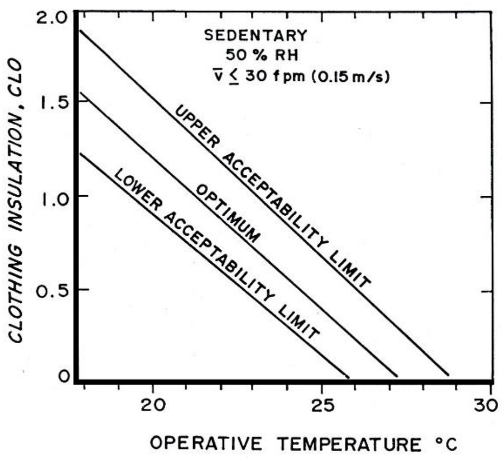


Figure 6 - 6: Relationship between clothing and ambient temperature necessary for comfort (Abrams, 1986)

6.1.2.3. Organic Determinants:

The human perception of thermal comfort is not only an absolute heat balance that can be expressed in physical terms, it rather includes other psychological as well as physiological variables. Although the human thermal sensation is processed mainly through physical parameters (such as environmental and personal parameters) before it leads to an expression of thermal preference or judgment, but it also encompass some other organic parameters that cannot be figured physically or measured numerically such as age, gender, race, and the national characteristics of the buildings' occupants (Santamouris & Asimakopoulos, 1996).

6.1.3. Thermal Comfort Standards:

Thermal comfort standards are the mechanisms that are used to define the acceptable ranges of the thermal comfort variables or parameters, usually inside buildings. Thus, it can indicate the physical boundaries of the human thermal comfort zone. Thermal comfort standards can be defined as "The ranges of climatic conditions within which the majority of persons would not feel thermal discomfort, either of heat or cold" (Givoni, 1998, p. 23). Several attempts have developed some empirical correlations for thermal comfort parameters in order to create a standard quantitative expression to human thermal sensation. Some of these standards are demonstrated in the following points:

6.1.3.1. Fanger Thermal Equilibrium Equation:

Fanger's comfort equilibrium equation is one of the most commonly used comfort indices. It has been empirically developed through using the six variables that affect the human physical thermal sensation (both environmental and personal variables). The equation investigated the thermal balance of the human body in terms of its net heat exchange based on an extensive study of the human being under varying conditions, followed by a comprehensive statistical analysis of their responses. The equality of Fanger's equation is an obligatory condition for thermal comfort, once satisfied, then the person is in thermal equilibrium state; where all the heat generated by the human body is dissipated to the environment and there is no change in the body temperature (Santamouris & Asimakopoulos, 1996).

6.1.3.2. Predicted Mean Vote (PMV):

The PMV is also introduced by Fanger to measure the degree of the human thermal sensation. Through complex experimental data and mathematical functions of the human activity, clothing level and the four environmental parameters, PMV method can predict a value for the imbalance between the actual heat flow of the human body and the required heat flow that gives optimum thermal comfort in any given environmental conditions. PMV quantifies the degree of thermal discomfort in a scale that range between -3 and +3 (Table 6-3). Positive values indicate thermal discomfort due to the sensation of hot, while negative values indicate thermal discomfort due to the sensation of cold. Typically, higher PMV values indicate higher degrees of discomfort. Zero scale indicate the thermal neutrality which is the optimum condition for the human thermal comfort. It is highly recommended to design with PMV index values from -2 to +2 (Santamouris & Asimakopoulos, 1996).

Expression	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
ASHRAE	1	2	3	4	5	6	7
Fanger	-3	-2	-1	0	1	2	3

Table 6 - 3: Thermal sensation scale for the PMV & the ASHRAE indices (Gallo, et al., 1998)

The predicted percentage of dissatisfied (PPD) has been introduced to establish a quantitative prediction for the thermally dissatisfied occupants, either feeling hot or feeling cold, i.e. the occupants that do not vote in the PMV scale with -1, +1 or 0. Figure 6 - 7 demonstrates the relationship between PMV and PPD; it shows that it is not possible to achieve the thermal comfort conditions for all the occupants within the same space. Even with zero PMV, nearly 5% of the occupants shows dissatisfaction; this could be attributed to the different dressing habits, different levels of activities, and different psychological influences. PMV values that ranges from -0.5 to 0.5 with corresponding PPD ≤ 10% are considered thermally acceptable conditions (Santamouris & Asimakopoulos, 1996).

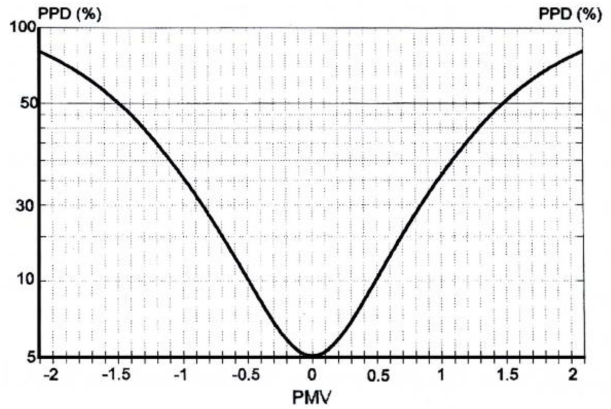


Figure 6 - 7: Predicted percentage of dissatisfied (PPD) as a function of predicted mean vote (PMV) (Gallo, et al., 1998)

6.1.3.3. Olgyay Bioclimatic Chart:

Olgyay Bioclimatic chart is one of the first attempts to quantify the effect of various combination of thermal conditions and include them into one chart. The chart encompasses a plot of five thermal comfort determinants that describes the thermal comfort range according to a set of combinations for an average person with light level of clothing (figure 6-8).

The dry-bulb temperature is plotted on the vertical axis and the relative humidity is plotted on the horizontal axis. The upper shaded area at the center of the chart defines the specific combinations of air temperature and humidity that create thermal comfort during summer, while the lower shaded area that is enclosed by the dashed line define the thermal comfort zone during winter, taking into consideration that in both zones, the subjects are assumed to be in the shade and the air speed is less than 6 m/min. Since air speed provides additional cooling effect, therefore, increasing the air speed gives the possibility to extent the comfort zone vertically in higher temperatures; this is presented through the series of parallel horizontal lines above the upper boundary of the comfort zone. The horizontal lines below the comfort zone shows the potential of the passive solar heat gain in increasing the comfort range in winter to lower temperatures. The mean radiant temperature (MRT) is the fifth and the last comfort determinant described in the bioclimatic chart; the two scales of the MRT are drawn in horizontal lines upper and lower to comfort zones giving the required radiant temperature values to maintain comfort conditions outside the comfort zone boundaries (Abrams, 1986).

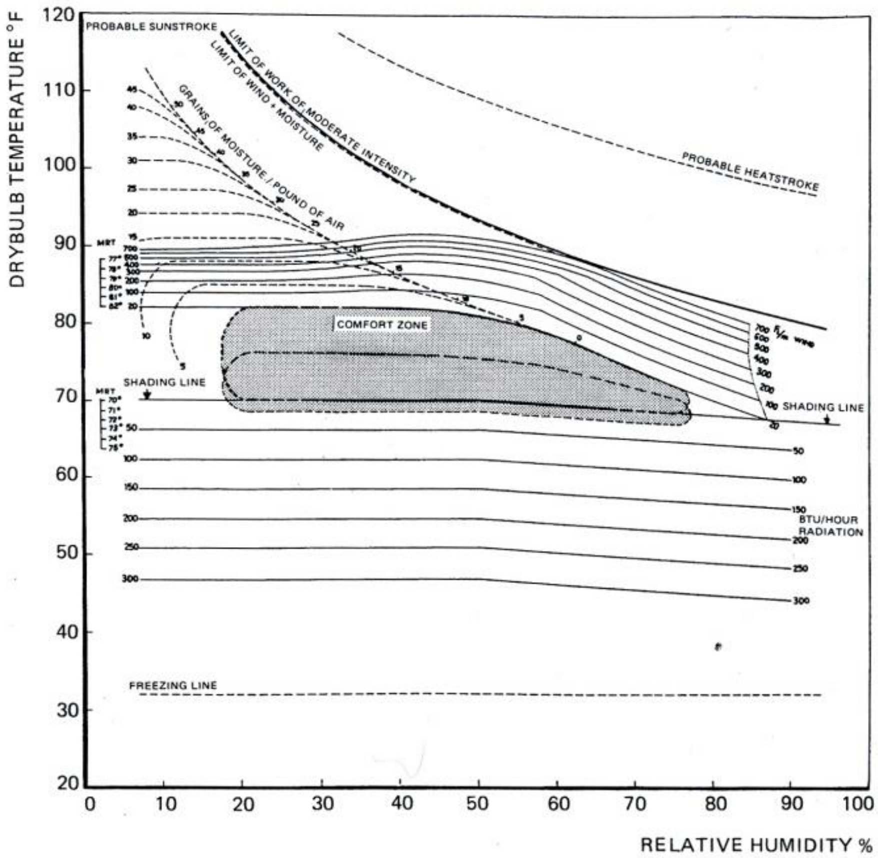


Figure 6 - 8: Olgyay Bioclimatic Chart (Abrams, 1986)

6.1.3.4. Givoni's Building Bio-climatic Chart (BBCC):

The building bio-climatic chart (BBCC) was introduced by Brauch Givoni based on the indoor temperatures in buildings. The BBCC is graphically drawn on the conventional psychometric chart (a linear relationship between the ambient temperature and the vapour pressure). It proposes the boundaries of the internal conditions within which various passive strategies as well as low-energy cooling systems can have the potential to provide internal comfort conditions in hot climates without integrating mechanical air-conditioning systems, these cooling strategies include:

- Daytime ventilation
- High thermal massed, with or without and nocturnal ventilation
- Direct evaporative cooling
- Indirect evaporative cooling

The boundaries of the comfort zone that are located on the BBCC are based on the expected internal climatic conditions in buildings. However, from his studies, Givoni found that the upper limits of the acceptable temperature and humidity can be higher for people living in hot and humid climates, where they are more acclimatized to such conditions (Givoni, 1998).

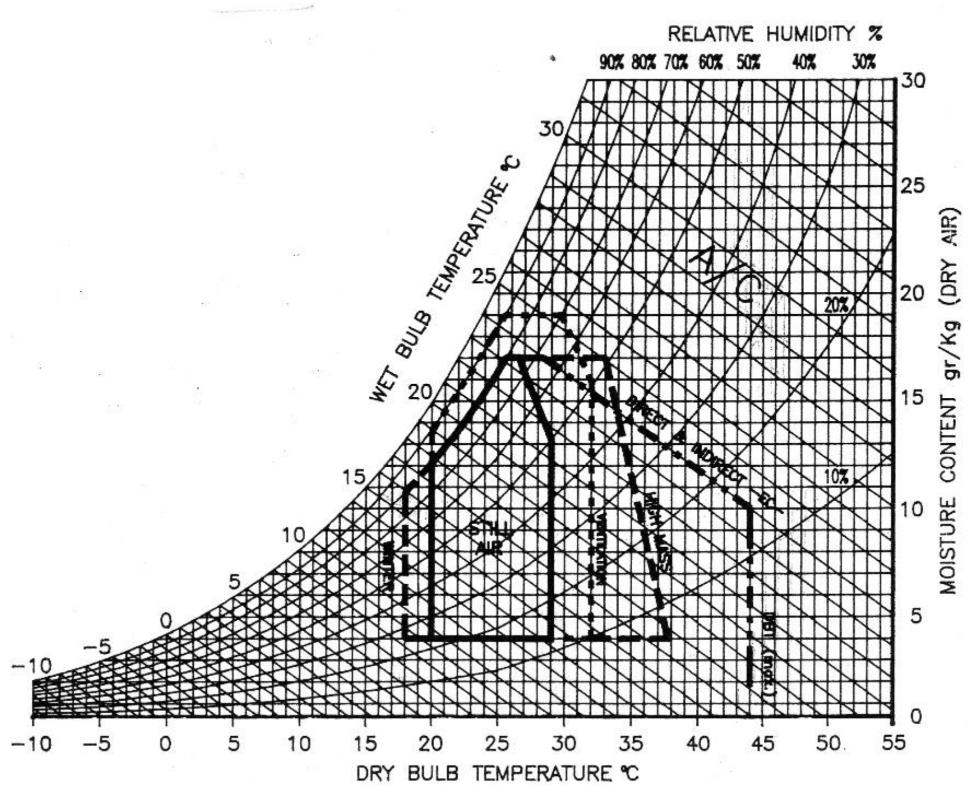


Figure 6 - 9: The boundaries of the comfort zone with different design strategies of passive cooling approaches for hot climates (Givoni, 1998)

6.2. Visual Comfort:

6.2.1. Visual Comfort Definition:

Vision is the prime sense of the human being. It is based on the selective property of the human eye to absorb and process the narrow band of the electromagnetic spectrum from 380 nanometers to 760 nanometers that is known as visible light (Flynn, et al., 1992). The sense of vision is particularly vital; from 80 to 90% of the human input data depend on what he can see and process. However, the brain cannot manage all the received date via vision, its quantity is therefore reduced and supplemented with own experience to form the complete picture (Hegger, et al., 2008).

Following the general definition of human comfort; visual comfort describes the human visual well-being and the absence of any visual discomfort in any given environment. literatures and research work had agreed that the main parameters or determinants that involve visual comfort concepts in buildings are lighting levels, glare, color rendering, and view to the outside. Gallo, et al. (1998) declared that the human visual system basically depends on the appropriate amount of light; where it affects our visual acuteness, our ability to distinguish details, and how ease we can perceive the visual information. Therefore, the first parameter of visual comfort is the adequate levels of lighting or illuminance (lx), both too little or too much light can produce eye strain and visual discomfort. Baker & Steemers (2000) further mentioned that the quality of light delivered on the task plane largely influence the effectiveness of the lighting system and disturbs the human visual comfort. This requires avoiding the glare conditions such as veiling reflections, and taking more considerations to color rendering, particularly in case of artificial lighting. Altomonte (2009) added that the presence of windows in buildings can afford natural lighting and the provision for external views; these issues had a great impact on the occupants' visual comfort and their general well-being, and potentially enhance their productivity. The human visual comfort determinants will be introduced in the following points:

6.2.2. Visual Comfort Determinants:

6.2.2.1. Lighting Levels (Illuminance):

Light is a fundamental and basic human need; the different patterns of light affects our visual experience of space and controls our psychological responses, impressions, and consequently our actions. In addition, it affects the human visibility in his working tasks and regulates his performance (Flynn, et al., 1992). Therefore, the lighting designer had to take into considerations the needs of the occupants with the other economic, environmental, and architectural objectives; then, to translate the results to create a functional and suitable visual environment, figure 6 - 10 (Rea, 2000).

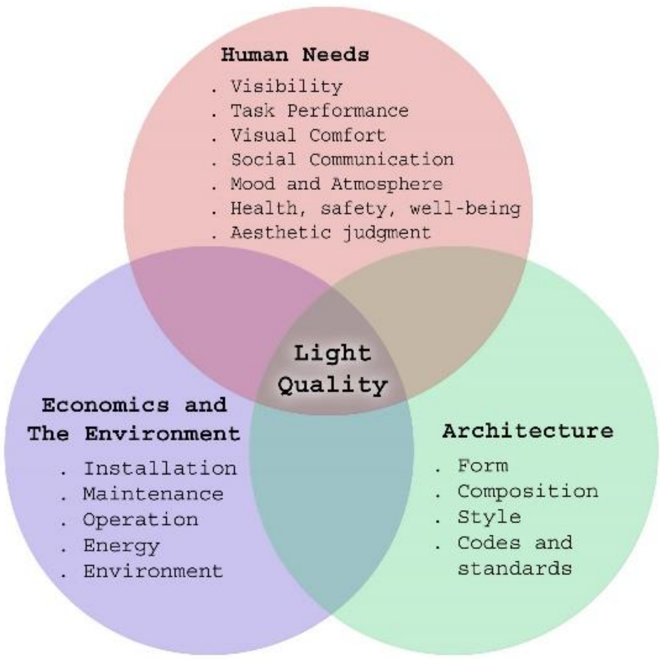


Figure 6 - 10: Lighting Quality: the integration of the Human needs, the architecture, and the economics and environmental factors (Rea, 2000)

The luminous flux is a quantitative unit that describes the output of the entire light flow emitted by a lighting source; it is measured in the unit lumens (lm). While, the illumination describes the total luminous flux incident on a certain surface area; it is measured with the unit lux (lx) or lumens per unit area (Hegger, et al., 2008). However, it should be noted that light is continuously spreading out in straight rays and the amount of incident illumination on any surface is inversely proportional to the square of the distance from the lighting source. In addition, it is also useful to consider that when light rays encounter any surface, it is either absorbed, reflected or transmitted through the surface according to the surface material and the angle of incidence of the light rays (Bradshaw, 2006).

Generally, it is necessary to establish the required level of illumination and to avoid unnecessary high levels of lighting throughout the space or the task plane according to the performed tasks, space activity, occupant density, traffic patterns, and the proportion of the workspace to the circulation area (Bradshaw, 2006). The Illuminating Engineering Society of North America (IESNA) handbook provides illumination levels guidelines to help in planning the appropriate task illuminance (table 6-4):

Visual Task Sets	Illuminance category	Performed Task	Illumination level (lux)
Orientation and simple visual tasks. Visual performance is largely unimportant. These tasks are found in public spaces where reading and visual inspections are only occasionally performed. Higher levels are recommended for tasks where visual performance is occasionally important.	A	Public spaces	30 lx
	B	Simple orientation for short visits	50 lx
	C	Working spaces where simple visual tasks are performed	100 lx
Common visual tasks. Visual performance is important. These tasks are found commercial, industrial and residential applications. Recommended illuminance levels differ because of the characteristics of the visual task being illuminated. Higher levels are recommended for visual tasks with critical elements of low contrast or small size.	D	Performance of visual tasks of high contrast and large size	300 lx
	E	Performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size	500 lx
	F	Performance of visual tasks of low contrast and small size	1000 lx
Special visual tasks. Visual performance is of critical importance. These tasks are very specialized, including those with very small or very low contrast critical elements. Recommended illuminance levels should be achieved with supplementary task lighting. Higher recommended levels are often achieved by moving the light source closer to the task.	G	Performance of visual asks near threshold	3000 to 10,000 lx

Table 6 - 4: Determination of spaces Illuminance levels (Rea, 2000)

However, for office spaces and particularly for the modern electronic office, where a combination of paper and video display terminals (VDT) tasks is performed, it is appropriate to keep the general illuminance level relatively low, and should not exceed 500 lx. Where low illumination level produces low brightness reflections, less effect on the screen contrast, and does not create glare from VDT screens. While, higher illuminances at other task locations, if required, can be provided by task-light luminaires (Rea, 2000).

6.2.2.2. Glare:

Glare, is a visual discomfort parameter, it is the unpleasant effect of contrast to the naked eye in the field of vision due to excessive luminance level caused by a lighting source (normally lamp or window) in a considerably lower mean lighting values (Gallo, et al., 1998). When the eye attempts to even out this contrast, its muscles start to work harder and more frequently, this cause tired eyes and increases its levels of stress (Carmody, et al., 2004).

Glare is defined by the Commission Internationale de l'Eclairage (CIE) as the "condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or extreme contrasts" (Erell, et al., 2014, p. 2). Glare effect caused by a light source sufficiently bright enough to create annoyance and discomfort within the range that the human eye can endure is called discomfort glare, while glare that prevent doing the required tasks, and can eliminate the visual performance or visibility is called disability glare (Carmody, et al., 2004). Glare can also be classified to direct and indirect glare according to the relation of the incident light beam to the field of vision. Direct glare is caused when the source of illumination directly strikes the eye's fovea (center of vision), i.e. the lighting source is in the field of vision. Therefore, direct glare can be a consequence of the space geometry and its lighting design. Glazed or transparent surfaces of the building envelope are often a basic source of direct glare. Indirect glare results from the reflected lighting beams off surfaces to the eye, it is best avoided by using flat or matte surfaces. Indirect glare that is caused by reflections of light sources on task surfaces such as glossy papers or screens are often known as veiling reflections; they reduce the required contrast for good visual performance, especially when the light angle of incidence equals to the angle of reflection established by the eye's location. Veiling reflections is one of the most crucial problem that the lighting designer can face, basically for the occupants that are working with visual display terminal (VDT) (Lechner, 2015).

Figure 6 - 11: Direct and indirect glare: (A) Veil reflections on visual display terminal VDT; (B) Direct glare from windows; (C) Indirect glare from glossy surfaces (by researcher)

Since brightness is a function of both reflectance and illumination, glare could be also controlled by adjusting the brightness ratios of surfaces in any space (Carmody, et al., 2004). Gallo, et al. (1998) noted that for any working environment, the brightness ratios of the observed object; to the immediate background; to the working surface (task surface) as a whole; to other surfaces in the field of vision should be 1:3:5:10 respectively. Hegger, et al. (2008) added that Bright wall and ceiling surfaces create more consistent distribution of the luminance; since they increase the light reflections from the surroundings, optimize the effect of both daylight and artificial light, and reduce the risk of relative glare. The excessive brightness ratios of the interior can be minimized by keeping the reflectance factor of its surfaces within the levels shown in table 6 - 5.

Area	Degree of Reflection
Ceiling	80-92 %
Vertical surfaces	40-60 %
Work surfaces	25-45 %
Floors	20-40 %

Table 6 - 5: Recommended value of surface reflectance and brightness ratios in any interior (Bradshaw, 2006)

Glare is very difficult to evaluate; however, many measuring mechanisms were introduced to evaluate the glare effect. One of these mechanisms is the visual comfort probability (VCP) which indicate the potential of the lighting source to cause glare. The VCP factor predicts the percentage of people who will find a specific lighting system or fixture acceptable regarding their visual comfort conditions (Lechner, 2015). Daylight glare index (DGI) is another mechanism that is based on the subjective response of the occupant to windows brightness within the field of view. Daylight glare index can vary according the orientation of the window, the presence of shading devices, solar-thermal properties of the window, and the window design conditions (Carmody, et al., 2004).

6.2.2.3. Color Schemes and Rendering:

Color is the third parameter of the human visual comfort. Color perception results from the interaction of different complex factors that includes the object characteristics, light source characteristics, the direction of the incident light, the surroundings, the viewing direction, the observer’s characteristics, and the observer's adaptation (Rea, 2000). However, it is convenient to differentiate between two physical issues: the color of the illuminated surfaces within the space, and the color of the light source. The combination of both is very important for the quality of lighting. The color of any surface is determined by the selective property of that surface to modify the incident light color by absorbing a portion of it and reflecting or transmitting a spectrally modified light that emphasize a single hue perceived by the eye as the color of the surface (Bradshaw, 2006). On the other hand, the color of the light source should be carefully considered, it is not only a perceptional factor but rather an element of comfort or discomfort, where the color of the light source and its spectral composition largely impact the color of surfaces within the space (Gallo, et al., 1998). This interrelation of light spectral characteristics and surface colors means that in order to provide the accurate color rendition, the light source must emit the band of wavelengths that the object can either reflect or transmit. The wrong mixture will change the required perception and can cause a deficient impression that the specific colors are completely lacking (Flynn, et al., 1992).

The color of light can be quantified in terms of color temperature (T_c) and color rendering index (R). The color temperature (T_c) is defined as "The temperature to which a black body must be heated for the light it emits to be of a similar color to the light being measured." T_c is measured in the degree kelvin (K). Since the black body changes the spectrum of its emitted light according to its temperature, at nearly 3000K, the light color is warm reddish, and over 5000K it turns cool blueish, while the color temperature of natural light lies between 6000 - 6500K. Kruithof graph (figure 6 - 12) show the relationship between the color temperature of the light and its illuminance, the shaded are defines the field of compatibility between the two values (Gallo, et al., 1998, p. 120).

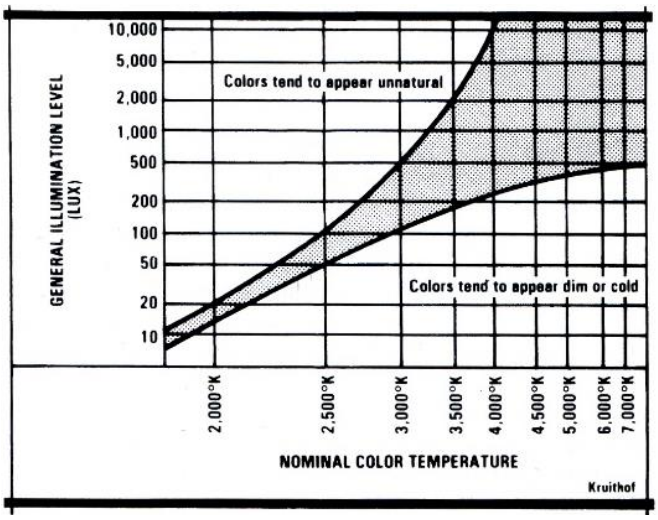


Figure 6 - 12: Amenity Curve by A. A. Kruithof, The shaded area defines the preferred combinations of the color temperature of a light source and the illuminance, the upper left corner tend to appear reddish, while the lower wright corner appear bluish (Flynn, et al., 1992)

While the color rendering index (R-value) measures "how well a given light source renders a set of standard test colors relative to their rendering under a standard reference light source of the same correlated color temperature as the light source of interest". For light sources with correlated color temperature lower than 5,000K, incandescent light is used as the reference light source. While for temperatures above 5,000K, some form of daylight is used (Boyce, 2003, p. 23).

In the real word, judgements of the actual color appearance of the lighting source are more common than its color matching. In an experimental study, the effect of different light sources on color judgements were examined; where the participants were asked to arrange a series of colored discs that differs only in their degree of hue into a consistent series under different commonly used light sources. The average value of the discs misplacements, i.e. mean error score were plotted against the color rendering index of each of the examined lighting sources (Figure 6 – 13). The results showed that the widely used high pressure sodium discharge light scored the highest error values, while the artificial daylight florescent light scored the lowest error values (Abdou, 1997)

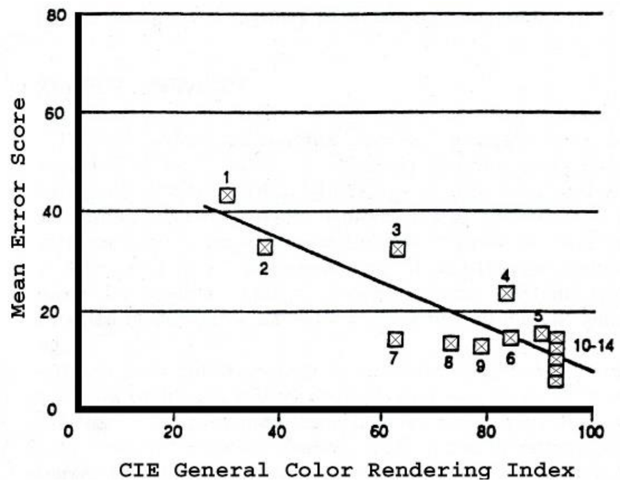


Figure 6 - 13: Mean errors as a function of light source plotted against CIE general color rendering index of source: (1) high pressure sodium discharge; (2) high pressure mercury discharge; (3) home light fluorescent; (4) TL84 fluorescent; (5) Kolor-rite; (6) natural fluorescent; (7) daylight fluorescent; (8) puls-white fluorescent; (9) metal halide discharge; (10-14) artificial daylight fluorescent (Abdou, 1997)

6.2.2.4. View to Outside:

View is the most subjective visual comfort determinant. It was traditionally considered as a function of buildings. However, view to the outside requires to have more attention from the architect for its highly desirable characteristic of maintaining the contact with the outer spaces, in which it clearly influence the design and selection of the glazed component (Carmody, et al., 2004). For that role, Button, et al. (1993, p. 53) resembled glazing as "the eyes of the building". Many information can be gained by the viewer through a simple glance out of the interior such as the time of the day, the prevailing weathering conditions, or the nearby people activities. In addition, external views can contribute to our sense of orientation and general well-being. For office spaces, the visual relief is considered as a very crucial issue; for a person sitting for hours behind a desk, view to the outside can be mentally restful and very stimulating (Carmody, et al., 2007). Further research had given an evidence that the glazing size, shape, proportions, and the visual content of the outside can largely influence the perceptions of the occupants to the space such as spaciousness, attractiveness, and acceptability (Carmody, et al., 2004).

The view index factor was introduced to measure the view. It results from the multiplication of the following factors: window area, visible transmittance of glass, the fraction of window area that is not obstructed by exterior shading devices, the percentage time that interior shades do not obstruct the view, and a factor for windows that cause interior reflections when the interior light levels are comparatively low. The view index is calculated at a point 3.0 m (10 feet) from the window. Higher view index value is considered better, since it gives more potential for larger visual area. View index does not take into considerations the shape of the glazing, the visual blockage due to the subdividing members, or to the color of the glass, although it is evident that strongly monochromatic transmitted light is less acceptable in rendering the interior (Carmody, et al., 2004).

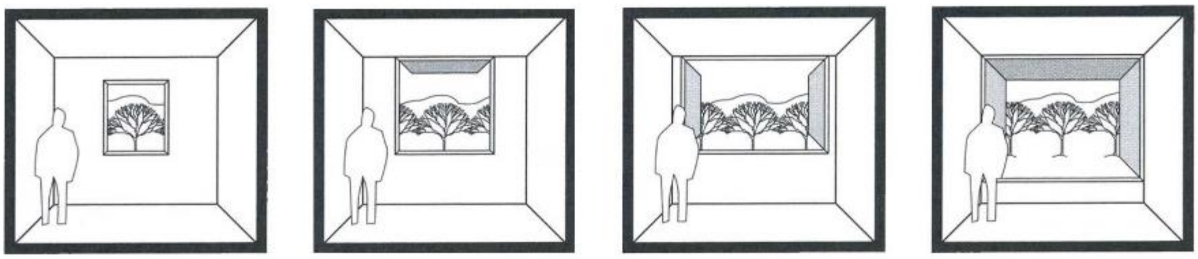


Figure 6 - 14: View index analysis cases (Carmody, et al., 2004)

6.2.3. Sources of Lighting:

Hegger, et al. (2008) noted that for any working space, the optimum visual comfort conditions can be attained if the light intensity at the working place is enough to the respective visual task. This can be achieved through three mechanisms are: natural daylighting, artificial lighting, or integrated lighting through daylight mechanism assisted by electrical light as will be presented in the following points:

6.2.3.1. Natural Day Lighting:

The sun is the dominant lighting source in nature, it radiates a huge spectrum of energy that includes long, short, and visible wavelengths. However, the earth's atmosphere modifies the received radiation by absorption, reflection, and selective transmission. The water vapor content of the atmosphere can also produce some changes on the solar transmission properties; its effect ranges from clear sky to overcast sky conditions. In addition, the daily rotation of the earth and its declination axis produces a constantly changing angular relationship between the solar radiation and any location on earth. Even the pollution and the other air suspended particles can influence the diffusion properties of natural light. These characteristics continuously produce variable daylighting conditions and changes the intensity of solar radiation on both hourly and seasonal basis (Flynn, et al., 1992) and (Bradshaw, 2006). (Hegger, et al. (2008) added that the daylight varies in intensity, heat content, color, diffuseness, and efficacy according to its source or type. Bradshaw (2006), Gallo, et al. (1998) and Flynn, et al. (1992) declared the three basic types or sources of daylight in the following points:

- **Direct sunlight:** It is the directional sunlight that strikes any surface in parallel beams with the maximum solar intensity. In the northern hemisphere, sunlight impinges directly on the east, south, and west facades where it generates well defined patches of light at the interior. This effect produces uncomfortable interior visual conditions in which it creates an excessive contrast and uncomfortable glare conditions. The position of the sun and the direction of its direct radiation with respect to any location at any time could be predicted through the graphic projection of solar rays by using the specific solar azimuth and altitude angles.

- **Skylight:** It is the nondirectional solar light that is scattered and diffused in the atmosphere according to the cloud condition producing sky luminance. Skylight is the most consistent source of daylight where it's light is distributed in all directions. However, the lighting intensity of skylight is weaker from direct sunlight by 10% to 20%. According to the its intensity, color quality, and directional uniformity, skylight can be distinguished into three forms: (1) Clear sky: where daylight comes from both the direct intense sunlight and the clear blue sky, (2) Partly cloudy sky: when the daylight varies from diffuseness to strong directionality in clear sky with continuous changes in condition by the minute, and (3) Overcast sky: when daylight is diffused, stable, uniform, and coming from all directions over the entire sky.

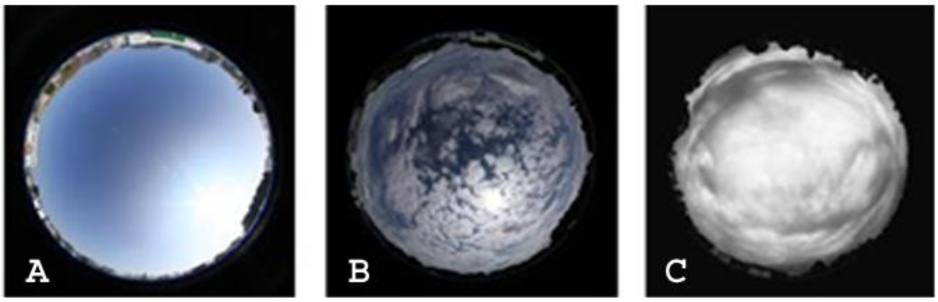


Figure 6 - 15: Types of skies: (A) Clear sky, (B) Partially cloudy sky, (C) Overcast sky (Hegazy, 2013)

- **Reflected light:** It is the reflected light from the ground and other nearby surfaces toward the building. Therefore, the selection of adjacent landscape materials can be used to influence the intensity of the incident daylight on the building envelope. In overcast sky conditions, the reflected daylight from the ground will be approximately range from 10% to 25% of the incident light on the envelope, while in sunny days, it will approach to 50% of the incident daylight on the envelope. The previous ratios could be increased if the building is surrounded by highly reflective or bright surfaces such as sand, light concrete, or snow cover.

Daylight factor is the most commonly used physical metric in building design to quantitatively evaluate the internal natural lighting levels. It is defined as "the ratio between the illuminance of a horizontal unshaded surface in the open air under an overcast sky condition to the illuminance of a horizontal interior surface, usually taken at the height of 0.85 m above the floor". While in buildings types which requires specific level of illuminance at specific working hours such as office buildings, the daylight autonomy measure could be better used. Daylight autonomy value is "a percentage represents the proportion of a typical period of usage during which the lighting requirements are guaranteed exclusively by daylight". For office buildings, daylight factor of 3% which is equivalent to daylight autonomy of nearly 50% is recommended (Hegger, et al., 2008, p. 102). However, it should be noted also the recommended level of illuminance for spaces (Thomas & Fordham, 1999).

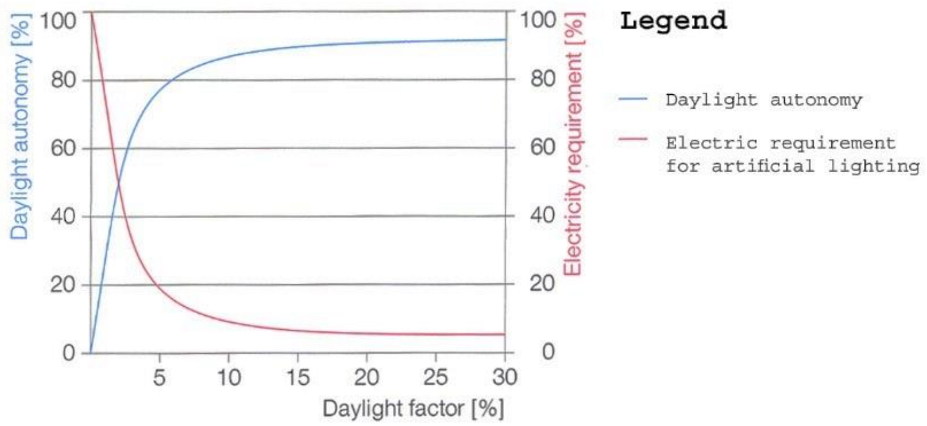


Figure 6 - 16: Relation between daylight autonomy, daylight factor and electricity requirements for artificial lighting (Hegger, et al., 2008)

Daylight is very efficient source of lighting for buildings. However, the quality and the quantity of the transmitted daylight to the interior should be controlled. the sun provides from 86000 to 108000 lux of light to earth, but only a small fraction of that amount is required for performing most of our tasks. Even if direct sunlight is avoided, the indirect daylight is still providing more illuminance than needed and can produce undesired glare and excessive brightness effects (Bradshaw, 2006). Therefore, to achieve the useful use of daylight, Bradshaw (2006), Lechner (2015), and Flynn, et al. (1992) introduces some daylight guidelines for designing the building facades in the following points:

- Integrated light control devices: They are very effective tools to avoid glare, excessive brightness, contrast, veiling reflections, and to enhance daylight distribution throughout the interior. Light control devices can be categorized into three forms: exterior, interior, and integrated within the glazing system. They include overhangs, light shelves, louvers, fins, egg crates, and other site works. Light control devices can be installed either fixed or movable. Sometimes the designer can integrate one or more device for the same opening.

Figure 6 - 17: The effect of external horizontal fins as a light control device to regulate the perceived glare; the figure shows its reformation effect for the same cases that are presented in figure 6 - 12

- **Orientation:** The south orientation is considered the best for useful usage of daylight; it usually affords the maximum quantities of sunlight and gives a consistent daylight on both daily and annually basis. However, in hot climates it is not desirable for its overheating effects in summer. The second choice is the north orientation; it provides a constant and cool daylight. While, the worst are the west and the east orientations; they receive direct sunlight with very low angle during the morning and the afternoon hours which create severe glare and shading problems.

- **Space form and planning:** Since light intensity is a function of distance, therefore the form and the planning of any space can determine the quantity of natural light penetration through it. For this reason, the decision of using daylight could lead to the use of open space to bring more light into the interior, or to design relatively narrow building that permit light penetration through both sides, or to use internal atriums and light wells. Figure 6 - 18 shows three floor planes with the same area, however, the variation in their forms affects their daylighting performance.

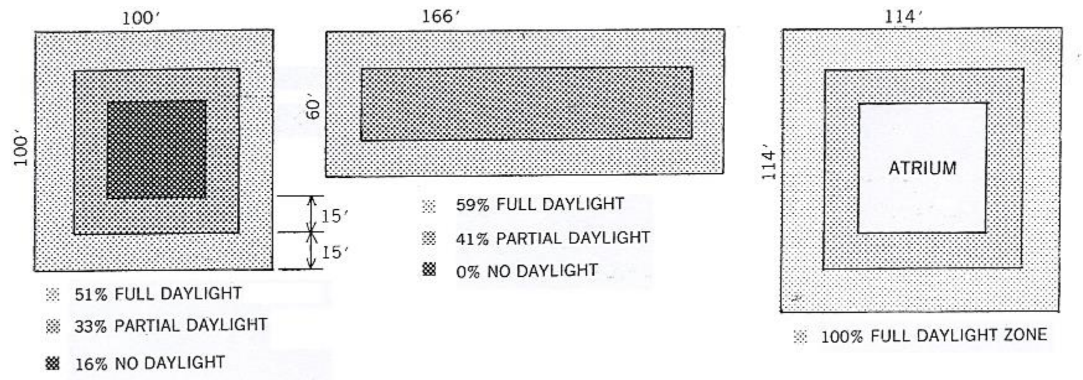


Figure 6 - 18: Effect of the building form on daylight availability (Lechner, 2015)

- **Envelope planning:** For better daylight penetration to the interior, high-leveled windows and skylights are usually very effective. However, Horizontal wide windows are more preferred to the occupants because they distribute the daylight illumination more uniformly within the surfaces of the interior. In addition, windows should be placed adjacent to light colored interior walls, so the light can be reflected from those walls to deeper areas. Placing windows in more than one wall can reduce the contrast and glare effect between the window and its surroundings.

- **Surfaces Color and brightness:** The usage of light colors internally as well as externally increases daylight reflectivity towards the building and further into its deep interior. In addition, light colored interiors can contribute in defusing the transmitted light and can reduce dark shadows, glare, and excessive brightness ratios. The ceiling should have the highest reflectance factor to diffuse the light uniformly throughout the space, while the floor and the pieces of furniture should have the least reflections to avoid the possibility of glare. The appropriate descending order of the surface reflecting ratios of the interior should be ceiling, back wall, sidewalls, floor, and furniture.

6.2.3.2. Artificial Lighting:

The primary measure of the efficiency of any light source is the efficacy; which is defined as "the ratio of the light emitted to the power input"; its unit is expressed in lumens per watt. The lighting source efficacy did not only determine its energy efficiency, but also indicate the amount of heat that it generate, in which this had a corresponding effect on the heat loads of the interior (Thomas & Fordham, 1999, p. 104). Many types of artificial lighting sources exist, according to Boyce (2003), electric light sources can be characterized upon several dimensions, these are: luminous efficacy, correlated color temperature, general CRI, lamp life time, warm-up time, and re-strike time. Table 6 - 6 show the previous characteristics for the most commonly used artificial lighting sources:

Lighting Source		Efficacy (Lm/watt)	Lumen Maintenance @50% life	Color Temp. (°K)	Color rendering index	Lamp life (hours)	Warm-up time (min)	Re-strike time (min)
Incandescent	Standard	8 - 19	80-90%	2,700	100	750 – 2,000	Instant	Instant
	Tungsten Halogen	8 - 20	95%	2,900	100	2,000 – 6,000	Instant	Instant
Fluorescent	Tubular Florescent	60 - 110	85-90%	3,000 – 5,000	50 - 95	9,000 - 20,000	Instant	Instant
	Compact Florescent	50 - 70	85-90%	2,700 – 4,200	80 - 85	9,000 - 20,000	Instant	Instant
Mercury Vapor		30 - 60	70-80%	32,00 – 7,000	15 - 50	16,000 – 24,000	4	3 - 10
Metal Halide		50 - 110	75-85%	3,000 – 6,500	65 - 95	3,000 - 20,000	6	5 - 20
High Pressure Sodium		60 - 140	80-90%	2,100 – 2,500	20 - 70	20,000 - 24,000	10 - 12	0 - 1
Low Pressure Sodium		100 - 180	-	1,800	poor	16,000 – 18,000	4 - 6	1
LED		30-160	95%	2,700 – 8000	65-97	30,000 - 90,000	Instant	Instant

Table 6 - 6: Properties of the most widely used electric sources (Boyce, 2003), (Bradshaw, 2006), (Lechner, 2015) and (Koch, et al., 2015)

Once the suitable lighting source is chosen, the luminaires or the lighting fixtures had to be determined. According to Lechner (2015), luminaires had three main functions: (1) support the lamp with the needed socket, (2) supply electric power to the light source, and (3) modify the emitted light from the source to process the required light pattern and reduce glare. Generally, typical luminaires can be divided according to the way they distribute light into six categories as shown in table 6 – 7:

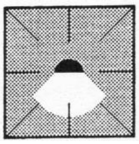
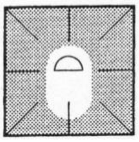
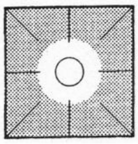
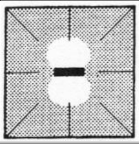
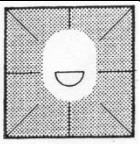
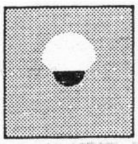
Type	Illustration	Light distribution	Distribution
Direct		$\frac{0\% - 10\%}{90\% - 100\%}$	Most of the light is directed downward to the work plane. This type is considered an efficient way to achieve high illumination level on the work-plane. Direct glare, veiling reflections and shadows are often a problem on the task, especially when the spacing between fixtures is large.
Semi-direct		$\frac{10\% - 40\%}{60\% - 90\%}$	They are very similar to the direct type except that a small amount of light is directed upward and then reflected off the ceiling. Since this process creates some diffused light, shadows and apparent brightness of the fixtures are then reduced, however, veiling reflections can be still a problem
General diffuse		$\frac{40\% - 60\%}{40\% - 60\%}$	The light is distributed equally in all directions. The horizontal component of the light can cause severe glare. The large indirect component minimizes shadows and veiling reflections
Direct-indirect		$\frac{40\% - 60\%}{40\% - 60\%}$	This luminaire type divides the light equally upward and downward. This type is preferable than the general diffuse as it solve the horizontal component problem.
Semi-indirect		$\frac{60\% - 90\%}{10\% - 40\%}$	Much of the light is reflected off the ceiling, and thus yields high quality lighting. However, the efficiency is reduced, especially when the ceiling and walls are nor of high reflectance.
Indirect		$\frac{90\% - 100\%}{0\% - 10\%}$	Almost all the emitted light is directed upward to the ceiling. The walls and the ceiling should have high reflectance factor. The diffused lighting almost eliminates glare, veiling reflections and shadows.

Table 6 - 7: Luminaires (lighting fixtures) types (Lechner, 2015)

The next step in artificial light design is to determine the number of luminaires and the required spacing for the planned illumination level. Bradshaw (2006) mentioned that the number of luminaires can be determined from the following equation:

$$number\ of\ fixtures = \frac{required\ lux \times m2}{maintenance\ factor\ \times lamps\ per\ fixture\ \times lumens\ per\ lamp\ \times CU}$$

Where: CU is the coefficient of utilization (already given from the manufacturer).

6.2.3.3. Integrated Daylighting and Electric Lighting Systems:

Hegger, et al. (2008) noted that, the main objective of designing any lighting system for any building should be to provide first the maximum daylight autonomy into the interior through the appropriate optimization of the building envelope. Then, in situations where natural daylighting is insufficient or even undesired, the required lighting level should be maintained with supplementary artificial lighting, while taking into consideration their energy input.

Daylight is considered the most practical and efficient method of using passive solar energy for almost all building types; particularly for commercial buildings. It diminishes the required energy for lighting and reduces the cooling loads that results from generating electrical lighting. Comparatively to other lighting sources, daylight is considered a very efficient and cool source of light; it provides from 90 to 160 lumens per watt of total energy, while the common fluorescent light provides from 35 to 100 lumens per watt, and the incandescent light only provides from 8 to 20 lumens per watt (figure 6 - 19). In addition, daylight creates the most pleasing color rendition at the interior (Bradshaw, 2006).

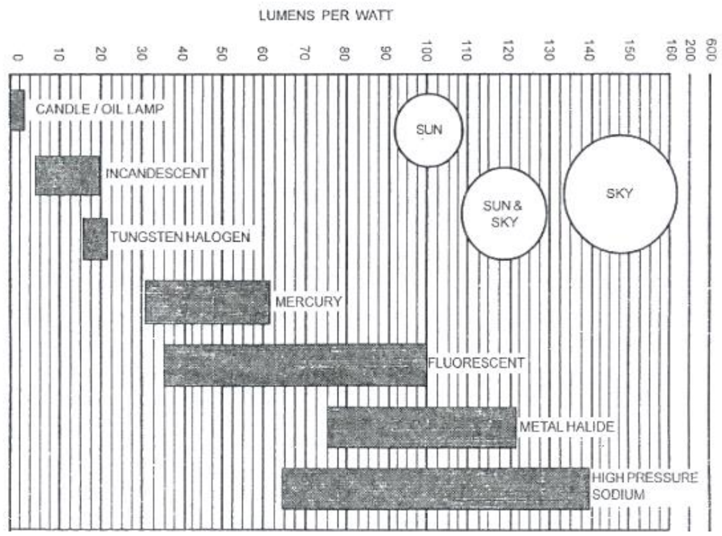


Figure 6 - 19: the efficacy of different artificial lighting sources compared to natural daylighting conditions (Lechner, 2015)

Lechner (2015) added that for a typical office building, nearly 40% of its energy usage is attributed to artificial lighting. Figure 6 - 20 shows the energy consumption rate in a typical office building during an average hot and clear summer day. Due to the intensive impact of solar radiation, the peak value of the electrical energy demand occurs during the afternoon hours when the air conditioning is working with its full capacity. At the same time, the sun provides the maximum quantity of lighting. Therefore, if daylighting is planned properly, some or even most of the electric lighting energy can be preserved, and consequently, the peak energy demand of the building can be significantly reduced up to 40%.

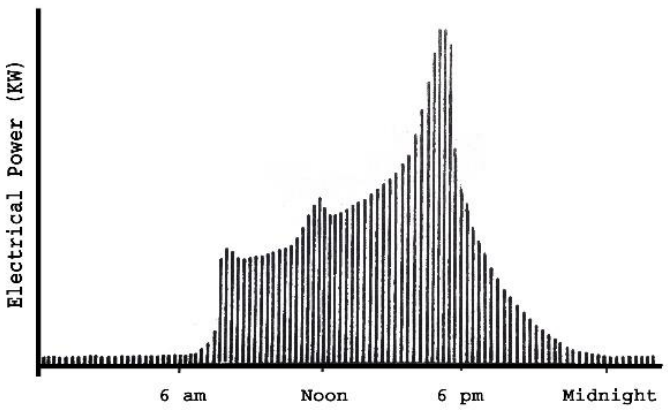


Figure 6 - 20: Electrical energy consumption in a typical office building during hot sunny summer day (Lechner, 2015)

However, even if the building is planned to be completely daylit, an electrical lighting is still needed for night occupancy or any other prevailing environmental conditions. The proper integrated lighting system should achieve the effective combination of both natural and artificial lighting sources, in which electric light is used as a supplementary lighting source to insure the adequate level of the required task illumination. In this case, Lechner (2015) suggest that for better and more efficient use of artificial lighting, it should have some automatic controllers to either switch on/off or dimming the light according to the daylighting conditions at the interior. In addition, the luminaires (lighting fixtures) should be arranged in rows parallel to the window, so any row can be turned on/off as required to complement the illumination of daylight, and to create more uniform lighting level (figure 6 -21).

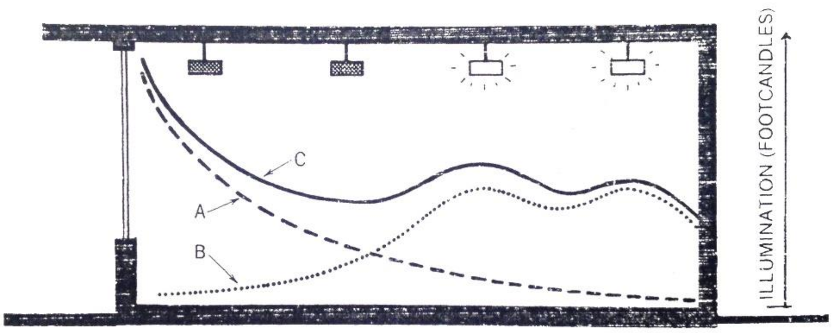


Figure 6 - 21: Curve A: Daylighting, curve B: Supplementary electric lighting, and curve C: combined effect of both electric and natural light to create uniform lighting level (Lechner, 2015)

Also, it should be noted that the color of daylight is quite variable, where during typical clear sunny day, daylight will produce a color range between 4000 °K and 5000 °K equivalent color temperature. In most office spaces, where daylight is used extensively, the light designer should attempt to match the color of the required electric light with the perceived daylight temperatures. In addition, the color of the glass should be also considered, as for example, the transmitted daylight from a bronze tinted window will gain a lower color temperature (warmer) than clear glazed window (Flynn, et al., 1992).

Chapter VII

Solar Protection

7. Solar Protection:

Solar protection is one of the most important energy efficient strategies; since almost all buildings encounters from some overheating periods in summer, and the usual response for this issue is to intervene with the energy-consuming air conditioners. Consequently, the energy needed for mechanical AC will increase exponentially as more people, particularly in the developing countries, can afford it. This huge increase in cooling energy demand should be reduced through its avoidance, then, any remaining needs could be satisfied by the use of mechanical equipment to cool whatever the passive cooling strategies could not accomplish (Lechner, 2015).

In order to define the role of the solar protection tools and components for an efficient transparency, this part of the research highlights the importance of solar protection in reducing the buildings cooling loads. Its relevant fundamentals are presented based on two main tools: First, the external shading devices, and second, the solar control glazing technology. Each tool will be studied briefly to select the most adequate types for the upcoming operational studies.

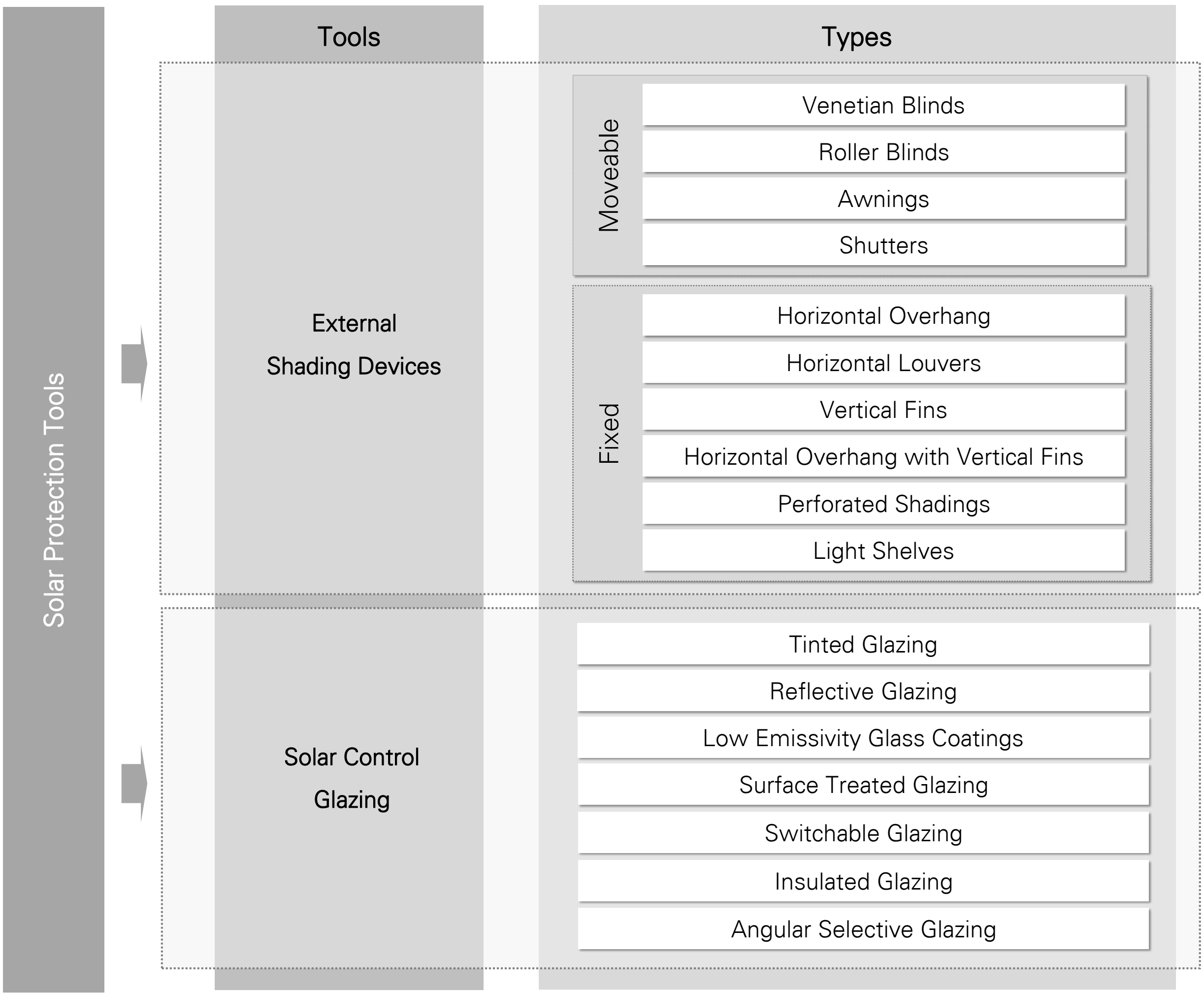


Figure 7 - 1: Solar Protection Tools

Kuhn (2006) argued that the current architectural trend of modern international office buildings leads to highly transparent glazed façades. Nevertheless, these building models should provide the occupants with the required thermal and visual comfort conditions, and to have a low-energy consumption. This goal cannot be reached unless the facade is carefully designed in order to provide the effective protection against excessive solar gains. In glazed office buildings, internal heat loads caused by electronic equipment and occupants are much lower than heat gained from the transparent glazed envelopes. Therefore, careful design and planning of solar protection systems is an essential requirement. As an evidence, in some rooms of the fully glazed high-rise building GALLILEO, in Frankfurt, 70% of the peak cooling loads are caused due to solar heat gains. Solar gains can therefore have a massive impact on the occupant's comfort, building energy consumption, CO^2 emissions, investment costs for HVAC systems, and some additional costs.

Figure 7 - 2: GALLILEO, new high-rise building for the Dresdner Bank in Frankfurt, by Novotny Mähner Associates, 1999-2003 (City of Frankfurt am Main, 2016)

Voss, et al. (2007) noted that the amount of the transmitted solar radiation, or the solar load, of the buildings' transparent areas is primarily determined by:

- The size of the glazed areas.
- The orientation of the glazed areas.
- The external layout and the presence of any obstructions like surrounding buildings or trees.
- The solar and thermal properties of the glazing.
- The properties of the solar protection devices and how they are operated.

Figure 7 - 3 Demonstrate the solar load per floor area as a function of the weighted solar aperture of a room for different levels of irradiation; where the weighted solar aperture area is a function of both the glazed area per floor and the total energy transmittance of the used glass. Solar control devices can effectively reduce and diminish the effects of total solar energy transmittance (Voss, et al., 2007).

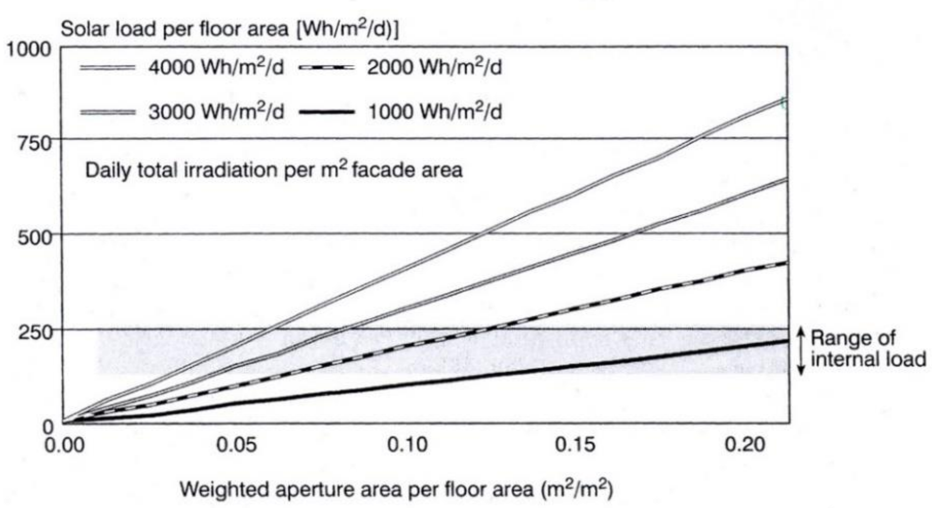


Figure 7 - 3: Total daily solar load per floor area as a function of the weighted specific aperture area and the total daily irradiation on a building façade (Voss, et al., 2007)

In addition to its role in enhancing the energetic performance of the building, especially in hot climates, solar protection devices such as external shading devices can also add some values upon the outer appearance of the glazed buildings. Hestnes (1999, p. 184) noted that the solar protection elements can be used to enhance the aesthetic appeal of the building; the key to the success of this issue, is that architects had to use the approach of "aesthetic compatibility" rather than invisibility. This is only possible if the design of solar protection systems is considered from the early design of the building.

Figure 7 - 4: Modernized Mashrabiya shadings of Al-Bahr Towers, Abu Dhabi (Oborn, 2013)

7.1. Solar Geometry Fundamentals:

Owing to the path of the sun across the sky, solar radiation is a dynamic variable in terms of its hourly, daily and annual trajectory. Accordingly, in order to establish the adequate solar protection potentials, the planning process of any building must consider the prevailing solar geometry with regard to its specific location as an important and fundamental requirement (Hegger, et al., 2008).

The sun is a huge fusion reactor in which light atoms are fused into heavier atoms, thus releasing huge amount of energy; this process can occur only inside the sun in a temperature of 14,000,000 °C. Solar radiation reaching earth's surface is much cooler than the emitted radiation from the sun, the reached radiation is equivalent to radiation that is emitted from a body having a temperature of about 5,500 °C. The earth's orbit around the sun is elliptical; therefore, the distance between the earth and the sun varies. While the earth revolves in its orbit around the sun, it spines around its North-South axis, which is tilted by 23.5° off the normal of the orbital plane. This resulting the seasonal changes and the annual variation in solar radiation intensity, in addition, it has major implications for solar design (figure 7 - 5). Since the sun lies very far away, and it lies in the plane of the earth's orbit, solar radiation reaching the earth's surface is considered always parallel to this plane (Lechner, 2015).

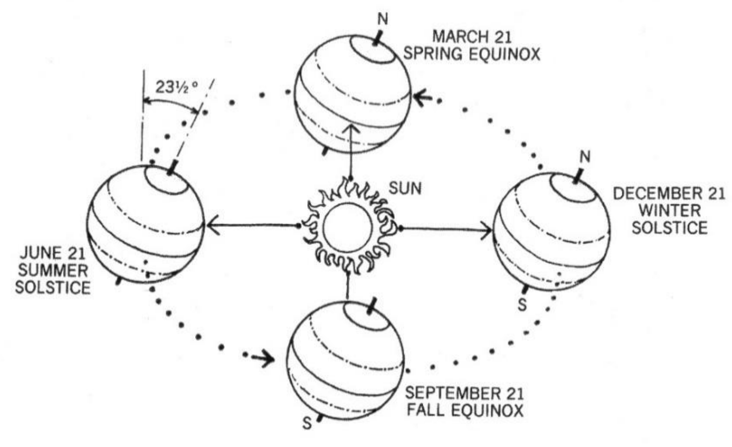


Figure 7 - 5: The elliptical path of the earth and its tilted axis of rotation and their consequences of seasonal changes (Lechner, 2015)

7.1.1. Solar Angles:

The geometric relation between any surface and the incoming beam of solar radiation can be easily predicted through the graphic projection of the direct solar rays by using the incident angle, solar azimuth angle, and solar altitude angle (Flynn, et al., 1992). The solar angles are defined by Duffie & Beckman (2006, p. 12) as:

- **Angle of incidence (θ):** "The angle between the direct beam radiation on a surface and the normal to the same surface"
- **Solar Altitude angle (α_s):** "The vertical angle between the horizontal and the line to the sun".

- **Solar Azimuth angle (γ_s):** "The angular displacement from the south of the projection of direct beam radiation on the horizontal plane. Displacements east of south are negative and west of south are positive".

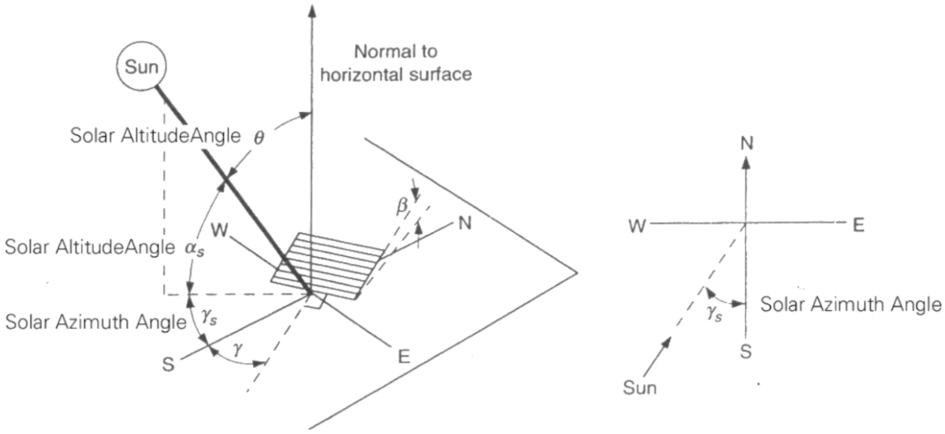


Figure 7 - 6: a) Isometric view of the Angle of incidence, solar attitude angle and solar Azimuth angle, b) plan view shoeing solar azimuth angle (Duffie & Beckman, 2006).

Lechner (2015) noted that it is important to recognize that the solar angles refer only to the direct radiation component. Both, water contents and dust particles of the atmosphere scatter some of the solar radiation, and influence the amount and the composition of the radiation reaching the earth's surface. Therefore, in cloudy, humid, or dusty days, diffuse radiation becomes dominant.

7.1.2. Sun Path Diagrams:

For better understanding to the solar geometry, Lechner (2015) demonstrated that it is more convenient to imagine the sun revolves around the earth in a sky dome placed over the building site. The points where these sunrays penetrate the sky dome are marked. On connecting all the points for one day, we get the sun path for that day (figure 7- 7). The sun's path is completely symmetrical around the north-south axis.

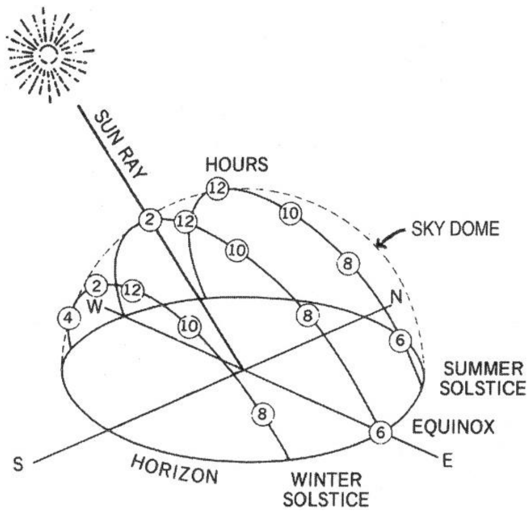


Figure 7 - 7: The sky dome and the three sun paths of June 21 (summer solstice), September/March 21 (Equinox), and December 21 (winter solstice) (Lechner, 2015)

Although both the solar altitude angles and the solar azimuth angles could be obtained from predefined tables, it is more informative for architects to get them from the sun-path diagrams. Figure 7 - 8 shows a plot of the horizontal projection of the sky dome at 36° N latitude. In the diagram, the sun path of day 21 of every month is labeled with the Roman numbers (from I to XII). The daily hours are labeled along the monthly sun path. The concentric circles define the altitude angle, while the radial lines describe the azimuth angles (Lechner, 2015).

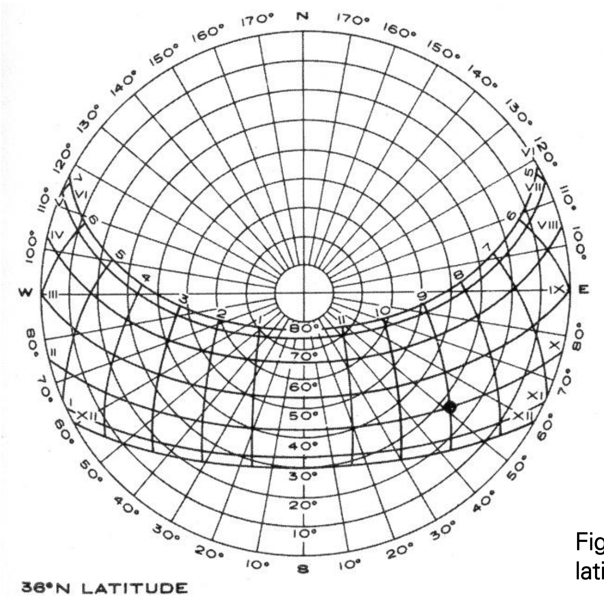


Figure 7 - 8: The horizontal sun path diagram for 36° N latitude (Lechner, 2015)

Figure 7 - 9 shows the vertical projection of the sky dome for the same 36°N latitude. Altitude angles are plotted on the vertical axis, while azimuth angles are plotted on the horizontal axis. In addition of being an informative source of the sun angles, sun path diagrams also help in creating a mental model of the sun's motion across the sky dome. The accurate representation of the direct solar beam aids the designer to evaluate the logic and test the validity of his solar responsive design (Lechner, 2015).

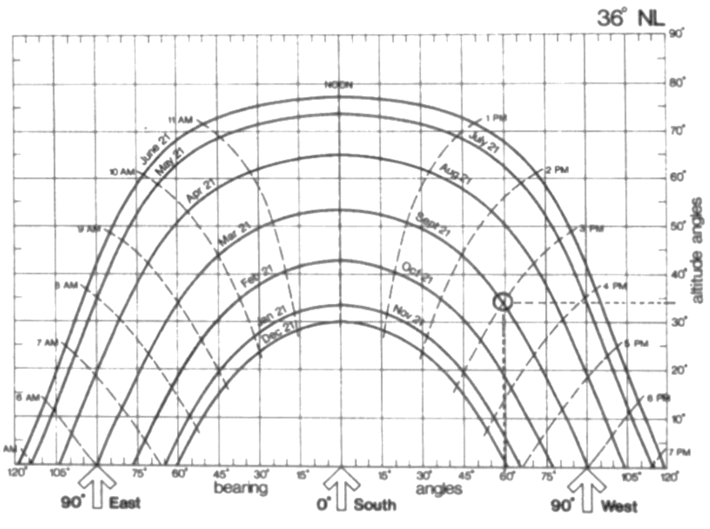


Figure 7 - 9: The vertical sun path diagram for 36° N latitude (Lechner, 2015)

7.1.3. Solar Radiation Heat Gain:

Solar heat gains are purely sensible heat loads. The solar radiations heavily contributed to the buildings' cooling loads in two ways; first, directly through the transparent component of the envelope, and second, indirectly by increasing the surface temperature of external surfaces such as walls and roofs. (Abrams, 1986). Duffie & Beckman (2006, p. 10) defined the different terms and components used to describe solar radiation components as:

- **Beam Radiation:** "The solar radiation received from the sun without having been scattered by the atmosphere. Beam radiation is often referred to as direct solar radiation".
- **Diffuse Radiation:** "The solar radiation received from the sun after its direction has been changed by scattering by the atmosphere. Diffuse radiation is referred to in some meteorological literature as sky radiation or solar sky radiation".
- **Total Solar Radiation:** "It is the sum of the beam and the diffuse solar radiation on a surface. The most common measurements of solar radiation are total radiation on a horizontal surface, it is often referred as global radiation on the surface".
- **Irradiance (W/m2):** "The rate at which the radiant energy is incident on a surface per unit area of surface with appropriate subscripts for beam, diffuse, or spectral radiation".

The energy distribution of the solar radiation changes according to cloud cover conditions; the main change is in the diffuse to the direct beam radiation ratio. Whereas, on clear days, from 10 to 20% of the incident radiation is diffuse, while this component could increase to 90% or even 100% on a complete overcast sky day. In addition, the intensity and the beam to diffuse ratio is also dependent on the location (latitude), orientation, and surface tilting angle. These factors are important criterial for designing and selecting the required solar protection systems (Voss, et al., 2007).

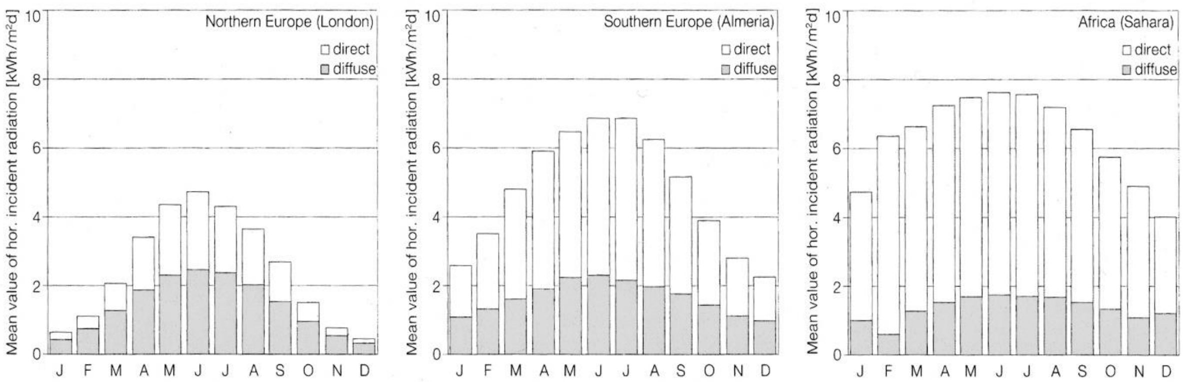


Figure 7 - 10: Comparison of the monthly mean values for diffuse and direct solar radiation in different latitudes (regions) (Hegger, et al., 2008)

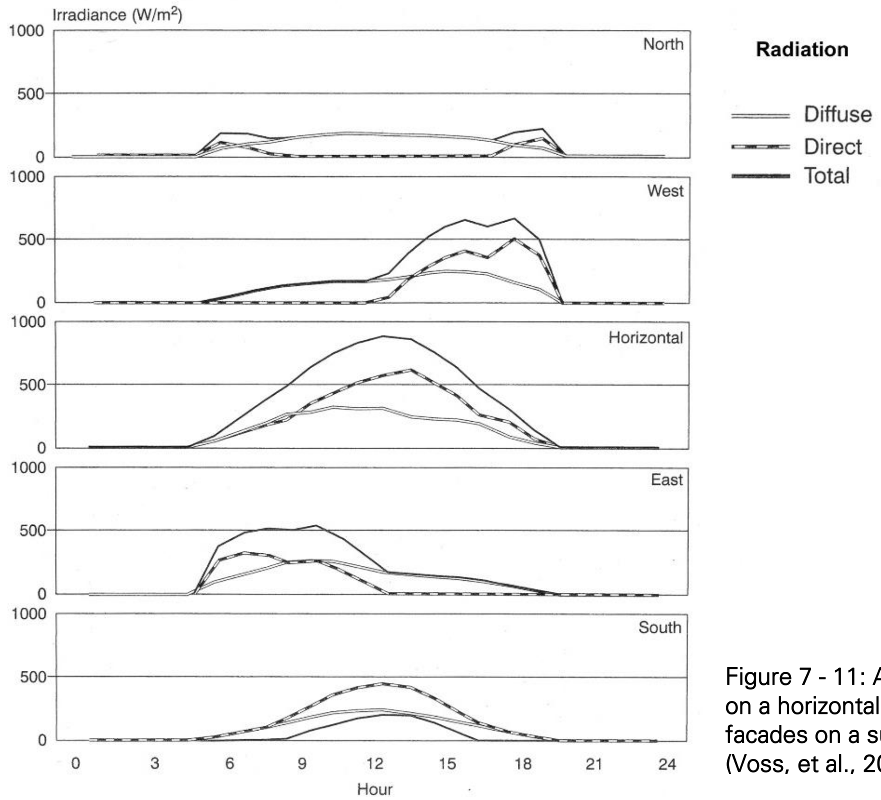


Figure 7 - 11: Average hourly irradiance profile on a horizontal plane and differently oriented facades on a sunny day at 42°N latitude (Voss, et al., 2007)

However, the crucial question is always which window needs the most shading measures in summertime? Figure 7 - 12 shows that on the 21 of June at latitude 42, the horizontal surface collects solar radiation almost four times higher than the south window. This implies to have very effective shadings over skylights, or better to be avoided. In addition, east and west windows collect solar radiation more than two times than the south facades for the same day. Therefore, placing shading devices at windows of the east and west are more significant than south and north. In winter, the south oriented facades collect more solar radiation than any other orientation. Thus, for having an efficient shading in summer and passive gain in winter, south windows are optimum (Lechner, 2015).

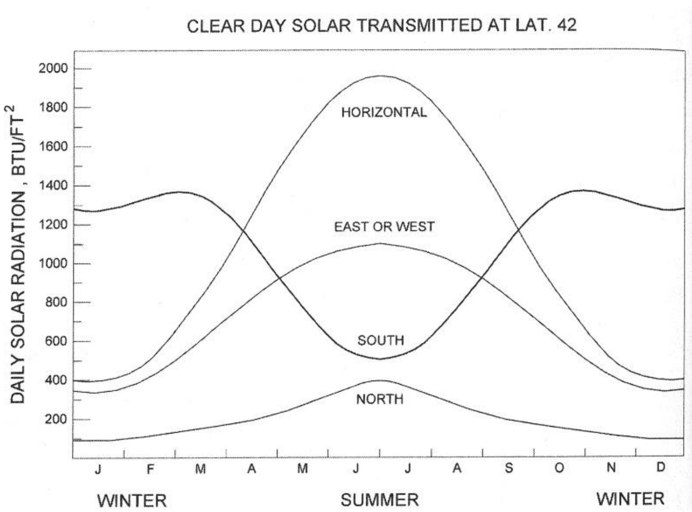


Figure 7 - 12: Average monthly solar radiation on a clear day at latitude 42°N (Lechner, 2015)

7.2. Prominence of Solar Protection in Buildings:

The architect should establish the appropriate objectives and criteria to control solar radiation in his designs. Un-shaded large glazed panes can contribute in enhancing the lighting quality and efficiency of the space, however, it will also cause massive solar heat gain (Flynn, et al., 1992). There are three fundamental objectives can briefly describe the prominence of solar protection devices and their need:

7.2.1. Reduction of Solar Overheating:

Solar loads are significantly higher than any typical internal loads in office spaces. Under the Central European climatic conditions, solar Protection is a fundamental tool to reduce the buildings' cooling loads to a point that could meet the expectations of the internal thermal comfort standards, especially in summer, without the intervention of air conditioning systems. However, in hot-arid climates, with regard to the long-lasting hot periods and the relatively clear sky conditions, it is much harder to achieve this goal without an effective solar protection strategy. Voss, et al. (2007) demonstrates in the following points, the basic principles that had to be considered in order to achieve the proper solar protection with regard to the overheating problem:

- **Limitation of solar heat loads:** This process aims to reduce the actions of heating the interior indirectly. Transmitted solar loads do not impact the interior at once, but rather after a certain delay time determined by the heat storage capacity of the building masses. Therefore, their loads should be limited and minimized before the overheating effect became tangible to the occupants. Solar control devices work on the limitation of the transmitted radiations, and thus gives the potential to increase the overheating time delay.
- **Protection against direct irradiation by the sun:** If any person is subjected to the direct solar irradiation his body surface will immediately and tangibly absorb the solar energy. This effect is generally undesirable for the working environment, especially in summertime or under high temperature condition. Therefore, all solar control systems should prevent direct solar irradiation from being transmitted into the interior or at least to limit it effectively.

All solar protection devices reduce, to some extent, heat gain from solar radiation. However, undoubtedly, external shading devices are always considered more efficient than the internal ones; since they partially keep the radiation out of the interior. In order to reduce solar overheating, it is advised that the solar protection device should have low total solar energy transmittance or low g-value which is a physically measurable parameter of the total fraction of incident solar radiation transferred into the building to the total incident energy (Littlefair, 1999). However, as defined, the g-value is a parameter that only applies to specific boundary conditions. In particular, it is unrealistic and less reliable for comparing different forms of solar protection devices, or when the sun hits the windows at an oblique angle (Littlefair, 2005) & (Voss, et al., 2007).

The effective g-value (g_{eff}) is more realistic measuring tool, it allows for introducing the effects of both the directly and the diffused radiation coming in from different angles, as well it allows the involvement of multiform and combination of shading devices with glazing. Effective g-value is defined as the ratio between the total solar gain in a period of potential overheating through the glazed system with the shading device to the total solar gain through unshaded and unglazed aperture for the same period, under specific boundary conditions. The interval from May till August has been chosen to represent the basis for solar gain calculations. This method means that for most solar control devices the effective g-value will vary with changing the orientation or if the glazing is not vertical (Littlefair, 2005).

Kuhn (2006) proposed a model (figure 7 – 13) to measure the effective g-value. The hourly direct and diffuse solar irradiation are determined from the typical meteorological data. taking into consideration the hourly direct and diffuse irradiation, the average total solar energy transmittance and the monthly average total solar energy transmittance can be then calculated. This should be done for every facade orientation. The hourly and monthly g-values are then proposed as the basis to compare the efficiency of different systems and products. Since it is too much time-consuming to perform the required measurements of the total g-value for many directions of incident radiation with many different tilt angles, the total g-value is calculated with a specific thermal-optical model which is able to take these conditions into account. This model could be also used in building simulation programs; where it can be used to incorporate the complex angular dependency of total g-value into these software programs. In addition, the model provides a method to generalize calorimetric measurements to various boundary conditions and to make them usable for building simulation programs.

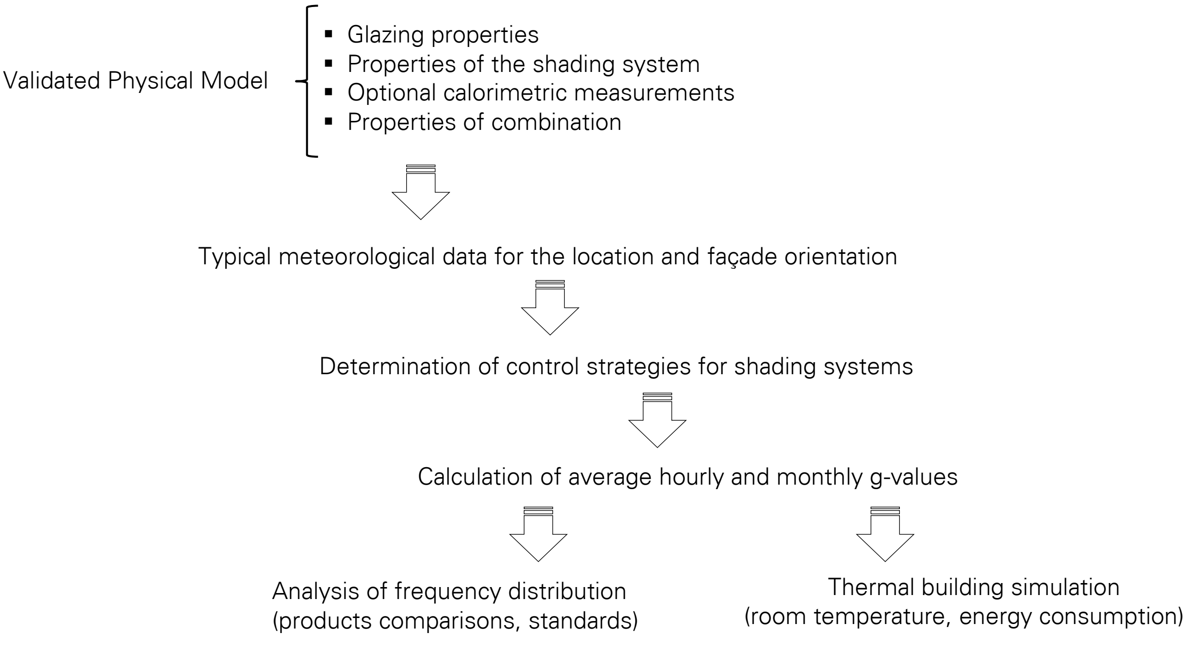


Figure 7 - 13: Fundamental idea of the proposed methodology to determine effective g-value, based on validated model calculations for solar control, glare protection and daylight supply (Kuhn, 2006)

7.2.2. Enhancing Lighting Qualities:

Nowadays, office buildings represent the main application for the need of solar control devices. In addition to the previous objective of reducing the solar overheating in summer, the prevalence of working tasks means that high degree of visual comfort should be guaranteed; particularly glare, since high luminance and high contrast levels encountered in the direction of windows especially with the penetration of direct sunlight can cause some kinds of glare that reduces the required contrast on working surfaces and computer monitors. These glare effects reduce the workers' visual satisfactions and should be avoided (Voss, et al., 2007).

Therefore, in order to preserve the required conditions for the workers' visual comfort, it is more convenient to regulate the transmission of direct solar radiation into the interior (Flynn, et al., 1992). Bradshaw (2006) demonstrate the role of solar control devices in enhancing the lighting qualities of the interior in the following points:

- Control glare through limiting the direct and excessive bright sunlight from being transmitted in to the interior, and especially at the perimeter zones of the space. While at the same time, allowing the transmission of diffused illumination.
- Balance the light patterns in the space through redirecting sunlight towards the ceiling for indirect distribution and deeper penetration in to the space. And thus, enhance the space overall luminance distribution.

Glare from the transparent parts of the façade can happen in other various ways; it can come directly from sunlight, or from a bright patch of the sky illumination, or by reflection from an opposite building or from a near horizontal surface (direct or indirect glare as seen in chapter 6). If direct sunlight causes glare, transparent solar control concepts such as tinted glazing will not help much due to the high level of sun brightness, in such cases, opaque shading devices such as venetian blinds is a better solution. Translucent shadings such as light-colored fabrics or blinds gives some protection from glare, but they may become uncomfortably bright if they exist in the field of vision (Littlefair, 1999).

7.2.3. Provision of Privacy:

Privacy is a subsidiary function of solar protection devices. However, it is important and crucial need for the behavioral functions that normally occurs in any space. Privacy should be determined precisely whether it is desired or not. The internal context as well the external one considerations to privacy should be entered into the envelope design decisions. Visual privacy is likely to be important need when the occupant's behaviors are of a personal, secret, or intimate nature, or when high levels of concentration are important to perform the required tasks, or even when there is a need for security or protection, especially if the functions occurs at the buildings' ground level (Heerwagen, 1990).

Movable or adjustable solar protection devices can give the occupants the chance to have the required degree of privacy that they desire at any time. While opaque shading devices provides them the best protective screening. Translucent and transparent shadings such as net curtains and reflecting glazing concepts provide privacy by superimposing a reflected bright light screen; the reflected light is much brighter than the light rays that came from interior which obstruct the view to the inside, although these shadings can be effective during the daytime, but they do not work at night since the interior is brighter inside than the exterior (Littlefair, 1999).

However, regarding the previous three objectives of solar protection in buildings, it is not an easy task to define a shading device that could meet all of them. For example, reflective glazing may reduce solar overheating and provide some privacy, but it is poor in reducing glare. An external overhang or light shelf can protect from overheating and glare in summer, but it didn't provide privacy. In office spaces, solar overheating can be crucial if the glazed ratios are relatively large, especially if the building is from lightweight structure or the office equipment's produce a lot of heat. Privacy is often becoming important for ground floor spaces or for offices that lies beneath a major circulation route. The internal lighting qualities is also an important issue; nearly all office spaces nowadays have computer workstations, the health and safety regulations for display screen equipment require that the space windows shall be fitted out with a suitable system of adjustable coverings in order to attenuate the required daylight intensities that falls on the workstation. Usually this means an adjustable blind, which the occupants can control (Littlefair, 1999).

7.3. Solar Protection Tools:

Prevention of solar radiation from transmission or penetration into the building is one of the fundamental principles to avoid overheating conditions of the interior in summer. Nowadays, highly transparent or highly glazed applications in buildings are widespread in most countries around the world. Solar overheating of these buildings such as offices became a crucial problem, even in countries with moderate or even cold climates. Thus, the manipulation of the shading devices and the solar-thermal properties of glazing should become as an effective multi-functional tool to elaborate better thermal and visual performance of any building (Santamouris & Asimakopoulos, 1996).

> "The sun control device has to be on the outside of the building, an element of the façade, an element of architecture. And because this device is so important a part of our open architecture, it may develop into as characteristic a form as the Doric column".
>
> Marcel Breuer quote, cited from (Lechner, 2015, p. 229)

External solar protection concepts are considered more effective than their similar internal ones; since the interception of solar radiation occurs outside the occupied space, then the rest can be dissipated to the interior with minimum effect (Flynn, et al., 1992). Figure 7 - 14 shows that solar protection could be better achieved through creating obstacles to the direct solar radiation path by means of exterior shading devices; they can block about 80% of the solar transmission through unprotected clear glazing. The manipulation of the solar-thermal properties of the glazed material through the intervention of solar control concepts can reach almost 60% protection from the total solar transmission (Lechner, 2015).

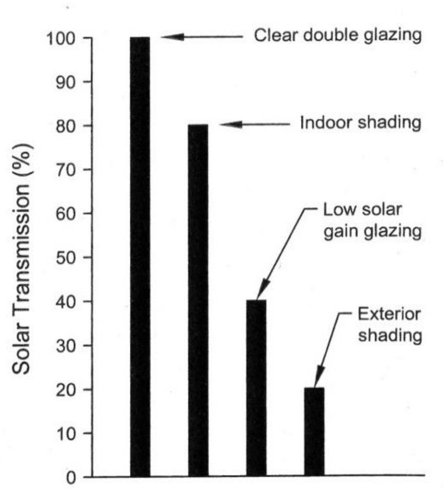


Figure 7 - 14: Comparison of the solar transmittance of solar protection tools with clear double-glazing (Lechner, 2015)

The need for an efficient daylighting might seem to conflict with the need for solar protection. However, if solar energy is planned probably, it can afford a high-quality daylighting with low rates of solar heat gain than what would be produced by artificial lighting. When the solar radiation is not used for daylighting, it should be blocked during the overheat period of the year (Lechner, 2015). According to the ASHRAE (2011), natural lighting planning can also increase the building's energy performance measures and impact its initial costs, since as the overall cooling loads are reduced, the fans, ductwork, and cooling equipment can be consequently downsized. In addition, it can be translated into more savings when electrical lighting is replaced with daylight which offset of the electrical lighting heating loads. When designed properly, daylighting lowers energy consumption and reduces operating and investment costs through the following points:

- Reducing electrical loads used for lighting and peak electrical demand,
- Reducing cooling energy and peak cooling loads,
- Reducing fan energy and fan heating loads,
- Reducing maintenance costs associated with lighting fixtures replacement,
- Reducing HVAC equipment and building size and cost.

However, to achieve the appropriate reduction in cooling loads and the efficient use of daylighting, high-performance glazing should be used to meet the interior lighting criteria and block solar radiation, in addition to apply an effective sun shading concept that is sized to minimize solar radiation during peak cooling periods (ASHRAE, 2011). In this part of the research, solar protection tools will be presented based on the following two tools:

7.3.1. External Shading Devices:

The selective exclusion of the direct portion of solar radiation by means of external shading devices is of great value in hot and arid climates. Shading devices also adds a new architectural element to the building form that ranges from a simple overhang or a fin to a huge balcony that shades the lower space. The provision of shading devices in buildings to protect the interior from solar heat gains should be a regulatory measure and one of the initial priorities that have to be considered at the early stages of the design. Blocking the solar radiation before it transmits through the envelope to its interior had a considerable effect on the energy requirements of the building and its thermal and visual performance (Santamouris & Asimakopoulos, 1996).

Lechner (2015) argued that of all known solar protection strategies, shading from direct sunlight is the most effective one. The benefits of shading are so obvious that we see its application throughout history and across cultures. In order to prevent the excessive solar heat gain of the interior, glazed areas must be shaded from the direct solar radiation and in some cases from the diffused components.

Voss, et al. (2007) added that the most efficient solar protection is generally achieved with externally installed shading devices. If three identical shading devices are installed externally, internally and inter-pane (in the space between the glazed panes), the total energy transmittance measure is reduced mostly at the external position. In addition, only external shading devices could ensure the solar protection effect even when the window is opened. However, a disadvantage is their exposure to the external weathering conditions; particularly wind loads, where they usually require higher production and maintenance costs.

Olgyay & Olgyay (1957) noted that temperature is considered the primary measure for any given climatic conditions; it gives a clear index for outlining the cool and warm periods, in which they can be sorted as "under-heated" period and "over-heated" periods. Shading devices are needed during the daytime of over-heated periods. The size of external shading devices for any specified opening could be determined by the angular detection of the overheated periods from the corresponding shading mask. The following two charts could be used to detect the shading mask at any given direction:

- **The vertical shading chart**: which is used in conjunction with the vertical sun-path chart of any specific orientation. The curves of the shading chart that ranges from 10˚ to 80˚ detect the relevant vertical angle of horizontal shading devices and their corresponding projections, while the vertical axis corresponds to the horizontal angles of the vertical shading devices and their projections (figure 7 – 15 a) (Santamouris & Asimakopoulos, 1996).

- **The horizontal shading chart:** which is used in conjunction with the horizontal sun-path charts of any specific orientation. The lower curves, ranging from 10˚ to 80˚ detect the vertical angle of horizontal shading devices projections, while the upper radial lines plot the horizontal angle of the vertical shading devices projections (figure 7 – 15 b) (Olgyay & Olgyay, 1957).

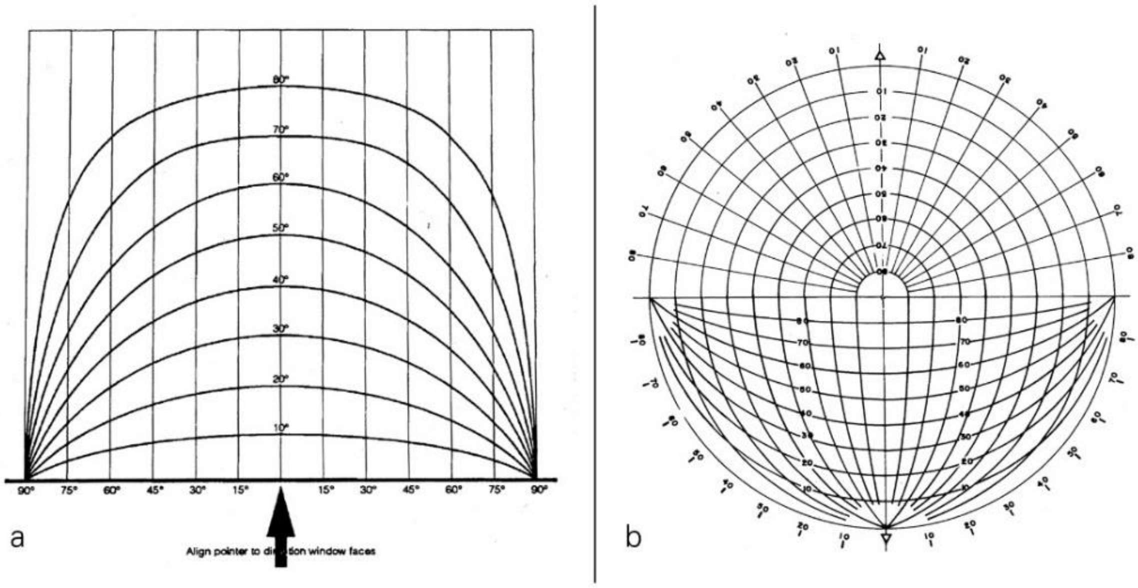


Figure 7 - 15: a) Procedure for aligning vertical shading protractor overlay solar chart (Santamouris & Asimakopoulos, 1996), b) horizontal shading protractor (Olgyay & Olgyay, 1957). However, it is important to note that both charts have to be plotted on the same scale.

