Guidelines for High-Rise Building Facades in Terms of Energy Efficiency

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ABSTRACT

In today's world, energy is one of the most important factors in each individual's life, people cannot imagine their life without energy. Due to increasing human needs in different types of energy in everyday life, energy efficiency has become a significant issue, especially after the energy crises in 1970s. Thus, one of the main challenges in recent years is finding ways to use passive solar design strategies in order to respond to human needs.

When it comes to architecture, again finding ways in order to benefit from passive systems become an important. This is especially valid for high rise buildings which consume huge amount of energy due to their scale and function. If their large facade areas are considered, they may provide great opportunities to make use of passive solar design strategies.

Accordingly, Because of global warming that the Earth is facing today, if designed with passive solar design strategies, buildings could play a vital role in the reduction of energy costs during their life cycle.

Although, there is considerable research on how to design sustainable facades, nonetheless, there is a gap in the literature relating to facade design in different climatic zones to minimize energy use.

In order to achieve this task, high rise buildings in four major climatic zones are analyzed in terms of passive solar design strategies and materials utilized in the building.

Meanwhile, the author's main attempt is to make viewpoint of architects more clear about the influence of benefiting from passive design systems for façade of the high rise buildings. Thereby, this study is based on a theoretical research where relevant literature and selected case studies of Norman Foster have been reviewed to arrive at conclusion.

On the other hand, it is mainly qualitative method of data collection. Finally, High rise buildings in vertically growing cities of Dubai, Frankfurt, Kuala Lumpur and Moscow for example need to be designed in accordance with passive solar design strategies so that maximum reduction in the energy costs can be achieved from manufacturing to operation stage of high rise buildings. Furthermore, the results of this study prove that high rise buildings can be energy efficient if appropriate passive solar design strategies are used in their design to make maximum use of natural light, ventilation, passive solar heating and cooling.

Keywords: High Rise Building- Energy Efficiency- Design Strategies- Solar Heat Gain- Natural Lighting- Natural Ventilation

ÖZ

Günümüz dünyasında insanlar hayatlarını enerjisiz düsvşünemeyeceklerşi için. enerji her bireyin hayatı için en önemli faktörlerden birdir. Özellikle 1970'lerderki enerji krizinden sonra insanların günlük haşamlarındaki değişik enerji ihtiyaçlarından donyaı enerji verimliliği çok önemli bır konu olmuştur. Bu sebepten donyaı, son yıllardakien en önemli meydan okuma insanlarınihtiyaçlarını karşılamak için pasif güneş tasarım stratejilerin kullanma yolları bulmaktır.

Mımariye gelindiği zaman, pasif güneş sistemlerin den yararlanmanın yollarını bulmak çok önemli bir mesele olmuştur. Bu, ölçü ve işlerlerinden donyaı yüksek miktarda enerji harcayan yüksek binalar içşn geçerlıdır.

Eğer bu vinaların geniş cepheler göz önüne alınırsa, pasif güneş tasarım stratejilerinin kullanıla bilirliğine önenli ölçüde olanak sağlanabilirç

Buna bağlı olarak, dünyamızın bugün karşı karşıya kaldığı kürsel ısınmadan dolayı binalar pasif güneş tasarım stratejilerine uygun tasarlanırlarsa var oldukları süreç içerisinde enerji masraflarının azaltılması konusunda hayari önem taşıyabilirle.

Uzun soluklu cepheler dizayn etme üzerine oldukça fazla araştırma olmasına rağmen, değişik iklim alanlarında enerji kullanımnın azaltılmasıyla ilgili literatürde açık bulun maktadır.

Bunu başarabilmek için dört değişik iklim alanındaki yüksek yapılar pasif güneş tasarımı ve kullanılan materyaller göz öngünde bulundurularak

Dolayısıyle bu çalışma Norman Foster' ın kontrol edip sonucuna vardığı örnek inceleme ve literatüre uygun olarak teorik araştırmaya dayamaktadır.

Bir diğer yandan bilgi toplanımı nitelik metodu esas alınarak yapılmıştır. Son olarak, dikine büyüyen şehirler olan Dubai, Frankfurt, Kuala Lampur ve Moskova daki yüksek bibaların pasif güneş tasarımstratejilerine göre dizayn edilmesi maksimum enerji masraflarının azaltılması ancak bu binaların işlemsel evrekerinde elde edilebilir.

Bunla birlikte, bu çalışmanın sonuçları eğer uygun pasif güneş tasarım stratejileri binaların yapımında kullanılırsa, doğal gün ışığı, havalandıma pasif güneş ısıtma ve soğutmada maksimum derecede kollanım elde edilebileceğiniç dolayısıyle yüksek binaların enerji verimliliğinin olabileceğini kanıtlamaktadır.

Anhatar kelimeler: yüksek Binalar- Enerji Verimliliği-Dizayn Stratejileri- Güneş Isisi Kazanımı- Doğal Işık- Doğal Havalandırma

I dedicate this thesis to my family who have always had faith in me and supported finalization of this work in every possible way.

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PREFACE

Besides theoretical meaning of sustainability, to me sustainability means making earth a livable place for future generation, which requires individuals not to be selfish. This is essential for making decisions which is beneficial for all human beings as well as next generations.

If each individual thinks like this sustainability can be achieved. To have sustainable education, sustainable economy, sustainable tourism and of course sustainable architecture. As Norman Foster said:

Unless architecture is truly your passion, Norman Foster thinks you should simply find something else to pursue.

"Live every living second of your life doing what you love."