Santamouris & Asimakopoulos (1996) noted that the choice of the appropriate external shading device from a wide range of fixed and adjustable elements depends on the latitude, sky conditions, orientation, building type, the overall design of the building, and its required performance. According to Lechner (2015), Voss, et al. (2007), Littlefair (1999), Santamouris & Asimakopoulos (1996), Fathy (1986) and Olgyay & Olgyay (1957) external shading devices could be classified into the following types:

7.3.1.1. Fixed Shading Devices:

Externally fixed shading devices are individually designed and integrated on the building envelope as a part of its architecture. They improve the performance of the internal climate independently from the occupant's behavior. In many cases, they are preferred for their simplicity, low maintenance cost, and sometimes low construction cost. In addition, they can allow an undisturbed view to the outside for longer intervals. However, to some extent, view is already restricted. Highly reflective surfaces are not necessary needed to achieve better solar control, since heat generated by solar absorption in the device is transferred directly to the ambient air. However, care should be taken to the heat released locally at the façade in order not to cause an additional thermal load to the building by ventilation.

The transmission behavior of external fixed shading devices is not rotationally symmetric in all directions, it fluctuates with the seasonally varying angle of incidence of the direct solar radiation. However, their fundamental concept is to block as much as possible angular range of the direct solar radiation during the over-heated periods. Whereas the direct solar radiation is of predetermined direction, they can be largely obstructed through the external shading devices. However, dimensioning the diffused component of solar radiation is more difficult to control due to its wider angle of incidence. The most common types of external fixed shading devices are the following:

- **Horizontal Overhangs:** Horizontal overhangs with its many types are considered as a very efficient choice for shading the South oriented façades. Particularly, in climatic zones with high solar incidence angle. They can block the direct radiation and allow much of the view. Horizontal overhangs are directionally selective in a desirable way; they can be designed to block direct radiation from the high summer sun while allow the lower winter sun to transmit through the window. Slightly less efficient, horizontal overhangs are also recommended for South-West, South-East windows. Since view has got the highest priority for most windows, a single large horizontal overhang usually prevails the best preference of the users. Although, it obstructs the high sky view, but the more important horizontal view is unimpeded. The length of the overhang can be determined from the relevant shading mask through determine the appropriate shading altitude angle on either the vertical or the horizontal shading charts.

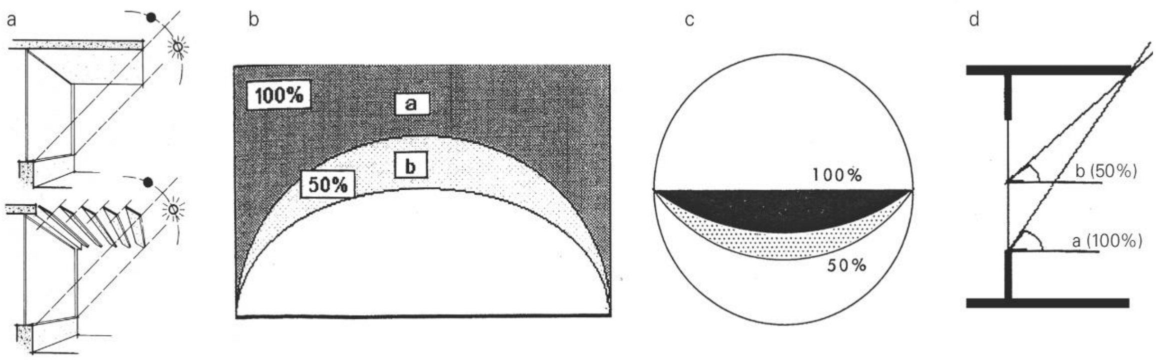


Figure 7 - 16: a) Different alternatives of horizontal overhang shading (Flynn, et al., 1992), b) Conceptual vertical shadow mask of horizontal overhang (Santamouris & Asimakopoulos, 1996), c) Conceptual horizontal shading mask of horizontal overhang (Olgyay & Olgyay, 1957), d) Section view demonstrating the selection of 100% and 50% shading angles (Santamouris & Asimakopoulos, 1996)

- **Horizontal Louvers**: Shading the Eastern and the West windows poses a very critical problem to the architect due to their low solar altitude angle in the early morning and the late afternoon. One of the efficient solutions is to minimize the window height as possible or to divide it using multi-louvered horizontal overhangs. These shadings are also very beneficial when the projecting distance from the wall must be imitated or when the architecture calls for small scale elements that creates a richer texture. However, it should be taken into consideration that if horizontal louvers are designed to perform effectively on the East and West directions, they will dimension some of the visual contact to the outside.

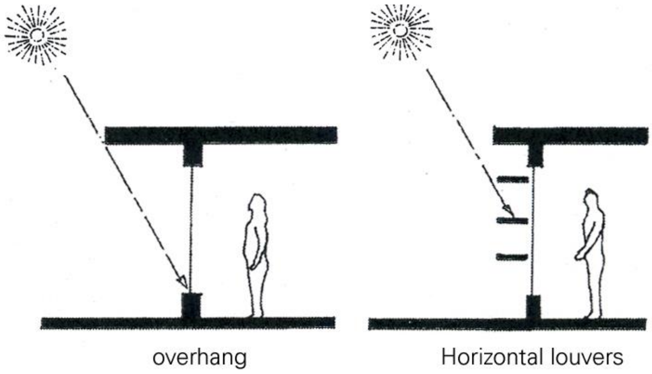


Figure 7 - 17: Several smaller horizontal louvers can create the same shading effect as one large overhang, however view is more obstructed (Lechner, 2015)

- **Vertical Fins:** In hot and arid climates, Northern windows can also need to be shaded. During summer the sun rises North of East and sets down North of West. Regarding that the solar altitude angle is very low at these times, horizontal shadings will not be effective. However, in this case, only small vertical fins on Northern apertures will be very efficient. For East and West facades, vertical louvers are preferred to be used slanted toward the North to give better solar control performance. However, all vertical fins restrict and direct the views very significantly.

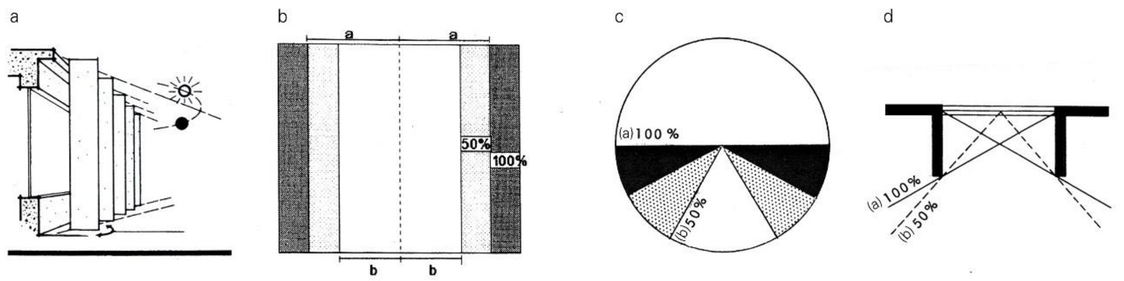


Figure 7 - 18: a) Vertical louvers or fins (Flynn, et al., 1992), b) Conceptual vertical shadow mask of vertical shading (Santamouris & Asimakopoulos, 1996), c) Conceptual horizontal shading mask of vertical shading (Olgyay & Olgyay, 1957), d) plan view demonstrating the selection of 100% and 50% shading angles (Santamouris & Asimakopoulos, 1996)

- **Horizontal Overhang with Vertical Fins:** When using horizontal overhang for shading Southern windows, it must be taken into consideration that the sun come from the South-East before noon toward the South-West after noon. Therefore, it will outflank any overhang have the same width of the window. This requires that the overhang should be either very wide or have vertical fins.

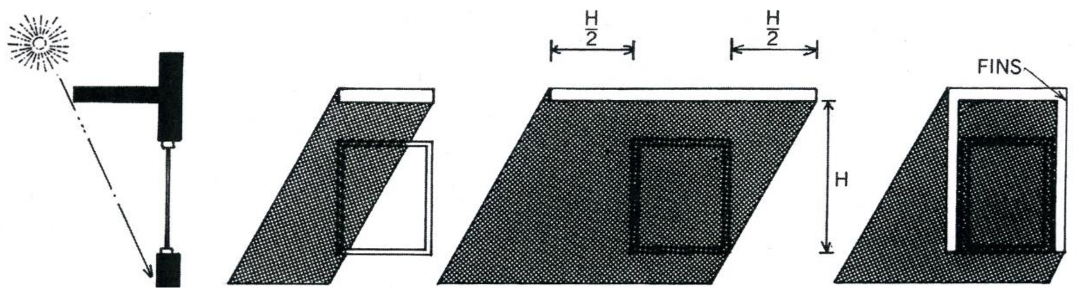


Figure 7 - 19: Direct radiation outflanks any overhang the same width as the window, wider overhang or side fins can retrieve the shading (Lechner, 2015)

- **Perforated Shadings:** Since shading is a geometric problem, many small devices can be equivalent to few large ones. Perforated shading devices are a combination of different intersecting small shading elements on the vertical plane. They are very efficient shading tool for very hot and arid climates, especially when its elements are closely spaced or had a convenient depth. Perforated shadings can be made from a single piece of marble, wooden lattice (Mashrabiya), concrete fins, masonry units, fabrics, or metal mesh. Their shading performance at different scales can be easily detected. The required dimensions of each unit are best determined experimentally by means of a sun path models. However, the view from the inside and the aesthetic appearance from the outside show a great variation, this require from the designer to consider the general appearance of the perforated shading system in his early stages.

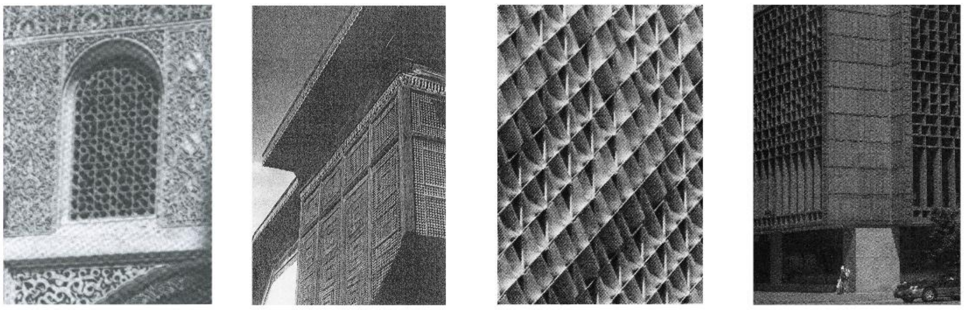


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Figure 7 - 20: a) Perforated stone lattice sun screen in the Alhambra, Granada (Carmody, et al., 2004), b) Wooden Mashrabiya of Al-Suhaymi house, Cairo (Fathy, 1986), c) Metal eggcrate shading (Lechner, 2015), Small and medium sized concrete eggcrate (Lechner, 2015)

Mashrabiya is a kind of perforated solar screens that were traditionally used in the MENA area for centuries. They were fixed externally in front of window openings (Sherif, et al., 2012). Fathy (1986) described the functions of mashrabiya in the following points: (1) controlling solar light passage, (2) controlling the ventilation and air flow, (3) reducing the temperature of the air current, (4) increasing the humidity of the flowing air current and (5) insuring privacy from the outside for the users while at the same time allowing them to view the outside through the screen (can see without being seen).

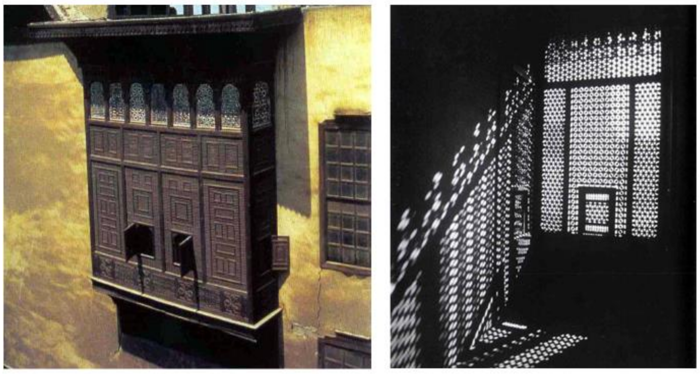


Figure 7 - 21: External and internal view of mashrabiya (Fathy, 1991)

However, El Zafarany (2000) demonstrated on Solararc-2 software the shaded patterns of the mashrabiya on a vertical glazed surface (figure 7 - 22). When these patterns are projected on horizontal working plane, they might cause a sort of disability glare due to the high contrast of dark shaded and light patterns. Sherif, et al. (2012) noted that in order to get the optimal energetic and visual performance of the traditional solar screens (mashrabiya), the transmitted direct solar radiation should be highly controlled during the overheated time periods. Therefore, increasing the depth of these screens can reduce their solar transmittance by blocking the high incidence angle radiation and dimension the received glare effect. However, it also reduces some of the sky view factor and decreases the diffused solar radiation as well.

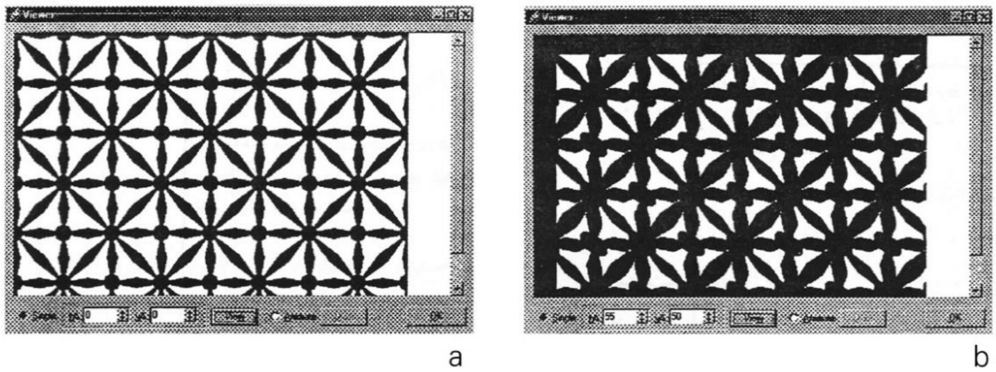


Figure 7 - 22: a) Mashrabiya shading on perpendicular solar projection, which is the same silhouettes shape of the mashrabiya. b) Mashrabiya shading on solar incidence with 50° azimuth angle and 55° altitude angle (El Zafarany, 2000)

Perforated shadings are mainly very efficient for the East, West, Southeast and Southwest orientations in very hot and sunny climates. The combination of both the horizontal and the vertical elements of the perforated shadings successfully control the sun's penetration and provide a very effective method of shading. Their dimensions can be estimated through the same procedure of the horizontal and vertical louvers, where the resultant of the two shading masks can be combined to get the perforated shadow mask (figure 7-23).

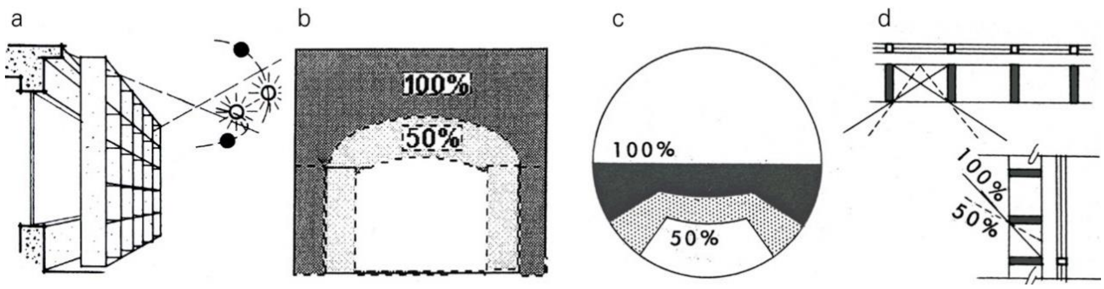


Figure 7 - 23: a) Perforated concrete shading (Carmody, et al., 2004), b) Conceptual vertical shadow mask of perforated shading (Santamouris & Asimakopoulos, 1996), c) Conceptual horizontal shadow mask of perforated shading (Olgyay & Olgyay, 1957), d) Plan and section views demonstrating the selection of 100% and 50% shading angles (Olgyay & Olgyay, 1957)

- **Light Shelves:** The light-colored and reflecting projections that horizontally divide the window opening are called light shelves. The lower window provides the view, while the upper improve both the quality and the quantity of natural light in the space. Part of the incident solar radiation is obscured, while the other is diffusely reflected by the upper side of the light shelf and passes through the upper glazed area towards the ceiling, then a second reflection occurs by the ceiling towards the back of the space, thus on using light shelves, white ceilings are the most effective. Therefore, light shelves had the advantage of reducing solar thermal gains and controlling daylight (figure 7-24). However, due to some weathering conditions, it is not possible to preserve the external upper surfaces of light shelves with high reflectance factor. It should be noticed that, as long as the glazed area remains unchanged, daylight is enhanced over the depth of the room, but is not increased. On the other hand, light shelves are less effective under overcast sky conditions, since they reduce the availability of daylight appreciably.

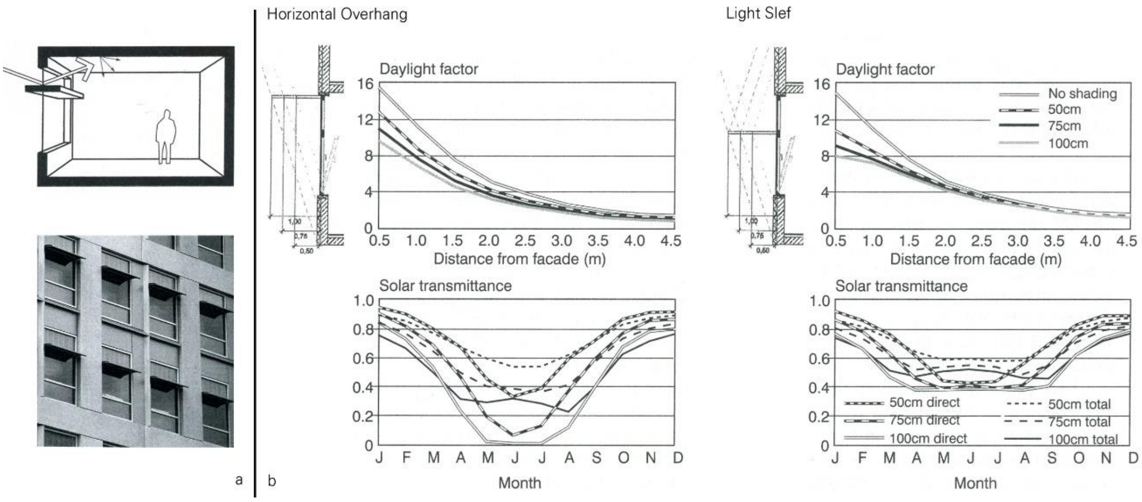


Figure 7 - 24: a) (upper) Light shelf solar radiation controlling concept, (lower) Curved exterior light shelves on the Hoffmann-La Roche Ltd. Office building (Carmody, et al., 2004), b) Energy-relevant and lighting characteristics of an opaque horizontal overhang (left) and a light shelf (right) for a glazed window of 1.25m height (Voss, et al., 2007)

7.3.1.2. Moveable Shading Devices:

The building is a static and rigid construction, but the sun and the sky conditions are very dynamic. Movable shading devices had the privilege of being more flexible; they respond more efficient to the dynamic nature of the ambient environmental conditions and to the solar movement than fixed shadings do. Moveable shadings allow better control on the direct and the diffused solar radiation; which means more controlled protection against solar overheating and glare. While, at the same time, they could afford less or negligible sun obstruction during winter. Since complete shading is needed during the over-heated periods, while solar radiation is required during under-heated periods, shading devices should be then adaptable with the prevailing conditions. The most commonly used moveable shading devices are the following:

- **Venetian Blinds:** Venetian blinds are shading devices that can be used externally as well internally. They provide a significant wide range of angular adjustments for better thermal and lighting control. In addition, they can increase the g-value by 10% or less if the slats are completely closed and installed in front of glazing unit with U values of 1.1 W/m²/K or better. Highly reflective slates such as white or silver slates can achieve the lowest g-value when the blind is totally closed (vertically positioned). However, they are not always beneficial, on the horizontal (cut-off) position, the situation is reversed, reflective slats can record higher g-values by 15 percent since more solar radiation will be re-directed into the space through multiple reflection processes between the slats.

Figure 7 - 25: Venetian blinds divided into two independently functional sections, University of Karlsruhe (Voss, et al., 2007)

- **Roller Blinds:** External roller blinds can be made of variety of materials such as water repellent fibers, weather-resistant textiles, stainless steel or wood. However, it should be considered that roller blinds can severely block the view. large openings covered by textile or fiber roller blinds are more susceptible to be affected by wind loads than venetian blinds or other roller materials.

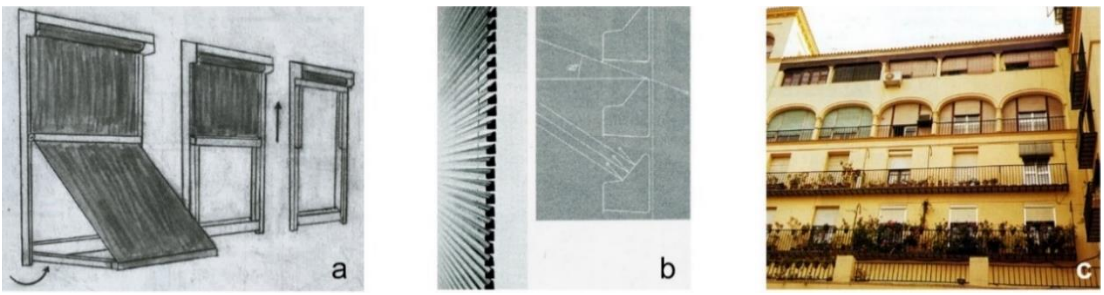


Figure 7 - 26: a) fabric / plastic vertical roller blinds (Lechner, 2015), b) stainless steel roller blind with special rod profile to selectively blocks light from certain directions (Voss, et al., 2007), and c) roller blind shutters in Seville, Spain (Littlefair, 1999)

Vertically operated roller blinds do not allow any angular selection to block direct solar radiation, therefore, their solar protection property is mainly determined by their transmittance value. Materials with low transmittance (below 0.8), can provide sufficient glare protection, while opaque materials (i.e. had no transmittance) can be used for openings that are highly exposed to direct solar radiations. Stainless steel roller blind comprise flexible band of thin metal rods can provide some angular-selective solar protection depending upon the rod profiles. In addition, they can be more wind resistant due to their greater masses. It should be noticed that, the building users do not often open the roller blinds completely, so that only the upper part of the window is shaded, this significantly decreases the daylighting condition at the back of the space.

- **Awnings:** Awnings are traditional moveable shading devices that were commonly used in luxury buildings. They were used for shading windows in summertime and removed in wintertime in order to introduce more sun and light into the interior. Modern awnings are very effective shading devices; they are durable, attractive and easily adjustable. However, they largely obstruct view, especially the upper view.

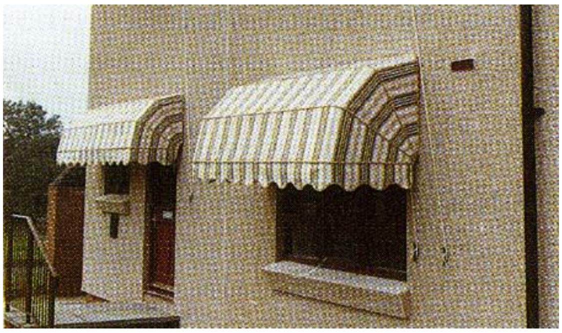


Figure 7 - 27: Foldaway awning; after giving some effective shading in summer, they were removed or pulled up to allow more sun and light to enter the building in winter (Littlefair, 1999)

- **Shutters:** Traditional wooden shutters can provide very good protection against solar-thermal gain and afford high degree of privacy. However, they totally block the view and deprive the interior from any daylighting conditions. Shutters can be opened during daytime when there is no occupancy in the space, that's why they were used in the majority of residential buildings.

7.3.2. Solar Control Glazing:

Since the establishment of modern glass industry, clear glass became the formal glazing material for windows in the whole building industry. However, regarding its solar-thermal properties, clear glass has the highest visible transmittance, the highest shading coefficient and the lowest coolness index values. Over the last few decades, several research and industrial achievements have created multiple glazing technologies to acclimatize the glazing properties according to the environmental conditions. The new generation of glazed materials succeeded to have enhanced physical properties and improved environmental performance (ElKadi, 2006). In hot and sunny climates, the main environmental requirements concerning glazed applications in buildings are: to reduce both solar heat gain and air conditioning loads, to give some control over glare, and to provide the required levels of natural lighting and view to the outside (Button, et al., 1993). In terms of glazed solar protection applications, many enhanced concepts exist. Some of those concepts are discussed in the following points:

- **Tinting Glazing:** Among all modern window technologies, tinting the glazed panes is the oldest. Under normal conditions, tinted glazing can reduce solar heat gain from 25 to 55 percent during the overheated periods (ElKadi, 2006). They are characterized by being highly absorptive to some portions of the solar spectrum. Basically, to the long-wave radiation, that's why tinted glass panes are commonly referred to as "heat absorptive glazing". However, their high absorptivity is also extended to some of the visible portion of light, therefore, they can change the color and the characteristics of the transmitted daylight to the interior (Santamouris & Asimakopoulos, 1996).

  All the absorbed solar energy is mainly transformed into heat within the glass pane and subsequently raise its temperature. According to the prevailing climatic conditions, up to 50% of the absorbed heat could be transmitted to the interior through radiation and convection, this may lead to some discomfort near tinted windows. The fundamental functions of tinted glazing are to reduce the amount of the transmitted solar energy to the interior through the glazed panes, to reduce glare effect from the bright sun, and to increase the visual privacy during daytime. The most common colors of the tinted glasses are neutral grey, bronze, blue and green. These colors were found to have the least altering effect on the perceived color of the view and had the tend to blend well with the other architectural colors. Tinted glass is made either by altering inorganic additives to the chemical formulation of the glass (body tinted glass) or by applying special surface coatings after manufacture. Every change in color, thickness, or the combination of different glass types affects the solar-thermal properties of the panes such as transmittance, reflectivity, and solar heat gain coefficient. Tinted glass can provide more efficient performance when used as the outer layer of a double-glazed window (Carmody, et al., 2004).

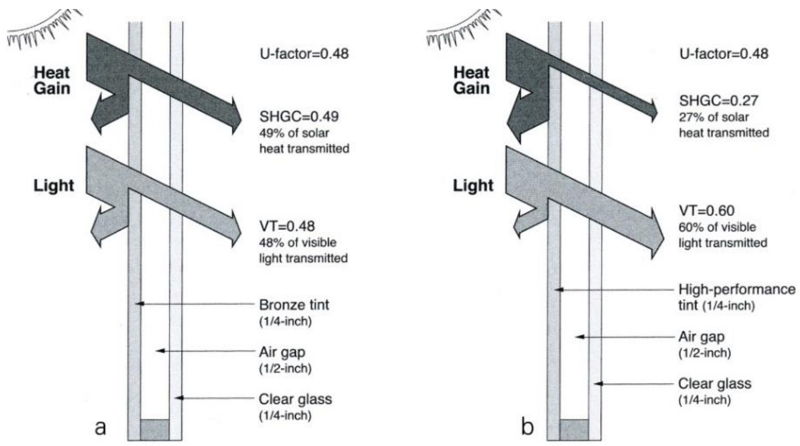


Figure 7 - 28: a) Double glazing with bronze-tinted glass on the outside layer, b) double glazing with high-performance tint on the outside layer (Carmody, et al., 2004)

- **Reflective Glazing:** Reflective glazing is produced by the deposition of micro semi-transparent coating films of metals or metallic oxides on the glazed surface. The metal coating usually increases the surface reflectivity of glass in both the infrared and the visible radiation regions. Reflective glazing can have lower shading coefficient than tinted glazing, where it can reach 0.11, however, in this case, its light transmittance declines to be very low. Basically, reflective coatings block more light than heat, but when they are incorporated in multiple glazing unit or applied to tinted or clear glass, they can also slow heat transmission. Therefore, it should be taken into consideration that they should not be used in windows that are designed for high daylight admittance. In hot climates, reflective glazing is commonly used to reduce cooling energy. However, this should be carefully estimated, since the achieved reduction might be compensated by the need for additional electrical lighting (ElKadi, 2006).

Reflective coatings are produced in a wide range of colors, such as silver, copper, bronze and gold. Some of these colors have an increased reflectivity in the far infrared radiation. Concerning the urban surroundings, special considerations should be taken before using reflective glazing, since it reflects the solar radiation to the surrounding buildings and neighboring spaces causing glare disturbance and intensified solar effect (Santamouris & Asimakopoulos, 1996).

Outer Glazing	Reflective Coating Type (SHGC and VT)	Single Glazed		Double Glazed	
		SHGC	VT	SHGC	VT
Clear	Low	0.06	0.08	0.05	0.08
Clear	Moderate	0.15	0.20	0.12	0.18
Clear	High	0.32	0.40	0.26	0.36
Bronze	Low	0.04	0.05	0.03	0.04
Bronze	Moderate	0.09	0.12	0.08	0.11
Bronze	High	0.20	0.24	0.16	0.22
Spectrally Selective Tint	Low	0.3	0.06	0.02	0.06
Spectrally Selective Tint	Moderate	0.07	0.15	0.06	0.13
Spectrally Selective Tint	High	0.14	0.30	0.12	0.27

Table 7 - 1: Typical properties of glass with reflective Coatings (Carmody, et al., 2004)

- Low Emissivity Glass Coatings: Emissivity is the ability of any material to re-radiate energy when heated. According to their temperatures, all materials (including glass) re-radiate heat energy in a form of long-wave (far-infrared) radiation. Therefore, reducing the emittance property of any glazing assembly can improve its insulating values (U-value). Standard clear class has an emittance value of 0.84 over the long-wave radiation of the solar spectrum, i.e. it emits 84% of the energy possible for an object at its temperature. Or in other words, only 16% of the long-wave radiation striking the glass surface is reflected and 84% is absorbed and re-radiated. Low-E glass coatings can reach an emittance value of 0.04, meaning that they can emit only 4% of the energy possible at its temperature and 96% of the incident long-wave radiation is reflected. The effects of low-E coatings are usually incorporated into enhancing the thermal insulation or the total U-value for any glazing assembly (Carmody, et al., 2004). Bessoudo (2008) noted that there are two main applications for the low-E Coatings; in hot climates, they are used for low-solar gain through reflecting infrared solar radiation and transmitting the visible light portion. While in cold climates, it is used for high solar gain through transmitting both visible and infrared radiation and reflecting the longwave heat radiation emitted by the interior surfaces back inside.

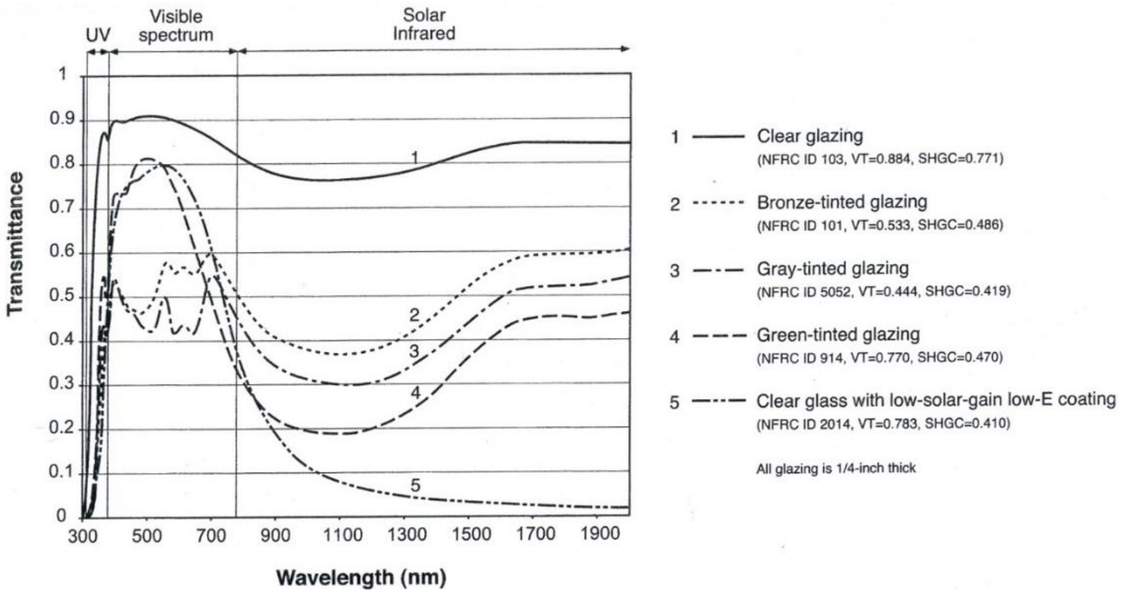


Figure 7 - 29: Spectral transmittance curves for common tinted and low-E glazing (Carmody, et al., 2004)

Recent advances in the glass technology succeeded in manipulating the reflectance property of low-E coatings to include some specific portions of the visible as well as the infrared solar radiation, where it can permit the transmittance of a desired portion of radiation and reflect the other. This achievement is the origin bases for the "spectrally selective coatings". Thus, the glazed assembly can be then optimized according to the required energy flows such as solar protection, solar heating, or daylighting. For better solar control in hot climates, this new generation of low-E coatings can maintain the low U-value of the glazed assembly and reduce its total SHGC through reflecting the solar near-infrared radiation while transmitting high levels of daylight (Carmody, et al., 2004). If spectrally selective coating is applied to clear glass, it could filter out from 40% to 70% of the transmitted solar heat, while transmit the full band of visible light. However, it should be considered that these coatings are not suited to buildings in cold climates because they reduce the benefit of the winter solar heat gain (ElKadi, 2006).

- **Surfaces Treated Glazing:** The deposition of either opaque or translucent ceramic silk-screening frit on the glazed surface can contribute in reducing solar heat gain and controlling glare effect. In addition, it gives the architect the chance to use deferent colors and patterns in his designs. Frit within the glazed assembly can affects many of its solar-thermal properties such as absorption, shading coefficient, reflectivity and even can change its appearance. Glass producers offers some standard frit patterns such as dots, lines and holes. The coverage of these patterns is specified mostly in the 40% to 60% range. Acid-etched and sandblast glazing are other types of surface treated glazing, both give translucent matt finish the provides diffused daylight patterns to the interior. However, they diminish the glass transparency and obscure the view to the outside (Carmody, et al., 2004).

Frit		Single Glazed		Double Glazed	
		SHGC	VT	SHGC	VT
None		0.81	0.88	0.70	0.78
Dots 40%		0.64	0.63	0.54	0.57
Lines 50%		0.59	0.56	0.49	0.51
Holes 60%		0.54	0.49	0.44	0.45

Table 7 - 2: Typical properties of glass with ceramic frit treatment (Carmody, et al., 2004)

- Switchable Glazing: This solar control glazing concept work on modifying the solar transmission properties of the glazing according to specific conditions such as the external climate, the occupant's preference, or the building system requirements. This control would lead to lower energy consumption and increase the occupant's comfort (Carmody, et al., 2004). Voss, et al. (2007) demonstrated the different types of switchable glazing according to their optical switching mechanisms or to the configuration that activate their switchable state the following points:
  - Electrochromic: Switching by darkening (blue coloration) through introducing a small electric current to specific coatings on the glass surface.
  - Gasochromic: Same as electrochromic, however, it is switched to the dark state due to the contact of the inter-pane specific gas with an electric current.
  - Thermochromic: Switching by a change in color or its light scattering properties when crossing a certain temperature threshold.
  - Suspended Particle Devices (SPD): Switching into a more transparent state according to the orientation of an optically anisotropic absorbing particles through applying a voltage.
  - Photo-chromic: Switching to the darker state in response to the level of illumination.
  - Photo-electro-chromic: Switching state is activated by the exposure to solar radiation.

In commercial buildings, switchable glazing systems can reduce the peak electric loads from 20% to 30% through managing the solar transmission property (Carmody, et al., 2004). However, when darkened, they tend to reduce the visible portion of the spectrum, reduce the visual contact to the outside, and increase the glazing absorptivity (ElKadi, 2006).

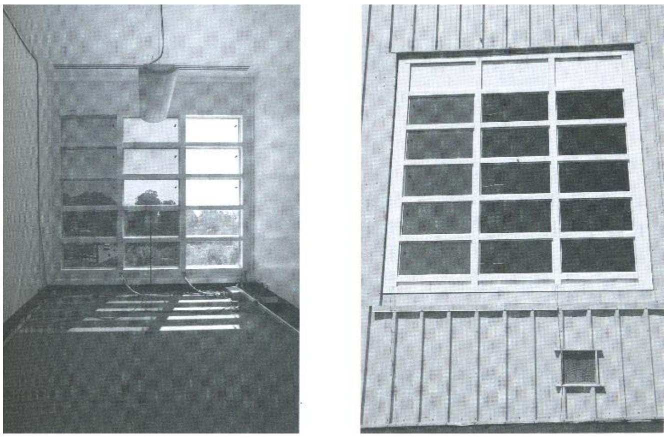


Figure 7 - 30: Internal and external view of electro-chromic glazing at field test (Carmody, et al., 2004)

The use of switchable glazing is still limited due to its very high cost and low durability. In addition, there is an undergoing debate on its performance; for example, in winter photochromic glass will block the transmission of solar radiation when it is desired, while thermo-chromic glazing will not function properly if used in a mechanically conditioned space. Furthermore, changing the transmittance property of thermochromic or photochromic glazing during the day, will give the users wrong information about the prevailing external weathering conditions or the day timing (getting darker on increasing the solar radiation or the temperature), thus losing one of the main visual functions of glass transparency (El Zafarany & Fikry, 2006).

- Insulated glazing: Insulated glazing focus on the opportunities of the glazing cavity to increase the insulating value (U-value) between the glazing layers without interfering their transmittance property. The way in which the cavity may be used range from the modest insertion of an air gap (up to 12.5 mm, where increasing the gap will lead to an increase in heat gain by convection) or evacuate cavity, to the insertion of low thermal conductivity inert gas like argon, krypton, xenon, or introducing transparent insulation materials (TIMs) such as acrylic, polycarbonate, aerogels or xerogels (ElKadi, 2006).

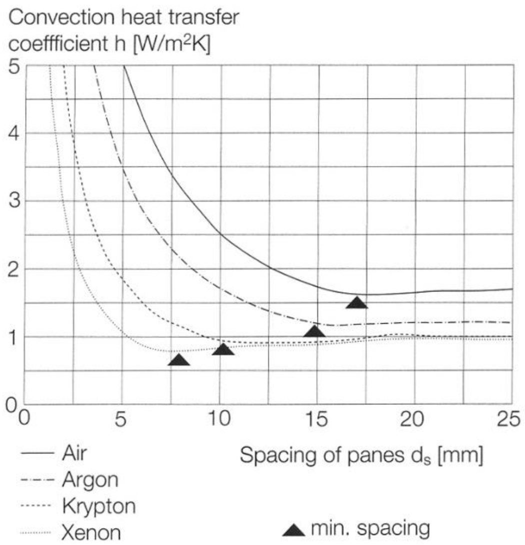


Figure 7 - 31: U-value as a function of cavity width for different gas fillings (Schittich, et al., 2007)

- **Angular selective glazing:** This concept is used in the glazing assembly itself to modify the direction of the incident solar radiation. It either admit, reflect or refract (i.e. redirect) the solar radiation according to its angle of incidence. Generally, it is desirable to reflect high-elevation radiation and redirect it to the ceiling to avoid glare near the window, while permit the low-elevation radiation that involve the view and useful daylight to penetrate through the space (ElKadi, 2006). However, this kind of glazing can spoil the view and to see through the glass. In addition, it can be a source of severe glare if installed below eye level (Littlefair, 1999)

7.3.3. Combined Mechanisms:

Solar control glazing concepts and approaches alone are usually less suitable for the efficient solar protection. They do not provide sufficient protection against solar heat gains and glare due to the impact of the direct solar radiation. In order to reduce its impact to efficient and acceptable levels for working without the intervention of energy consuming devices, a combined mechanism of solar protection along with fixed or moveable external shading devices should be integrated together during the planning phase of the buildings' external envelope (Voss, et al., 2007). Carmody, et al. (2004) added that any discussion concerning glazing is incomplete unless it considers the methods of controlling and tempering the solar radiation in an integral approach. Generally, the design of the glazed component does not only encompass the proper selection of solar control glass, but also the use of the related shading and light control devices.

7.4. Criteria of Solar Protection System Selection:

Santamouris & Asimakopoulos (1996) noted that although solar protection is mainly concerned to avoid solar heat gain from being transmitted to the interiors during over-heated periods, however, its applications should consider the following points:

- The obstruction of the solar radiation, basically the direct component, from penetrating the façade to the interior of the building.
- Not interfere, as much as possible, solar heat gain during the under-heated periods.
- Control and regulate the intense daylight, especially during summer months or high illuminating periods, by diffusing or redirecting it in a uniform way along the interior.
- Do not obstruct the view from the glazing to the outside.
- Allow the admission of ventilation and provide a way to control it.

However, these considerations can vary according to the prevailing climatic conditions, the latitude, the location, the orientation, the building type, its operational schedule, the specific usage of its spaces and the expected levels of comfort. Voss, et al. (2007) added that the shading effect of many solar protection devices can meet the protection design criteria well, but cannot installed in all buildings, such as tall buildings where wind load is too high, or the devices may not be favored from the aesthetic point of view. Voss, et al. (2007) demonstrated in the following table the selection criteria of different solar protection tools:

		Glazing technologies				*Mechanical shading devices*			*Fixed shading devices*	
		Fixed properties		**Switchable properties**						
		Solar-control glazing	**Special glazing***	**Electrochromic, gasochromic, SPD**	**Thermo-tropic***	**Venetian blind**	**Roller blind with opaque slats**	**Transparent polymer roller blind**	**Overhang**	**Light shelf**
Solar control	**Load reduction****	Moderate	Moderate, seasonal variation	High	High/ moderate	High to moderate, depending on the position and slat angle			Moderate, seasonal variation	
Solar control	**User or control dependent**	No	No	Yes	No	Yes	Yes	Yes	No	No
Daylighting	**Visual contact**	Excellent	Disturbed	Variable, moderate	Variable, poor	Variable	Variable	Variable, excellent	Good	Good
Daylighting	**Glare protection**	No	Yes	No	No	Variable	Variable	Variable	Seasonal	Seasonal
Daylighting	**Main daylight effects**	Slightly reducing	Direct light cut-off	Variable, not colour neutral	Light diffusing	Light-guiding	Variable, diffusing	Variable, reducing	Seasonal direct light cut-off	Seasonal direct light cut-off, light-guiding
	Single system sufficient to tackle both issues?	No	No	No	No	Generally yes, but not all products			No	No
Economy	**Passive solar gain reduction (winter)**	Moderate	Moderate	Slightly	Slightly	No	No	No	Slightly	Slightly
Economy	**Investment costs**	Moderate	High	Not yet clear		Low to moderate, depending on position			High	High
Economy	**Maintenance**	No	No	Not yet clear		Moderate to high, depending on position			Low	Low
Selected architectural design consideration	**Site-dependent solution?**	No	Yes	No		No	No	No	Yes	Yes
Selected architectural design consideration	**Identical system for all orientations?**	Yes	No	Yes		Yes	Yes	Yes	No	No
Selected architectural design consideration	**Potential synergetic effects**	No	No	No		No	No	No	Yes (security path, façade cleaning)	
Selected architectural design consideration	**Design dominance**	Low	Moderate	Moderate		Moderate to high, depending on mounting position			High	High
Mounting position	**Exterior**					X	X		X	
Mounting position	**Interior**					X	X	X	X (no load reduction)	
Mounting position	**Inter-pane**					X	X	X	X (second skin façade)	

Table 7 - 3: Selected performance criteria for common solar protection systems for office spaces (Voss, et al., 2007)

PART III: THE OPERATIONAL STUDY

Chapter VIII

Cairo: Contextual Study

8. Cairo: Contextual Study:

This part of the research represents the first pillar of the research operational study. It discusses the contextual study of Greater Cairo Region (GCR) as the research case study area. The study investigates the research points of interest in Cairo region; presenting a verification to the research problem and providing the upcoming sections of the research with the required input data. The following points will be discussed in the study:

- Brief description of Greater Cairo Region (GCR) and its geographical location.
- study and analysis of the prevailing climatic conditions in Greater Cairo Region (GCR) in order to determine its passive potentials that can be used in the planning of highly transparent façades and contribute in reducing the total energy consumption of the building.
- Study of the current energy stats in Egypt; through demonstrating the energy demand and consumption charts, showing the deficit in supplement and the need for efficient solutions.
- Investigation of the office building energy consumption rates in Cairo through literature and extended meetings with office buildings' managers in Cairo. The average energy consumption rates will provide a benchmark to Cairo's office buildings' energetic performance. These rates will be used in the upcoming research studies.

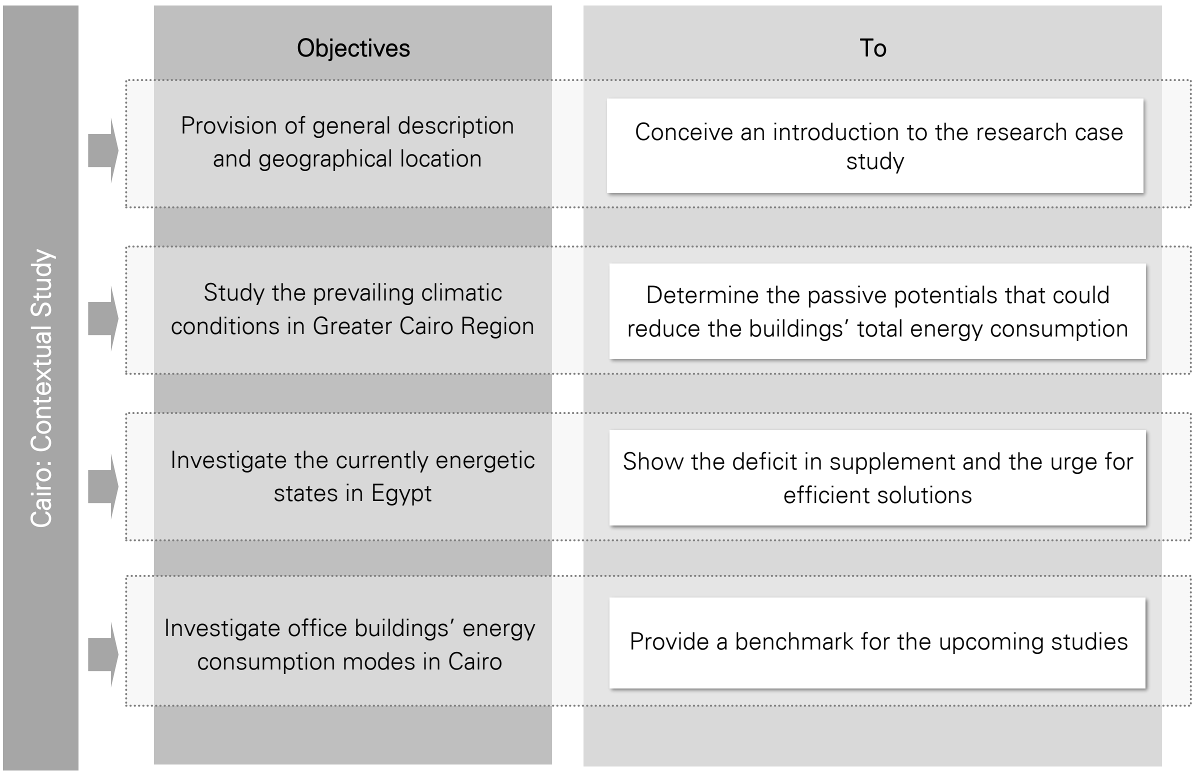


Figure 8 - 1: Cairo's contextual study framework (by researcher)

8.1. Description and Geographical Location:

Egypt is as an African-Asian and Mediterranean country located on the Northeast border of the African continent, including Sinai Peninsula, which is an Asian territory extension. Egypt occupies an area of about one million square kilometers, between Latitude 22ºN and 32ºN and Longitude 24ºE and 37ºE (Nour El-Din, 2013). Although most of its land is a desert, Egypt's geographic location is one of the major factors that affected its built environment (figure 8 - 2).

Since the establishment of Cairo city in 969 AD, it has continued to represent the main political, historical, economic and urban capital for Egypt. The city is located to the south of the Delta area on the Nile basin before it branches into the Delta at 30º05′ N latitude and 31º17′ E altitude (Robaa, 2006). According to 2006 census results, a huge Urbanization and industrialization expansion has occurred in Cairo since the second half of the last century forming the Greater Cairo Region (GCR). Merging continuous urbanized areas of three provinces that include five major cities (Cairo, Giza, parts of Qalubia, Helwan, and Shubra Alkhema) along with their immediate suburbs (6th of October, Al-Sheikh Zayed, 15th of May, New Cairo, Sherouk, Badr and Obour) has made it the largest urban area in Africa, and the world's 7th largest urban agglomeration (Ministry of Housing, Utilities, and Urban Development in corporation with Japan International Cooperation Agency, 2008).

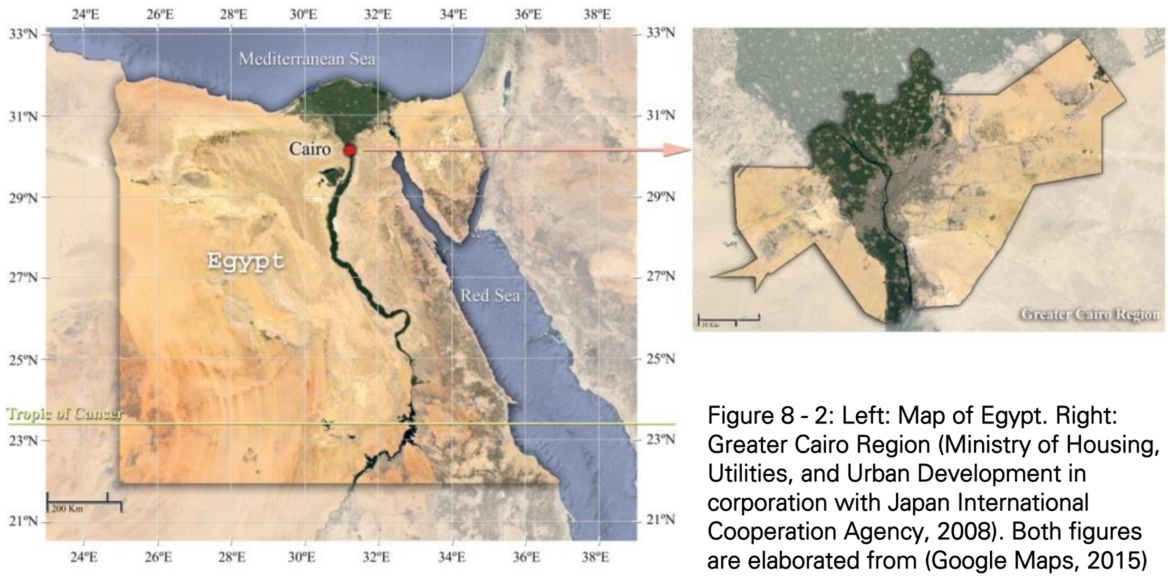


Figure 8 - 2: Left: Map of Egypt. Right: Greater Cairo Region (Ministry of Housing, Utilities, and Urban Development in corporation with Japan International Cooperation Agency, 2008). Both figures are elaborated from (Google Maps, 2015)

8.2. Cairo's Climate Profile:

"We must begin by taking note of the countries and climates in which homes are to be built if our design for them are to be correct. One type of house seems appropriate for Egypt, another for Spain … It is obvious that design for homes ought to conform to diversities of climate"

Vitruvius, Architect, first century BC. (Lechner, 2015, p. 79).

Vitruvius's quote indicates that design in harmony with the prevailing climate is a dated idea; and to achieve it properly, the designer has to understand and analyze the local climatic constraints and opportunities in order to maximize the possible use of passive measures and to decrease the rate of energy consumption in his designs taking into consideration the comfort requirements of the occupants (Lechner, 2015). The following points in this chapter describe and analyze the main features of Cairo climate as a research case study area.

8.2.1. Climate Classification:

Generally, Egypt experiences a variety of the domestic climatic conditions that ranges from extremely hot climate in the Western Desert to relatively cold climate in the Mountain of St. Catherine in Sinai. However, the whole country in general exhibits hot-arid climate with very high rates of solar radiation for most times of the year (Mahdy & Nikolopoulou, 2014).

8.2.1.1. Modified Köppen-Geiger Climate Classification:

According to Kottek, et al. (2006), the modified Köppen-Geiger climate classification method is considered the most frequently worldwide classification method used. In this method, all Egyptian territories are located in the BWh area; where (B) indicates dry arid climates, which are characterized by little rain and a relatively average high daily temperature, (W) stands for desert, which are mostly coupled with the (B) climates, and (h) stands for hot-arid with an average annual temperature over 18°C as shown in figure 8 - 3.

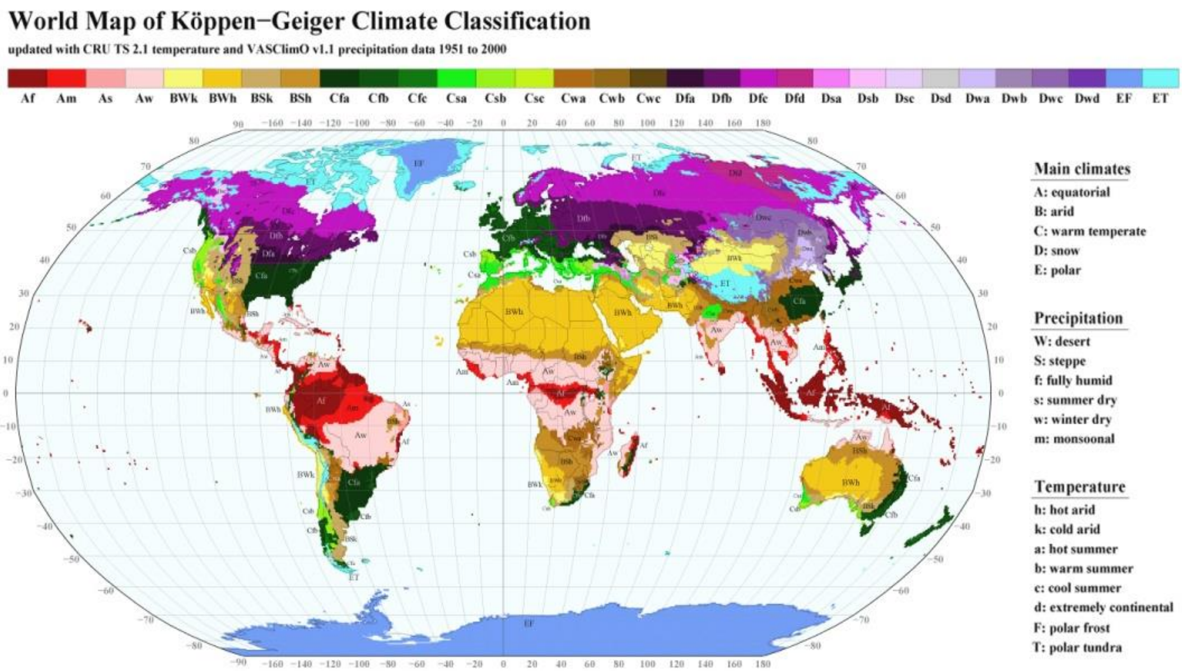


Figure 8 - 3: world map of Köppen-Geiger climate classification update (Kottek, et al., 2006)

However, the general climate profile of Egypt is characterized with hot and dry summer all over the country, with high temperatures. The maximum temperature ranges from 38 ºC to 43 ºC with some extreme areas that could record 49 ºC especially in the southern and western deserted areas, while the northern parts of the country are relatively much cooler with an average maximum temperature of about 32 ºC. Winter climate is moderate with a little rain, mainly over the coastal northern areas. In the south, winter climate is partially dry, warm, and sunny during day and cold at night (Nour El-Din, 2013).

8.2.1.2. The Egyptian Code for Enhancing Energy Efficiency Domestic Climate Classification:

Under the broad Köppen-Geiger climate classification, the Egyptian territory experiences a significant variation in local climates as a result of the geographical influence of its shorelines, Delta area, the Nile valley, and its various altitudes. The Egyptian Code for Enhancing Energy Efficiency in Buildings, code number ECP 306 – 2005, introduces another more precise domestic climate classification (Standing Committee of Planning the Egyptian Code for Engancing Energy Efficiency in Buildings, 2009). This classification divides the Egyptian climate internally into eight identified sub-climatic regions as follows:

1. **Mediterranean coastal region:** Extended in the north area of the country along the Mediterranean coast with some few kilometers in depth.

2. **Cairo and Delta region:** Lies to the south of the Mediterranean region, it includes the Nile Delta area, Cairo region and some areas in north Sinai.

3. **North of Upper Egypt region:** Located south of Cairo and Delta regions in narrow longitudinal areas, lined along the river Nile banks.

4. **South of Upper Egypt region:** Transitional region, located to the south of the north of Upper Egypt region along the riverbanks of the Nile till the south of Egypt region.

5. **East coast region:** The eastern narrow band region along the Red sea coast with some few kilometers in depth.

6. **Elevated regions of Sinai:** Mounted areas at the middle and southern part of Sinai Peninsula.

7. **Desert regions:** the largest region in the country, extended to the south and east of the Nile banks, it includes large areas of the eastern and the western deserts

8. **South Egypt region:** located in the southern part of Egypt along the Nile banks, extended till the borders with Sudan.

The previous climate classification will be applied later in the research modeling operations (Chapter X) to determine some of the input data for the office - space profiles modeling.

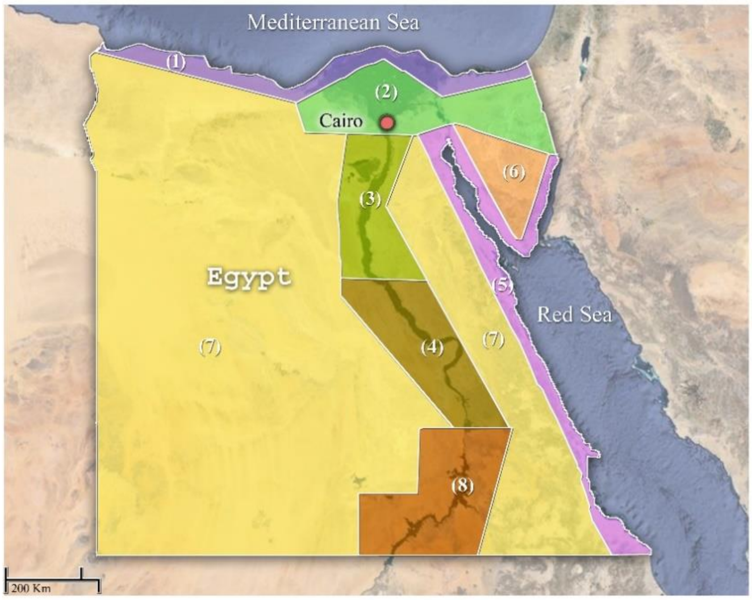


Figure 8 - 4: Egypt domestic climatic regions (Standing Committee of Planning the Egyptian Code for Engancing Energy Efficiency in Buildings, 2009). Elaborated from (Google Maps, 2015)

8.2.2. Cairo Climate Determinants:

According to the domestic climate classification, Greater Cairo Region (GCR) is located in the Cairo-delta regions, which is considered a transitional region linking the Mediterranean areas in the north with the desert and Upper Egypt regions in the south. This region is considered a medium region in terms of temperature values, relative humidity, and solar radiation among all other climatic regions of Egypt. Cairo's climate is characterized by a relatively long hot dry summer and somehow mild to cold winter with little rain. The level humidity is relatively high in both summer and winter (Asar, 2008).

The following weather data and analysis is generated from literature, Climate Consultant software version 6.0 (2016), and Meteonorm software version 7.0 (2015). The EPW weather data file format for Cairo is downloaded from the US Department of Energy's (DOE) - EnergyPlus on-line website (EnergyPlus, 2016). The thermal comfort ranges and the building Bio-Climatic Charts were optimized in climate consultant V 6.0 according to the ASHRAE standard 55 - 2004 using the predicted mean vote (PMV) model.

8.2.2.1. Temperature:

Dry bulb temperature is the most important meteorological parameter that is relevant to issues of the building's cooling/heating loads and the human comfort in both the external and internal environments. Cairo's average annual temperature is 22.4 °C; ranging from nearly 13.8 °C in January to 28 °C in July; the monthly minimum average temperature ranges from 10.5 °C to 23, and the average maximum temperature ranges from 18 °C to 34.5 °C. The lowest recorded temperature is 6 °C in January, and the highest recorded temperature is 43.5 in June, as shown in figure 8 - 5.

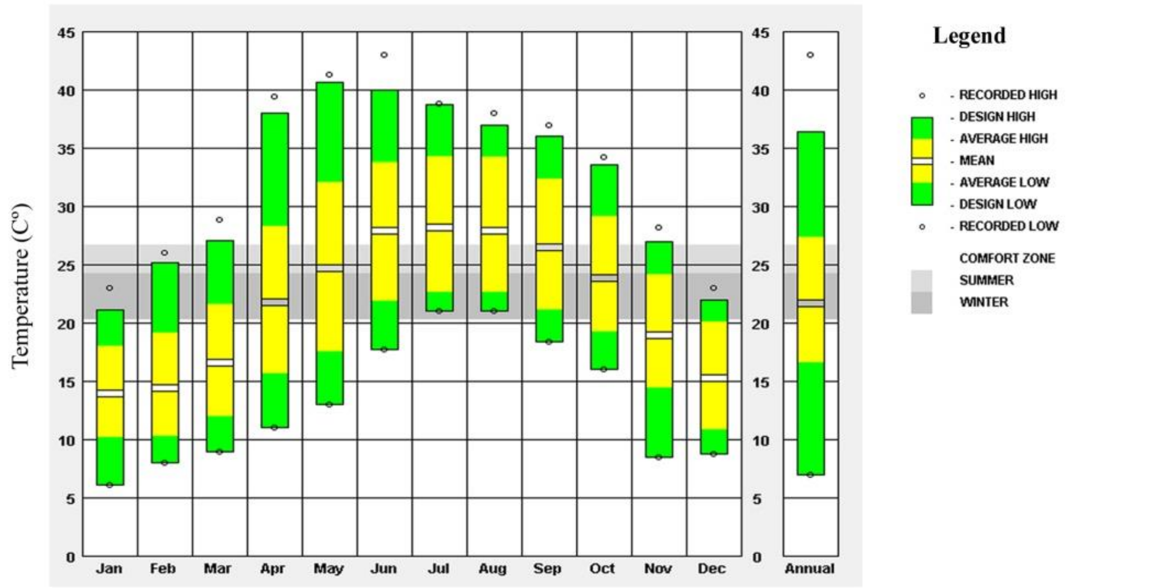


Figure 8 - 5: Monthly average dry bulb temperature range of Cairo (Climate Consultant)

8.2.2.2. Humidity:

The second comfort climatic determinant is the atmospheric humidity for its significant role in modifying the comfortable conditions by evaporation at particular air temperatures. Cairo's monthly average relative humidity varies from a maximum range of 68% in January to a minimum range of 45% in May, with an annual average range of 57.5%. The dew-point temperature ranges from a minimum of 7 °C in January to a maximum of 19 °C in August, as shown in figure 8 – 6.

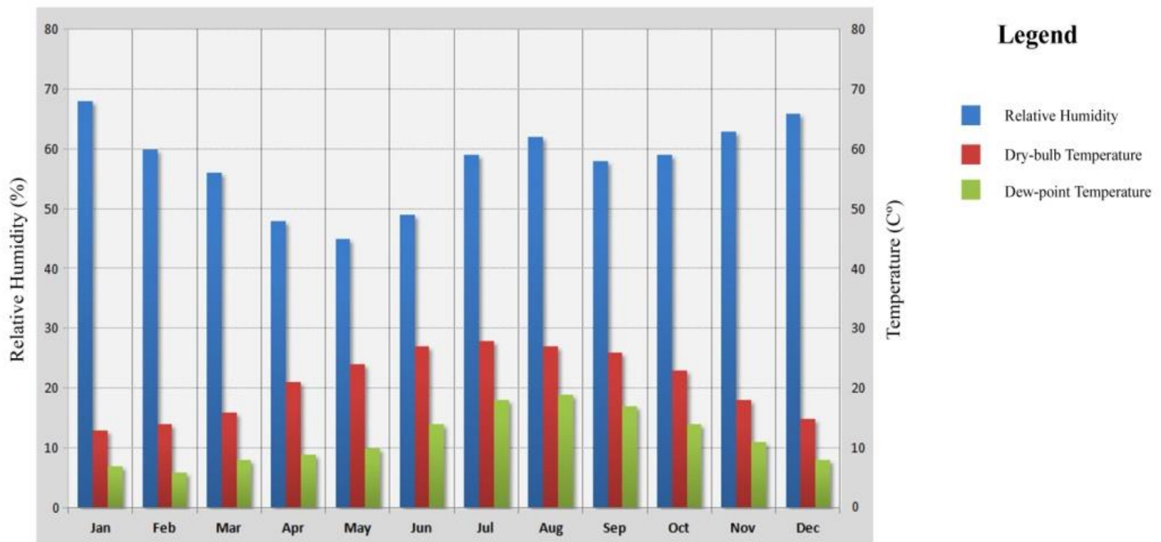


Figure 8 - 6: Monthly average relative humidity, dry-bulb temperature and dew-point temperature (Climate Consultant)

8.2.2.3. Solar radiation:

Solar radiation is the radiant energy received from the sun; knowing of its values is a fundamental requirement in any climate analysis for to its crucial importance in determining the buildings' thermal and solar loads and its total energy-balance. Cairo's climate is characterized by relatively high daily irradiation rates, in both global and beam. According to the meteorological records of Cairo station, the monthly mean values of global solar radiation (G) ranges from 11.06 MJ/m^2 in December to 25.09 MJ/m^2 in June, with an annual mean value equals to18.57 MJ/m^2. In addition, Cairo has a high frequency of clear sunny days as shown in table 8 - 1, and also a high level of daily sun shine duration where the cloud cover in Cairo is relatively low; it ranges from 0.1 octa in July to nearly 2.4 octa in January (Robaa, 2006) and (Trabea & Shaltout, 2000).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
Clear sky	22	21	26	28	29	30	31	31	30	29	26	25	27
Cloudy sky	2	1	0	0	0	0	0	0	0	0	0	1	0
Partial cloud sky	7	6	5	2	2	0	0	0	0	2	4	5	3
Season	Winter		Spring			Summer			Autumn				
Clear sky	23		28			31			28				
Cloudy sky	1		0			0			0				
Partial cloud sky	6		3			0			2				

Table 8 - 1: The monthly, seasonal and annual mean number of days of the sky-cover occurrence over Cairo during the period 1992–2003 (Robaa, 2006)

Figure 8 - 7 shows the difference of the monthly mean values of the global radiation (G) between the two periods from 1969 – 1973 and from 1999 – 2003. This difference is attributed to the effect of the heavy urbanization processes that Cairo has witnessed during the last 50 years (Robaa, 2006).

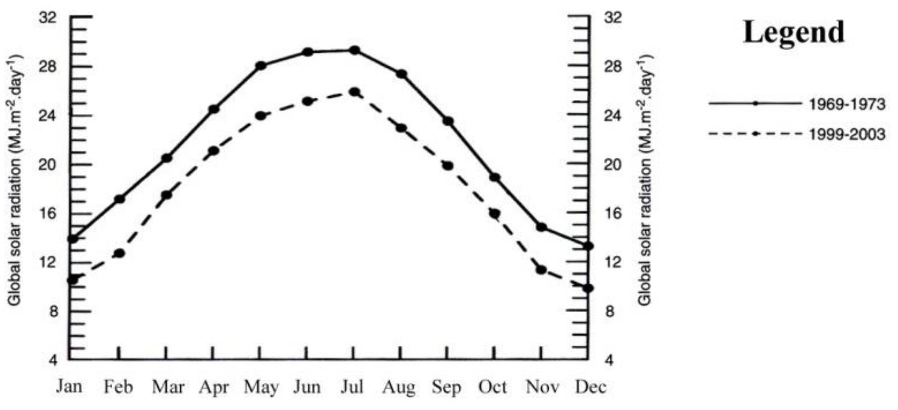


Figure 8 - 7: The monthly variation of Global radiation (G) during the non-urbanized period 1969–1973 and urbanized period 1999–2003 (Robaa, 2006)

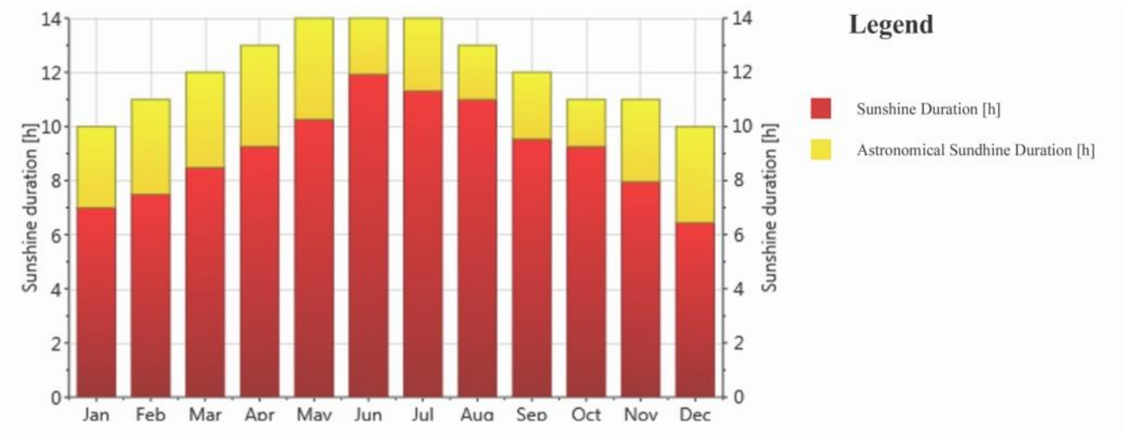


Figure 8 - 8: Sunshine daily average duration over Cairo (Meteonorm)

Figure 8 – 9 shows the horizontal sun path diagram and the solar duration for Latitude 30˚ north, which could be applied on the case of Cairo (El Zafarany, 2000).

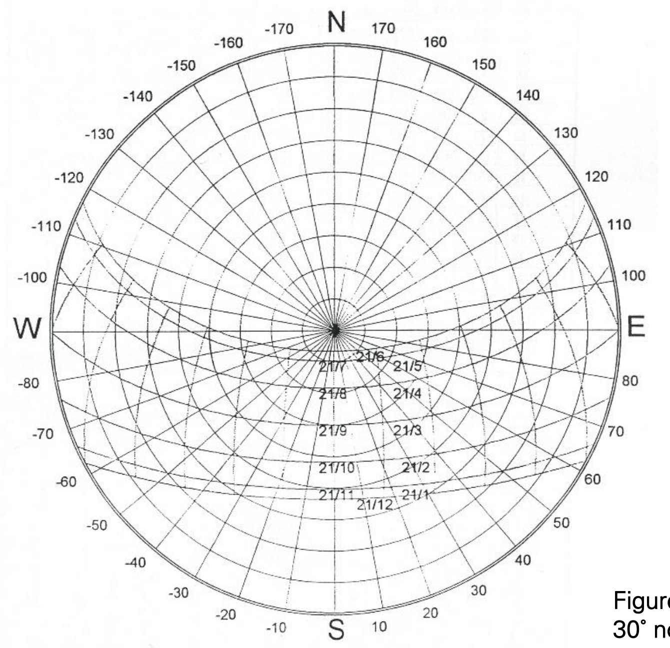


Figure 8 - 9: Horizontal sun path diagram for latitude 30˚ north (El Zafarany, 2000)

Vertical sun - path diagrams from climate consultant V 6.0 software were used to propose the solar shading angles in the four main directions. These proposed angles will be used later to elaborate the external shading devices in the modeling and simulation part of the research (Chapter X); whereas for each direction, the proposed vertical solar shading angle (altitude angle) and the horizontal solar shading angle (azimuth angle) are used to determine the dimensions of the horizontal and the vertical shading devices respectively. Solar shading angles are proposed to avoid, as much as possible, direct solar radiation during the over - heated periods in which the ambient temperature is over 27˚C. This process is elaborated through two intervals: First, winter - spring interval from December 21 to June 21, and second, summer - fall interval from June 21 to December 21.

- North Orientation:

Northern facades are the least exposed to the sun. The exposure occurs only during the early morning hours and the late afternoon hours in summer (from April to August) where the altitude angle is low, and the solar rays are almost tangible to the façade. This gives an advantage to the north oriented openings, making them ideal for diffused and evenly distributed illumination (Fathy, 1986). Vertical 30˚ shading altitude angle could shade 219 hours out of 303 overheated hours in summer – fall interval and 147 hours out of 191 overheated hours in winter - spring interval. The remaining unshaded ratios of the overheated hours are almost before 6:00 am and after 6:00 pm (figure 8 – 10).

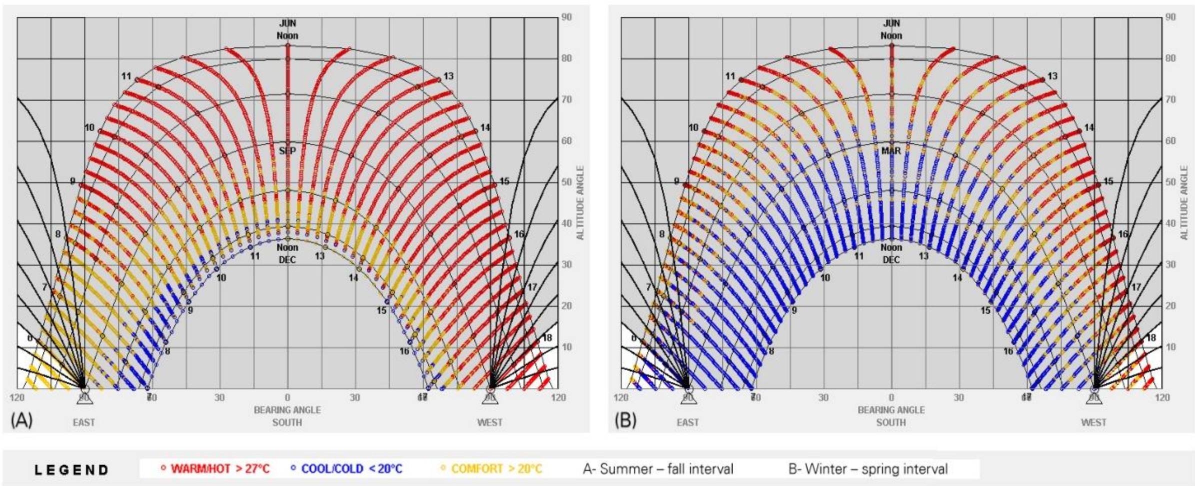


Figure 8 - 10: Vertical 30˚ shading altitude angle on north direction solar charts (Climate Consultant)

Vertical shading devices are more appropriate for the north oriented openings. Vertical devices with horizontal 65˚ shading azimuth angle can shade 300 hours out of 303 overheated hours in summer – fall interval and 188 hours out of 191 overheated hours in winter - spring interval (figure 8 – 11).

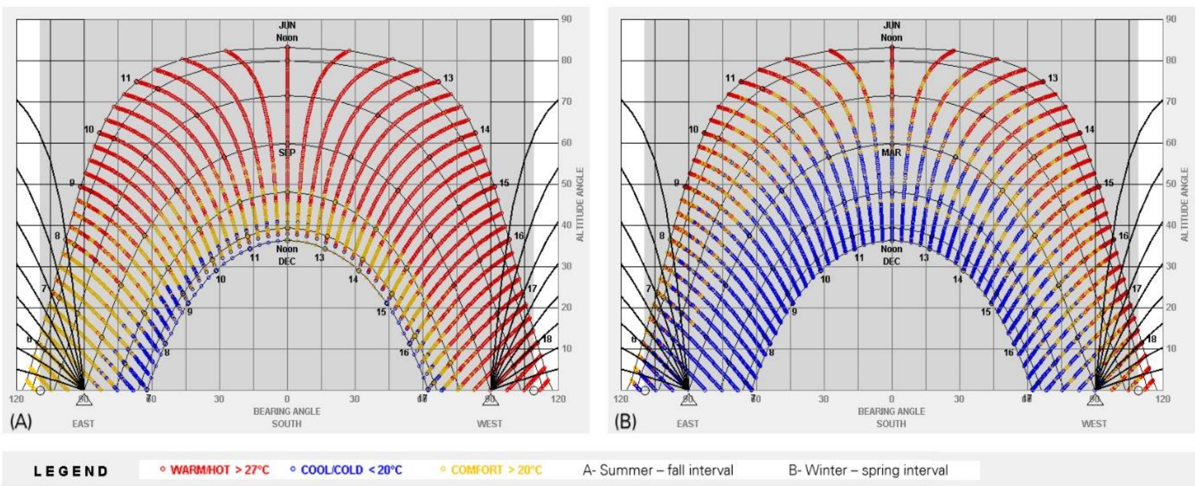


Figure 8 - 11: Horizontal 65˚ shading azimuth angle on north direction solar charts (Climate Consultant)

- East Orientation:

East facades are exposed to the direct solar radiation from the sunrise to noontime. During the early morning hours, it is not possible to protect the interior from direct radiations without obstructing the view, since the solar altitude angle is very low (Fathy, 1986). However, after 8:00 am when the sun rises higher at the sky-dome, horizontal shadings could be effective. Vertical 40˚ shading altitude angle could shade 375 hours out of 460 overheated hours in summer – fall interval, and 165 hours out of 206 overheated hours in winter - spring interval (figure 8 – 12).

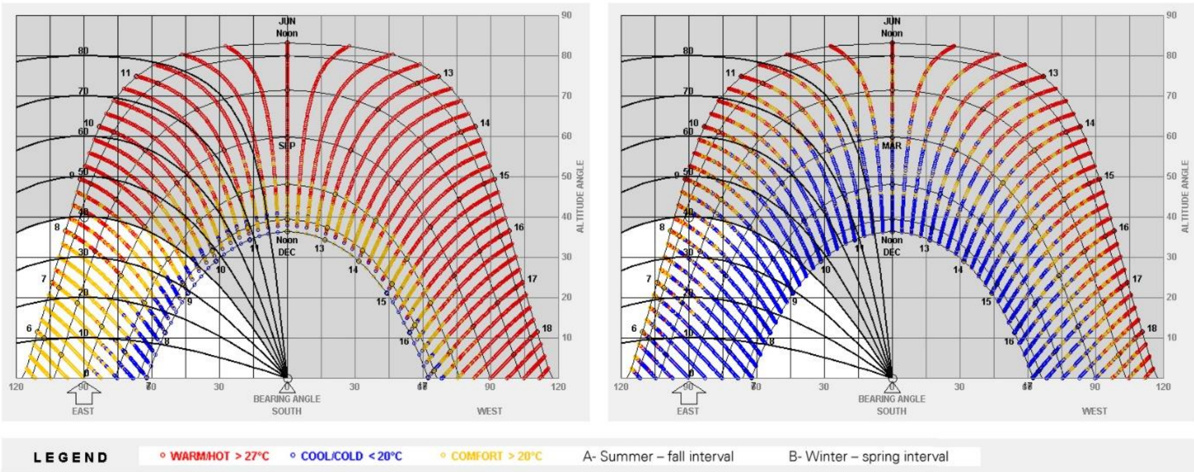


Figure 8 - 12: Vertical 40˚ shading altitude angle on east direction solar charts (Climate Consultant)

Vertical shading devices are less efficient for east oriented openings. They require a very small shading angle, although this will not score high shading ratios during overheated hours. Vertical devices with horizontal 25˚ shading azimuth angle can only shade 184 hours out of 460 overheated hours in summer – fall interval, and 52 hours out of 206 overheated hours in winter - spring interval (figure 8 – 13).

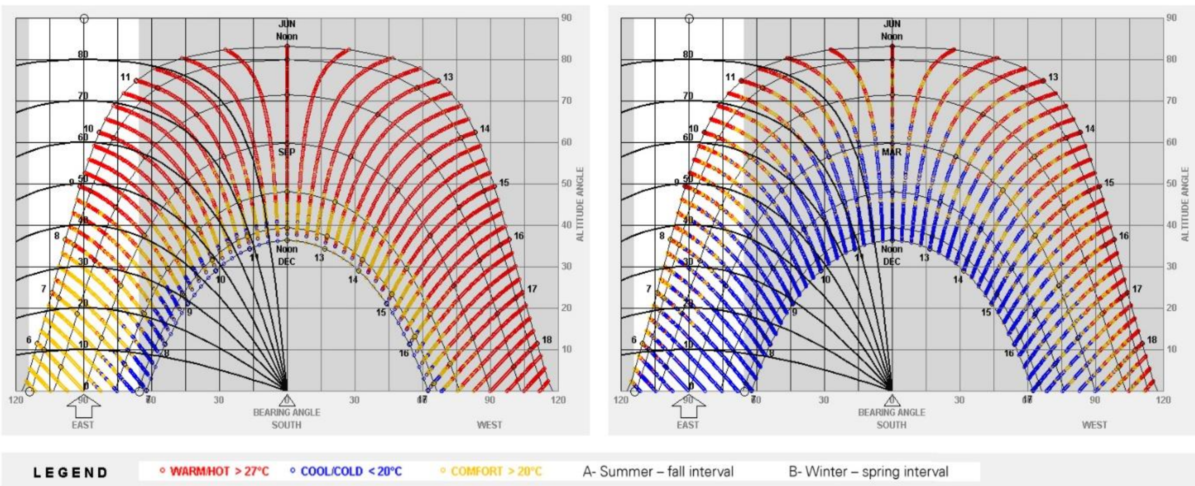


Figure 8 - 13: Horizontal 25˚ shading azimuth angle on north direction solar charts (Climate Consultant)

▪ South Orientation:

Regarding the solar charts, it is an advantage for the south oriented facades in the tropical and subtropical latitudes that the sun is high in the sky-dome during the summer season (i.e., altitude angle is high). Therefore, direct radiation can be easily shaded through using a relatively small overhang. While in winter season, the solar altitude angle turns low, in which it can allow for some solar penetration into the interior when it is most preferred (Fathy, 1986). Vertical 50˚ shading altitude angle could shade 930 hours out of 1034 overheated hours in summer – fall interval, and could shade all of the overheated hours in winter - spring interval (figure 8 – 14).

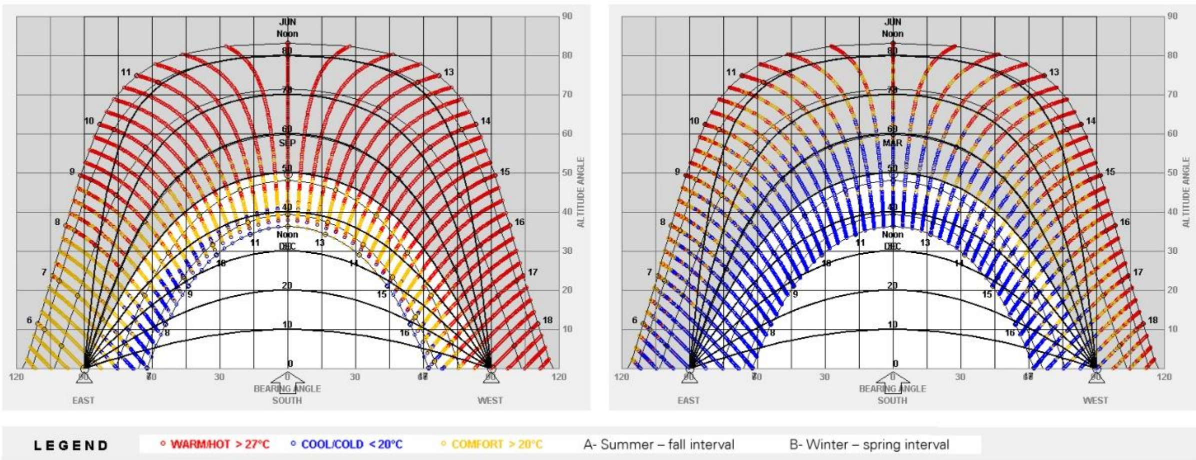


Figure 8 - 14: Vertical 50˚ shading altitude angle on south direction solar charts (Climate Consultant)

Vertical shading devices are less efficient for south oriented openings. It is not possible to obstruct the direct radiation on the overheated hours through only vertical devices. Vertical shadings with horizontal 45˚ shading azimuth angle can shade 708 hours out of 1034 overheated hours in summer – fall interval, and 316 hours out of 422 overheated hours in winter - spring interval (figure 8 – 15).

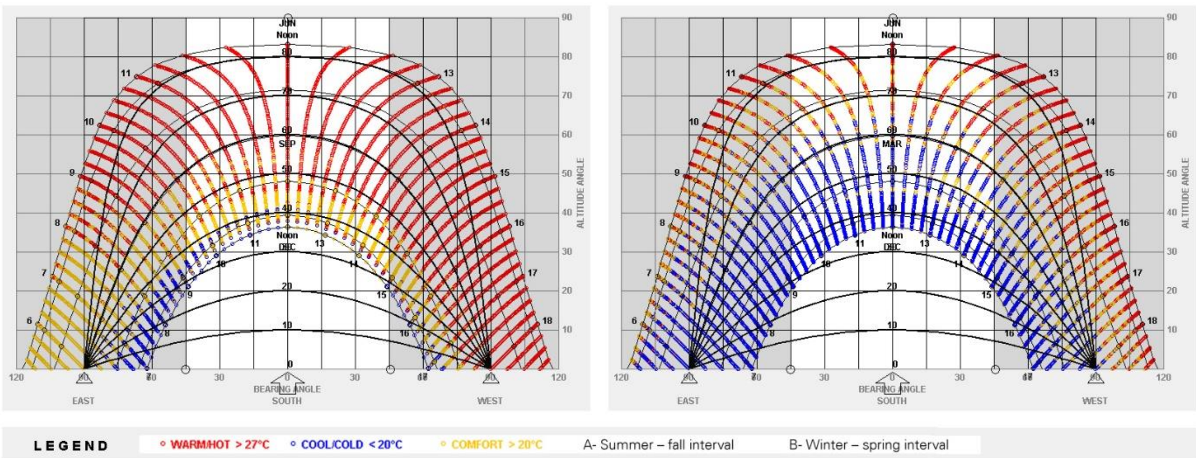


Figure 8 - 15: Horizontal 45˚ shading azimuth angle on south direction solar charts (Climate Consultant)

- West Orientation:

West oriented façade facades are generally considered the worst encountered scenario; owing to its low solar altitude angle that is gradually decreasing. In addition, it allows the direct solar radiation to penetrate into the interior during the daily average hottest hours (Fathy, 1986). It is not possible to obstruct direct radiation on overheated hours from the western openings through horizontal shadings, even with very low vertical shading altitude angles, since both the solar altitude and azimuth angles are getting very low and almost perpendicular. Vertical 35˚ shading altitude angle could shade only 488 hours out of 822 overheated hours in summer – fall interval, and 266 hours out of 403 overheated hours in winter - spring interval (figure 8 – 16).

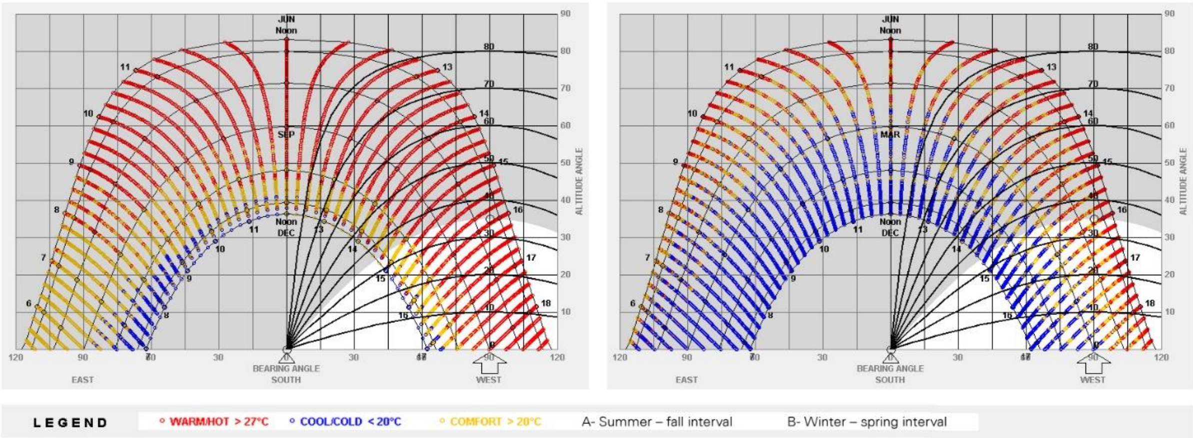


Figure 8 - 16: Vertical 35˚ shading altitude angle on west direction solar charts (Climate Consultant)

Vertical shading devices are also not efficient solutions for west oriented openings. It is not possible to obstruct the direct radiation on the overheated hours through only vertical perpendicular shading devices, even with very low shading azimuth angles. Vertical shadings with horizontal 20˚ shading azimuth angle can only shade 283 hours out of 822 overheated hours in summer – fall interval, and 98 hours out of 403 overheated hours in winter - spring interval (figure 8 – 17).

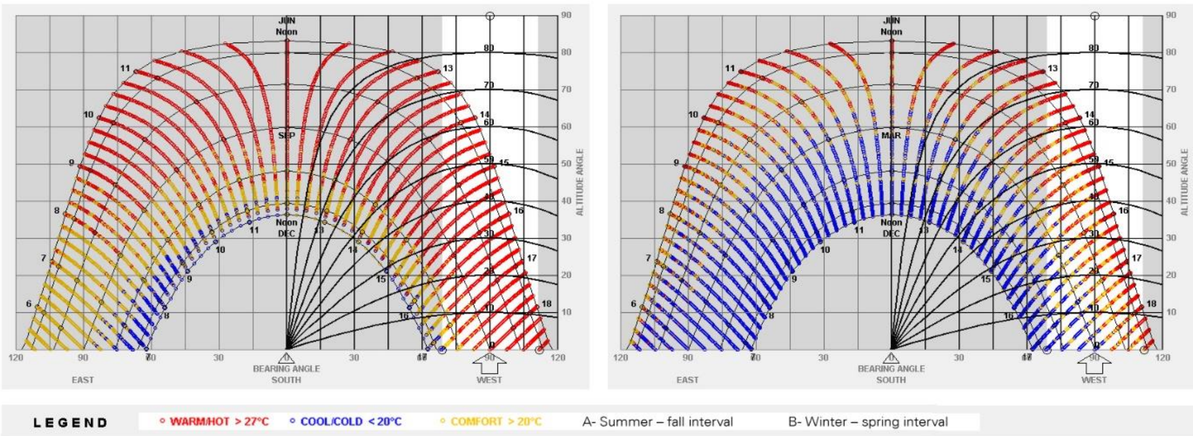


Figure 8 - 17: Horizontal 25˚ shading azimuth angle on west direction solar charts (Climate Consultant)

8.2.2.4. Wind Speed:

Wind movement occurs due to the difference in atmospheric pressure caused by differential heating of land and water mass on the earth's surface by solar radiation and rotation of the earth. Cairo's wind speed annual average rate is 3.4 m/s, with an average monthly range from 2.9 m/s during November to 4.3 m/s during May (figures 8 - 18 and 8 - 19).

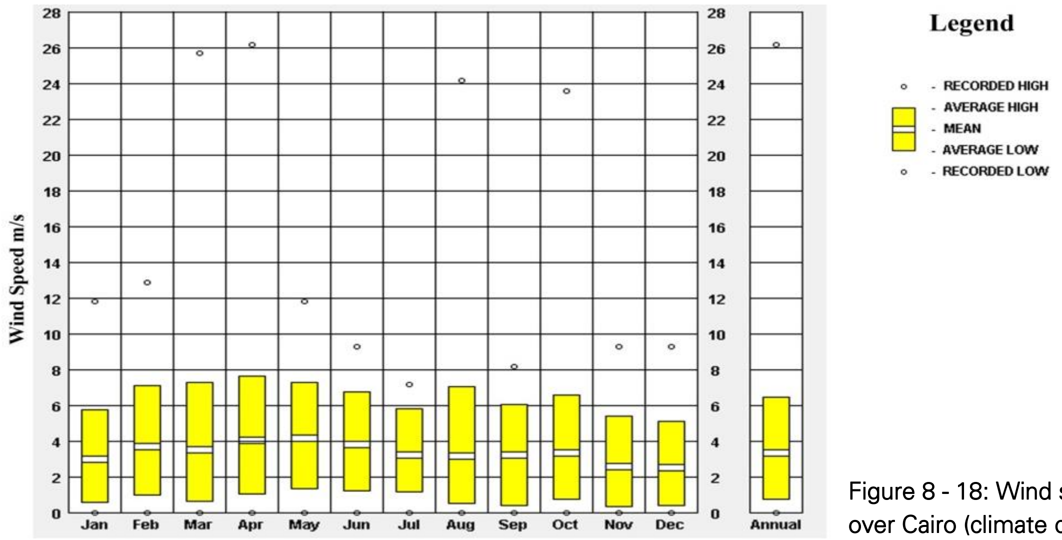


Figure 8 - 18: Wind speed range over Cairo (climate consultant)

The prevailing wind directions in Cairo are north to northwest in summer and south to southwest winds in winter, with periods of west to northwest winds in winter (Asar, 2008). The high-recorded values of wind speed are in March and April due to a seasonal weathering event of dusty sandstorms that frequently blow in the spring (from March to May) known as the El-Khamasin winds which are always associated with hot-dry winds, in addition of being full of massive amounts of dust and sand which increases the atmospheric pollution and raises the ambient temperatures (Robaa, 2006).

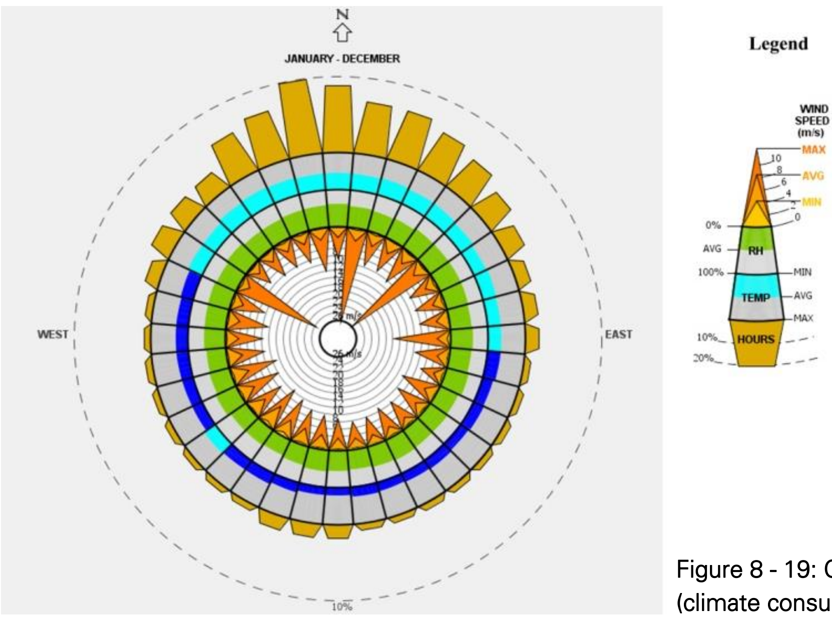


Figure 8 - 19: Cairo's average annual wind wheel (climate consultant)

8.2.2.5. Rain (precipitants):

Precipitation includes water in all its forms; such as rain, snow, hail or dew, measured in millimeters. Generally, rainfall rates in Cairo are very low throughout the whole year (dry climate). The monthly rainfall rate ranges from 0.3 mm in October to 6.8 mm in January, while from April to September, the climate is usually dry (Robaa, 2006).

8.2.2.6. Ground Temperature:

The average monthly ground temperatures of Cairo for 3 different depths (0.5m, 2.0m and 4.0m) are shown in figure 8 - 20. The highest average record of the ground temperature occurs in August and September, while the average lowest ground temperature occurs in February. At the depth of 0.5m the average monthly temperature ranges from 15.5 °C to 27 °C, at the depth of 2.0m, the temperature ranges from 16 °C to 26 °C, while at the depth of 4.0m, the temperature varies from 18 °C to 25 °C. The difference between the monthly average ambient temperature (above ground) and the underground average temperatures is due to the high specific heat capacity of earth. This could pin out a possibility for some passive cooling strategies.

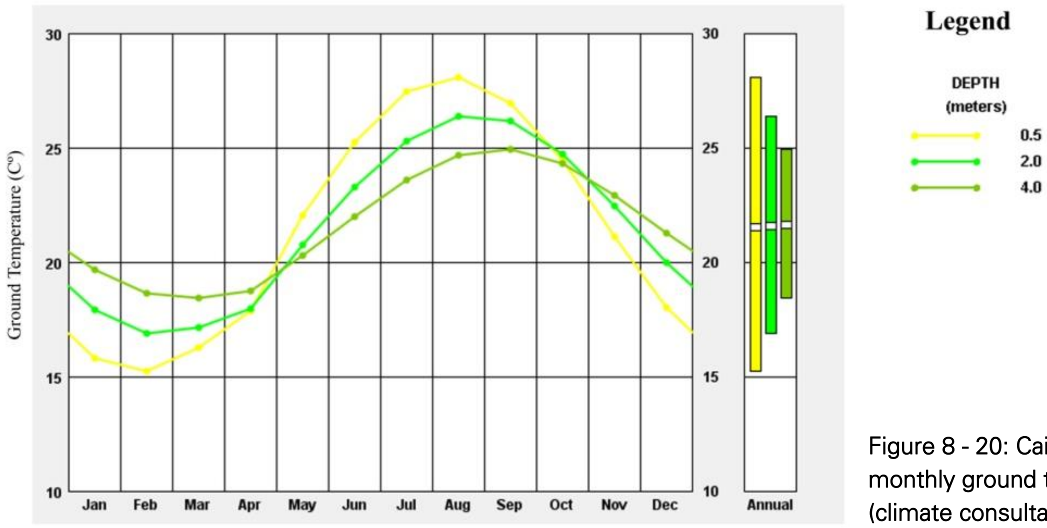


Figure 8 - 20: Cairo's average monthly ground temperatures (climate consultant)

8.2.3. Cairo's Building Bio-climatic Chart:

As mentioned before, the building bio-climatic chart (BBCC) defines the climate in relation to the occupant's thermal comfort, and recommends design strategies that aid in creating the required conditions to thermal comfort. Figure 8 - 21 shows the building bio-climatic chart of Cairo. The chart is elaborated from climate consultant 6.0 (2016) software. The thermal comfort boundaries are optimized according to ASHRAE standard 55 using predicted mean vote (PMV) model for non-residential buildings based on dry bulb temperature, clothing level, metabolic activity, air velocity, humidity, and mean radiant temperature, assuming that the mean radiant temperature is close to the dry bulb temperature.

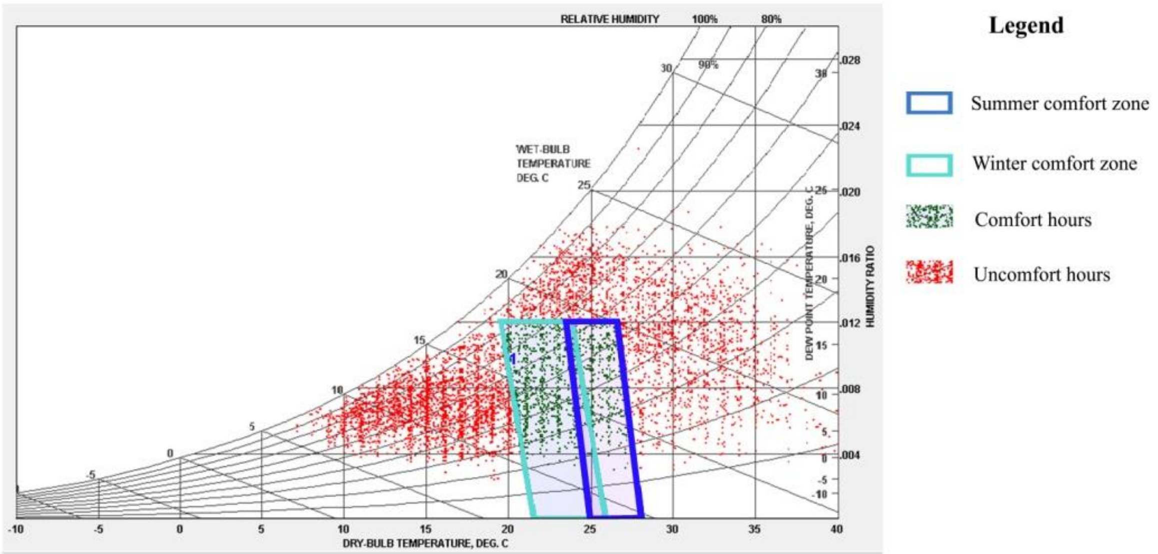


Figure 8 - 21: Building Bio-climatic chart of Cairo (climate consultant)

Figure 8 - 21 shows the thermal comfort zones of Cairo's building bioclimatic chart (BBCC). According to the level of clothing, the comfort zones are divided into summer comfort zone (on the right) and winter comfort zone (on the left). The chart defines the comfort hours of Cairo's climate by 1538 hours out of 8760 annual hours representing 17.6%. Figure 8 - 22 shows the monthly percentages of thermal comfort hours to un-comfort hours.

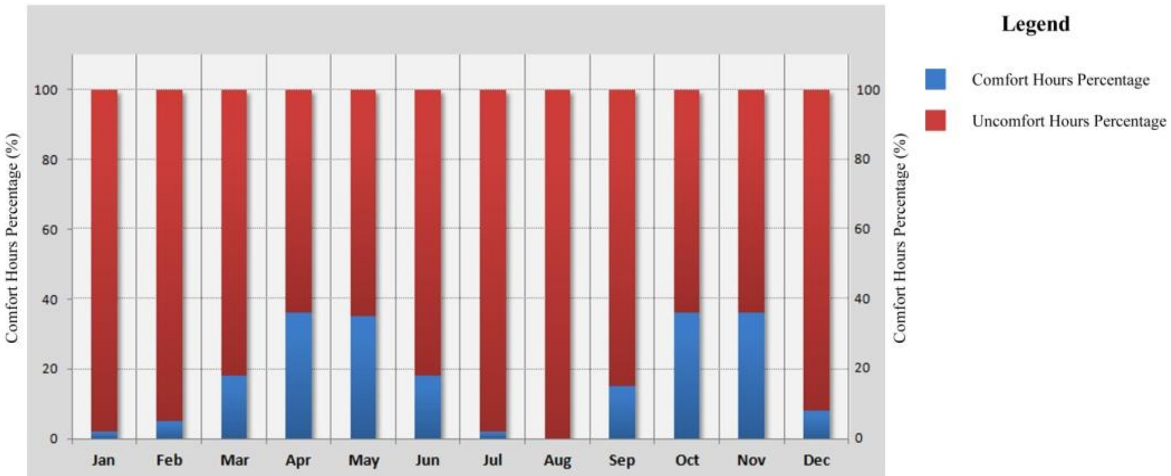


Figure 8 - 22: Monthly percentages of thermal comfort hours to un-comfort hours (climate consultant)

The building bio-climatic chart of Cairo also provides a patch of passive and low energy design strategies to achieve the thermal comfort conditions that could reach up to 7233 hours representing 82.6% of the total annual hours. Figure 8 – 23 and table 8 – 2 demonstrate the building bio-climatic chart of these strategies, the additional comfort hours that they could perform, and their percentage to the total number of occupancy hours.

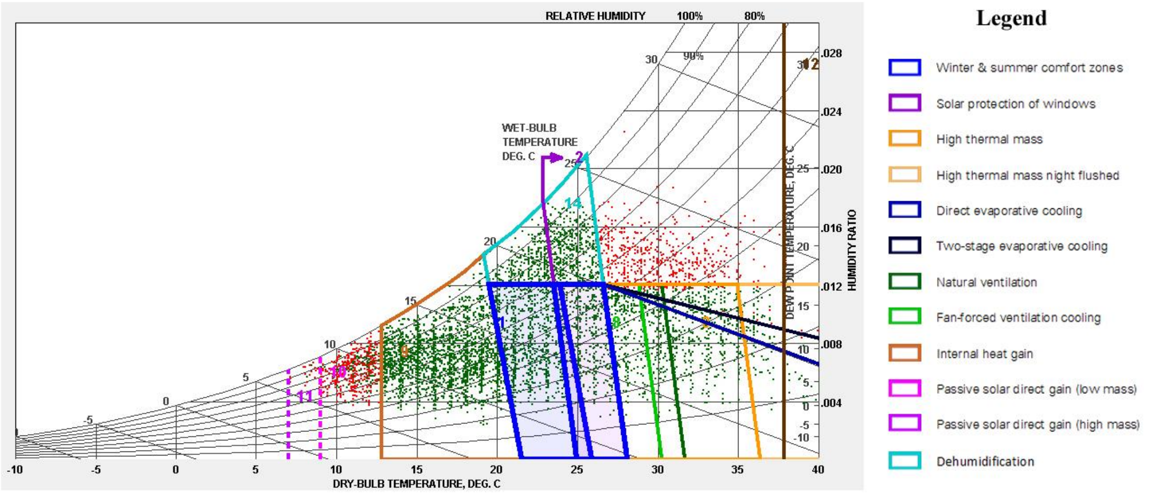


Figure 8 - 23: The Building's Bio-climatic chart of Cairo showing the passive and low – energy design strategies (Climate consultant)

Passive and low-energy design strategies	Extra comfortable hours (h)	Extra comfort percentage (%)
Solar protection of windows	1688	19.3
High thermal mass	859	9.8
High thermal mass night flushed	1113	12.7
Direct evaporative cooling	785	9.0
Two-stage evaporative cooling	953	10.9
Natural ventilation	414	4.7
Fan forced ventilation cooling	218	2.5
Internal heat gain	2954	33.7
Passive solar direct gain (low mass)	622	7.1
Passive solar direct gain (high mass)	1201	13.1
Dehumidification only	1281	14.6

Table 8 - 2: Passive and low – energy design strategies for Cairo's climate (Climate consultant)

Figure 8 - 24 and table 8 - 3 show the optimization of the occupancy hours of the building bio-climatic chart of Cairo from 7:00 am to 18:00 pm, which are the same occupancy hours that will be used in the modeling and simulation study of the research. The results show that the solar protection of the glazed components of the facades is the most influential passive strategy. It gives the potential of an extra 1688 comfort hours representing 38.5% of the total occupancy hours.

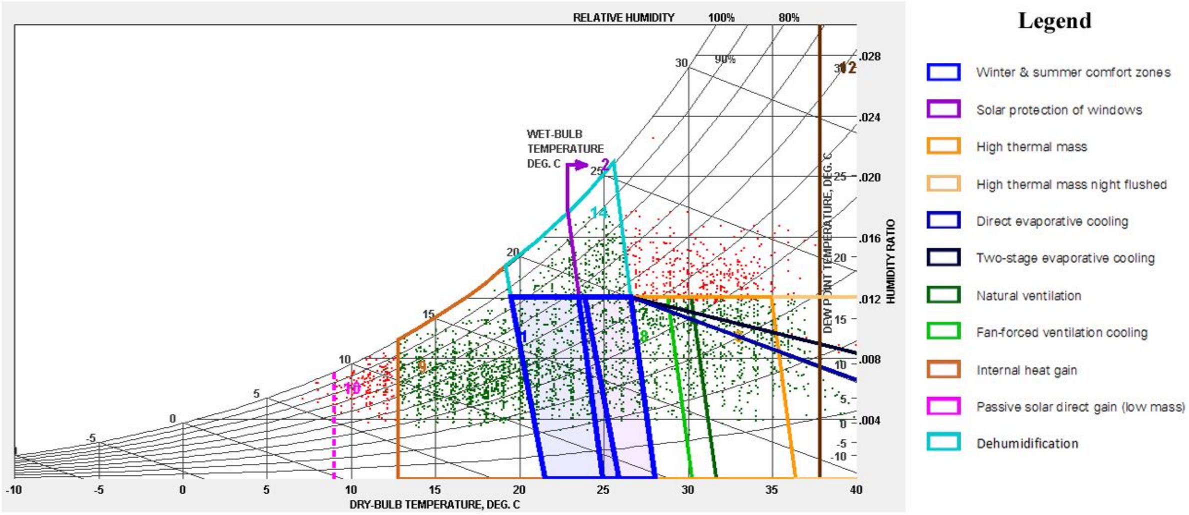


Figure 8 - 24: The Building's Bio-climatic chart of Cairo optimized for office hours occupancy showing the passive and low – energy design strategies (Climate consultant)

Passive and low-energy design strategies	Extra comfortable hours (h)	Extra comfort percentage (%)
solar protection of windows	1688	38.5
High thermal mass	793	18.1
High thermal mass night flushed	955	21.8
Direct evaporative cooling	604	13.8
Two-stage evaporative cooling	752	17.2
Natural ventilation	272	6.2
Fan forced ventilation cooling	132	3.0
Internal heat gain	1300	29.7
Passive solar direct gain (low mass)	498	11.4
Dehumidification only	321	7.3

Table 8 - 3: Passive and low – energy design strategies for Cairo's climate optimized for office hours' occupancy (Climate consultant)

In the same context, the ASHRAE's advanced energy design guide for small to medium office buildings underpins the prominence of windows' solar protection for hot-arid (B2) climates and its effective role in reducing the heat gain from the solar radiation. It recommends using sized glazed area with window to wall ratio (WWR) ranging from 20% to 40%, in addition to an appropriate and efficiently designed external shading devices, and to use advanced solar control glazing concepts. The used glazing concept is preferred to be multi-layered with low value of SHGC. Low-E coatings for spectrally selective transmission of sunlight can reduce the solar heat gain content while allowing light to enter. Sometimes an Inter-pane blind or some prismatic elements are useful to provide shading meanwhile shifting light in a specific direction (ASHRAE, 2011).

8.3. The Building Sector Energy Predicaments in Egypt:

Currently, Egypt is facing a severe electric energy crisis. The shortfall between electricity production and consumption is increasing, which is in turn due to a shortage in fuel supply, specifically natural gas and oil. This situation forced the government to reduce the loads on electric power supply grids which has consequently led to a frequent series of electricity blackouts across all Egyptian governorates. This problem is the culmination of accumulated factors for years; it has started since August 2008, and has been mostly limited to summer times due to the relatively high temperatures and high levels of radiation that affect the building's cooling loads. However, since the political turmoil in 2011, the crisis dramatically intensified. In 2012, power cuts became more frequent in Egypt even in winter when consumption is considerably low. Cairo and its suburbs have seen blackouts nearly every day which had lasted from one hour or two to even more, leaving streets in dark condition and forcing business to shut down (Ahramonline, 2014) and (Dailymail, 2014).

Figure 8 - 25: Frequent electricity outage in Egypt as an electrical energy subsidizing policy to cover the shortage in power production (Dailymail, 2014)

Electricity is the main secondary energy source in Egypt and the major consumer to the country primary energy resources. It consumes almost 38.5% of the primary energy production in the country (Abdallah, 2008). According to the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EEUCPRA) 2013 annual report, the electric power in Egypt is generated mainly from natural gas and oil as fundamental energy resources with 91.11%, while other resources including renewable ones contribute with a share less than 10% as shown in figure 8 - 26. The electric sector in Egypt has planned an ambitious policy that by the year 2020 it will maximize the usage of renewable resources to reach

20% of the total electric consumption in the country, and save 20% of the electric power usage through the efficient usage, and expand power generation capacity by 30 GW (EEUCPRA, 2014).

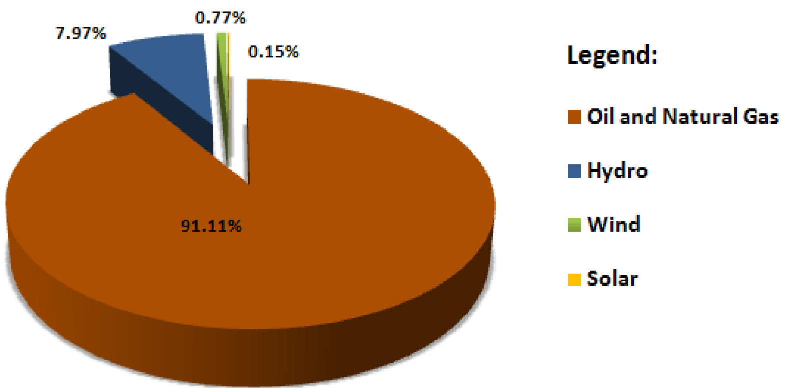


Figure 8 - 26: Electrical energy production in Egypt by resource (EEUCPRA, 2014)

The building sector relies on electricity as its fundamental source of energy. It is the major electric energy-consuming sector in Egypt. 58.48 % of the total electricity produced in 2013 is attributed to residential, commercial, and governmental buildings, as shown in figure 8 - 27. Such energy goes mainly for lighting, HAVC systems (cooling and heating), and operating the different electric appliances and services. While the use of liquefied natural gas (LNG) and natural gas in buildings is limited to heating water and cooking (EEUCPRA, 2014). Many reasons and manifestations are responsible for this predicament situation among which are the following:

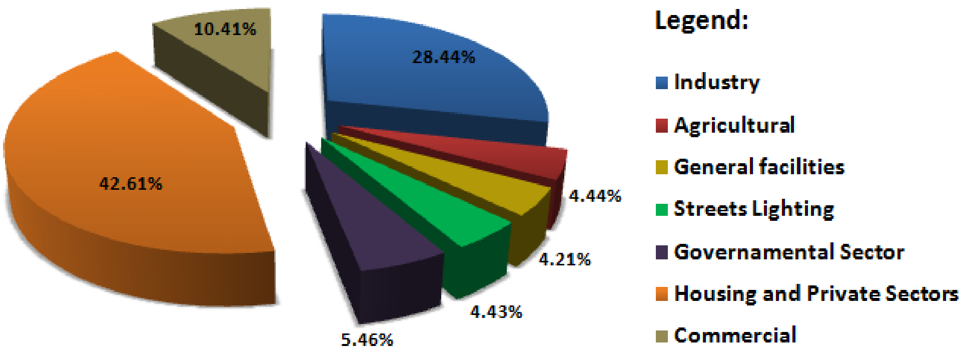


Figure 8 - 27: Electrical energy consumption in Egypt by sector (EEUCPRA, 2014)

8.3.1. Increase in the Electric Energy Demand:

The electric energy demand in Egypt has been facing a significant growth in the last 20 years. It has increased with an annual average rate of 7% (Rationalization Committee, 2013). In 2012, the electric power consumption increased from 146796 TWh to 157406 TWh (EEUCPRA, 2014). Figure 8 - 28 shows the exponential growth in electric power production/consumption in Egypt since 1972 by fuel.

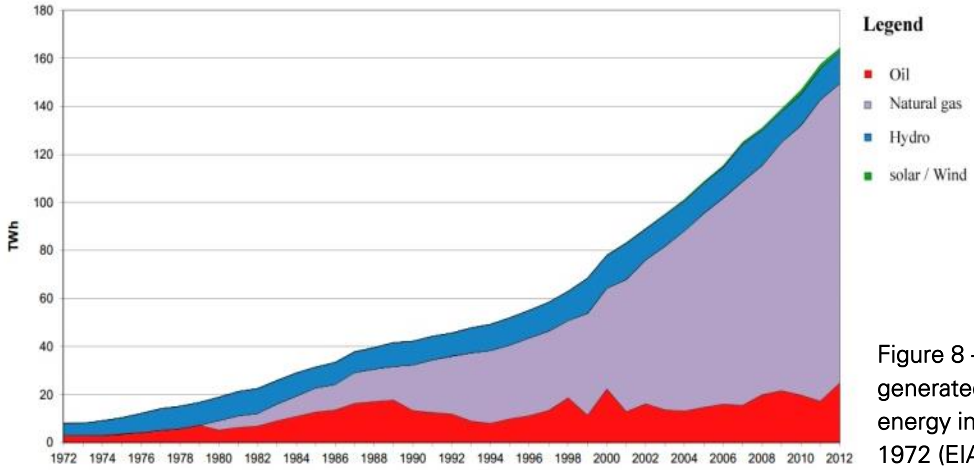


Figure 8 - 28: Total annual generated/consumed electric energy in Egypt by fuel since 1972 (EIA, 2014)

This growth is revealed in the increased usage of air conditioners due to high temperatures in summertime, and the increased usage of electrical devices and appliances. Such trends must be considered to be able to understand the present and future dynamics of Egypt's electric energy needs (Ali, et al., 2013). The major factors contributing to this rapid growth in electric energy demand in Egypt includes population growth, high rate of urbanization and the increased standards of living and services.

8.3.1.1. Increase in Population:

In 2000, Egypt was the 16th most populated country worldwide and the second among the African countries. According to some future speculations of the United Nations Department of Economic and Social Affairs - Population Division, Egypt will continue to be among the top 20 populated countries worldwide until 2300 (UN: Population Division, 2004). The Central Agency for Public Mobilization and Statistics in Egypt (CAPMAS) 2013 annual report showed that the total population of Egypt has duplicated from 36.6 to 72.82 million in the period from 1976 to 2006, and has reached 83.7 million in January 2013 with an annual increasing rate of 2.5% as shown in figure 8 - 29. Egypt population is expected to reach 102 million by the year 2030 (CAPMAS, 2013).

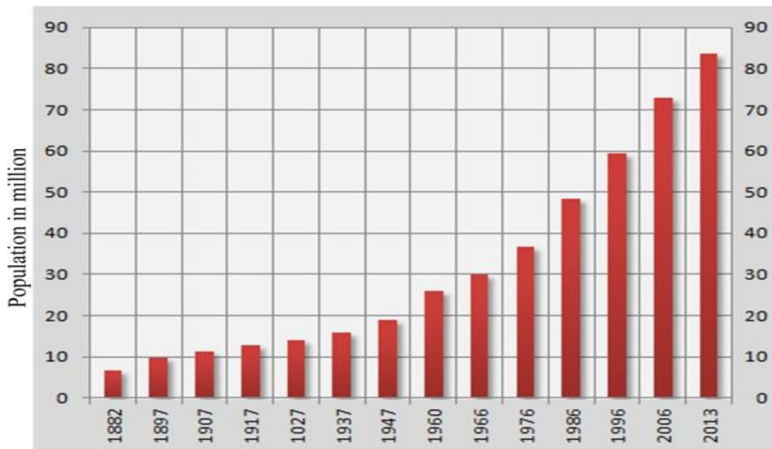


Figure 8 - 29: Population in Egypt from 1882 until 2013, modified from (CAPMAS, 2013)

Cairo is the capital and the largest populated city in Egypt. In January 2013, it was inhabited by 8.92 million people representing 10.67% of the total population in Egypt, while the Greater Cairo Region (GCR) was populated by approximately 20.74 million persons, representing 24.45 % of the total population of Egypt (CAPMAS, 2013).

8.3.1.2. High Rate of Urbanization:

Large scales of urbanization impinge on all cities of Egypt as a natural repercussion for the high rate of population increase, and also for seeking higher standards and better conditions of living (CAPMAS, 2013). According to the UNDP report 2010, Egypt witnesses relatively high rates of Urbanization, it has recorded 2.8% from 1976 to 1986, and 2% from 1996 to 2006. (Institute of National Planning, Egypt in cooperation with the United Nations Development Programme, 2010). In addition, the number of urban population is expected to rise from 31 million in 2005 to 52 million in 2030 (Liu, et al., 2010). For the case of Greater Cairo Region, the build-up area has witnessed a huge incensement since the 50's, as it had expanded from 120 Km^2 in 1950 to 525 Km^2 in the year 2000 (El-Shafie & Khalifa, 2011). Figure 8 - 30 shows Cairo's urban expansion from 1968 to 2000 (Metge, 2000).

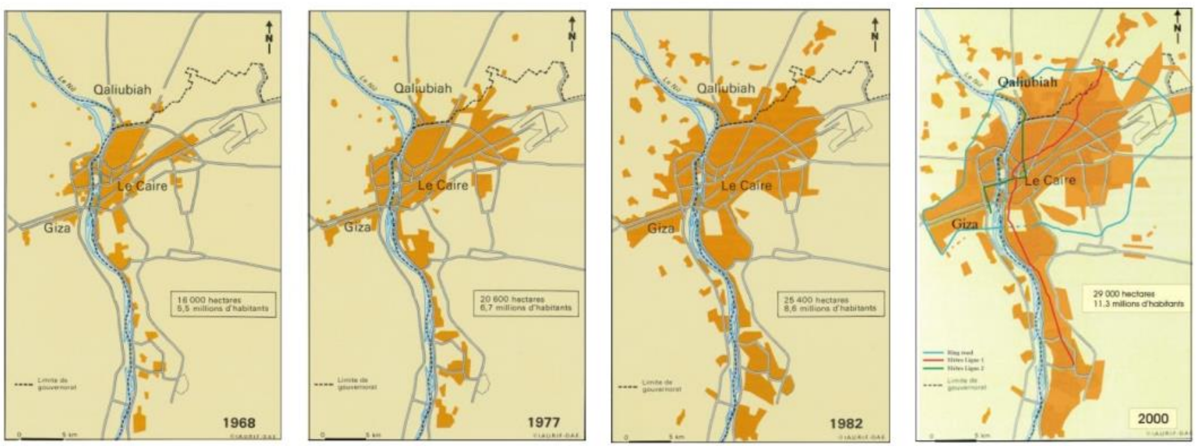


Figure 8 - 30: Greater Cairo Region urban development from 1968 to 2000 (Metge, 2000)

In 2008, The Ministry of Housing, Utilities, and Urban Development in Egypt (MHUUD) in cooperation with the Japan International Cooperation Agency (JICA) founded the borders of the Greater Cairo Region (GCR). It includes the whole of Cairo Governorate, some parts of Giza and Qaliobeya governorates, 10th of Ramadan city, and some new urban communities (NUCs) with total area of 4,367 km^2, including: (i) The built-up areas in the main cities; (ii) Villages and small towns that are mostly located in agricultural areas outside the main agglomeration; and (iii) New urban communities (NUCs). These borders make GCR Area the seventh largest urban agglomeration in the world and the largest agglomeration in the Middle East and Africa (Ministry of Housing, Utilities, and Urban Development in corporation with Japan International Cooperation Agency, 2008).

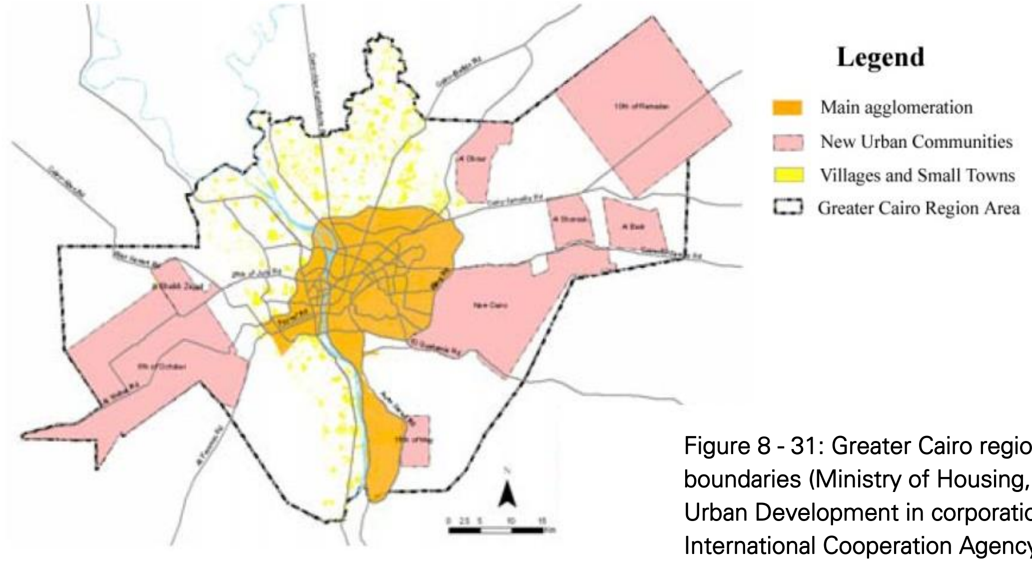


Figure 8 - 31: Greater Cairo region (GCR) boundaries (Ministry of Housing, Utilities, and Urban Development in corporation with Japan International Cooperation Agency, 2008)

8.3.1.3. Increased Standards of Living and Services

The impact of the increased standards of living and services in Egypt is revealed on the exponential increase in the number of subscribers in the national electricity network which have increased in the last ten years from 19.2 million subscribers in 2003 to 29.7 million in 2013. Approximately, 98% of the population in Egypt has access to electricity. In addition, the rise in living standards and comfort demand has been triggered by the continuously growing urban population coupled with some economic growth rates. Accordingly, the average rate of electricity consumption per person in Egypt has increased in the same period from 1350KWh to 1955KWh (Ministry of Electricity and Energy, 2014).

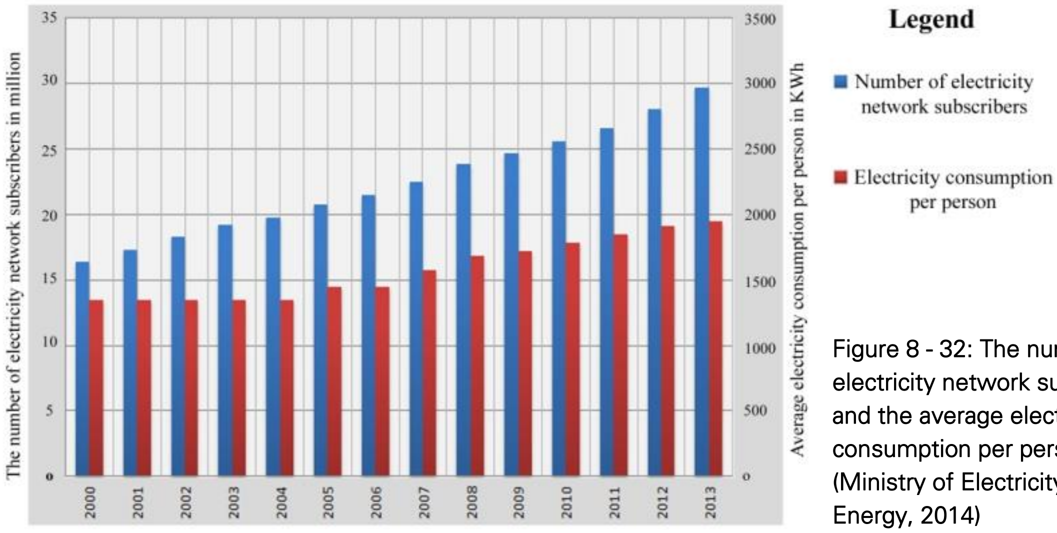


Figure 8 - 32: The number of electricity network subscribers and the average electric consumption per person (Ministry of Electricity and Energy, 2014)

8.3.2. Primary Energy Resources Incapability Against Consumptions

The current domestic energy situation in Egypt is very drastic, the continuous thirst for energy consumption is increasing substantially, and the state of primary energy supply is very serious and predicts worse future consequences. Egypt's general energy strategy depends mainly on oil and natural gas as the primary used fuels. In 2013, they represent 94% of the total primary energy consumption in the country and the rest is secured by hydroelectricity, coal, and wind power, figure 8 – 33 (EIA, 2014) and (BP Stats, 2014).

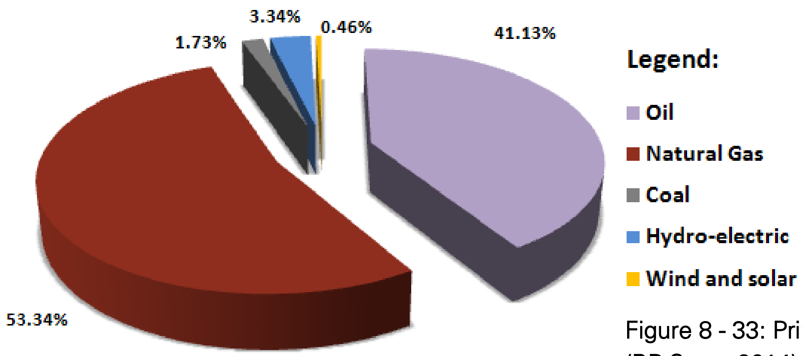


Figure 8 - 33: Primary energy consumptions in Egypt (BP Stats, 2014)

According to the BP statistical review of world energy, the total primary energy consumption in Egypt had doubled almost 5 times in the last 33 years. It has increased from 18 mtoe in 1980 to 86.8 mtoe in 2013, with an average annual growth rate of 4.84% (BP Stats, 2014). With this trend of increase, energy consumption is expected to reach 130 mtoe in 2020 (Gouda, 2010).

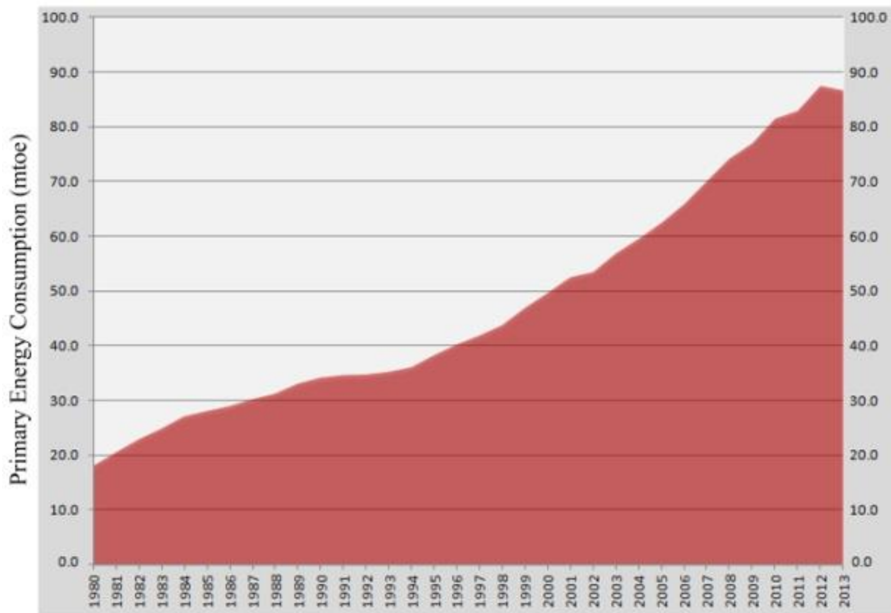


Figure 8 - 34: The primary energy consumption evolution in Egypt Since 1980 (BP Stats, 2014)

The previous figures rank Egypt as the largest oil and natural gas consumer in Africa. In 2013, it consumed nearly 20% of oil consumptions and 40% of natural gas consumptions in the whole continent. This rapid growth rate of oil and natural gas consumptions over the last decades could be attributed to the increased industrial growth, energy subsidies, gas and oil extraction projects, population growth, and the vast increase in vehicles number (EIA, 2014).

8.3.2.1. Oil:

According to the BP 2014 statistical review of world energy, Egypt's proven oil reserves stands at 3.9 billion barrels in 2013, representing 0.2 percent of the world's oil reserves, while its total oil production in 2013 averaged 714,000 bbl/d. Despite discoveries and enhanced oil recovery techniques at mature fields, figures of the annual oil production in Egypt have been declining after reaching its peak in the mid-1990s with a production rate of more than 900,000 bbl/d. On the other hand, the oil consumption in the country grew by an annual average range of 3.54% during the last 10 years; reaching 770,000 bbl/d in 2013. Since 2010, Egypt's oil consumption has exceeded its production, leading the former oil exporter country to require oil imports in order to meet its domestic energy demand. According to OPEC's Annual Statistical Bulletin, in 2013, Egypt imported about 170,000 bbl/d of oil products (BP Stats, 2014) and (EIA, 2014).

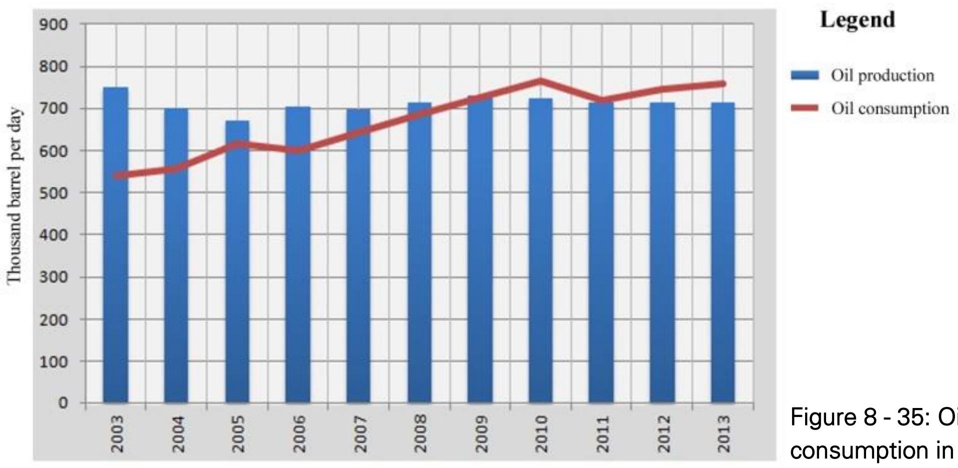


Figure 8 - 35: Oil production versus consumption in Egypt (BP Stats, 2014)

8.3.2.2. Natural Gas:

According to BP 2014 annual statistical report, Egypt held 65.2 Trillion cubic feet (Tcf) proved natural gas reserves at the end of 2013 (BP Stats, 2014). Since the 1990's, the government has started to compensate the declining oil production through shifting the reliance to natural gas as a domestic energy resource and to maintain a certain level of hard currency revenues from oil and gas exports (Georgy & Soliman, 2007). However, despite the new discoveries, Egypt's production of natural gas has declined from 2009 to 2013 by an annual average rate of 3% due to some economical burdens with foreign gas exploring partners. The total production of natural gas in Egypt has almost reached 2.0 Tcf in 2013, out of which 1.9 Tcf, representing 95% was consumed and only 0.1 Tcf was exported. The figure of natural gas exports in Egypt have declined substantially since 2009 due to the decline in production and the rapid rise in domestic demand; mainly in the electricity sector. Egypt started to import liquefied natural gas (LNG) in 2012 to satisfy its natural gas demands, which has been growing with an annual average rate of 7% during the last 10 years (EIA, 2014).

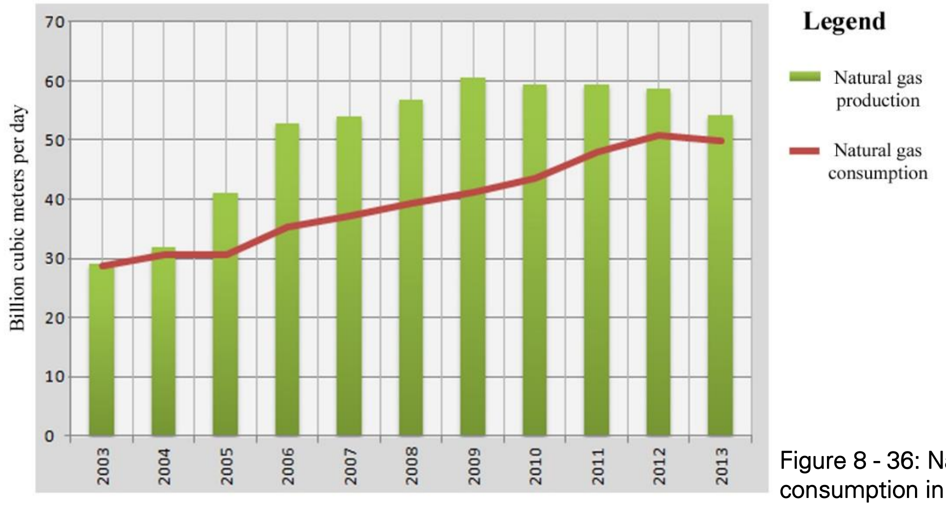


Figure 8 - 36: Natural gas production vs. consumption in Egypt (BP Stats, 2014)

8.3.2.3. Coal:

Egypt is not a coal producing country; its coal resources are limited, besides being known for its low quality. Egypt began coal mining in 1996; Coal reserves are estimated at 27 million tons. According to the BP statistical review of world energy report, Egypt consumed 1.5 mtoe of coal contributing with only 1.7% of its total primary energy production in 2012; most of the consumed coal was imported from foreign countries including USA and Canada, and are mostly directed to the national heavy industries (BP Stats, 2014) and (Georgy & Soliman, 2007).

8.3.2.4. Renewable Resources:

In 2013, Egypt has generated 14429 million KWh from renewable resources representing almost 4.3% of the total primary energy production in the country; that energy is mainly generated from hydroelectric, solar and wind power stations (BP Stats, 2014).

Hydropower is the third-largest energy source in Egypt after natural gas and oil; Egypt generated 13121 million KWh of hydroelectricity power in 2013, (EEUCPRA, 2014), almost all of which came from the River Nile, Aswan reservoir, the high-Dam, Esna, and Nagah Hamady hydropower stations (Hanna, 2013). While, both solar and wind energy production generally participate with a very low share of the primary energy production; in 2013, they contributed with only 1597 million KWh (EEUCPRA, 2014). Much of renewable energy potential in Egypt has already not been exploited yet. As a result, the New and Renewable Energy Authority in Egypt (NREA) is developing some renewable energy strategies that are mainly depending on solar and wind power projects as an objective to diversify the country's energy mix. In April 2007, the Supreme Council of Energy of Egypt adopted an ambitious plan to expand the share of the Renewable energy resources in the total electricity production to reach 20% by the year 2020 (Ministry of Electricity and Energy, 2014).

8.3.3. Economic Burdens:

Currently, Egypt is facing an economic turmoil since the last years that followed the revolution of January 2011. The Annual Gross Domestic product (GDP) growth in Egypt has fluctuated from 7.2% in 2008 to 5.1% in 2010, then dropped sharply to 1.8% in 2011. Recently, the GPD has progressed, but remains far below the pre-revolution level; in 2013, it averaged 2.1%. Some of oil and LNG shipments from Persian Gulf countries have supported and aided Egypt financially to meet its primary energy demands (EIA, 2014).

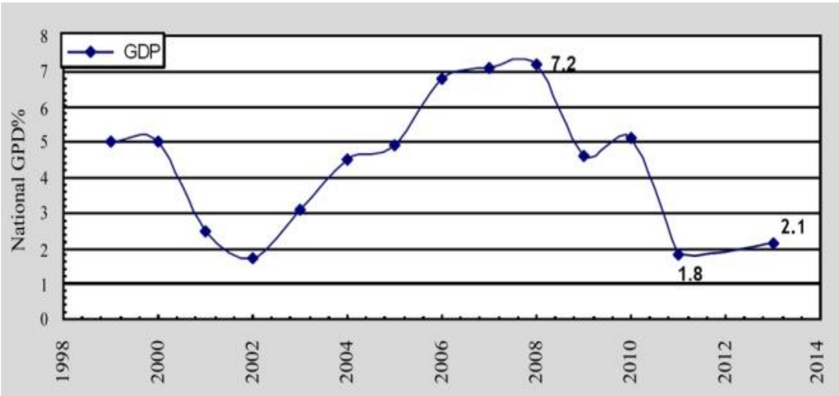


Figure 8 - 37: The annual gross domestic product (GDP) Growth Rate in Egypt (Hanna, 2013)

The energy sector plays a very crucial role in Egypt's economy. The rapid change in the rates of energy production and consumption is mutually affecting and being affected by the Egyptian economy in various aspects. On the one hand, oil and natural gas export are sources for foreign currency, while on the other, the exponential growth of consumption and the decline in production rates had forced the government to reduce its fossil exports. Moreover, currently, almost all energy carriers in Egypt are subsidized. According to the ministry of petroleum in Egypt, the government continues to fund energy subsidies that had cost the government 128.2 Billion Egyptian Pound (EGP) in 2012, while the total subsidizing from 2000 to 2012 had cost Egypt 695.2 Billion EGP (Ministry of Petroleum in Egypt, 2014). Energy subsidies figures in Egypt is growing rapidly; it accounts for nearly 25% of the total annual government spending. These subsidies ranked Egypt as the eighth-highest spender country on fossil fuel worldwide. (figure 8 – 38) (EIA, 2014).

The previous reasons have contributed to high budget deficit in the country during the last few years; this has led to the inability of the Egyptian General Petroleum Corporation (EGPC) to pay off its debt to foreign oil and gas operators. In June 2014, the accumulated arrears have reached $7.5 billion, which has led the foreign operators to delay their current investments in the existing and new projects. In early 2013, the Egyptian government has approved subsidy reform strategy; it has planned to increase the energy prices for the heavy industries, for electricity producers, and for house-hold electricity through reducing the total energy subsidies by 22% in the 2014/15 fiscal year (EIA, 2014).

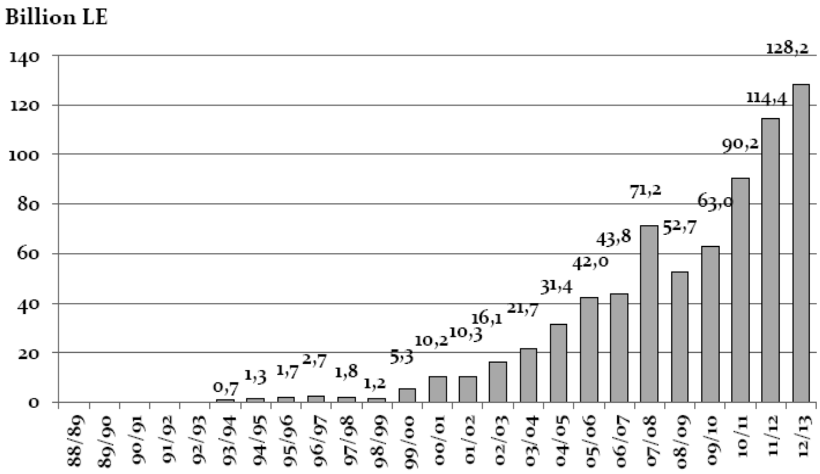


Figure 8 - 38: Energy subsidy expenses in Egypt (Ministry of Petroleum And Mineral Resources, 2014)

8.3.4. Inefficient Energy Use:

The simplest statistical indicator to describe the energy efficiency in any country is the primary energy intensity; it is the ratio of total primary energy supply/consumption to the total output of the country (GDP per capita). According to Jochem, et al. (2008), the primary energy intensity for Egypt has been relatively constant from 1981 to 2007; it ranges between 0.9 and 1.1. This indicates that both the primary energy consumption and the economic growth per capita are strongly conjugated, their ratio is nearly constant with minor fluctuations of ±10% over more than 25 years.

In comparing similar series of some countries, Egypt's final energy intensity was found to be higher than most of other developing North African countries with almost the same GDP per capita figures like Tunisia and Morocco; meaning that the country uses more energy with near GPD output. In addition, the Egyptian economy consumes almost 50% more energy than that of Germany and any typical European county, where people of these countries have higher income by nearly six times. This clearly indicates the need for enhancing the energy consumption policy in Egypt, which has to be defined sector by sector (Jochem, et al., 2008).

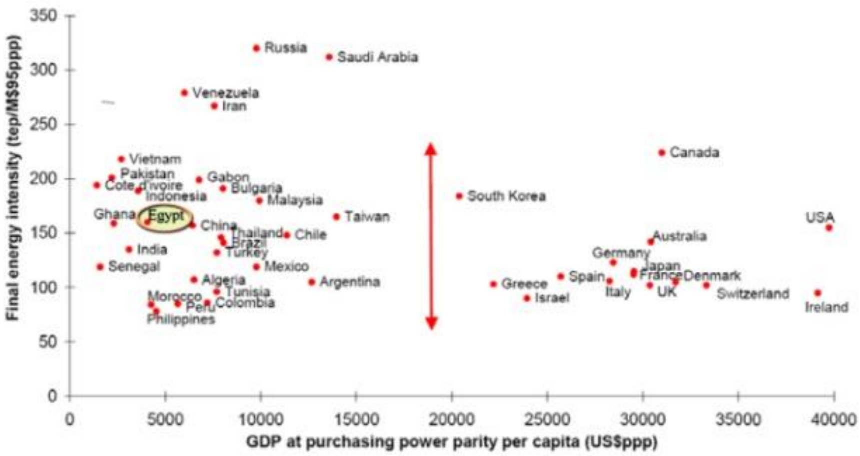


Figure 8 - 39: Final Energy Intensity and GDP per Capita (PPPs) in 2006 for Egypt and other selected countries (Jochem, et al., 2008)

In order to put Egypt on the right sustainable energy path, the increasing energy consumption rates and the economic growth should be de-coupled. This objective is very crucial for the future; the whole country has to invest more efforts on improving its energy efficiency policy and increasing its economic growth. This should be reflected in higher GDP growth rate figures that are not related to the annual energy consumption rate (Georgy & Soliman, 2007).

In order to get a complete overview on the energy efficiency potentials in Egypt, it is important to understand the barrier factors, its related sectors, and their impact on the economy and the implementation of energy efficient programs and projects in Egypt. These factors or barriers can be summarized in the following points:

- **Financial and economic barriers:** This is the most significant barrier due to the conventional governmental energy subsidies strategy. All energy prices including oil products, natural gas, and electricity are subsidized in Egypt. Hanna (2013) argued that this is the main factor that had contributed to the rise in energy demand in Egypt; the very low energy prices have led to the overuse of the scarce energy resources. Gouda (2010) added that subsidizing energy prices set back any energy efficiency efforts; it diminishes the incentives for the people to reduce their energy consumption rates and led the private sector to withdraw from implementing efforts in energy efficiency projects. Energy subsidies reduce the required sense to value energy savings and provide it at a marginal cost that does not justify the cost of implementing energy efficient projects. The following table states the different categories of electrical consumption for commercial and residential use in Egypt and their corresponding tariff starting from June 2014.

Monthly Electric Consumption Tariff For Commercial Use			
Category	Monthly Consumption (KWh) From	Monthly Consumption (KWh) To	Tariff in EGP/KWh
1	0.00	100	0.34
2	101	250	0.52
3	151	600	0.67
4	601	100	0.84
5	More than 1000		0.90

Monthly Electric Consumption Tariff For Residential Use			
Category	Monthly Consumption (KWh) From	Monthly Consumption (KWh) To	Tariff in EGP/KWh
1	0.00	50.0	0.08
2	51.0	200	0.18
3	201	350	0.24
4	351	650	0.37
5	651	1000	0.67
6	More than 1000		0.84

Table 8 - 4: Monthly electric consumption tariff for commercial and residential use in Egypt, starting from June 2014 (EEUCPRA, 2014)

- **Legislative barriers:** Building Energy Efficiency Codes (BEEC) in Egypt was introduced between 2005 and 2009 under the supervision of the Housing and Building Research Centre (HBRC). In three different code volumes, they propose some guiding energy performance regulations for residential, commercial, and public buildings. However, up till now, no single legislation has issued to support these regulations. In addition, the training of the building chain actors has not been accomplished. Consequently, at the local level, the required compliance and enforcement procedures are not available for the responsible municipalities in order to take the enforcement actions of these building codes (Liu, et al., 2010).

- **Organizational and institutional barriers:** The energy sector in Egypt is managed through too many parties. The main responsibilities are led by the Ministry of Electricity and Energy (MOEE) and the Ministry of Petroleum (MOP). The Supreme Council for Energy (SCE) is responsible for formulation and long-term planning of the energy policies in Egypt representing the Technical Cabinet of Ministers. In August 2009, the SCE introduced another unit to act as responsible for the national energy efficiency strategies under the direct supervision of the Ministry Cabinet. Moreover, in 2009, the Supreme Council of Green Buildings was formulated to adopt a New Green Building Code for the New Urban Communities and the New and Renewable Energy Authority (NREA) (Hanna, 2013). All of the previous mentioned authorities make an integrated energy planning more difficult, and in need for a huge coordination to be handled to some extent. This situation can explain the reasons for the non-existence of a clear and applicable national strategy for the efficient use of energy with well-defined targets (Georgy & Soliman, 2007).

- **Technical barriers:** These issues are related to the use of Unified Power Systems (UPS) such as technical power loss, load shifting and load management; where generally, there is a lack of awareness, skills, and training on the use of these techniques in Egypt. In addition, the load shifting technique has not been introduced in Egypt for the following reasons: First, the lack of the necessary knowledge to implement these technical activities, second, the un-implementation of time-of-day tariffs, and third, the lack of the required cooperation between suppliers and consumers (Gouda, 2010).

- **Capacity and awareness barriers:** The level of knowledge, information dissemination, training, and skills in energy efficiency and renewable energy strategies in Egypt are still relatively lower than what is needed to foster the ever-growing interest in energy efficiency utilization. Professional training and educational programs at different levels starting from experts to the end users are likely to be important tools to speed up the implementation of energy efficient solutions and renewable energy strategies wherever they become economically feasible (Georgy & Soliman, 2007) and (Jochem, et al., 2008).

8.4. Office Buildings Energy Consumptions Modes in Cairo:

Office buildings in Cairo region consumes from 5 - 7% of the total energy consumption of the country. In addition, the facade configuration is estimated to be responsible for nearly 40% of the total building's cooling loads. The increasing trends of reliance in the commercial and governmental buildings in Cairo on air conditioning systems indicate the failing role of the envelope to achieve its main function as a climatic moderator, and leading to a tremendous increase in electricity consumption (Hamza, 2004).

Figure 8 - 40 shows four samples of office buildings façade configurations in Cairo that are built in different times. From analyzing the pictures, it is evident that the office façades have elaborated over the previous decades towards more light masses and more transparency measures through increasing the window to wall ratio (WWR) to a complete transparent glazed skin. However, such developments are leading to more irrational consumption of electrical energy far away from any passive or energy efficiency means.

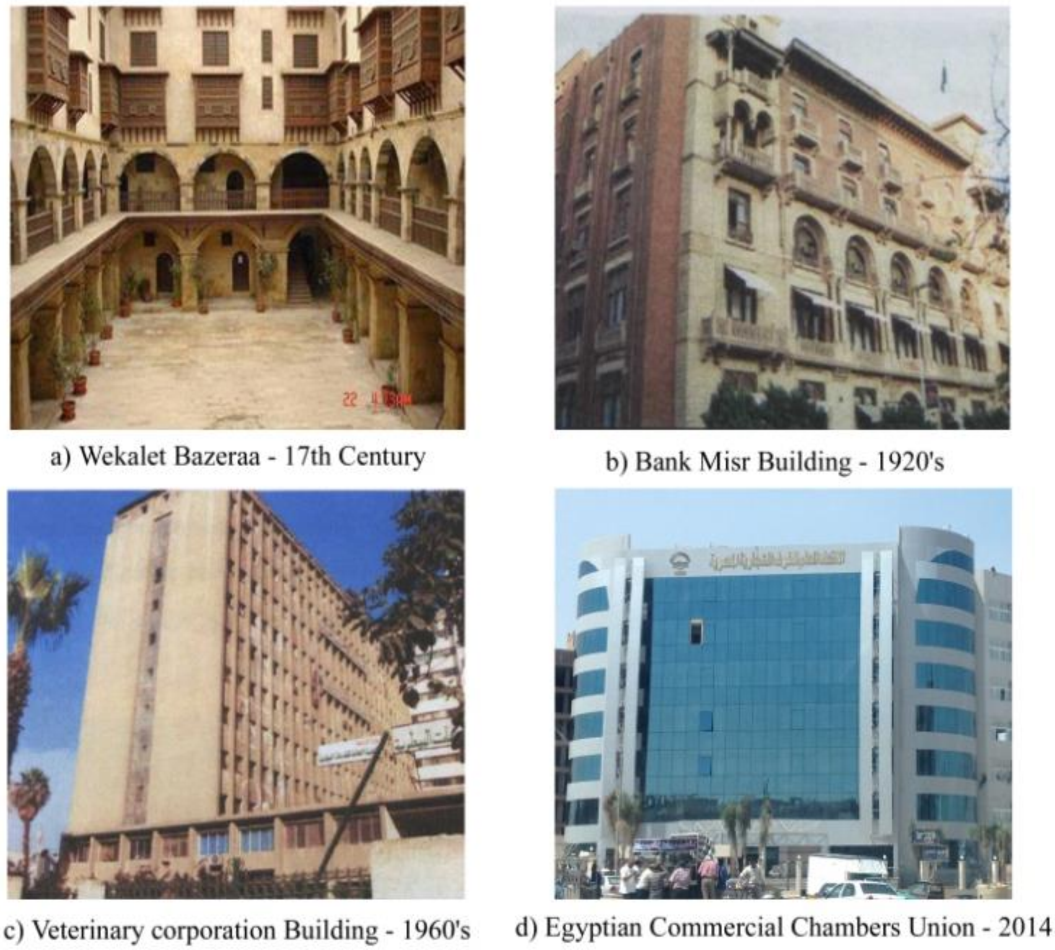


Figure 8 - 40: a) Wekalet Bazeraa (Hasan, 2012), b) Bank Misr, c) Veterinary Corporation building (Hamza, 2004), d) Egyptian Commercial Chambers Union (by researcher)

Building (a): Wekalet Bazeraa from the 17th century is a sample of commercial and administrative building in Old Cairo. The building reflects an awareness of the environmental, vernacular, and passive design strategies that are revealed in the internal court, and high thermal masses. In addition, the colonnades provide shading to the ground floor, and the external wooden shading devices including mashrabya for upper floors afford solar protection. Building (b): Bank Misr, built in the twenties, showing a typical classic building. The glazed windows appeared in the facade with WWR ranges from 20 to 40%, with massive construction, recessed openings, and external shading devices for the windows. Building (c): Veterinary Cooperation Administrative building from the sixties; the building is a typical modern office building with recessed module openings, shaded with external vertical lovers (Bries-soleil). Building (d): the Egyptian Commercial Chambers Union, located in the administrative district in New Cairo and still under construction. The building had a completely sealed glazed façade, giving no sign of any environmental conscious design except for the tinting solar control glazing as a protection against heavy solar radiation, and typically rely on the mechanical cooling. The previous buildings reveal how far office buildings in Egypt have become modernized and more depending on energy consumption to achieve the internal thermal and visual comfort.

During the last decades, the traditional knowledge of the environmental conscious design and construction is dimensioning in Egypt. Appropriate passive design strategies such as external shading, orientation, thermal mass, natural lighting, and ventilation are scaled down. In addition, the construction sector in Egypt is generally characterized by its poor environmental quality. These factors among others have accelerated the dependence on the environmental control equipment all over the country. Evidently, fans and air-conditioners sales rates are growing very rapidly; Between 1996 and 2006, the average annual sales rate of mechanical air-conditioning units reached nearly 54,000 units per year, while between 2006 and 2010, this rate has doubled 14 times to reach almost 766,000 units per year (Attia & Evrard, 2013). Such increase impacts the recent sudden peak increase in electricity consumption, particularly during the hot weathering days. Peak electricity consumption during summer started to be an annual regular problem for the energy sector in Egypt (Georgy & Soliman, 2007).

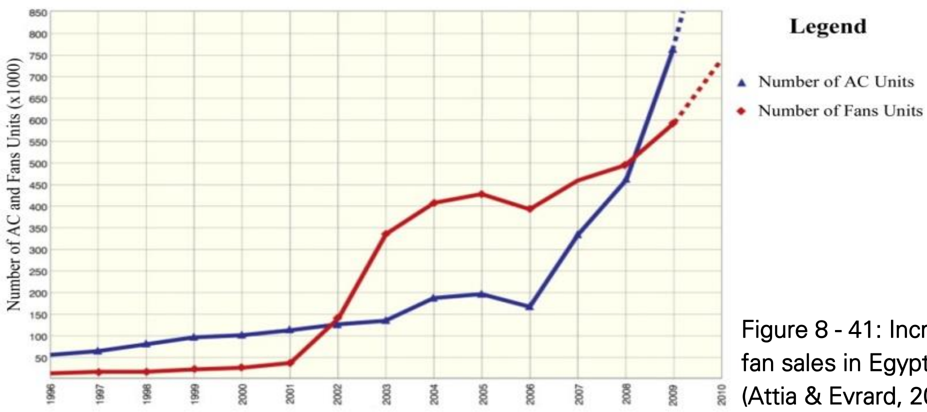


Figure 8 - 41: Increasing air-conditioner and fan sales in Egypt between 1996 and 2009 (Attia & Evrard, 2013)

The reliance on mechanical equipment contributes to the exponential increase of the electrical power demand in the building sector in Egypt, and ranks it as the most energy-consuming sector over the last ten years. Many surveys and research indicate that in Egypt lighting and cooling loads account for the biggest share of the end use of electricity in any building. Liu, et al., (2010) noted that sectorial patterns of commercial and administrative buildings in Egypt indicate that air conditioning along with lighting consumes more than two thirds of the consumed electrical energy; air-conditioning systems consume almost 34.8%, while electrical lighting consumes 33.6% of the total annual energy used (figure 8 – 42).

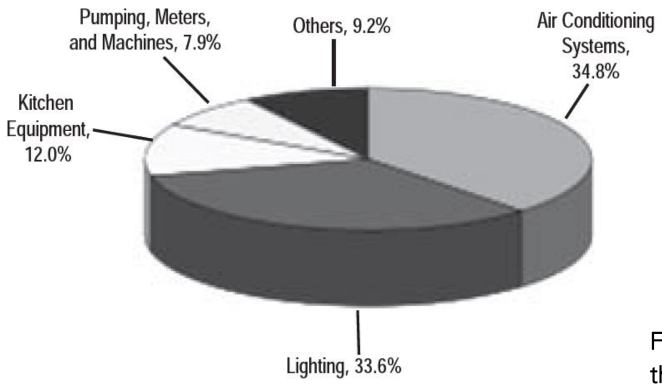


Figure 8 - 42: Electricity consumption patterns for the commercial sector in Egypt (Liu, et al., 2010)

In another study, Hanna (2011) found out that for non-residential buildings in Egypt (mainly offices and commercials), 36% of the energy used is consumed in lighting, 35% consumed in HVAC, and 29 % goes for other appliances and services. While Gouda (2010) study demonstrated that for office buildings in Cairo, 34% of the consumed energy is attributed for HVAC, 32 % for lighting, 22% for plugs and electrical appliances, and 3% for lifts and pumps. Hamza (2004) explained that it should be noted that energy consumption rates in office buildings vary according to the total built-up area, age of the building, the percentage of occupation, the working hours per days, type and age of the used equipment and systems, and the envelope configuration. These factors could explain and clarify the difference in consumption rates.

In the following points, from 8.4.1 to 8.4.7, six office buildings in Cairo's context will be studied; the presented data is based on the available literature and extended meetings with the building managers. The main objectives of the following study are directed towards exploring and gaining knowledge of the office building stock in Cairo's region in order to:

- Understand the common physical configuration of office buildings in Cairo, and especially the façade configuration, and their impact on the building's energy consumption.
- Investigate the monthly and annual rates of energy consumption in different examples of office buildings in Cairo's hot arid climate.
- Determing the average rate of the office space energy consumption per square meter in Cairo, this value will be used in the following modeling and simulation study.

8.4.1. World Trade Centre in Cairo Office Building:

- **Building Description:** Cairo's World Trade Centre in Cairo is a multi-use building, located in Cornish El-Nile Street along the banks of the River Nile. It was designed by SOM in 1982 and opened in 1989. The Building complex comprised from a commercial podium, two towers for commercial accommodation and a third tower that function as an office building. The office tower (figure 8 - 43) consists of one basement level used as a car parking area, ground level including the entrance of the building, mezzanine floor, and 18 typical floors that could be used as one unit or divided to four different office units. The total built area for all floors is 42720 m^2. The typical floor height is 3.75 m and the clear height is 2.75 m. Working time starts at 8:00 am till 18:00 pm every day, except for Fridays which is a holiday in Egypt (Hamza, 2004) and (Abdel-Gawad, 2011).

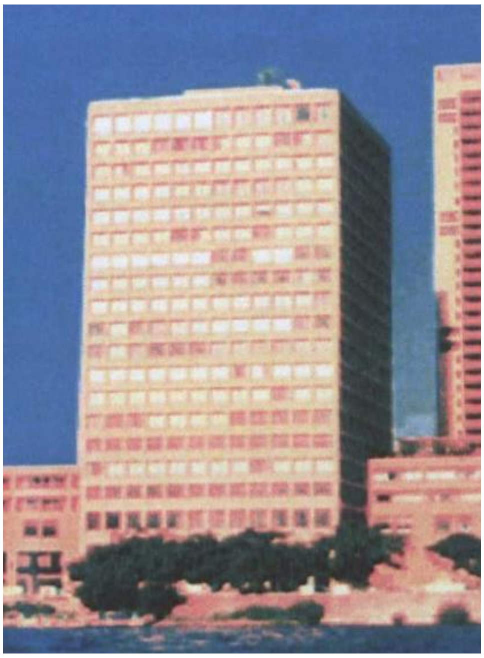


Figure 8 - 43: The World Trade Centre (WTC) Office Building in Cairo (Hamza, 2004)

- **Envelope Configuration:** The building's facades are composed of reinforced concrete coated with a layer of granulate as a finishing material without any insulating layer. The transparent component of the building consists of module operable sliding windows with dimension of 2.4 m width and 2.0 m height, forming an overall window-wall ratio range between 65 to 75%; each window consists of a single clear glass layer of 6mm thickness and an un-insulated aluminum framing system. The whole building is shaded internally, with no presence of any means of external shading systems except for 20 cm relief of the solid external wall. The roof of the building is insulated with foam as a typically used thermal insulation material (Abdel-Gawad, 2011).

- **Cooling and Lighting Facilities:** The building has a central cooling system; it consists of three cooling towers with capacity of 217 m^3 of water, two chillers each of 560 ton placed on the roof of the building, and one air handling unit for each typical floor. The system is optimized on using two cooling towers and keeping the third one as a reserve. The design temperature ranges from 24 °C to 26 °C. The system is switched on from 5:00 am to 18:00 pm. The building users' can neither control the operation of the fan coil nor the temperature level (Abdel-Gawad, 2011).

The building lighting system comprised a series of fluorescent lamp units; the dimensions of each unit is 120 cm x 60 cm with reflecting sheets to maximize the light distribution. The unit includes 4 fluorescent lamps, each of 40 watts in power and 120 cm in length. The units are distributed according to a module 2.8 m x 2.8 m in the office spaces with no relation to the working places. Lighting control system is operated manually according to the user's needs (Abdel-Gawad, 2011).

- **Energy Consumption:** The building depends on the electricity from the network to operate all systems in the building such as lighting, HVAC, computers and deferent appliances (Abdel-Gawad, 2011). The building total annual Energy consumption rate per square meter is approximately 396 KWh/m^2, with a monthly average consumption rate of 33.0 KWh/m^2, figure 8 - 44 shows the building's monthly energy consumption rate per square meter (Hamza, 2004).

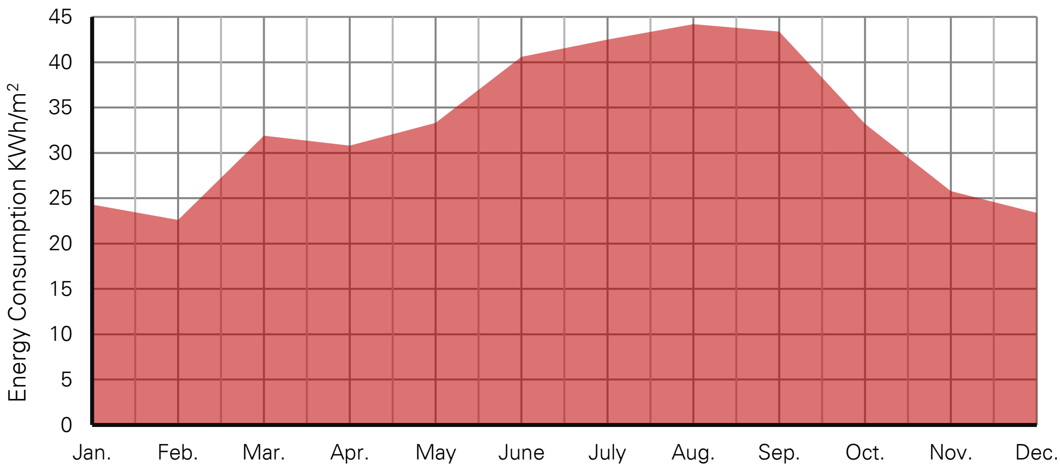


Figure 8 - 44: Monthly Energy consumption rate per meter square for the world trade centre office building in Cairo (Hamza, 2004)

8.4.2. The Nile Office Tower:

- **Building Description:** The Nile Tower is a private office building, located on the Nile Street in Giza (part of Great Cairo Region). The building was designed in 1978 and operated in 1982. It consists of one basement floor used as a car parking area, ground floor includes the entrance of the building and some parking areas as well, mezzanine level, and 23 typical floors each of an area of 1944 m^2. Each typical floor can be used as one unit or divided into six small office units. The total built-up area for all floors is 46600 m^2. The typical office floor height is 3.5 m, and the net clear height is 2.7 m. The working hours in the building start from 8:00 am to 18:00 pm except for Fridays and Saturdays (Abdel-Gawad, 2011).

Figure 8 - 45: The Nile Tower building in Cairo (Sabbour Consulting, 2015)

- **Envelope configuration:** The building is constructed from reinforced concrete skeleton and coated with aluminum cladding sheets that is separated from the concrete structure by a cavity of 10 cm between the two layers. The glazing system consists of module windows, each with dimension of 1.5 m in width and 1.9 m in height forming an overall window-wall ratio range between 60 to 70%. Each window has an un-insulated and non-operable aluminum framing and a single layer of reflecting glass with 10 mm in thickness and 97% reflection factor. The external envelope design has no means of external shading devices for solar protection, where the users of the building depend only on internal shading elements. The buildings' external walls have no insulating layer rather than the cavity between the structure and the cladding. The roof of the building is insulated by foam as a thermal insulation material (Abdel-Gawad, 2011).

- **Cooling and Lighting Facilities:** The building is cooled and ventilated by a central mechanical HVAC system that consists of eight cooling towers, eight chillers placed on the roof of the building, and a series of air handling units in every space. The design temperature ranges from 25 ºC with 60 % relative humidity in summer to 22 ºC with 40 % relative humidity in winter. The cooling system gives the users the chance to control the operation of each unit separately and to control the temperature level. The system is switched on from 6:00 am to 18:00 pm (Abdel-Gawad, 2011).

  The building relies completely on an artificial lighting system that consists of units of 2-fluorescent lamps with dimensions of 120 x 30 cm covered by a semi-transparent sheet; each fluorescent lamp is with 120 cm in length and 40 watts in power. The units are distributed according to a module of 2.25 m x 2.25 m without any relation to the distribution of the working places. The lighting units are controlled manually according to the users' needs (Abdel-Gawad, 2011).

- **Energy Consumption:** The building depends on the electricity from the national network to operate all the building systems such as lighting, HVAC and electricity for computers and different electrical appliances (Abdel-Gawad, 2011). The building's total annual Energy consumption rate per square meter is approximately 302 KWh/m², with an average monthly consumption of 25.1 KWh/m², figure 4 - 46 shows the monthly energy consumption rate per m² of the Nile Tower (Hamza, 2004).

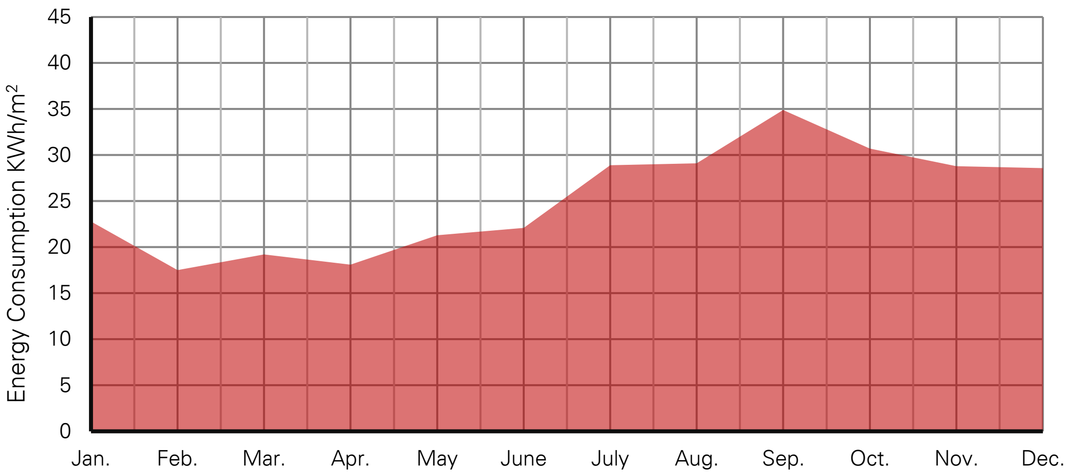


Figure 8 - 46: Monthly Energy consumption rate per m² for the Nile Tower (Hamza, 2004)

8.4.3. Abuel-Feda Office Tower:

- **Building Description:** The tower is an office building located in El-Zamalek Island along the banks of the River Nile in Cairo. The building was designed in 1980 and opened in 1987. It consists of one basement floor used as a car parking area, ground floor including the entrance of the building, mezzanine level and 14 typical floors each of an area of 995 m². Each typical floor can be used as one unit or divided to three smaller office units. The total built-up area of all floors is 17910 m². The typical floor height is 3.5 m. The working hours of the building starts from 8:00 am to 17:00 pm except for Fridays (Abdel-Gawad, 2011).

Figure 8 - 47: Abuel-Feda Office Tower, El-Zamalek, Cairo (Hussien, 2005)

- **Envelope configuration:** The building is from steel construction, coated with colored metal cladding from outside and with colored fiber materials from inside. The glazing system consists of module horizontal strips that fill the spaces between the external columns; every group consists of four sliding windows, each with dimension of 1.5 m width and 1.0 m height forming overall window-Wall ratio range between 30 to 35 %. The window consists of an operable un-insulated aluminum framing with double 6 mm clear glass layers separated by a gab of 1.5 cm filled with air. The external envelope design has no means of external shading devices; it only depends on internal shading elements behind every window. The building's external walls have an insulation layer between the external and internal cladding, while the roof is thermally insulated by foam layer (Abdel-Gawad, 2011).

- **Cooling and Lighting Facilities:** The building is cooled and ventilated by a central mechanical HVAC system which consists of two cooling towers, two chillers each of 450 ton placed on the roof of the building, and a series of fan coil units distributed under each window along the building parameter. The design temperature ranges from 20 °C to 25 °C. The users of the building had no control on the operation of the fan coil units or the supply air temperature. The HVAC system is switched on from 7:00 am to 19:00 pm (Abdel-Gawad, 2011).

  The building lighting system consists of a series of fluorescent lamp units; each unit consists of 6 lamps with dimension of 120 x 120 cm and is covered with semitransparent cover, each fluorescent lamp is 40 watt and 120 cm long. The units are distributed according to a module of 3 m x 3 m showing no relation to the distribution of the working places. The lighting system is controlled manually according to the needs of the users (Abdel-Gawad, 2011).

- **Energy Consumption:** The building depends on electricity from the national network to operate all the system in the building such as lighting, HVAC and electricity for computers and different electrical appliances. The buildings' total annual Energy consumption rate per m^2 is approximately 285 KWh/m^2, with an average consumption of 23.75 KWh/m^2 monthly, figure 8 - 48 shows the monthly energy consumption rate per m^2 of the building (Abdel-Gawad, 2011).

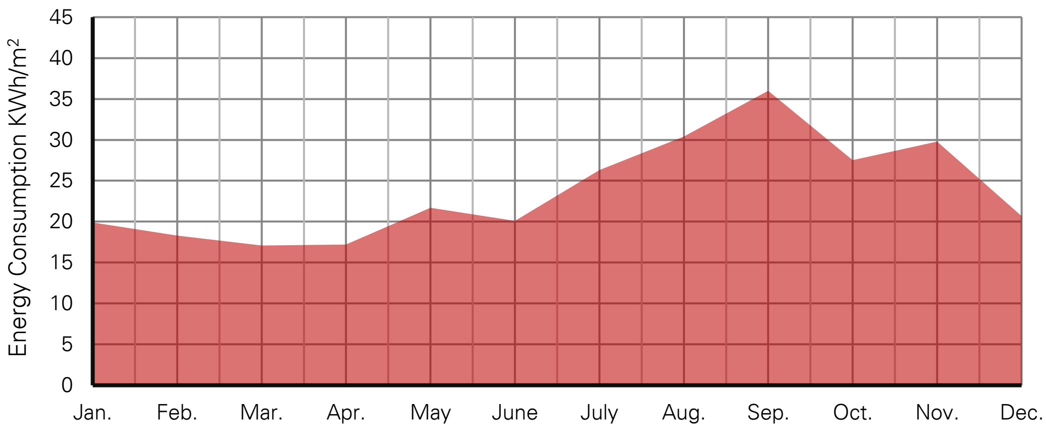


Figure 8 - 48: Monthly Energy consumption per m^2 in Abuel-Feda office Tower (Abdel-Gawad, 2011)

8.4.4. Ministry of Communication and Information Technology:

- **Building Description:** The ministry of communication and information technology (figure 8 - 49) is located in the smart village in Giza (part of the GCR) near Cairo - Alexandria toll station gates. The building compromises a typical modern and highly glazed office building. It was designed in 2001 by the Engineering Consultant Group (ECG) and operated in 2004. The building consists of a basement which is used as a car parking area, ground floor that includes the entrance, and two other floors. The building has an internal central foyer space covered with a pyramid skylight. The total built-up area of all floors is 12500 m^2 (El-Haggar, 2015).

Figure 8 - 49: Ministry of Communication and Information Technology, Smart Village (by researcher)

- **Envelope Configuration:** The building skeleton is made from reinforced concrete structure whereas the external wall is made from concrete hollow blocks 20 x 40 x 20 cm and covered with white granulate finishing. The glazing system is non-operable glazed curtain wall system which consists of an insulated aluminum framing with 2 panes of bluish tinted glass; each glass pane is 6 mm in thickness separated by an air gap of 15 mm with low-emissivity coating on layer number 3 from the outside. The overall light transmittance of the glazing is 36%, with total window-wall ratio ranges between 45 to 55%. The building has no means of external shading devices and depends on internal shading elements. The external wall has no insulation material. A thermal insulation material (foam) is used on the roof of the building (El-Haggar, 2015).

- **Cooling and Lighting Facilities:** the building is cooled through a central HVAC planet. The central HVAC planet supplies the building with chilled water, which is then distributed to two secondary loop chilled water pumps. The chilled water feeds twenty-one single zone air-handling coils, four of which are dedicated for providing fresh air to the indoor areas. The fan coil units are distributed in every space above the suspended ceiling. The design temperature ranges from 22 ºC to 25 ºC. The cooling system is operated centrally; the users of the building have no control on the internal temperature. The cooling system is switched on from 6:00 am to 20:00 pm (Gouda, 2010).

The building depends completely on an artificial lighting system that consists of uncovered fluorescent lamp units with optical reflecting sheets to maximize the light distribution; each unit is with dimension of 60 x 60 cm containing 4 fluorescent lamps each of 60 cm in length and 18 watts in power. The numbers of units are designed for every space to provide illuminance level of 500 lux per space. The lighting units don't have any relation to the distribution of the work places. A manual controlling system is controlling the lighting units, according to the users' needs (Gouda, 2010).

- **Energy Consumption:** The building depends on the electricity from the network to operate all the building systems such as lighting, HVAC and electricity for computers and different electrical appliances. The building total annual Energy consumption rate per m^2 is approximately 259.05 KWh/m^2, with an average consumption of 21.59 KWh/m^2 monthly, figure 8 - 50 shows the monthly energy consumption rate per m^2 of the building (Gouda, 2010).

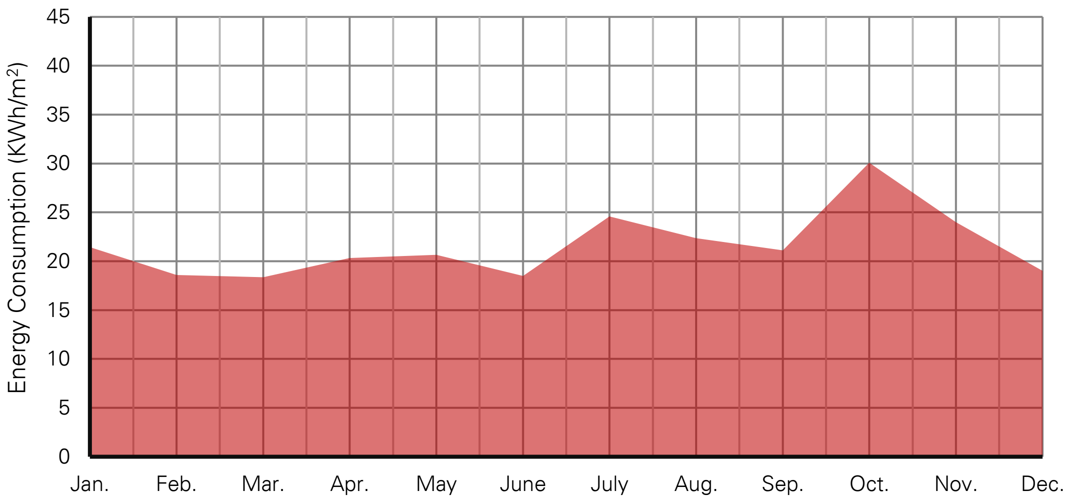


Figure 8 - 50: Monthly Energy consumption per m^2 in the Ministry of Communication and Information Technology Building (Gouda, 2010)

8.4.5. Enppi Headquarters:

- **Building Description:** Enppi Headquarters (figure 8 - 51) is the corporate office building of the Engineering for the Petroleum and Process Industries company. The building is located at the end of Abbas El-Akkad Street in Nasr City (A district in east Cairo). The building was designed in 1987 by Perkins & Will International and was operated in 1990. The building itself is very much a product that expresses the edge technology at that time. It consists of a ground floor that includes the entrance of the building and three typical floors connected through an internal court. The total built up area of all floors is 22000 m^2. The typical floor height is 3.6 m. The working time of the building starts at 7:30 am to 3:30 pm except for Fridays and Saturdays (Kahera, 1991).

Figure 8 - 51: Enppi Headquarters, Nasr City, Cairo (Enppi, 2015)

- **Envelope Configuration:** The building is constructed from a prefabricated (fair face) concrete structure. trough moulds of Glass Reinforced Plastic (GRP) with various dimensions and steel forms were introduced as an external finishing material. The skin of the building used a double glazed insulated curtain wall system. Two types of glazed panels were selected to give an aesthetic quality to the building and to provide solar protection; the first is mirrored grey tinted glass, and the second is dark blue tinted glass. Both types form a composition of vertical bands on the buildings' facades. The overall window-Wall ratio ranges between 65 to 75 %. The roof of the building is covered with foam as an insulating material, while the atrium is covered with a sky glazing pyramid cover. The building depends on internal shading elements and has no external shading devices rather than a 20cm recession on the southern facade (Kahera, 1991).

- **Cooling and Lighting Facilities:** The building is cooled and ventilated centrally through a mechanical HVAC system. The system consists of four water chillers, four cooling towers placed on the roof of the building, two air-handling units in each floor, and a series of fan coil in every space placed above the suspended ceiling. The design temperature ranges from 20 ºC to 24 ºC. The system is controlled through a building automation system (BAS). The building system is switched on from 6:00 am to 18:00 pm except for Fridays.

  The building relies completely on an artificial lighting, the lighting system consists of units of 2-fluorescent lamps with dimension of 120 x 30 cm covered by a semitransparent cover and are arranged in rows with 3.2m separation distance between each row. The lighting units are controlled manually according to the user’s needs (Kahera, 1991).

- **Energy Consumption:** The building depends on the electricity from the network to operate all its systems in the building such as lighting, HVAC and electricity for computers and different electrical appliances. The building total annual Energy consumption rate per m^2 is approximately 382.29

KWh/m², with an average consumption of 31.86 KWh/m² monthly, figure 8 – 52 shows the monthly energy consumption rate per m² of the building (Hamza, 2004).

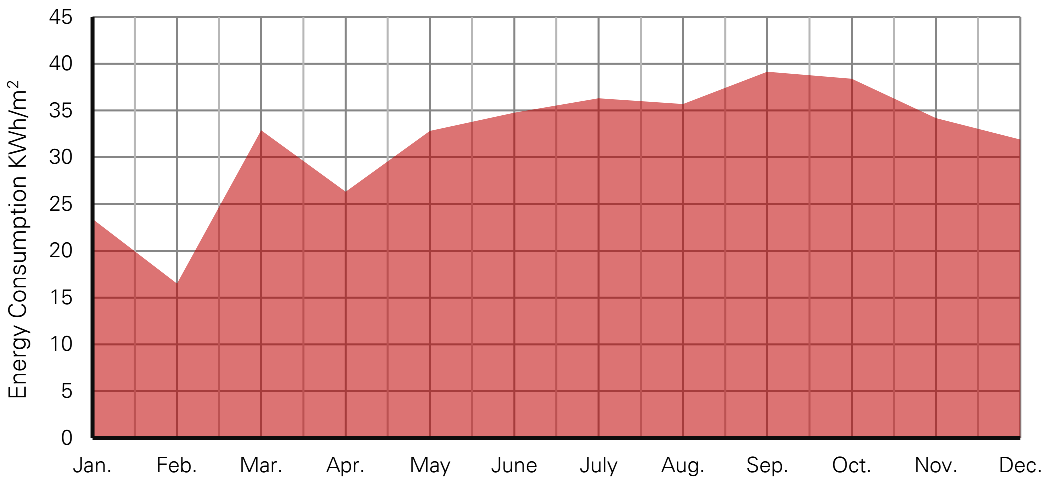


Figure 8 - 52: Monthly Energy consumption per m² in Enppi headquarters (Hamza, 2004)

8.4.6. Engineering Consultants Group (ECG) Building:

- **Building Description:** The Engineering Consultants Group (ECG) is one of the biggest engineering firms in the Middle East. Their Headquarter building (8 - 53) is located in smart village in Giza (part of the GCR) near the toll station gates of Cairo - Alexandria high way. It was designed in 2001 by the ECG and operated in 2004. It consists of one basement floor used as a car parking area, ground floor that includes the entrance of the building, and three typical office floors. The total built up area for all floors is 12000m². The floor height is 3.9 m and the clear height is 3.1 m. Working time of the building starts from 9:00 am to 17:00 pm except for Fridays and Saturdays (El-Haggar, 2015).

Figure 8 - 53: Engineering Consultants Group Building, Smart Village, Cairo-Alexandria Gates (El-Haggar, 2015)

- **Envelope Configuration:** The building skeleton is from reinforced concrete structure and the external wall is from concrete hollow blocks 20 x 40 x 20 cm covered with white granulate finishing. The glazing system is non-operable glazed curtain wall which consists from an insulated aluminum framing and low emissivity blue tinted glass with an overall 36 % light transmittance. The two layers of glass are with 6 mm in thickness and separated with an air gap of 15 mm in thickness, the low-e coating is placed on layer number 3 from the outside. The overall window-wall ratio ranges between 50 to 55%. The building has no external shading devices and depends on internal shading elements. A thermal insulation material (foam) is used on the roof of the building (El-Haggar, 2015).

- **Cooling and Lighting Facilities:** Cooling is provided from a central HVAC planet with capacity of 3.52 kWh/TR. The central HVAC planet provides the building with chilled water which is then distributed to a series of fan coil units that are placed in every space above the suspended ceiling. The design temperature ranges from 22 °C to 25 °C. The cooling system is operated manually; the users of every space can control the internal temperature. The system is switched on from 8:00 am to 18:00 pm.

  The building depends completely on an artificial lighting system which consists of fluorescent lamp units with optical reflecting sheets to maximize the light distribution; each unit is with dimension of 60 x 60 cm containing 4 fluorescent lamps each of 120cm in length and 18 watts in power. The number of units is designed for every space to provide illuminance level of 500 lux per space without any relation to the distribution of the work places. A manual controlling system is used to control the lighting units according to the user needs (El-Haggar, 2015).

- **Energy Consumption:** The building depends on the electricity from the network to operate all its systems in the building such as lighting, HVAC and electricity for computers and different electrical appliances. The building total annual Energy consumption rate per m^2 is approximately 269.7 KWh/m^2, with an average consumption of 22.47 KWh/m^2 monthly, figure 8 - 54 shows the monthly energy consumption rate per m^2 of the building (El-Haggar, 2015).

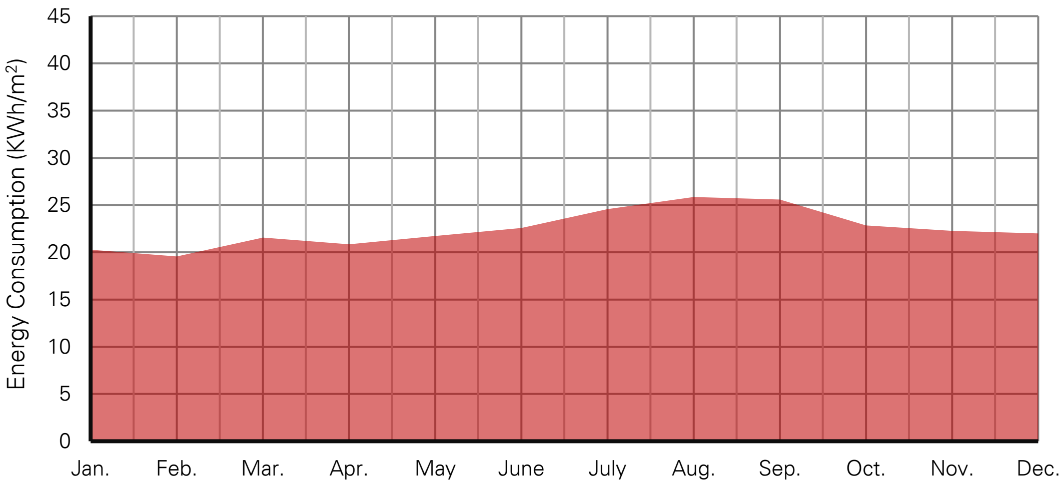


Figure 8 - 54: Monthly Energy consumption per m^2 in Engineering Consultants Group (ECG) building (El-Haggar, 2015)

8.4.7. Average Rates of Office-Building's Energy Consumption in Cairo:

According to the previous office buildings case studies in Cairo, figure 8 – 55 shows their maximum, minimum and average monthly total energy consumptions rates per square meter.