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Chapter 1

INTRODUCTION

Architecture is a field which can give clue about culture of people, climate and also resources of a specific place in a specific time from previous generations to the future generations. Therefore, it is possible to name architecture as “journalism in stone”. Nowadays, in field of architecture the topic which is getting most of the attention is energy efficiency and there are more architects now who consider designing energy efficient buildings. Among all human activities, building construction and building itself after construction consume most of the energy resources and has various impacts on the environment. Thus, this fact gives an opportunity and at the same time responsibility to architects to be part of creating sustainable earth. This aim can be achieved by using “the best of the old and the best of new” (Bennetts, et al, 2003).

Continuing or having changes which can even cause the replacement of the issues, usually happening because of the innovation in technologies, developments in science or political events. Shadows of sustainability and energy efficiency have been seen in early 1970s, but it was after 1973 energy crisis that labels and concepts such as “energy efficient”, “green” and “environmental friendly” were created which were referred to designing a building by considering the relation of the building with nature and building impacts on the environment (Minke, 2012).

Thus, energy efficient architecture, is the modify meaning of architecture which is answers many concerns about impacts of human activities on environment. To sum up, energy efficient buildings and architects are used for architects and designs which the resource consumption and global climate change is one of their concerns, and the always take sustainability as one of their considerations.

It should be mentioned that, during the history of humanity, good design was a designed to protect human beings from environment and climate issues but since this concept changed, however, today it is environment which needs protection from human activities and creating good quality space. The environment should be well considered. As Giddens (1991) said:

> At certain point… - very recently in historical terms- we started worrying less about what nature can do to us, and more about what we have done to nature. This marks the transition from the predominance of external risk to that of manufactured risk (p.34).

In 1987, the World Commission on Environment and Development, published a report which introduced the term sustainable development. This report was named as Brundtland Report (Sev, 2009).

> Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs… sustainable development is not a fixed state of harmony, but rather process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs (Sev, 2009).

Since 1992, discussions related to sustainable development was more theoretical, it was in 1992 in Rio de Janeiro at the Earth Summit where 27 principles were named for achieving global sustainability and it was aimed towards moving the topic from theory to plan of action. A frame work was designed which would help countries develop the better social, economic and environmental quality of life by eight keys:

- Creating sufficient shelter;
- Developing urban settlement management;
- Advanced sustainable land-use planning;
- Creating environmentally sound infrastructures;
- Developing energy efficiency technologies;
- Enabling disaster-prone countries to plan for and recover from natural disasters;
- Advanced sustainable construction industry;
- Human resource development (Summit, 1992).

Sustainability covers many issues but most important one is energy consumption. Buildings are responsible for using 48 percent of the energy in the world and this factor change and destroy the planet more than anything (Pérez-Lombard, et al, 2008).

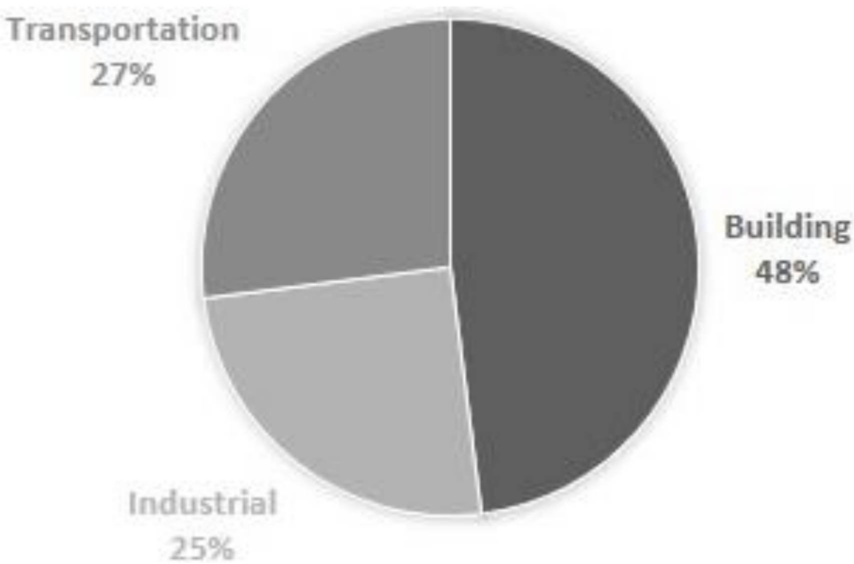


Figure 1: Energy Consumption of Human Activities (Pérez-Lombard, et al, 2008).

It is possible to achieve energy efficient buildings by taking in heating, cooling and lighting through solar design strategies (Bossink, 2007). The first important criteria is related to design decisions of architects. If architects use natural resources for their buildings during the design process and utilize passive solar design strategies for decision making, then, it is possible to accomplish 60 percent of the heating, cooling and lighting by building itself (John, et al, 2005).

The second criteria that should be taken into consideration is using and designing new mechanical and electrical equipment to reduce energy consumption and this will account to five percent. Thus, building energy consumption can drop to 15 percent (Grondzik, et al, 2014). As Wines (2000) believed:

> Architecture and sustainability should go hand to hand. And architects should design according to nature and according to reasons (p.67).

Understanding what is meant by energy efficiency and importance of buildings in sustainable development and energy consumption was the motivation to shape this study.

As discussed previously, energy consumption is an important issue in today's world and energy efficiency is a major challenge for human beings. This thesis aims to show strategies in designing energy efficient façades by paying attention to climate characteristics in order to increase the energy efficiency and reduce energy consumption of buildings by proving natural lighting, natural ventilation and passive heating and cooling.

Although, there have been lots of researches related to this topic there is a gap in analyzing high rise buildings based on their façade design, due to their vast amount of façade, and therefore potential to benefit from sun's energy they should be investigated in more details.