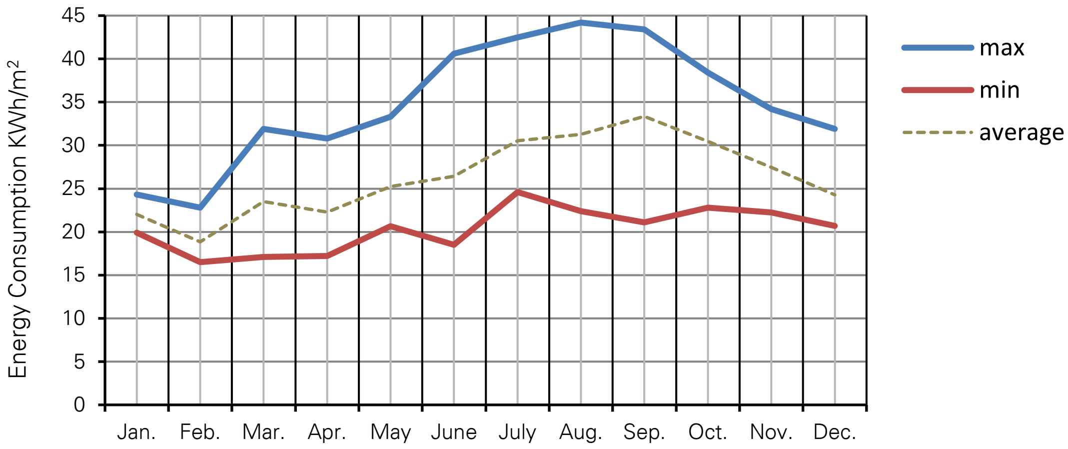


Figure 8 - 55: The monthly average energy consumption rates in Cairo's office buildings

The average annual energy consumption rate per square meter for the previously studied office-building cases is 315.67 KWh/m^2. Figure 8 – 56 shows their average annual energy-consumption rates in relation to their total annual energy consumption. The average annual energy consumption value will be used to represent the annual energy consumption rates of office buildings in Cairo, this value will be used for the upcoming modeling and simulation study. Some energy-conscious concepts assign values for the efficient total annual energy consumption per square meter; according to Abdel-Gawad (2011), the passivhaus concept set the value of 120 KWh/m^2.a.

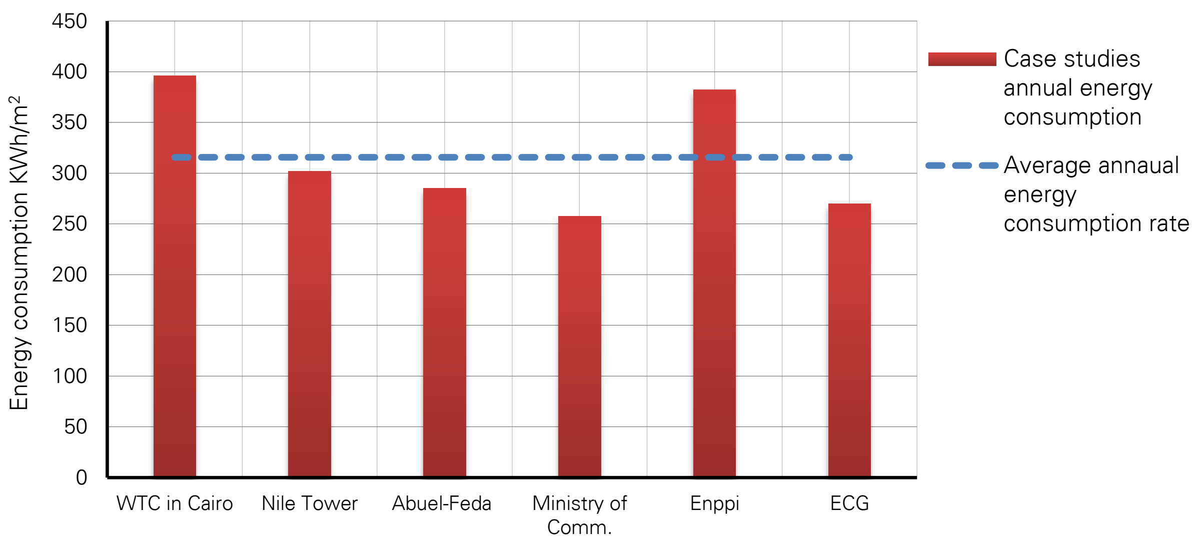


Figure 8 - 56: The annual energy consumption of the case studies in relation to their average annual energy consumption rate

Chapter IX

Surveying the Psychological Preference of Transparency

9. Surveying the Psychological Preference of Transparency:

After the theoretical demonstration of the crucial psychological value of transparency to the office space occupants in chapter IV. It is convenient on this part of the research to perform a quantitative survey in order to investigate these values in Cairo's office spaces. The main objectives of this part of the research are to investigate the following:

- The occupants' preference and their need for the values of transparency.
- The office occupants' behavior and their interaction with the current trend of highly transparent and glazed office building facades in Cairo, with regard to both their thermal and visual comfortable conditions.
- The office occupant's psychologically acceptable and preferred design criteria to transparency that contributes to their sense of satisfaction and well-being, and the reasons that govern their preference to those criteria.

The results of the survey will be used as a threshold value/margin for the input data profiles in the energetic modeling and simulation section of the research (Chapter X).

9.1. Survey Methodology and Sequence:

9.1.1. Questionnaire modelling:

The questionnaire form gives first an introduction to the research motive and its main topic. Then, the survey questions are introduced in 4 parts, the first part is general demographic questions, while each of the other 3 parts (from Part II to Part IV) investigates one of the survey objectives as follows:

- Part I: General Demographic Questions: This part of the survey is an introductory general (warming-up) demographic questions. It asks the participants five questions (from Q1 to Q5) about their age, gender, place of work, profession and working hours.
- Part II: Importance of Transparency: Part II is the first in-depth research questions related to the specific objectives of the survey. It consists of five questions (from Q6 to Q10) that investigate the importance and the need for transparency in Cairo's office environments. In addition, it inquires the principal functions of the glazed area (window) according to the office occupant's point of view and their preference to windows proximity.
- Part III: Interaction with Transparency: This part surveys the office-building occupant's psychological interaction with the transparent glazed component (window) in their office spaces, and their response to restore the required thermal and visual comfortable conditions. It consists of 10 questions (from Q11 to Q20) that inquires the office space user's degree of satisfaction

and behavior towards their internal thermal environment, operating HVAC (either for cooling or heating), natural ventilation, shading device utilization, view, and the general lighting conditions (either daylighting or artificial lighting). The results of this part will give an indication of the occupant's perceived values of transparency with regard to the current trend of highly glazed office buildings in Cairo.

- **Part VI: Preferred Design Criteria to Transparency:** This part of the questionnaire elucidates the design criteria of the transparent glazed component in Cairo's office spaces that provide the occupants with their required level of satisfaction and psychological well-being. The subjects were asked 11 questions (from Q21 to Q31) about their psychologically preferred glazed area (window to wall ratio), glazed shape, light transmittance (glazed tinting level), glazed position, external visual content, external reflection ratio, level of access/exposure, perception to external glazed ratio, shading devices, view importance, and the view to energy efficiency balancing ratio.

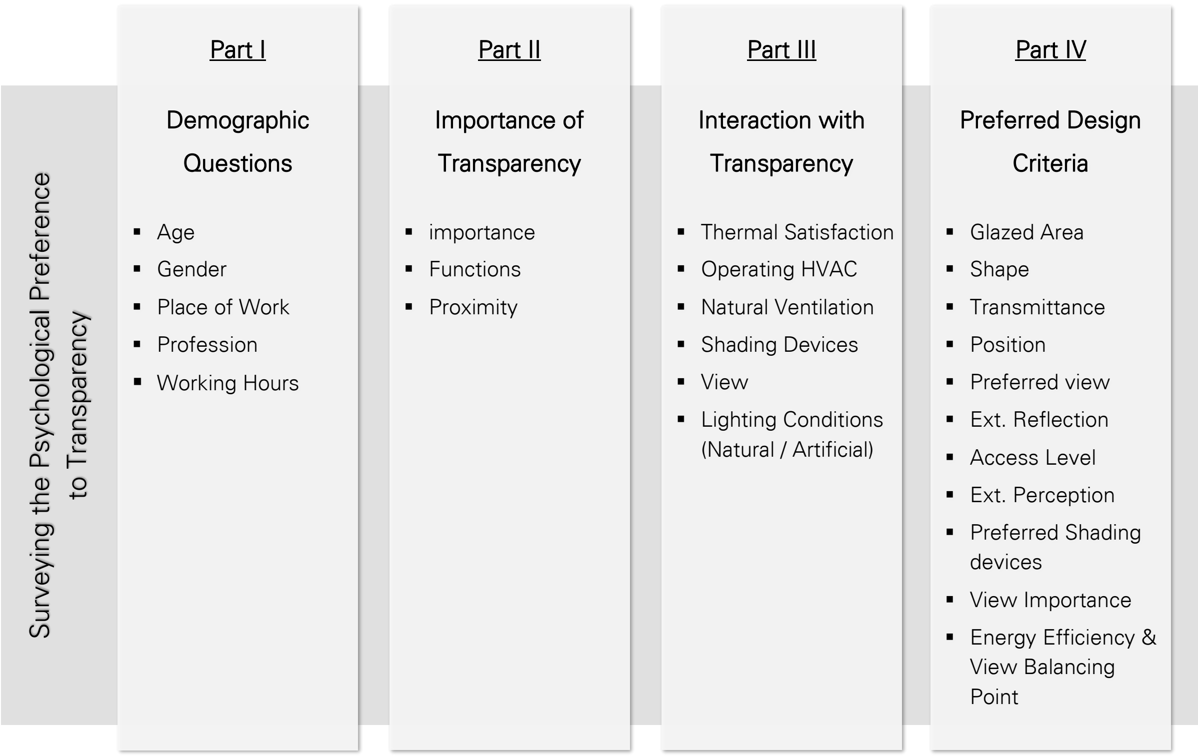


Figure 9 - 1: Questionnaire design concept

9.1.2. Population and Sampling:

The research targets white collar office workers employed in Greater Cairo region (CGR). According to the Central Agency for Public Mobilization and Statistics, Arab Republic of Egypt, in 2013, the total working labor of Cairo has reached 2,377,200 people, with 1,906,100 males and 471,100 females, all are employed in different fields and specialties (CAPMAS, 2013). Referred to Serkan & Bougie (2013) table to determine the minimum returned sample size for a given population size, which is accounting more than one million, and with a significance level of 5% which is equivalent to 95% confidence level, the minimum accepted sample size was calculated to be 384 subjects. The research targets this figure as a threshold value to ensure the sample representability and the validity of the results. Accordingly, a total sample size of 402 subjects were conducted.

9.1.3. Gathering Survey Data:

Several data gathering techniques could be used, however, in the main survey's data were collected from the required research sample size through two means:

9.1.3.1. Self-administrated Questionnaire:

The questionnaire form was color-printed on high quality printing materials in order to better clarify the included pictures, and are personally administered by the researcher in six different office places in Cairo region (GCR), are: Misr International University (MIU), ENPPI headquarters, World Trade Center in Cairo, Engineering Consultants Group (ECG), the Egyptian Natural Gas Holding Company (EGAS), and the National Bank of Egypt (El-Ahly Bank). This type of data collection gives the researcher the possibility to collect completed responses within one or two visits to every office place, and it also gives the chance to clarify any doubts that the respondents had upon any question on the spot. A total number of 350 copies were distributed, and 219 subjects responded to it.

9.1.3.2. E-Link Questionnaire:

A questionnaire E-form is constructed online in Google forms survey provider tool and stored on Google drive. The questionnaire E-form was published and distributed through the following Google form E-link https://goo.gl/forms/aQv9r1SyO6a0vhE32 among the researcher's emailing list and several social networks. The E-link data gathering method gives the possibility to the widespread of the survey at a relatively short time, where respondents could receive and perform the questionnaire at any time. It was taken into consideration that the subjects received the E-link are office employees in the area of Cairo region. Nearly 600 subjects received the questionnaire E-link, and only 183 responded to it.

9.1.4. Methods of Analysis:

The research used the Statistical Package the Social Science (SPSS) software version 16.0.1 to conduct the surveyed data analysis. The results of the surveyed questions are demonstrated through one-way analysis for categorical/nominal variables in frequency tables, column charts, histogram bars and pie charts. Each frequency table is constructed by arranging collected data values in ascending order of magnitude with their corresponding frequencies, in addition to the percentage distribution of all data values to the total valid sample size. Further validated results are presented in bar/columns charts to summarize categorical variables and displaying either frequency or percentage distribution of the variable's categories.

9.1.5. Survey Procedures:

9.1.5.1. Pilot Study:

Clark-Carter (2005, p. 34) defined the pilot study or the feasibility study as "a trial run of the main survey, that should be conducted on a smaller sample than that to be used in the final version of the survey". He added that it is particularly important to conduct a pilot study first in order to test both the basic aspects of the survey and its methodology, so it can work appropriately in the main survey. Therefore, pilot studies give wide overview of whether the participants understand the given survey, and whether the measuring criteria face validity or not. In addition, it also gives an idea of how long the survey takes from every participant, so they could be given an indication of how long it will require. Wimmer & Dominick (2011) added that the pilot study could also allow the researcher to try different data gathering approaches and to observe different responses from several trial perspectives. Pilot study should be conducted on a limited scale of participants from the survey's target population. General guidelines recommend using from 5% to 10% of the sample required for a full study. However, Hertzog (2008) argued that the sufficient pilot study sample size can range from 10 to 40 participants. Accordingly, a sample size of 26 subjects are performed for the research pilot study.

The research pilot study was conducted in 11 days, from the 15th of August till the 26th of August 2015, through an extended meeting (self-administration) with 21 subjects and 5 subjects completed the Google form E-link, all are office employees in Cairo region (CGR). It was intended to perform the survey in the summertime with high temperature and solar radiation ranges for the proper investigation of the survey variables. According to The Weather Channel (2015), the prevailing weathering conditions in Cairo during the survey period was generally hot-summery; the maximum temperatures (at day time) ranges from 42 to 34 °C and the minimum temperatures (at night) ranges from 29 to 24 °C, the maximum relative humidity (at night) ranges from 80 to 63% and the minimum relative humidity (at day time) ranges from 53 to 32%, while airspeed ranges from 8 to 23 km/h.

9.1.5.2. Main Survey:

The pilot study is followed by an extensive main survey. The general structure of the main survey is basically the same as the questionnaire pilot study but with some required improvements that are based on the pilot study findings (will be discussed in the following point). The main survey was performed in 24 days, from 31st of August till the 23rd of September 2015. 350 printed colored forms of the questionnaire were manually distributed by the researcher (self-administrated), and nearly 600 on-line Google form E-link were sent to office employees in Greater Cairo Region (CGR), a total number of 402 complete questionnaire forms was received, it was taken into consideration that the previous number did not include the pilot study sample.

For the same reason as the pilot study, it was also intended to finish the main questionnaire in hot summery days. According to The Weather Channel (2015), during the main questionnaire surveying period, the prevailing maximum temperatures in Greater Cairo Region (CGR) (at day time) ranges from 39 to 33 °C, and the minimum temperatures (at night) ranges from 27 to 21 °C, the maximum relative humidity values (at night) ranges from 75 to 62% and the minimum relative humidity (at day time) ranges from 49 to 29%, while the air velocity ranges from 10 to 23 km/h.

9.2. Survey Findings:

9.2.1. Pilot Study Findings:

The research pilot study is used as an exploratory study to refine and polish the questionnaire form and to examines the survey procedure. The outcome of the pilot study is used as input for the extensive main survey (which will be described in the later point). The main findings of the pilot study could be summarized in the following points:

- Open-ended questions are not preferred to most of the subjects; they recommended to minimize it as possible, since it takes from them more time to answer, especially with the large number of questions in the questionnaire form. Accordingly, they were replaced by closed multiple choice question forms derived from the nature of the question with the related literature and the answers of the participants.
- Relevant questions were grouped and reintroduced in one main question with two or more subtitled questions in order to:
  - Give the participants the chance to better understand and focus their responses on the main theme of the question.
  - Better analyzing and driving precise conclusion for the same topic.
  - reduce the total number of the survey main questions to be psychologically convenient to the participants, as most of them complained from the large number of questions.
- An introductory explanatory phrase was added to question number 31, since most of the participants asked about the relation that govern the energy efficient thermal solutions with the external view aspects.
- Both data gathering techniques (self-administrated & google form E-link) shows reliability in utilization, and could be depended upon in the main survey.

- In average, most of the participants finished the survey within nearly 15 minutes. This duration is given to the subjects on the introductory part on the main survey.

- The results of the pilot survey analysis came encouraging to the main objectives of the survey, it could be briefly summed up in the following points:

  - Participants show positive preference to windows and its proximity to their working places. 92.3% of them preferred to have windows in their working space, and 69.2% preferred to sit near to the windows zone, mainly seeking for daylighting and view to the outside.

  - The vast majority of the subjects with 96.2% shows dissatisfaction towards their internal thermal environment in case they are deprived of turning on A/C system, they reveal high reliability on mechanical air condition for cooling in summertime, where 84.6% turn it on more than 6 hours per day and for almost 8 months in a year. In addition, they show a poor usage of natural ventilation. Regarding shading devices, 84% of the subjects had internal shading devices in their office space, 54.8% of them close it more than 4 hours per day, mostly to avoid glare and solar heat gain, this deprives 75.2% of them of the desired visual contact to the outside. The dependence on daylighting is convenient, where 53.9% of the subject uses daylighting more than 4 hours per day, however, 65.4% always turn on their artificial lighting, mainly, due to the insufficiency of daylight illuminance level.

  - The results of the psychologically preferred design criteria of windows reveal a variety of responses. However, the values give a directional preference to some specific design criteria. 73.1% of the subjects preferred their window to wall ratio to be more than 60% in order to provide them with daylighting and view. The same previous ratio also preferred the shape of their office space window to be wide, and 80.7% preferred its position to be centered on the wall. For the glazed tinting level, 76.9% of the subjects liked it to be lower than 20%, i.e. light transmittance is more than 80%. The most preferred visual content to the subjects was the green view with 88.5%, followed by the river Nile view with 7.7%. The preference to the external reflection shows a split in results; 38.5% of the subjects prefer their windows to have a kind of external reflection, and the same ratio did not prefer. Concerning the preference to the glazed office building perception, 76.9% of the subjects preferred the external glazed area of their office building to be more than 60% glazing for the beauty of the glazed material and its modern expressionism. Regarding the importance of the visual contact with the outside, 61.5% of the subject see it important, and 30.8% responded with very important. The psychologically accepted shading devices are the horizontal overhang, perforated shading (mashrabiya), horizontal louvers, transparent roller blinds, horizontal fins and vertical fins. And for the desired balance between view and energy efficient thermal concepts, the results came balanced with a split around 50% ratio.

9.2.2. Main Survey Findings:

In this part of the research, the findings of the main survey will be demonstrated briefly. For each section of the main survey, the objective of the section, a brief description of the included questions, the statistical analysis, and a brief conclusion will be presented in the following points:

9.2.2.1. Part I: General Demographic Questions:

This is the first part of the survey. It consists of 5 warming- up questions (from Q1 to Q5), the questions are generally demographic. Participants were asked respectively about their age, gender, place of work or company, profession, and their working hours (when it starts, when it ends, breaking time/duration and their actual working hours).

The subjects covered all of the selection age groups. The highest percentage lies in the 30 to 39 age group with valid 41.3 percentage and frequency of 166 subjects, followed by the 20 to 29 age group with 34.1 valid percent. While the least age percentage lies in the over 60 age group with valid 1.2 percentage and frequency of 5 subjects (figure 9 - 2 & table 9 - 1).

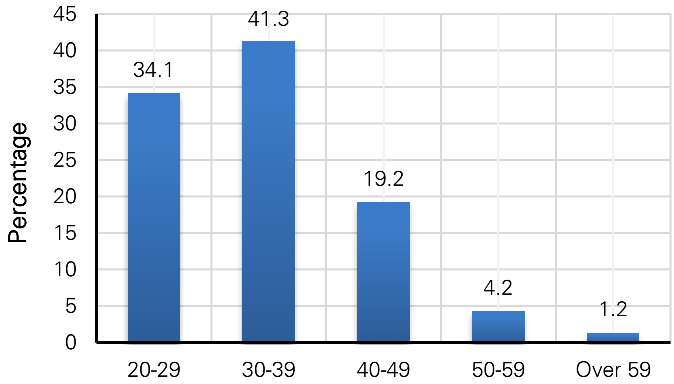


Figure 9 - 2: Age groups of the survey sample

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	20-29	137	34.1	34.1	34.1
	30-39	166	41.3	41.3	75.4
	40-49	77	19.2	19.2	94.5
	50-59	17	4.2	4.2	98.8
	Over 59	5	1.2	1.2	100.0
	Total	402	100.0	100.0	

Table 9 - 1: Age groups of the survey sample

The genders of the survey sample size almost split in equal ratios. Males are with a frequency of 209 subjects representing 52.8 valid percent, while female subject's frequency are 186 representing 46.5 valid percent (figure 9 - 3 & table 9 -2).

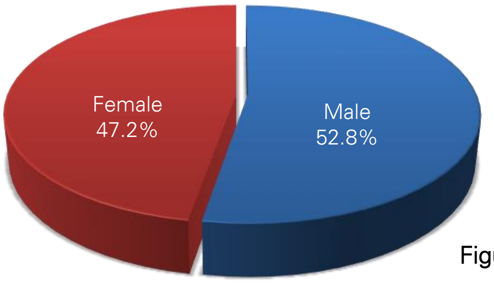


Figure 9 - 3: Survey sample gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	209	52.0	52.8	52.8
	Female	187	46.5	47.2	100.0
	Total	396	98.5	100.0	
Missing system		6	1.5		
Total		402	100.0		

Table 9 - 2: Survey sample gender frequency table

The subject's place of work and profession questions (Q3 & Q4) are typically open-ended questions. The answers show a variety of deferent working places and specialties. Regarding the working hours question; for the vast majority, their working hours starts between 7:00 am and 9:00 am, this accounts for 376 subjects representing 94.9 valid percent. While the working hours ends for the majority from 3:00 pm to 6:00 pm, for 385 subjects representing 97.3 valid percent (tables 9 - 3 & 9 - 4).

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	7:00:00 AM	3	.7	.8	.8
	7:30:00 AM	65	16.2	16.4	17.2
	8:00:00 AM	89	22.1	22.5	39.6
	8:30:00 AM	146	36.3	36.9	76.5
	8:45:00 AM	2	.5	.5	77.0
	9:00:00 AM	71	17.7	17.9	94.9
	9:30:00 AM	2	.5	.5	95.5
	10:00:00 AM	15	3.7	3.8	99.2
	12:00:00 PM	3	.7	.8	100.0
	Total	396	98.5	100.0	
Missing system		6	1.5		
Total		402	100.0		

Table 9 - 3: Start of working hours

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	2:00:00 PM	4	1.0	1.0	1.0
	3:00:00 PM	24	6.0	6.1	7.1
	3:15:00 PM	2	.5	.5	7.6
	3:30:00 PM	44	10.9	11.1	18.7
	4:00:00 PM	50	12.4	12.6	31.3
	4:15:00 PM	3	.7	.8	32.1
	4:30:00 PM	148	36.8	37.4	69.4
	5:00:00 PM	67	16.7	16.9	86.4
	5:15:00 PM	1	.2	.3	86.6
	5:30:00 PM	9	2.2	2.3	88.9
	6:00:00 PM	37	9.2	9.3	98.2
	6:30:00 PM	1	.2	.3	98.5
	7:00:00 PM	2	.5	.5	99.0
	8:00:00 PM	1	.2	.3	99.2
	9:00:00 PM	1	.2	.3	99.5
	3:00:00 AM	2	.5	.5	100.0
	Total	396	98.5	100.0	
Missing system		6	1.5		
Total		402	100.0		

Table 9 - 4: End of working hours

Only 4 subjects (out of 402) responded to the question of break time, indicating that in Egypt, the scheduled time for a break during the working day is not valid. The actual working hours for the majority is between 7 and 9 hours for 368 subjects representing 93% valid percent, with a mean value of 8.14h, median 8h, and mode of 8h (table 9-5). Those tips will be used as an input data for the working timetable profile in the energetic modeling and simulation section of the research.

		Frequency	Percent	Valid Percent	Cumulative Percent		
Valid	4.00	1	.2	.3	.3		
	5.00	1	.2	.3	.5		
	5.50	3	.7	.8	1.3		
	6.00	4	1.0	1.0	2.3		
	6.50	6	1.5	1.5	3.8	Mean	8.14
	7.00	27	6.7	6.8	10.6	Median	8.00
	7.25	3	.7	.8	11.4	Mode	8.00

		Frequency	Percent	Valid Percent	Cumulative Percent	
	7.50	20	5.0	5.1	16.4	Std. Dev. 0.91
	8.00	220	54.7	55.6	72.0	
	8.50	12	3.0	3.0	75.0	
	9.00	86	21.4	21.7	96.7	
	9.25	1	.2	.3	97.0	
	9.50	2	.5	.5	97.5	
	10.00	7	1.7	1.8	99.2	
	11.00	1	.2	.3	99.5	
	15.00	2	.5	.5	100.0	
	Total	396	98.5	100.0		
Missing	System	6	1.5			
Total		402	100.0			

Table 9 - 5: Actual working hours

9.2.2.2. Part II: Importance of Transparency:

This part of the survey investigates from Q6 to Q10 the importance and the need for transparency to the office space occupants in Cairo. Participants were asked about the importance of their working space glazed component (window), its principal functions, and their preference to its proximity.

- Windows Importance:

To investigate the glazed component (windows) preference to the office space occupants, they were asked a simple yes/no question about the importance of having a glazed area (window) in their working place. 372 subjects representing 92.5 valid percent answer positively to the importance of windows and its preference in their workplace, 29 subjects answer negatively with not important, representing 7.2 valid percent and only one participant answer not sure (figure 9 - 4 & table 9 - 6).

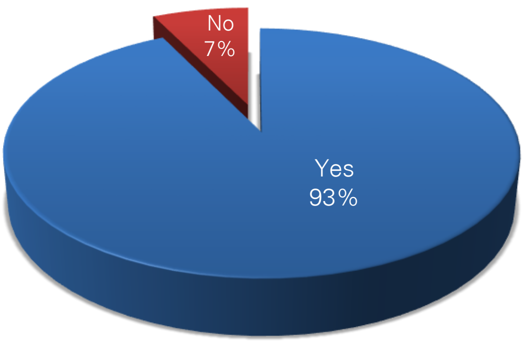


Figure 9 - 4: Importance of the glazed area (window) to the office users in Cairo (yes = important, no = not important)

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	372	92.5	92.5	92.5
	No	29	7.2	7.2	99.8
	Not sure	1	.2	.2	100.0
	Total	402	100.0	100.0	

Table 9 - 6: Importance of the glazed area (window) to the office users in Cairo

The highly positive preference to the glazed component (window) in Cairo's office spaces indicates its importance to the occupants. These results confirm the previous research work findings of Soliman (2000), Leather, et al. (1998), Nagy, et al. (1995), and Kheria (2004).

- Window Functions:

The principal functions of the glazed component (window) to the office space occupants in Cairo were investigated in two questions. Based on windows functions literature; the first question acquires from the participants to specify the main function of the glazed component (window) in their office space from its given main functions (view, daylighting and natural ventilation). Secondly, in order to Give more evidence and validation for the previous question, they were asked in a multiple response question to rank the previous functions according to their preference.

Daylighting was found to be the most preferred function of the window to Cairo's office occupants with 46 valid percent and frequency of 185 subjects, view to the outside came second with 35.1 valid percent and frequency of 141 subjects, and natural ventilation came third with 16.2 valid percent and frequency of 65 subjects (figure 9 - 5 & table 9 - 7).

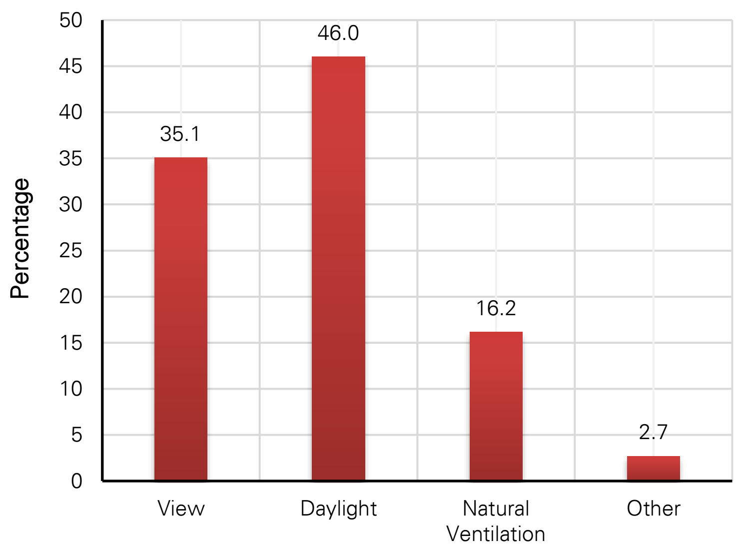


Figure 9 - 5: The glazed component (window) functions in Cairo's office spaces

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	View	141	35.1	35.1	35.1
	Daylight	185	46.0	46.0	81.1
	Natural Ventilation	65	16.2	16.2	97.3
	Other	11	2.7	2.7	100.0
	Total	402	100.0	100.0	

Table 9 - 7: The glazed component (window) functions in Cairo's office spaces

For ranking the previous function of the glazed component, also daylighting got its highest frequency in the first rank with 193 responses and 48.4 valid percent. For the second rank, view got the majority with a frequency of 163 responses and 40.5 valid percent. While natural ventilation had its major frequency in the third rank with 248 responses and 61.8 valid percent. (figure 9 - 6 & table 9 - 8).

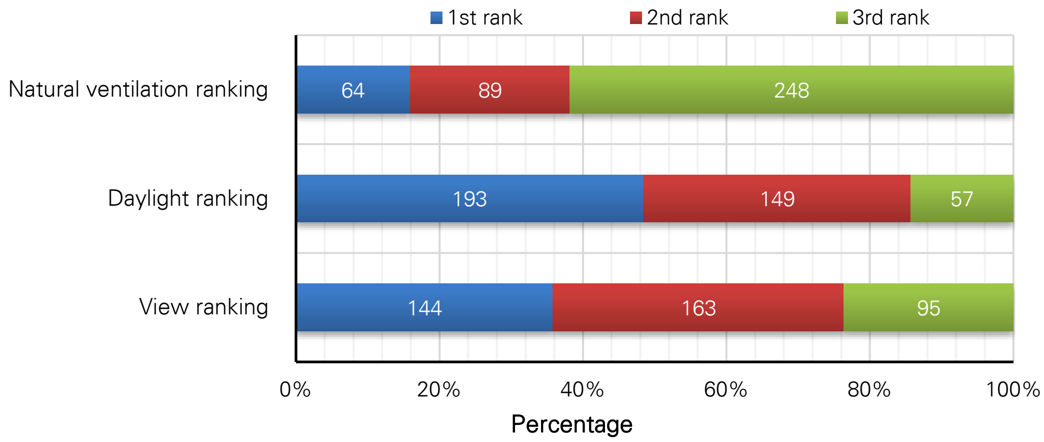


Figure 9 - 6: The glazed component (window) functions ranking

	Rank	1st	2nd	3rd	Total
View ranking	Frequency	144	163	95	402
	Valid Percent	35.8	40.5	23.6	100.0
Daylight ranking	Frequency	193	149	57	399
	Valid Percent	48.4	37.3	14.3	100.0
Natural ventilation ranking	Frequency	64	89	248	401
	Valid Percent	16.0	22.2	61.8	100.0

Table 9 - 8: The glazed component (window) functions ranking table

From the previous results, it is evident that daylighting and external view are the principal and the most preferred functions of the office space windows in Cairo, the difference in their preference is not so wide (only 10.9 valid percent). While natural ventilation came least with relatively poor preference ratio;

this could be attributed to the increasing dependence on mechanical air conditioning from the office space users to maintain their thermal comfort conditions and ignoring the main role of passive natural ventilation. In the second question, the results demonstrate that there is a rapprochement in the results, daylighting and view also got their highest responses in the first and the second rank respectively, and natural ventilation got the highest responses in the third rank. Those results accentuate and validate the same results of the previous question.

The previous findings came consonant with the findings of Hegazy (2013) in Cairo, where daylighting is the principal function of the windows. However, the results of Kheria (2004), Farley & Veitch (2001), and Hellinga (2013) shows that provision of view to the outside is the most preferred function, followed by daylighting and natural ventilation.

- Windows Proximity:

To investigate the preference to windows proximity in Cairo's office spaces, a typical office space plan picture (figure 9 - 7) is given to the participants. The plan is comprised of 3 sitting zones; zone (1), near to the window, zone (2), an intermediate zone, and Zone (3), far zone from the window and near to the door. The participants were asked to choose the most preferred zone to sit and work on, and then to choose the reason that justifies their choices through multiple response question in accordance with the window functions (daylighting, view and natural ventilation). In a second question, they were asked to specify to whom places near to the window or with pleasant views are dedicated to.

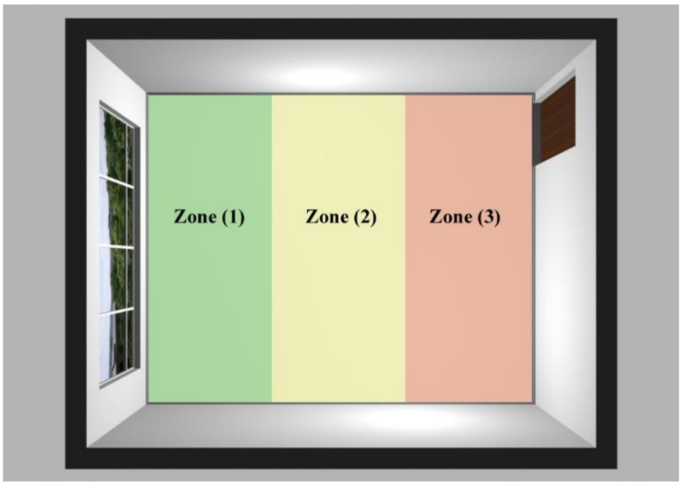


Figure 9 - 7: Typical office space with the predefined three sitting zones

The results show that Zone (1), which is nearer to the glazed area (window) is the most preferred sitting zone to the office space occupants, the vast majority of the participants choose it with a frequency of 324 subjects representing 80.6 valid percent. Zone (2) came second with a frequency of 55 subjects and 13.7 valid percent. While zone (3) came last with only a frequency of 21 subjects and 5.2 valid percent (table 9 - 9 & figure 9 - 8).

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Zone1	324	80.6	80.8	80.8
	Zone2	55	13.7	13.7	94.5
	Zone3	21	5.2	5.2	99.8
	Other	1	.2	.2	100.0
	Total	401	99.8	100.0	
Missing system		1	.2		
Total		402	100.0		

Table 9 - 9: Preferred sitting zone in a typical office space in Cairo

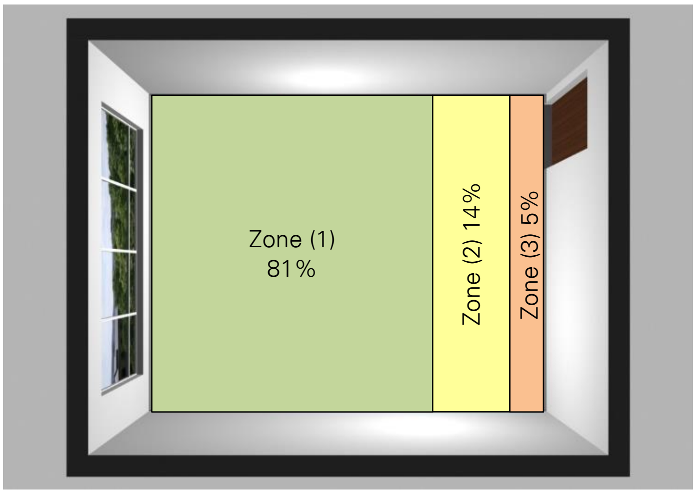


Figure 9 - 8: Preferred sitting zone in a typical office space in Cairo

The rationale for the preference of the office occupants to windows proximity came compatible with the preferred functions of the office windows; occupants prefer windows proximity mainly for daylighting with 44.9 valid percent, secondly for the provision of external view with 36.7 valid percent, and last for the provision of natural ventilation with 15.2 valid percent. Some other answers were not relevant to windows functions represented 3.3 valid percent such as better for furnishing, away from distraction caused by the window, and away from glare (figure 9 - 9 & table 9 - 10).

		Responses		Percent of Cases
		N	Percent	
Multiple response	Better in view	225	36.7%	56.0%
	Better in daylight	275	44.9%	68.4%
	Better in natural ventilation	93	15.2%	23.1%
	Other	20	3.3%	5.0%
Total		613	100.0%	152.5%

Table 9 - 10: Rationale for windows proximity preference in Cairo’s office spaces

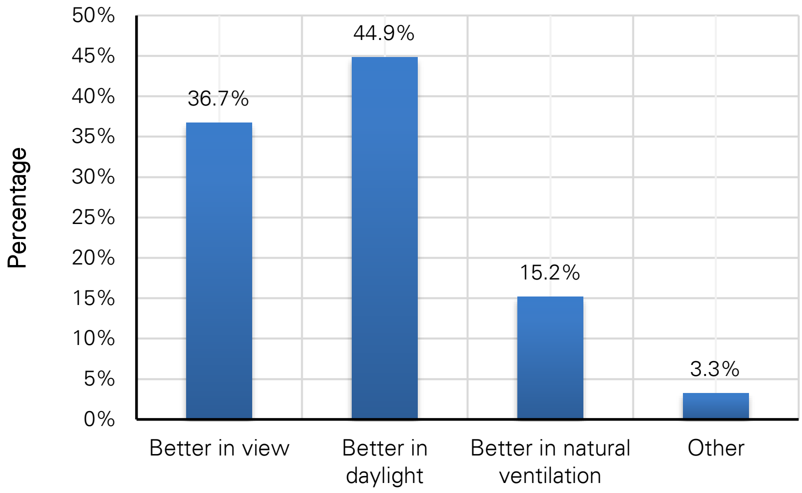


Figure 9 - 9: Rational for windows proximity preference in Cairo's office spaces

The placement criteria of the employees in accordance to windows proximity in Cairo's office places show a split in responses. Either it is random, i.e. no criteria in 46.5 valid percent of the cases and frequency of 185 responses, or it is awarded to high-ranked employees (managers and seniors) in 52.3 valid percent of the cases and frequency of 208 responses (figure 9 - 10 & table 9 - 11).

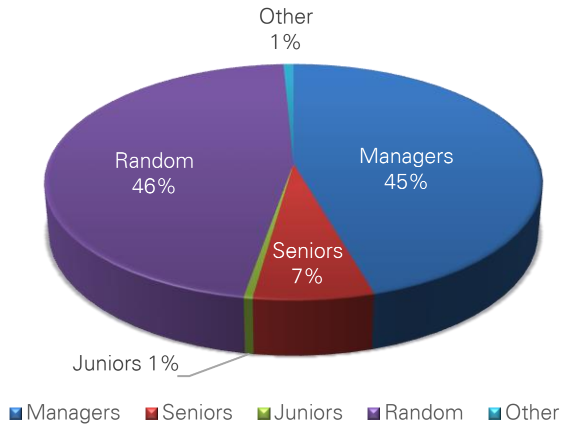


Figure 9 - 10: Placement criteria in Cairo's office spaces in accordance to windows proximity

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Managers	181	45.0	45.5	45.5
	Seniors	27	6.7	6.8	52.3
	Juniors	2	.5	.5	52.8
	Random	185	46.0	46.5	99.2
	Other	3	.7	.8	100.0
	Total	398	99.0	100.0	
Missing system		4	1.0		
Total		402	100.0		

Table 9 - 11: Placement criteria in Cairo's office spaces in accordance to windows proximity

Undoubtedly, proximity to the glazed component (window) in office spaces is considered as a Preferred placement criterion to the users; 81% of Cairo's employees preferred to sit and work near to their working space windows, mainly to gain natural daylighting and visual contact with the outside. In some office places in Cairo, nearly 52%, where there is a placement system for its employees (i.e. not random), working places with windows proximity and better views to the outside are mainly awarded to high-ranked employees (managers and seniors) as a kind of incentive or promotion to them.

Many previous research works addressed windows proximity in working places. Kaplan (1993), Boyce (2003), Kim & Wineman (2005), and Yildirim, et al. (2007) all accentuate that the proximity to the windows in office spaces is one of the most preferred placement criteria to the occupants.

9.2.2.3. Part III: Interaction with Transparency:

This part of the survey target to investigate and predestine the office occupant's psychological interaction with their office spaces transparent components (windows). In ten questions, from Q11 to Q20, distributed among five sections, participants were asked to specify with regard to their thermal and visual comfort conditions their levels of satisfactions and their responsive behavior in their office spaces towards: the internal thermal environment, HVAC operations, natural ventilation, shading devices utilization, and the general lighting conditions. The results will give an evidential indication to the occupant's perceived values from transparency, especially with the current trend of highly glazed office building constructions in Greater Cairo Region (CGR).

- **Internal Thermal Satisfaction:**

To assess the office's internal thermal environment in Cairo, participants were asked to determine their level of thermal satisfaction in their office spaces without the intervention of (turning-on) mechanical air conditioning. A frequency of 206 subjects and 51.4 Valid percent were very dissatisfied, 30.6 Valid percent were dissatisfied with a frequency of 123 subjects, 11.3 valid Percent were neutral, 5.2 percent were satisfied, and only 1.5 percent feels very satisfied (figure 9 - 11 & table 9 - 12).

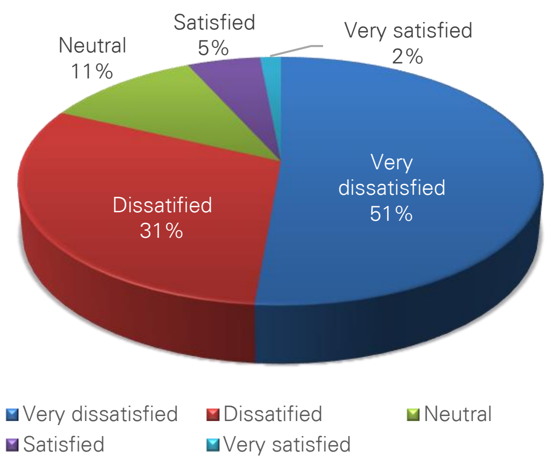


Figure 9 - 11: Thermal satisfaction of the office space occupants in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent	
Valid	Very dissatisfied (-2)	206	51.2	51.4	51.4	
	Dissatisfied (-1)	123	30.6	30.6	82.0	Mean -1.25
	Neutral (0)	45	11.2	11.3	93.3	Median -2.00
	Satisfied (+1)	21	5.2	5.2	98.5	Mode -2.00
	Very satisfied (+2)	6	1.5	1.5	100.0	Std. Dev. 0.95
	Total	401	99.8			
Missing system		1	.2			
Total		402	100.0			

Table 9 - 12: Thermal satisfaction of the office space occupants in Cairo

Obviously, the results indicate a failure of the office space thermal design to achieve the required comfort conditions to its occupants in Cairo; 82% of them are from very dissatisfied to dissatisfied with their internal thermal environment. Figure 9 - 12 shows thermal satisfaction of the occupants towards their internal office environment histogram. The median and mode values are in the very dissatisfied range (-2), and the mean value of satisfaction is -1.25, indicating dissatisfaction (-1) with some tendency towards very dissatisfaction (-2).

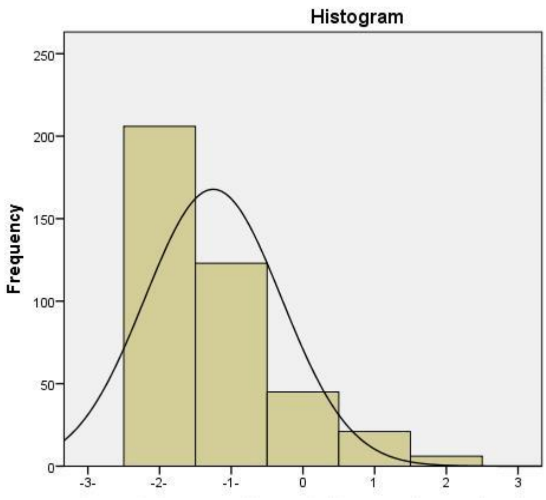


Figure 9 - 12: Thermal satisfaction of the office space occupant's histogram

- HVAC System Interaction:

This section investigates the dependence of the office space occupant's in Cairo on mechanical HVAC systems, either for cooling on summer times or hearing in winter, to retrieve their required thermal comfortable conditions. For cooling, participants were asked to specify the interval of turning on their air conditioning during a typical summer working day, and to specify the month when they start using A/C and the month when they turn it off. While, for heating, they were asked a simple Yes/No question, whether they need a heating system in their working places during wintertime or no.

For cooling intervals during a typical summer working day, the majority of the participants keep their office space air conditioning always turned on during the whole working day with a frequency of 297 subjects representing 74.4 valid percent and 14.3 Valid percent with a frequency of 57 subjects turn it on from 6 to 8 hours daily. While with relatively small ratios; 6.3 valid percent turn it on from 4 to 6 hours daily, 1.8 valid percent turn it on from 2 to 4 hours, 1.5 valid percent turn it on less than 2 hours daily, and 1.8 valid percent prefer not to turn it on (figure 9 - 13 & table 9 - 13).

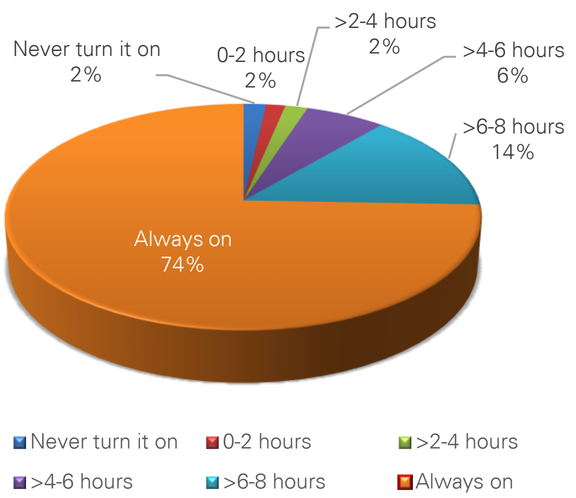


Figure 9 - 13: Daily intervals of turning-on A/C in Cairo's office spaces during summertime

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never turn it on	7	1.7	1.8	1.8
	0-2 hours	6	1.5	1.5	3.3
	>2-4 hours	7	1.7	1.8	5.0
	>4-6 hours	25	6.2	6.3	11.3
	>6-8 hours	57	14.2	14.3	25.6
	Always on	297	73.9	74.4	100.0
	Total	399	99.3	100.0	
Missing system		3	.7		
Total		402	100.0		

Table 9 - 13: Daily intervals of turning-on A/C in Cairo's office spaces during summertime

Regarding the monthly duration of using mechanical cooling per year in Cairo's office space, 85.3 valid percent with a frequency of 336 subjects starts turning on their air conditioning for cooling purpose from March to May, with median and mode values of (4) April month (table 9 - 14). Nearly the same ratio, with 87.5 valid percent and a frequency of 343 subjects turn off their mechanical cooling from October to December, with median and mode values of (11) November month (table 9 - 15).

Switch ON air Conditioning month		Frequency	Percent	Valid Percent	Cumulative Percent		
Valid	Jan	5	1.2	1.3	1.3		
	Feb	2	.5	.5	1.8		
	Mar	68	16.9	17.3	19.0		
	Apr	154	38.3	39.1	58.1	Median	4.00
	May	114	28.4	28.9	87.1	Mode	4.00
	Jun	36	9.0	9.1	96.2	Std. Dev.	1.16
	Jul	12	3.0	3.0	99.2		
	Aug	2	.5	.5	99.7		
	Dec	1	.2	.3	100.0		
	Total	394	98.0	100.0			
Missing system		8	2.0				
Total		402	100.0				

Table 9 - 14: Turning on A/C month for cooling in Cairo’s office spaces

Switch OFF air conditioning month		Frequency	Percent	Valid Percent	Cumulative Percent		
Valid	Jan	23	5.7	5.9	5.9		
	Feb	1	.2	.3	6.1		
	Aug	4	1.0	1.0	7.1	Median	11.00
	Sep	21	5.2	5.4	12.5	Mode	11.00
	Oct	96	23.9	24.5	37.0	Std. Dev.	2.46
	Nov	189	47.0	48.2	85.2		
	Dec	58	14.4	14.8	100.0		
	Total	392	97.5	100.0			
Missing system		10	2.5				
Total		402	100.0				

Table 9 - 15: Turning off A/C month for cooling in Cairo’s office spaces

While, for the need of mechanical heating in Cairo’s office spaces during wintertime, the vast majority with 74.3 valid percent and frequency of 298 subjects did not need heating systems, and only 25.2 valid percent with a frequency of 101 subjects respond with yes (figure 9 - 14 & table 9 - 16).

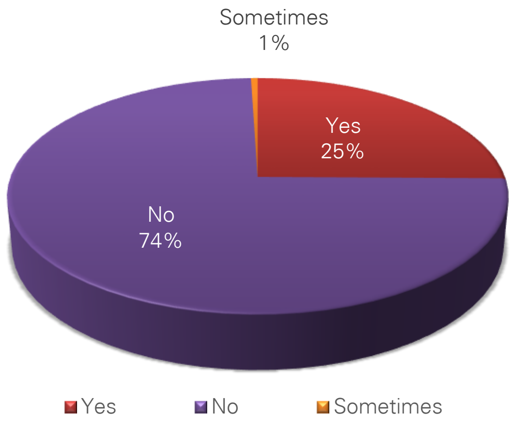


Figure 9 - 14: The need for mechanical heating in Cairo's office spaces (Yes = need, No = not need

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	101	25.1	25.2	25.2
	No	298	74.1	74.3	99.5
	Sometimes	2	.4	.4	100.0
	Total	401	99.8	100.0	
Missing system		1	.2		
Total		402	100.0		

Table 9 - 16: The need for mechanical heating in Cairo's office spaces

The results of this section indicate the heavy dependence on HVAC systems in Cairo's office spaces and mainly for cooling. 88.7% of the occupants turn on their mechanical cooling for more than 6 hours in a typical summer working day, and for a whole seven months; starts from April till November. While, obviously, there is no need for mechanical heating, 74.3% of the office occupants in Cairo did not prefer to have heating systems in their working spaces during winter times.

- Interaction with Natural Ventilation:

This part investigates the office space occupant's behavior and their interaction towards natural ventilation. Participants were asked first about the frequency of using natural ventilation in their office spaces, and second, they were asked in a multi-response question to specify the reason for using natural ventilation in their working spaces.

The majority of the subjects used natural ventilation in their office spaces either rarely (less than 2 hours per day) with a frequency of 187 subjects and 46.5 valid percent, or sometimes (from 2 to 4 hours per day) with 130 subjects and 32.3 valid percent. While, with small ratios, 41 participants representing 10.2 valid percent never used it, and 44 participants representing 10.9 valid percent used natural ventilation in their offices more than 6 hours per day (figure 15 & table 17).

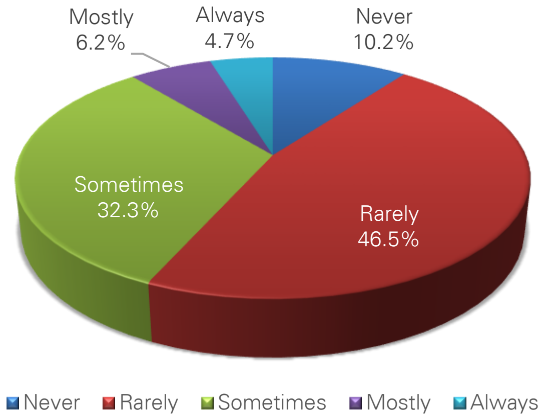


Figure 9 - 15: Frequency of using natural ventilation in Cairo's office spaces

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never	41	10.2	10.2	10.2
	Rarely	187	46.5	46.5	56.7
	Sometimes	130	32.3	32.3	89.1
	Mostly	25	6.2	6.2	95.3
	Always	19	4.7	4.7	100.0
	Total	402	100.0	100.0	

Table 9 - 17: Frequency of using natural ventilation in Cairo's office spaces

On specifying the reasons for using the natural ventilation in office spaces in Cairo (multi-response question); avoid unpleasant smells (Olfactory reasons) was the first choice to the subjects with 302 responses and 39.8 valid percent. Provide an air-flow to enhance thermal comfort conditions came second with 253 responses representing 33.4 valid percent. While to reduce internal carbon dioxide content came third with 138 responses and 24.1 valid percent (figure 9 - 16 & table 9 - 18).

		Responses	
		N	Percent
Multiple response	Avoid unpleasant smells (Olfactory reasons)	302	39.8%
	Provide an air-flow to enhance thermal comfort	253	33.4%
	Reduce internal carbon dioxide content	183	24.1%
	Other	20	2.6%
Total		758	100%

Table 9 - 18: Reasons for using natural ventilation in Cairo's office spaces

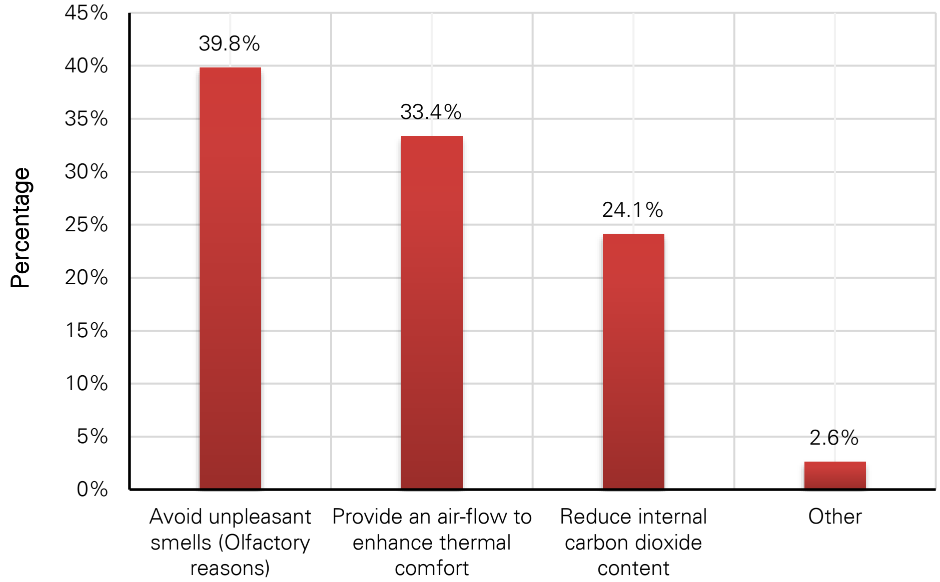


Figure 9 - 16: Reasons for using natural ventilation in Cairo's office spaces

Clearly, from the previous responses, 89.1% of the office space occupants in Cairo uses natural ventilation less than 4 hours per day. Even the first reason for using it is for olfactory reasons and the avoidance of bad smells indoors. This indicates the poor air quality in the office spaces environment, in addition to, the lack of awareness of passive & low energy thermal measures, and the vast reliability on the mechanical HVAC systems for cooling.

- Interaction with Windows Shading Devices:

To investigate the office space occupants in Cairo interaction with their windows shading devices, they were asked first to determine their shading device type from either, external and fixed, external and moveable, internal and fixed, internal and moveable, inter-pane, or don't have any means of shading or other. Second, in the case of having a movable shading they were asked about the time intervals where they close their shadings, the reason for closing the shading device in the working place (multiple response question), and the possibility of having a visual contact to the outside while closing the office space window shadings.

Undisputedly, internal and movable shading devices are the mostly used shadings in Cairo's office spaces with a frequency of 313 subjects and 78.3 valid percent. By far, and with small ratios, the second choice was internal and fixed shadings with a frequency of 25 subjects representing 6.3 valid percent, external & moveable shadings came third, and external & fixed came fourth with 5.3 and 2.3 valid percentage respectively. While 23 subjects representing 5.8 valid percent don't have any means of shading in their working space (figure 9 - 17 & table 9 - 19).

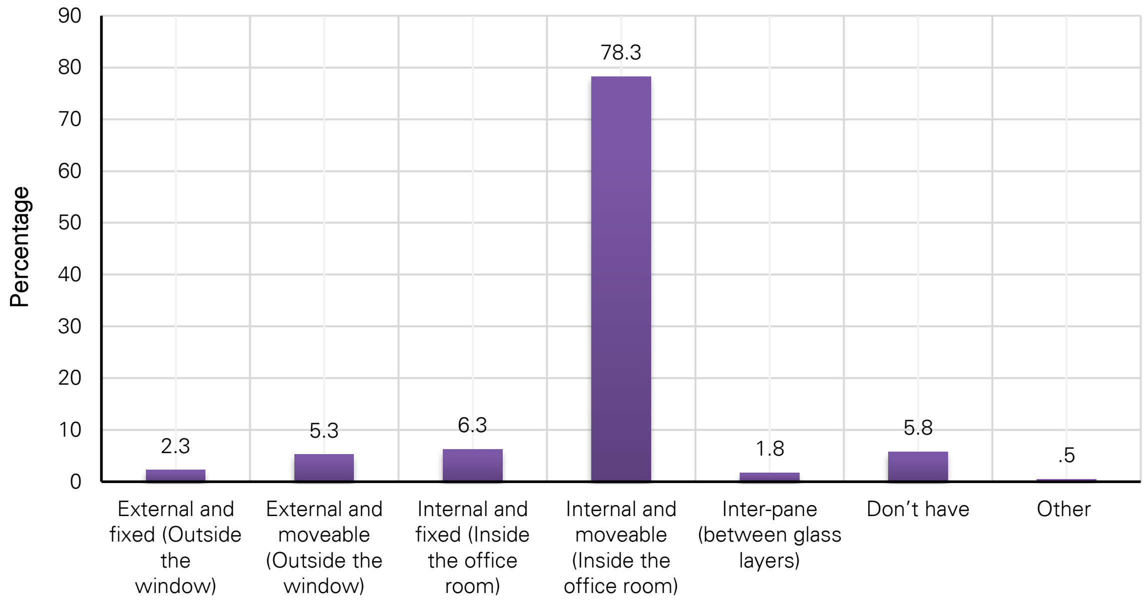


Figure 9 - 17: Position and movability of shading devices in Cairo's office spaces

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	External and fixed (Outside the window)	9	2.2	2.3	2.3
	External and moveable (Outside the window)	21	5.2	5.3	7.5
	Internal and fixed (Inside the office room)	25	6.2	6.3	13.8
	Internal and moveable (Inside the office room)	313	77.9	78.3	92.0
	Inter-pane (between glass layers)	7	1.7	1.8	93.8
	Don't have	23	5.7	5.8	99.5
	Other	2	.5	.5	100.0
	Total	400	99.5	100.0	
Missing system		2	.5		
Total		402	100.0		

Table 9 - 19: Position and movability of shading devices in Cairo's office spaces

For window shades closing intervals, a frequency of 40 subjects representing 10.3 valid percent never close their shadings, 77 subjects representing 19.8 valid percent close it from 2 to 4 hours, while the majority of the subjects with frequency of 161 and 41.4 valid percent close their window shadings from 2 to 4 hours per day, 74 subjects representing 19 valid percent close the shadings from 4 to 6 hours daily, 23 subjects representing 5.9 valid percent close it more than 6 hours daily, while only 14 subjects representing 3.6 valid percent close their window shadings the whole day (figure 9 - 18 & table 9 - 20).

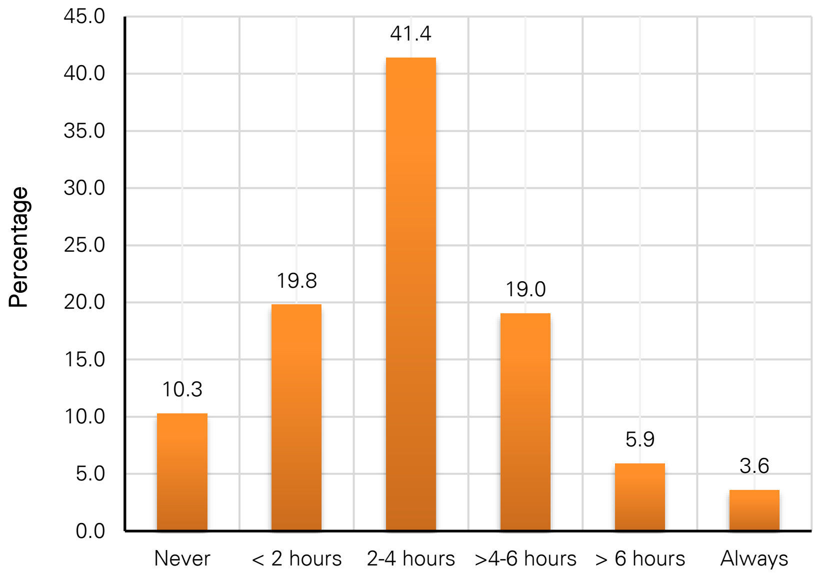


Figure 9 - 18: Intervals of closing the office window's moveable shading devices in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never	40	10.0	10.3	10.3
	< 2 hours	77	19.2	19.8	30.1
	2-4 hours	161	40.0	41.4	71.5
	>4-6 hours	74	18.4	19.0	90.5
	> 6 hours	23	5.7	5.9	96.4
	Always	14	3.5	3.6	100.0
	Total	389	96.8	100.0	
Missing system		13	3.2		
Total		402	100.0		

Table 9 - 20: Intervals of closing the office window's moveable shading devices in Cairo

The avoidance of glare from direct solar radiation came the first reason for closing the office space window shadings with a frequency of 244 responses and 38.9 valid percent. To prevent annoying reflections from computer screens (which is also a type of glare) came second with 188 responses and 30 valid percent. While, the avoidance of heat gain from the solar radiation came third with 144 responses representing 23 valid percent, and finally, for privacy came the fourth reason with only 45 responses representing 7.2 valid percent (figure 9 - 19 & table 9 - 21).

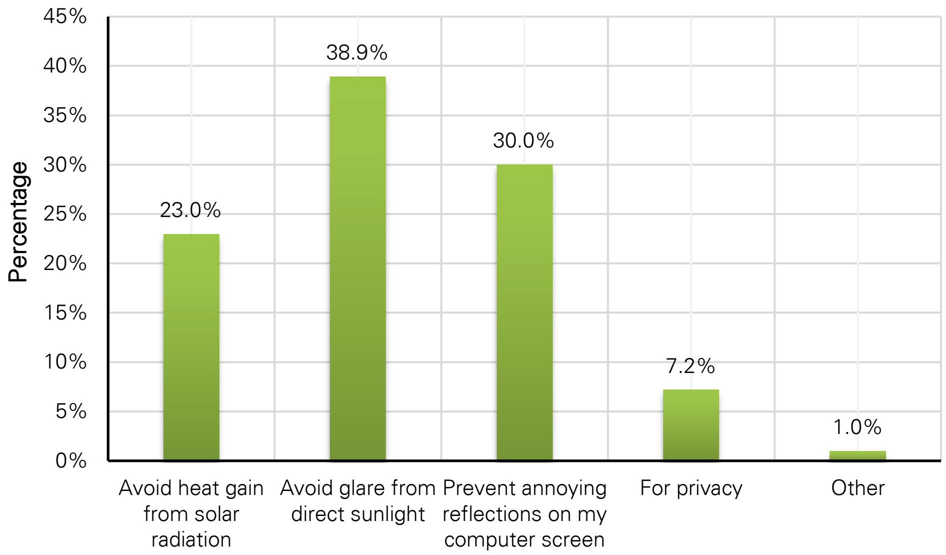


Figure 9 - 19: Reasons for closing window's shading devices in Cairo's office spaces

		Responses N	Responses Percent	Percent of Cases
Multiple response	Avoid heat gain from solar radiation	144	23.0%	38.3%
	Avoid glare from direct sunlight	244	38.9%	64.9%
	Prevent annoying reflections on my computer screen	188	30.0%	50.0%
	For privacy	45	7.2%	12.0%
	Other	6	1.0%	1.6%
Total		627	100.0%	166.8%

Table 9 - 21: Reasons for closing window's shading devices in Cairo's office spaces

regarding the possibility of having visual contact to the outside while closing the window shades, the majority with frequency of 156 subjects representing 40.8 valid percent cannot have any possibility to the external view, 130 subjects representing 34 valid percent can have partial view, and only 96 subjects represent 25.1 valid percent can have visual contact to the outside (figure 9-20 & table 9-22).

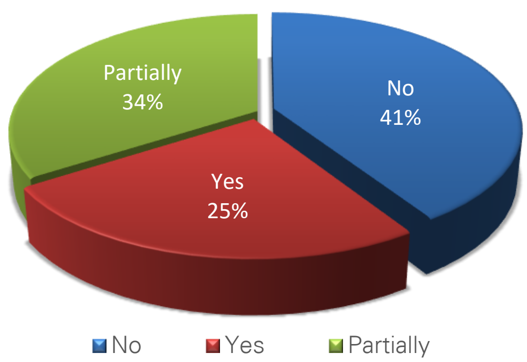


Figure 9 - 20: The possibility of having visual contact to the outside while closing the window's shades

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	No	156	38.8	40.8	40.8
	Yes	96	23.9	25.1	66.0
	Partially	130	32.3	34.0	100.0
	Total	382	95.0	100.0	
Missing system		20	5.0		
Total		402	100.0		

Table 9 - 22: The possibility of having visual contact to the outside while closing the window's shades

The previous results indicate that 85% of office space occupant's in Cairo had an internal window shading devices (either movable or fixed). This contributes to the tremendous solar heat gain which definitely raises the overall cooling loads of the space, and consequently the needed cooling energy. Even with the presence of internal shading, a portion of solar radiation could be reflected to the outside, and the far infrared radiations (heat radiation) will be trapped inside the office space owing to the selectivity property of glass (greenhouse effect). While for office employees who had moveable shadings, almost 60.4% of them close it from 2 to 6 hours out of 8 working hours daily (from 25% to 75% of the total working hours), mainly to avoid glare, either from direct solar radiation or indirect glare due to the veiling reflections on their computer screens. Closing the window shading devices deprive almost 74.8% of the employees of having their required visual contact to the outside.

- Interaction with lighting conditions:

The office occupant's behavior and their interaction with their space general lighting conditions (either daylighting or artificial lighting) were investigated in this section. For daylighting, participants were asked to specify the intervals of dependence on daylighting only in their office spaces. While for artificial lighting, they were asked a conditional yes/no question for whether they use artificial lighting in their morning working hours or no. If yes, they were questioned to determine the intervals of using artificial lighting and the reasons that makes them to turning it on and avoid a plenty of natural light outside.

The dependence on daylighting only in Cairo's office spaces shows a variety of responses, 82 subjects with 20.5 valid percent never depend on daylighting only during office hours, while the majority of the participants with frequency of 143 subjects and 35.8 valid percent uses daylighting less than 2 hours per day, and 74 subjects with 18.4 valid percent uses daylighting from 2 to 4 hours per day. While with relatively small ratios, 13.3 valid percent uses daylight from 4 to 6 hours daily, 6 valid percent uses daylighting more than 6 hours, and an equal number with the same previous percentage always depends on daylighting in their working places (figure 9 - 21 & table 9 - 23).

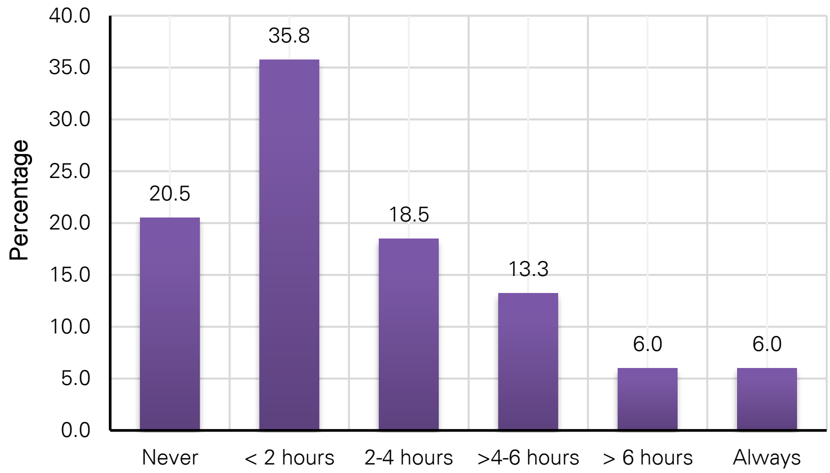


Figure 9 - 21: Intervals of dependence on daylighting only in Cairo's offices

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Never	82	20.4	20.5	20.5
	< 2 hours	143	35.6	35.8	56.3
	2-4 hours	74	18.4	18.5	74.8
	>4-6 hours	53	13.2	13.3	88.0
	> 6 hours	24	6.0	6.0	94.0
	Always	24	6.0	6.0	100.0
	Total	400	99.5	100.0	
Missing system		2	.5		
Total		402	100.0		

Table 9 - 23: Intervals of dependence on daylighting only in Cairo's offices

For the usage of artificial lighting in Cairo's office space, the vast majority of the participants with a frequency of 390 subjects and 97.5 valid percent used it, while only 10 subjects with 2.5 valid percent don't prefer to use artificial lighting in the working places (figure 9 - 22 & table 9 - 24).

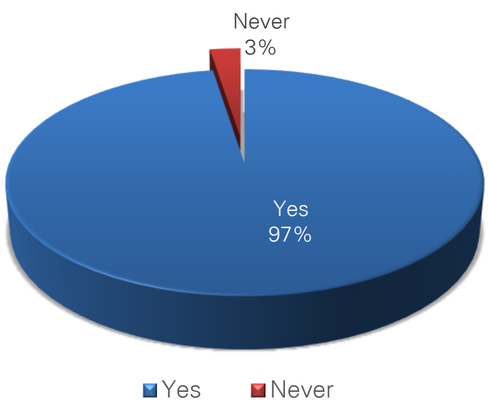


Figure 9 - 22: The usage of artificial lighting in Cairo's office spaces

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	390	97	97.5	97.5
	Never	10	2.5	2.5	100.0
	Total	400	99.5	100.0	
	2	.5			
Missing system		402	100.0		

Table 9 - 24: The usage of artificial lighting in Cairo's office spaces

From the office space occupants who use artificial lighting in their office spaces (97.5%), the vast majority turns on their artificial lighting more than 6 hours per day, 122 subjects representing 31 valid percent turn it on more than 6 hours, and 150 subjects representing 38.1 valid percent always keep it on during the whole working hours. While 6.3 valid percent opens artificial lighting less than 2 hours per day, 10.4 valid percent opens it from 2 to 4 hours daily, and 14.2 valid percent uses artificial lighting from 4 to 6 hours per normal working day (figure 9 - 23 & table 9 - 25).

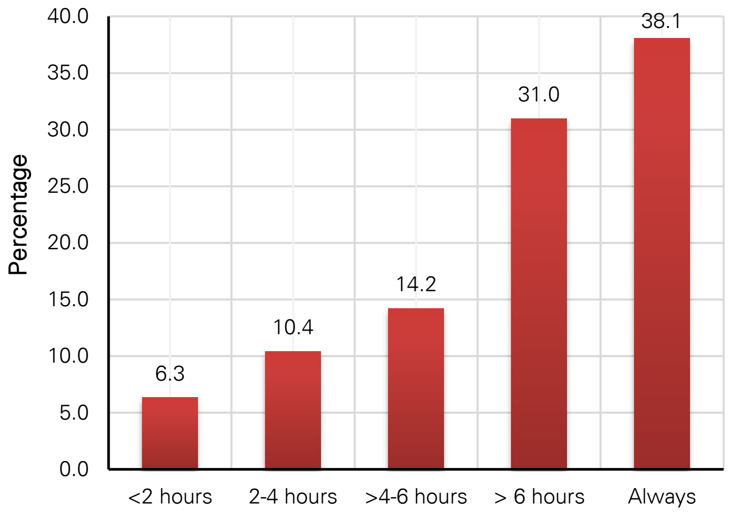


Figure 9 - 23: Intervals of switching on artificial lighting in Cairo's office spaces

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	< 2 hours	25	6.2	6.3	6.3
	2-4 hours	41	10.2	10.4	16.8
	>4-6 hours	56	13.9	14.2	31.0
	> 6 hours	122	30.3	31.0	61.9
	Always	150	37.3	38.1	100.0
	Total	394	98.0	100.0	
Missing system		8	2.0		
Total		402	100.0		

Table 9 - 25: Intervals of switching on artificial lighting in Cairo's office spaces

Regarding the reasons that makes the office space occupants in Cairo to open their artificial lighting (multiple response question), insufficiency of daylighting illumination level and the need to increase the general lighting conditions came the first reason with 330 responses representing 56.5 valid percent, closing the window shades came second with 210 responses and 36 valid percent, while 32 participants representing 5.5 valid percent had no other source of lighting (figure 9 - 24 & table 9 - 26).

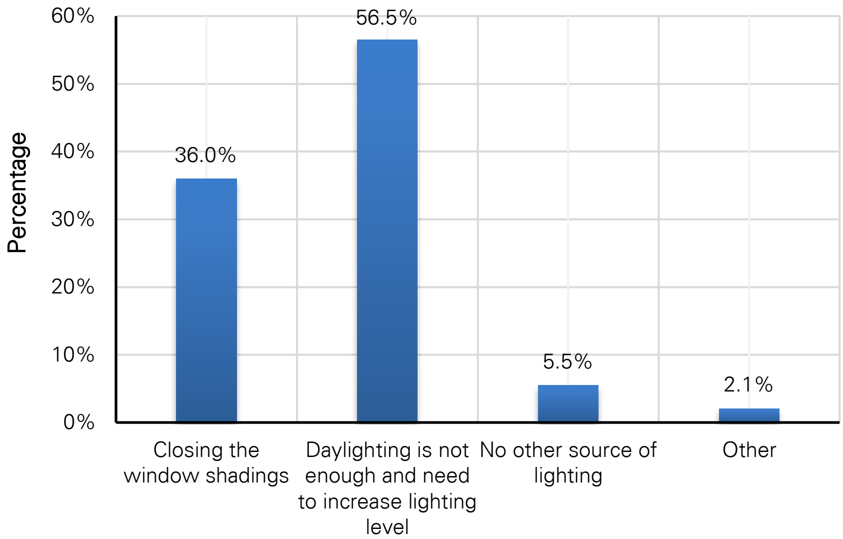


Figure 9 - 24: Reasons for turning on artificial lighting in office working hours

		Responses		Percent of Cases
		N	Percent	
Multiple response	Closing the window shadings	210	36.0%	53.2%
	Daylighting is not enough and need to increase lighting level	330	56.5%	83.5%
	No other source of lighting	32	5.5%	8.1%
	Other	12	2.1%	3.0%
Total		584	100.0%	147.8%

Table 9 - 26: Reasons for turning on artificial lighting in office working hours

The results of this section indicate a variety in daylighting usage in Cairo's office spaces. However, the figures give evidence to the poor dependence on it as an efficient, very abundant, free and costless lighting source. Nearly 74.8% of the office space occupants in Cairo depends on natural daylighting less than 4 hours per day, i.e. less than 50% of the daily working hours. In addition, the office occupants are highly depended on artificial lighting, 97.5% of the occupants turn on the artificial lighting during the daily working hours, and 69.1% of them turn it on for more than 6 hours per day, mostly, due to the insufficient illuminance level received from daylighting and closing the windows shadings. The comparison of those figures and reasons with the global solar radiation hitting on Cairo reveals the poor environmental design of the building's envelope and especially its external façade.

9.2.2.4. Part IV: Preferred Design Criteria to Transparency:

This part of the survey is the most significant section. It investigates the glazed component design criteria in Cairo's office spaces that psychologically contributes to the occupant's sense of satisfaction and well-being. It consists of 11 main questions (from Q21 to Q31), each investigates one of the office windows design criteria. Participants was questioned to define their psychologically preferred glazed area (window to wall ratio), glazed shape, light transmittance (glazed tinting level), glazed position, external visual content, external reflection ratio, level of access/exposure, perception to external glazed ratio, preferred shading devices, importance to view, and the view to energy efficiency balancing ratio. The results of this part will be consequentially used as a threshold value/margin for the inputs data profiles in the upcoming energetic modeling and simulation section of the research (Chapter X).

- **Preferred Glazed Area (Window to Wall Ratio):**

The glazed area is the most crucial criterion that influences the design of the building's transparency. It was investigated in this part through inquiring the participants to define their psychologically preferred window to wall ratio (wwr) range in their working spaces from a given 5 picture, representing 5 windows having the same external view, but with different wwr as follows: picture (A) with wwr of 90% representing the range from fully glazed wall to wwr of 80%, picture (B) with wwr of 70% representing the wwr range from 80% to 60%, picture (C) with wwr of 50% representing the wwr range from 60% to 40%, picture (D) with wwr of 30% representing the wwr range from 40% to 20% and picture (E) with wwr of 10% representing the wwr range from 20% to solid wall. Then, they were asked in a multiple response question to choose from the given window functions (view, daylighting and natural ventilation) the reason(s) that justifies their choices.

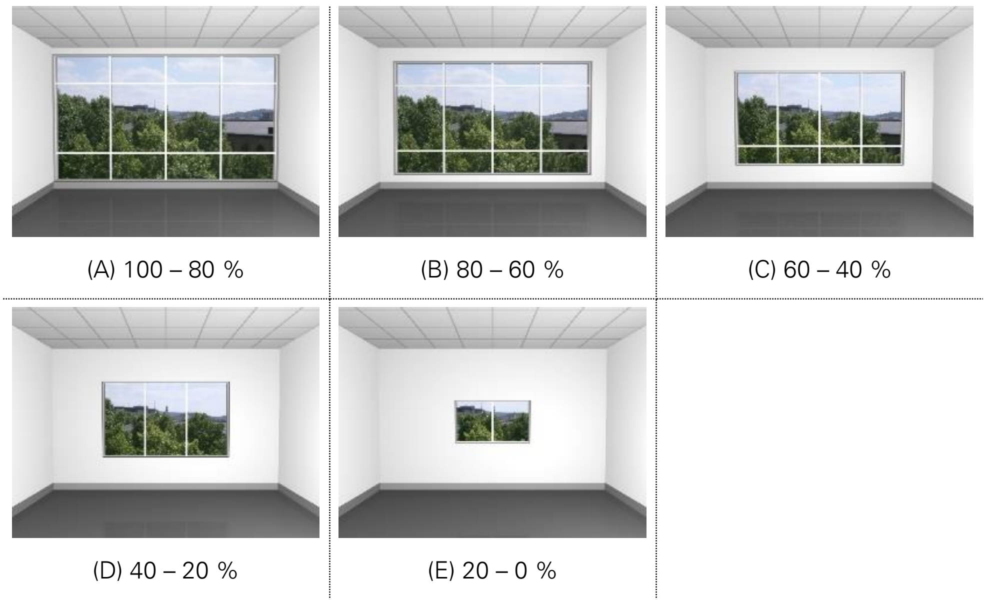


Figure 9 - 25: The given five pictures representing the categories of window to wall ratio (wwr) configurations

Highly glazed window to wall ratios are the most chosen by the subjects. Nearly half of the subjects with a frequency of 202 subjects representing 50.2 valid percent preferred wwr more than 80%, 105 subjects representing 26.1 valid percent preferred wwr range between 60% to 80% and 81 subjects representing 20.1 valid percent preferred wwr range from 40% to 60%. While with small valid percentages, 13 subjects with 3.2 valid percent choose wwr range between 20% to 40%, and only one subject choose wwr between 0 and 20% (figure 9 - 26 & table 9 - 27).

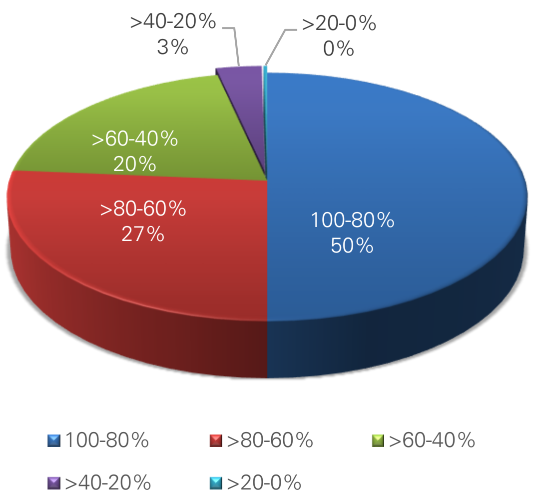


Figure 9 - 26: The preferred wwr to the office space occupants in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent		
Valid	100-80% (1)	202	50.2	50.2	50.2	Mean	1.77
	>80-60% (2)	105	26.1	26.1	76.4	Median	1.50
	>60-40% (3)	81	20.1	20.1	96.5	Mode	1.00
	>40-20% (4)	13	3.2	3.2	99.8	Std. Dev.	0.90
	>20-0% (5)	1	.2	.2	100.0		
	Total	402	100.0	100.0			

Table 9 - 27: The preferred wwr to the office space occupants in Cairo

The windows functions that govern the subjects' choices for their preferred wwr is not far from the previously mentioned preferred functions of office spaces windows (Questions 7 and 8). For better daylighting came first with 324 responses and 41.9 valid percent, to have a better visual contact with the outside came second with 305 responses and 39.5 valid percent and to have better natural ventilation came third with 133 responses and 17.2 valid percent (figure 9 - 27 & table 9 - 28).

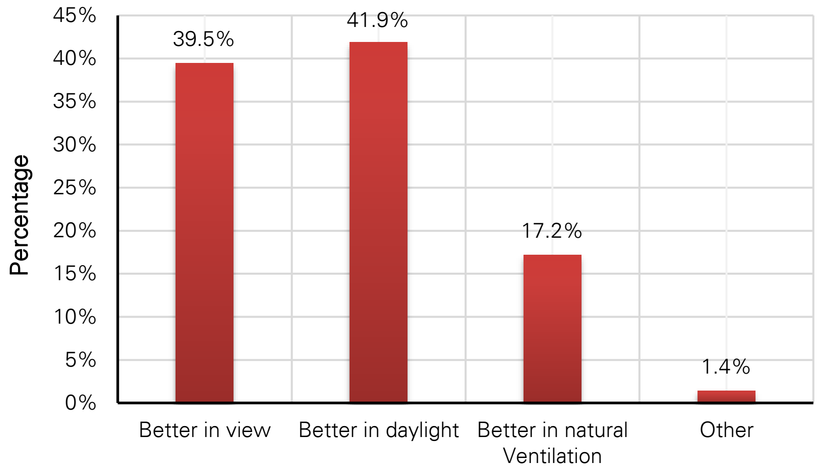


Figure 9 - 27: Window's functions that govern the office space user's choices to their preferred wwr

		Responses		Percent of Cases
		N	Percent	
Multiple response	Better in view	305	39.5%	76.3%
	Better in daylight	324	41.9%	81.0%
	Better in natural Ventilation	133	17.2%	33.3%
	Other	11	1.4%	2.8%
Total		773	100.0%	193.3%

Table 9 - 28: Window's functions that govern the office space user's choices to their preferred wwr

Obviously, from the results of the previous question, the office space users in Cairo psychologically inquires high levels of transparency. Nearly 96.5 percent of them preferred the window to wall ratio to be higher than 40%, mainly to enhance their quality of daylighting and the visual contact to the outside. This psychologically preferred margin (from wwr 40% to wwr 100%) will be energetically modeled and simulated in the upcoming part of the research.

Having large glazed areas in office spaces are substantially preferred criteria (Mccoy, 2002). However, previous research work that investigated the preferred window to wall ratio to the office space occupants showed a variety in glazed area preferences. Dogrusoy & Tureyen (2007) find that the most preferred window ratio is between 44 to 100%. While Ne'eman & Hopkinson (1970) argued that only 15% finds that the minimum acceptable wwr is 32%. Christoffersen, et al. (1999) post occupancy evaluation on Danish office buildings results showed that 87% considered glazing area of 35% or higher are considered too large and offices glazing area less than 20% are too small. Hellinga (2013) argued that the required minimum size of the windows in a room for visual comfort range from 20% to 25% of the wall area. While Farley & Veitch (2001) indicate that windows should occupy at least 20% to 30% of the window wall.

- **Preferred Glazed Shape:**

This part investigates the psychologically preferred window shape to the office space occupants in Cairo. Participants were asked first to choose their preferred window shape from five pictures, each picture represents different window shape with the same area (wwr) and the same external view for a typical office room as follows: picture (A) for squared shape window, picture (B) for wide window, picture (C) for longitudinal window, picture (D) for fragmented window openings, and picture (E) for circled shape window. In the second part, the participants were asked a multiple response question to choose from the window functions the reason(s) that govern their preferred window shape choices.

Figure 9 - 28: The given five pictures representing the different alternatives of window shape

The vast majority of the subjects chose the wide window as the most accepted window shape with a frequency of 321 representing 79.9 valid percent. Followed by squared window shape with 34 subjects representing 8.5 valid percent. 21 subjects with 5.2 valid percent chose the circled window, 16 subjects with 4.0 valid percent chose the longitudinal window, and the fragmented window openings came last with a frequency of 9 subjects representing 2.2 valid percent (figure 9 - 29 & table 9 - 29).

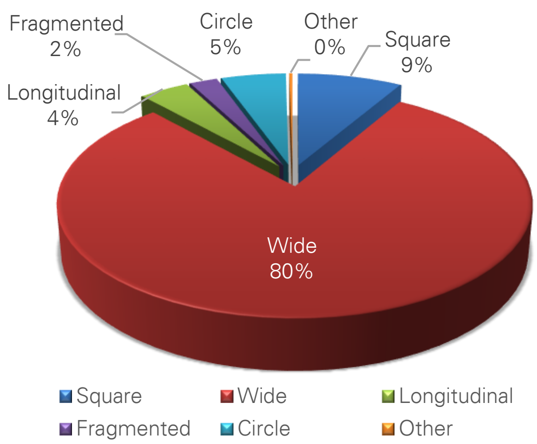


Figure 9 - 29: Preferred window shape to the office space occupants in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Square	34	8.5	8.5	8.5
	Wide	321	79.9	79.9	88.3
	Longitudinal	16	4.0	4.0	92.3
	Fragmented	9	2.2	2.2	94.5
	Circle	21	5.2	5.2	99.8
	Other	1	.2	.2	100.0
	Total	402	100.0	100.0	

Table 9 - 29: Preferred window shape to the office space occupants in Cairo

The window's functions that govern its shape preference to the office space occupants in Cairo came differently from the previous question. Enhancing the visual contact to the outside came first with 321 responses representing 51.2 valid percent, while for the provision of better daylighting quality came second by 225 responses representing 35.9 valid percent, and the improvement of natural ventilation came third with only 63 responses representing 10.0 valid percent (figure 9 - 30 & table 9 - 30).

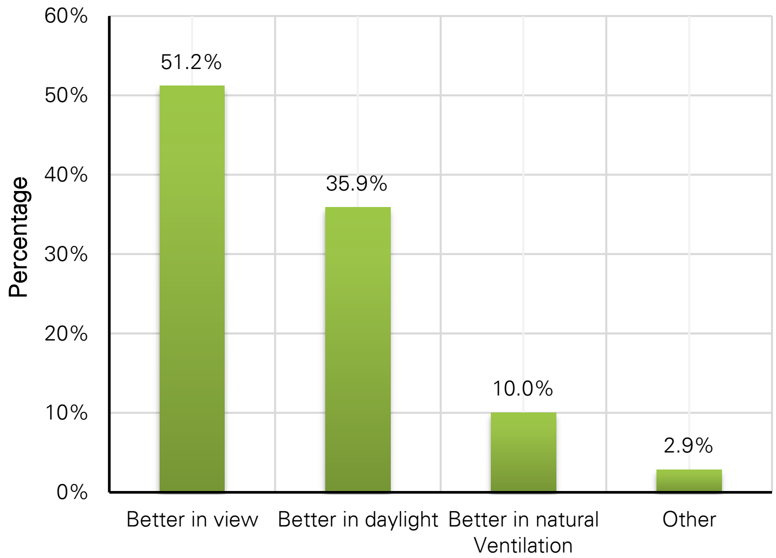


Figure 9 - 30: Window's functions that govern the office space users' choices to their preferred shape

		Responses		Percent of Cases
		N	Percent	
Multiple response	Better in view	321	51.2%	80.3%
	Better in daylight	225	35.9%	56.3%
	Better in natural Ventilation	63	10.0%	15.8%
	Other	18	2.9%	4.5%
Total		627	100.0%	156.8%

Table 9 - 30: Preferred window position to Cairo's office space occupants

The results of this part show that, undoubtedly, the most psychologically accepted window shape for the office space occupants in Cairo is the wide window shape with almost 80% of respondents. The reason behind this choice is mainly to enhance the external visual contact in the first place, and second, to improve the quality daylighting conditions. In the same context, Dogrusoy & Tureyen (2007), Keighley (1973), Farley & Veitch (2001) and Abdou (1997) research results also find that uninterrupted, horizontally wide and continuous windows are the most preferable window shape in office environments for unrestricting the view to the outside.

- **Preferred Glazed Tinting Level (Light Transmittance):**

In order to define the psychologically accepted criteria of light transmittance, the research investigates the preferred windows tinting level in Cairo’s office spaces. Windows tinting level or its light transmittance is one of the solar control tools that could be quantified through physical measures. However, it had also a very crucial psychological impact on the office space users and their preferred level of transparency. Participants were asked first to choose their most preferred tinting level from a given 5 picture (figure 9-31), each picture represents a different window tinting level with the same external view and the same area as follows: picture (A) for window with tinting level of 90% representing the range from opaque glazing to 80% tinting; picture (B) for window with tinting level of 70% representing the range from 80% to 60% tinting; picture (C) for window with tinting level of 50% representing the range from 60% to 40% tinting; picture (D) for window with tinting level of 30% representing the range from 40% to 20% tinting; and picture (E) for window with tinting level of 10% representing the wwr range from 20% to clear white glazing. Second, they were asked in a multiple response question to choose from the given window functions the reason(s) that govern their choices.

Figure 9 - 31: The given five pictures representing the categories of tinting level values

The vast majority preferred picture (E) for tinting level less than 20% with a frequency of 281 subjects representing 70.3 valid percent, followed by picture (D) for tinting level less than 40% with 85 subjects representing 21.3 valid percent. While, with low percentages, 6.5 valid percent prefer it between 40% and 60%, 0.5 valid percent choose it to be between 60 - 80% and 1.3 valid percent preferred their office window's tinting level to be more than 80% (figure 9 - 32 & table 9 - 31).

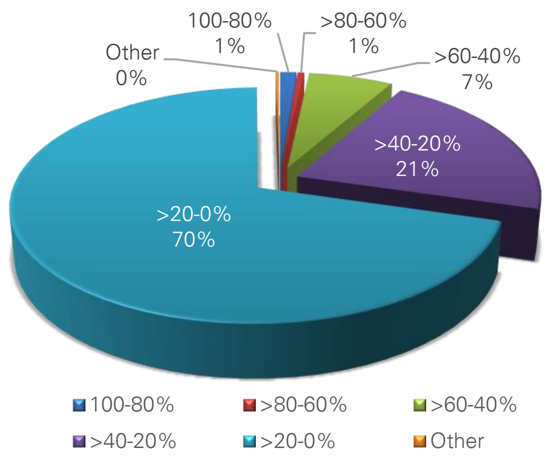


Figure 9 - 32: Preferred window's tinting levels to the office space occupants in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent		
Valid	100-80% (1)	5	1.2	1.3	1.3		
	>80-60% (2)	2	.5	.5	1.8	Mean	4.60
	>60-40% (3)	26	6.5	6.5	8.3	Median	5.00
	>40-20% (4)	85	21.1	21.3	29.5	Mode	5.00
	>20-0% (5)	281	69.9	70.3	99.8	Std. Dev.	0.75
	Other (6)	1	.2	.3	100.0		
	Total	400	99.5	100.0			
Missing system		2	.5				
Total		402	100.0				

Table 9 - 31: Preferred window's tinting levels to the office space occupants in Cairo

Enhancing the daylighting qualities is the first reason that governs the participant's choices for their preferred office space window's tinting level with 291 responses representing 29.8 valid percent. Avoiding glare came the second reason with 281 responses representing 28.8 valid percent either to avoid direct solar radiation glare (direct glare) with 183 responses and 18.8 valid percent or to prevent veiling reflections on computer screens (indirect glare) with 98 responses representing 10.0 valid percent. While to have better view qualities was the third choice with 246 responses representing 25.2 valid percent, followed by to avoid solar heat gain with 130 responses and 13.3 valid percent, and for privacy came last with only 25 responses representing 2.6 valid percent (figure 9 - 33 & table 9 - 32).

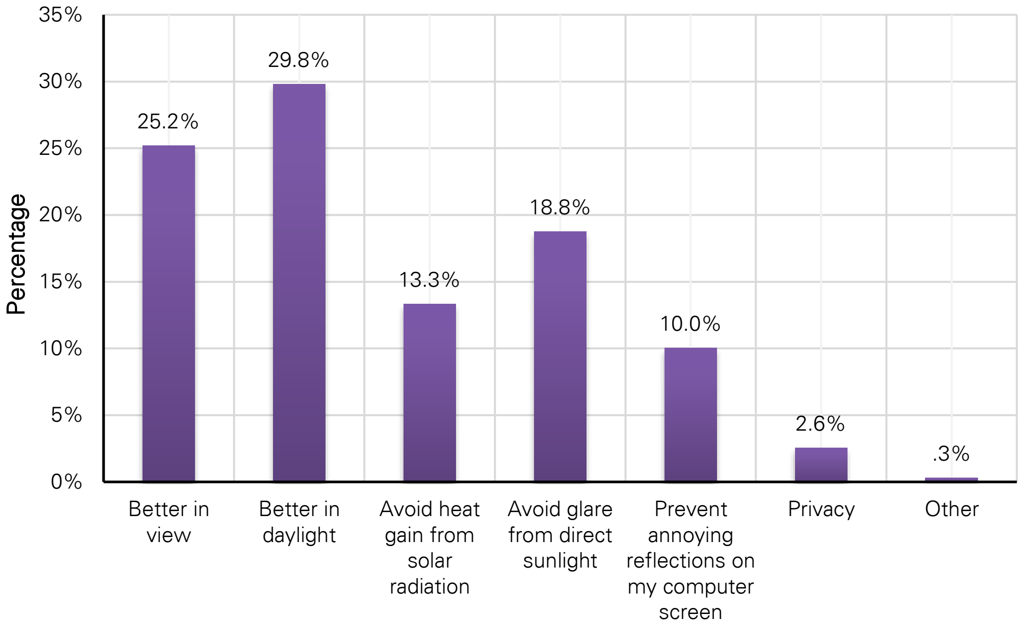


Figure 9 - 33: Reasons that govern the office space window's tinting level preference

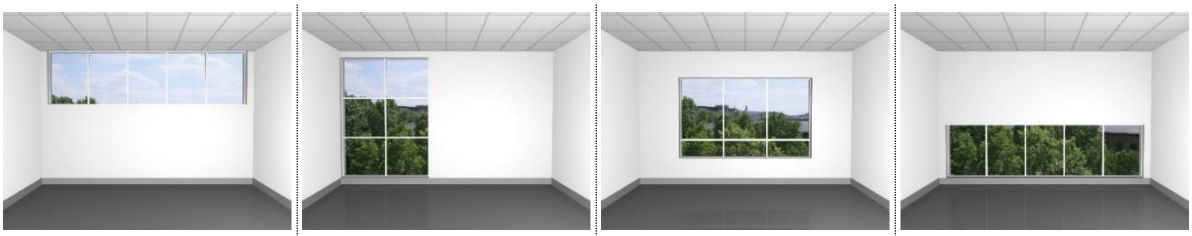
			Responses		Percent of Cases
			N	Percent	
Multiple response		Better in view	246	25.2%	61.2%
		Better in daylight	291	29.8%	72.4%
		Avoid heat gain from solar radiation	130	13.3%	32.3%
	Glare	Avoid glare from direct sunlight	183	18.8%	45.5%
		Prevent annoying reflections on my computer screen	98	10.0%	24.4%
		Privacy	25	2.6%	6.2%
		Other	3	0.3%	0.7%
Total			976	100.0%	242.8%

Table 9 - 32: Reasons that govern the office space window's tinting level preference

The results of the previous question clarify that the vast majority of office space users in Cairo with almost 91% preferred their working place window's tinting level to be lower than 40%. Meaning that the minimum accepted level of light transmittance in Cairo's office spaces is 60%, and it is unacceptable to 392 subjects representing 98.1 valid percent to have window tinting more than 60% i.e. light transmittance of 40%. The reasons are mainly to enhance daylighting performance, avoid glare, and not to lose the external visual quality. Previous literature and research work that addressed the acceptable glass tinting level came congruent with these findings. Littlefair (1999) noted that the windows tinting level should not be too dark where its minimum light transmittance should not be less than 35%, and (Boyce, et al. (1995) finds that the minimum acceptable transmittance in office spaces lies in the range of 25% to 38%, the variation is associated with the sky conditions and the type of glass. Subsequently, in the energetic modeling and simulation section, it will be taken into consideration that the transmittance value for the examined glazing should be more than 60%.

- **Preferred Glazed Position:**

To investigate the psychologically preferred position of the glazed component in Cairo's office spaces, participants were asked to choose their preferred office space window position from a given 4 different pictures (figure 9 – 34). Each picture represents different window position but with the same area (wwr) and the same external view for a typical office space as follows: picture (A) for top window position; picture (B) for Corner window position; picture (C) for center window position; and picture (D) for lower window position. Then they were asked a multiple response question to choose from the given windows functions the reason(s) that govern the choices.



(A) Top | (B) Corner | (C) Center | (D) Lower

Figure 9 - 34: The given four pictures representing the different alternatives of office space window's position

The vast majority chooses the centered window position with a frequency of 364 subjects representing 90.5 valid percent. By far, the corner window position came second with 30 subjects and 7.5 valid percent, while 5 subjects chose the bottom position with 1.2 valid percent, and 2 subjects with 0.5 valid percent chose the top window position (figure 9 - 35 & table 9 - 33).

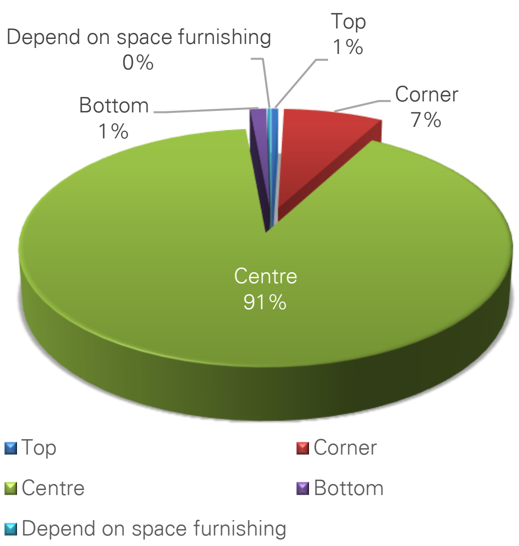


Figure 9 - 35: Preferred window position to Cairo's office space occupants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Top	2	.5	.5	.5
	Corner	30	7.5	7.5	8.0
	Centre	364	90.5	90.5	98.5
	Bottom	5	1.2	1.2	99.8
	Depend on space furnishing	1	.2	.2	100.0
	Total	402	100.0	100.0	

Table 9 - 33: Preferred window position to Cairo's office space occupants

Enhancing the visual contact to the outside came the first reason that governs the subjects' choices for their preferred office window position with 345 responses representing 54.9 valid percent. For improving daylighting performance came second reason with 215 responses and 34.2 valid percent, while for better natural ventilation conditions came last with 68 responses representing 10.8 valid percent (figure 9 - 36 & table 9 - 34).

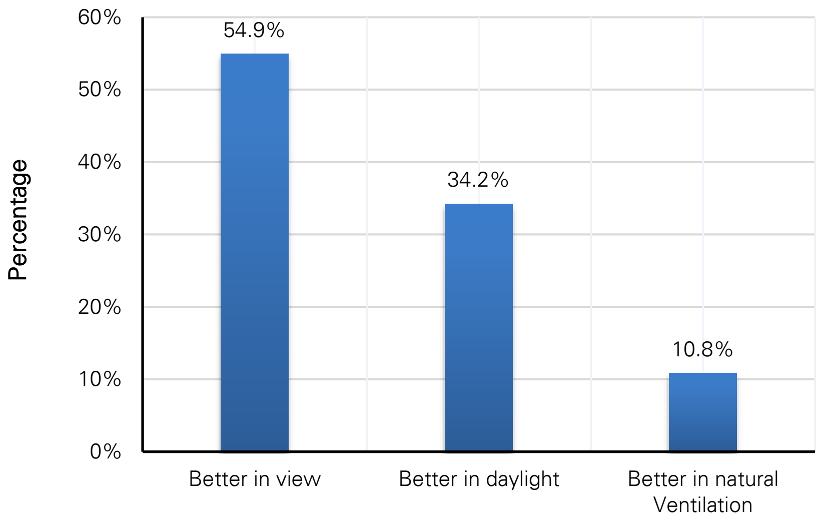


Figure 9 - 36: Functions that govern the office space user's choices to their preferred window position

		Responses		Percent of Cases
		N	Percent	
Multiple response	Better in view	345	54.9%	86.9%
	Better in daylight	215	34.2%	54.2%
	Better in natural Ventilation	68	10.8%	17.1%
Total		628	100.0%	158.2%

Table 9 - 34: Functions that govern the office space user's choices to their preferred window position

Undisputedly, centered window is the most preferred window position in Cairo's office spaces with 90.5% preference ratio, mainly to provide the occupants with better visual contact to the outside, and to improve the daylighting qualities.

- **Preferred External Visual Content:**

This section investigated the psychosocially preferred external visual content to the office space occupants in Cairo. Participants were asked to choose their preferred view from a given six pictures (figure 9 – 36); each picture represent a typical office space window with the same area (wwr) but with different external visual content possibility in Cairo as follows: picture (A) for window with the Nile - river view; picture (B) for window with green view, picture (C) for window with city - scape view, picture (D) for window with an empty land view, picture (E) for window with neighbor building view and picture (E) for window with view over slums area.

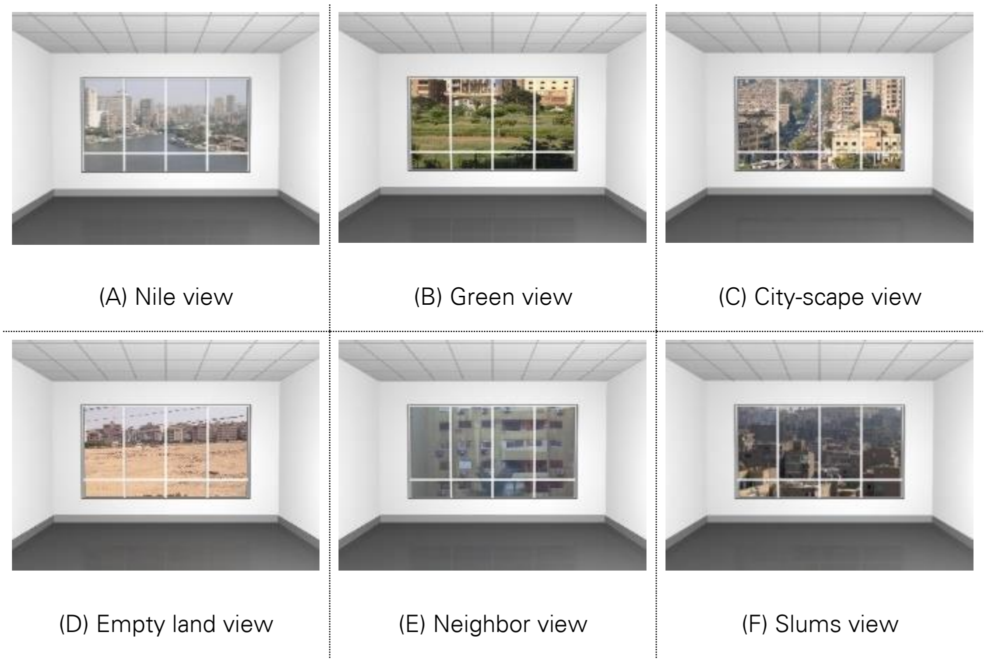


Figure 9 - 37: The given six pictures representing different possibilities for the window's visual content in Cairo

The river - Nile and the green views are the most preferred external visual content to the office space occupants in Cairo. The river - Nile view came first with a frequency of 237 subjects representing 59.3 valid percent, followed by the view of a green content with 141 subjects representing 35.3 valid percent. While city-scape view came third with only 11 subjects and 2.8 valid percent, followed by the empty land view with 7 subjects representing 1.8 valid percent. And almost with a negligible percentage came the neighbor view and the slums view with 0.5 valid percent for each (figure 9 - 38 & table 9 - 35).

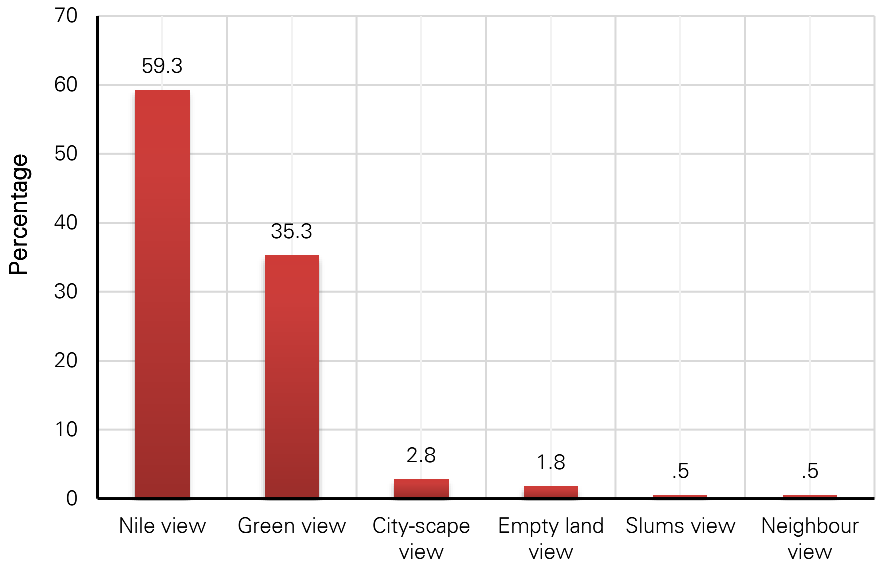


Figure 9 - 38: Preferred views for Cairo's office space occupants

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Nile view	237	59.0	59.3	59.3
	Green view	141	35.1	35.3	94.5
	City-scape view	11	2.7	2.8	97.3
	Empty land view	7	1.7	1.8	99.0
	Neighbor view	2	.5	.5	99.5
	Slums view	2	.5	.5	100.0
	Total	400	99.5	100.0	
Missing system		2	.5		
Total		402	100.0		

Table 9 - 35: Preferred views for Cairo's office space occupants

Obviously, from the previous responses that the psychologically preferred visual content for the office space occupants in Cairo could be classified into 3 categories: the first category is the most preferred visual contents; it includes natural views of the river Nile view and the green view with high acceptance ratios of 59.3% and 35.3% respectively. The second category is the low preferred views; it includes the city scape views and the empty land views with low acceptance ratios (2.8 and 1.8 respectively). While the third category is the undesired views; it includes neighbor and slum views with an acceptance ratio of 0.5% for each. These findings came compatible with Ulrich (1981), Cooper, et al. (2008), and Mccoy (2002) for the user's preference to natural visual contents than urban scenes for its positive contribution to enhance their mental well-being, with more preference to the water views.

- **Preferred External Reflectance Factor:**

Reflective glazing is a type of solar control concept, in addition, it provides the occupants with some privacy measures. Participants were asked first a conditional yes/no question about whether they prefer their working place window to have a kind of external reflection or no, then for those who replied with yes, they were inquired to choose their accepted window reflection factor from given set of choices as follows: mirror like (100% reflective), very high reflective (more than 80% reflection), high reflective (from 60% to 80% reflection), medium (from 40% to 60% reflection), low reflective (from 20% to 40% reflection), very low reflective (less than 20% reflection) and not reflective (0% reflection).

The majority of the participants preferred to have a kind of external reflection on their office space windows with a frequency of 243 subjects representing 60.4 valid percent, 74 subjects with 18.4 valid percent didn't prefer to have external window reflections, and 85 subjects with 21.1 valid percent are not sure (figure 9 - 39 & table 9 - 36).

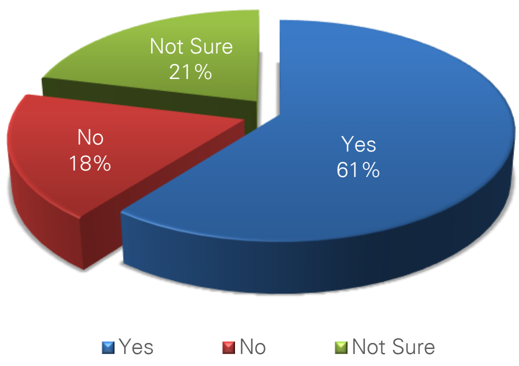


Figure 9 - 39: Office space user's acceptance to external reflections on their windows

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	243	60.4	60.4	60.4
	No	74	18.4	18.4	78.9
	Not Sure	85	21.1	21.1	100.0
	Total	402	100.0	100.0	

Table 9 - 36: Office space user's acceptance to external reflections on their windows

The results of the preferred reflective factor showed diversity in answers. However, the majority with a frequency of 127 subjects representing 39 valid percent preferred that the external reflection factor for their office space window would be medium (between 40% and 60%). 70 subjects preferred the reflective factor to be high (between 60% and 80%) with 21.5 valid percent, 25 of them prefer it to be very high reflective (between 80% and 99.9%) with 7.7 valid percent, and 33 subjects prefer it to be mirror like with 10.1 valid percent. On the other hand, 32 subjects choose low reflective (between 20%

and 40%) representing 9.8 valid percent, 12 choose very low reflective with 3.7 valid percent, and 27 prefer it not reflective with 8.3 valid percent. While 76 subjects didn't answer this part which is nearly to the number participants that didn't prefer their working place window to have any kind of reflections (figure 9 - 40 & table 9 - 37).

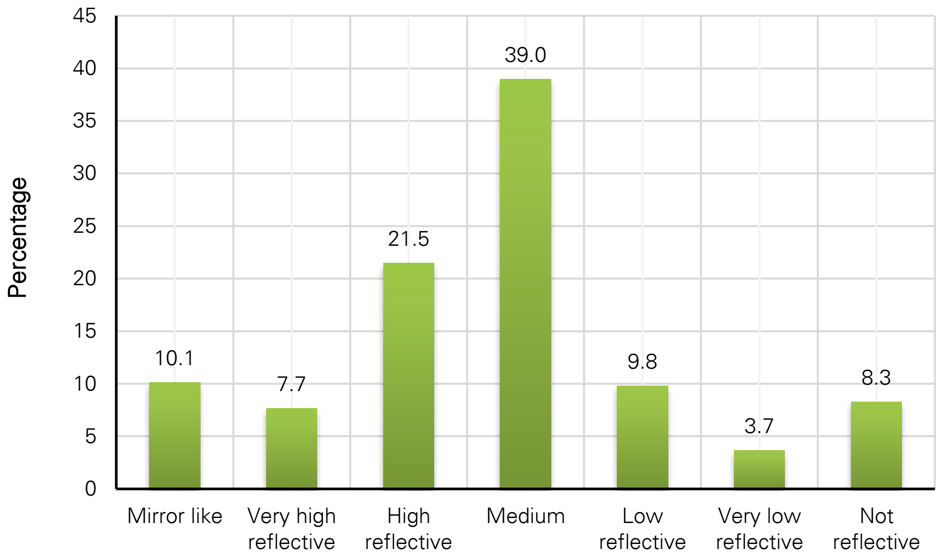


Figure 9 - 40: The preferred reflective factor for the office space occupants in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Mirror like	33	8.2	10.1	10.1
	Very High reflective	25	6.2	7.7	17.8
	High reflective	70	17.4	21.5	39.3
	Medium	127	31.6	39.0	78.2
	Low reflective	32	8.0	9.8	88.0
	Very low reflective	12	3.0	3.7	91.7
	Not reflective	27	6.7	8.3	100.0
	Total	326	81.1	100.0	
Missing system		76	18.9		
Total		402	100.0		

Table 9 - 37: The preferred reflective factor for the office space occupants in Cairo

The results show a tendency of office space users in Cairo to have a kind of external reflectance factor on their windows. Nearly 60.5% of them prefer their windows reflectance factor to range from medium to high reflective. i.e. between 40% and 80%.

- Preferred Level of Access & Exposure:

This section investigates the psychologically preferred level of access and the preferred level of exposure of the office space occupants in Cairo, which also give an indication of their desired level of privacy. Participants were asked to choose their desired levels of access and exposure from the given 4 levels that are discussed previously in Chapter IV of the research which are: see the outside and be seen (the gold-fish bowel), see the outside without being seen (the ideal), cannot see the outside but can be seen (the interrogation room) and cannot see the outside and cannot be seen (the cave).

The vast majority of the participants requires some privacy and choose the ideal (to see outside without being seen) with frequency of 324 subjects representing 82.9 valid percent, the golden-fish bowel (see the outside and be seen) came second with frequency of 61 subjects representing 15.6 valid percent, while with almost a negligible ratio the cave (cannot see the outside and cannot be seen) and the interrogation room (cannot see the outside but can be seen) came third and fourth with 1.3 and 0.3 percent respectively (figure 9 - 41 & table 9 - 38). The majority of choices to ideal came correspondent with the most frequently desired outcome for a window as mentioned by Heerwagen (1990).

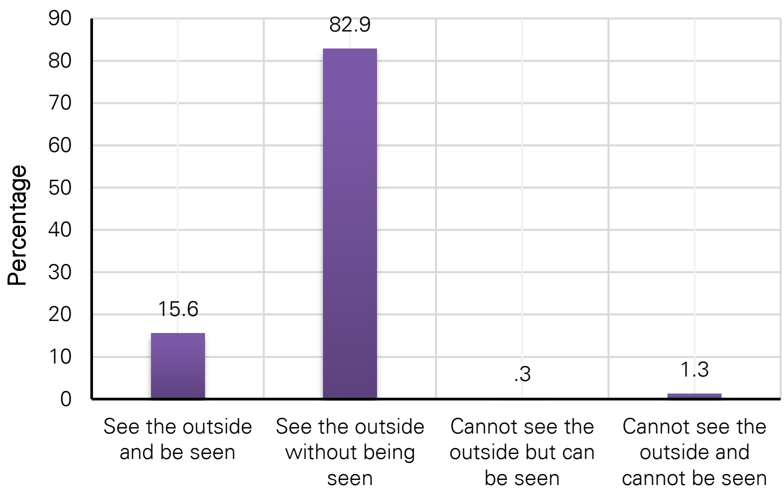


Figure 9 - 41: The desired level of access and exposure for the office space occupants in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	See the outside and be seen	61	15.2	15.6	15.6
	See the outside without being seen	324	80.6	82.9	98.5
	Cannot see the outside but can be seen	1	.2	.3	98.7
	Cannot see the outside and cannot be seen	5	1.2	1.3	100.0
	Total	391	97.3	100.0	
Missing system		11	2.7		
Total		402	100.0		

Table 9 - 38: The desired level of access and exposure for the office space occupants in Cairo

- **Preferred External Glazed area:**

The psychological preference to the glazed office building's perception in Cairo and the reasons for this preference is investigated in this section. First, participants were asked to define their preferred external glazing ratio from a given 5 pictures representing 5 buildings having the same size and number of floors but with different external glazing ratios as follows: picture (A) is an office building with external glazed ratio of 90% representing the range from fully glazed façade to 80% glazing, Picture (B) is an office buildings with external glazed ratio of 70% representing the range from 60% to 80% glazing, Picture (C) is an office buildings with external glazed ratio of 50% representing the range from 40% to 60% glazing, Picture (D) is an office building with external glazed ratio of 30% representing the range from 20% to 40% glazing, and Picture (E) is an office building with external glazed ratio of 10% representing the range of less than 20% glazing (figure 9 – 42). Second, the participants were asked a multiple response question to choose the reason(s) that govern their choices.

Figure 9 - 42: The given 5 pictures representing different external glazing ratios for an office building in Cairo

The majority with a frequency of 203 subjects and 51 valid percent preferred the first choice of the fully glazed office building. 127 subjects representing 31.9 valid percent preferred office building with external glazing ratio between 60% and 80%, frequency of 57 subjects representing 14.3 valid percent preferred the glazed ratio to range from 40% to 60%, and only frequency of 11 subjects with 2.8 valid percent chooses the external glazing range between 20% and 40%, while no choices go to the last picture (less than 20% glazing) (figure 9 - 43 & table 9 - 39).

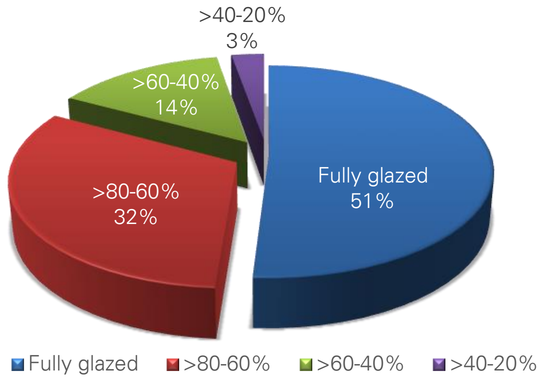


Figure 9 - 43: Preference to the office buildings external glazing ratios in Cairo

		Frequency	Percent	Valid Percent	Cumulative Percent		
Valid	Fully glazed (1)	203	50.5	51.0	51.0	Mean	1.69
	>80-60% (2)	127	31.6	31.9	82.9	Median	1.00
	>60-40% (3)	57	14.2	14.3	97.2	Mode	1.00
	>40-20% (4)	11	2.7	2.8	100.0	Std. Dev.	0.82
	Total	398	99.0	100.0			
Missing system		4	1.0				
Total		402	100.0				

Table 9 - 39: Preference to the office buildings external glazing ratios in Cairo

The difference in score between reasons that govern the participant's choices are not wide. However, for the elegancy and beauty of the glazed building came first with frequency of 301 responses representing 32.7 valid percent, followed by the expression of modernity with 246 responses and 26.7 valid percent, to express richness came third with 180 responses and 21.0 valid percent, and to express power came last with 193 responses representing 19.6 valid percent (figure 9 - 44 & table 9 - 40).

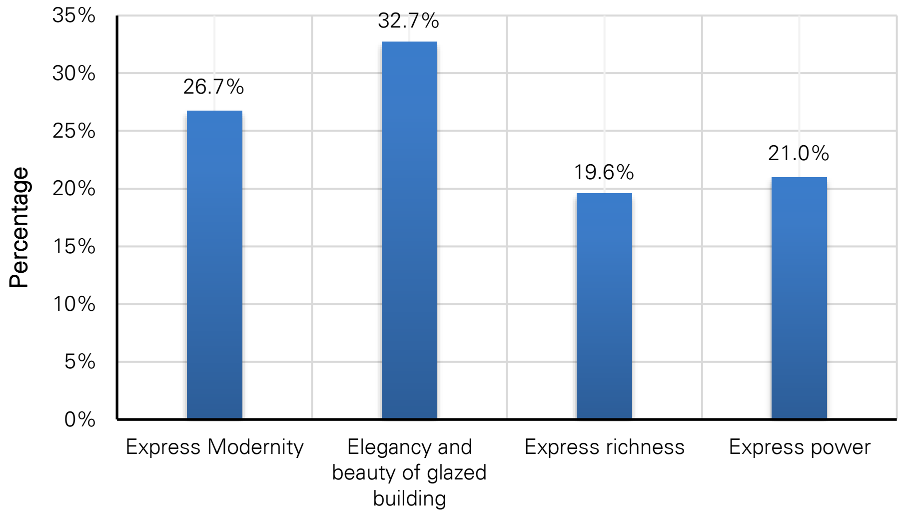


Figure 9 - 44: Reasons of the glazed office buildings preference in Cairo

		Responses		Percent of Cases
		N	Percent	
Multiple response	Express Modernity	246	26.7%	65.8%
	Elegancy and beauty of glazed building	301	32.7%	80.5%
	Express richness	180	19.6%	48.1%
	Express power	193	21.0%	51.6%
Total		920	100.0%	246.0%

Table 9 - 40: Reasons of the glazed office buildings preference in Cairo

From the previous question results, it is obvious that the preference is to the highly-glazed office buildings in Cairo, 51% prefer a fully glazed office building and almost 97.2% prefer the glazing ratio to be more than 40% glazing. These figures indicate a nearly coincidence with the user's preference to the wwr in their office space, indicating that the preference to the highly-glazed office buildings in Cairo is for the provided value of transparency internally as well as externally and nearly with the same ratios.

- **Preferred Solar Shading Devices:**

Since external shading devices are rarely used in office buildings in Cairo, it is convenient to investigate their level of psychological acceptance to the office space occupants. Participants were given eight types of external shading devices and were asked to decide if they accept or not accept each type of the given shadings. Each shading is demonstrated with 2 pictures representing an external and internal view of the device with the same window area and the same external view. The given external shading devices are horizontal overhang, horizontal overhang with side fins, perforated shading (Mashrabiya), horizontal louvers, transparent roller blinds, light shelf, horizontal fins and vertical fins (figure 9-45). Then, participants were asked an open-ended question for the reason(s) that regulate their choices.

Horizontal overhang	Horizontal overhang with side fins	Perforated shading (Mashrabya)	Horizontal louvers
			
			

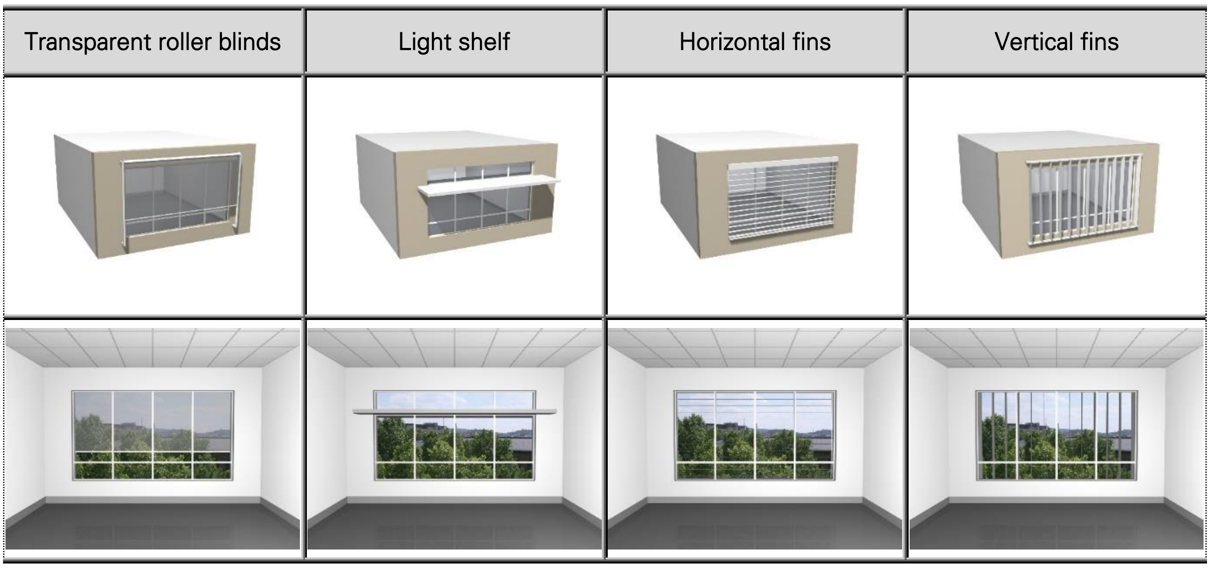


Figure 9 - 45: The given pictures demonstrating the outside and inside views for the external shadings

Five out of the given eight shading devices got a valid acceptance ratio of more than 50% acceptance. Horizontal fins came first with the highest acceptance valid ratio of 73.6, horizontal overhang came second with a valid acceptance ratio of 67.7, horizontal louvers came third with a valid acceptance ratio of 64.5, vertical fins came fourth with valid acceptance of 56.5, and the least accepted external shading devices is the perforated shading (Mashrabiya) with a valid acceptance ratio of 50.9. On the other hand, the unaccepted shading devices (got less than 50% acceptance) are the transparent roller blind with 44.8 valid acceptance ratio, the horizontal overhang with side fins with 43.3 valid acceptance ratio and last the light shelf with only 28.6 valid acceptance ratio (figure 9 - 46 & table 9 - 41).

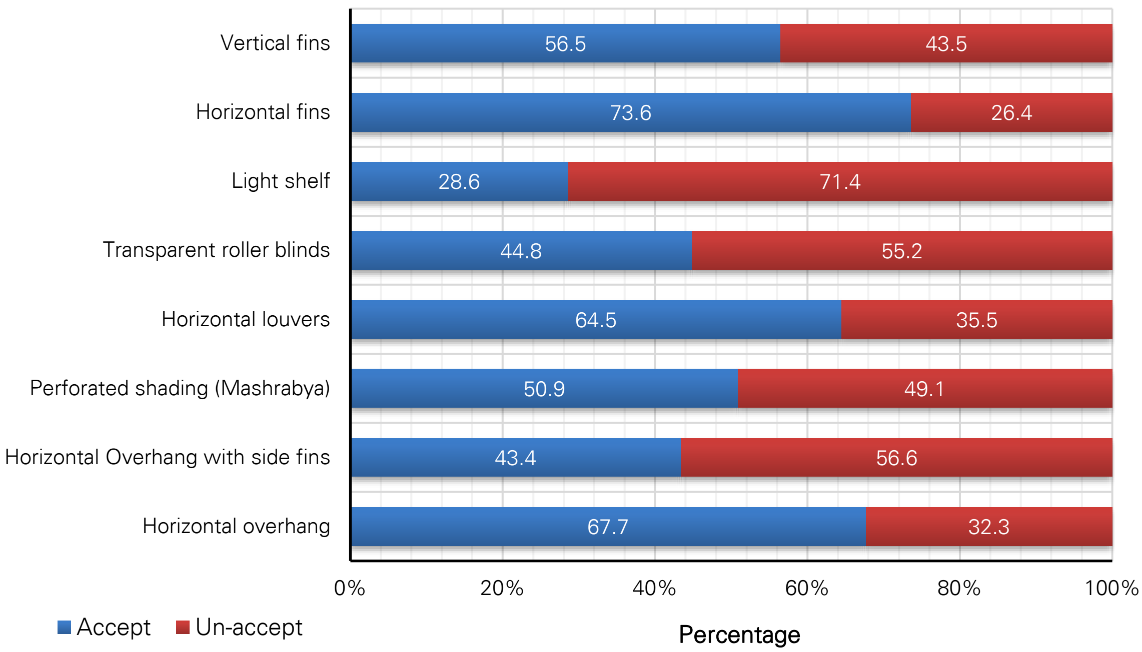


Figure 9 - 46: Accepted and unaccepted ratios to the given external shading devices in Cairo’s office spaces

Shading type	Accept		Un-accept		Total	
	Frequency	Valid Percent	Frequency	Valid Percent	Frequency	Valid Percent
Horizontal overhang	268	67.7	128	32.3	396	100.0
Horizontal Overhang with side fins	171	43.4	223	56.6	394	100.0
Perforated shading (Mashrabya)	201	50.9	194	49.1	395	100.0
Horizontal louvers	254	64.5	140	35.5	394	100.0
Transparent roller blinds	178	44.8	219	55.2	397	100.0
Light shelf	112	28.6	280	71.4	392	100.0
Horizontal fins	290	73.6	104	26.4	394	100.0
Vertical fins	223	56.5	172	43.5	395	100.0

Table 9 - 41: Accepted and unaccepted ratios to the given external shading devices in Cairo's office spaces

Only 174 Participants answered the open-ended question of the reasons that govern their choices for the external shading devices acceptance. Their answers varied in reasons, however, they could be classified to 247 responses in 6 categories; the majority of the responses, nearly more than half of them with 124 responses and 50.2 valid percent mention the external view as the main reason that governs their choices for the external shading devices preference, regulating both daylight and sunlight reasons came second with 53 responses and 21,5 valid percent, the acceptance to the shape and the appearance of the shading device without giving any functional reasons came third with 31 responses and 12.6 valid percent, the ease to control and operate came forth with 18 responses and 7.3 valid percent, to avoid heat gain came fifth with 14 responses and 5.7 valid percent, and for the durability and the ease to maintain came last with only 7 responses and 2.8 valid percent. The energetic performance of the five accepted external shading devices will be further investigated in the energetic modeling and simulation section of the research (figure 9 - 47 & table 9 - 42).

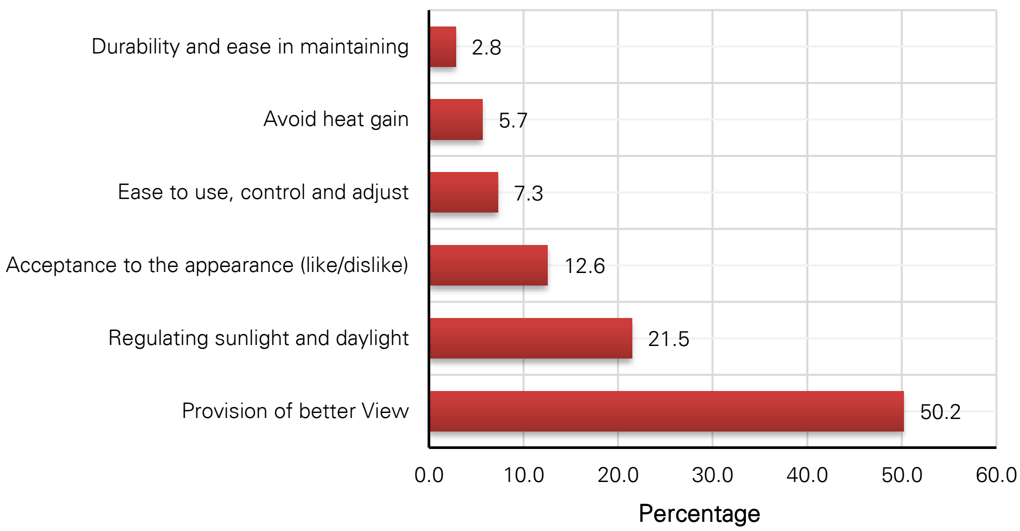


Figure 9 - 47: Reasons that regulated the acceptance to the external shading devices in Cairo

		Responses	
		N	Percent
Open Ended	Provision of view	124	50.2%
	Regulating sunlight & daylight	53	21.4%
	Acceptance to the appearance	31	12.6%
	Ease to use and control	18	7.3%
	Avoid heat gain	14	5.7%
	Durability and ease o maintain	7	2.8%
Total		247	100.0%

Table 9 - 42: Reasons that regulated the acceptance to the external shading devices in Cairo

Lechner (2015) argued that since the view is one of the highest requirements for windows, a single horizontal overhang is usually the most preferred. Although it obstructs view of higher levels to the sky, but the more important horizontal view is uninterrupted. In addition, vertical fins obstruct the view much more than horizontal shadings, they limit the visual exposure angle, especially when the fins are deep. Nielson (1990) added that, with the existence of a beautiful view, the placement of vertical divisions or shadings is not recommended. This can give an explanation to the high acceptance ratio for the horizontal shading devices for giving the occupants wide visual angle, while shading devices with Vertical elements came with low acceptance ratios, and consequently, the mashrabiya (perforated shading) with both vertical and horizontal elements came the least accepted shading device.

- Importance of View to the Outside:

This point Investigates the psychological preference of office space occupants to the external view in Cairo's. Participants were asked to specify the degree of importance to the external view preference in their working place. Frequency of 196 subjects representing 48.9 valid percent considered the visual contact with the outside very important, 179 subjects with 44.6 valid percent consider it important, while frequency of 25 subjects considered it neutral, only one subject considered the external view unimportant and no choices for very unimportant (figure 9 - 48 & table 9 - 43).

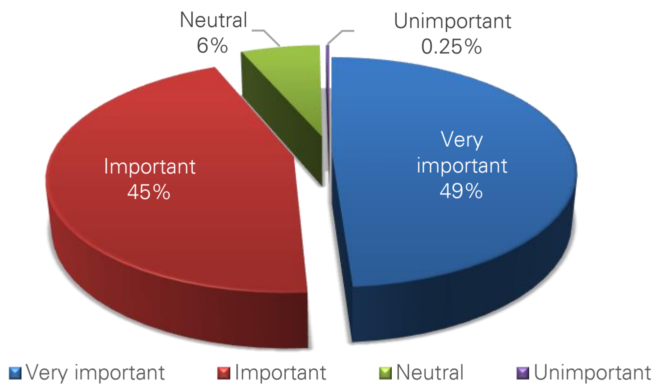


Figure 9 - 48: Degree of importance to the external view in Cairo's office spaces

		Frequency	Percent	Valid Percent	Cumulative Percent		
Valid	Unimportant (-1)	1	.2	.2	.2	Mean	1.42
	Neutral (0)	25	6.2	6.2	6.5	Median	1.00
	Important (+1)	179	44.5	44.6	51.1	Mode	2.00
	Very important (+2)	196	48.8	48.9	100.0	St. Dev.	0.62
	Total	401	99.8	100.0			
Missing system		1	.2				
Total		402	100.0				

Table 9 - 43: Degree of importance to the external view in Cairo's office spaces

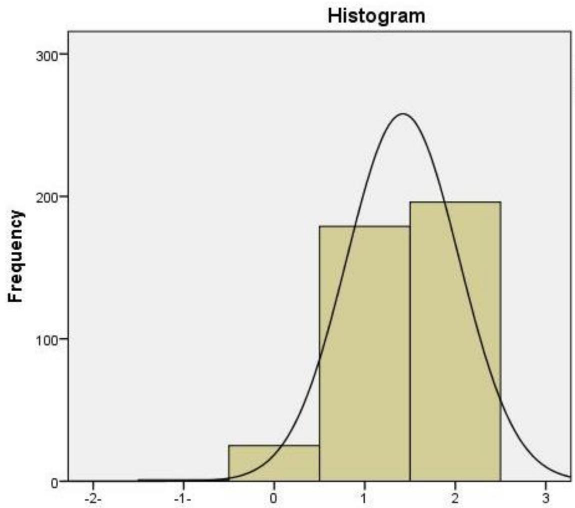


Figure 9 - 49: Degree of importance to the external view in Cairo's office spaces histogram

It is obvious from the results that 93.5% of the office space occupants in Cairo considered the visual contact to the outside as an important issue. Regarding the results of the histogram, the mean value of the view importance scored 1.42, i.e. important with more tendency to very important, and the mode is 2.0 (very important). In a similar study, Voss, et al. (2007) shows congruous findings (figure 9 - 50)

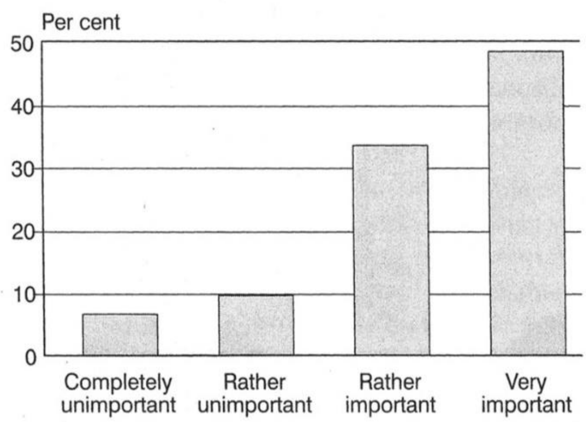


Figure 9 - 50: Importance of a view outdoors (Voss, et al., 2007)

- Preferred View to Energy Efficient Thermal Concepts Balance:

This section is a very significant point for the research work. It investigates the preferred balance between the visual contact to the outside and the energetic efficient thermal concepts in the office spaces. In order to make the question clear for the participants, they were given the following statement: "Increasing the glazed area (window) will enhance the visual contact to the outside for the users, but will contribute to high energy consumption to achieve the desired thermal comfort. While decreasing the glazed area will improve the energetic performance, but it will reduce the external visual preference for the users". Then, participants were asked to indicate their preference ratio between the desired visual contact to the outside and the energy efficient thermal concepts.

The results showed almost a split of the participants' preference ratios around 50% visual to 50% energy efficient thermal concepts. Also, the majority chose this ratio of preference with a frequency of 90 participants representing 22.6 valid percent (figure 9 - 51 & table 9 - 44). Table 9 – 45 shows that the mean value for the visual preference is 49.2 and 50.8 for the energy efficient thermal comfort, and both the median and the mode values are 50 to 50.

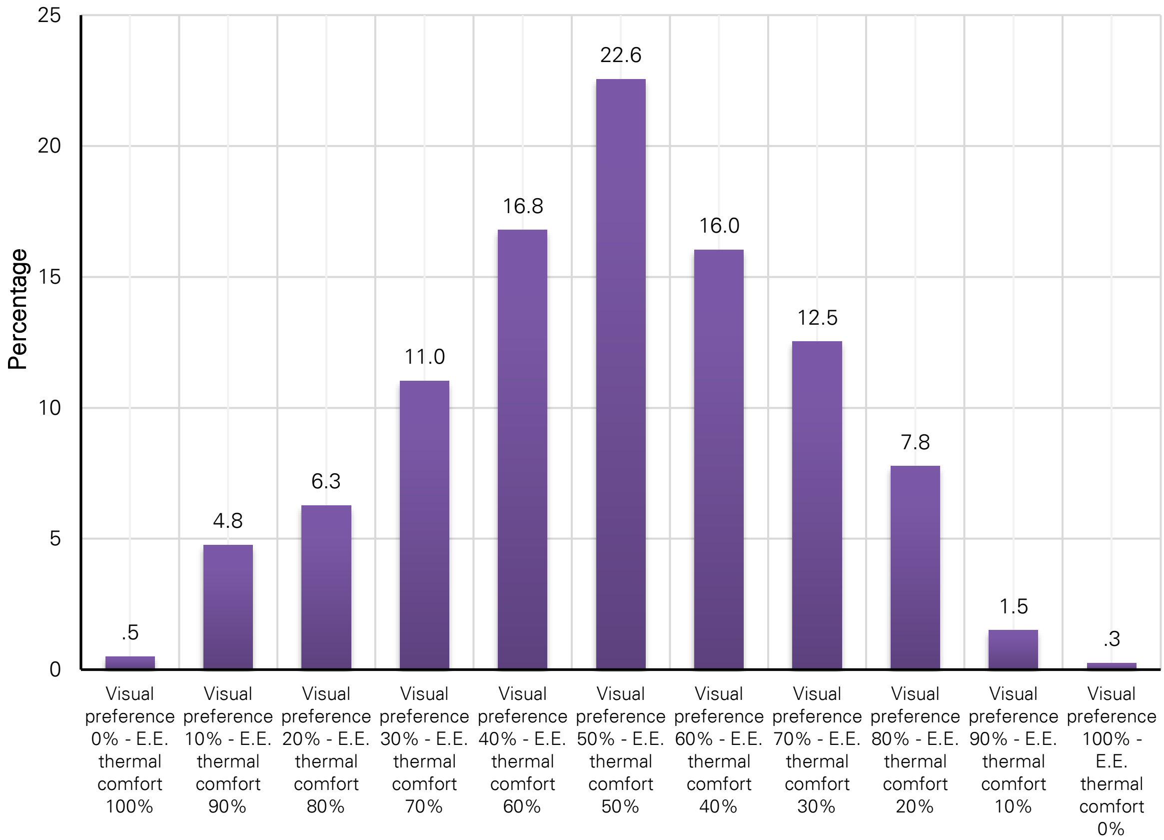


Figure 9 - 51: The office space occupants in Cairo preferred ratios of the external visual preference to the energy efficient thermal comfort concepts

		Frequency	Percent	Valid Percent	Cumulative Percent	
Valid	Visual preference 0% - E.E. thermal comfort 100% (1)	2	.5	.5	.5	
	Visual preference 10% - E.E. thermal comfort 90% (2)	19	4.7	4.8	5.3	
	Visual preference 20% - E.E. thermal comfort 80% (3)	25	6.2	6.3	11.5	Mean 5.92
	Visual preference 30% - E.E. thermal comfort 70% (4)	44	10.9	11.0	22.6	Median 6.00
	Visual preference 40% - E.E. thermal comfort 60% (5)	67	16.7	16.8	39.3	Mode 6.00
	Visual preference 50% - E.E. thermal comfort 50% (6)	90	22.4	22.6	61.9	St. Dev. 1.93
	Visual preference 60% - E.E. thermal comfort 40% (7)	64	15.9	16.0	77.9	
	Visual preference 70% - E.E. thermal comfort 30% (8)	50	12.4	12.5	90.5	
	Visual preference 80% - E.E. thermal comfort 20% (9)	31	7.7	7.8	98.2	
	Visual preference 90% - E.E. thermal comfort 10% (10)	6	1.5	1.5	99.7	
	Visual preference 100% - E.E. thermal comfort 0% (11)	1	.2	.3	100.0	
	Total	399	99.3	100.0		
Missing system		3	.7			
Total		402	100.0			

Table 9 - 44: The office space occupants in Cairo preferred ratios of the external visual preference to the energy efficient thermal comfort concepts

		Visual Preference (0-100%)	E.E. thermal comfort (100-0%)
N	Valid	398	398
	Missing	4	4
Mean		49.20	50.80
Median		50.00	50.00
Mode		50	50
Std. Deviation		19.304	19.304

Table 9 - 45: Mean, median and mode values for the external visual preference to the energy efficient thermal comfort concepts in Cairo's office spaces

Chapter X

Energetic Modeling and Simulation

10. Energetic Modeling and Simulation:

The ISO 9000 defines efficiency as "the relationship between the result obtained and the means used". In other words, being efficient is a way of behaving that leads to achieve the goal meanwhile keeping potentials and efforts to the minimum. Efficiency is not the question of doing the right things, it is rather doing things right". To make the energetic planning any building efficient means to guarantee that the necessary interior climate conditions can be maintained over the whole year with low-energy requirements and, wherever possible, without any costly energy supply technologies. Such planning requires an accurate understanding and analysis to the prevailing climatic conditions and the proper usage of energy (Hegger, et al., 2008, p. 24).

IEA (2008) added that, since the use of energy in buildings accounts for a significant share of the worldwide end-use of energy, therefore, energy efficiency in buildings should be a basic requirement for the whole construction industry. The decisions that are taken during the early conceptual phase determine energy consumption of the building over its lifetime. In addition, developing the energetic performance of the building at the design phase is relatively simple when compared to the required retrofitting and improvements that had to be made after its construction which will be much more difficult and very costly. Moreover, certain measures to improve the building's energy efficiency are only possible during the initial construction, otherwise it would need major refurbishments which are likely to be carried out after some decades with larger costs, while other improvements could be even with negative costs when implemented at a certain stage.

On the other hand, Miller, et al. (2009) noted that healthier working environments that increase the office workers' performance require some favorable lighting and visual conditions, acceptable sound levels, and thermal comfort levels, all of which are energy consuming measures, and are negatively affected by many energy efficiency concepts.

This part of the research is the third pillar of the research operational study. Its main principal is based on exploring the impact of the research solar protection parameters, as an energy efficient strategy, on the total energy consumption of office spaces with high degree of transparency in hot-arid climates, applied on the example of Cairo. The solar protection parameters are deducted from the psychologically preferred design criteria of the glazed component of office façades that was previously discussed in the research survey findings (Chapter IX – Point 9.2.2.4). These findings were used as a threshold to define the acceptable determinants for each parameter.

However, it is convenient to investigate first the interaction of two different building profiles in order to choose from them the more efficient profile configuration and apply it on the research base-case in the main simulation process; the first represents a typical Egyptian office space configuration, while the other is based on the ASHRAE standards.

The main objectives of this chapter of the research are the following:

- To validate the simulation software and to investigate the impact of applying two different office profile configurations on the energy consumption of the research office space model. The first profile (Profile A) represents a typical Egyptian office space. Its results will be compared with the average energy consumption rates of Cairo's office buildings from Chapter XIII (point 8.4.7). While the second profile (Profile B) is based on the ASHRAE standards for small to medium office buildings. Its findings will be compared with the typical Egyptian office space profile to analyze their impact on the energy consumption of office spaces in Cairo. Then, from both profiles, the more efficient one is chosen for the main modeling and simulation operations.
- To investigate the energy consumption rates which resulted from applying the solar protection strategy parameters to the research base-case model; basically, the lighting, cooling, and total energy consumption. These rates will be used in the later optimization process.

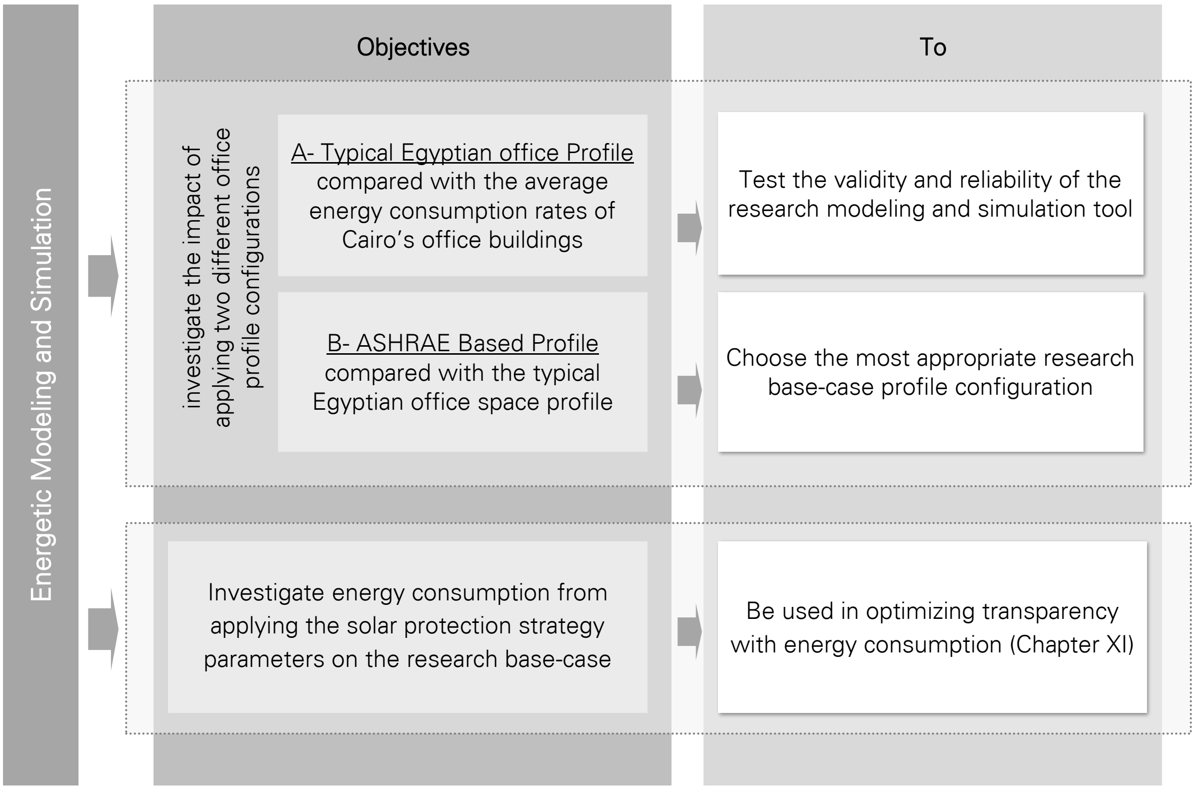


Figure 10 - 1: Research energetic modeling and simulation objectives

The findings of the previous objectives will be investigated with the aid of building information modeling and simulation (BIMS) software tool (DesignBuilder, V. 5.0.1.024). In the following sections (10.1 and 10.2), a detailed description of the modeling and simulation methodology and sequence, and the simulation findings will be presented.

10.1. Modeling and Simulation Methodology and sequence:

Through this part of the research, two main modeling and simulation operations were conducted. The first operation is a prerequisite of the second to determine the appropriate and the more efficient office space profile configurations:

Modeling and simulation Operations Phase - 1: In 8 modeling and simulation processes, two building profile configurations are modeled and simulated on the research office space model, where each profile is conducted for a different objective as follows:

- **Profile (A):** Represents a typical Egyptian office space profile. Profile A was applied on 4 modeling and simulation processes; each was conducted on one of the four main directions. The results are then compared to the actual energy consumption figures of Cairo's office buildings in order to investigate the validity and the reliability of the research BIMS software.
- **Profile (B):** Represents an ASHRAE based office space profile. Profile B was also applied on 4 modeling and simulation processes, each was conducted on one of the four main directions. Its findings were analyzed and compared to the findings of profile (A) in order to investigate the impact of the profile configurations on the energy performance of the office spaces in Cairo's climatic context. Then, the more energy efficient profile will be chosen to be used as a base case for the next main modeling and simulation operations (phase – 2).

Through Phase - 1 operations, both profiles (A & B) are modeled and simulated on the same research office space model with the same façade configuration. In other words, with the same solar protection parameters that are commonly used in the average Egyptian office space, which are: window to wall ratio of 50%, clear single 6 mm glazing, and internal transparent roller shading devices optimized for solar control, this will be discussed briefly in the later sections.

Modeling and Simulation Operations Phase - 2: These operations are the main modeling and simulation processes of the research work. A series of 448 parametric modeling and simulation processes are conducted, in which the more energy efficient profile configuration was applied first on the base-case model (operation 1 findings). Then, the research solar protection strategy parameters were modeled and simulated to assess their energetic performance. Through 420 operations, the following three solar protection parameters are examined:

- Window to wall ratio; with 7 variables
- External shading devices; with 5 variables
- Solar control glazing; with 3 variables

In every process, only one variable is changed with respect to the others. This was applied on the four main directions. In addition, 28 operations were conducted for modeling and simulating the case of clear 3 mm single glazing with no external shading for all the seven window-to-wall ratio variables and were also applied on the four main directions.

In each of the modeling and simulation operations phase - 2, the lighting, cooling, and total annual energy consumption per square meter are computationally measured. These measures will be used in the later optimization process through Chapter XI.

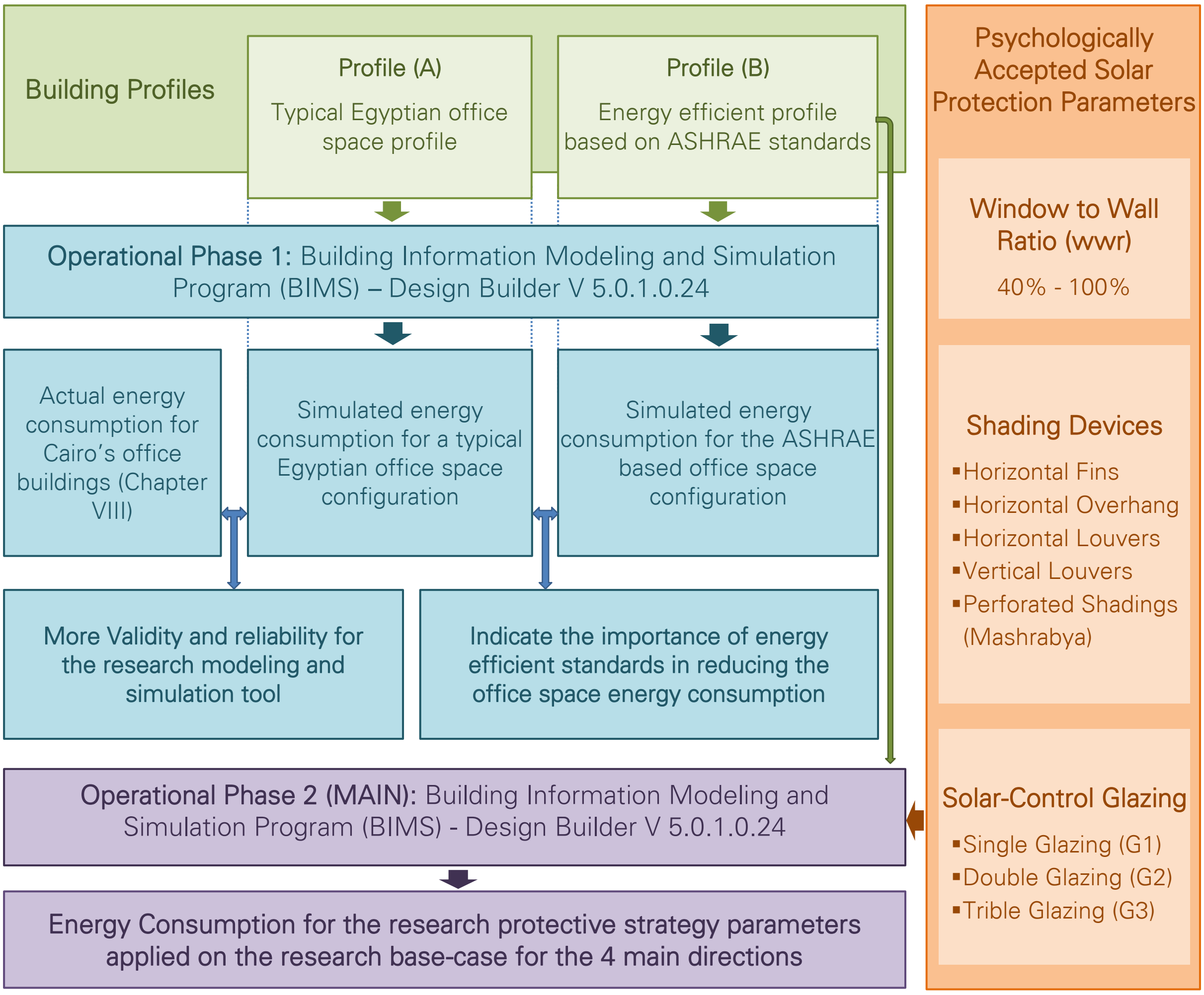


Figure 10 - 2: Research energetic modeling and simulation methodology

10.1.1. Base-Case Model Description:

The research base-case model is an imaginary reference of a single office space located on the outer perimeter of a typical office building. A design module for the office space of 1.2 m is considered. The total occupied area of the base-case model is 17.28 m^2, with dimensions of 3.60 m in width, 4.80 m in depth and 3.00 m in height (Figure 10 - 3). The office base-case has only one external wall, in which the transparent glazed component is located. Both the research modeling and simulation operation (A & B) are applied on this model.

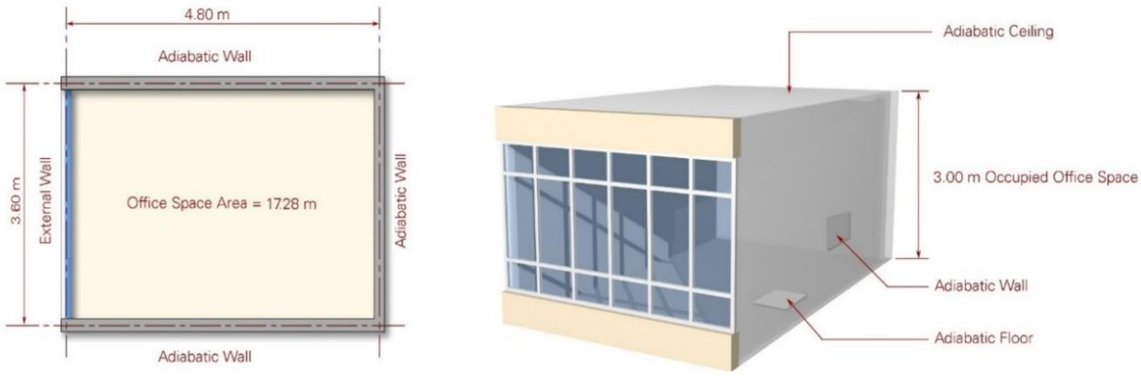


Figure 10 - 3: The research base-case model

In order to study the energetic performance of the research solar protection variables that are typically applied on the façade's glazed component, only the external wall is set to be interactive with the exterior environmental conditions. The other three walls are set to be adiabatic, i.e. there is no thermal interaction between the modeled office space and the external environment through these walls. The base-case model ceiling and floor are also set to be adiabatic.

10.1.2. Modeling and Simulation Software:

DesignBuilder Software V 5.0.1.0.24 © 2000-2016 is used in this section as the research building information modeling and simulation (BIMS) software. It is a user-friendly modeling software for engineers, architects, and energy assessors. It works with virtual building models through an easy-to-use graphically represented interface. DesignBuilder can provide a wide range of accurate and reliable building environmental performance data such as energy consumption, carbon emissions, comfort conditions, daylight illuminance, maximum summertime temperatures and HVAC component sizes in order to help in figuring out the design decisions from the conceptual phase to completion. A series of DesignBuilder validation tests are demonstrated in the DesignBuilder EN ISO 13790 standard report in accordance with European Standard EN 152652. The tests' results were compared to the EN 152653 using accuracy criteria. They have indicated positive agreement within the acceptable range of the resulting temperatures and energy flows (DesignBuilder, 2012).

DesignBuilder software integrated the Energy-Plus dynamic simulation engine to generate the building's performance data. EnergyPlus is the U.S. DOE building's energy simulation program. It is built on the most popular features and capabilities of BLAST and DOE-2; it also includes many innovative simulation capabilities such as modular systems for integrating the building heating and cooling balance-based zone simulation, multi-zone airflow, lighting, ventilating, and other energy flows. (DesignBuilder, 2015).

10.1.3. Computationally Measured Criteria:

Energy consumption is one of the most crucial criteria in planning the transparent component of the façade. Throughout the research parametric modeling and simulation processes, the solar protection variables are modeled and applied on the research base-case in DesignBuilder, then simulated using energy plus simulation engine for one complete year. Usually, DesignBuilder uses the year 2003 for its annual simulations. The annual energy demand for cooling, annual energy demand for lighting, and the total annual energy demand (which includes: cooling, lighting, domestic hot water, and other office equipment energy loads) are computed. The used unit for calculation is the annual energy consumption per meter square, measured in KWh/m^2.a (Kilowatt hour per meter square annually).

10.1.4. Modeling input profiles:

In both profiles, the used weather file in the modeling and simulation processes is an EnergyPlus weather file format (.epw) of Cairo's international airport weather station (623660 ETMY), downloaded from the US Department of Energy's (DOE) - EnergyPlus on-line website (EnergyPlus, 2016). Through the following points, a full description of the research profiles (A & B) will be demonstrated:

10.1.4.1. Profile A: Typical Egyptian Office Profile

This profile is basically assumed to represent an average performance of a typical Egyptian office space. Its configuration is mainly based on both the research survey findings, part III, point 9.2.2.3 (the office occupant's interaction with transparency) and the research work of Abdel-Gawad (2011).

- Occupancy Profile: The space function and its occupancy profile are the key divers for most of its internal heat loads, in which the occupant's space density leads to heat gain from the user's bodies, and from the office equipment, computers and other appliances. In the typical Egyptian office space occupancy profile, the space function is defined as generic office space; its occupancy density is set to be 0.2 person/m^2. The clothing factor values are chosen to be 1 clo in winter times clothing, and 0.5 clo in summer times clothing.

  The working time schedule is set to be on/off schedules. Working hours starts starting at 6:00 am and ends at 20:00 pm. The working time schedule is operated five days per week, from Sundays to Thursdays, since Fridays and Saturdays are the weekends in Egypt.

Occupancy Item	Value	Unit
Occupancy Density	0.20	People/m^2
Clothing Factor	Winter clothing = 1	clo
	Summer clothing = 0.5	clo

Occupancy Item	Value	Unit
Working hours	6:00 am – 20:00 pm	Hours/day
Working Days	5	Days/week
Holidays	14	Holiday/year

Table 10 - 1: Profile (A) occupancy schedule

Through the research modeling and simulation processes, the Georgian holidays calendar of Egypt for the year 2015 is applied. It was taken into consideration that in 2015 calendar, there are 14 official annual holidays in Egypt. Nine of them are fixed days, i.e. related to the Georgian calendar; these are: the Coptic Christmas day (7th January), 25th January revolution (25th January), Coptic Easter (12th April), Sham El-Nassim (13th April), Sinai liberation day (25th April), labor's day (1st May), 30th June revolution (30th June), Egypt's national day (23th July), and the Armed Force day (6th October). While, the other 4 holidays are related to Islamic calendar, therefore they are changed annually; these are: birth of prophet Mohamed (3rd January), end of Ramadan (small) Feast (17th - 19th July), Grand Feast (22nd - 25th September), and the Islamic New Year (14th October). Due to the difference between the Islamic and the Georgian calendars in nearly 12 days per year, the birth of prophet Mohamed holiday coincided to coexist two times in 2015; once on the 3rd of January and the other on the 23rd of December.

Vacation		Date	No. of Days
1	Birth of profit Mohamed	3rd January	1
2	Coptic Christmas day	7th January	1
3	25th January revolution	25th January	1
4	Coptic Easter	12th April	1
5	Sham El-Nassim	13th April	1
6	Sinai Liberation day	25th April	1
7	Labor's day	1st May	1
8	30th June revolution	30th June	1
9	End of Ramadan (small) Feast	17th - 19th July	3
10	Egypt's national day	23rd July	1
11	Grand Feast	22nd - 25th September	4
12	Armed force day	6th October	1
13	Islamic New Year	14th October	1
14	Birth of profit Mohamed	23rd December	1

Table 10 - 2: Holidays in Egypt for the year 2015

- **Internal Loads Profile:** Heat generated from the office space occupants or their metabolic rate per person is optimized for light office working activity, this generates energy equals to 120 W/person. However, since the average metabolic factor for a woman equals to 0.85 and for a man equals to 1.0, an average value of 0.9 is used for the profile metabolic factor. The internal heat loads generated from computers and other office equipment per unit area in the typical Egyptian office profile is set to be 25 W/m^2, with a radiant factor equals to 0.2. While the average lighting radiant factor is 0.37, and its convective factor equals to 0.45.

Item		Value	Unit
Occupants	Metabolic rate	120	W/person
	Metabolic factor	0.90	---
Lighting	Radiant factor	0.2	---
	Convection factor	0.2	---
Office Equipment	Office equipment heat gain	25	W/m^2
	Equipment radiant fraction	0.2	---

Table 10 - 3: Profile (A) internal loads schedule

- **External wall Profile:** The overall heat transfer coefficient (U-value) of the external mass wall configuration used in profile (A) equals to 3.6 W/m^2.K, while the other wall surfaces, roof and floor are set to be adiabatic, i.e. there is no thermal interaction between them and the environment. The window to wall ratio is set to be 50%, as an average value to the studied office buildings cases in Cairo, Chapter VIII. The used external glazing is a clear single 6 mm glass with an overall U-value equal to 6.12 W/m^2.K, total solar transmission (SHGC) of 8.19, and visible light transmission equal to 0.881. Solar shading system is set to be internal transparent roller shadings, since according to the research survey findings, it is the most used type of office shadings in Cairo's office spaces. The office space internal shadings are operated from 6:00 am till 20:00 pm, and are optimized for solar control type.

External Wall Item		Value	Unit
Mass wall U-value		3.60	W/m^2.K
Window to wall ratio		50%	---
Glazing	U-Value	6.12	W/m^2.K
	SHGC	0.810	---
	Visible light transmittance	0.881	---
Shading		Internal transparent shading, optimized for solar control	---

Table 10 - 4: Profile (A) external wall configuration schedule

- **Visual Profile:** The target illuminance level is set for 500 lux, where it is needed for the performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size (Rea, 2000). The used lighting system is fluorescent lighting, with normalized lighting power density (LPD) equals to 5.0 W/m^2-100 lux, and a visible fraction of 0.18. The luminaire type is recessed with semi-transparent cover. No lighting sensors are used in this profile.

Visual Item	Value	Unit
Target Illuminance	500	lux
Lighting type	Florescent	---
Lighting power density (LPD)	5.0	W/m^2-100 lux
visible fraction	0.18	---
Luminaire	Recessed	---
Lighting sensor	Not used	---

Table 10 - 5: Profile (A) visual profile schedule

- **HVAC Profile:** Profile (A) HVAC system is a fan coil unit with air cooled chiller template, where it is the most used system in Cairo's office buildings. The used fuel for the system is electricity from the grid. The cooling set-point temperature is 24 °C and the cooling setback temperature is 28 °C. The HVAC system provides a 12 °C minimum supply air temperature, with 0.0077 g/g for minimum supply air humidity ratio. The cooling system seasonal coefficient of performance (CoP) is 2.5. The heating system is set off since 74.3% of the office space occupants reject having heating systems in their working places. The HVAC system is operated (on/off) from 6:00 am till 20:00 pm for the 5 working days per week.

HVAC item	Value	Unit
System	Fan coil unit	---
Cooling set-point	24	°C
Cooling setback	28	°C
Supply air temperature	12	°C
Supply air humidity ratio	0.0077	g/g
Coefficient of performance	2.5	---
Operating time	6:00 – 20:00	---

Table 10 - 6: Profile (A) HVAC profile schedule

- **Ventilation Profile:** Both the mechanical and natural ventilation were used in the profile. The mechanical ventilation rate is set to be 2 ac/h, providing minimum fresh air per area equal to 15 l/s-m^2. For natural ventilation, the temperature set point is 22 °C, the minimum fresh air is set to be 2.5 l/s-person, and the operable window area is adjusted to 25%. The ventilation system is operated from 6:00 till 20:00 pm, 5 days per week. The profile air tightness or the infiltration rate is 0.8 ac/h and set to be on 24/7.

Ventilation item		Value	Unit
Mechanical ventilation	Mechanical ventilation rate	2	ac/h
	Minimum fresh air per area	15	l/s-m^2
Natural ventilation	Temperature set point	22	°C
	Minimum fresh air	2.5	l/s-person
operable window area		25%	---
Operating time		6:00 – 20:00	---
infiltration rate		0.8	ac/h.24/7

Table 10 - 7: Profile (A) ventilation profile schedule

10.1.4.2. Profile B: ASHRAE Based Office Profile:

The U.S. Department of Energy (DOE) has identified eight primary climate zones of the United States. Each zone is then further subdivided according to their moisture levels into: moist or humid (A), dry (B), and marine (C) to characterize their seasonal values. Sixteen cities have been identified as sufficient to represent all of the climatic zones. Figure 10 - 4 shows this climate classification.

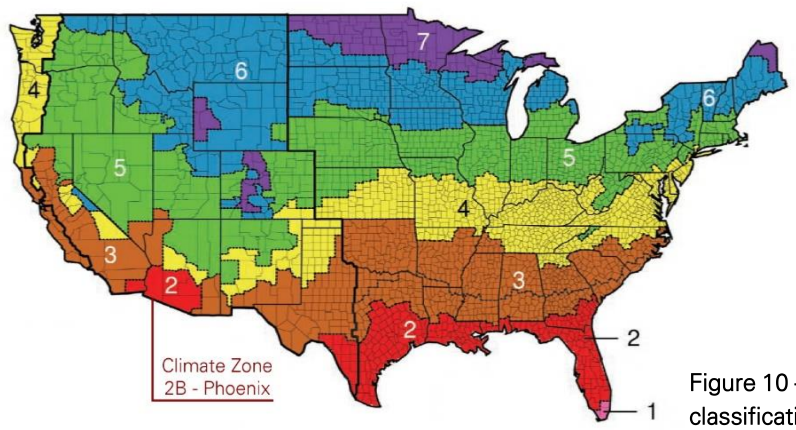


Figure 10 - 4: U.S. department of energy climate classification to the USA (ASHRAE, 2011)

Referring to Köppen - Geiger climate classification, and by determining climate similarities, it was found that both the Greater Cairo Region climate and the U.S. 2B - Phoenix climate zone show the same climatic characteristics. Both areas lie in the BWh region indicating hot, dry and desert climates. These similarities allow for applying the ANSI/ASHRAE/IES standards and its design recommendations of the B2 climate zone on the research modeling profiles data. The following section demonstrates the research profile (B) data based on the advanced energy design guide for small to medium office buildings (ASHRAE, 2011):

- **Occupancy Profile:** According to the ASHRAE/AIA/IESNA design guides and ASHRAE 90.1 standard 62.1 category, profile (B) space function is defined as enclosed office space, its occupancy density is set to be 0.0538 person/m^2. The clothing factor values are chosen for normal office clothing; winter clothing equals 1 clo, and summer clothing equals 0.5 clo. The working time schedule is set according to the ASHRAE 90.1 standard for office occupancy; working hours starts at 7:00 am and ends at 18:00 pm. Table 10 - 8 demonstrates profile (B) typical working day occupancy schedule.

Duration	Occupancy %
6:00 am – 7:00 am	10%
7:00 am – 8:00 am	20%
8:00 am – 17:00 pm	95%
17:00 pm – 18:00 pm	30%
18:00 pm – 22:00 pm	10%
22:00 pm – 24:00 pm	5%
24:00 pm – 6:00 am	0.00%

Table 10 - 8: Profile (B) daily occupancy

The basic working time schedule is operated five days per week from Sundays to Thursdays as the weekend in Egypt is on Fridays and Saturdays. The same holiday's schedule of profile (A) is also applied on profile (B).

Occupancy Item	Value	Unit
Occupancy Density	0.0538	People/m^2
Clothing Factor	Winter clothing = 1	Clo
	Summer clothing = 0.5	Clo
Working hours	ASHRAE 90.1 office occupancy	---
Working Days	5	Days/week
Holidays	14	Holiday/year

Table 10 - 9: Profile (B) occupancy schedule

- **Internal Loads Profile:** Heat generated from the office space occupants or their metabolic rate per person is also optimized for light office working activity such as working, standing or working; this generates energy equal to 120 W/person, the profile metabolic factor is set to be 1.0. According to Wilkins & Hosni (2000), the internal heat loads generated from computers and other office equipment per unit area ranges from 0.44 W/ft^2 (4.74 W/m^2) to 1.05 W/ft^2 (11.30 W/m^2), within range of 0.81 W/ft^2 (8.72 W/m^2). The average range value is chosen for the profile internal heat gain from all office equipment, with a radiant fraction equal to 0.2. The average lighting radiant factor is 0.42, and its convection factor is 0.40.

Item		Value	Unit
Occupants	Metabolic rate	120	W/person
	Metabolic factor	1.0	---
Lighting	Radiant factor	0.42	---
	Convection factor	0.40	---
Office Equipment	Office equipment heat gain	8.72	W/m^2
	Equipment radiant fraction	0.2	---

Table 10 - 10: Profile (B) internal loads schedule

- **External wall Profile:** According to the ASHRAE guides, the recommended heat transfer coefficient (U-value) for the external mass walls in B2 climatic conditions, which is corresponding to Cairo's climate, is 0.69 W/m^2.C (ASHRAE, 2011). This value is also consonant with the Egyptian code for enhancing energy efficiency in commercial buildings (Standing Committee of Planning the Egyptian Code for Enhancing Energy Efficiency in Buildings, 2009). While the other wall surfaces, roof and floor are also set to be adiabatic. For the window to wall ratio, glazing system and solar shadings parameters, the same configuration that was previously demonstrated in profile (A) were also used in modeling profile (B) to make it more convenient for comparing the simulated findings of the two profiles.

External Wall Item		Value	Unit
Mass wall U-value		0.69	W/m^2.K
Window to wall ratio		50%	---
Glazing	U-Value	6.12	W/m^2.K
	SHGC	0.810	---
	Visible light transmittance	0.881	---
Shading		Internal transparent shading, optimized for solar control	---

Table 10 - 11: Profile (B) external wall configuration schedule

- **Visual Profile:** The target illuminance level is set for 500 lux; where it is defined by Rea (2000) as the needed illuminance for the performance of visual tasks of high contrast and small size, or visual tasks of low contrast and large size. The used lighting system is LED with linear control template, the normalized lighting power density (LPD) equals to 25.0 W/m^2 with visible fraction of 0.18. The luminaire type is suspended with semi-transparent cover. One light level control sensor is used in this profile, in which the artificial lighting level is adjusted in accordance to the natural daylighting level to provide the required illuminance level (500 lux) on the working plane, which is defined to be at 80 cm above the floor level.

Visual Item	Value	Unit
Target Illuminance	500	lux
Lighting type	LED	---
Lighting power density (LPD)	2.5	W/m^2-100 lux
visible fraction	0.18	---
Luminaire	Suspended	---
Lighting sensor	Used	---

Table 10 - 12: Profile (B) visual profile schedule

- **HVAC Profile:** The HVAC system for profile (B) is chilled ceiling with air cooled chiller template. The used fuel for the system is electricity from the grid. The cooling set-point temperature is 26 °C, and the cooling setback temperature is 30 °C. The HVAC system provides 18 °C for minimum supply air temperature, with 0.0077 g/g for minimum supply air humidity ratio. The cooling system seasonal coefficient of performance (CoP) is 2.5, and the heating system is also set off. The profile HVAC system is operated according to the ASHRAE 90.1 office occupancy schedule.

HVAC item	Value	Unit
System	Chilled ceiling	---
Cooling set-point	26	°C
Cooling setback	30	°C
Supply air temperature	18	°C
Supply air humidity ratio	0.0077	g/g
Coefficient of performance	2.5	---
Operating time	ASHRAE 90.1 office occupancy schedule	---

Table 10 - 13: Profile (B) HVAC profile schedule

- **Ventilation Profile:** Both the mechanical and natural ventilation were used in profile (B). The mechanical ventilation minimum fresh air per area equals to 0.305 $l/s\text{-}m^2$. For natural ventilation, the minimum temperature control set point is 15 °C, and the maximum temperature control set point is 25 °C. The minimum fresh air is set to be 5.5 l/s-person, and the operable window area is adjusted to 25%. The ventilation system is operated according to the ASHRAE 90.1 office occupancy schedule. The profile air tightness rate is 0.2 ac/h and is set to be 'on' 24/7.

Ventilation item		Value	Unit
Mechanical ventilation	Mechanical ventilation rate	2	ac/h
	Minimum fresh air per area	15	l/s-m^2
Natural ventilation	Temperature set point	22	°C
	Minimum fresh air	2.5	l/s-person
operable window area		25%	---
Operating time		6:00 – 20:00	---
infiltration rate		0.2	ac/h.24/7

Table 10 - 14: Profile (B) ventilation profile schedule

10.1.5. The Research Solar Protection Parameters:

The research protective strategy’s main conception works on protecting the office interior from solar radiation, basically, the direct portion, and dimensioning its impact on the total energy consumption. Through a series of an interactional parametric modeling and simulation processes applied on the research base-case model, three solar protection parameters were examined as discussed in the following points:

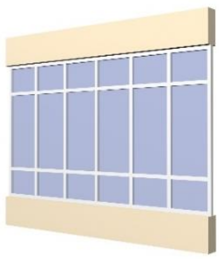
10.1.5.1. Window to Wall Ratio (WWR):

According to the research survey findings, 96.5 valid percent of the participants confirmed that in their working places window to wall ratios more of than 40% give them their required psychological satisfaction and sense of well-being. Therefore, the research work examines the energetic performance of the window to wall ratio that ranges from 40% to the full glazed external wall (wwr = 100%). Figure 10 - 5 demonstrates the examined glazed ratios, their areas, and their dimensions. It was also taken into consideration that the glazed component proportions are always wide, and placed centered on the external wall, referring to the survey Q22 and Q24 findings.

WWR = 40%
Glazed area = 4.32 m^2
Width = 3.00 m
Height = 1.44 m

WWR = 50%
Glazed area = 5.40 m^2
Width = 3.00 m
Height = 1.80 m

WWR = 60%
Glazed area = 6.48 m^2
Width = 3.00 m
Height = 2.16 m



WWR = 70%
Glazed area = 7.56 m^2
Width = 3.60 m
Height = 2.10 m

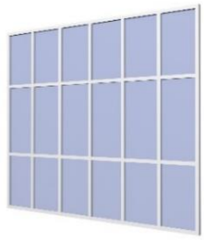
		
WWR = 80% Glazed area = 8.64 m^2 Width = 3.60 m Height = 2.40 m	WWR = 90% Glazed area = 9.72 m^2 Width = 3.60 m Height = 2.70 m	WWR = 100% Glazed area = 10.80 m^2 Width = 3.60 m Height = 3.00 m)

Figure 10 - 5: Examined window-wall ratios

10.1.5.2. External Shading Devices:

Referring to the research survey findings, five externals shading devices were accepted from the office occupants in Cairo and have scored an acceptance ratio of more than 50%. Their order according to the acceptance ratio from the highest to the lowest are: horizontal fins (73.6%), horizontal overhang (67.7%), horizontal louvers (64.5%), vertical fins (56.5%) and perforated shading (Mashrabya) (50.9%) respectively. Each of the previous external shading devices, plus the case of a no-shading window were applied on the base-case model; their energetic performance was then examined through the modeling and simulation operations phase - 2. The examined shading devices were integrated with an angle of 90 degrees, i.e. perpendicular to the glazed plane in order not to obstruct the view to outside.

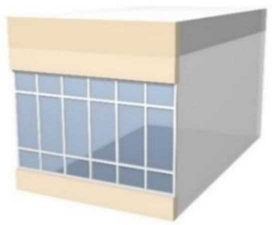
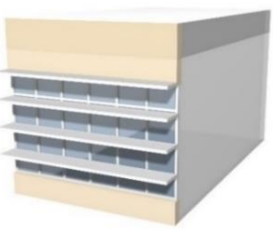
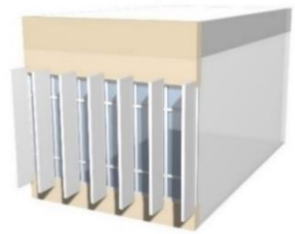
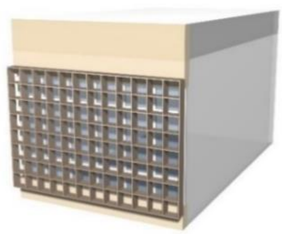
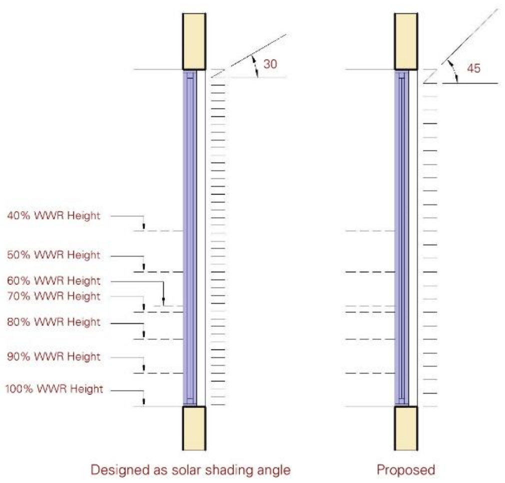
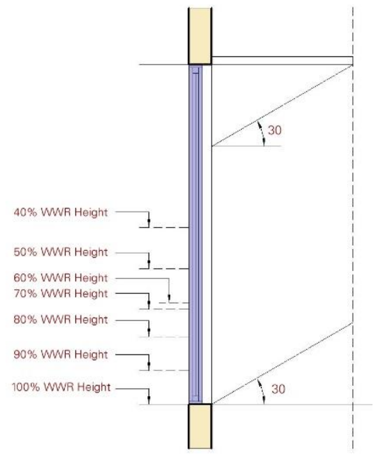
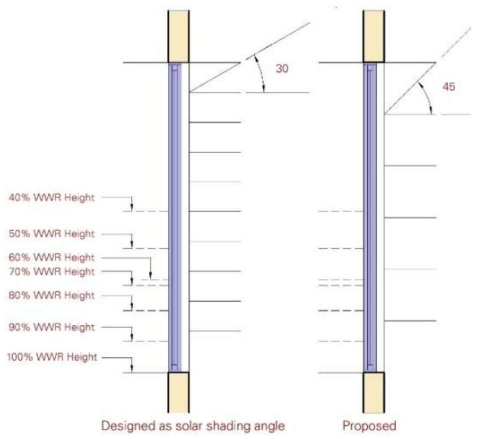
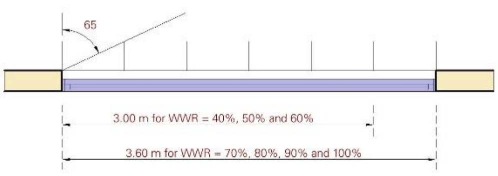
		
No Shading (SH0)	Horizontal Fins (SH1)	Horizontal Overhang (SH2)
		
Horizontal Louvers (SH3)	Vertical Louvers (SH4)	Perforated Shading/Mashrabya (SH5)

Figure 10 - 6: Examined shading devices

It was taken into consideration that all of the five examined shading devices had the same material, same reflectivity, and with a negligible thickness (Figure 10 - 6). The dimensions of each shading device were determined according to its proposed solar shading angle based on the solar shading analysis, Chapter VIII - Cairo's climate analysis, as shown in the following tables (from table 10 - 15 to 10 - 18).

<table>
<tr><th colspan="3">Proposed North Shading Devices: Horizontal shading Angle = 45˚, Vertical shading angle = 65˚</th></tr>
<tr><td>Horizontal Fins
(SH1)</td><td>
</td><td>Applying the specific solar shading angle on the horizontal fins according to the shading analysis (Chapter VIII), gives very narrow slats spacing, this blocks much of the view to the outside. However, referring to the solar chart of Cairo, the direct solar radiations penetrate to the interior only in the early morning hours and the late afternoon, in addition, increasing the horizontal shading angle from 30° to 45° gives a minimal change to the needed shading hours. Therefore, fins with shading angle equal to 45 degrees were proposed and examined. It gives 0.12 m vertical space between fins and 0.12 m depth.</td></tr>
<tr><td>Horizontal
Overhang
(SH2)</td><td>
</td><td>The horizontal solar shading angle gives a very long and extended horizontal overhang, especially with high glazing ratios. However, according to the unified buildings law in Egypt (Ministry of Housing, Utilities and Urban Development, 2008), the maximum protrusions over the façade is 1.50 m. This value is used for the proposed horizontal overhang.</td></tr>
<tr><td>Horizontal
Louvers
(SH3)</td><td>
</td><td>Similar to the horizontal fins condition, applying the horizontal shading angle for horizontal louvers gives very narrow louvers spacing. Thus, horizontal louvers with solar shading angle equal to 45 degrees were then proposed and examined, giving 0.50 m vertical space between louvers and 0.50 m in depth.</td></tr>
<tr><td>Vertical Louvers
(SH4)</td><td>
</td><td>Vertical louvers for the North direction was integrated according to the vertical solar shading angle = 65 degrees. It gives 0.60 m horizontal space between louvers and 0.28 m in depth.</td></tr>
</table>

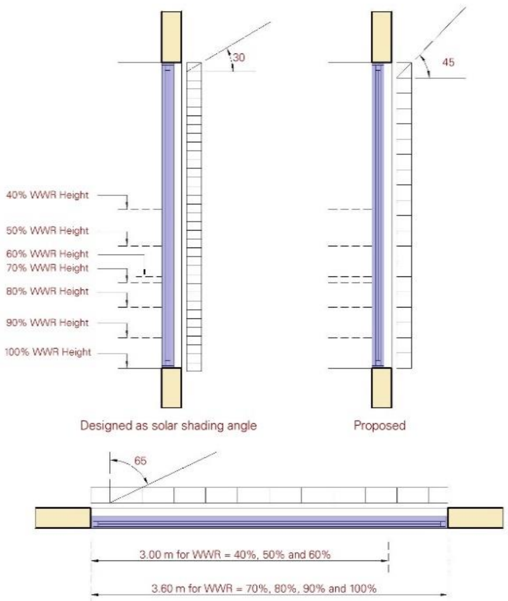
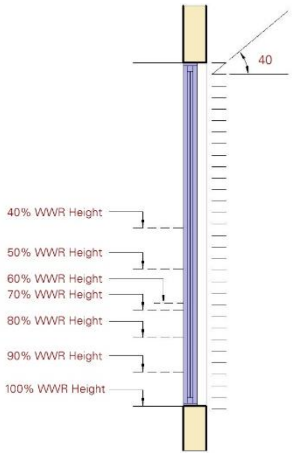
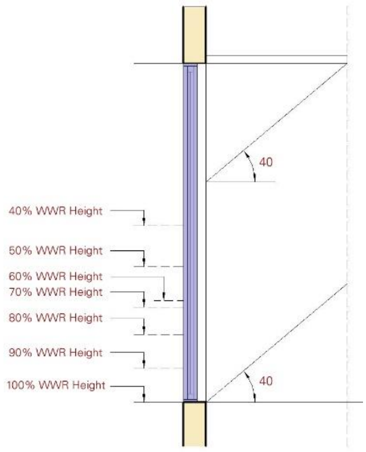
Perforated Shadings (Mashrabya) (SH5)		For mashrabya, the same condition of horizontal fins and horizontal louvers were applied, horizontal solar shading angle equals to 45 degrees was then proposed and examined. The horizontal spacing was set according to the vertical solar shading angle for the north direction = 65 degrees. This gives openings with 0.15 m in vertical space between horizontal members, 0.32 m for horizontal spacing between vertical members, and 0.15 m in depth.

Table 10 - 15: Examined North shading devices

Proposed East Shading Devices: Horizontal shading angle = **40˚**, Vertical shading angle = **45˚**		
Horizontal Fins (SH1)		Horizontal fins for the East direction was integrated according to its horizontal solar shading angle = 40 degrees. It gives 0.10 m vertical space between fins, and 0.12 m in depth.
Horizontal Overhang (SH2)		The horizontal solar shading angle gives a very long and extended horizontal overhang (especially with high glazing ratios). However, according to the unified buildings law in Egypt (Ministry of Housing, Utilities and Urban Development, 2008), the maximum protrusions over the façade is 1.50 m. This value is used for the proposed horizontal overhang.