In this study, a checklist for energy efficient façade design has been created in order to help architects to choose best strategies for façade design of high rise buildings in different locations around the world.

1.1 Problem Statement

The main function of buildings is to create shelter for human being and protect them from extreme weather conditions and as well as creating space which is convenient for their activities. However as previously mentioned, these buildings are huge energy consumers. What is more, among buildings, high rise buildings are consuming energy the most due to their scale and their functions. Thus, they are one of the most critical building types that requires attention in the field of energy efficiency (Choi, et al, 2012).

Building façade it is the most important element of the high rise buildings towards achieving energy efficiency. Since high rise buildings have a vast amount of façade, so this element require extra importance for sustainable development. Strategies in designing the energy efficient façade to provide natural lighting, natural ventilation and passive cooling and heating for high rise buildings becoming more important (Sadineni, et al, 2011).

Although this should be of high importance for architects, not all pay significance attention to this topic. As pioneer of this field of study Sir Norman Foster projects have been successful in designing high rise buildings which with sustainable façades responding positively to nature. In last 40 years his and his company (Foster + Partners) were worked in wide range from urban master plan to cultural renter and mixed used buildings, to achieve sustainable architecture.

Accordingly, the research problem of this study is understanding effectiveness of designing energy efficient façade by considering the climate characteristic on the energy efficiency of the building and energy consumption.

1.2 Aims and Objectives

It appears that energy has an important role in today's world, and by growth in population this issue is becoming large and receiving more attention. However, there are few architects which studied energy in high rise buildings. Hence this study aims to clarify appropriate design strategies and technologies for façade design so that, architects may apply them in their projects for achieving energy efficient building.

Thus, finding best strategies for designing energy efficient façade for high rise buildings in different locations with different climate zones, where natural lighting, natural ventilation and passive heating and cooling techniques are used to reduce the energy consumption of the building and this fact should be the main aim considered during this study.

Within this perspective the thesis attempts to answer following questions:

- What are the characteristics of the sustainable façade?
- How does climate characteristics affect façade design?

- What are the best strategies and design decisions for sustainable façade by considering climate zones?

By answering the mentioned questions it is aimed to prepare a check list for architects which can help them to find the best strategies for their building's façade design which can respond to nature positively.

1.3 Research Methodology

The theoretical part of the thesis is based on a literature review and outcomes from internet sources, books and articles. Hence, the methodology of this study is descriptive method, and this method used to provide information about design strategies and characteristics of sustainable façades by considering the climate zones.

Data collection method which is based on qualitative research, reviews information about two main topic of the study. One, energy efficient façade characteristic and second group of study was on climate characteristics and classifications. After collecting information and preparing tables for each research study, collected data were compared in order to gives a final table or check list, which is explaining which design strategies and design decisions should be made for which climate zone.

After preparation of a check list which is the aim of this study, results were studied on case studies. In the case study stage, author tries to study cases by documentary survey and compare the result with outcome check list.

1.4 Limitation of the Study

As mentioned before, this study is mainly focusing of the energy efficiency of the building and since building façade has the great impact on reducing the energy use of the building, energy efficient façade is topic of the study. However, it is based on theoretical research and does not contain any quantitate data.

The other limitation of the study is the function of the chosen buildings. As discussed before high rise buildings are massive energy consumers therefore focuses on mixed used high rise buildings' façades. Furthermore, climate in included as another limitation for the thesis where best strategies are studied for each climate zone. And this research covers all climate zones, and proposing best design strategies for high rise building's façades for different climate zones.

For the case study, mixed used high rise buildings designed by Sir Norman Foster were chosen. As he is considered as a pioneer in sustainable architecture. Selected projects are from countries with different climate zoned (Germany, Russia, UAE and Malaysia), projects are well known for being energy efficient and environmentally friendly, so they are giving this opportunity to compare the design strategies which are suitable for each climate zone to find out best design strategy for each climate zone.

1.5 Structure of the Thesis

This thesis contained six chapters. Chapter one is talking about general energy issues and sustainability and defines aim and limitation of the study by defining the methodology of the research. After understanding the importance of the sustainability and sustainable façade in chapter one, in coming chapter, chapter two, study will focused more on the façade, impacts of the façade on economy, environment and social and defining the definition of the sustainable façade and importance of sustainable façade on environment and users comfort.

Chapter three is including main information of this study, which is related to characteristics of sustainable façade and types of the façade and suitable materials, result of the studies in chapter three can provide a general table about the sustainable façades characteristic. But as mentioned in chapter one it is not possible to talk about the sustainability without considering the climate issues, so in following in chapter three climate factor is added to the study, and in this part of chapter three classification and types of the climates were studied, and one classification were chosen to continue the study with that. In beginning of the chapter four all data were collected and in this chapter author tried to prepared the final table and check list which is coming from chapter three, and comparing the design strategies with climate characteristics and offering best strategies and methods of the design for each climate.

Chapter five is the case study, and accordingly cases were analyzed by the check list from the previous chapter. And finally chapter six is concluding the thesis study.

Chapter 2

BUILDING FAÇADES TOWRDS ACHIEVING ENERGY EFFICIENT BUILDINGS

Buildings are important components of urban settlements which provide people with the opportunity to deal with energy in various activities. Buildings' style, security, ecological quality and economy are fundamental to the personal satisfaction and users comfort. Nonetheless, in making these spaces to address human issues and prerequisites, buildings additionally affect enormously upon the natural environment.

The negative impact of buildings on the environment has brought the need for energy efficient design which aimed for consuming energy and dimishing environmental pollution. Be that as it may, at the same time, energy efficient building need to address the practical necessities for the issues of human activities (Goudie, 2013).