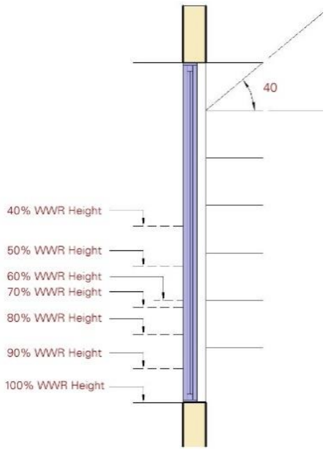
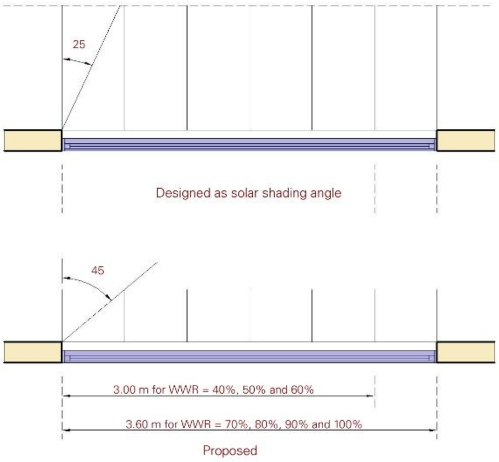
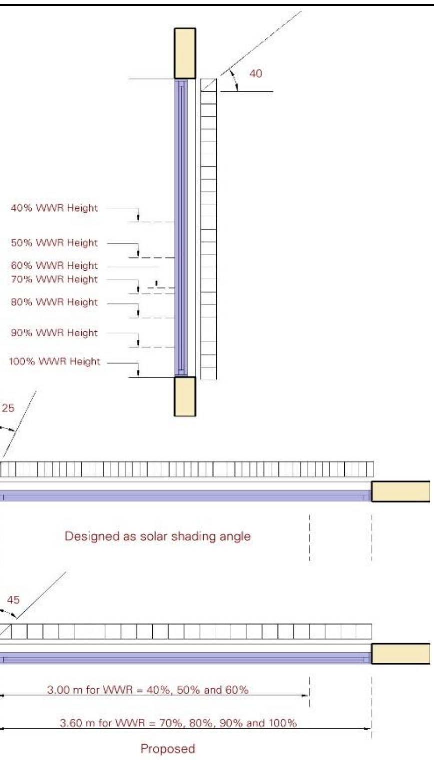
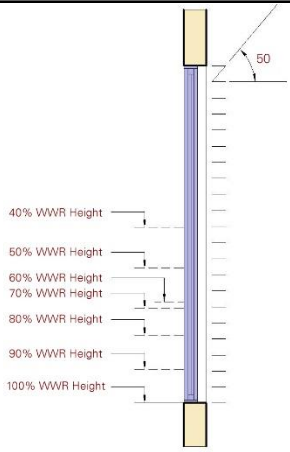
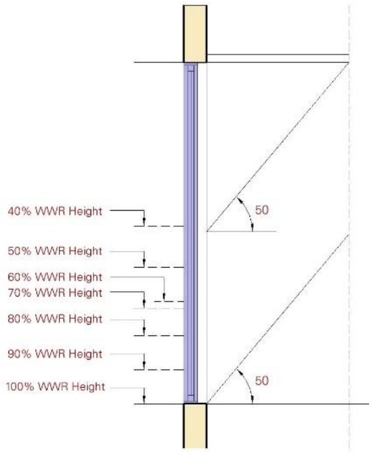
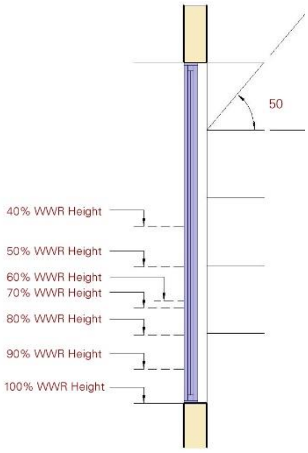
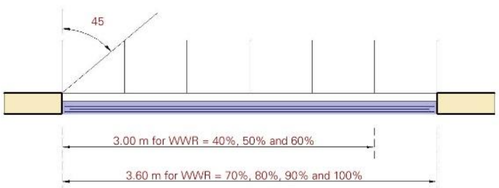
Horizontal Louvers (SH3)		Horizontal louvers for the East direction was also integrated according to its horizontal solar shading angle = 40 degrees. It gives 0.42 m vertical space between louvers and 0.50 m in depth.
Vertical Louvers (SH4)		The vertical shading angle for the East orientation (25°) gives very long louvers; this block much of the view. However, referring to the solar chart of Cairo, direct radiations penetrates to the interior from the east direction almost perpendicular, and no vertical shading angle could obscure it, in addition, increasing the horizontal shading angle from 25° to 45° gives small changes to the needed shading hours. Accordingly, louvers with shading angle of 45° was proposed and examined, giving 0.60m horizontal space between louvers and 0.60m in depth.
Perforated Shadings (Mashrabya) (SH5)		The vertical spacing of the east oriented mashrabya was designed according to the horizontal shading angle = 40 degrees. While the vertical shading angle gives very narrow horizontal spacing (same case of vertical louvers), accordingly, a 45 degrees vertical shading angle was proposed and examined, giving 0.13 m vertical space between horizontal members and 0.15 m horizontal spacing between vertical members and 0.15 m in depth.

Table 10 - 16: Examined East shading devices

Proposed South Shading Devices: Horizontal shading angle = 50˚, Vertical shading angle = 45˚		
Horizontal Fins (SH1)		Horizontal fins for the South facade was applied according to its solar shading angle = 50 degrees. It gives 0.14 m vertical space between fins and 0.12 m in depth.
Horizontal Overhang (SH2)		The horizontal solar shading angle gives a very long and extended horizontal overhang (especially with high glazing ratios). However, according to the unified buildings law in Egypt (Ministry of Housing, Utilities and Urban Development, 2008), the maximum protrusions over the façade is 1.50 m. This value is used for the proposed horizontal overhang.
Horizontal Louvers (SH3)		Horizontal louvers for the South direction was applied according to its solar shading angle = 50 degrees. It gives 0.60 m vertical space between louvers and 0.50 m in depth.
Vertical Louvers (SH4)		Vertical louvers for the South direction was designed according to its vertical solar shading angle = 45 degrees. It gives 0.60 m horizontal space between louvers and 0.50 m in depth.

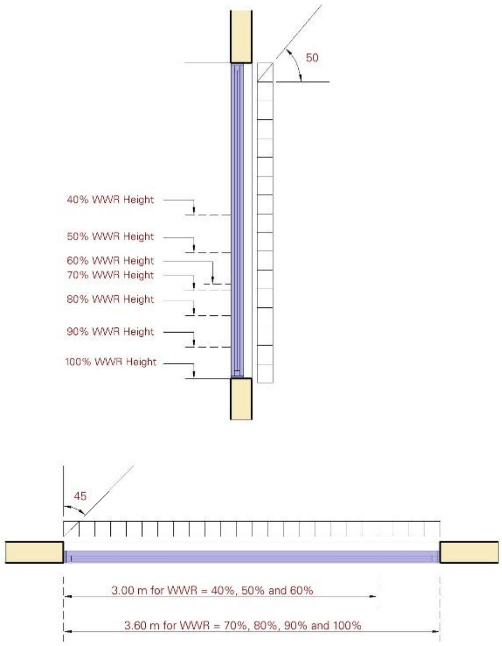
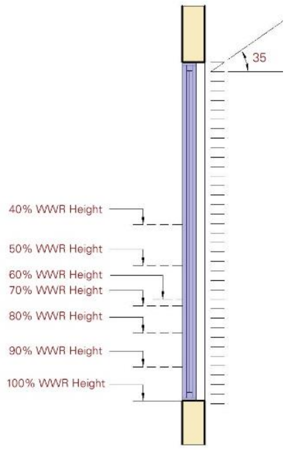
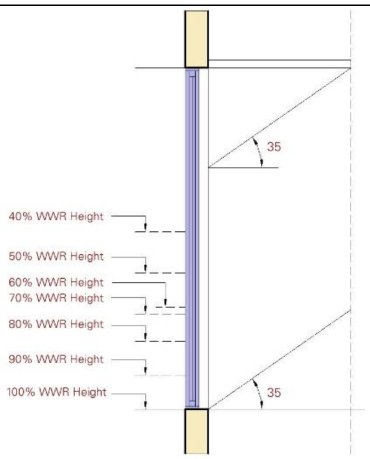
Perforated Shadings (Mashrabya) (SH5)		The vertical spacing of the south oriented mashrabya was applied according to the horizontal solar shading angle = 50 degrees, and the horizontal spacing was designed according to the horizontal solar shading angle = 45 degrees, giving 0.18 m vertical space between horizontal members and 0.15 m horizontal spacing between vertical members with 0.15 m in depth.

Table 10 - 17: Examined South shading devices

Proposed West Shading Devices: Horizontal shading angle = 35˚, Vertical shading angle = 45˚		
Horizontal Fins (SH1)		Horizontal fins for the West direction was applied according to its solar shading angle = 35 degrees. It gives fins with 0.08 m vertical space between fins and 0.12 m in depth.
Horizontal Overhang (SH2)		The horizontal solar shading angle gives a very long and extended horizontal overhang (especially with high glazing ratios). However, according to the unified buildings law in Egypt (Ministry of Housing, Utilities and Urban Development, 2008), the maximum protrusions over the façade is 1.50 m. This value is used for the proposed horizontal overhang.

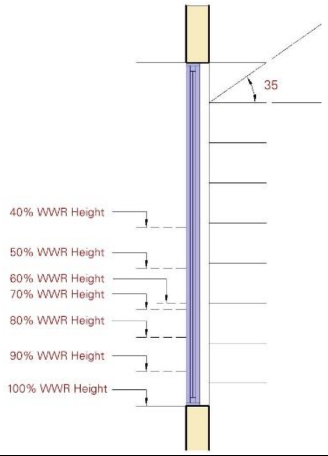
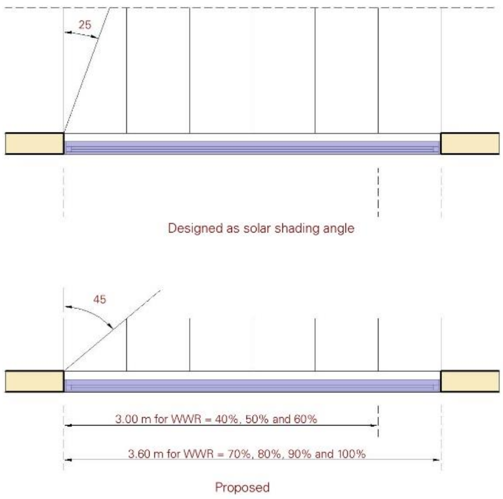
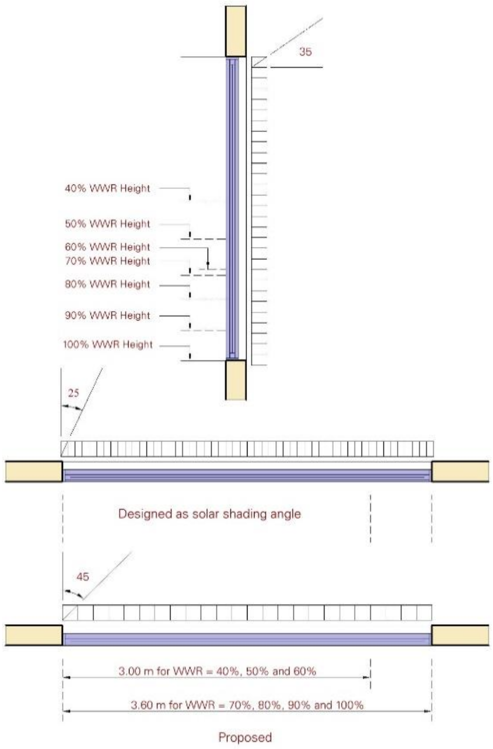
Horizontal Louvers (SH3)		Horizontal louvers for the West direction was applied according to its solar shading angle = 50 degrees. It gives louvers with 0.35 m in vertical space between fins and 0.50 m in depth.
Vertical Louvers (SH4)		The vertical shading angle for the West orientation (20°) gives very long louvers; this block much of the view. However, referring to the solar chart of Cairo, direct radiations penetrates to the interior from the west direction almost perpendicular, and no vertical shading angle could obscure it, in addition, increasing the horizontal shading angle from 20° to 45° gives small changes to the needed shading hours. Accordingly, louvers with shading angle of 45° was proposed and examined, giving 0.60m horizontal space between louvers and 0.60m in depth
Perforated Shadings (Mashrabya) (SH5)		The vertical spacing of the west oriented mashrabya was designed according to the horizontal shading angle = 35 degrees. While the vertical shading angle gives very narrow horizontal spacing (same case of vertical louvers), accordingly, 45 degrees vertical shading angle was proposed and examined, giving 0.11 m vertical space between horizontal members, 0.15 m horizontal spacing between vertical members and 0.15 m in depth.

Table 10 - 18: Examined west shading devices

10.1.5.3. Glazed Solar Control:

Glazed solar control concepts are the third set of variables in the research protective strategy. Three solar control concepts are selected and examined in the research modeling and simulation operational phase II. The three glazed concepts vary in their configurations, number of glazed layers, and their solar-thermal properties, each concept is coded from G1 to G3. Referring to the questionnaire survey findings (Chapter IX), it was taken into consideration that the examined glazing concepts had a total light transmittance more than 60% in order to lie within the psychologically accepted range. The following points demonstrate the detailed configuration of each of the examined glazed concepts:

- **Solar control glazing G1:** G1 glazing concept consists of a single clear glazing, with 6 mm in thickness. The inner layer is coated with a low-emissivity coating. The total solar transmission (SHGC) is 0.710, the direct solar transmission is 0.680, the light transmission = 0.811, and the overall heat transfer coefficient (U-value) is 4.233 $W/m^2.C$

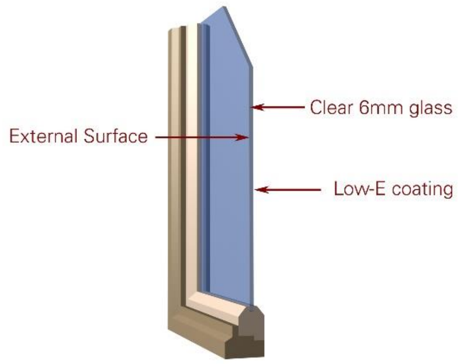


Figure 10 - 7: Solar control glazing concept G1

- **Solar control glazing G2:** The second solar control glazing consists of double glazing unit. The outer pane is clear generic glass with 6mm in thickness, coated on the inner side with a low-emissivity coating. The gap between the panes is 13mm thickness, filled with Argon gas. The innermost pane is clear glass with 6 mm thickness. The total solar transmission (SHGC) is 0.568, the direct solar transmission is 0.474, the light transmission = 0.745, and the overall heat transfer coefficient (U-value) is 1.357 $W/m^2.C$

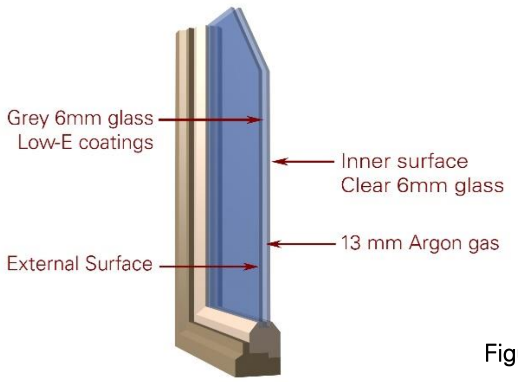


Figure 10 - 8: Solar control glazing concept G2

- **Solar control glazing G3:** The third solar control glazing concept is a triple glazing unit. The outermost pane is clear glass with 3mm in thickness, coated with a low-emissivity coating. The gap between the outermost pane and the middle pane (window gas1) is 13 mm in thickness, filled with Argon gas. The middle pane is generic clear glass with 3 mm in thickness. The gap between the middle pane and the inner pane (window gas2) is 13 mm in thickness, also filled with Argon gas. The innermost pane is clear 3 mm clear glass coated with a low-emissivity coating. The total solar transmission (SHGC) is 0.453, the direct solar transmission is 0.325, the light transmission = 0.646, and the overall heat transfer coefficient (U-value) is 0.772 W/m^2.C

Figure 10 - 9: Solar control glazing concept G3

10.2. Modeling and Simulation Findings:

10.2.1. Modeling and Simulation Operations Phase - 1 Findings:

Modeling and simulation operations in Phase - 1 could be considered as a prerequisite or a preliminary stage for the upcoming main modeling and simulation operations (phase - 2). Through phase -1, eight modeling and simulation operations were conducted. These operations are basically divided into two main parts A & B, each one meets different objective as follows:

- **In part A,** the typical Egyptian office space profile (profile A) is applied on the research base case, then simulated on the four main directions. The average annual and monthly energy consumption of the simulated findings is compared with the actual average energy consumption rates of the Egyptian office spaces based on the studied office buildings case-studies (Chapter VIII) for more investigation to the validity and reliability of the research modeling and simulation tool. The average annual fuel breakdown and the internal heat balance of the simulated findings are also presented and analyzed in this part.

- **In part B,** the ASHRAE based office profile (profile B) is applied on the research base case, then it is also simulated on the four main directions. The simulated annual energy consumption rates are compared with the annual energy consumption rates of profile A (from the part A) in order to rationalize the selection of the used office profile configuration for the research main modeling and simulation operations in phase - 2.

10.2.1.1. Part A: Typical Egyptian Office Space Profile Findings:

The findings of modeling and simulating profile A on the four main directions show that the total annual energy consumption measured in KWh per square meter of the North orientation recorded the least total annual energy consumption with 292.68 KWh/m^2, East direction came second with 320.68 KWh/m^2, South direction came third with 344.3 KWh/m^2, and finally the West direction recorded the highest total annual energy consumption with 346.92 KWh/m^2. Figure 10 - 10 shows the simulated monthly and annual total energy consumption findings of profile - A.

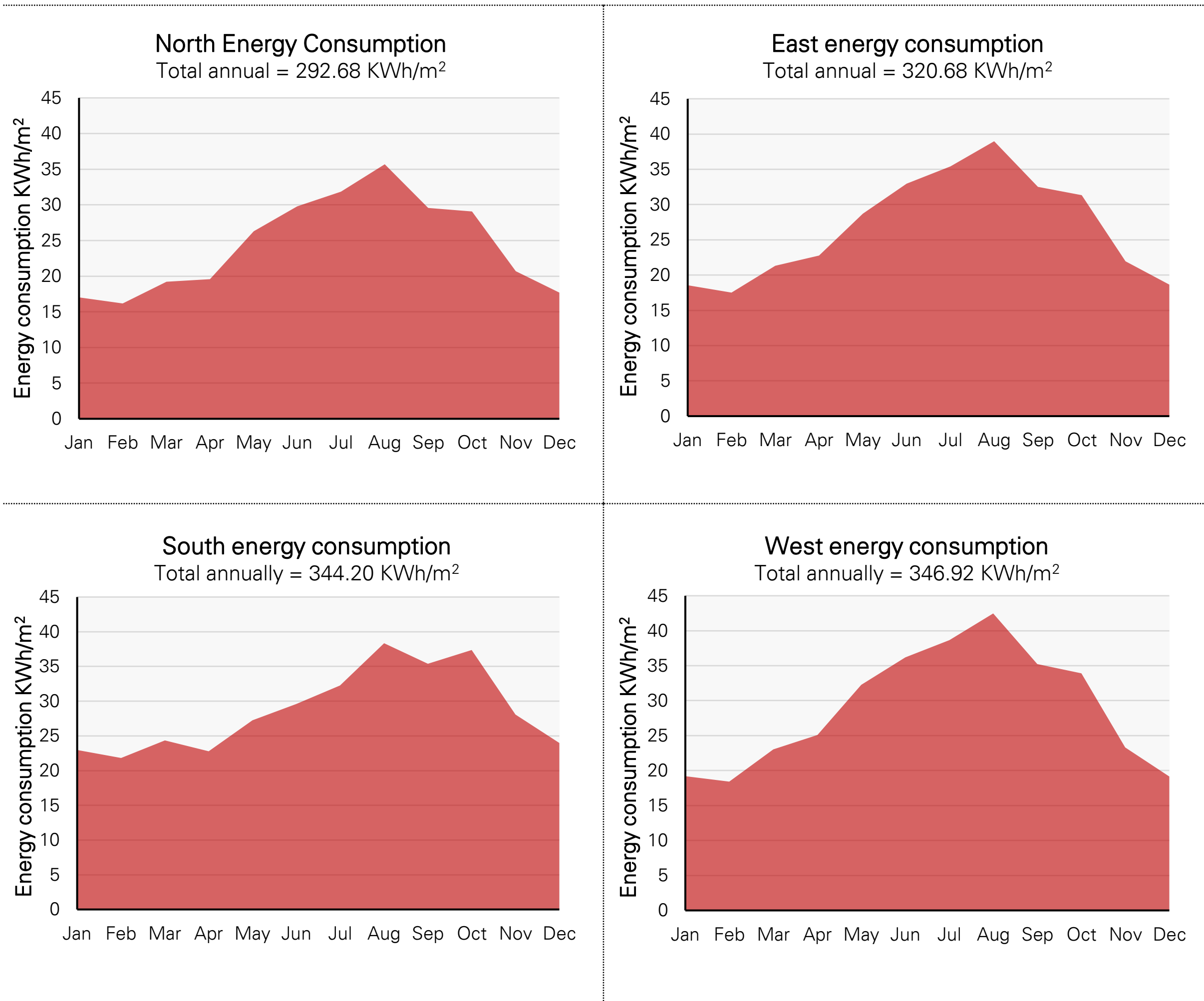


Figure 10 - 10: Total annual and monthly energy consumption of the typical Egyptian office profile applied on the main four directions

Comparing the average of the simulated energy consumption rates of profile A with the actual average rates from the previously studied Egyptian office buildings case studies (chapter XIII) shows some convergence. Profile-A's average annual energy consumption rate from the four main directions is 326.12 KWh/m^2, while the actual annual energy consumption rate of the studied Egyptian office buildings is 315.67 KWh/m^2 with 10.5 KWh/m^2 in difference representing only 3.2%. Figure 10 – 11 shows the average monthly total energy consumption rates of both cases. These findings give more validity and reliability to the research building information modeling and simulation (BIMS) tool.

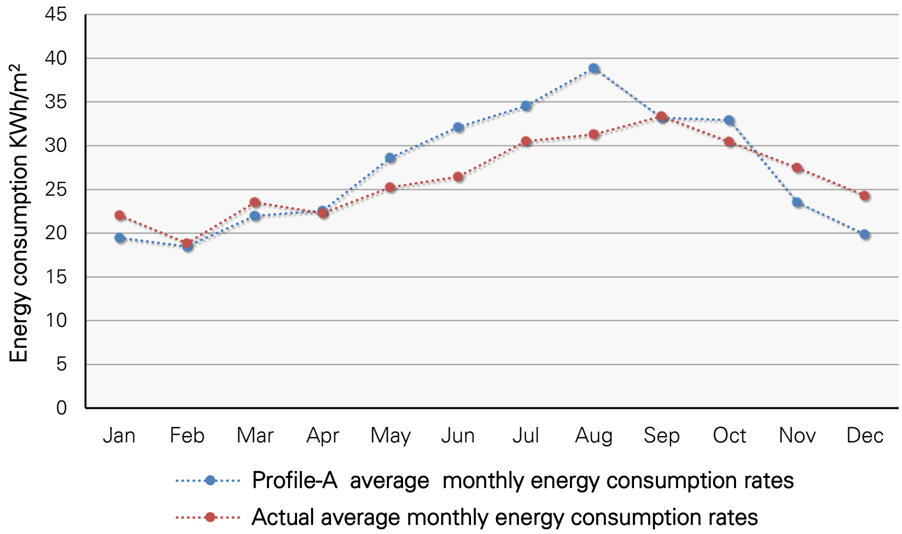


Figure 10 - 11: Monthly energy consumption of the simulated typical Egyptian office profile compared with the actual average energy consumption of the Egyptian office buildings

The average annual fuel breakdown of profile - A for the 4 main directions reveals high energy consumption rates for cooling and lighting energy demands. The cooling energy consumption accounts for 134.6 KWh/m^2 representing 41% of the total annual energy consumed, lighting energy consumption accounts for 90.64 KWh/m^2 representing 28%, while the room electricity for computers and other electric appliances plus the domestic hot water (DHW) consume 100.89 KWh/m^2 representing 31% of the total annual energy consumption (figure 10 – 12).

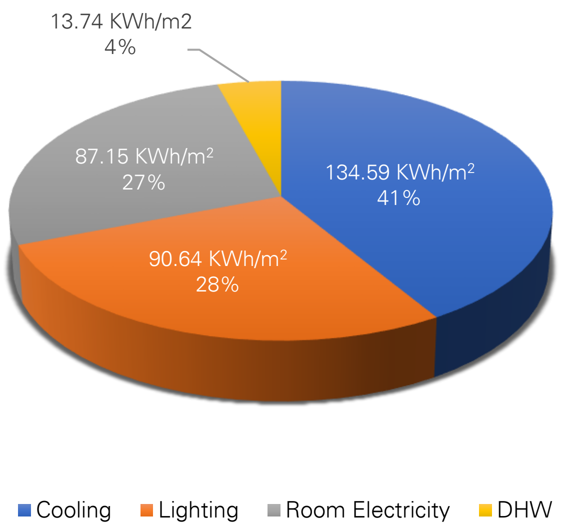


Figure 10 - 12: Average annual fuel breakdown of profile-A on the four main directions

Figure 10 - 13 demonstrates the internal heat balance of profile - A on the four main directions, showing the internal gains from the lighting, electrical office appliances, occupants, and solar gains from windows compared to the zone sensible cooling loads. The findings indicate that solar heat gains from windows is the major heat gaining mechanism, especially in the West, South and East directions. This accentuates on solar protection prominence and its efficient role in reducing the cooling energy consumption for office space in Cairo's hot-arid climate. i.e. rationalize solar protection for the research as its main energy efficient strategy.

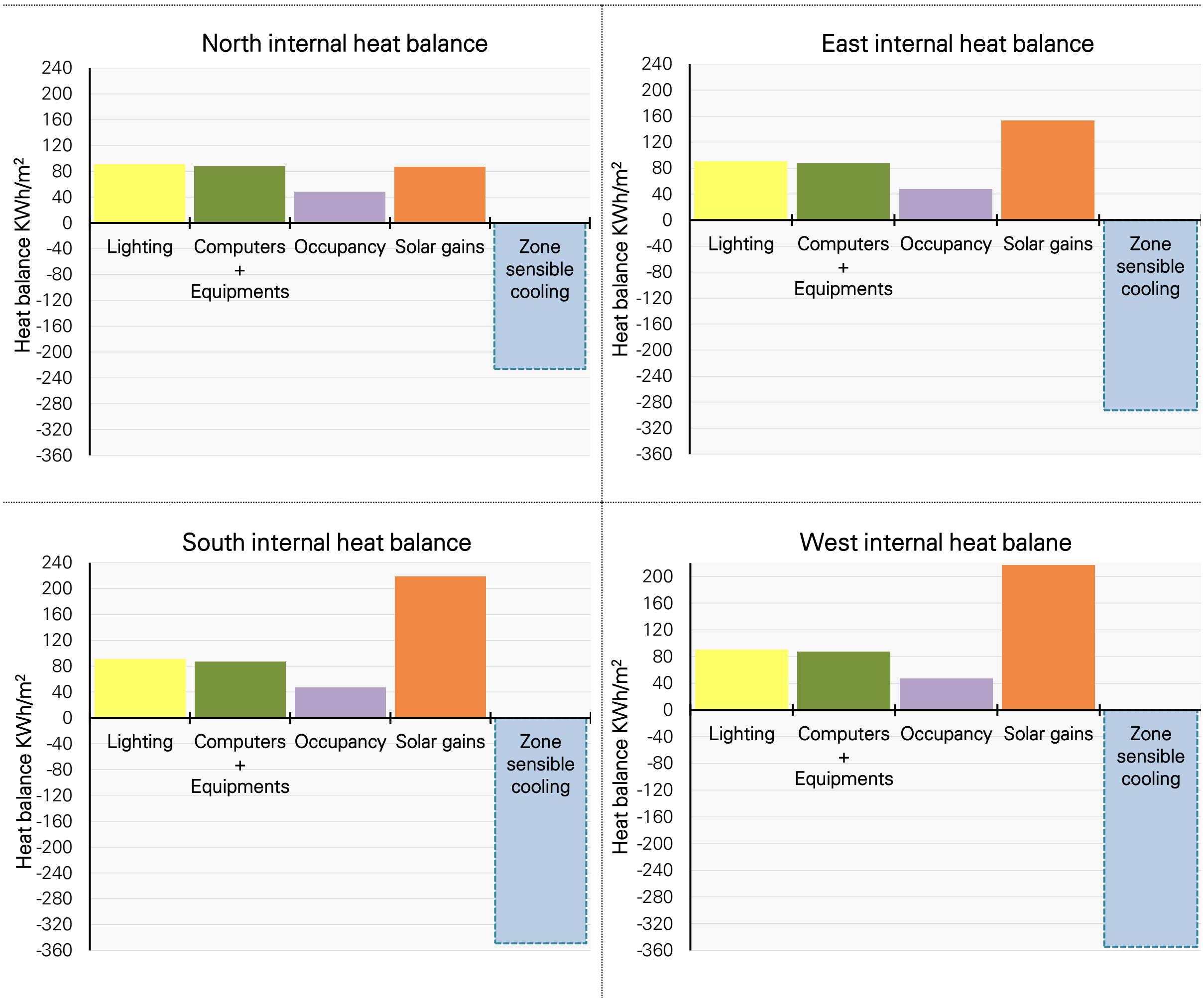


Figure 10 - 13: Internal heat balance of profile-A applied on the four main directions

10.2.1.2. Part B: ASHRAE Based Office Space Profile Findings:

In this part, the ASHRAE based office profile configuration is applied on the research base case and simulated in the four main directions. The simulated annual energy consumption rates are then compared with the consumption rates of profile - A. The results show a considerable reduction in the annual total energy demand from profile - A to profile - B with various percentages depending on the simulated direction. In North, the total energy demand is reduced from 292.68 to 115.544 KWh/m² with a reduction of 60.52%. In the East, the total energy demand is reduced from 320.68 to 148.537 KWh/m² with a reduction of 53.68%. In the South, the total energy demand is reduced from 344.2 to 132.92 KWh/m² with a reduction of 61.38%. While in the West, the total energy demand is reduced from 346.92 to 180.17 KWh/m² with a reduction of 48.07%. The average total energy demand reduction of the four directions is 55.91% (figure 10 - 14).

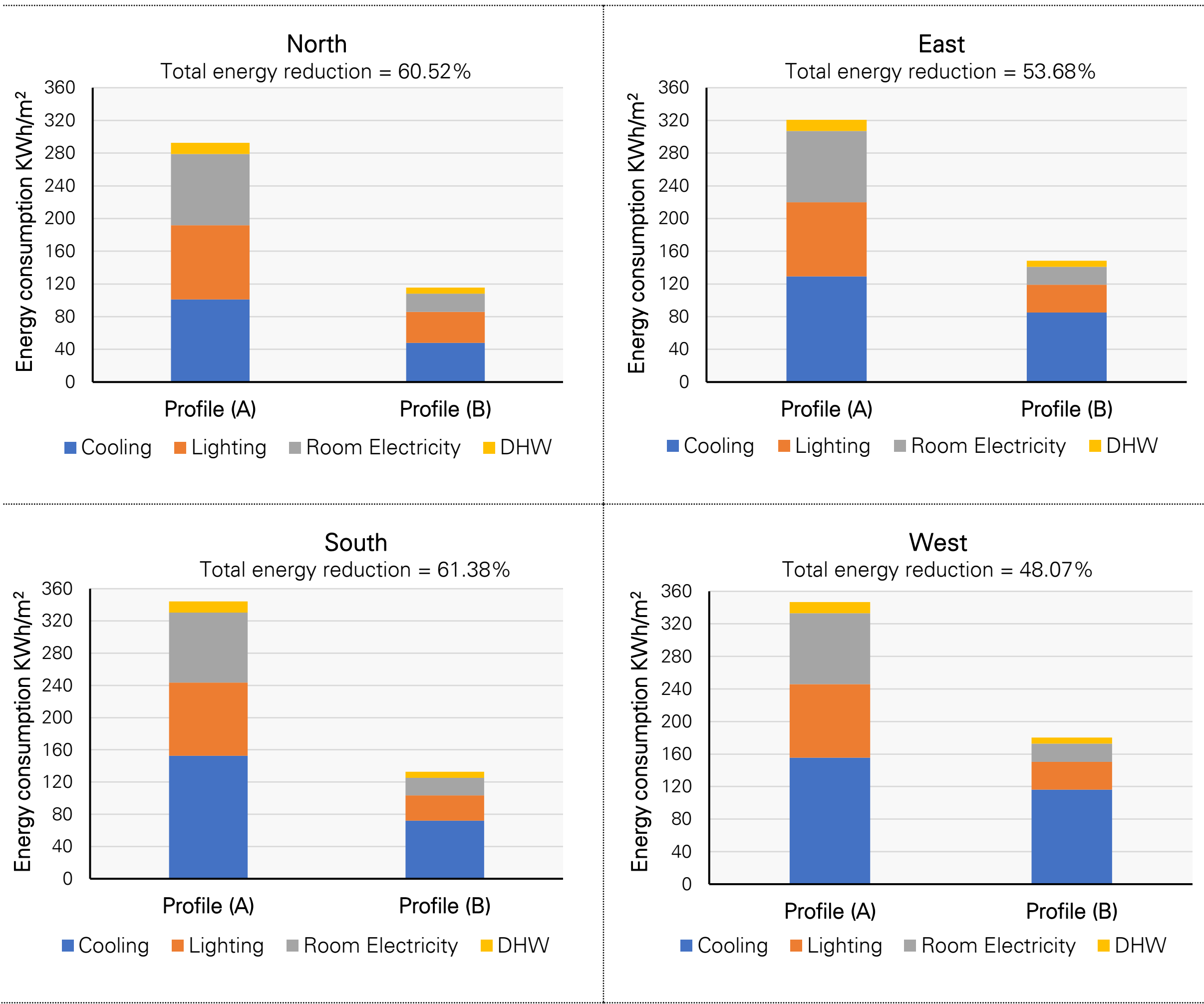


Figure 10 - 14: Total annual fuel breakdown of the ASHRAE based office profile (Profile - B) compared to the typical Egyptian office profile (Profile - A)

Regarding the previous findings, it is more convenient for the research work to choose in advance the ASHRAE based profile configuration as the more energy efficient profile, and apply it on the research base - case through the upcoming main modeling and simulation operations (phase - 2).

Generally, developing and upgrading the buildings profile configurations in Egypt to enhanced and standardized energy efficient configurations is considered an urgent need, and should be taken into serious attention. It could be one of the primary beginnings towards the transformation of the building sector to the more rational use of energy.

10.2.2. Modeling and Simulation Operations Phase - 2 Findings:

Phase - 2 operations are the main modeling and simulation operations for the research work. Its main objective is to investigate the annual energy consumption rates of the research solar protective variables to be utilized through the optimization of office space transparency with its energy consumption in the upcoming operational study (Chapter XI).

Through a series of 420 modeling and simulation operations, the ASHRAE based profile was applied first on the base case model. Then, the possible combinations of the research solar protection variables were modelled and simulated; the psychologically accepted seven window to wall ratios (from wwr = 40% to wwr = 100%), the accepted five shading devices (horizontal fins, horizontal overhang, horizontal louvers, vertical louvers and Mashrabya) with the selected three glazed solar control concepts (G1, G2 and G3) were alternately examined with each other on the four main directions. For each simulation process, the lighting, cooling, and total annual energy consumption were measured in KWh per meter square annually. In the following points (from 10.2.2.1 to 10.2.2.4) the findings of each direction will be discussed separately.

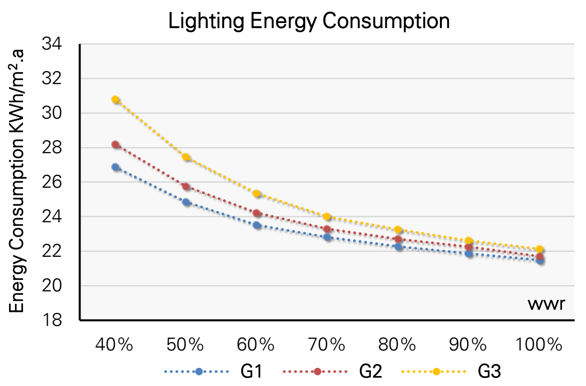
10.2.2.1. North Direction Findings:

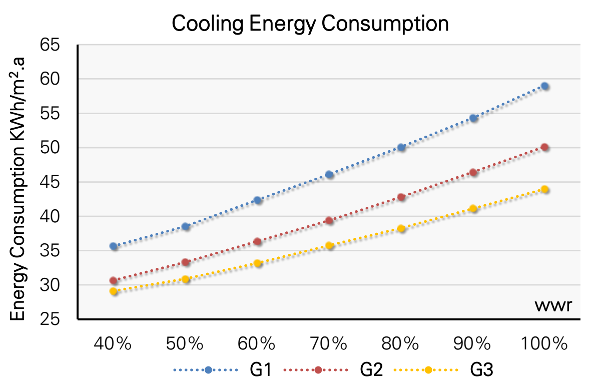
- **Lighting energy consumption:** Typically, increasing the glazed area (wwr), decreases the lighting energy consumption rates. Glazing concept G1 achieved the least lighting energy consumption, followed by G2, while glazing concept G3 achieved the highest lighting consumption rates. The highest lighting consumption measure is 33.951 KWh/m^2 conducted in the case of horizontal overhang with G3 for wwr 40%, while the lowest lighting energy consumption measure is 21.485 KWh/m^2 achieved in the case of horizontal fins with G1 for wwr 100%.

- **Cooling energy consumption:** Contradictory to the lighting consumption, cooling energy consumption increased with increasing the window to wall ratio. Owing to their solar control properties, G3 glazed concept achieved the least cooling consumption rates, followed by G2, then G1. The highest cooling consumption measure is 67.702 KWh/m^2 conducted in the case of horizontal overhang with G1 for wwr 100%, while the lowest cooling energy consumption measure is 27.619 achieved in the case of Mashrabya with G3 for wwr 40%.

- **Total energy consumption:** The North direction total annual energy consumptions recorded the least rates among the other directions. from wwr 40% to 60% the vertical louvers with G3 achieved the least total energy consumption measures, while for wwr 70% and more, the Mashrabya with G3 achieved the least consumption measures. The highest total consumption measure is 119.413 KWh/m^2 conducted in the case of horizontal overhang with G1 for wwr 100%, while the lowest total energy consumption is 85.14 KWh/m^2 achieved in the case of vertical louvers with G3 for wwr 40%.

- Horizontal Fins (SH1):





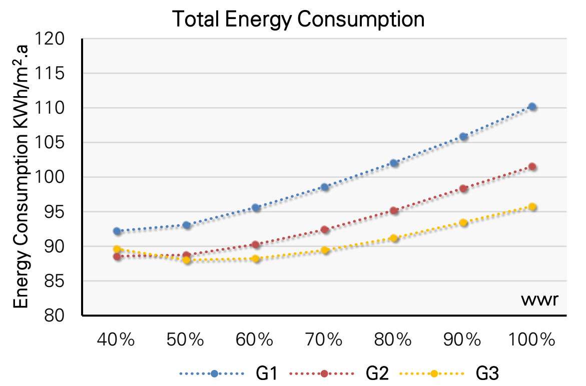
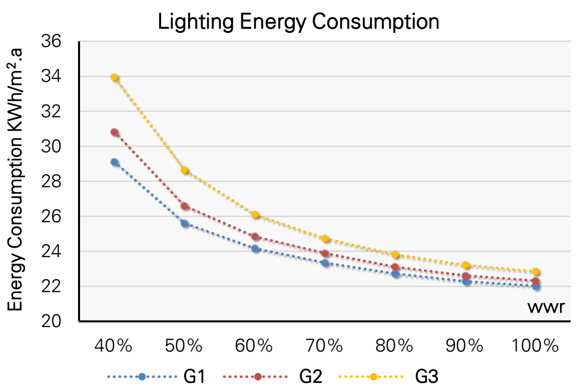
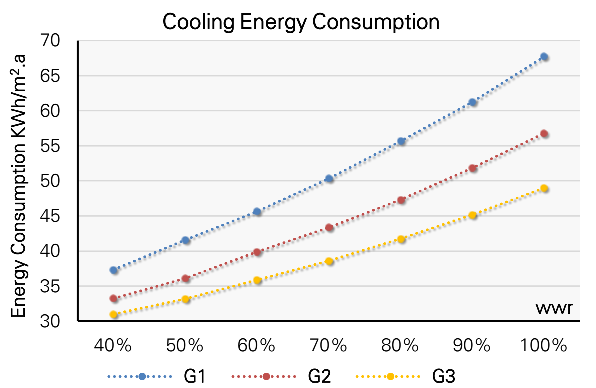


Figure 10 - 15: Lighting, cooling and total energy consumption for horizontal fins examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the North direction

- Horizontal Overhang (SH2):





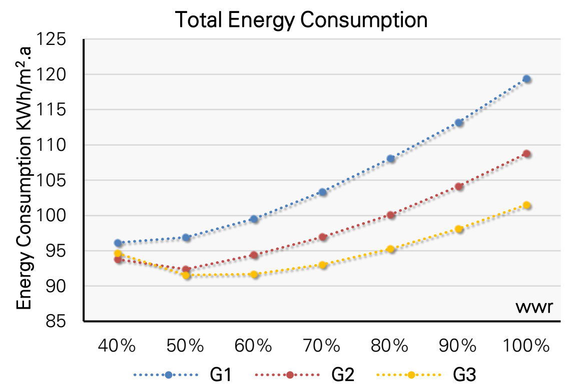
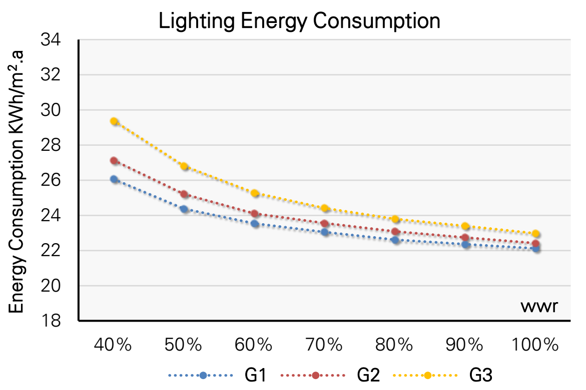
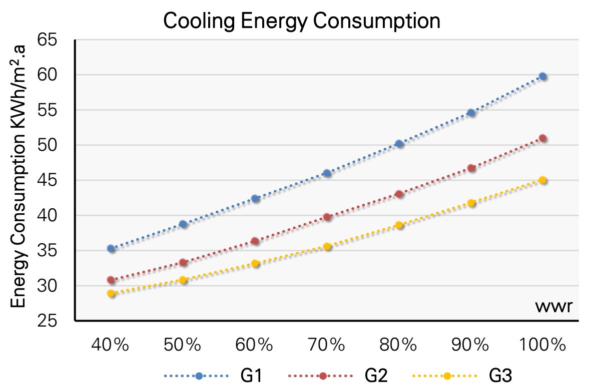


Figure 10 - 16: Lighting, cooling and total energy consumption for horizontal overhang examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the North direction

- Horizontal Louvers (SH3):





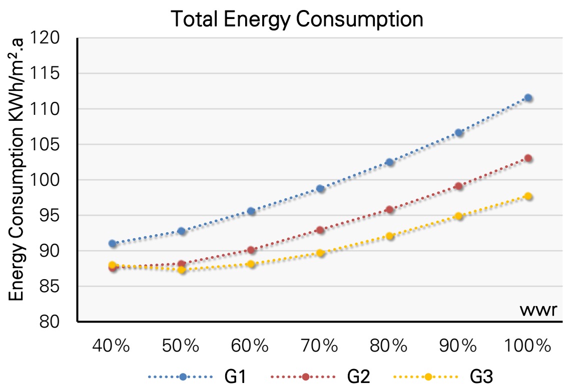
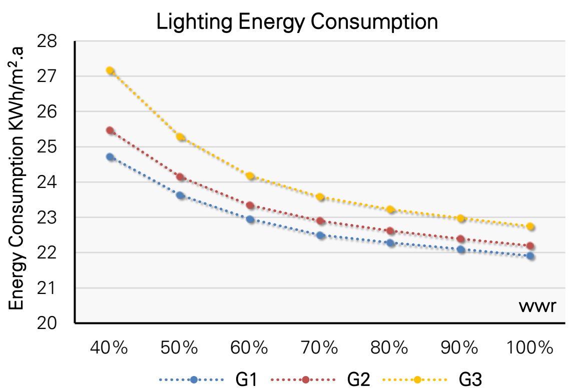
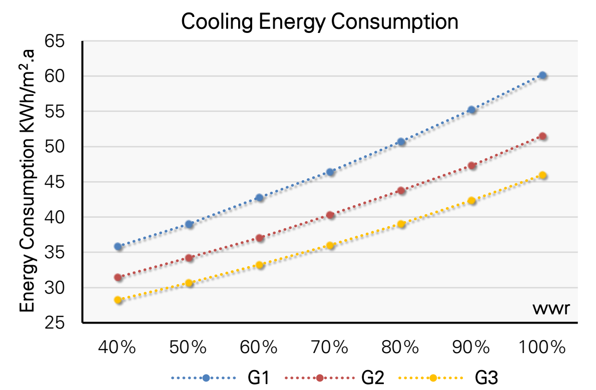


Figure 10 - 17: Lighting, cooling and total energy consumption for horizontal louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the North direction

- Vertical Louvers (SH4):





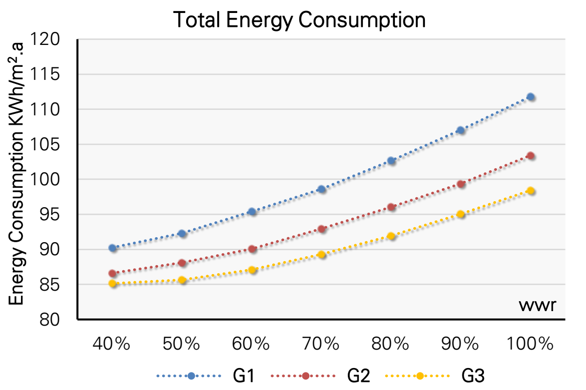
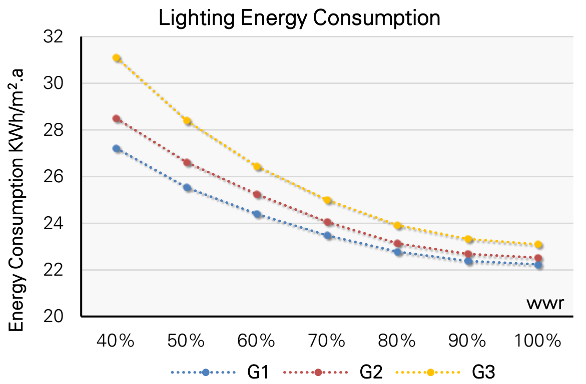
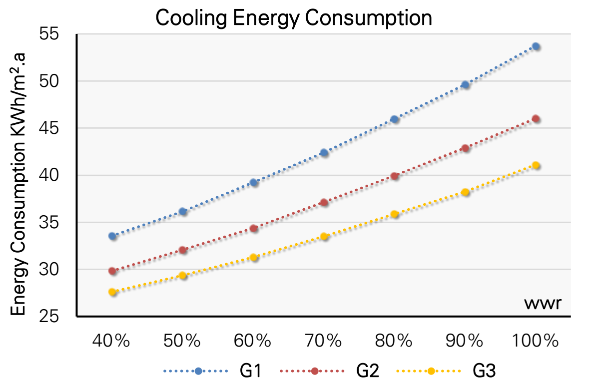


Figure 10 - 18: Lighting, cooling and total energy consumption for vertical louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the North direction

- Perforated Shadings (Mashrabya) (SH5):





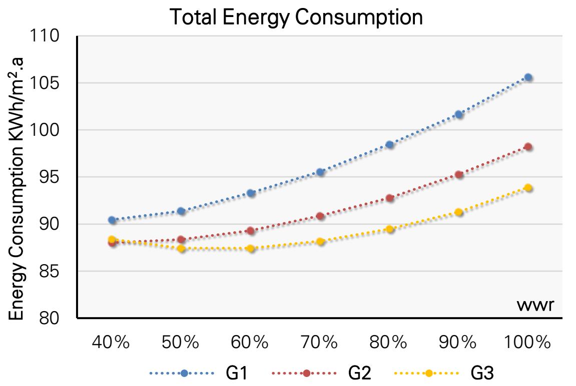


Figure 10 - 19: Lighting, cooling and total energy consumption for Mashrabya examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the North direction

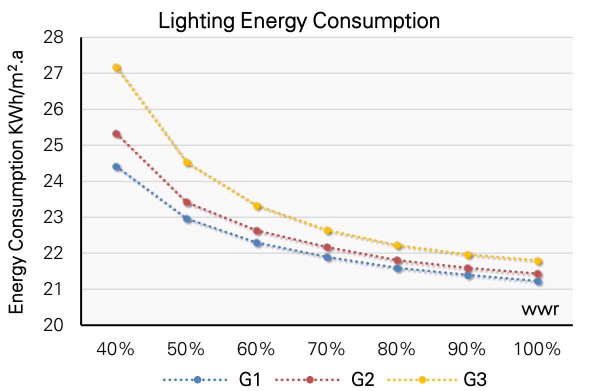
10.2.2.2. East Direction Findings:

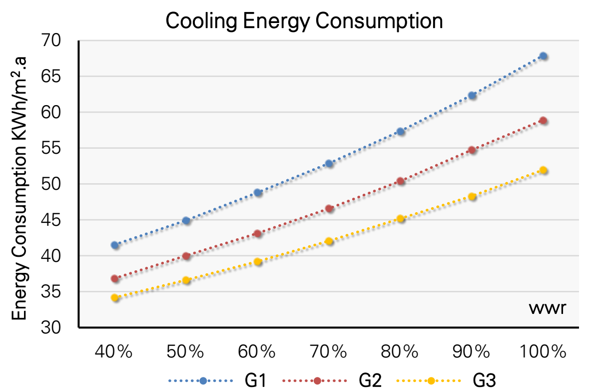
- **Lighting energy consumption:** All shadings except Mashrabya recorded comparatively near measures for lighting consumptions. The least measures are typically with G1 for higher wwr, while the highest are with G3 for the lower wwr. The highest lighting consumption measure is 29.314 KWh/m^2 conducted in the case of horizontal overhang with G3 for wwr 40%, while the lowest lighting energy consumption measure is 21.228 KWh/m^2 achieved in case of horizontal fins with G1 for wwr 100%.

- **Cooling energy consumption:** For wwr lower than 60% the horizontal fins, horizontal louvers and mashrabya with G3 achieved the lowest cooling consumption measures, while for wwr more than 60%, undisputedly, the mashrabya achieved the lowest measures. The highest cooling consumption measure is 108.467 KWh/m^2 conducted in the case of vertical louvers with G1 for wwr 100%, while the lowest cooling energy consumption measure is 31.895 KWh/m^2 achieved in the case of Mashrabya with G3 for wwr 40%.

- **Total energy consumption:** For wwr 40% and 50% the horizontal fins and horizontal louvers with G3 achieved the lowest total energy measures. While for wwr more than 60%, the mashrabya with G3 recorded lowest consumptions. The highest total consumption measure is 159.536 KWh/m^2 conducted in the case of vertical louvers with G1 for wwr 100%, while the lowest total energy consumption measure is 89.655 KWh/m^2 achieved in case of horizontal louvers with G3 for wwr 40%

- Horizontal Fins (SH1):





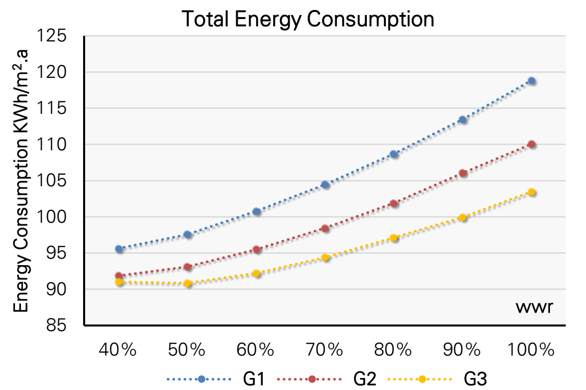
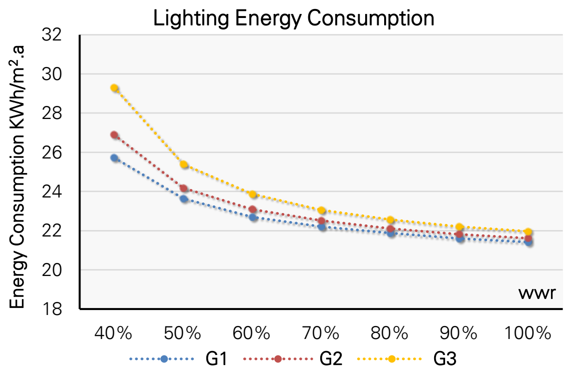
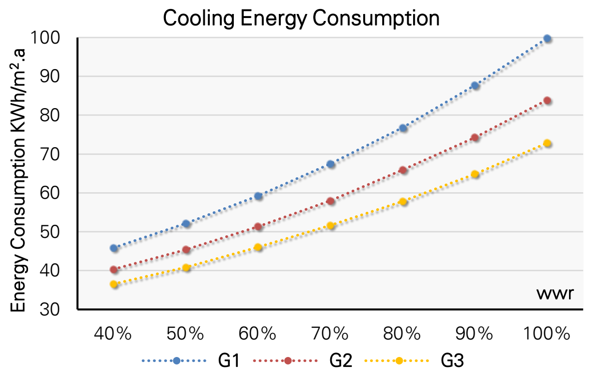


Figure 10 - 20: Lighting, cooling and total energy consumption for horizontal fins examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the East direction

- Horizontal Overhang (SH2):





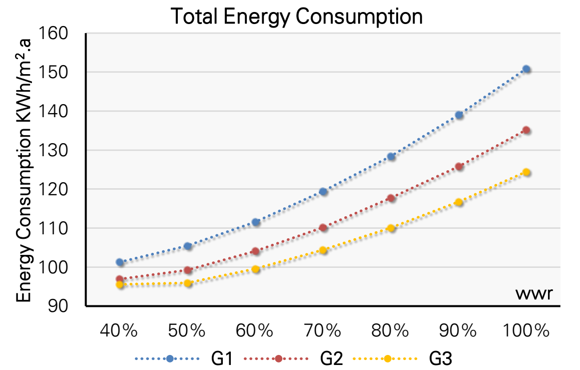
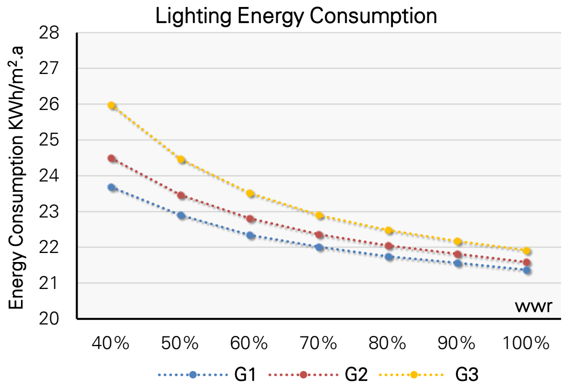
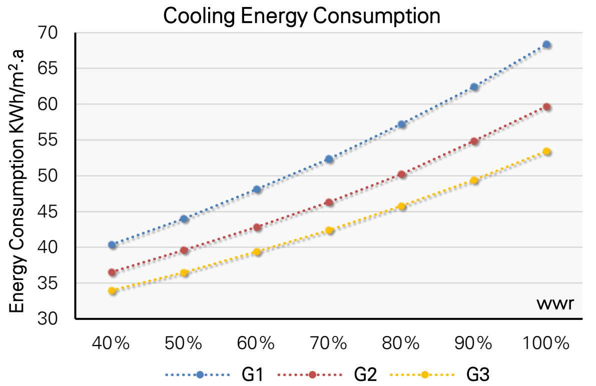


Figure 10 - 21: Lighting, cooling and total energy consumption for horizontal overhang examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the East direction

- Horizontal Louvers (SH3):





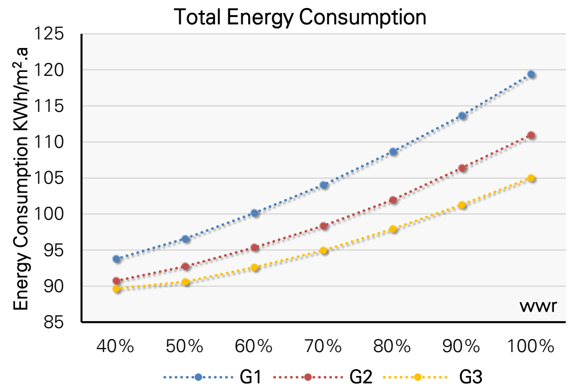
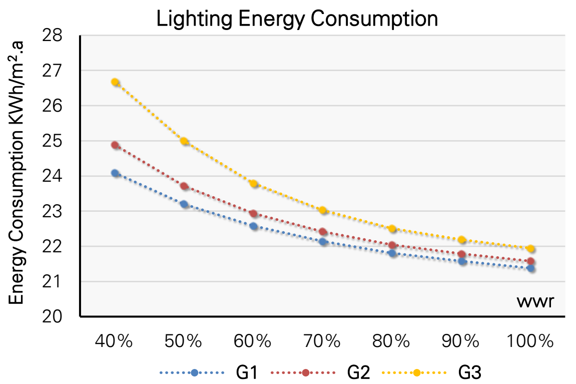
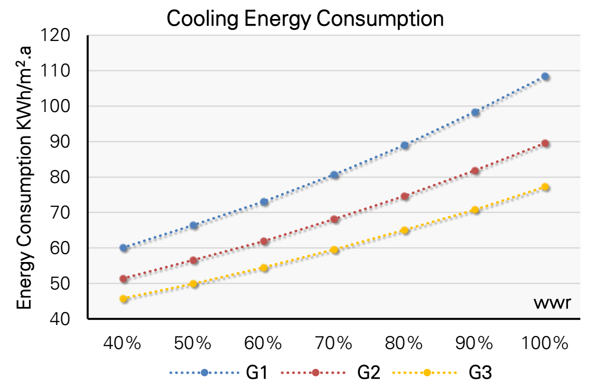


Figure 10 - 22: Lighting, cooling and total energy consumption for horizontal louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the East direction

- Vertical Louvers (SH4):





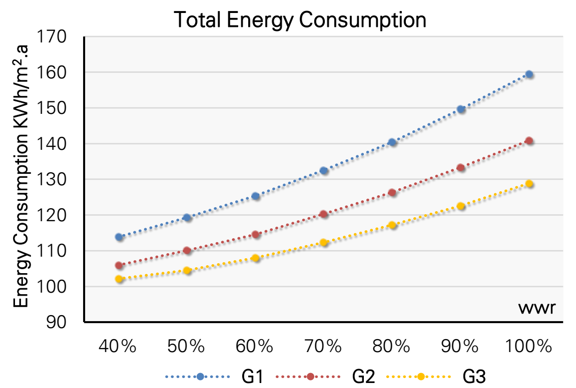


Figure 10 - 23: Lighting, cooling and total energy consumption for vertical louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the East direction

- Perforated Shadings (Mashrabya) (SH5):

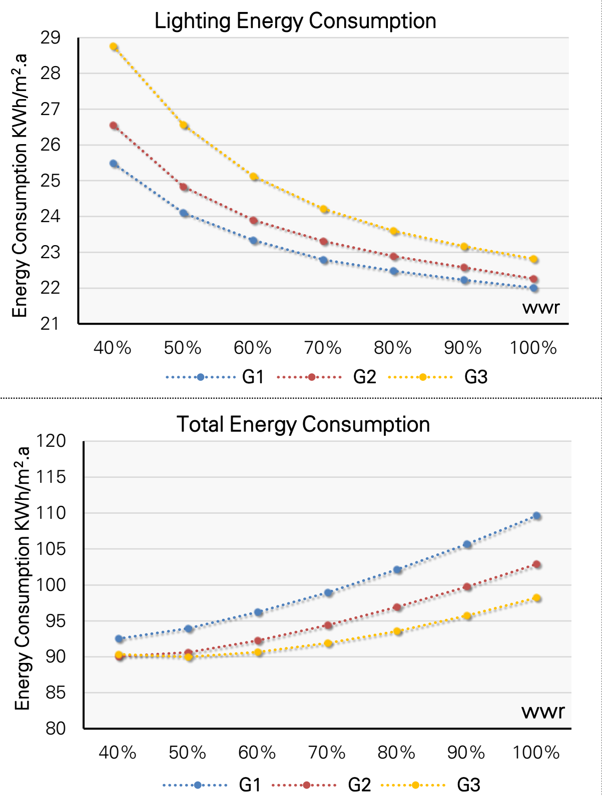


Figure 10 - 24: Lighting, cooling and total energy consumption for Mashrabya examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the East direction

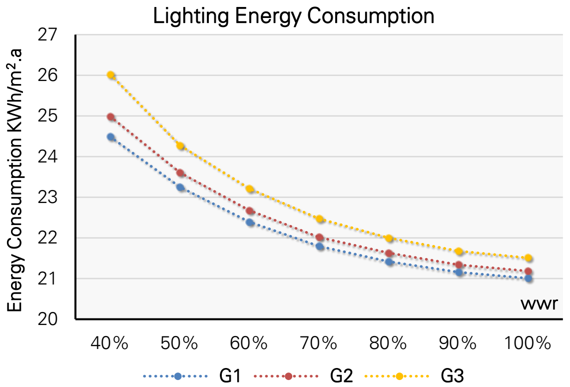
10.2.2.3. South Direction Findings:

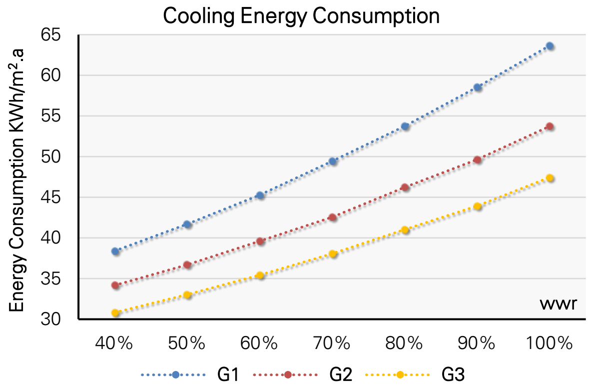
- **Lighting energy consumption:** Horizontal fins and horizontal louvers with G1 glazing concept achieved the lowest lighting consumption measures for all window to wall ratios. The highest lighting consumption rate measure is 28.112 KWh/m^2 conducted in the case of Mashrabya with G3 for wwr 40%, while the lowest lighting energy consumption measure is 21.007 KWh/m^2 achieved in the case of horizontal fins with G1 for wwr 100%.

- **Cooling energy consumption:** The Mashrabya measures, followed by horizontal fins and horizontal louvers measures with G3 glazing concept achieved the lowest cooling consumption rates for all the examined window to wall ratios. The highest cooling consumption measure is 82.339 KWh/m^2 conducted in the case of horizontal overhang with G1 for wwr 100%, while the lowest cooling consumption measure is 29.361 KWh/m^2 achieved in case of Mashrabya with G3 for wwr 40%

- **Total energy consumption:** For wwr 50% and less, horizontal fins and horizontal louvers with G3 glazing recorded the lowest total energy consumption measures, followed by the Mashrabya and G3 with comparatively near measures. While for wwr 60% and more, the Mashrabya recorded the lowest total consumption measures. The highest total consumption measure is 133.623 KWh/m^2 conducted in the case of horizontal overhang with G1 for wwr 100%, while the lowest total energy consumption measure is 85.887 KWh/m^2 achieved in case of horizontal louvers with G3 for wwr 40%

- Horizontal Fins (SH1):





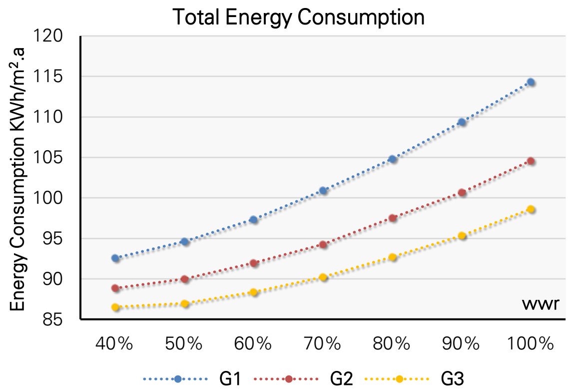
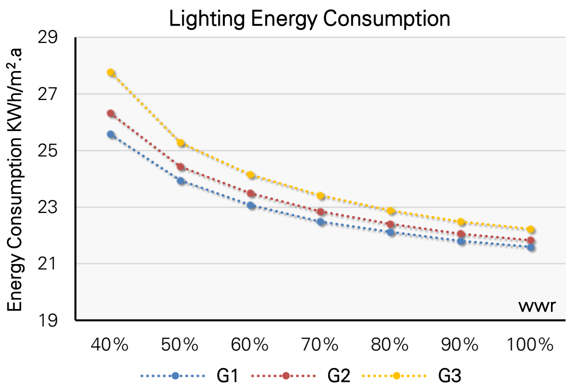
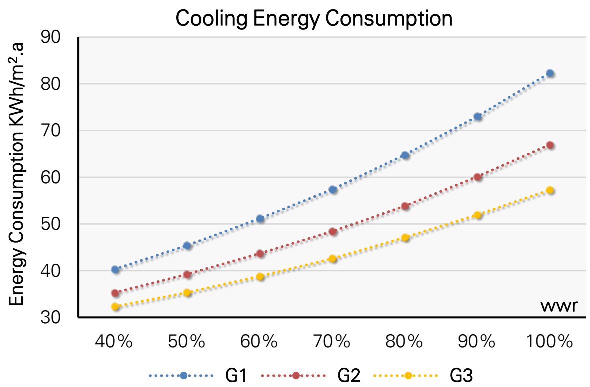


Figure 10 - 25: Lighting, cooling and total energy consumption for horizontal fins examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the South direction

- Horizontal Overhang (SH2):





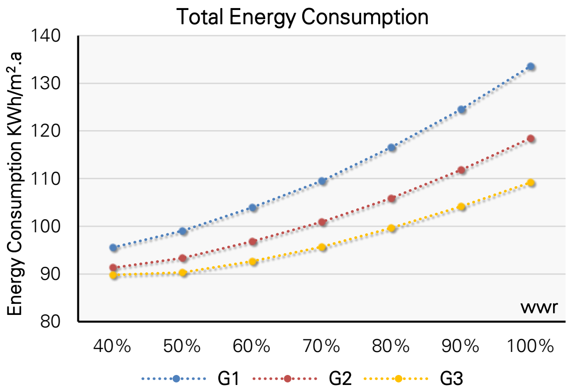
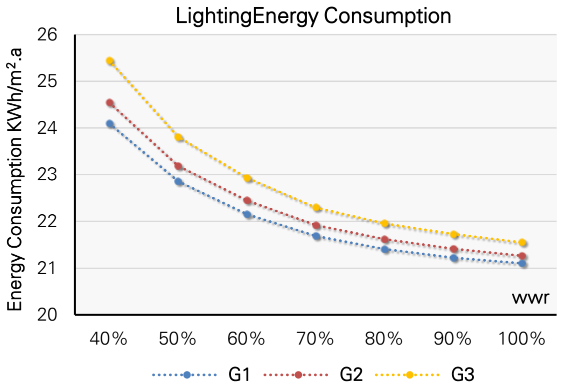
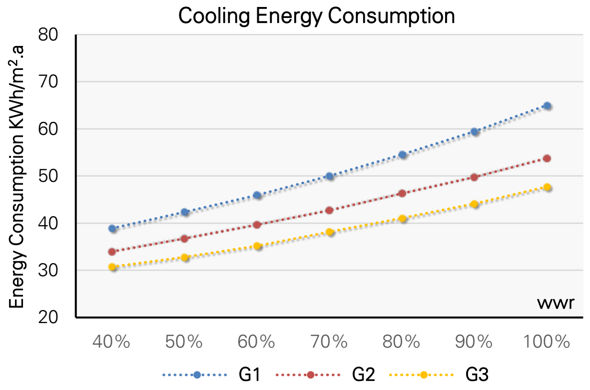


Figure 10 - 26: Lighting, cooling and total energy consumption for horizontal overhang examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the South direction

- Horizontal Louvers (SH3):





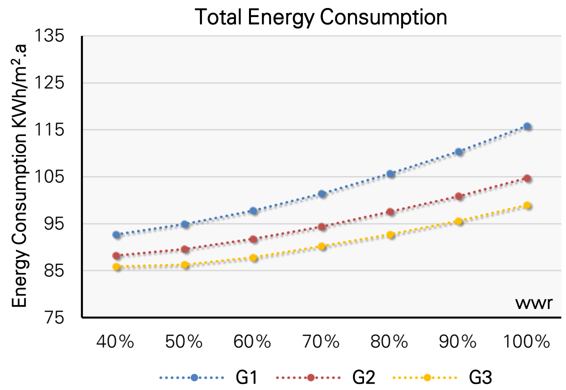
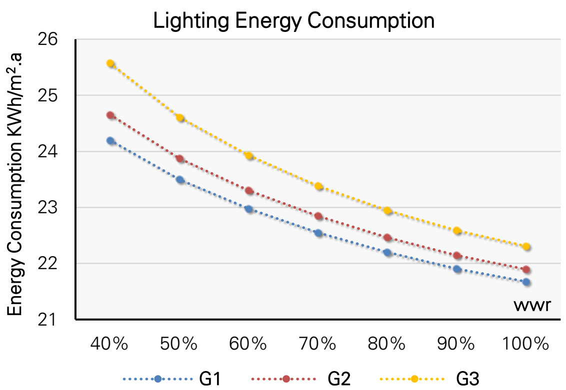
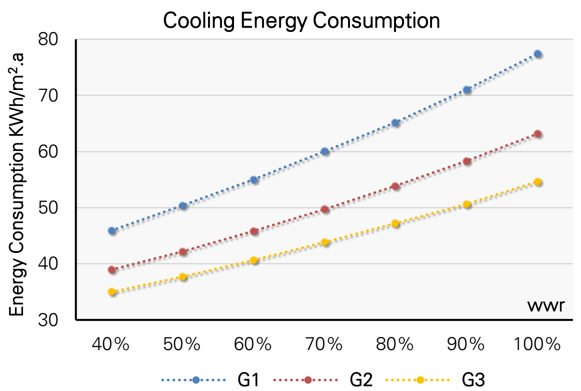


Figure 10 - 27: Lighting, cooling and total energy consumption for horizontal louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the South direction

- Vertical Louvers (SH4):





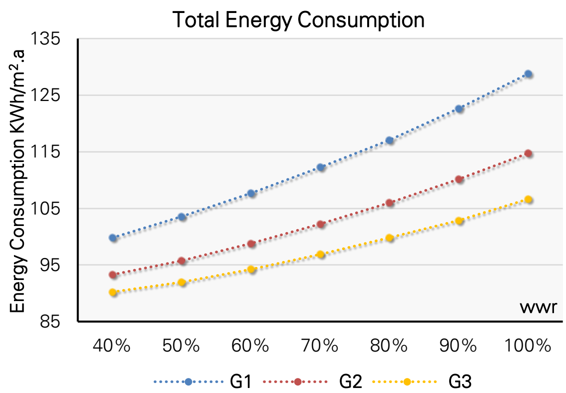
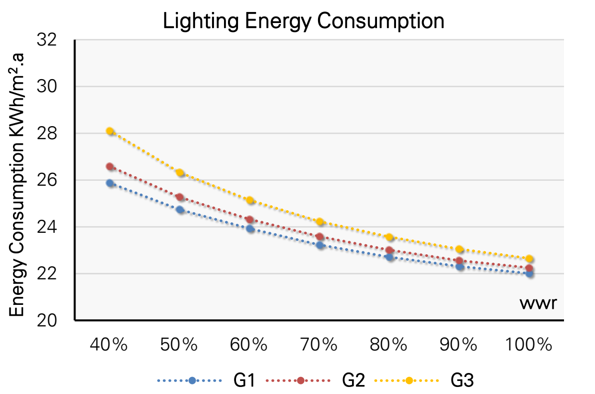
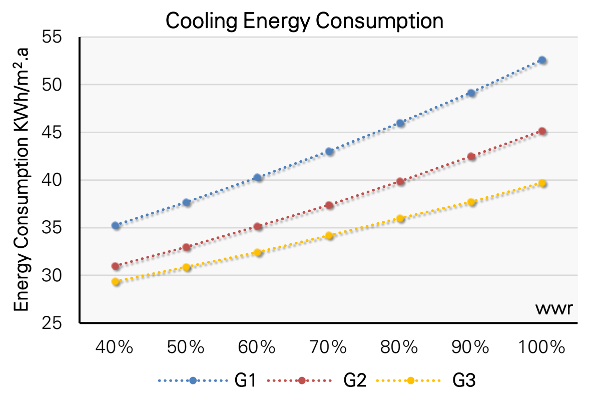


Figure 10 - 28: Lighting, cooling and total energy consumption for vertical louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the South direction

- Perforated Shadings (Mashrabya) (SH5):





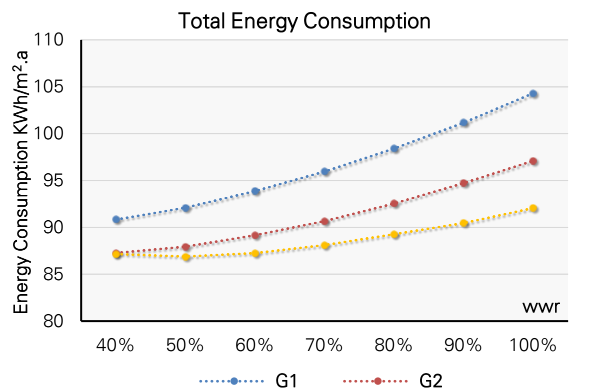


Figure 10 - 29: Lighting, cooling and total energy consumption for Mashrabya examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the South direction

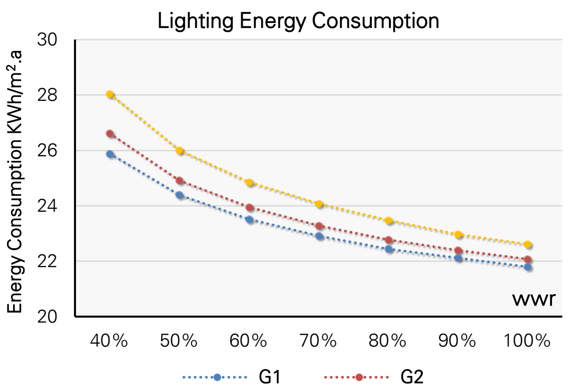
10.2.2.4. West Direction Findings:

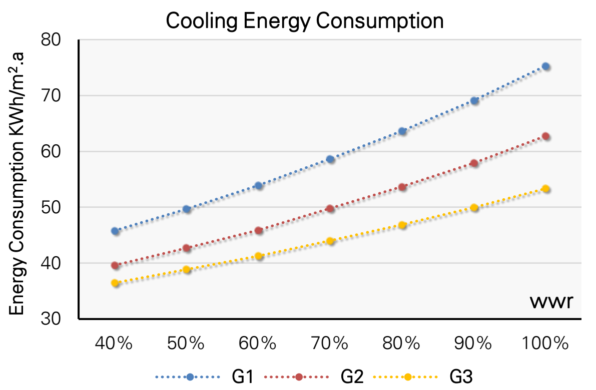
- **Lighting energy consumption:** Horizontal fins, horizontal louvers, horizontal overhang and vertical louvers recorded comparatively near measures for lighting energy consumptions. Typically, the lowest consumptions are with G1 glazing for higher window to wall ratios. The highest lighting consumption rate measure is 30.353 KWh/m^2 conducted in the case of Mashrabya with G3 for wwr 40%, while the lowest lighting energy consumption measure is 21.796 KWh/m^2 achieved in the case of horizontal fins with G1 for wwr 100%.

- **Cooling energy consumption:** The Mashrabya G3 glazing concept achieved the lowest cooling energy measures for all the examined window to wall ratios. The highest cooling consumption measure is 155.23 KWh/m^2 conducted in the case of vertical louvers with G1 for wwr 100%, while the lowest cooling energy consumption is 39.011 KWh/m^2 achieved in case of Mashrabya with G3 for wwr 40%.

- **Total energy consumption:** For wwr 60% and less the horizontal fins, horizontal louvers and Mashrabya with G3 glazing achieved the least total energy consumption measures. While for wwr higher than 70%, the Mashrabya with G3 achieved the lowest total measures. The highest total consumption measure is 206.949 KWh/m^2 conducted in the case of vertical louvers with G1 for wwr 100%, while the lowest total energy consumption measure is 94.202 KWh/m^2 achieved in the case of horizontal fins with G3 for wwr 40%.

- Horizontal Fins (SH1):





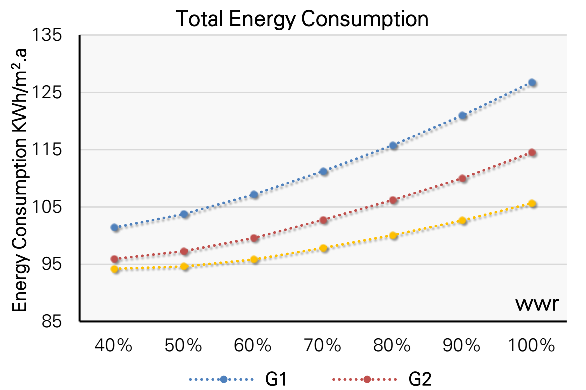
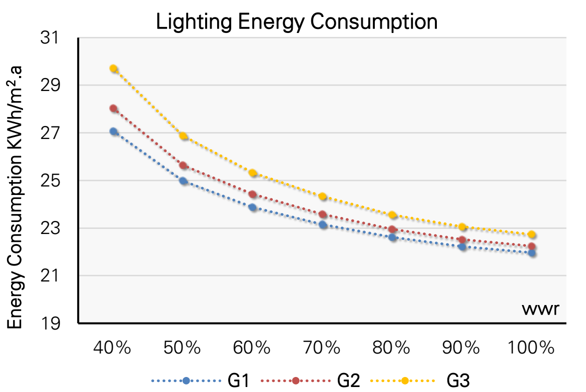
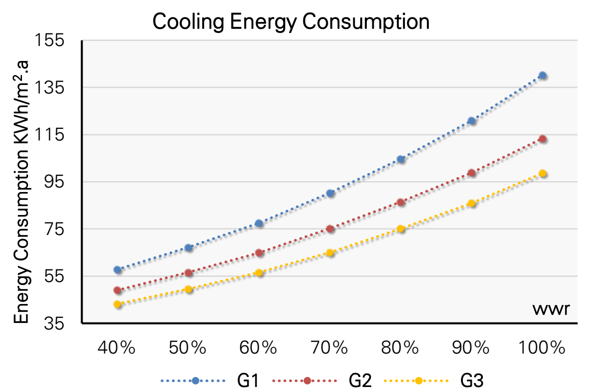


Figure 10 - 30: Lighting, cooling and total energy consumption for horizontal fins examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the West direction

- Horizontal Overhang (SH2):





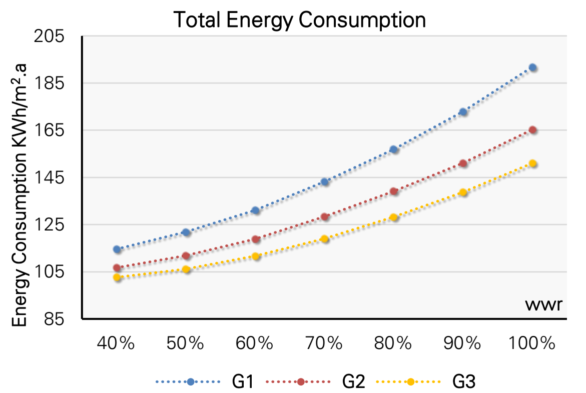
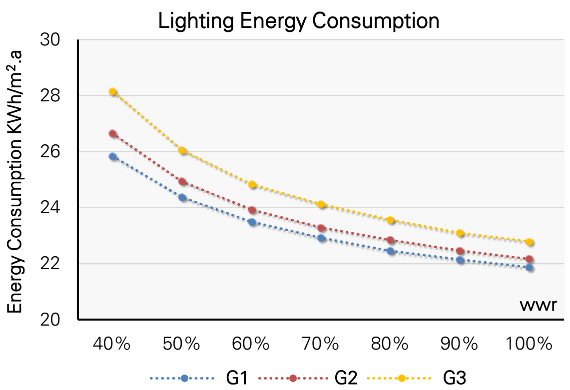
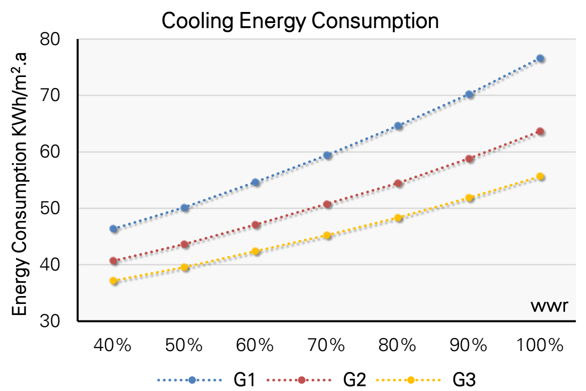


Figure 10 - 31: Lighting, cooling and total energy consumption for horizontal overhang examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the West direction

- Horizontal Louvers (SH3):





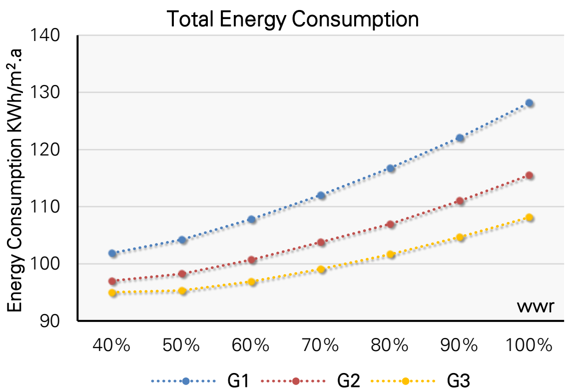
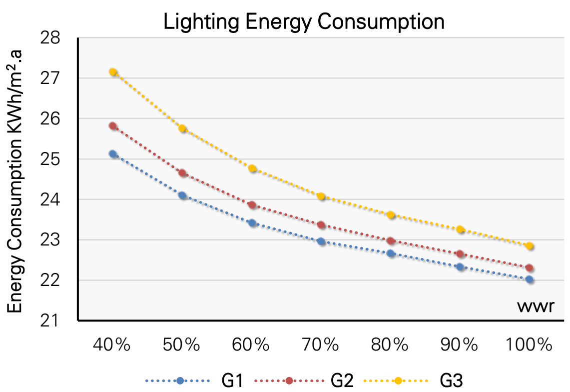
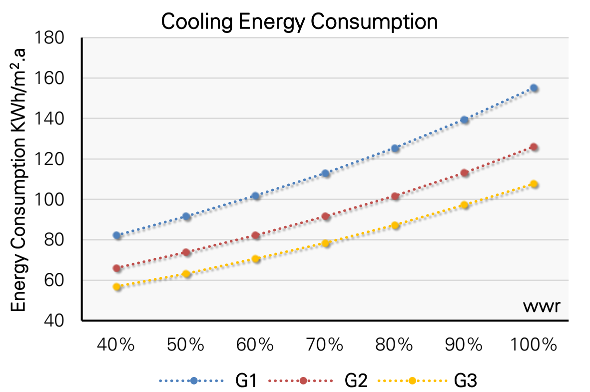


Figure 10 - 32: Lighting, cooling and total energy consumption for horizontal louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the West direction

- Vertical Louvers (SH4):





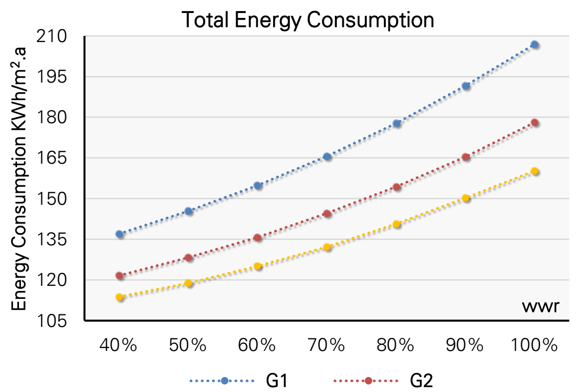
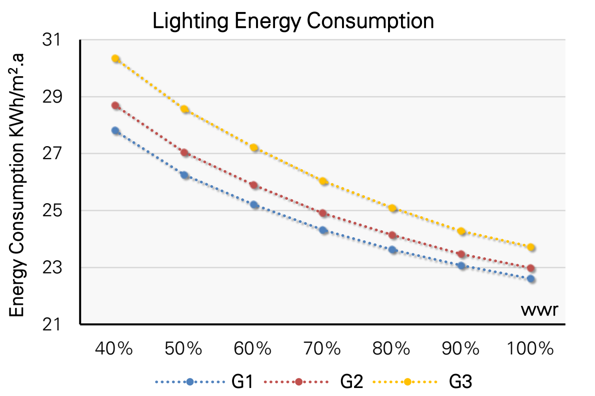
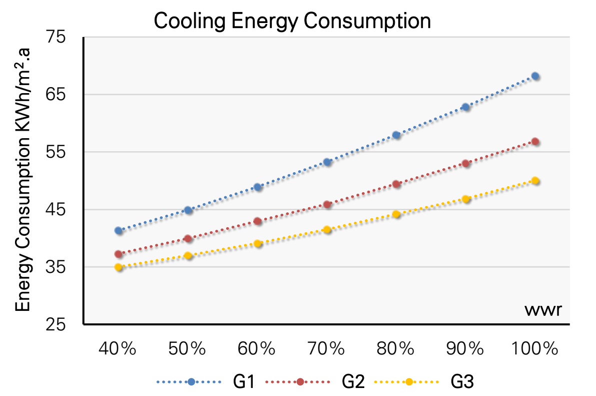


Figure 10 - 33: Lighting, cooling and total energy consumption for vertical louvers examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the West direction

- Perforated Shadings (Mashrabya) (SH5):





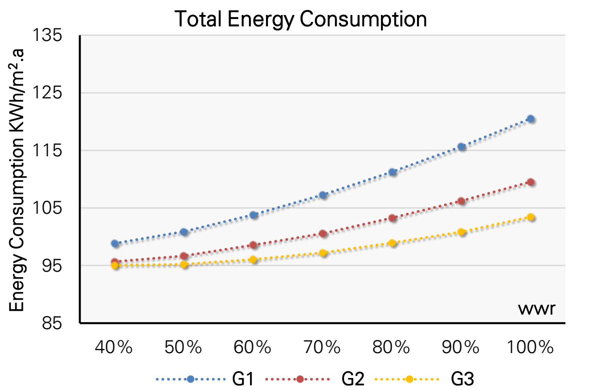


Figure 10 - 34: Lighting, cooling and total energy consumption for Mashrabya examined with the three solar control glazing concepts and wwr variables (from 40% to 100%) applied on the West direction

Chapter XI

Optimizing Energy Consumption with Transparency

11. Optimizing Energy Consumption with Transparency:

Nowadays, energy efficiency applications should be added as an essential parameter during the planning process of any building. Careful considerations should be given to the selection of the buildings' systems and its components with regard to their energetic performance (Bradshaw, 2006). Lechner (2015) noted that the architect's main objective had to care for the reduction of the total energy demand for his buildings. This could be achieved through; first, the initial design of the building itself, then, the integration of the appropriate passive measures, and finally by the selection of efficient mechanical systems.

Over the last few years, a considerable progress has been made on the reduction of the buildings' total energy needs. The level of technology we had reached nowadays, allows for high potentials of energy efficiency in our buildings. However, this may not be enough especially in a time when we are running out of our fossil energy resources. The buildings' total end use of energy is still too high, and needs some extra efforts to achieve developed building concepts for further significant reduction in the energy requirements for cooling, heating, ventilation, lighting, electrical appliances, and hot water production (IEA, 1997) & (Hegger, et al., 2008).

Glazed facades and its current technologies and developments are reintroduced as a crucial tool in tackling the buildings' energy efficiency concepts and the relevant environmental concerns (ElKadi, 2006). Chapter X of the research has investigated this issue. Where a considerable reduction was achieved to the total energy consumption of the office space in hot-arid climates which was applied on the example of Cairo through the integration of passive solar protection strategy.

On the other hand, the quest for high performance buildings is not just a matter of delivering buildings with less energy demand and following a number of technical and environmental standards; The building should be of high performance with regard to its occupant's needs, it should also contribute to their health, well-being, and productivity. Transparency plays a crucial role in achieving these goals; the design and selection of the buildings' glazed components involve various functional requirements such as affording daylight and view, in addition to many other functions. These issues contribute to the physical as well as the psychological wellbeing of the occupants. Therefore, there should be a need for a more integrated approach to the glazing conceptional design and for the selection of its components that give consideration to these expanded sets of issues (Carmody, et al., 2004).

Laurentin, et al. (2000) further underpinned the importance of considering the human factors in the glazing design. They argued that the provision of the visual contact to the outside and affording natural daylighting conditions are even more important than any other environmental parameters such as the ambient temperature or the illuminance level.

This part of the research is the fourth and the last pillar of the research operational study. Its main principal aims to provide the needed information for optimizing the office façade configuration in hot-arid climates, applied on the example of Cairo. The optimized office façade configurations are mainly based on achieving the appropriate balance between the visual measure of transparency with the office energetic performance based on the research solar protection parameters (Window to wall ratio, external shading devices, and glazed solar control concepts). The balancing ratio of the optimization processes is conducted according to the occupant's preference ratio which provides them with the physical and psychological well-being and the required sense of environmental satisfaction.

11.1. Optimizing Energy Consumption with Transparency Methodology and Sequence:

Optimizing the transparency of office spaces in hot-arid climates applied on the example of Cairo can be elaborated through the following three phases:

11.1.1. Calculating the View Index Values:

The view index represents the research main visual measure to the office transparency. According to Carmody, et al. (2004, p. 49), view index is defined as "the fraction of area available as view resulting from multiplying the window-wall area, the visible transmittance of the glass, the fraction of window area not obstructed by permanent exterior shading devices, and the percentage time that interior shades do not obstruct view, times a factor near 1 that corrects for excessive reflectance from the window as seen by the occupant". The view index is calculated at exactly the midpoint between the side walls of the space, at 3.0 m (10 feet) from the glazed surface for a normal standing person at the height of 175 cm. Typically, higher view index values are considered better and most preferred. The view index could be expressed by the following equation:

View index = WWR x % of exterior shade x % of int. shade x visible transmittance x R x 10

In the research analysis, it was assumed that there is no interior shading, where its value is considered to be (1), and the correcting factor for the internal reflections is set to be 1. The view index values are calculated through two steps: First, the fraction of the visual area from the external shading devices is calculated from the inside, then, the visual area fraction is multiplied by the other factors to give the corresponding view index value.

View index values are calculated for each of the 420 cases that were energetically examined in Chapter X. For each case, only one parameter is changed from the research solar protection parameters, i.e. the view index value is calculated for each window to wall ratio with every external shading device and with every glazed solar control concept on the four main directions. In addition, the case of no external shading with clear 3 mm glass and full glazed area (wwr=100%) is also calculated to be used as a threshold for the maximum view index value in the optimization analysis.

11.1.2. Determining the Optimized Points:

The determination of the optimized points for the office space transparency configurations in hot-arid climates is mainly based on a parametric analysis process that aims to investigate the appropriate balance between the research energetic measures with their relevant visual measure according to the preference ratio of the office occupants' in Cairo. The optimized points determination could be summarized in the following five steps:

- **First:** The total energy consumption values and their corresponding view index values (for the same cases) are graphically represented. Each graph defines three curves representing the variation of the three glazed solar control concepts (G1, G2 & G3) for a specific external shading device on one of the four main directions.

- **Second:** Point A is allocated representing the case of no external shading with 3 mm clear unprotected glass and with a full glazed area (wwr=100%). This point is considered as a threshold for the maximum view index value (i.e. maximum preference to view), and also, a threshold to the maximum total energy consumption rate among the four main directions (i.e. minimum efficiency). Point A of the west orientation was chosen as a reference point over the other three, since it represents the worst-case scenario regarding energy consumption. This go with the other orientations, particularly by the North orientation, through giving it a distinct bonus as the most favorable one in energetic terms. At the same time, this reference value advantageous the decisive influence of the orientation according to the cardinal points, which might on well be considered a design factor in its own right.

- **Third:** Point B and point C are located. Theoretically, point C, which is the projection of point A on the energy axis, represents a virtual reference to the worst-case scenario, where the energy consumption is maximum, and the view index value is zero. While point B, which is the projection of point A on the view index axis, represents a virtual reference to the best-case scenario, where the total energy consumption is zero and the view index value is maximum.

- **Fourth:** The ray CB is drawn from the minimum preference point (point C) to the maximum preference point (point B), dividing the area of the graph into two equal parts to represent the proposed axe of preference. The upper right part of the graph, defined by triangle ABC represent more preference to view, while the lower left part of the graph, defined by triangle OCB represents more preference to energy efficiency. The proposed axe of preference balance between the preference to view with the preference to energy efficiency in equal ratios; or in other words, 50% visual preference and 50% preference to the energy efficiency. Based on the research survey findings, this ratio represents the required preference ratio to the office space occupants in Cairo. Other preference ratios could be obtained by revolving CB around point C based on the angle of rotation.

- **Fifth:** The balancing axe CB intersect with the previously mentioned three curves in three points that define the optimized configuration for the external façade which, according to the evaluation criteria defined above, balances between the visual preference and the energetic performance of the office space for every shading device with the glazed solar control concept. The corresponding energy consumption and view index values could be then detected from the points projection. While the equivalent window to wall ratio could be then easily obtained from the view index calculation graphs.