Among building components, it is the facade of the building which can act as a barrier between interior and exterior and by having this role it can control both interior atmosphere by making it safe from outside environment and also controls solidarity between building and environment. And hence influencing the sum and rate of recourse usage and natural decline by the buildings for keeping inside conditions regulated (Mateas, et al, 2003).

As mentioned previously the main role of building façades in terms of passive solar strategies that it helps form a resistance barrier for a buildings. Passive solar systems are giving the opportunity to building in order to provide natural lighting and ventilation and passive heating/cooling. There is possibility to adopt passive strategies to building façade and by this method help the sustainability of the building. Strategies such as appropriate orientation, shading, color, low conductivity materials and etc.

Exterior environment of the building is a factor which is specify the condition of the interior space and defining the amount of usage of mechanical systems. In this case reconsidering the role and importance of the building façade, its positive and negative impacts on sustainability and also as a controller factor between interior and exterior environment becoming highlighted (Sadineni, et al, 2011).

Buildings are designed essentially to assert the activities of its users. In general there are six implementation orders which there were shown in table one. The best way for achieving these implementations and that is if all the building component work together and in coordination with each other such as mechanical system and structural system and etc. (Omer, 2008).

Building façade dose not only keep interior space safe from outdoor factors such as heat, noise and so in, but help the building systems achieve a better performance. Hence, the general performance of the building is depended on how building façade can coordinate with other systems (You, et al, 2013).

In table 1, six implementation were shown and also it is possible to understand the importance of the building façade on building general performance.

Table 1: Building Performance and the Various Building Systems (Becker, 1984).

Performance mandates	Building Envelope System	Mechanical System	Interior System	Structural System
Acoustic performance	X		X	X
Thermal performance	X	X	X	X
Visual performance	X	X		
Indoor air quality	X	X	X	
Building integrity	X			X
Spatial quality	X	X	X	

Thus, the importance of the façade of the building related to functional and its effects on the energy consumption of the building become appeared, façade also has an impacts on three pillars of the sustainability which are economic, environmental and social, which will be discussed in the following.

2.1. Impacts of Building Façade and Environment on Energy Efficiency of the Building

One of the purposes of building structure is to upheld the building façade, which is one of the important components in building, and the main aim of this component is to create a safe place for users from all perspectives, such as, creating thermal comfort by preventing the thermal energy transfer between the interior and exterior or controlling the air quality and etc. (Keene, 2012).

Notwithstanding this essential function, there are different necessities of the building facade. The building facade should accommodate the psychological needs of the building inhabitants. It ought to permit view to the outside and give adequate natural lighting in order to maintain an isolation by the building inhabitants. Likewise, building façade also have other effect which is on aesthetic quality and by this mean it can develop attractiveness of the building Different prerequisites of the building façade incorporate cost adequacy and least effect on nearby or worldwide environment.

Hence, it can be seen that, notwithstanding the arrangement of physical protection and sanctuary, it is commonly agreed that building facade can effect on the building, socially, economically and environmentally so it means it has impacts on the sustainability of the building (Heidarian, et al, 2014).

Building that is sustainable, plans to diminish energy and recourse consumption and environmental decay. The building façade, being the biggest size single building component and the most critical parameter of the passive system, impacts fundamentally on the resource consumption and environmental decay by the building.

Being the biggest size single building component, the building façade utilizes much material for its distinctive parts. The building façade can diminish the building's effect on environment by recycling. Building facade designers can help in accomplishing building sustainability environmentally by guaranteeing that every sub-component contains resembling materials so recycling is effectively accomplished (Council, 2004).

The building façade is in charge of detached the interior of the building from the outer environment. Thus, it is the essential determinant of the indoor climate and subsequently, influences the level of supplementary mechanical energy required. The design of the building façade can influence enormously the measure of heat going into and leaving from the interior space of the building. The building façade assumes an imperative part in heat control and thus, therefore its effect on the general energy consumption of the building. At the point when passive thermal building façade design strategy," insulation, shading, glazing and color, are perform together they can diminish measure of cooling and heating load of the building (Wang, et al, 2014).

2.2. Definition of Energy Efficient Façade

Sustainable facade can mainly be described as a component of the building which chip in to the sustainability of building by boosting the economic returns, minimizing the negative impact on the environment, increasing the social benefits and amplifying the functional building performance.

Energy efficient façade aims to minimize the effect on the environment, the building façade can combine new technologies, for example, double skin façades to diminish the energy consumption of the building. Thus, the environmental impact is minimized. However, these new technologies and systems are more costly to perform. Accordingly, the economic return is traded off. To accomplish adjust among the criteria is not a simple task as every criteria is esteemed diversely by various partners (Horner, et al, 2007).

The design phase of the energy efficient facade is the most essential as the decision make at this stage has principal impact on the later phases of the building facade's entire life. For instance diminish artificial lighting energy consumption, the building facade parameters, orientation of the façade and the transparency ratio are vital and ought to be considered at the design phase of the building facade. Energy efficient façade design ought to dependably consider its effect on the three criteria of the building sustainability in all phases of its entire life.

By understanding the definition of energy efficient façade design, and also importance of designing façades sustainably after the long discussion before, it is important to study sustainable façade on three component which it effects directly. These components are environment, users and mass itself (West, 2001).

During this study sustainable façade and environment will be studied by covering the role of this element in sustainable development. Other component is users, so it is must to study sustainable facades and its effect on users comfort since sustainable façade is designing to provide comfort for users, and finally mass, this study is covering high rise buildings, thus, sustainable façade and high rise buildings were subject of the research in the end of this chapter.

2.2.1. Role of Energy Efficient Façade in Sustainable Development

Building facade have noteworthy effect on the 3 criteria of sustainable building. Basic this noteworthy effect is an exceptionally potential building sustainability contribution. The building energy efficient façade presents numerous chances to improve the sustainability of the building. The essential part of energy efficient façade as the filter of undesirable environmental components needs to develop in the recent call for sustainable building. The energy efficient façade can assume a bigger role in improving the sustainability of the building (Fergus, et al, 2005).

Building facade perform two tasks: to start with, they are the obstructions that different a building's interior from the outer environment, and second, more than some other elements, they make the picture of the building. sustainable façade can be characterize as exterior enclosure that utilization the minimum amount of energy to keep up an comfortable interior environment which advances the wellbeing and profitability of the building occupants. This implies sustainable facades are not just boundaries amongst inside and outside, rather they are building systems that make comfortable spaces by effectively reacting to the buildings outside surroundings and altogether diminish building's energy consumption hence, they are important elements for sustainable development (Omer, 2008).

2.2.2. Energy Efficient Façade and User Comfort

As mentioned before about the importance of building façade, this component provides a boundary between the exterior environment and interior spaces by creating this barrier, they provide comfortable spaces in terms of thermal, visual and acoustical so they can answer users comfort. It is important to note that sustainable façades can do more. They can provide mentioned comfort at the maximum level by using minimum of the resources.

For achieving this high performance, architects should take various components into consideration such as, thermal insulation, daylighting, solar heating, and shading and so on while they do the design process for providing sustainable environment for the habitants and users (Braganca, et al, 2007).

Natural lighting and importance of it for users comfort were forgotten till mid twenty century and that was because of the cheap new technologies such as fluorescent lamps. After energy crist in 1973 importance of the natural lighting for reducing the energy used by building and leading building towards sustainability become appeared and it was the time when human developed their knowledge and they could built façades with large glazed area. So architects start thinking about providing natural lighting for their buildings more (Bell, et al, 1983).

According to the researches importance of the natural lighting is not only in field of energy, but it effect psychology and human wellbeing. Exposure to natural light emphatically influence people's circadian rhythms, which can prompt to higher productivity and greater satisfaction with internal environment (Knez, 1995).

Table 2: Daylighting Design Considerations (Webb, 2006).

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

The other component which should be taken into consideration is thermal comfort of users, which also can be provide by correct decision on sustainable façade design. Thermal comfort is the state of mind which express fulfilment with the thermal environment, since it is a state of brain, comfort is characteristically based on one's understanding and recognition, and there are huge variety in physiological and psychological reactions for various people. Few buildings are designed to meet the special thermal comfort needs of single individual (Epstein, 5006).

Among all façade components, windows have the major effect on the thermal comfort. These elements are the coldest element of the interior spaces in cold weathers and warmest in the hot climate zones and the can effect thermal comfort of the occupants. According to the researches the less window-to-wall ration can provide more thermal comfort for users. It is almost same even for high performance glazed buildings (Lyons, et al, 2000).

And the last factor to be concluded is natural ventilation, which can affect the indoor air quality and also heating and cooling load of the building. Indoor air quality in one of the most important elements for occupants comfort. Adequate indoor air quality (IAQ) is characterized as indoor air that has no contaminants at harmful focus and that fulfills no less than 80% of the users. Ventilation can help to achieve the thermal comfort easier (Daisey, et al, 2003).

Achieving user comfort depends on the strategies architects choose for their building façade specially by considering the climate issues of the design site. Strategies such as orientation of the main façade or ratio of the glazing areas, location of the fenestration to increase about of the natural lighting gain and at the same time solar heat gain which can be beneficial for cold climate. This is a wide and very important topic, which will be widely discuss in the coming chapter of this thesis. And by understanding the characteristics of sustainable façades which will be study, it will be possible to provide users comfort.

2.2.3. Energy Efficient Façade for High Rise Buildings

Due to their need high rise buildings are massive energy and resource consumers as well as environment polluters. And since nowadays humans moving from rural environment to cities having such buildings becoming more important because of the less about of the land architects should design upward and that’s the reason for having high rise buildings. It is the worldwide decision to go towards sustainability, thus, high rise buildings are very important to achieving this goal. This buildings because they have a small occupied ground area but at the same time huge surface they need a special structure and construction systems (Wood, 2007).

As Marion Campi (2000) believed that:

> The skyscraper is clearly identifiable not only by virtue of its historical development and the specific approach to architecture it embodies, but also because it has an identity easily readable as an architectural type. By this I mean that the skyscraper is a manifest product of a historical development, a creation of the altered nature of our cities and that it has often left its mark as an adequate response to the urban evolution of specific urban situation and the modern city in general; it has thus achieved legitimacy as a contemporary expression of modernity (p.48).

There are still some people which thinks that high rise buildings are huge urban elements which are consuming much of the energy and their materials polluting the environment and they cannot be environmental friendly and sustainable. Which this belief is not correct.

Materials and components used on high rise buildings, because of the large scale and surface of the building, can have the capacity of being recycled. Most of the non-renewable energy uses is in the transportation. If high density living achieved it will be possible to reduce amount of the travels in the city, parking area and so on. Which can help the sustainable development of the city. High density living also has an effect on the social development which is providing pedestrian life in the ground plane.

With high rise buildings less amount of land will be used for construction and built, and the land which is preserved can be used for agriculture or any unbuilt vegetated land (Burgess, et al, 2002).

By understanding the importance of the high rise buildings for our urban settelment, it is important to note that, among different elements in high-rise buildings again façade is the largest and most important element for leading the high-rise building towards sustainability. It is possible to have sustainable façade by choosing correct technologies, materials and design strategies according to climate and environmental factors from initial steps of design to achieve sustainable high-rise buildings. This will also keep reduce energy consumption of high rise buildings.