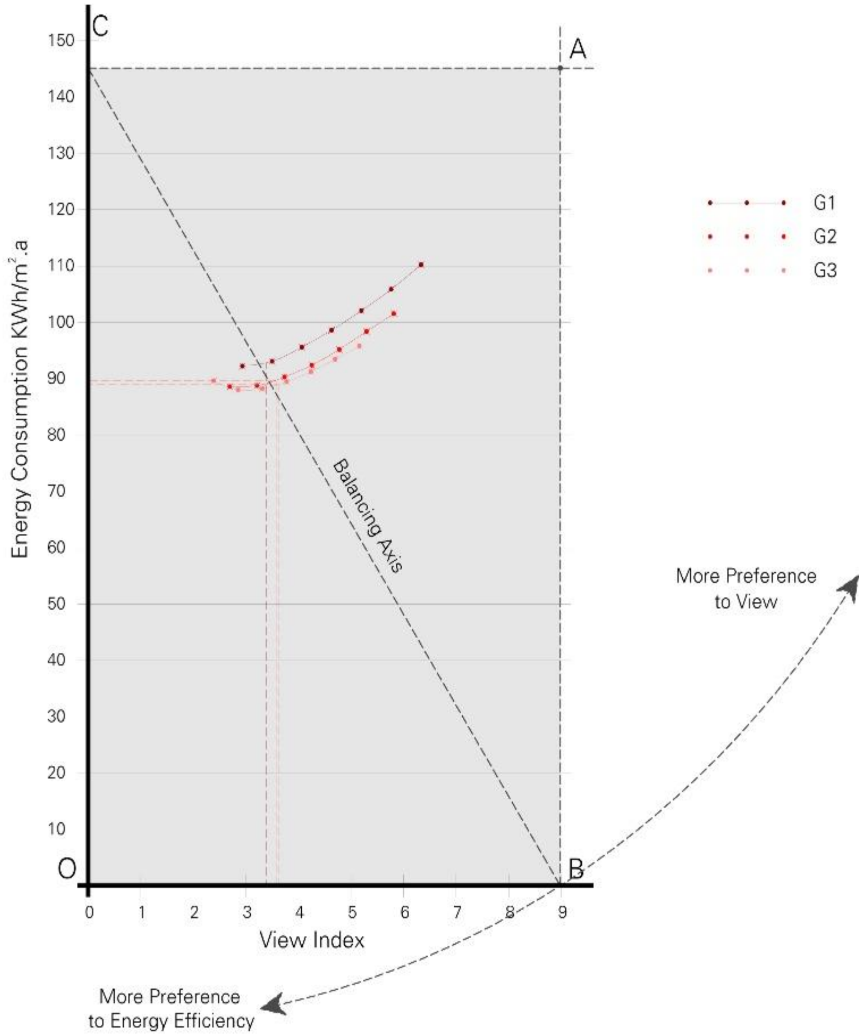


Figure 11 - 1: Optimizing Transparency Main Conception

11.1.3. Calculating the Energy-Transparency Balancing Factor (ETBF):

The research work proposed the "Energy-Transparency Balancing Factor" in order to compare the results of the energetic and visual optimized points. It could be defined as the ratio of the energetically and visually optimized façade configuration preference to a virtual point that affords the maximum visual measure with the minimum energy consumption values (i.e. point B). The higher Energy-Transparency Balancing Factor is the most preferred, since it indicates more view index measures with less total energy consumption rates.

The proposed Energy-Transparency Balancing Factor (ETBF) could be measured from the previously mentioned optimizing graphs in which the line BP drawn perpendicularly to the balancing axe CB at point B with a unit reference length. Joining the line PC gives a degradation in the perpendicular length measures from the line CP to the line BC, i.e. degradation from the best scenario point with the reference unit measure to the worst scenario with the zero measure. The perpendicular lines from the balancing axe at the optimized points (O_{G1}, O_{G2}, and O_{G3}) intersect with the line PC at the points P_{G1}, P_{G2} and P_{G3}. The measuring length of the lines $O_{G1}P_{G1}$, $O_{G2}P_{G2}$ and $O_{G3}P_{G3}$ are then divided by the unit reference measure of point B to determine the value of the proposed Energy-Transparency Balancing Factor (ETBF). The nearer optimized points to the point B, the more view index measure it indicates, the less total energy consumption it requires, and the highest ETBF it scores.

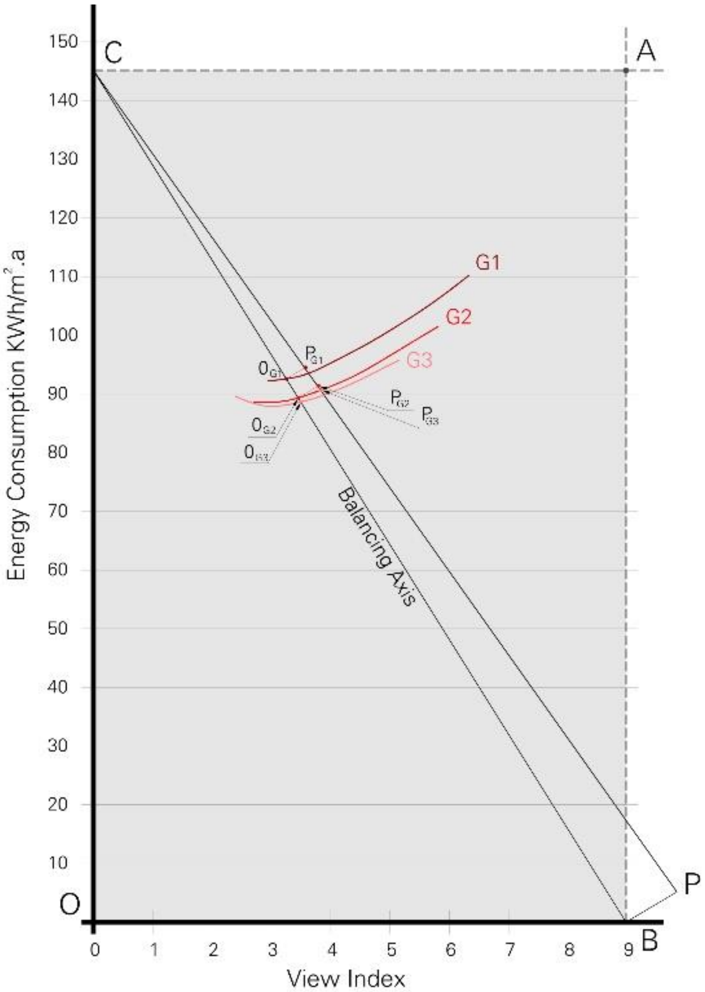


Figure 11 - 2: The Proposed Energy-Transparency Balancing Factor measuring concept

11.2. Optimizing Energy Consumption with Transparency Findings:

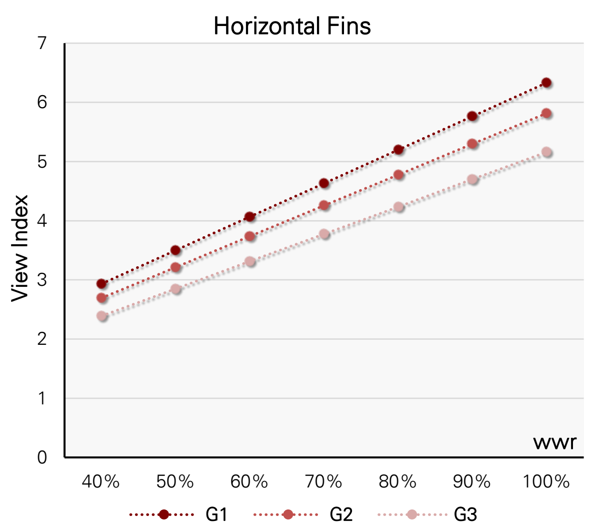
11.2.1. View Index Calculation Findings:

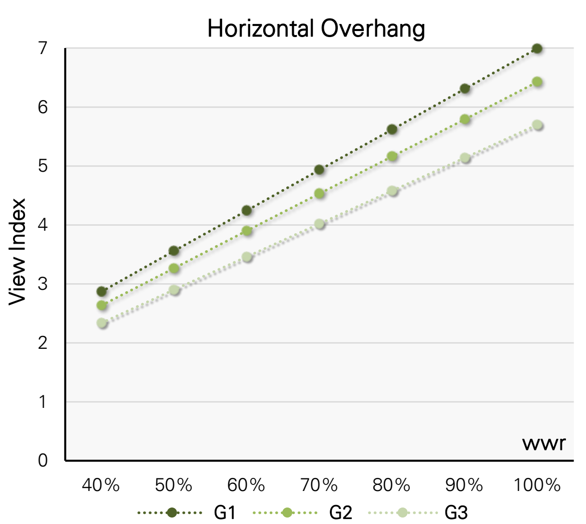
The visual area fraction of exterior shadings is calculated first. Its findings show a quite linear regression analysis with increasing the window to wall ratio for all the calculated shading devices. The analysis graphs and regression equations of the visual area fraction for each external shading device with regard to the change in the window to wall ratios in the four main directions are demonstrated in Appendix C. These values were then integrated into the view index equation to calculate the corresponding view index values for all the energetically modeled and simulated office cases.

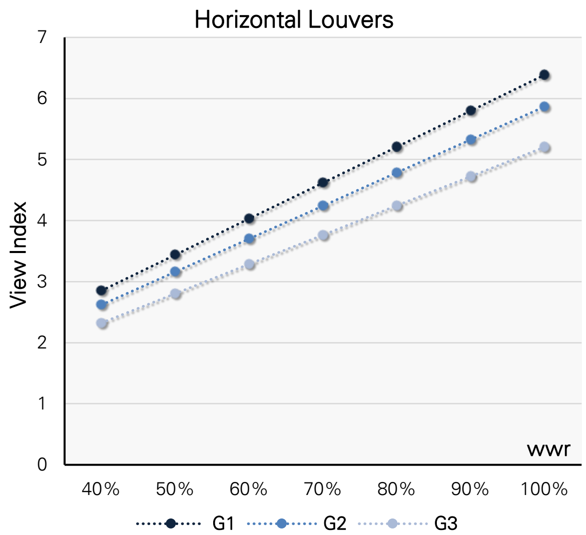
Through the followed points from 11.2.1.1 to 11.2.1.4 and figures from 11.3 to 11.6, the view index values are graphically represented for all the calculated office cases in the four main directions. Each graph represents the variation of the view index value for the three solar control glazing concepts with respect to the change in the window to wall ratio for each shading device in one of the main directions.

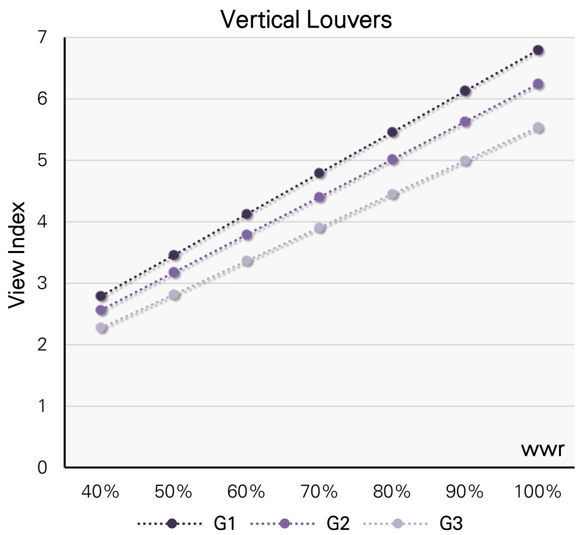
The view index graphs analysis shows that with the increase in the window to wall ratios, the view index values are increased substantially. Comparing the view index values of the five examined shading devices, it was found that in wwr of 40% and 50% the horizontal fins, horizontal overhang and horizontal louvers shadings scored near higher values for both the visual area fraction and the view index values, but for wwr of 60% and more, the horizontal overhang solitary achieved the highest values. While for all the window to wall ratios, the Mashrabya shading scored the lowest visual area fraction, and subsequently the lowest view index values. For the examined glazed solar control concepts, and owing to their solar transmission properties, solar control glazing G1 scored the highest view index values, followed by G2, then G3 came the least for its lowest light transmission value.

11.2.1.1. North Direction View Index Calculation:









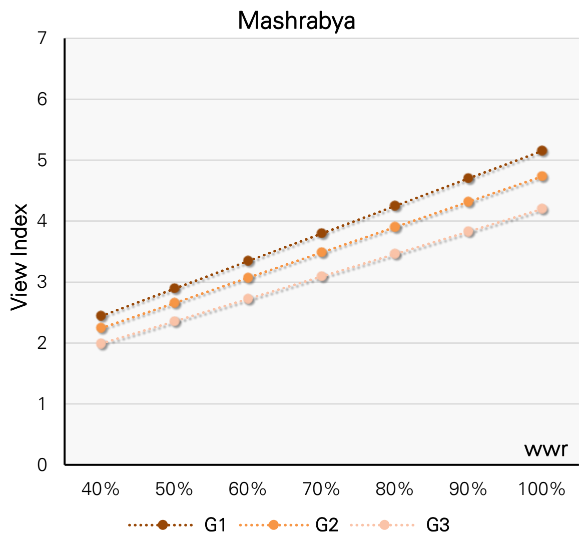
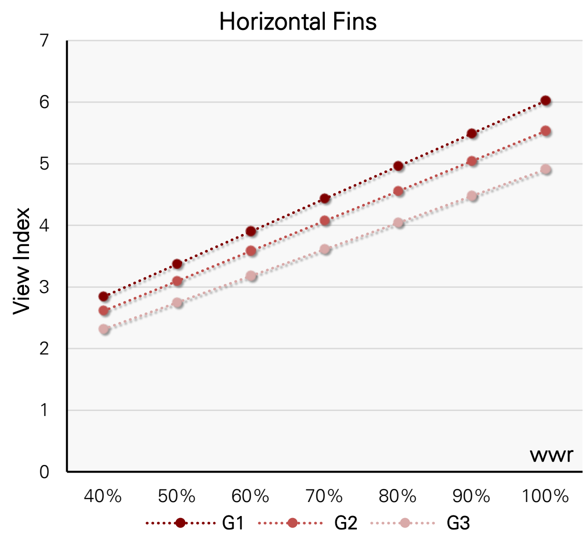
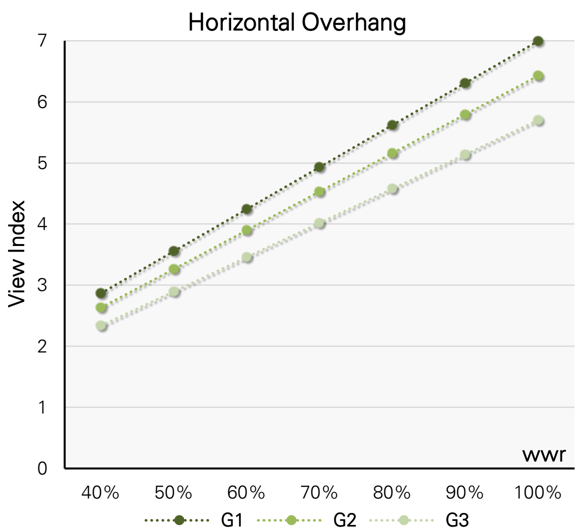
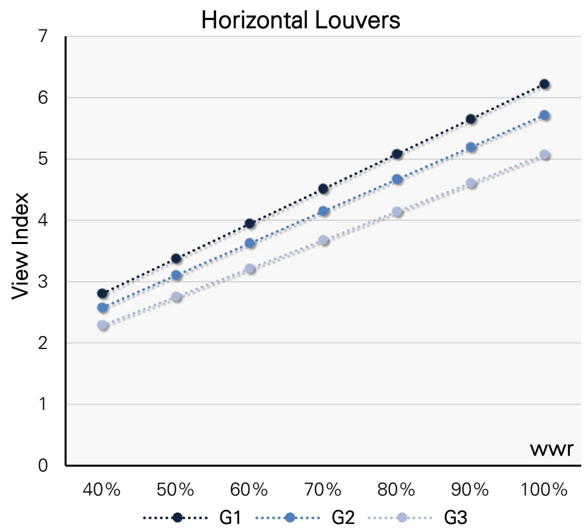


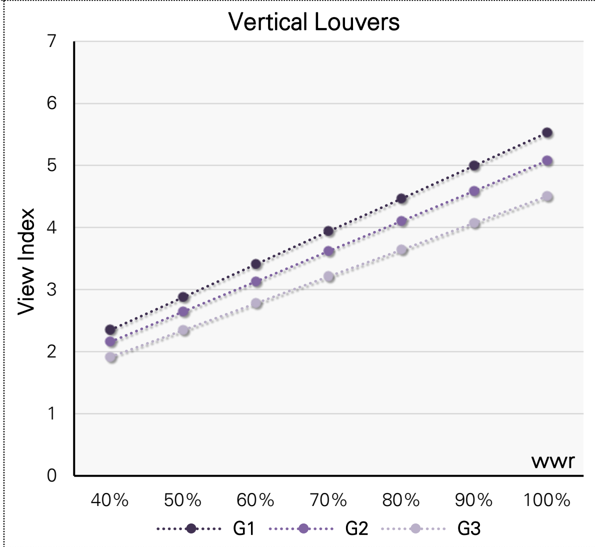
Figure 11 - 3: View index calculation findings for North direction. Each graph shows the calculated view index values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.

11.2.1.2. East Direction View Index Calculation:









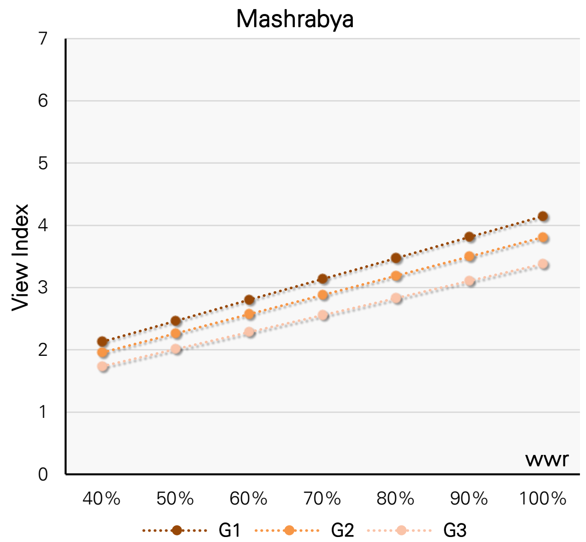
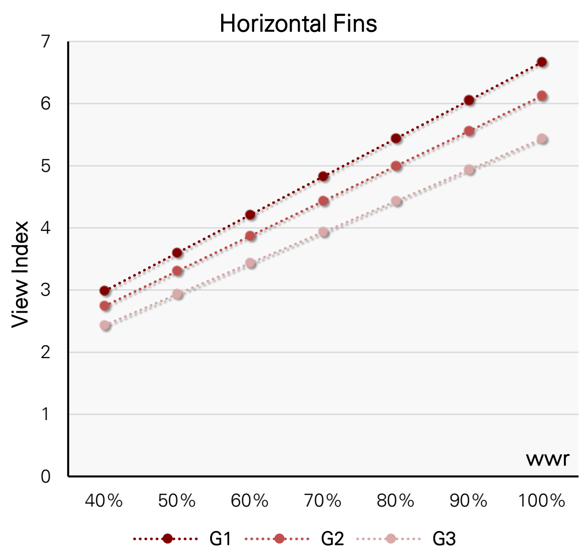
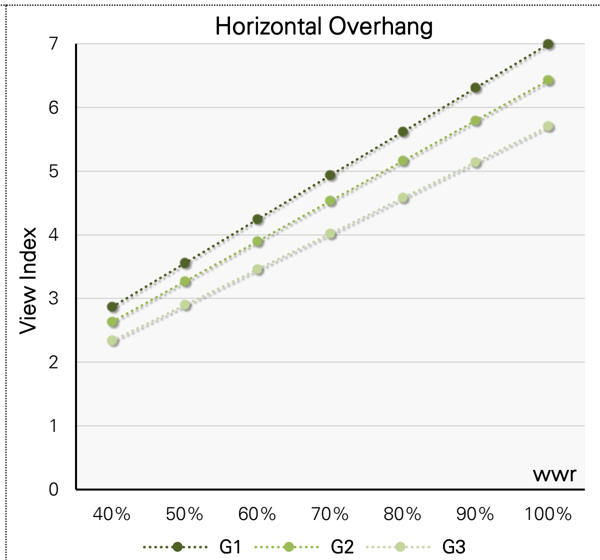
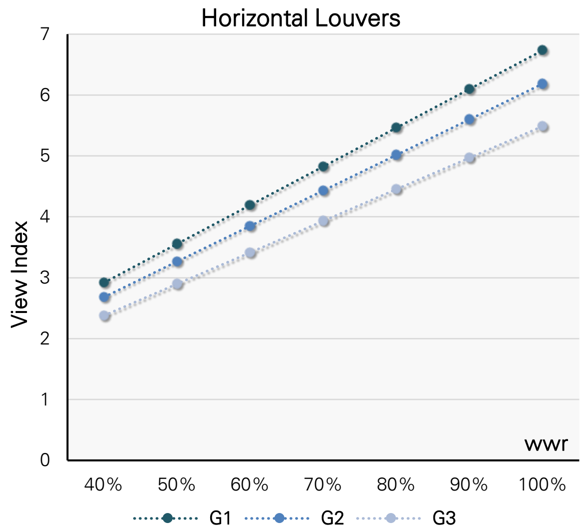


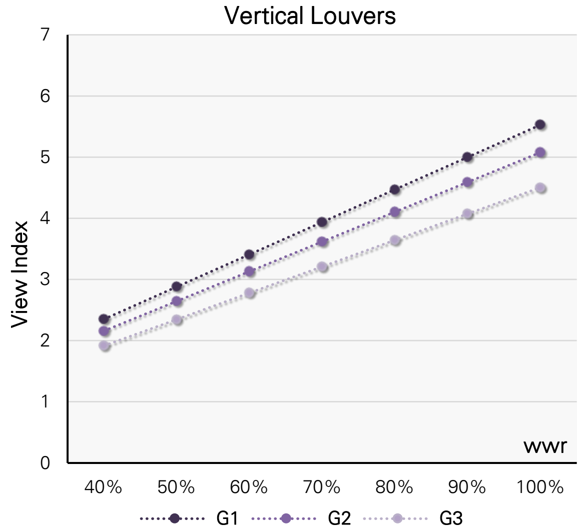
Figure 11 - 4: View index calculation findings for East direction. Each graph shows the calculated view index values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.

11.2.1.3. South Direction View Index Calculation:









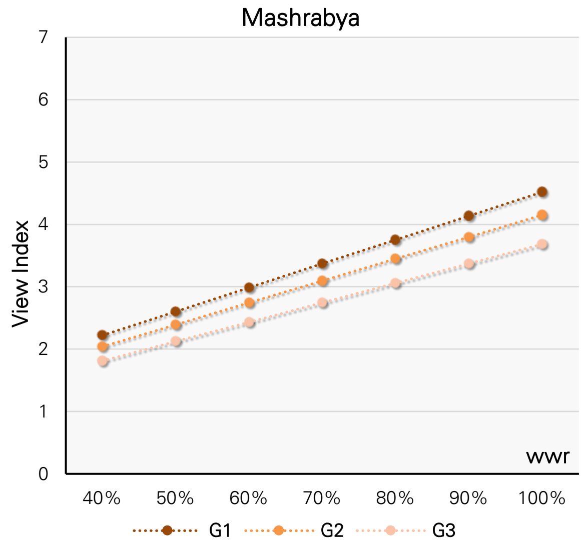
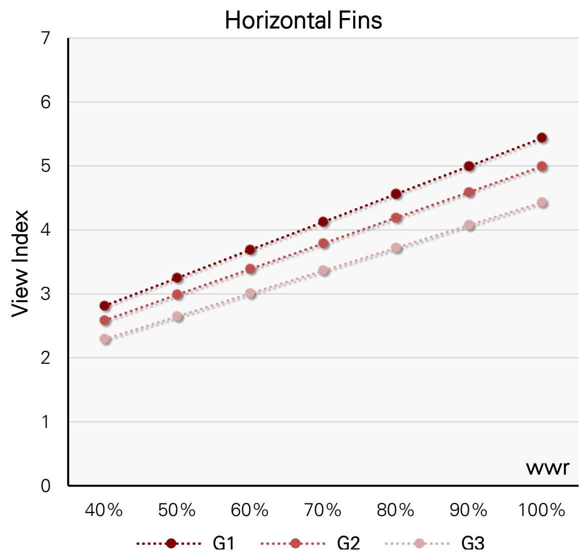
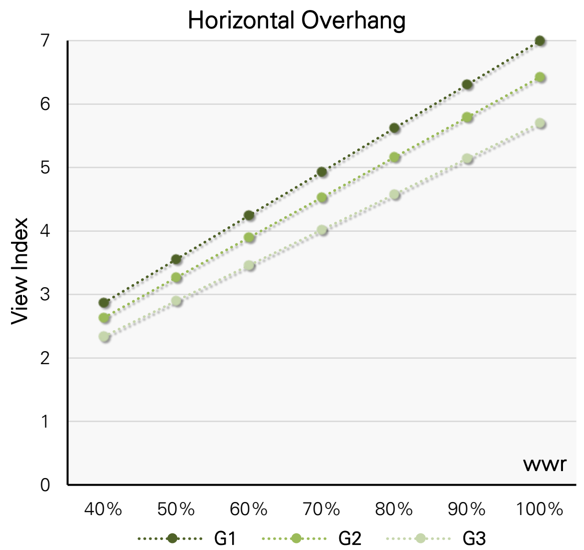
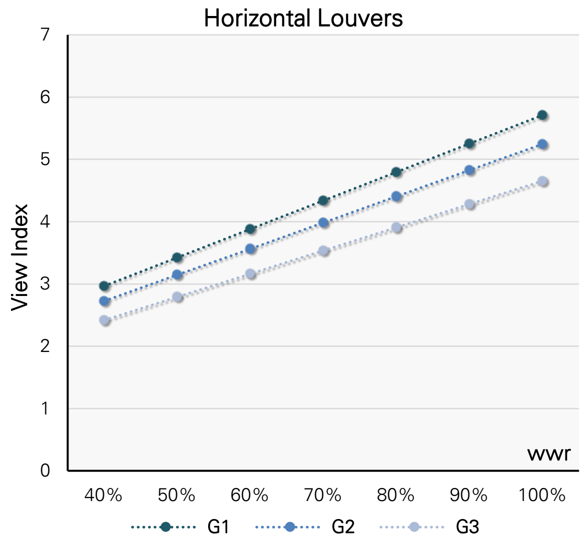


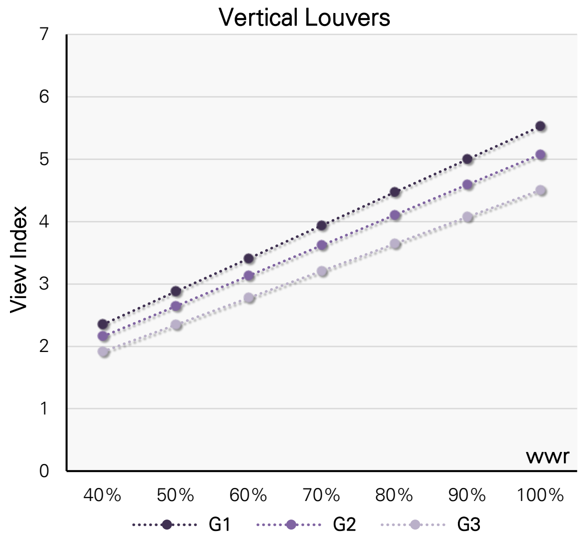
Figure 11 - 5: View index calculation findings for South direction. Each graph shows the calculated view index values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.

11.2.1.4. West Direction View Index Calculation:









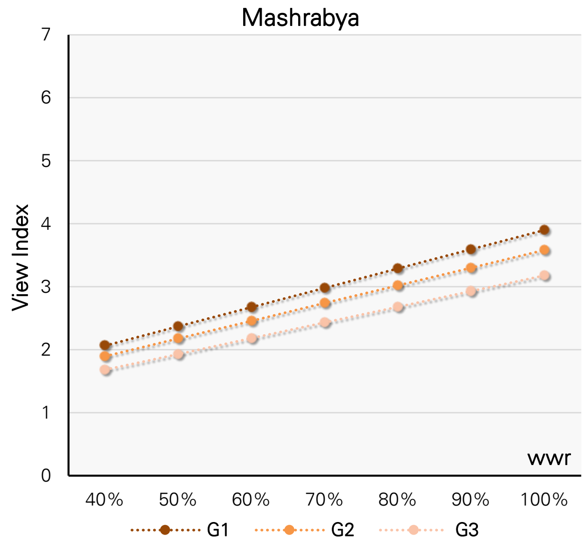


Figure 11 - 6: View index calculation findings for West direction. Each graph shows the calculated view index values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.

11.2.2. Optimized Points Determination Findings:

In this section, the optimized points are determined through the aid of the optimization graphs. Each graph demonstrates the energetic performance of the glazed solar control concepts (G1, G2 and G3) for the office space cases with respect to their corresponding visual measures for a specific external shading device on one of the four main directions. The optimization axe that balances between the energetic performance and the visual measures in every direction is drawn in each graph according to the previously mentioned optimization process. Where, the optimization axe is intersected with the three-glazed solar control concept curves for each specific external shading device in three optimized points. For each one of the optimized points, the total energy consumption and the view index value is drawn from the graph, in addition, the corresponding window to wall ratio is concluded from the visual area calculation graphs. These optimized points and their relevant properties are presented through this section in tables, where each table demonstrates all the optimized points for the five external shading devices and the three-solar control glazing concept combinations in one of the main directions.

11.2.2.1. North Direction Optimized Points:

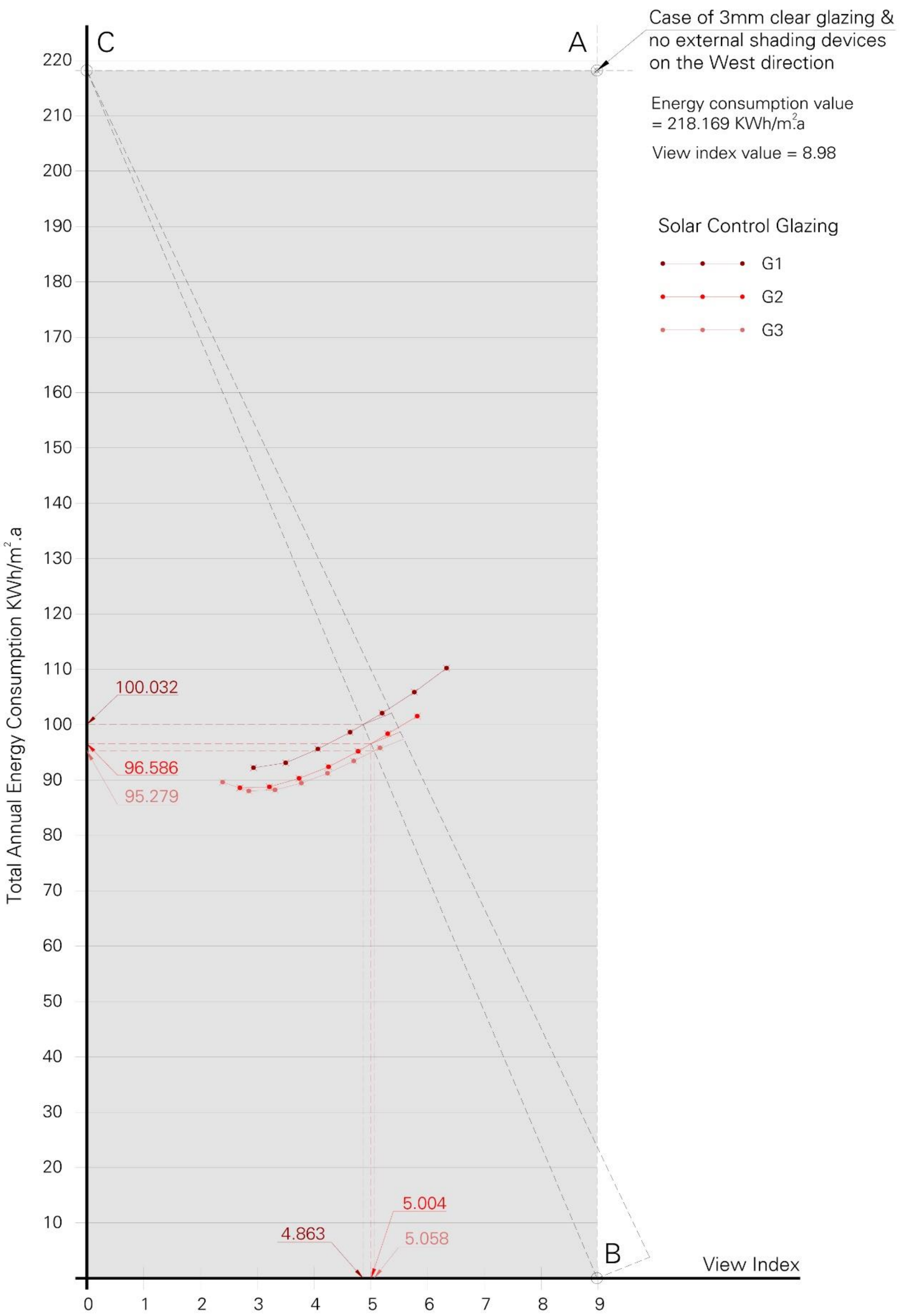


Figure 11 - 7: Horizontal fins optimized points on North direction

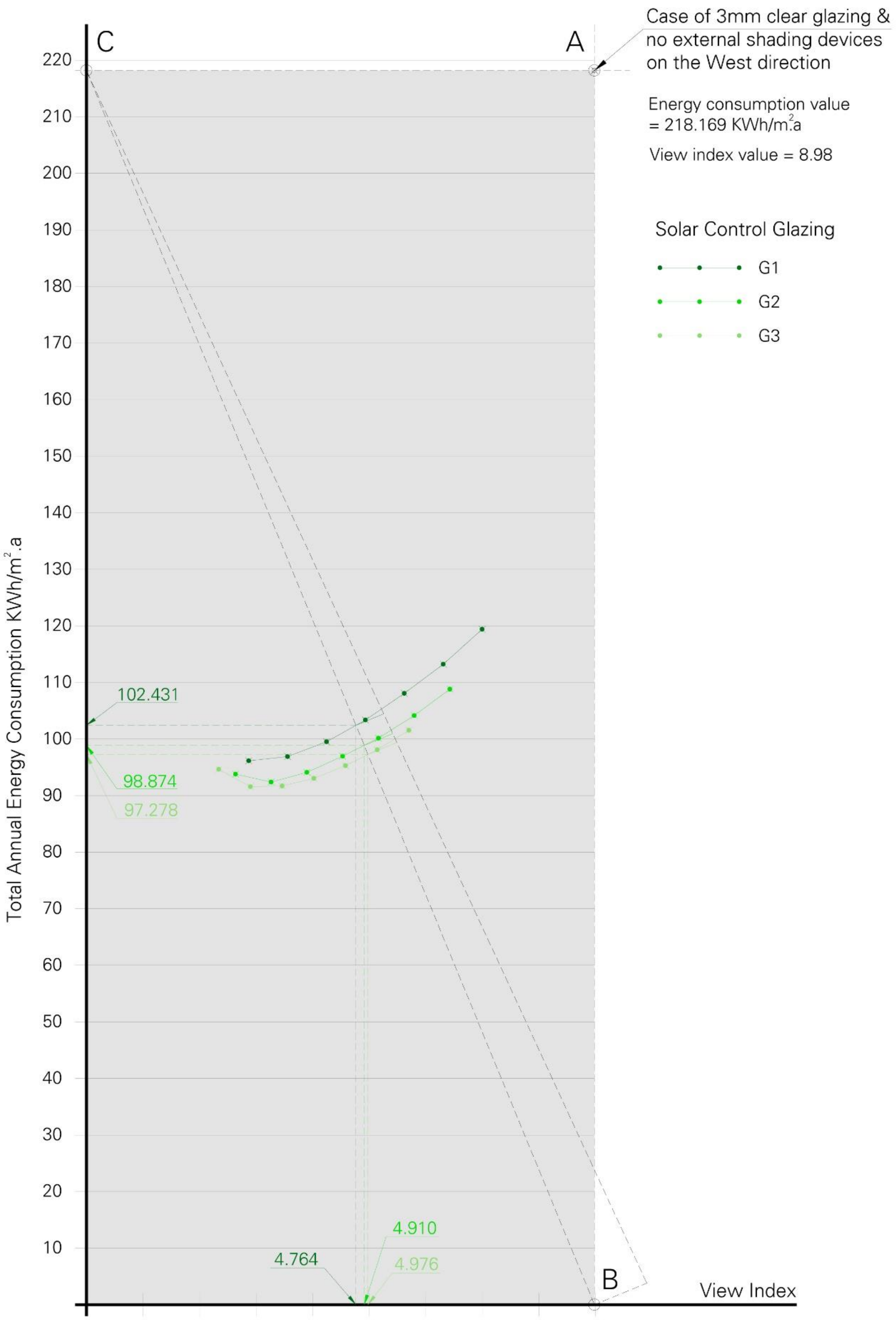


Figure 11 - 8: Horizontal overhang optimized points on North direction

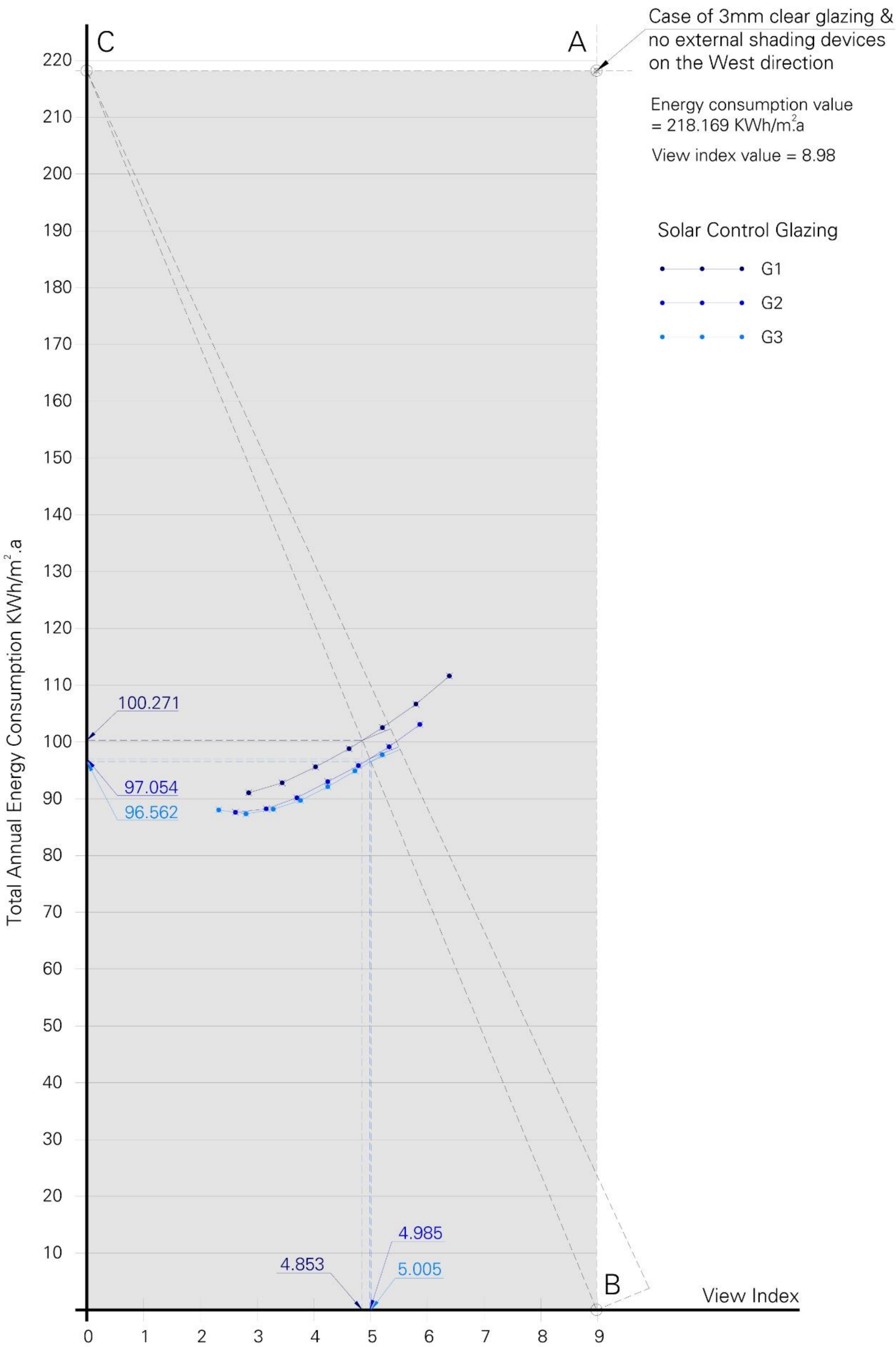


Figure 11 - 9: Horizontal Louvers optimized points on North direction

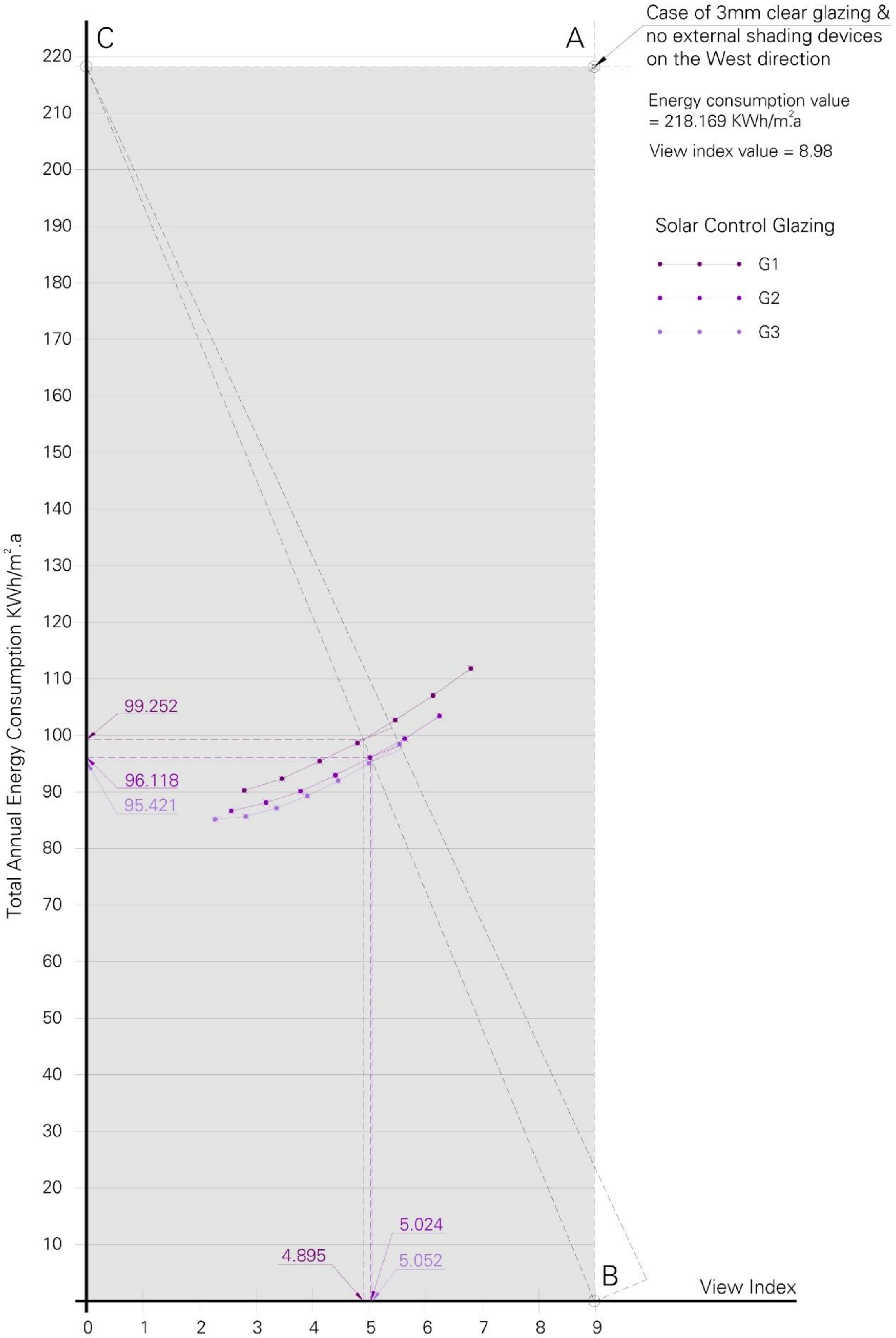


Figure 11 - 10: Vertical louvers optimized points on North direction

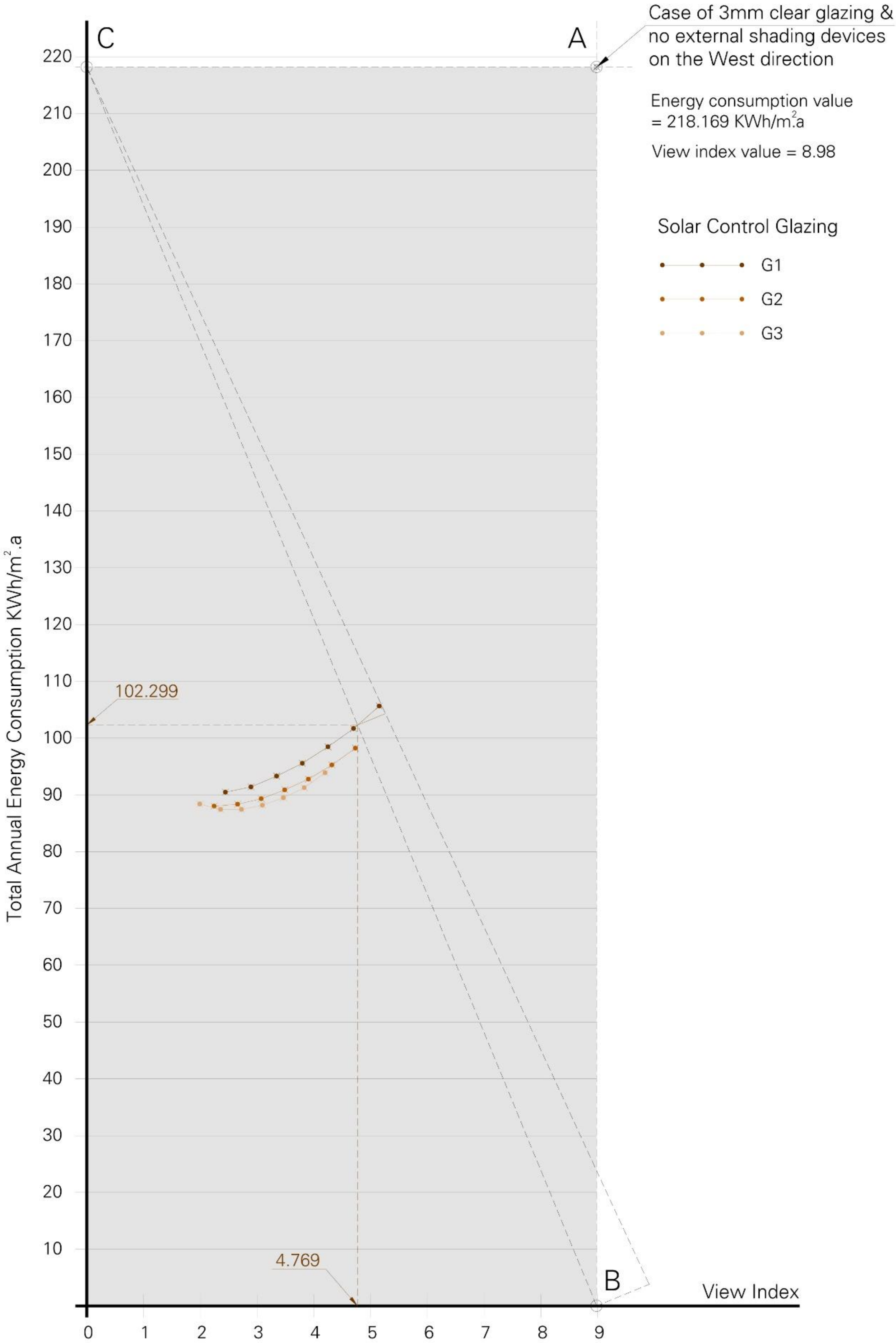


Figure 11 - 11: Mashrabya optimized points on North direction

11.2.2.2. East Direction Optimized Points:

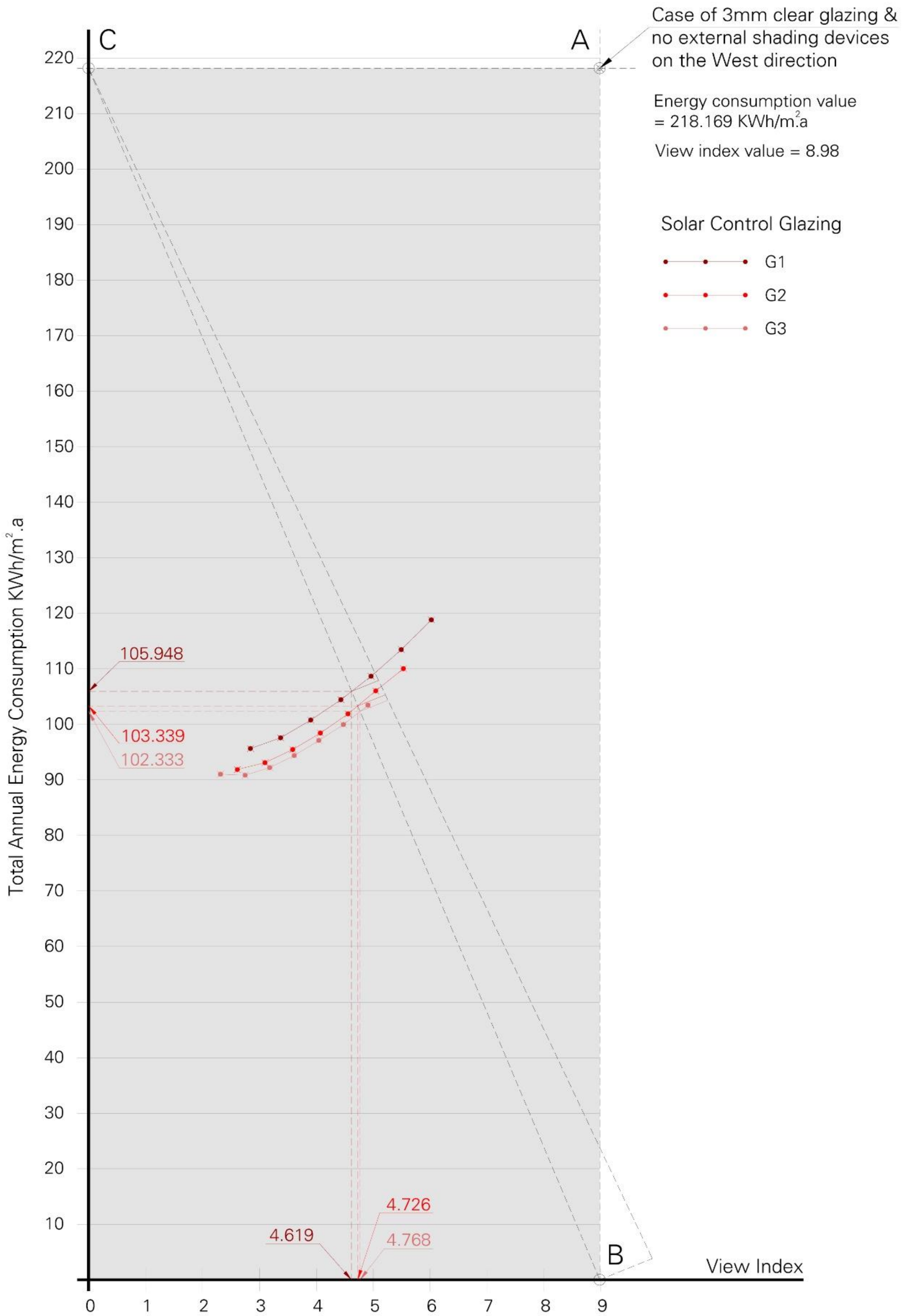


Figure 11 - 12: Horizontal fins optimized points on East direction

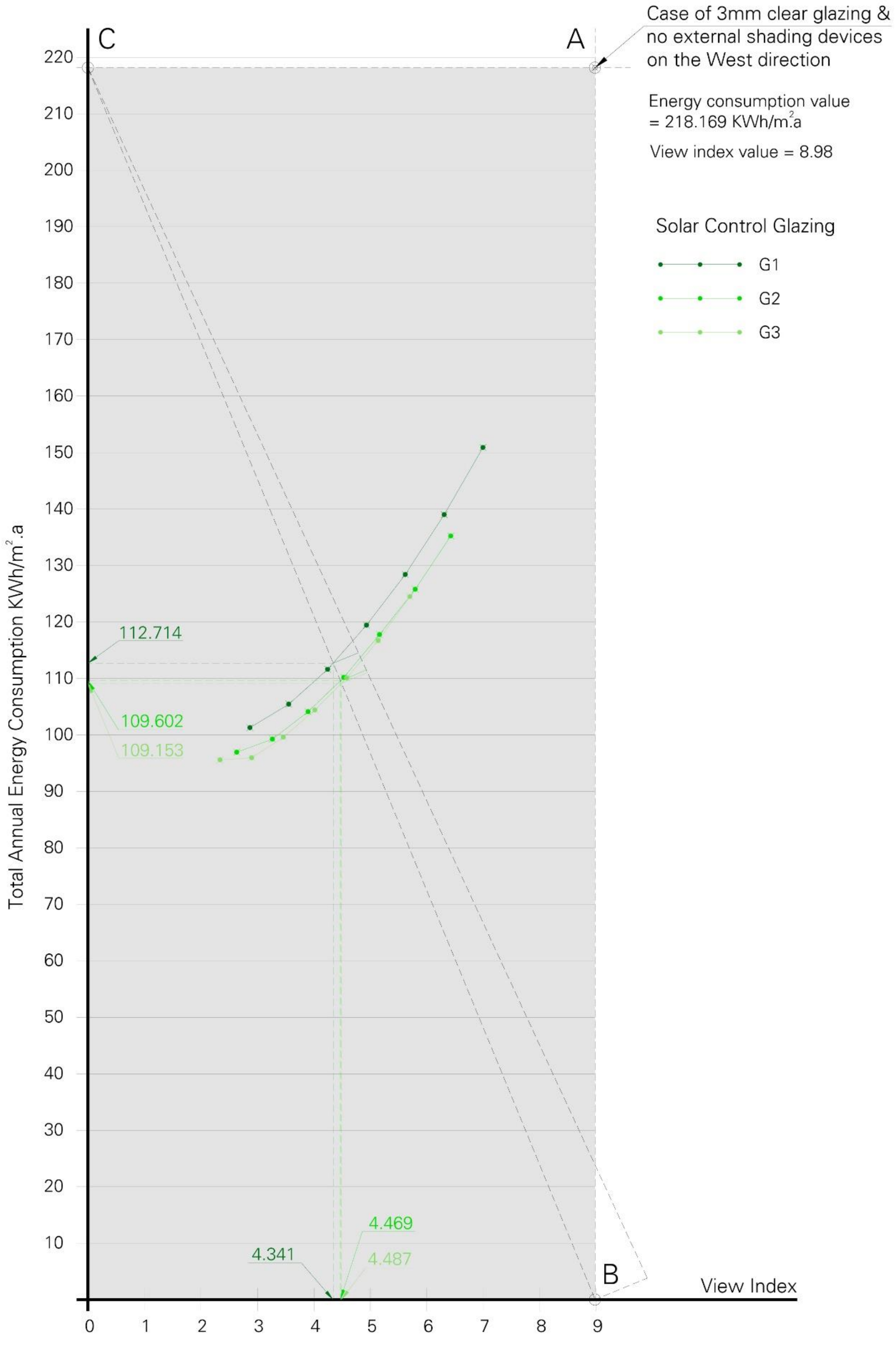


Figure 11 - 13: Horizontal overhang optimized points on East direction

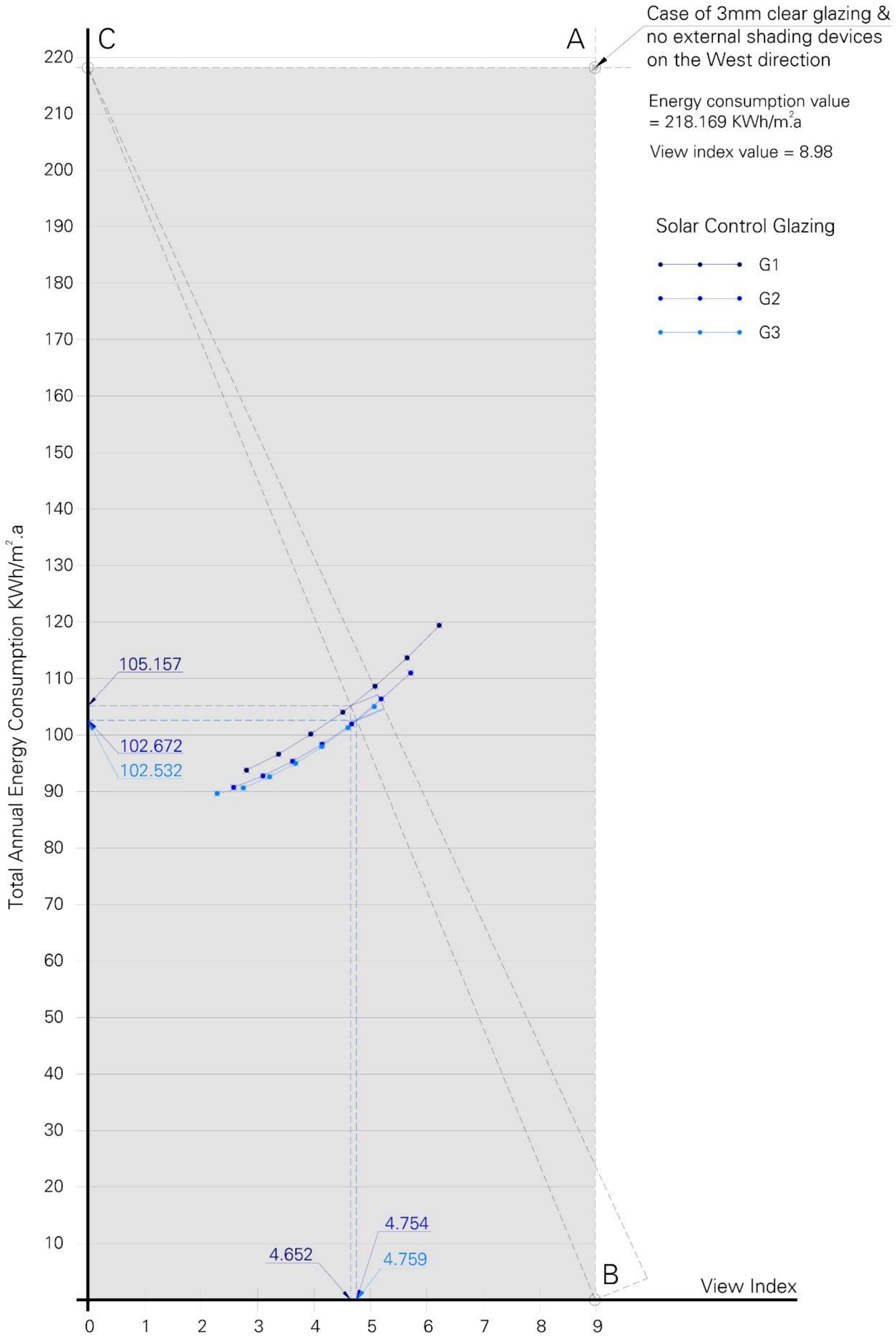


Figure 11 - 14: Horizontal Louvers optimized points on East direction

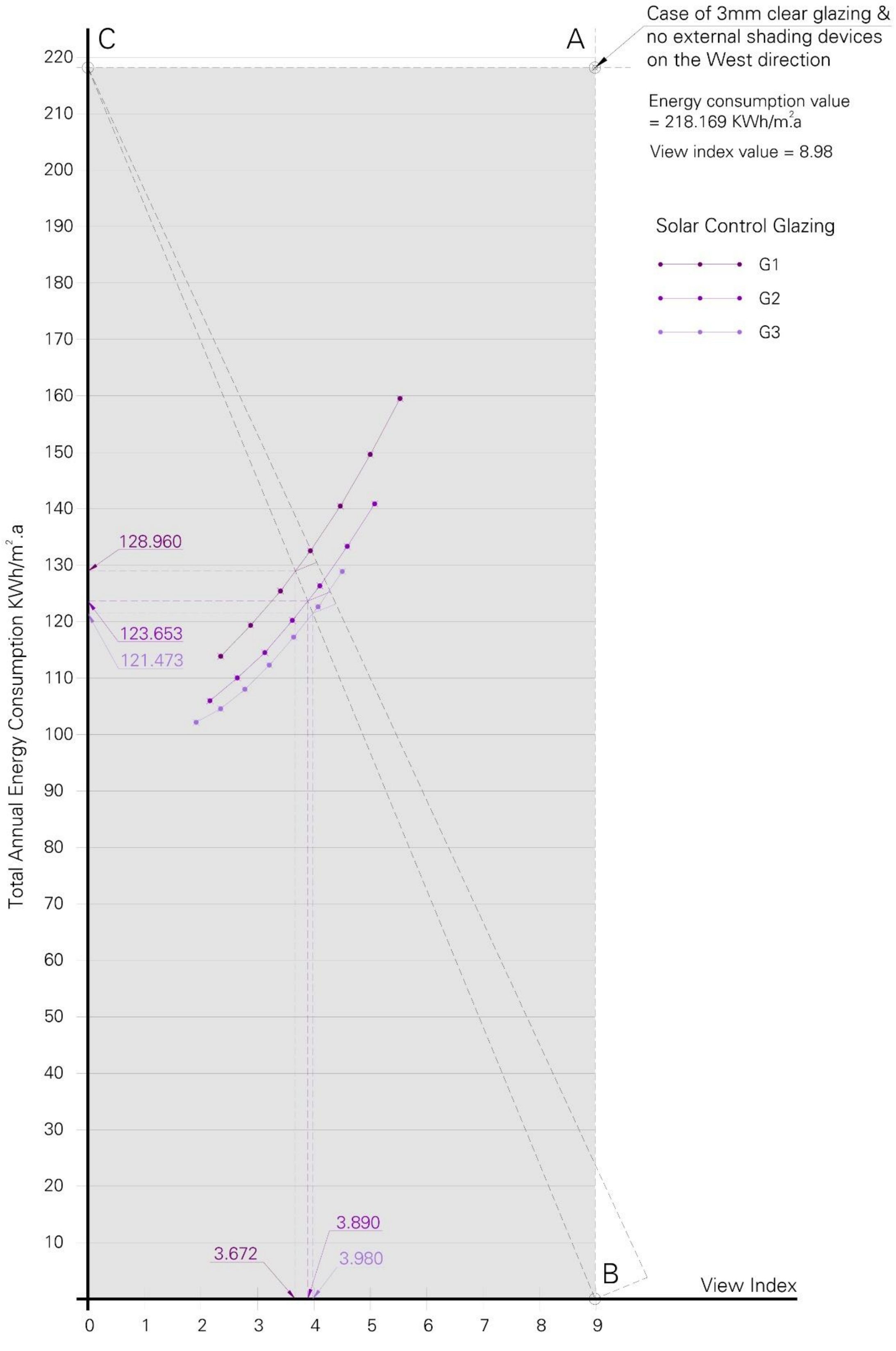


Figure 11 - 15: Vertical louvers optimized points on East direction

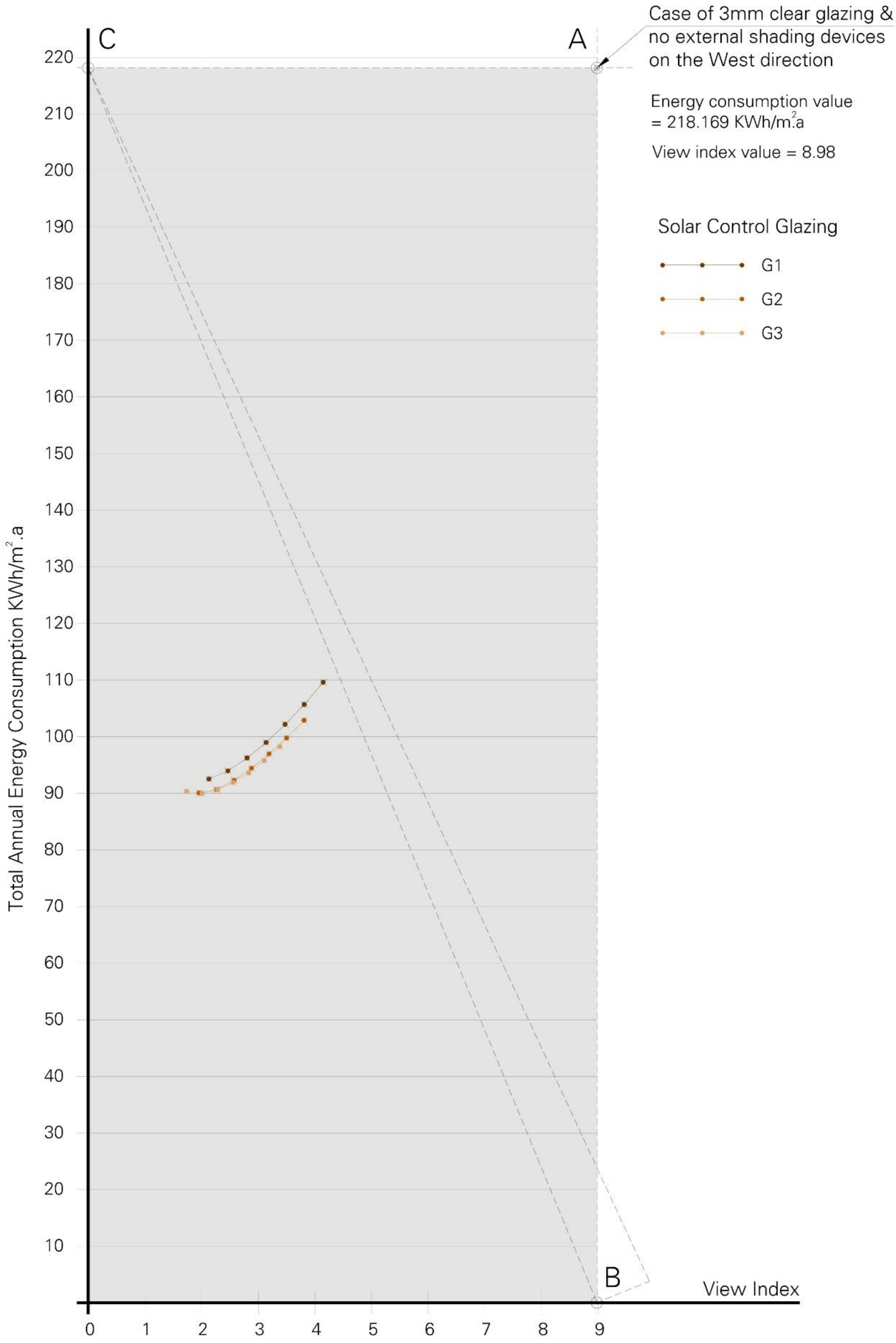


Figure 11 - 16: Mashrabya optimized points on East direction

11.2.2.3. South Direction Optimized Points:

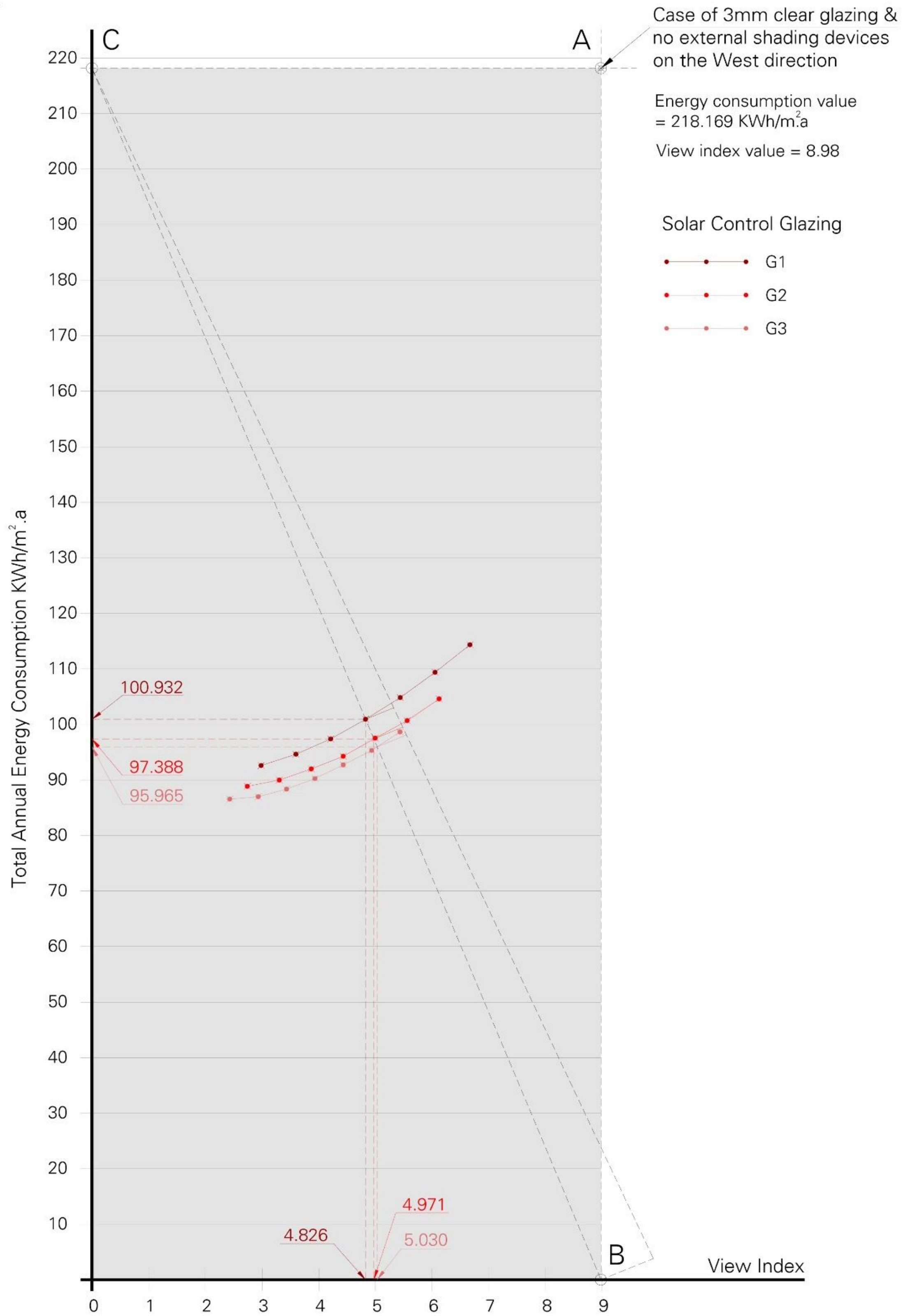


Figure 11 - 17: Horizontal fins optimized points on South direction

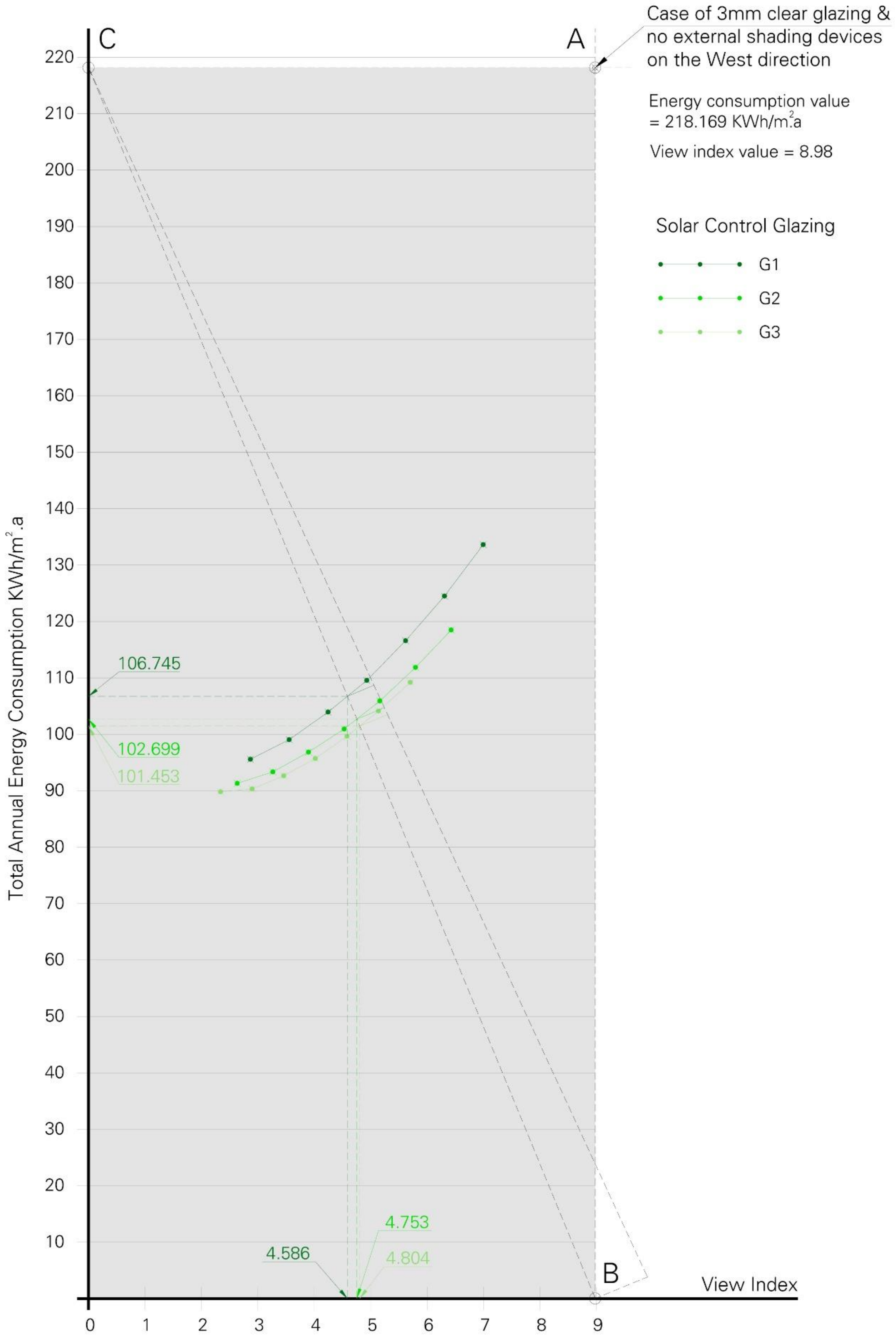


Figure 11 - 18: Horizontal overhang optimized points on South direction

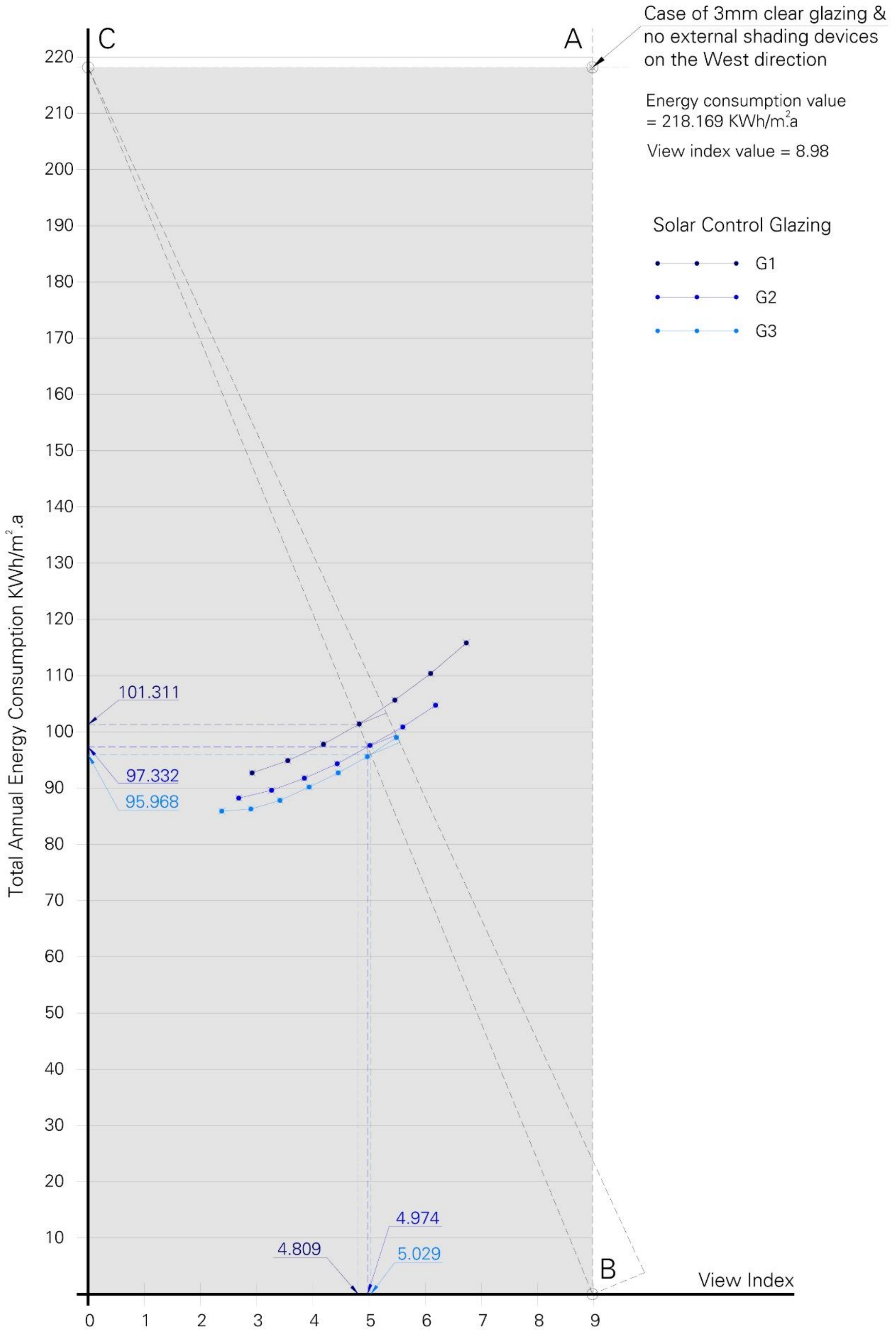


Figure 11 - 19: Horizontal Louvers optimized points on South direction

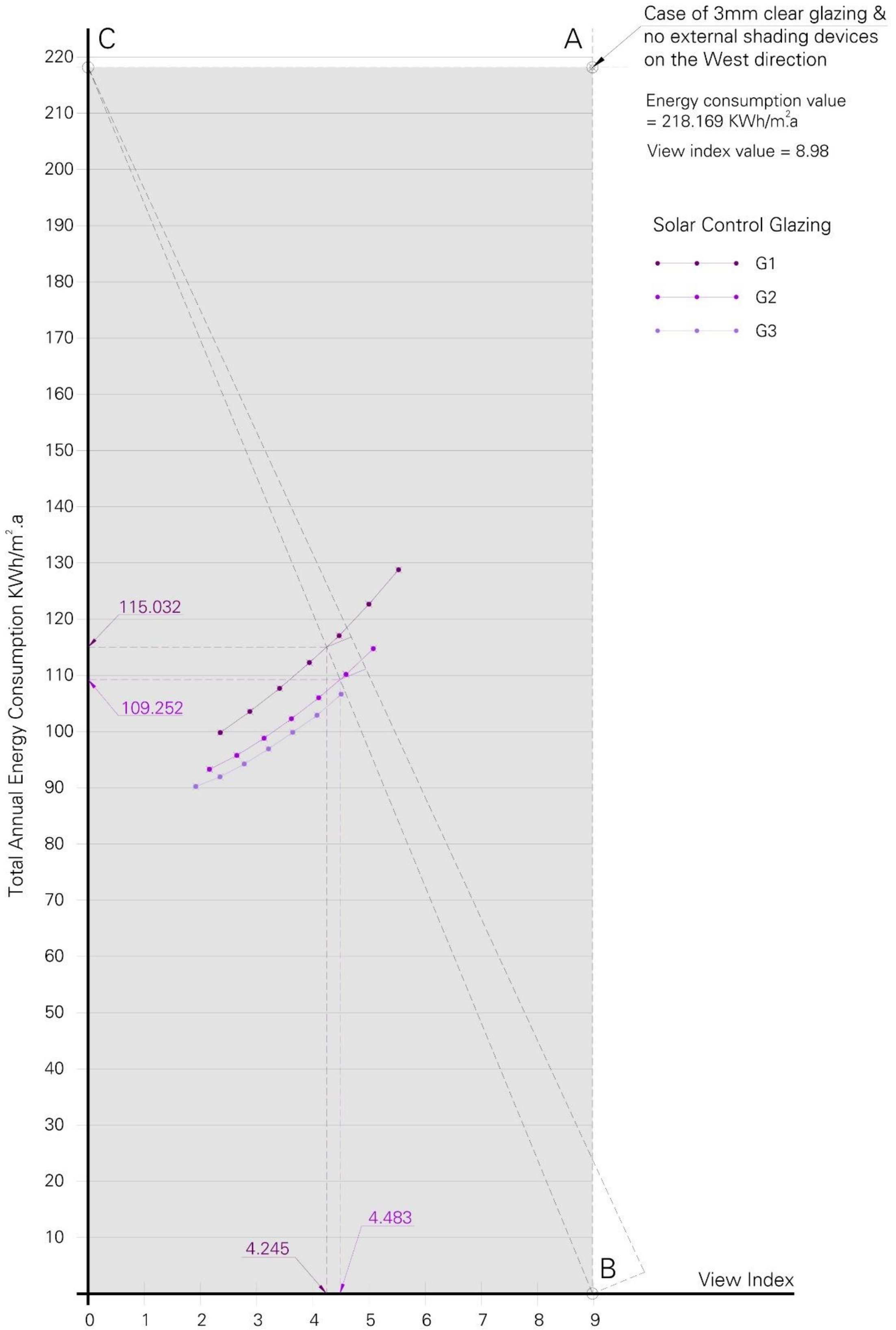


Figure 11 - 20: Vertical louvers optimized points on South direction

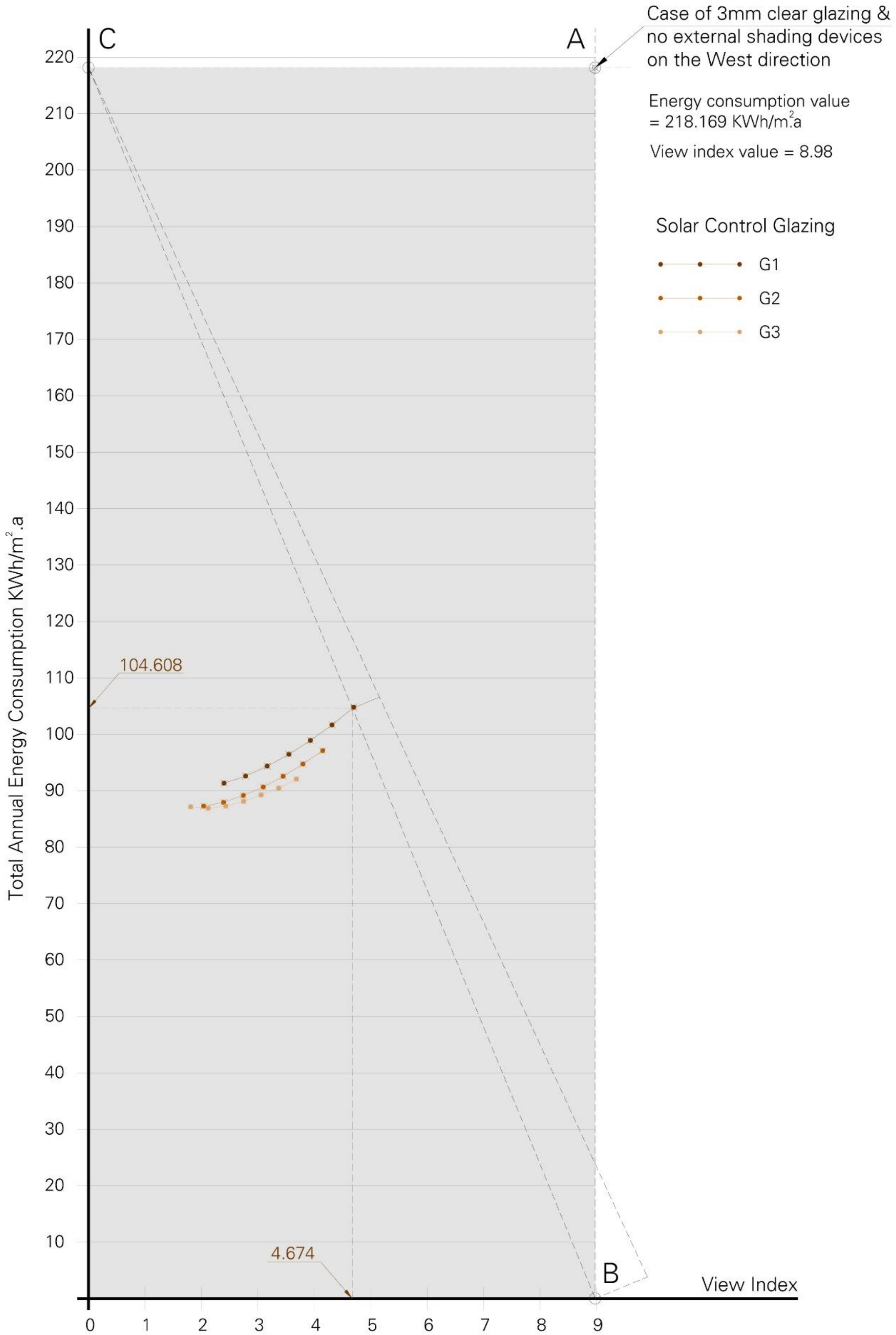


Figure 11 - 21: Mashrabya optimized points on South direction

11.2.2.4. West Direction Optimized Points:

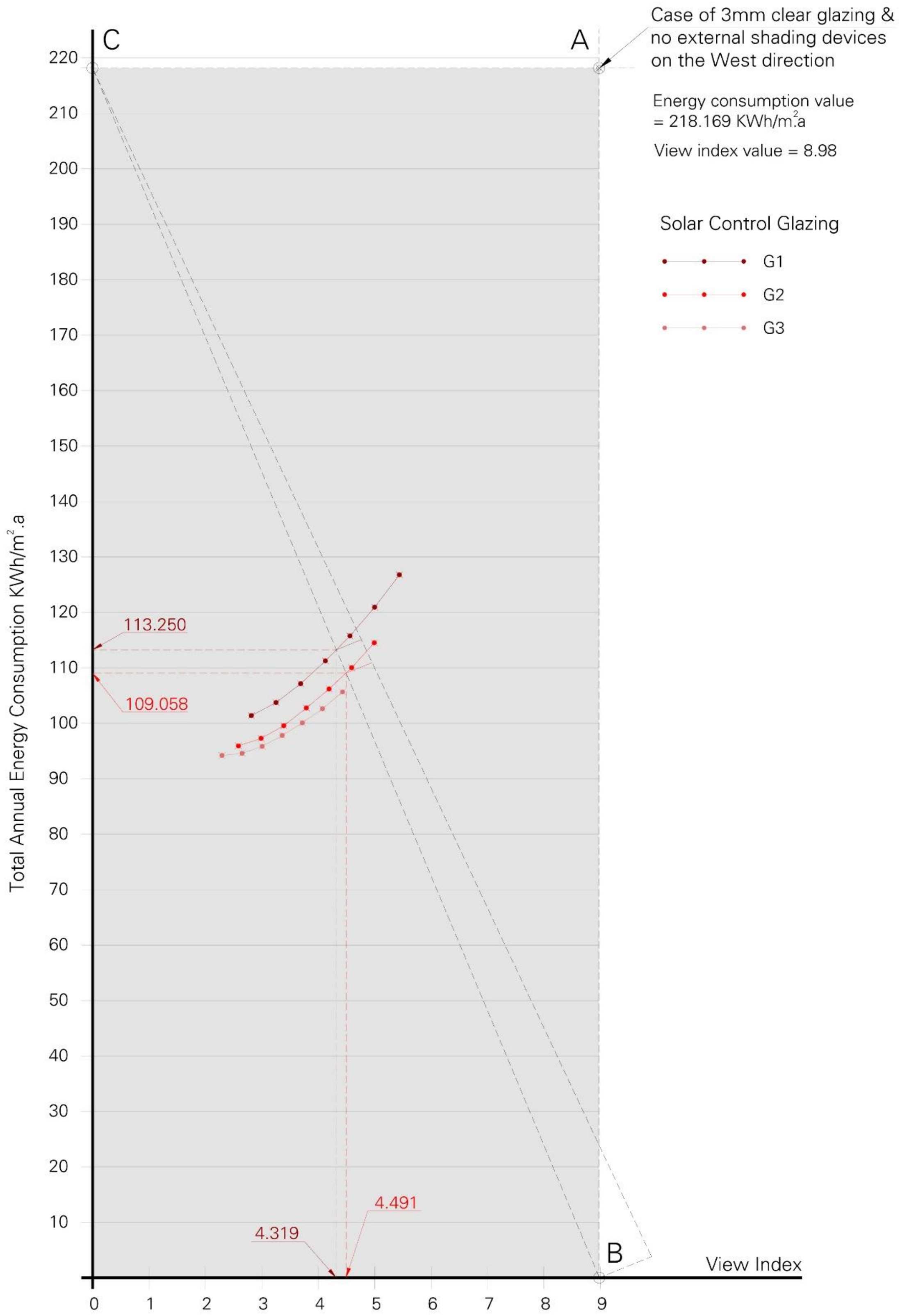


Figure 11 - 22: Horizontal fins optimized points on West direction

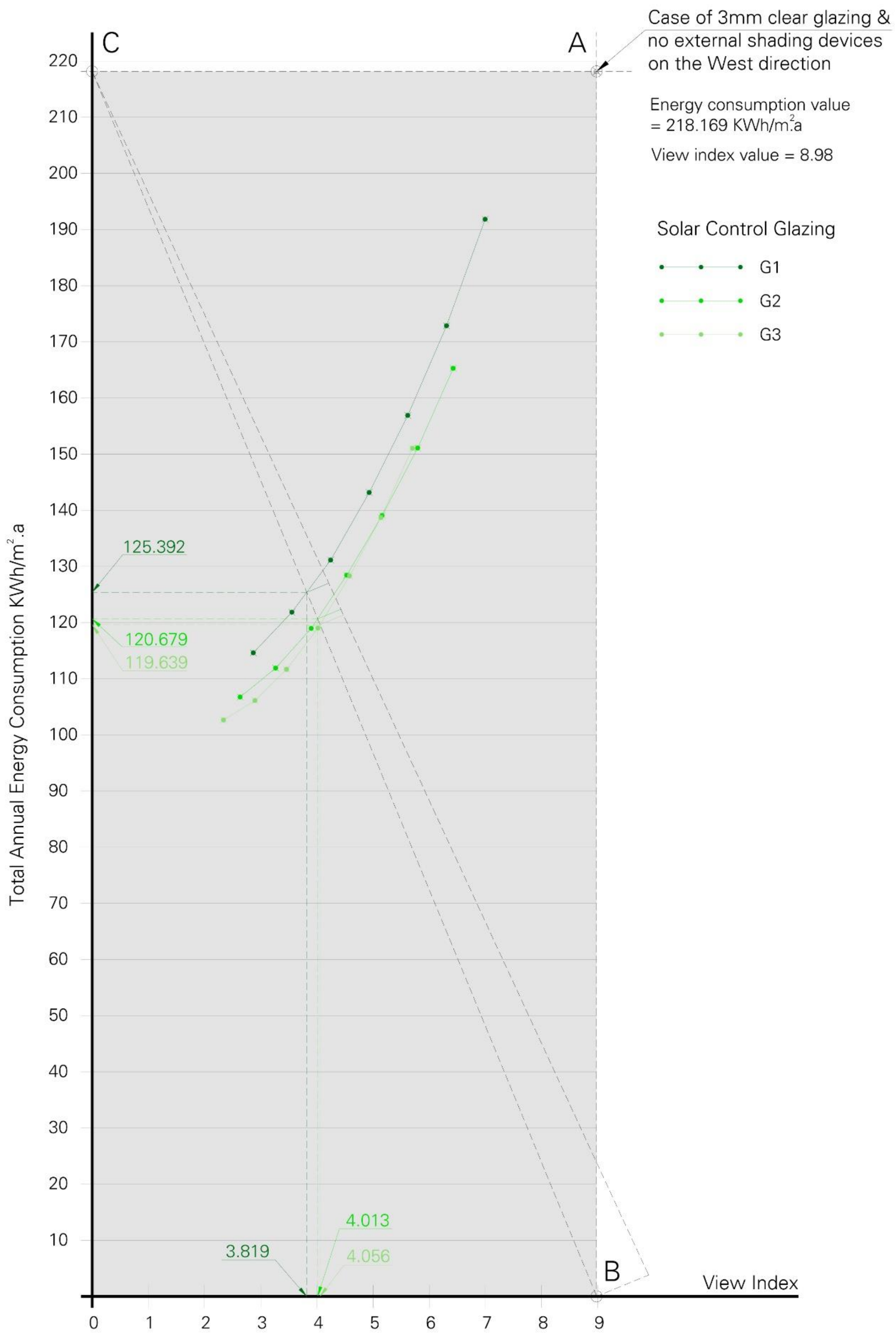


Figure 11 - 23: Horizontal overhang optimized points on West direction

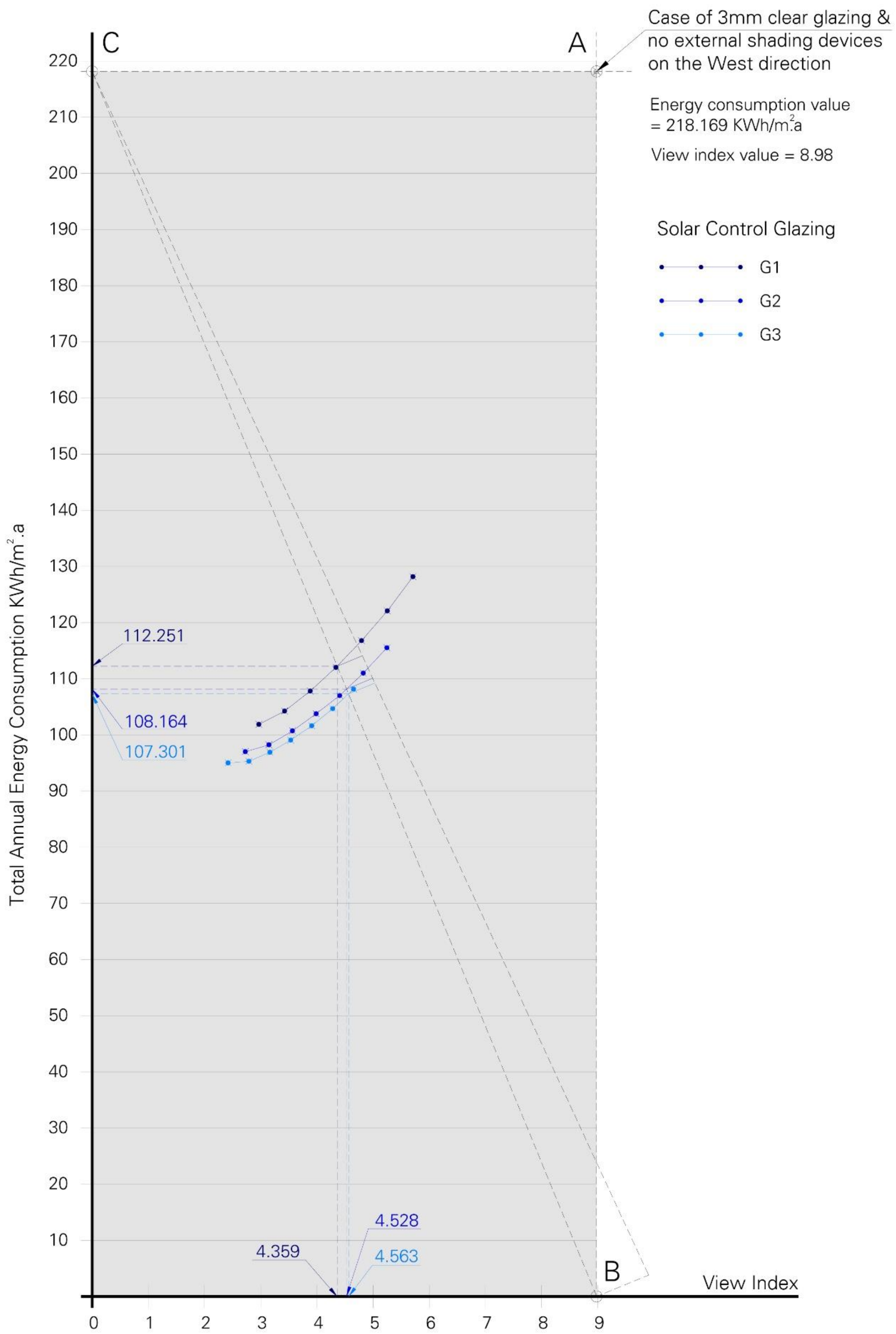


Figure 11 - 24: Horizontal Louvers optimized points on West direction

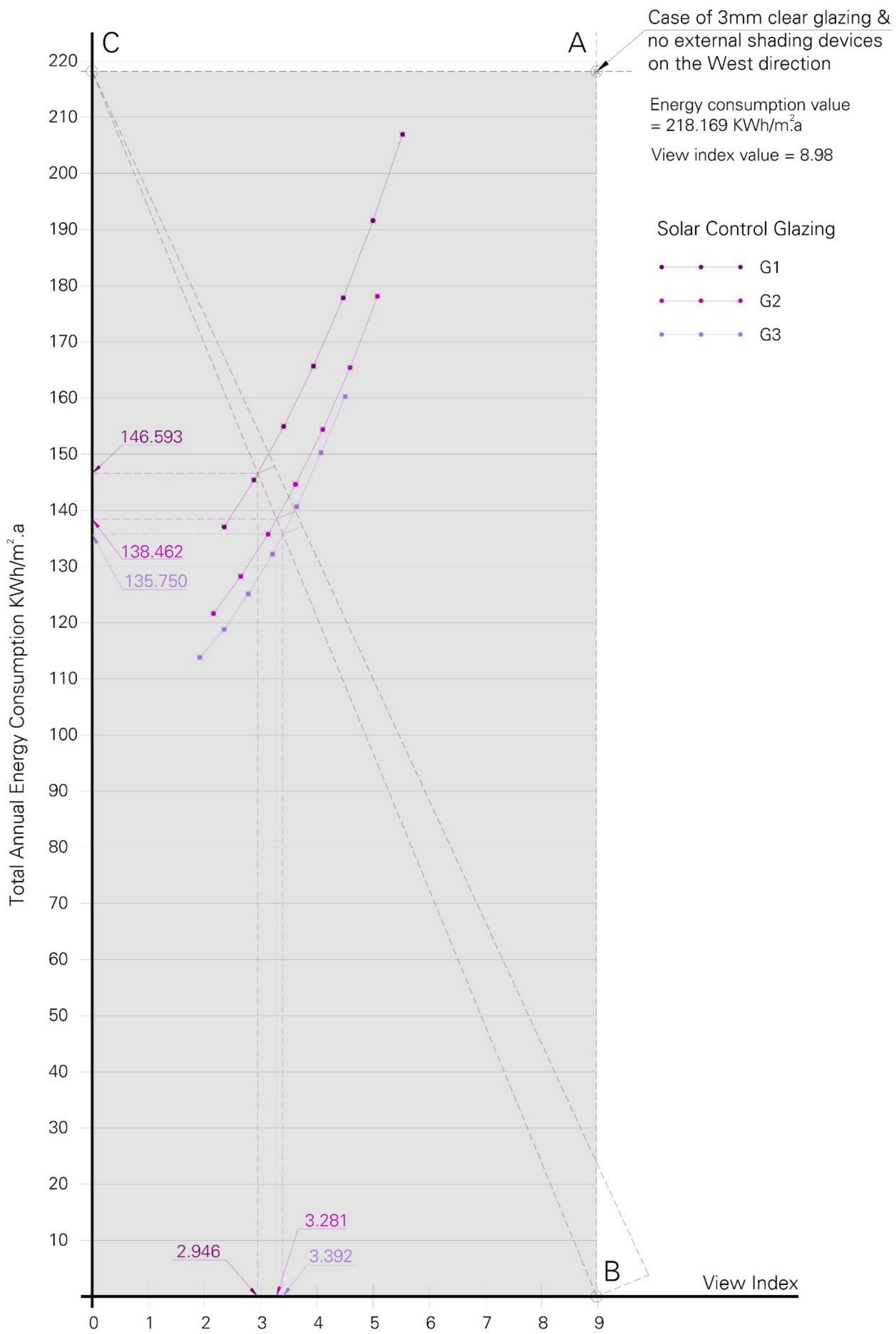


Figure 11 - 25: Vertical louvers optimized points on West direction

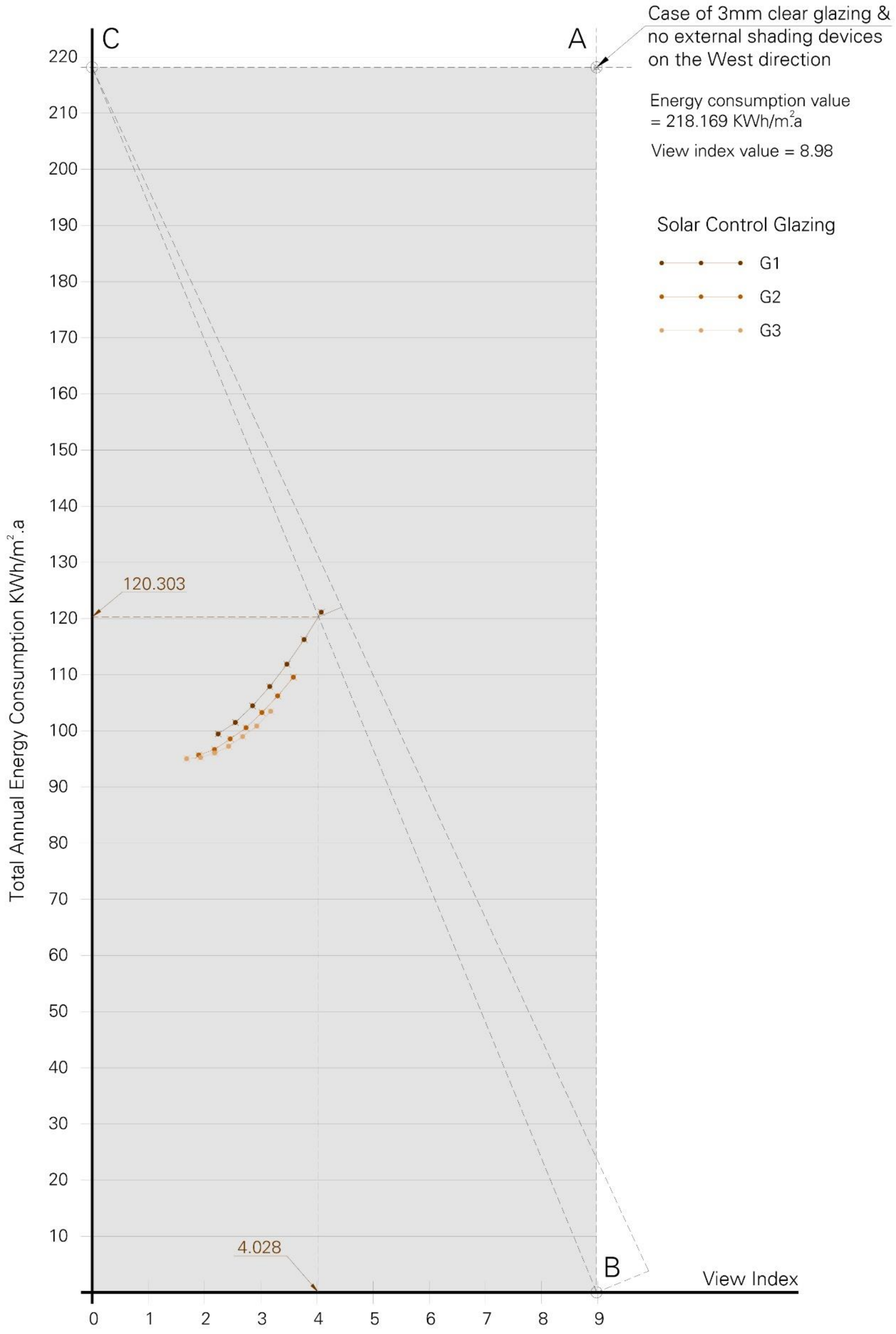


Figure 11 - 26: Mashrabya optimized points on West direction

11.2.3. Energy-Transparency Balancing Factor Calculation Findings:

This section of the research demonstrates in defined tables the Energy-Transparency Balancing Factor (ETBF) findings for the studied office space cases in accordance with their relevant optimized point properties. Each table demonstrates the total annual energy consumption in KWh/m², the view index measure, the window to wall ratio and the Energy-Transparency Balancing Factor for all the optimized points for the five external shading devices with the three-solar control glazing concept alternations on one of the four main directions as follows:

11.2.3.1. North Direction Energy-Transparency Balancing Factor Findings:

External Shading Device	Solar Control Glazing	Energy Consumption (KWh/m²)	View Index Measure	Window to Wall Ratio	Energy-Transparency Balancing Factor
Horizontal Fins	G1	100.032	4.863	74.064	0.542
	G2	96.586	5.004	84.385	0.557
	G3	95.279	5.058	97.771	0.563
Horizontal Overhang	G1	102.431	4.764	67.569	0.531
	G2	98.874	4.910	76.013	0.547
	G3	97.278	4.976	87.071	0.554
Horizontal Louvers	G1	100.271	4.853	73.956	0.540
	G2	97.054	4.985	83.697	0.555
	G3	96.562	5.005	95.833	0.558
Vertical Louvers	G1	99.252	4.895	71.544	0.545
	G2	96.118	5.024	80.147	0.559
	G3	95.221	5.062	91.083	0.563
Mashrabya	G1	102.299	4.769	91.527	0.531
	G2	N.A.	N.A.	N.A.	N.A.
	G3	N.A.	N.A.	N.A.	N.A.