Average energy use of Mixed-use High-Rise buildings shown in the Figure 2, Heating, Cooling, Lighting and Ventilating interior spaces account for more than half of the energy use. The performance of the building façade can significantly affect the energy consumed by these high-rise building, and it shows the importance of sustainable façades for high rise building for achieving the goal of the today’s world which is sustainability (Star, 2014).

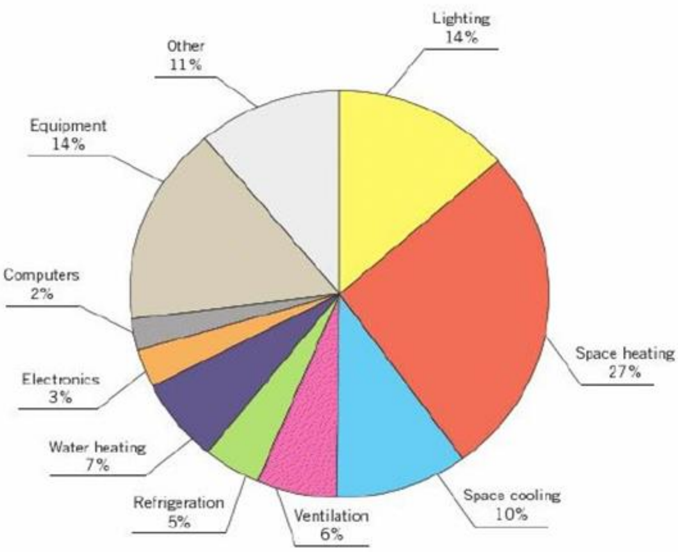


Figure 2: Energy Use by Mixed-Used High Rise Buildings (Star, 2014).

2.3 Chapter Summary

In this chapter the impact of façade on the energy performance of the building as well as on the environment were studied. Definition of the energy efficient façade were studied during this chapter and in following effects of energy efficient façade on sustainable development, users and high rise buildings as a urban settlement elements were studied. The following chapter characteristics of energy efficient façade will be studied in order to conclude with a table which can give characteristics and design decisions related to design of energy efficient façade.

CHAPTER 3

CHARACTERISTICS AND CLASSIFICATIONS OF ENERGY EFFICIENT FAÇADE

Starting from 1851 buildings with high glazed facades appeared in architecture and one of the most famous examples of such kind of design is Crystal palace. But it was from 1950s that curtain walls were part of the design more extensively and it was because of the progress in building technologies and also changes in economy in postwar period. From mentioned period and also till years after that, aesthetic of the building facades were more dominated rather than energy efficiency of the façades and how façade design can help energy efficiency of the whole building. It was from 1970s and with facing shortage in oil resources worldwide and global climate change, that energy resources became more important and since then architects while designing they give a massive importance to the building efficiency and sustainable façades (Turner, 1999).

As mentioned previously building façade can effect building energy use and this effects are because of the four factors which are thermal heat transfer, solar heat gain, air leakage and lighting load. For achieving sustainable façade and following with that sustainable building there are various strategies, design methods, materials and technologies which can help architects to design sustainable façade. For example using shadings and combine it with high performance glazing can help for controlling the heat loss (Saparauskas, et al, 2011).

In this chapter elements that can help architects to design sustainable façades which can list them as characteristics of sustainable façade were studied and these information will combine with climate factor and come as a final guideline and check list in chapter six.

3.1. Characteristics of Energy Efficient Façade Design

And along with understanding characteristics of the sustainable façade, it is important to understand the types of the façades and materials which can be used in the sustainable façade design, this subject also will be discussed during this chapter.

3.1.1. Solar Heat Gain and Lighting Load

Solar radiations is the renewable energy source and it can be categorized as direct energy and same as wind and wave it is a biological energy resource. Solar radiation can be used as an energy source for building development. Mainly there are two classification for solar radiation energy, which are passive solar energy and active solar energy. Passive solar energy strategies which are more related to design decisions were using in history of architecture for decades and since the climate change issue and global warming becoming bold in today’s world maximum gain of solar radiation for heating and lighting purposes becoming more important. Active solar energy focused on heat gain from the solar radiation by using technologies such as solar panels and Photovoltaic panels (Li, et al, 2000).

Solar radiation is an important factor for designing sustainable building and it is a very important factor for designing sustainable façade, with and by correct usage of solar radiation it will be possible to improve the solar heat gain for the building as mentioned above and also it is very important for natural lighting and can affect the lighting load of the building and beyond energy efficiency issues natural light can affect the aesthetic of the building.

As Louis I. Kahn said:

> 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 (Toft, 2005).

There are fixed conditions for architects while designing, such as location and climate. Climate is a very effective factor for designing sustainable façade which should be considered in design process and each façade should be design according to characteristic of each climate. This issue will be study in next chapter. And second fixed condition which is location, by elements such as trees, surrounding buildings, topography and etc. can affect the solar radiation gain and daylighting of the building. For being sure for availability of daylighting and solar radiation gain these factors should be studied and should considered by architects. These factors are, orientation, Fenestration, shading. In addition there are factors such as glare, lighting technologies and also glazing of the building sustainable façade that can affect lighting load and solar heat gain of the building (Booklet, 2010).

In the following pages these factors will be studied to understand how they can affect the sustainability of the façade in high rise buildings and how architects can use them for benefit of their sustainable façade design.

3.1.1.1. Orientation

As Le Corbusier said:

> It is the mission of modern architecture to concern itself with the sun. Orientation is the most valuable energy-saving strategy (Von Moos, 2009).

Human kind used to respect the sun during the history because they knew that life of the human is depend on sun, solar radiation and light. But in one point because of the development in technology these respect faded, but in today's world, the importance of sun again became important.

First of all it is important to understand the position of the sun and earth and their behavior. Sun is far from the earth and the radiations from the sun are parallel to the orbit plane of the earth. Earth is revolving around sun and at the same time revolving around itself. The spin around itself is on the north-south axis. The important note here is this axis is not perpendicular to earth orbit plane and 23.5 degree tilted and this is the reason that create different seasons and also Couse having summer in north hemisphere in 21 June but summer in south hemisphere on 21 December (Lynes, 1968).

By continuing studies about the behavior of sun radiation, four important dates were discovered. On 21st of June solar radiation is perpendicular to the earth surface and also it is the longest day in the year, and exactly six month later on 21st December sun radiation have lower angles and it is the longest night of the year these two days called summer solstice and winter solstice. In the middle of mentioned period on 21st of March and 21st of September and in these days, nighttime and daytime are equal. These days call spring equinox and fall equinox.

The highest sun path of the year is on the summer solstice and in the opposite the lowest one is on the winter solstice. Solar radiation is very weak during early morning and last hours of the day.

Orientation of the building is the factor which determine the sunlight exposure on the façade of the building. As mentioned previously because of the specific characteristics of the earth and its movements around the sun, amount of sun exposure of each façade of the building is changing during day. Orientation of the building façades important for solar heat gain strategies and also for achieving natural lighting and lighting strategies (Dekay, et al, 2013).

Strategies which are using for building heat gain control is directly depends on the building's façades orientation. In the cold climates gaining solar heat and in hot climates protecting building from solar heat gain is important.

Therefore optimal orientation of the building's façades which considering solar radiation gain can benefit building users in cold climates and shade the building and protect users in the summer months.

In hot climate solar radiation must be kept outside but in opposite in the cold climate it is preferable to bring the solar radiation inside and by this method it is possible to heat the building by passive strategy. It should be note that the orientation of the site is not always in the architects hands and control. But it is expected from architects to think about orientation of the façades of the building from initial steps of the design. According to different environmental conditions and climates, different decisions should be make for designing facades facing north, south east and west. For example south façade is beneficial for solar heat gain because the solar radiation is high in summer and can be controlled by overhang and it is low enough to enter to the building (Ander, 2003).

Beside solar heat gain, orientation is very important for achieving natural lighting, and it is an important factor for lighting. Therefore thinking about the façades orientation and design can optimize daylghting of the buildings. For example northern façade can be used for indirect daylighting, while southern façade is the best one because it can get sunlight constantly during the year. If according to the fixed conditions of the site location and etc. building must use east and west façades, it is important to use proper shadings. In these two orientations the sun radiation is low and can create a glare effect so deep vertical shading must be used. When building façades are using advantages of the orientation, building users can work and live in more comfortable area and in the same time energy consumption of the building will drop (Bell, et al, 1995).

Table 3 is showing that south façade is the most important façade for gaining natural light and solar heat for high rise buildings. However, north direction façade is the least important one since there is no direct sun light. And finally east and west façades are most critical ones, because of the angle of the sun, and designing fenestration in these façades is critical, and correct usage of shading is very important.

Table 3: Orientation for solar heat gain and natural lighting (Ander, 2003; Bell, et al, 1995).

Orientation		
Façade orientation	**Solar heat gain consideration**	**Natural lighting consideration**
North façade	Not preferred façade	Best façade if indirect daylight is needed
	Not direct solar radiation	
South facade	Most solar radiation	Optimum and best daylight
	Shading for summer is needed	Sun lighting constantly during the year
East and west façade	Not preferred façade	Not preferred
	Can be used only by shadings	Low angle of sun direction

3.1.1.2. Fenestration and Glazing

Fenestrations which include, windows, curtain walls, clerestories, sky lightings are elements of the façades which affect energy efficiency of the buildings by being one of elements which effect solar heat gain and also lighting of the building and at the same time effect aesthetic of the buildings also. Fenestrations are elements which allow sun radiation enters to the building through façades and it means they have significant effect on natural lighting and solar heat gain. Having poor fenestration can brings some effects such as glare, noise and heat loss and heat gain which can create discomfort for users.

As mentioned before one of the effects of fenestrations is solar heat gain for the buildings, and it is a problem for the buildings which are specially located in hot climate zones. Recently advanced building technologies are helping to solve this problem, and helping the façades of the building to go through energy efficiency. One of the methods which is using is inserting gas between two or three layers of the glass (curtain walls) and this method can help transmission of solar heat gain. By coloring the glass itself or by having films in the layer between the glasses it is possible to provide shading for the buildings. Study on different methods in this field is still developing and continually new methods and materials introduce to the markets (Carmody, et al, 2004).

Besides using correct material for the fenestration (glasses) there is one metric characteristic for sustainable façades design which is window-to-wall-ratio. This ration showing the percentage between opaque façade area and glazed area and it is important because it is contributor to solar gain of the façade and energy consumption of the building.

Studies are showing even by developing in the field of glazing technologies, but still insulated glazed areas are losing and gaining more solar heat which it can be more beneficial for temperate and cold climate but it is bigger issue in hot climates.

In general increasing WWR (Window Wall Ratio) increase the solar radiation entering to the building which can help reducing lighting load of the building and make building sustainable by using natural lighting, but at the same time increasing WWR increase solar heat gain of the building effect energy efficiency of the building by increasing cooling load. So either it is preferable to reduce WWR to improve energy efficiency or using proper shadings and materials to help energy efficiency of the building especially in hot climates which solar heat gain is not preferable (Xiangzhao, 2001).