Table 11 - 1: North Direction Energy-Transparency Balancing Factor Findings

11.2.3.2. East Direction Energy-Transparency Balancing Factor Findings:

External Shading Device	Solar Control Glazing	Energy Consumption (KWh/m^2)	View Index Measure	Window to Wall Ratio	Energy-Transparency Balancing Factor
Horizontal Fins	G1	105.948	4.619	73.528	0.514
	G2	103.339	4.726	83.449	0.526
	G3	102.333	4.768	96.759	0.531
Horizontal Overhang	G1	112.714	4.341	61.412	0.483
	G2	109.602	4.469	69.035	0.498
	G3	109.153	4.487	78.342	0.499
Horizontal Louvers	G1	105.157	4.652	72.425	0.518
	G2	102.672	4.754	81.625	0.529
	G3	102.532	4.759	93.297	0.530
Vertical Louvers	G1	128.960	3.672	64.953	0.409
	G2	123.653	3.890	75.576	0.433
	G3	121.473	3.980	87.824	0.443
Mashrabya	G1	N.A.	N.A.	N.A.	N.A.
	G2	N.A.	N.A.	N.A.	N.A.
	G3	N.A.	N.A.	N.A.	N.A.

Table 11 - 2: East Direction Energy-Transparency Balancing Factor Findings

11.2.3.3. South Direction Energy-Transparency Balancing Factor Findings:

External Shading Device	Solar Control Glazing	Energy Consumption (KWh/m²)	View Index Measure	Window to Wall Ratio	Energy-Transparency Balancing Factor
Horizontal Fins	G1	100.932	4.826	70.001	0.537
	G2	97.388	4.971	79.539	0.553
	G3	95.965	5.030	91.936	0.560
Horizontal Overhang	G1	106.745	4.586	64.978	0.511
	G2	102.699	4.753	73.529	0.529
	G3	101.453	4.804	84.011	0.535
Horizontal Louvers	G1	101.311	4.809	69.717	0.536
	G2	97.332	4.974	79.247	0.554
	G3	95.968	5.029	91.136	0.560
Vertical Louvers	G1	115.032	4.245	75.774	0.473
	G2	109.252	4.483	87.778	0.499
	G3	N.A.	N.A.	N.A.	N.A.
Mashrabya	G1	104.608	4.674	99.354	0.521
	G2	N.A.	N.A.	N.A.	N.A.
	G3	N.A.	N.A.	N.A.	N.A.

Table 11 - 3: South Direction Energy-Transparency Balancing Factor Findings

11.2.3.4. West Direction Energy-Transparency Balancing Factor Findings:

External Shading Device	Solar Control Glazing	Energy Consumption (KWh/m²)	View Index Measure	Window to Wall Ratio	Energy-Transparency Balancing Factor
Horizontal Fins	G1	113.250	4.319	74.439	0.481
	G2	109.058	4.491	87.488	0.500
	G3	N.A.	N.A.	N.A.	N.A.
Horizontal Overhang	G1	125.392	3.819	53.823	0.425
	G2	120.679	4.013	61.819	0.447
	G3	119.639	4.056	70.659	0.452
Horizontal Louvers	G1	112.251	4.359	70.438	0.485
	G2	108.164	4.528	82.905	0.504
	G3	107.301	4.563	97.554	0.508
Vertical Louvers	G1	146.593	2.946	51.245	0.328
	G2	138.462	3.281	63.059	0.365
	G3	135.750	3.392	74.199	0.378
Mashrabya	G1	120.303	4.028	98.308	0.449
	G2	N.A.	N.A.	N.A.	N.A.
	G3	N.A.	N.A.	N.A.	N.A.

Table 11 - 4: West Direction Energy-Transparency Balancing Factor Findings

Chapter XII

Conclusion

12. Conclusion:

The conceptual design of the office building transparency is a crucial issue. It hides multidisciplinary principles that each should be taken with careful consideration. One of the main principles is the efficient planning of its energetic performance, since the transparent components and surfaces of the building façade usually exhibit poor thermal performance that leads to a high increase in the buildings' cooling/heating loads. The planning of energy efficient facades presumes an accurate understanding and analysis to the prevailing climatic conditions as a prerequisite task for its design, where building facades has maximized passive potentials that are derived from its climatic context, these should be the foundation to optimize its viable energy efficient concepts. Previous literature and research work that investigated energy efficient facades in hot-arid climates recommended to diminish the buildings' transparency (window to wall ratio) and to use the appropriate solar control tools such as the external shading devices and solar control glazing concepts.

However, on the other hand, transparency has very significant psychological values that positively and beneficially affect the office occupants. It is generally a preferred physical feature for the vast majority of them, even larger windows are more preferred over smaller ones. Transparency provides the office occupants with view to the outside and natural lighting conditions that enhance their internal environment and give them the required sense of satisfaction and general well-being. View provides them with visual amenity, an opportunity for surveilling the outside, a chance to change their eye's focus, access to the environmental information, relief from claustrophobia and monotony, and access to sensory change. Moreover, it buffers the negative feelings of stress, depression, and restriction that are related to the working environment. While natural light affects the office occupant's mood and cognition through influencing the production of some required hormones and regulates their stimulation (such as cortisol, melatonin and serotonin), it also eliminates the Seasonal Affective Disorders (SAD), and improves the occupants' productivity in their workplaces. In addition, it helps in maintaining their healthy working environment. Moreover, daylight provide passive potential to reduce the electrical lighting loads and the relevant cooling loads that result from their operation.

The research main conception is to elaborate a scientific methodology that aims to optimize the adequate balance between two critical and at the same time conflicting tasks: First: providing the required level of transparency that affords the office space occupants with the psychological sense of satisfaction and general well-being. Second: achieving an energy efficient planning of the office transparency through protecting the interior from the excessive solar radiation. According to the research survey, this ratio was found to be 50% preference to transparence to 50% preference to energy efficiency measures. The research methodology is based on four operational studies that are conducted in a sequence, the main objectives of each study are demonstrated in the following points:

- To study the context of Cairo.
- To survey the psychological value of transparency to the office occupants in Cairo.
- To computationally measure the energetic performance of the psychologically accepted solar protection parameters.
- To optimize the office space transparency through balancing the research visual and energetic measures of the solar protection strategy parameters based on the occupants' preference ratio.

In the following points (from 12.1 to 12.4) the conclusion of each of the research operational studies will be demonstrated:

12.1. Cairo: Contextual study:

In order to have a complete overview of the context of Cairo, three points were studied. First: the climate profile in Cairo region is analyzed to underpin the appropriate passive potentials that could be utilized to elaborate an energy efficient strategy for the office transparency. Second: the current energy states of Egypt are discussed to express the deficiency in the energy sector of the country and the need for an urgent and efficient solution. And third: the energy consumption rate of six office buildings in Cairo are studied; their average annual energy consumption rate value will be used as a benchmark that represent Cairo's office buildings energy consumption in the next operational studies.

12.1.1. Cairo's Climate Profile:

Cairo experiences a hot-arid climate that is characterized by relatively long, hot, and dry summer, and somehow mild to cold winter with little rain. The average monthly temperature ranges from 13.8 °C in January to 28 °C in July, with an average annual temperature equal to 22.4 °C. The relative humidity is rather mild; its monthly average values range from a maximum of 68% in January to a minimum of 45% in May, with an annual average of 57.5%. However, Cairo has a relatively high solar irradiation rates, in both the global and beam with long periods of clear sky conditions especially in summer time. The global solar radiation in Cairo ranges from 10.5 MJ/m^2 in December to 26.8 MJ/m^2 in June, with an annual average equal to 18.57 MJ/m^2. In addition, Cairo has a high frequency of clear sky, the sky cover ranges from 0.1 octa in July to 2.4 octa in January. Based on the vertical sun path analysis, the research proposes four solar shading angles for the main directions that are demonstrated in the point 8.2.2.3. These shading angles will be used in elaborating the external shading devices in the energetic modeling and simulation study.

From analyzing the Building Bio-Climatic Chart (BBCC) of Cairo, optimized for occupancy hours from 7:00 am to 18:00 which is the typical occupancy hours in Cairo's office buildings, it was found that the solar protection of the glazed components of the facades is the most influential passive strategy. It gives the potential to increase the internal comfortable hours with an extra 1688 hours representing 38.5% of the total occupancy hours. Consequently, the research proposes a solar protection strategy based on a parametric analysis of three solar protection tools which are: (1) The window-to-wall ratio (wwr), (2) External shading devices, and (3) glazed solar control concepts.

12.1.2. The Building Sector Energy predicaments in Egypt:

The energy sector Egypt is currently facing a very critical situation due to the increasing rates of consumption and the shortage in fuel supplements. This situation is attributed to several factors that have accumulated for several years. Electricity is the fundamental energy source for the building sector in Egypt. Buildings and their associated activities consumed almost 58.48% of the total electric energy produced in the country. However, the rates of electricity consumption especially in the building sector is rapidly increasing. Several reasons are behind that increase, which are: (1) the rapid increase in population rate, (2) the high rate of urbanization, and (3) the increase in standards of living. On the other hand, the country faces some predicaments in producing the required rates of electricity; the most important is the deficiency in oil and gas supplements, where they represent the resource for 91.11% of the produced electricity in the country. This is in addition to the economic burdens that had occurred after the January 2011 turmoil and the inefficient energy usage in the country. This situation urges for efficient solutions on all levels and sectors.

12.1.3. Office Buildings Energy Consumptions Modes in Cairo:

Six office buildings in Cairo region were studied and analyzed. The annual energy consumption rate per square meter of these office buildings shows a wide variety due to the difference in their design, age, built-up area, and façade configuration. It is very significant to find out that the highest annual energy consumption rate per square meter was recorded in relatively older building with the maximum transparency, i.e. highest window to wall ratio. While the lowest energy consumption rates were recorded in relatively newer buildings and with lower transparency, i.e. smaller window to wall ratio. Where evidently, the World Trade Centre in Cairo office tower recorded the highest annual energy consumption with 396.4 KWh/m^2.a where the building was built in 1989 and had the largest window to wall ratio that range between 65% to 75%. While the lowest energy consumption rate was recorded in the ministry of communication and information technology building with 257.5 KWh/m^2.a where the building was opened in 2004 with window to wall ratio between 45%-55%. Another example, Abuel-Feda office tower that was built in 1987 with window to wall ratio range between 30%-35% recorded annual energy consumption rate equal to 285 KWh/m^2.a. The average annual total energy consumption rate per square meter of the studied six office buildings is 315.67 KWh/m^2.a. This value will be used as a benchmark in the following energetic modelling and simulation study to represent the annual energy consumption rate per square meter for the office buildings in Cairo.

12.2. Surveying the Psychological Preference to Transparency:

The research performs a quantitative survey to investigate the office occupants in Cairo preferences to transparency. The survey investigates three topics, each represents one of the survey objectives. These are: (1) the office occupants' preferences and need for transparency, (2) The office occupants' behavior and their interaction with their transparent components in their offices regarding their thermal and visual comfort conditions, and (3) The office occupants' psychologically acceptable and preferred design criteria to transparency that contributes to their sense of satisfaction and well-being.

The survey targets white-collar office workers in Cairo region. According to the relevant population in Cairo and with a significance level of 5%, a total sample size of 402 subjects are conducted. Both the "self-administrated questionnaire" and the "E-link questionnaire" are used for the data gathering process. The survey was carried out in two steps; a pilot study was performed first (from 15/8/2015 to 26/8/2015) to review the basic aspects of the survey design, followed by the main survey (from 6/9/2015 to 23/9/2015). The main survey comprises of 31 main questions that are categorized into three parts, each part represents one of the survey objectives. In the following points (from 12.2.1 to 12.2.3) the relevant conclusion of each part of the main survey will be demonstrated:

12.2.1. Importance of Transparency:

The transparent glazed component (window) in Cairo's office spaces are highly desired by the vast majority of the occupants; 92.5% showed preference to have windows in their working places, and considered it an important physical feature in the office environment. Regarding the functions of transparency, daylight came first with 46%, view came second with 35.1%, and natural ventilation came least with 16.2%. In addition, most of the occupants showed strong preference to the windows proximity in their working places; 80.8% of them preferred to sit and work near windows, mainly to gain natural lighting conditions and to have visual contact with the outside.

12.2.2. Interaction with Transparency:

Generally, the internal environmental design of Cairo office spaces showed a failure to achieve the required thermal conditions for the occupants' comfort. Without the intervention of the HVAC systems, 82% of the occupants showed dissatisfaction from their internal thermal environment. This explains the increasing dependence on mechanical HVAC systems (mainly for cooling) from the office space users to maintain their required thermal comfort conditions, where 88.7% of them always keep the mechanical cooling (AC) turned on in their offices for more than 6 hours in a typical working day. While there is no need for mechanical heating, since 74.3% of the occupants didn't need any heating system in their offices during wintertime or cold weather conditions. The usage of natural ventilation is rather poor; 89.1% of the occupants use it less than 4 hours per working day mainly for olfactory reasons.

This also indicates the poor air quality in the office spaces environment and the lack of awareness of passive & low energy measures.

Shading devices in Cairo offices are usually installed internally, 85% of the occupants had internal window shading devices (either movable or fixed) in their working spaces. This contributes to the tremendous solar heat gain which consequently raises the cooling loads of the space. 78.3% of the office employees had internal moveable shadings, almost 60.4% of them close it from 2 to 6 hours out of 8 working hours daily, mainly to avoid glare, either from direct solar radiation or indirect glare due to the veiling reflections on their computer screens. Closing the window shading devices deprive almost 74.8% of the employees from having their required visual contact with the outside.

Regarding the internal lighting conditions, the results reveal a poor dependence on natural lighting in Cairo office spaces. 74.8% of the office occupants depends on daylighting for less than 4 hours per day, i.e. less than 50% of the daily working hours. In addition, the office occupants are highly dependent on artificial lighting, as 97.5% of them usually use artificial lighting during the working day. Moreover, 69.1% turn their lights on for more than 6 hours per day due to the insufficiency of the general lighting conditions or for closing their window shadings. Comparing these figures with the solar radiation rates that are impinging on Cairo reveals the poor environmental design of the office buildings' envelopes, particularly its façades, and the failure to consider the efficient, very abundant, and free natural lighting source in its design.

12.2.3. Preferred Design Criteria for Transparency:

High transparency is a substantially and psychologically preferred criterion for the office occupants in Cairo. Nearly 96.5% of them preferred to have windows with window to wall ratio higher than 40% in their working places. In addition, 91% of them preferred that the visible light transmittance of the glazed area to be more 60%, i.e. glass tinting level are to be less than 40%. These results go the other way round from the energy efficiency literatures. For example, the ASHRAE's advanced energy design guide for small to medium office buildings recommends for hot-arid (B2) climates to reduce the influence of the solar radiation by the use of a sized glazed area with window to wall ratio ranging from 20% to 40% (ASHRAE, 2011). For the preferred shape and position of the office window, 79.9% the occupants preferred the wide window, and 90.5% of them preferred that their windows are centered in the external wall of the office space.

For the psychologically accepted external shading devices, it was found that horizontal fins, horizontal overhang, horizontal louvers, vertical louvers and the perforated shadings (Mashrabiya) are the most accepted external shadings. Each of them got an acceptance ratio of more than 50%. View dominated the occupants' choice for their preferred shading device with 50.2%, and for regulating the solar radiation and daylighting conditions came second with 21.4%.

The visual contact with the outside is highly desired from the office occupants in Cairo, 93.5% of them considered it as an important need in their working spaces. In addition, the office occupants did not prefer to be deprived of the visual contact to the outside in advance of the energy efficient measures. Most of them preferred a balanced ratio of 50% preference to view and 50% preference to the energy efficient measures. Even the rest of the results show a split around the ratio of 50% with both mode and median of 50.

12.3. Energetic Modeling and Simulation:

Solar protection is one of the most significant energy efficient strategies in hot-arid climates. In this study, the research investigates the energetic performance of a proposed solar protection strategy for office spaces in hot-arid climates, applied on the example of Cairo. The research solar protection strategy is based on elaborating three parameters, which are: (1) window to wall ratio, (2) external shading devices, and (3) glazed solar control concepts. These parameters are first deducted from the bioclimatic analysis of Cairo and the relevant literature, then further investigated psychologically in the research survey. Where their preferred criteria are used as an input threshold/margin to define the acceptable determinants of each solar protection parameter. However, the study investigated first the performance of two office space profiles (A&B). Profile (A) represent a typical Egyptian office space profile, and profile (B) represent an ASHRAE based profile) in order to test the validity and reliability of the research modeling and simulation tool, and to choose from both profiles the most efficient profile to be integrated into the main energetic modelling and simulation study.

The research energetic modeling and simulation study was performed on an imaginary reference of a single office space base-case model with an area of 17.28 m^2 located on the on the outer perimeter of a typical office building in Cairo. DesignBuilder V.5.0.1.024 is used as the study Building Information Modeling and Simulation (BIMS) software tool. The study is performed in two phases; the first phase is a prerequisite to the second main modeling and simulation operations as follows:

12.3.1. Modeling and Simulation Operations Phase - 1:

In 8 modeling and simulation operations, the energetic performance of profile (A) and profile (B) are examined on the four main directions. In the first part, the results of profile (A) are compared to the actual energy consumption figures of Cairo’s office buildings to investigate the validity and the reliability of the research BIMS software. In the second part, profile (B) results are compared to the findings of profile (A) in order to choose the most energy efficient profile to be integrated into the base-case model for the next main modeling and simulation operations (phase - 2). Phase - 1 operations are conducted on the base-case office model and with the same façade configurations that are commonly used in the average Egyptian office space which are: window to wall ratio of 50%, clear single 6 mm glazing, and internal transparent roller shading devices optimized for solar control.

The results of comparing the simulated energy consumption rates of profile (A) with the actual average rates of the studied Egyptian office buildings shows some convergence. The average annual total energy consumption rate of profile A from the four main directions is 326.12 KWh/m^2, while the actual annual total energy consumption rate of the Egyptian office buildings is 315.67 KWh/m^2 with 10.5 KWh/m^2 in difference representing only 3.2%. These findings give more validity and reliability to the research modeling and simulation tool. While, on the second part, on comparing the simulated annual total energy consumption rates of profile (B) with profile (A), the results reveal a considerable reduction in the annual total energy demand from profile (A) to profile (B) with various percentages depending on the simulated direction. In the North, the total energy demand has reduced from 292.68 to 115.544 KWh/m^2 with a reduction of 60.52%. In the East, the total energy demand has reduced from 320.68 to 148.537 KWh/m^2 with a reduction of 53.68%. In the South, the total energy demand has reduced from 344.2 to 132.92 KWh/m^2 with a reduction of 61.38%. While in the West, the total energy demand has decreased from 346.92 to 180.17 KWh/m^2 with a reduction of 48.07%. The average total annual energy demand reduction of the four directions is 55.91%.

Therefore, it is more convenient for the research work to choose in advance the ASHRAE based profile configuration as the more energy efficient profile, and apply it on the research base - case through the main modeling and simulation operations (phase - 2). In addition, these findings show the importance of developing and upgrading building's profile configurations in Egypt to the enhanced and standardized energy efficient configurations, where it could be one of the basic beginnings towards the transformation of the building sector to the more rational use of energy.

12.3.2. Modeling and Simulation Operations Phase - 2:

Through a series of 424 parametric modeling and simulation processes; profile (B) is applied first to the base case model, then the solar protection parameters were modeled and simulated to assess their energetic performance. Through 420 operations, the following three solar protection parameters are examined: First, window to wall ratio from 40% to full glazed wall with an increment of 10% (seven variables). Second, the psychologically accepted external shading devices (horizontal fins, horizontal overhang, horizontal louvers, vertical louvers, and Mashrabya), the dimensions of the external shading devices are determined according to the proposed solar shading angles (five variables). Third, solar control glazing concepts which are: G1-single glazing, G2-double glazing, and G3-triple glazing (three variables), the three glazing concepts vary in their solar and thermal properties; where from G1 to G3, their lighting transmittance decreased, and their solar protection properties increased, i.e. their heat transfer coefficient (U-value) and their total solar transmission (g-value) are increased. In every modeling and simulation process, only one variable is changed with respect to the others. This is applied to the four main directions. In addition, 4 modeling and simulating operations are conducted for the case of clear 3 mm single glazing with no external shading and full glazing area (wwr = 100%), and are also applied to the four main directions. In each of the phase - 2 operations, the lighting, cooling and total annual energy consumption per square meter are computationally measured. These measures will be used in the transparency optimization process.

Typically, in all of the four main directions, increasing the window to wall ratio, decreases the lighting energy consumption. In addition, owing to the light transmitting properties of the examined glazing concepts; solar control glazing G1(single glazing) recorded the least lighting consumption, followed by G2 (double glazing), while G3 (triple glazing) recorded the highest lighting consumption rates in all the examined window to wall ratios. For shading devices, the perforated shadings or the Mashrabya scored the highest rates of lighting energy consumption. While the horizontal overhang scored the least lighting energy consumption rates in all window to wall ratio.

Regarding the cooling energy consumption, the results was the other way around to the lighting consumption. Cooling energy consumption increases with increasing the window to wall ratio. Regarding the solar-thermal properties of the examined glazing concepts, the solar glazing concept G3 (triple glazing) achieved the lowest cooling consumption, followed by G2 (double glazing), while G1 (single glazing) achieved the highest cooling energy consumption rates in all the examined window to wall ratios. For external shading devices, the cooling energy consumption results vary according to the direction. In the North direction; for wwr lower than 60%, the vertical louvers scored the lowest cooling consumption, and for wwr of 60% and more, the Mashrabya scored the lowest cooling consumption. While for the East, South and West directions, undisputedly, the Mashrabya shading followed by the horizontal fins and horizontal louvers achieved the lowest cooling consumption measures for all of the examined window to wall ratios.

The total annual energy consumption rates per square meter were found to be very dependent on directions. In addition, the impact of the cooling energy consumption variations on the total annual energy consumption is much higher than the variation of the lighting energy consumption. In the North direction, the total annual energy consumption recorded the least rates among the other directions. From wwr of 40% to 60%, the vertical louvers with G3 achieved least the total energy consumption measures, while for wwr of 70% and more, the Mashrabya with G3 achieved the least consumption measures. For the East direction, in wwr of 40% the horizontal fins and horizontal louvers with G3 achieved the lowest total energy measures. While for wwr more than 50%, the mashrabya with G3 recorded the lowest consumption. In the South direction, for wwr of 50% and less, horizontal fins and horizontal louvers with G3 glazing recorded the lowest total energy consumption measures, followed by the Mashrabya and G3 with comparatively near measures. While for wwr of 60% and more, the Mashrabya with G3 recorded the lowest total consumption measures. The West direction scored the highest total energy consumption measures among the four main directions. For wwr of 60% and less, the horizontal fins, horizontal louvers and Mashrabya with G3 glazing achieved the least total energy consumption measures. While for wwr higher than 70%, the Mashrabya with G3 achieved the lowest total consumption measures.

Generally, for higher office transparency in climatic conditions of Cairo, basically for window to wall ratios of more than 60%, it was found that the integration of the Mashrabya shading with the triple solar control glazing concept (G3), significantly, achieves the lowest total annual energy consumption rates per square meter in all of the four main directions.

12.4. Optimizing Energy Consumption with Transparency:

This study is the main and the final pillar of the research operational study. Its main principle aims to provide the needed information for optimizing the office façade configurations in hot-arid climates, applied on the example of Cairo. The optimized façade configurations of office spaces are performed through achieving the required balancing ratio between the visual measures of transparency with the office space energetic performance based on the research solar protection parameters (Window to wall ratio, external shading devices, and glazed solar control concepts). The optimization balancing ratio was concluded from the research survey findings; which is 50% preference to the visual contact to the outside and 50% preference to energy efficiency. This ratio was found to be the most adequate ratio that provides the office occupants in Cairo with their physical and psychological well-being and gives them the sense of environmental satisfaction.

The view index was chosen to represent the research visual measure to the office transparency. View index values are calculated for each of the 424 cases that were energetically examined. For each case, only one parameter is changed from the research solar protection parameters, i.e. the view index value is calculated for each window to wall ratio with every external shading device and with every glazed solar control concept on the four main directions.

Through parametric analysis processes, the total annual energy consumption values were graphically plotted with their corresponding view index measure to all the 424 examined cases. Each graph includes three curves representing the performance of the three solar control glazing types with the change in the window to wall ratio for one of the shading devices at one of the four main directions. Then, an optimizing axe was proposed and drawn in each graph, in which it represents the balancing ratio of 50% preference to energy efficiency and 50% preference to visual measure (based on the research survey findings). The optimizing axe intersects with every curve in a point which could be defined as an optimized point. This point describes a specific configuration for the office space façade which gives the required balance between the visual measure (view index) and its corresponding total annual energetic consumption per square meter value for each solar control glazing with one of the shading devices in one of the four main directions. The corresponding window to wall ratio of the optimized point was then calculated from the relevant view index calculation graph (Appendix C).

In order to compare the results of these optimized points, the research proposed the Energy-Transparency Balancing Factor (ETBF) for each point. ETBF value can be defined as the ratio of the energetically and visually optimized façade configuration preference to a virtual point that affords the maximum visual measure with the minimum energy consumption value. Higher Energy-Transparency Balancing Factor (ETBF) measures are the most preferred ones, since they indicate higher view index (i.e. more transparency) with less total annual energy consumption values.

On comparing the Energy-Transparency Balancing Factor (ETBF) for the four main directions, it was found that the difference in its values for all the examined cases are relatively small. However, it gives a directional indication to the preference of using the optimized office facade configurations. In the following points, the relevant conclusion for the ETBF values in each direction will be presented:

- The North direction generally scored the highest ETBF values among the other directions. This could be attributed to its lowest total annual energy consumption values, since it is the least direction that is exposed to direct solar radiation. Where the exposure only occurs in the early morning hours and the late afternoon hours in summer when the altitude angle is already low, and the sun rays are almost tangible to the surface of the façade, which in turn, is revealed in its low cooling energy demands. In addition, the North direction did not require low shading angles which would obstruct the view. Therefore, it also scored the highest optimized view index values. The high ETBF values of the North gives an extra parametric evidence that it is the most preferred direction that the office façade openings could be oriented to.

- The South direction scored the second highest ETBF values. Although the South is exposed to direct solar radiation the longest periods among the other directions, however, it is advantageous that the sun is high over the horizon in summer (i.e. the altitude angle is high). Therefore, direct radiations could be easily avoided through relatively small horizontal shading devices. The total annual energy consumption of the South direction achieved the second lowest optimized values after the North. In addition, due to its relatively high shading angles, its gives quite highly optimized view index values.

- The East direction came with the third highest ETBF values. Where East is exposed to the direct solar beams from the sunrise to the noontime. During the early morning hours, it is not possible to prevent solar radiations from penetrating into the interior without obscuring the view, since the solar altitude angle is very low. However, as the sun rises higher in the sky dome the external shading devices could then be effective. Therefore, the East direction scored the third highest optimized energy consumption values. While for its low shading angles, it gives relatively low optimized view index values.

- The West direction represents the worst case for both the total energy consumption values and the view index measures, and it typically scored the lowest ETBF values among the four main directions. West directions are exposed to direct solar radiation from the noontime till the sunset where the external weather is already warmed. In addition, the solar altitude angles are continuously decreasing, and the direct solar radiation are almost perpendicular to the façade that hardly any shading device could obstruct without largely blocking the view. Therefore, the Western facades always require the lowest solar shading angles and the highest cooling energy demands. Subsequently, the West direction scored the highest optimized total annual energy consumption values and the lowest optimized view index measures, showing that highly glazed office spaces in Cairo are most likely to avoid that direction.

The performance of the examined glazed concepts was consistent with all the examined shading devices, and in all four directions. Owing to its advanced solar control properties, glazing concept G3 (triple glazing) always achieved the lowest total annual energy consumption values, G2 (double glazing) came second, while G1 (single glazing) scored the highest total annual energy consumption values. However, despite that glazing concept G3 has the lowest light transmittance property, it achieved the highest optimized view index measures, since it requires higher window to wall ratio to meet with the optimizing axe (i.e. to achieve the required balancing ratio of energy efficiency to visual measure). Solar control glazing G2 scored the second optimized view index measure, then glazing concept G1 came with the lowest optimized view index measures. Therefore, G3 Glazing always scored the highest ETBF values with all shading devices and in all direction, followed by G2, then G1 came with the lowest ETBF values. Accordingly, it could be concluded that the more efficient solar control glazing concept is the most preferred for the office spaces in Cairo's climate, since it consumes less energy, affords larger window to wall ratios, and gives higher view index measures. However, based on the research survey, it should be taken into consideration that the psychologically accepted light transmittance margins of the glazing system should be higher than 60%.

Regarding the five examined external shading devices on the four main directions, the results show some consistency in the performance of the Energy-Transparency Balancing Factor (ETBF) in the East, South and West directions. While the North direction showed a different performance, this could be attributed to its very low exposure to direct solar radiation. The following points could be concluded from analyzing the results of the external shading devices:

- The horizontal fins and the horizontal louvers shadings achieved a quite near total annual energy consumption values and near view index measures with the same solar glazing concepts in all directions, this is rational since both shadings were designed with the same solar shading angles in each direction. Therefore, both shadings generally scored near optimized points and near ETBF values in all directions. In the North direction, horizontal fins and horizontal louvers scored the second and the third highest ETBF values respectively, since they achieved the second and the third rank in both the optimized total annual energy consumption values and optimized view index values as well. While, in the East, South, and West directions, both shadings scored the highest ETBF values. They achieved the lowest optimized total annual energy consumption values and the highest optimized view index measure in these three directions.

- The horizontal overhang scored the highest view index measures with all glazing concepts in the four main directions. However, its total annual energy consumption rates were extremely high with all the examined glazing concepts and in all directions. Horizontal overhang scored the lowest ETBF values in the North direction, and the fourth ETBF values at the East, South, and West directions. Its optimized points also scored the highest total annual energy consumption values in the North, and the second highest total annual energy consumption values in the East, South and West directions.

- The Mashrabiya shading achieved the least total annual energy consumption values among all the examined external shading devices with all solar control glazing concepts and in all four directions, i.e., it achieved the highest energy efficiency rates. However, its view index measure is not as high; in which its performance tends to be more in the area that represents more preference to energy efficiency. In some cases, especially with solar control glazing concepts G2 and G3, the Mashrabiya curves did not intersect with the optimizing axe (i.e. did not achieve the required balancing ratio), since the curves were shifted towards the lower left corner of the optimizing graphs and showed more preference for energy efficiency. However, this is an advantageous to the Mashrabiya, where this gives it the potential to be designed with higher solar shading angles that provide higher view index measures and higher levels of transparency. In the North Direction, the Mashrabiya scored the fourth ETBF values with G1, in the South and the West Directions it scored the third ETBF values with G1, while with all the three glazing cases the East direction and with the solar control glazing G2 and G3 in the North, South, and west directions, its curves did not intersect with the optimizing axe.

- The vertical louvers showed some contrast in its performance with the four main directions. In the North direction, it scored the highest ETBF values, since it required high solar shading angles that give small vertical louvers which did not obstruct the view, and typically gives the highest view index measures. Vertical louvers achieved the highest optimized view index measures and the lowest optimized total annual energy consumption values in the North direction. While, in the East, South, and West directions, vertical shadings showed a very different performance; where they scored the least ETBF values in these directions. Despite being designed with low solar shading angle, vertical louvers scored the highest total annual energy consumption rates and gave the lowest view index measures in the East, South and West directions. Generally, vertical shadings are not energetically efficient in these façades. In addition, the verticality of the louvers is the major cause that reduce the view index measures.

While, regarding the quest for highly-glazed areas for office spaces / buildings in hot-arid climates, it is very significant to find out that the Mashrabiya exclusively achieved the highest optimized window to wall ratios in the North, South and West directions with solar control glazing G1. It got wwr of 91.5% in the North, wwr of 99.4% in the South, and wwr of 98.3% in the West. In the cases of the Mashrabiya with G2 and G3 in the North, South and West directions, and with all the examined solar control glazing types in the East direction, the Mashrabiya curves did not intersect with the optimizing axe; since in these cases, the Mashrabiya shadings are performing more energy efficient and need some extra transparency measures to meet the optimizing axe. Of course, this action will be accompanied with some extra energy consumption measures. However, these cases give the potential to achieve window to wall ratio of 100% (i.e. fully glazed façades) and at the same time provide the required balance between total annual energy consumption and the visual contact to the outside. The same scenario also takes place in the cases of the vertical louvers with G3 in the South direction, and with the horizontal fins with G3 in the West direction.

The Mashrabiya shadings are a kind of perforated shading devices that were traditionally introduced and developed for the hot-arid climates in the MENA area (Middle East and North Africa) under many names such as Mashrabiya in Egypt, Rawshan in Saudi Arabia, and Ganaria in Tunisia. These shadings evidently showed that they are the most energy efficient shading devices for the highly-glazed office facades in hot-arid climates. The revival of these shadings is highly recommended, and would give the potential to optimize the highest glazed ratios, or even fully glazed office facades for such climates that achieves the required 50% preference to energy efficiency and 50% preference to visual contact to the outside. The optimized highly glazed office facades will not only provide the occupants with the required psychological sense of satisfaction and general well-being, it will also satisfy their social aspiration to modernity through affording them the highly-glazed office building model.

12.5. Future studies:

The research methodology can be a starting point to provide an optimization methodology that defines the required balance of the energy efficiency concepts with the visual contact to the outside for office buildings in hot arid climates. In the following points, further possible research work will be presented:

- The research work can be further developed and elaborated into a computer software. The software can be used as a tool to assist the architect to design and define the configurations of the office building façade that provides the occupants with the psychological sense of satisfaction and general well-being through an energy efficient concept.

- The research methodology could be examined in other hot and sunny cities or countries (where solar protection is highly efficient) to experience the preference to transparency in other cultures. However, in these cases the psychological value to transparency should be further investigated.
- Different movable shading devices as well as advanced solar control concepts such as automated shading systems or switchable glazing concepts could be integrated and examined within the research methodology. But, it should be taken into consideration that on using solar protection concepts that change its shading characteristics on daily or hourly basis, the time factor should be taken into consideration while measuring view index values.
- Optimizing the perforated shadings / Mashrabya can be further investigated. Different types, patterns, solar shading angles and materials can be examined through the research methodology to increase its visual measure to transparency while preserve its efficient energetic performance.
- The research methodology could be applied to other building types such as residential, medical, educational …etc. However, for residential buildings, privacy should be considered as a crucial psychological factor.
- Other visual measures (such as glare index or daylight factor), as well as energy efficient concepts (such as natural ventilation or evaporative cooling), or even energy plus concepts (such as photovoltaics or solar panels) could be investigated and integrated within the research methodology.

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Appendix A: Main Survey

Main Survey

Greetings Dear participant,

I am conducting the following academic questionnaire as part of my PhD research study in Stuttgart University, institute of design and construction (IEK), under the supervision of Prof. Dipl.-Ing. José Luis Moro and Prof. Dipl.-Ing. Jürgen Schreiber.

Kindly, answer the following questions with your attention and completion, it will take from you nearly 15 minutes, your valuable opinions and input in this questionnaire is highly appreciated. The questionnaire survey consists of four main parts: the first part is general questions, and each of the following three parts represents one of the questionnaire objectives. If you have any question or concern about it, please contact me via e-mail address tamer_awny@yahoo.com. Thank you in advance for your kind assistance and cooperation.

Part I: General Demographic Questions:

1- What is your age?

20 - 29	30 - 39	40 - 49	50 - 59	Over 59

2- What is your gender?

Male	Female

3- Please specify your place of work / Company:

4- What is your profession?

5- Working hours:

Starts at	Ends at	Break (from – to)	Actual working hours

Part II: Importance of Transparency:

6- Is it important for you to have a glazed area (window) in your working place?

Yes	No	Not sure (please specify)

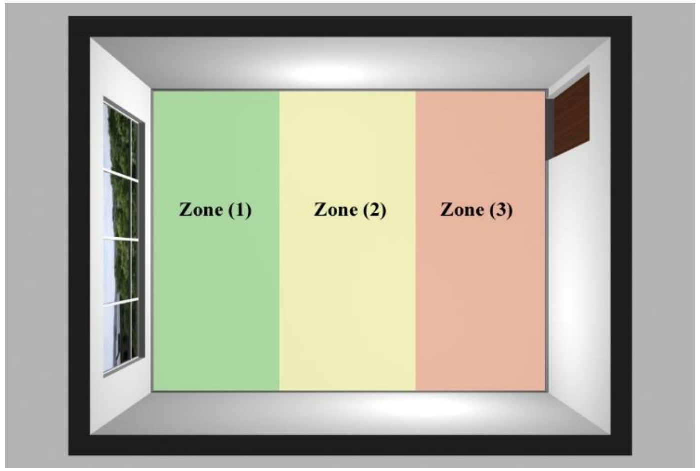
7- From your point of view, please choose the most important function provided by the glazed area (window) in your working place?

View	Daylight	Natural Ventilation	Other (please specify)

8- Rank the previous functions of your working place glazed area (windows) according to their importance to you

Rank	1	2	3
View			
Daylighting			
Natural ventilation			

9- The following figure shows an upper view for a typical office room plan (6 m x 4.8 m), please specify the following:



a. The sitting zone that you prefer to sit and work in:

Zone (1)	Zone (2)	Zone (3)	Other (please specify)

b. State the reason for choosing the previous zone

Better in view	Better in daylight	Better in natural ventilation	Other (please specify)

10- In your working place, who is assigned offices with pleasant views or sitting places adjacent to the windows?

Managers	Seniors	Juniors	Random	Other (please specify)

Part III: Interaction with Transparency:

11- In a typical working day, and without turning-on the air conditioning, please describe the level of your satisfaction with your office space thermal environment

Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied

12- During summer working days, how often do you turn-on the air condition in your working place?

Never turn it on	0 - 2 hours	2 - 4 hours	4 - 6 hours	6 - 8 hours	Always on

13- Specify the month when you usually start turning on the air condition in your working place, and at which month do you usually switch it off? (excluding unusual weather conditions)

Starting turning-on month	Switching-off month

14- Do you need heating system during winter times in your working place?

Yes	No	Sometimes (specify the month)

15- Natural ventilation:

a. How often do you use natural ventilation for your working place?

Never	Rarely (less than 2 hours)	Sometimes (2 - 4 hours)	Mostly (4 - 6 hours)	always

b. Please specify the reason for the previous question (you may choose more than one answer):

Avoid unpleasant smells (Olfactory reasons)	Provide an air-flow to enhance thermal comfort	Reduce internal carbon dioxide content	Other (please specify)

16- What kind of shading devices do you have for your glazed area (windows) in your working place?

External and fixed (Outside the window)	External and moveable (Outside the window)	Internal and fixed (Inside the office room)	Internal and moveable (Inside the office room)	Inter-pane (between glass layers)	Don't have	Other (please specify)

17- In case of moveable shading:

a. How often do you pull down (close) your windows shadings during a typical working day?

Never	Less than 2 hours	2 - 4 hours	4 - 6 hours	More than 6 hours	Always

b. Please specify the reason for pulling down (closing) the window shading device in your working place (you may choose more than one answer)

Avoid heat gain from solar radiation	Avoid glare from direct sunlight	Prevent annoying reflections on my computer screen	For privacy	Other (please specify)

c. Is it possible to have a part of the view while you close the window shading in your working place?

Yes	No	Partially	Other (please specify)

18- How often do you depend on natural daylight only in your working place for a typical working day?

Never	Less than 2 hours	2 - 4 hours	4 - 6 hours	More than 6 hours	Always

19- Do you turn on artificial light during daylight hours in your working place?

Yes	No

20- If always or sometimes:

a. How often do you switch on artificial lighting in your working place for a typical working day?

Less than 2 hours	2 - 4 hours	4 - 6 hours	More than 6 hours	Always

b. Please state the reason for turning on the artificial lighting in your working place while ignoring plenty of natural light outside (you may choose more than one answer)

Closing the window shadings	Daylighting is not enough and need to increase lighting level	No other source of lighting	Other (please specify)

Part IV: Preferred Design Criteria for Transparency:

21- The following figure shows 5 different glazing (window) areas for a typical office room with the same view, please specify the following:


(A) 100 – 80 %


(B) 80 – 60 %


(C) 60 – 40 %


(D) 40 – 20 %


(E) 20 – 0 %

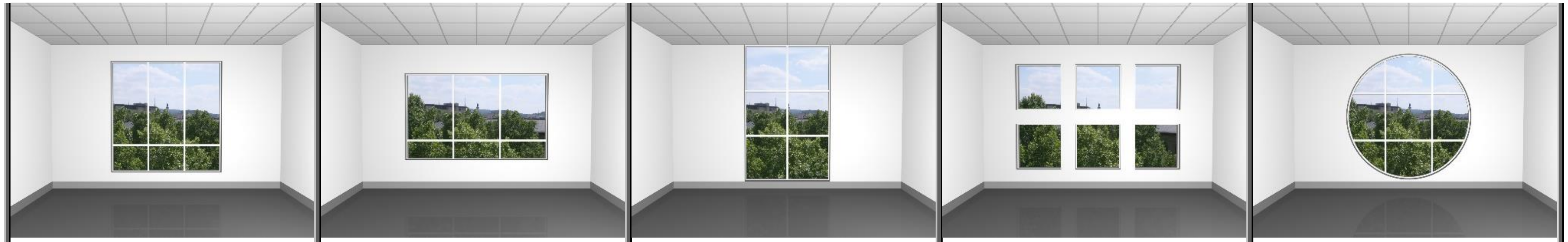
a. Choose the most visually accepted glazed (window) area

A	B	C	D	E	Other (please specify)

b. State the reason(s) for your choice (you may choose more than one answer)

Better in view	Better in daylight	Better in natural ventilation	Other (please specify)

22- The following figure shows five different glazing (window) shapes with the same area and same view for a typical office room, please specify the following:



(A) Square | **(B)** Wide | **(C)** Longitudinal | **(D)** Fragmented | **(E)** Circle

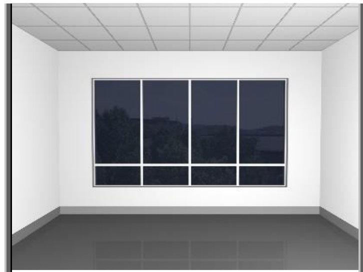
a. Choose the most visually accepted shape

A	B	C	D	E	Other (please specify)

b. State the reason for your choice (you may choose more than one answer)

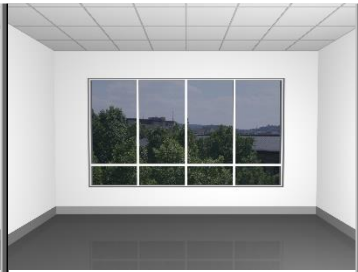
Better in view	Better in daylight	Better in natural ventilation	Other (please specify)

23- The following figure shows five different glazing (window) tinting levels with the same view and same area for a typical office space, please specify the following:



(A) 100 – 80 %

(B) 80 – 60 %



(C) 60 – 40 %

(D) 40 – 20 %

(E) 20 – 0 %

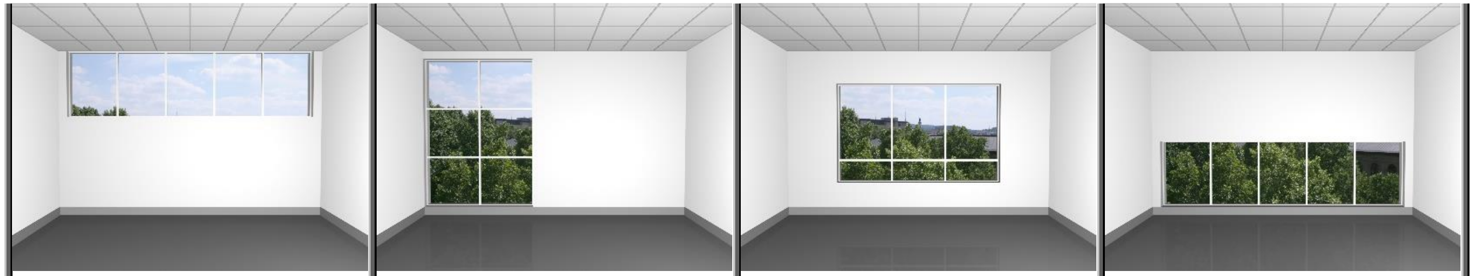
a. Choose the most visually accepted tinting level

A	B	C	D	E	Other (please specify)

b. State the reason for your choice (you may choose more than one answer)

Better in view	Better in daylight	Avoid heat gain from solar radiation	Avoid glare from direct sunlight	Prevent annoying reflections on my computer screen	Privacy	Other (please specify)

24- The following figure shows four different glazing (window) positions with the same area and same view for a typical office room, please specify the following:



(A) Top | **(B)** Corner | **(C)** Centre | **(D)** Bottom

a. Choose the most visually accepted glazing position

A	B	C	D	Other (please specify)

b. State the reason for your choice (you may choose more than one answer)

Better in view	Better in daylight	Better in natural ventilation	Other (please specify)

25- The following figure shows 6 different views with the same glazing (window) areas for a typical office room, please specify the following

(A) Nile view	(B) Green view	(C) City-scape view	(D) Empty land view	(E) Neighbour view	(F) Slums view

a. Choose the most visually accepted View

A	B	C	D	E	F	Other (please specify)

26- External reflection:

a. Do you prefer that the glass of the window in your working place would have a kind of external reflection?

Yes	No	Not Sure

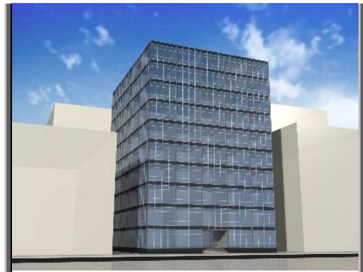
b. If yes, what is the level of reflection that you prefer in your working place glass?

Mirror like	Very High reflective	High reflective	medium	low reflective	Very low reflective	Not reflective

27- What is your desired level of access to the outside and level exposure in your working space

See the outside and be seen	See the outside without being seen	Cannot see the outside but can be seen	Cannot see the outside and cannot be seen	Other (please specify)

28- The following figure shows 5 different office building facade designs, If you are an owner of an office building please specify the following:



(A) Fully Glazed

(B) 80 – 60 %

(C) 60 – 40 %

(D) 40 – 20 %

(E) 20 – 0 %

a. What is the best façade design that reflects your perception for your office building?

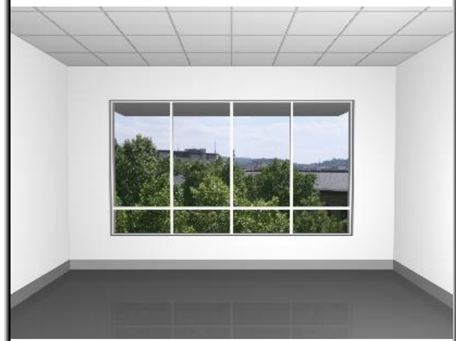
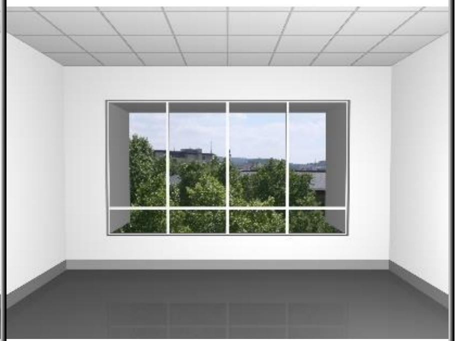
A	B	C	D	E

b. Specify the reason of choice (you may choose more than one answer)

Express Modernity	Elegancy and beauty of glazed building	Express richness	Express power	All the previous	Other (please specify)

29- The following figures shows 8 different shading devices for the same office space and with the same view, each figure presents an external and internal diagram for one of the most commonly used shading devices in office buildings.

a. According to your visual perception please accept or not accept each of the following shading devices:

Horizontal overhang		Horizontal Overhang with side fins		Perforated shading (Mashrabya)		Horizontal louvers	
							
							
Accept	Un-accept	Accept	Un-accept	Accept	Un-accept	Accept	Un-accept

Transparent roller blinds		Light shelf		Horizontal fins		Vertical fins	
							
							
Accept	Un-accept	Accept	Un-accept	Accept	Un-accept	Accept	Un-accept

b. What is the reason that regulates your acceptance for the shading devices?

30- From your point of view, and from the previous visual parameters that you had answered in the survey, please specify the importance of the visual preference of transparency to you in a working place:

Very important	important	Neutral	unimportant	Very unimportant

31- "Increasing the glazed area (window) will enhance the visual contact to the outside for the users, but will contribute to high energy consumption to achieve the desired thermal comfort. While decreasing the glazed area will improve the energetic performance, but will reduce the external visual preference for the users".

With regards to the previous statement, please indicate from your point of view the ratio preference between the desired visual preference to energy efficient thermal comfort conditions:

Visual %	0	10	20	30	40	50	60	70	80	90	100
Thermal %	100	90	80	70	60	50	40	30	20	10	0

Appendix B: Pilot Survey

Pilot Survey

Greetings Dear participant,

I am conducting the following academic questionnaire as a part of my PhD research study in Stuttgart University, institute of design and construction (IEK), under the supervision of Prof. Dipl.-Ing. José Luis Moro and Prof. Dipl.-Ing. Jürgen Schreiber.

Kindly, answer the following questions with your attention and completion, your valuable opinions and input in this questionnaire is highly appreciated. The questionnaire survey consists of four main parts: the first part is general questions, and each of the following three parts represents one of the questionnaire objectives. If you have any question or concern about it, please contact me via e-mail address tamer_awny@yahoo.com. Thank you in advance for your kind assistance and cooperation.

Part I: Personal Questions:

1- What is your age?

20 - 29	30 - 39	40 - 49	50 - 59	More than 60

2- What is your gender?

Male	Female

3- Please specify your place of work / Company:

4- What is your profession?

5- What is the number of your working hours per day?

Part II: Investigate the Need for Transparency and Highly Glazed Office Buildings:

6- Is it important for you to have a glazed area (window) in your working place?

Yes	No	Other (please specify)

7- From your point of view, please choose the most important function provided by the glazed area (window) in your working place?

View	Natural Daylight	Natural Ventilation	Other (please specify)

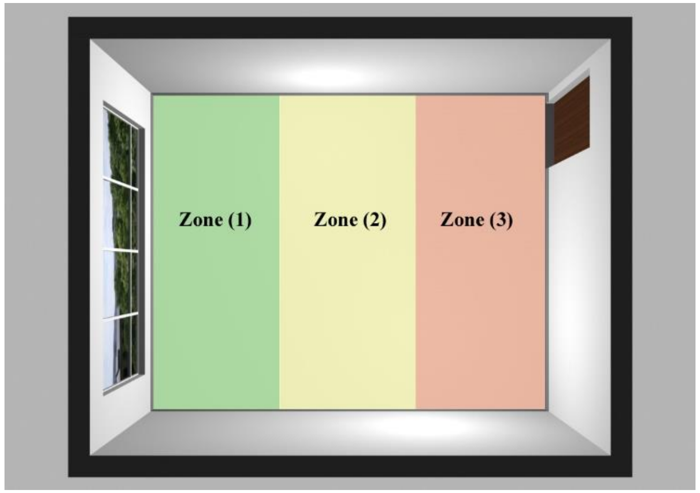
8- Arrange the previous functions of your working place windows (view – natural daylight – natural ventilation) according to their importance to you

Rank	1	2	3
View			
Natural daylighting			
Natural ventilation			

9- In your working place, who wins office rooms with pleasant views or sitting places adjacent to the windows?

High managers	Managers	Seniors	Juniors	Random	Other (please specify)

10- The following figure shows a typical office room plan (6 m x 4.8 m), please specify the following:

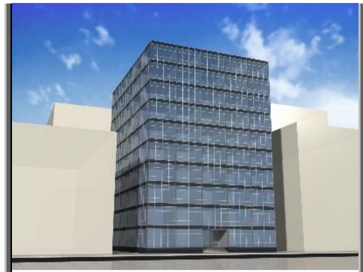


a. The sitting zone that you prefer to sit and work in

Zone (1)	Zone (2)	Zone (3)	Other (please specify)

b. State the reason for choosing the previous zone

11- The following figure shows 5 different office building facade designs, If you are an owner of an office building please specify the following:



(A) Fully Glazed

(B) 80 – 60 %

(C) 60 – 40 %

(D) 40 – 20 %

(E) 20 – 0 %

a. What is the best façade design that reflects your perception for your office building?

A	B	C	D	E

b. Specify the reason of choice

Express Modernity	Elegancy and beauty of glazed building	Express richness	Express power	All the previous	Other (please specify)

Part III: Investigate the Thermal and Visual Satisfaction for Office Buildings Users:

12- In a typical summer day, and without turning-on the air conditioning, please describe the level of your satisfaction with your office space thermal environment

Very Dissatisfied	Dissatisfied	Neutral	Satisfied	Very Satisfied

13- During summer days, how often do you turn-on the air condition in your working place?

Never turn it on	0 - 2 hours	2 - 4 hours	4 - 6 hours	6 - 8 hours	Always on

14- Specify the month when you usually start turning on the air condition in your office space and at which month when do usually you close it? (exclude unusual weather conditions)

Starting turning-on month	Switching-off month

15- Do feel that you need heating system during winter times in your working place?

Yes	No	Sometimes (specify the month)

16- How often do you use natural ventilation for your office? And please specify the reason

Never	Rarely	Sometimes	always	Other (please specify)

Reason:

17- What kind of shading device do you have for your windows in your working place?

External (Outside the window)	Internal (Inside the office room)	Inter-pane (between glass layers)	Don't have	Other (please specify)

18- How often do you pull down (close) your windows shadings during your working day?

Never	0 - 2 hours	2 - 4 hours	4 - 6 hours	6 - 8 hours	Always

19- Please specify the reason for pulling down (closing) your window shading device in your working place (you may choose more than one answer)

Avoid heat gain from solar radiation	Avoid glare from direct sunlight	Prevent annoying reflections on my computer screen	For privacy	Other (please specify)

20- Is it possible to have a part of the view while you close the window shading?

Yes	No	Partially	Other (please specify)

21- How often do you depend on natural daylight only in your working place for a typical working day?

Never	0 - 2 hours	2 - 4 hours	4 - 6 hours	6 - 8 hours	Always

22- How often do you switch on artificial lighting in your working place for a typical working day?

Never	0 - 2 hours	2 - 4 hours	4 - 6 hours	6 - 8 hours	Always

23- Do you turn on artificial light during daylight hours?

Yes	No	Sometimes	Other (please specify)

24- Please state the reason for turning on the artificial lighting while there is plenty of natural light outside

Part IV: Investigate the Physical Parameters that Contributes to the Users Sense of Psychological Satisfaction and Well-Being

25- The following figure shows 5 different glazing (window) areas for a typical office room with the same view, please specify the following:

(A) 100 – 80 %

(B) 80 – 60 %

(C) 60 – 40 %

(D) 40 – 20 %

(E) 20 – 0 %

a. Choose the most desired glazed (window) area

A	B	C	D	E	Other (please specify)

b. Choose the minimum acceptable glazed (window) area

A	B	C	D	E	Other (please specify)

c. State the reason for your choice

26- The following figure shows 5 different views to the same glazing (window) areas for a typical office room, please specify the following

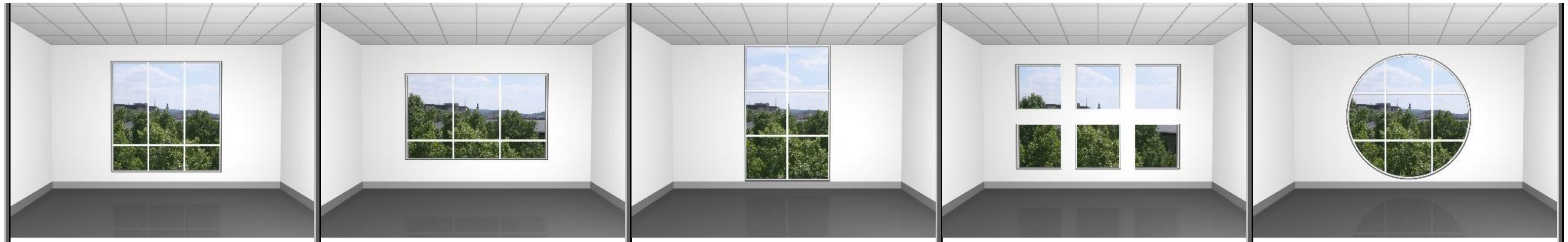
(A) City-scape view (B) Nile view (C) Slums view (D) Desert view

a. Choose the most desired View

A	B	C	D	Other (please specify)

b. State the reason for your choice

27- The following figure shows five different glazing (window) shapes with the same area and same view for a typical office room, please specify the following:



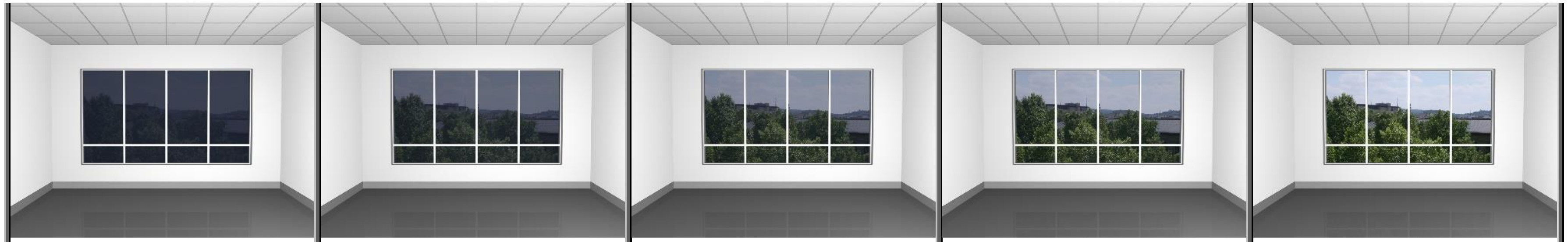
(A) Square (B) Wide (C) Longitudinal (D) Fragmented (E) Circle

a. Choose the most desired shape

A	B	C	D	E	Other (please specify)

b. State the reason for your choice

28- The following figure shows five different glazing (window) tinting levels with the same view for a typical office room, please specify the following:



(A) 100 – 80 % | **(B)** 80 – 60 % | **(C)** 60 – 40 % | **(D)** 40 – 20 % | **(E)** 20 – 0 %

a. Choose the most desired tinting level

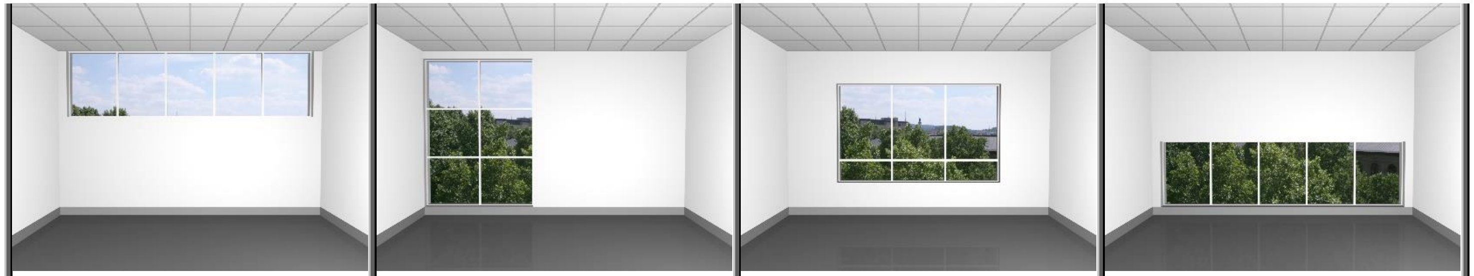
A	B	C	D	E	Other (please specify)

b. The minimum acceptable tinting level

A	B	C	D	E	Other (please specify)

c. State the reason for your choice

29- The following figure shows four different glazing (window) positions with the same area and same view for a typical office room, please specify the following:



(A) Top | (B) Corner | (C) Centre | (D) Bottom

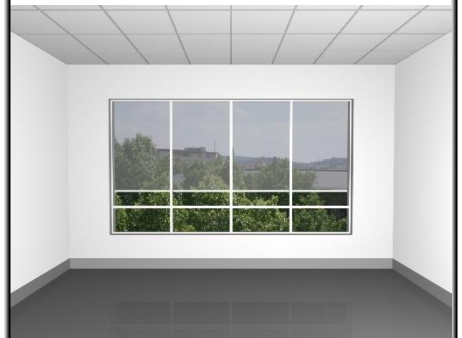
a. Choose the most desired glazing position

A	B	C	D	E	Other (please specify)

b. State the reason for your choice

30- The following figures shows 8 different shading devices for the same office space and with the same view, each figure present an external and internal diagram for one of the most commonly used shading devices in office buildings. According to your visual perception please accept or not accept each of the following shading devices:

Horizontal overhang		Horizontal Overhang with side fins		Perforated shading (Mashrabya)		Horizontal louvers	
							
							
Accept	Un-accept	Accept	Un-accept	Accept	Un-accept	Accept	Un-accept

Transparent roller blinds		Light shelve		Horizontal fins		Vertical fins	
							
							
Accept	Un-accepts	Accept	Un-accept	Accept	Un-accept	Accept	Un-accept

31- What is the reason that regulates your choice in the previous question (question 29)?

32- Do you prefer that the glass of the window in your working place would have a kind of reflection?

Yes	No	Not Sure

33- What is the level of reflection that you prefer in your working place glass?

Mirror like	Very High reflective	High reflective	medium	low reflective	Very low reflective	Not reflective

34- Form your point of view, and from the previous visual parameters that you had answered in the survey, please specify the importance of the visual preference to you:

Very important	important	Neutral	unimportant	Very unimportant

35- Form your point of view, please indicate the ratio preference between satisfactions of thermal comfort to the satisfaction of visual comfort:

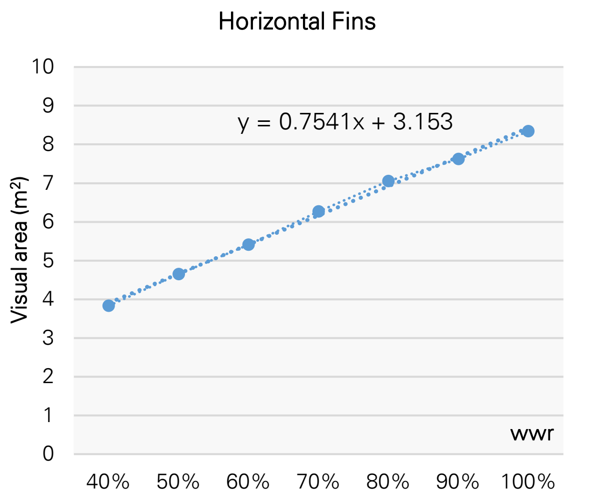
Visual %	0	10	20	30	40	50	60	70	80	90	100
Thermal %	100	90	80	70	60	50	40	30	20	10	0

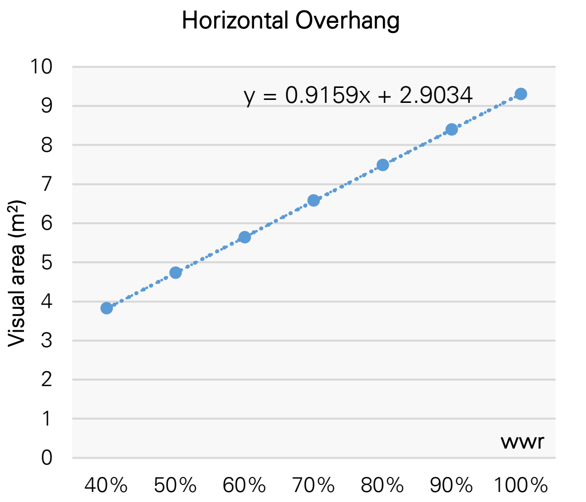
Comments and Feedback:

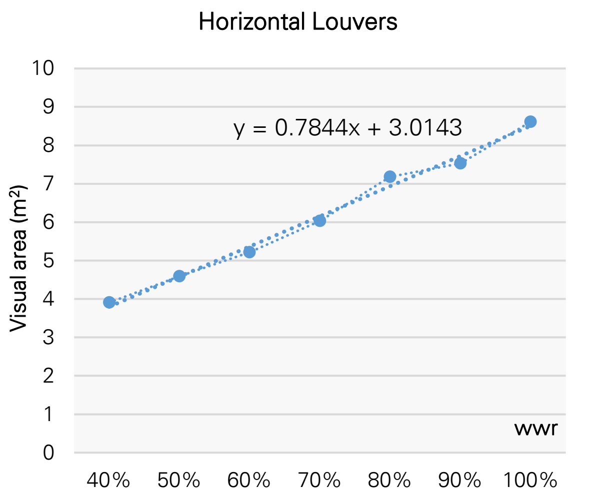
Appendix C: Visual Area Fraction

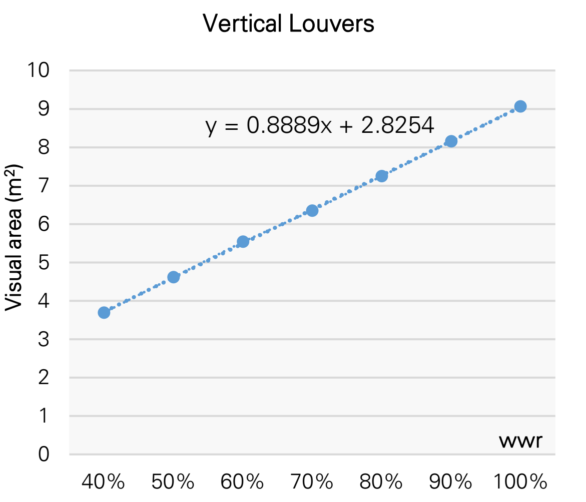
Visual Area Fraction:

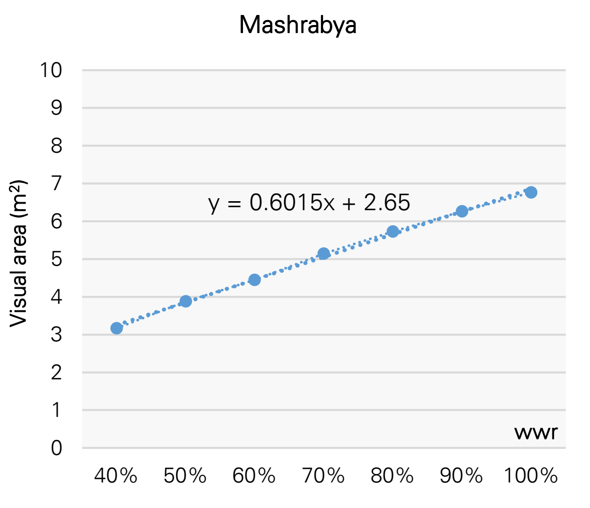
- North Direction:





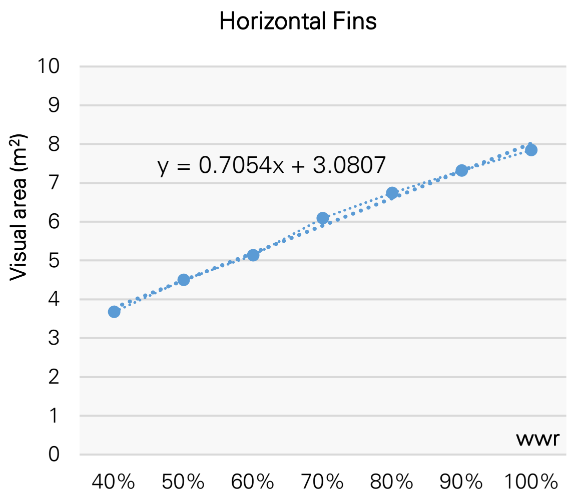


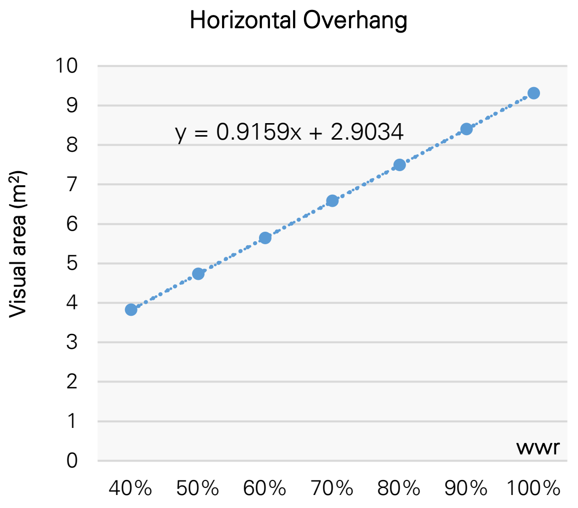


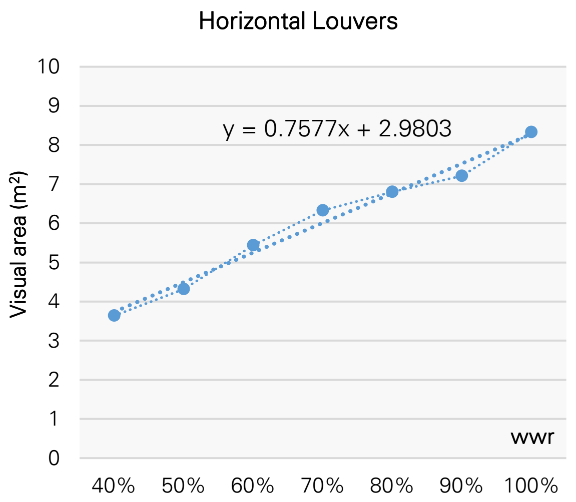


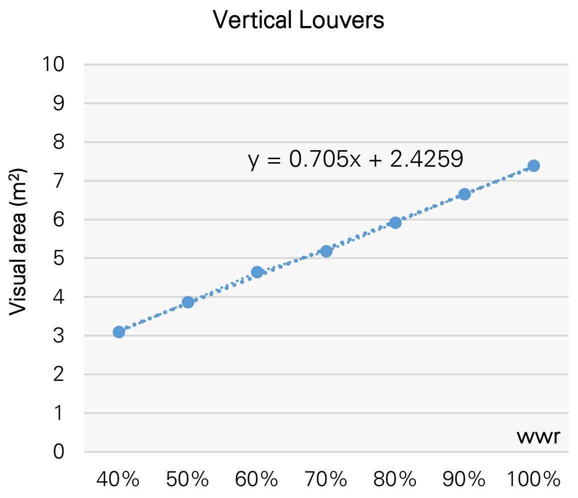
Visual area fraction calculation for North direction. Each graph shows the calculated visual area fraction values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.

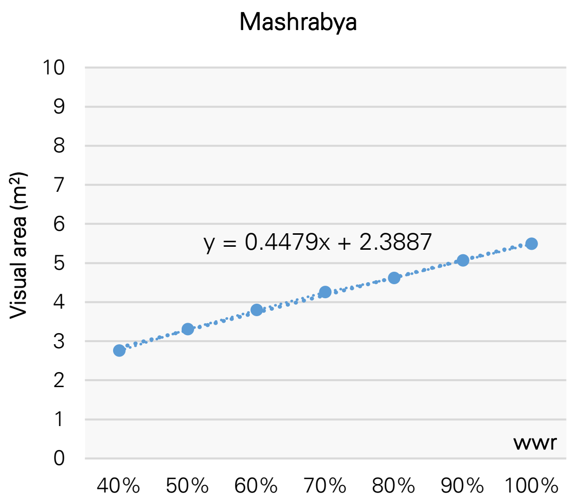
- East Direction:





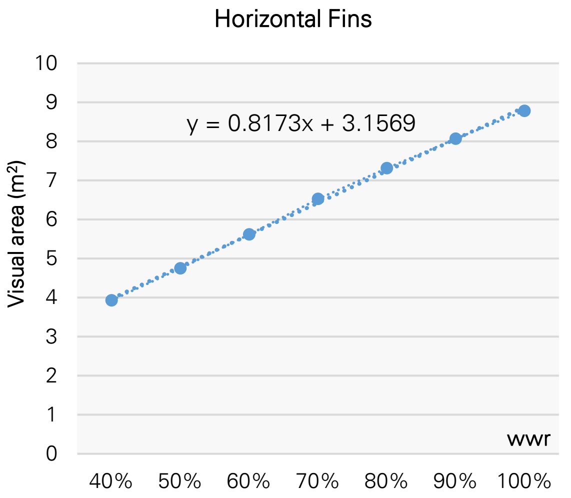


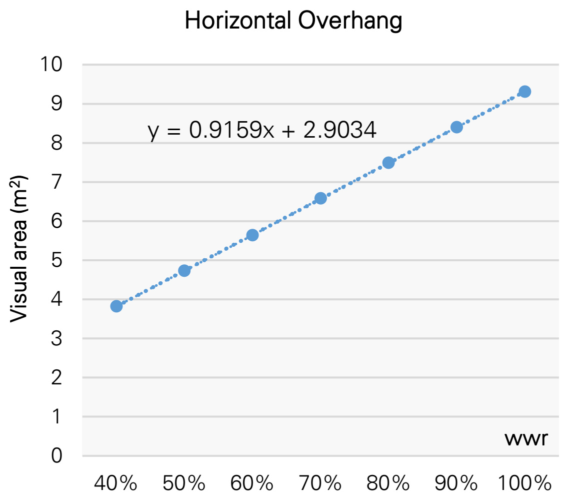


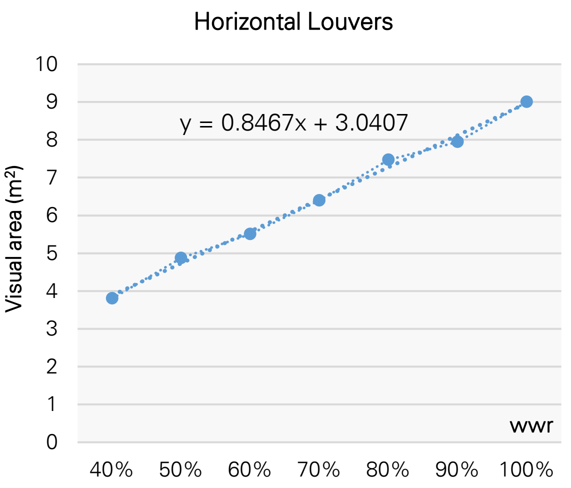


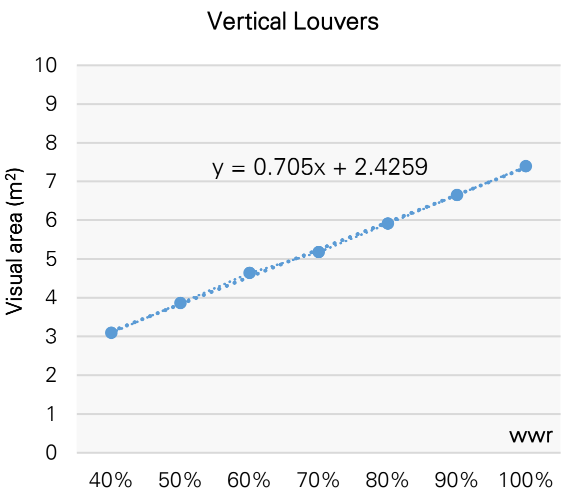
Visual area fraction calculation for East direction. Each graph shows the calculated visual area fraction values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.

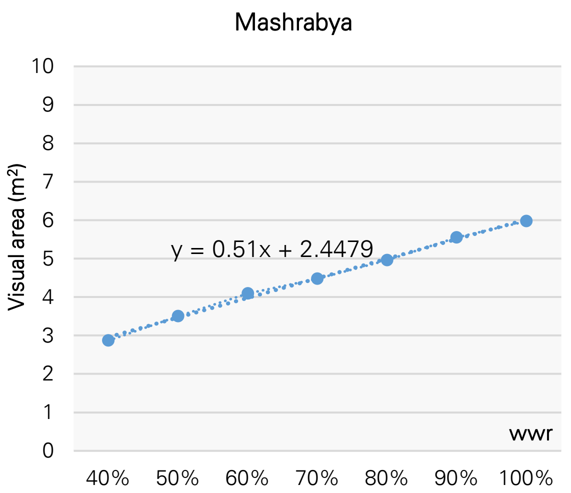
- South Direction:





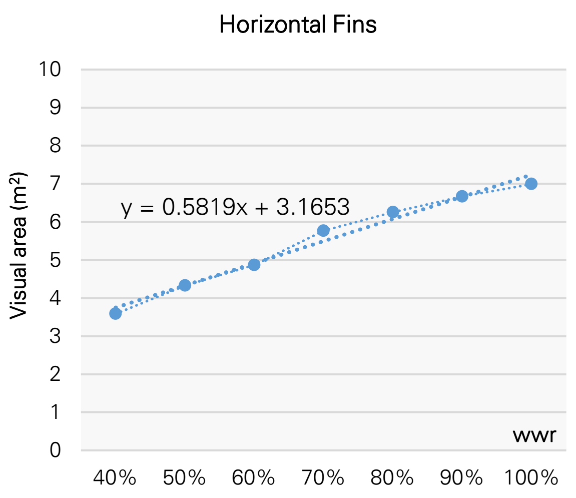


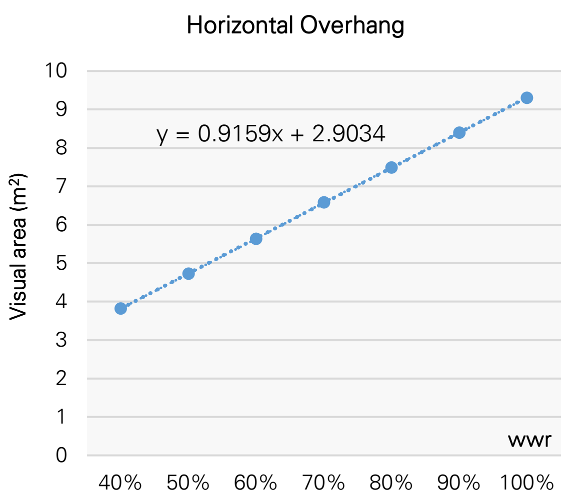


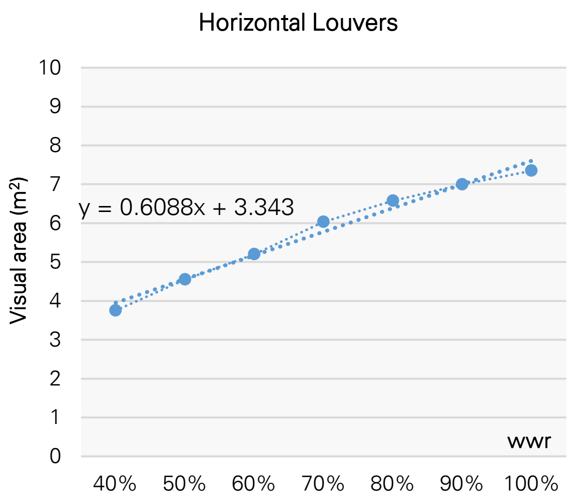


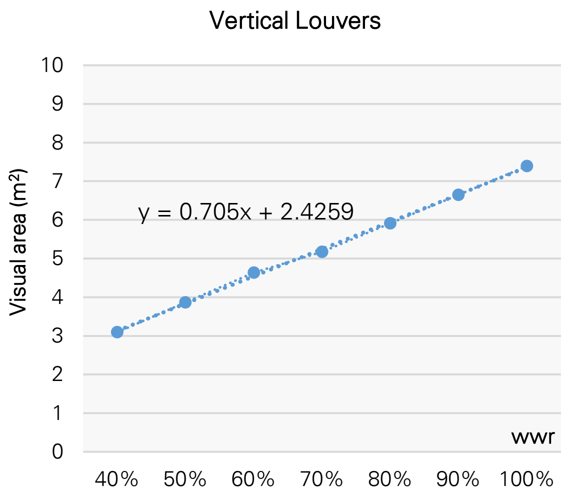
Visual area fraction calculation for South direction. Each graph shows the calculated visual area fraction values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.

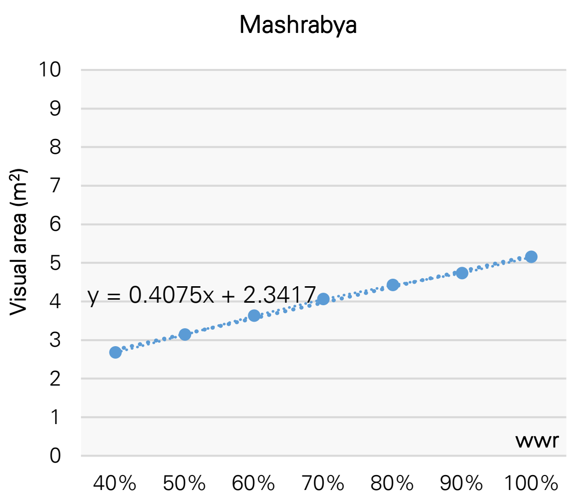
- West Direction:











Visual area fraction calculation for West direction. Each graph shows the calculated visual area fraction values of the three solar control concepts for a specific external shading device with regard to the examined window to wall ratios.