For designing the fenestrations there are some basic and advanced strategies for achieving best performance of the windows. Generally best position for windows are high on the wall and wide in dimension to distribute light better, and also as a percentage usually windows should not be more than 20% of the floor area, and it is mainly because of the unwanted heat gain and also heat lost in different climate zones. But it is important to note that correct using of the shading and also understanding about the glazing types and choosing proper one according to the climate is very important. For example using movable shading and also high performance window glazing can optimum the performance of the building.

It is important to place fenestrations on different façades (different orientations) it is called bilateral lighting. With this strategy glare is controllable and also by getting sun radiation from different direction it is possible to use it for different purposes (Gereffi, et al, 2008).

Shade windows from excess daylight in summer. Preferably, just a little amount of daylight ought to be admitted through the windows in the summer and a most extreme amount in the winter.

Overhangs on south facade windows can give seasonal control. They can likewise dispense with puddles of daylight, decrease glare, and level out the light gradient inclination the room (Lawrence, 1923).

Beside mentioned basic strategies for fenestration there are some advanced strategies also. One of the important methods for lighting techniques is reflection. In high rise building parts of structure can be used to reflect the light inside the building. Deep windowsills can be quite effective but they are a potential source of glare on the south, east, and west facades.

The light shelf can act instead of overhang for this lower glazing to keep direct sunlight from entering and making puddles of sunlight. The overhang additionally decrease glare by obstructing the view of the bright sky in the lower window.

Light shelves must be much longer on east and west windows than on south windows, and they are not required at all on north windows. Hence, all orientations needs a different alternative for their windows design. Since east and west windows are exposed to the low summer sun, they required extra-deep light shelves, louvers, ribbon windows, and an occasional view window. Light shelves are turning out to be more famous notwithstanding for high rise buildings (Littlefair, 1992).

To sum up it is important to consider following criteria while designing a fenestration to achieve advanced daylighting:

1. Utilizing light shelf on the south façade;
2. Utilizing windowsills projected on the east and west orientation;
3. Utilizing a dynamic system such as outdoor venetian blinds on the east and west facades;
4. Utilizing a backup system such as venetian blinds on interior facades for obstruction low sun angles and in addition control the glare effect.

Another essential issue in designing fenestration for sustainable façades is glazing materials. It is no longer proper to utilize the same glazing for all orientations. Rather, an effective, sustainable design will tune the glazing for every orientation as a function of building type and climate.

Picking the correct glazing material is basic to a successful daylighting design. Transparent glazing arrives in assortment of types: clear, tinted, heat absorbing, reflective, and spectrally selective.

The tinted, heat-absorbing, and reflective types are once is a while fitting for the accumulation of sunlight because they decrease light transmittance. They are sometimes used to control heat gain and the glare brought by the unnecessary brightness ratios between windows and walls. These three types of glazing do not take care of the issue automatically, because they decreasing the interior brightness as much as they decrease the brightness of the view (Hutchins, et al, 1996).

Whenever light but little or no heat is needed, in buildings where winter heat is craved, a conventional low-e glazing should be utilized, since it transmits both the visible and solar infrared. At the point when neither heat nor much light is needed, as in view windows on the east and west facades, then a low transmission, spectrally selective low-e coating ought to be utilized that hindered some light and most solar infrared.

Translucent glazing material with very high light transmittance is not generally fitting for window glazing for few reasons. It turns into a source of glare when illuminated by the sun. Then again, translucent glazing materials of relatively low light transmittance can be utilize effectively for daylighting when the glazing area is very huge. Glazing that can change from high- to low-light transmittance is called dynamic glazing. Since it neither changes the direction of the light being transmitted nor its spectral selection (Kunert, 2003).

To sum up this part of the study, following criteria must be considered for designing and choosing the glazing for fenestrations:

1. For the south oriented façade, high solar heat gain low-e clear glazing or high light-to-solar-gain (LSG) low-e glazing is required. Choosing them is depends on the climate conditions. First one is more proper for the cold climate zones which heat is needed during winter, and second one for hot climate zones;
2. For east and west glazing, it is beneficial to reduce amount of glazing. For cold climates high LSG low-e glazing and opposite in hot climates low solar heat gain selective low-e glazing must be used;
3. For north oriented façade, it is better to utilized high visible transmittance low-e clear glazing;
4. In general it is required to not use or minimize the usage of the skylight;
5. Clerestories are suggested to use, and for glazing of this kind of fenestration it is possible to Use translucent high solar gain low-e glazing in cold climates and utilize translucent high LSG low-e glazing in hot climates.

In table 4, it is showing the usage of the fenestration and glazing for solar heat gain and optimizing daylighting. And it is summary of the 3.1.2 part of this chapter.

Table 4: Fenestration and Glazing Characteristics (Kunert, 2003; Hutchins, et al, 1996)

Fenestration and glazing characteristics

Fenestration and orientation considerations

General considerations for fenestration	Not more than 20% of the floor			
	Movable shading is needed			
General considerations for orientations	North	Projection outdoor windowsill		
	south	Light shelves (shorter than east and west		
	East and west	Extra deep light shelf	louver	Ribbon windows

Glazing

Transparency types	Solar heat gain	Natural lighting
Clear	ok	X
Tinted	X	Ok
Heat absorbing	X	Ok
Reflective	X	Ok
Spectrally selective	Ok	x

Orientations	Fenestration Types		
	Windows	Sky lighting	Clerestories
North façade	x	x	x
South façade	Maximum	Minimum of usage	Maximum of usage
East and west façade	Minimum	Minimum of usage	Maximum of usage

Glazing types	Solar heat gain	Natural lighting
Low-e glazing	Ok	Ok
Spectrally selective low e coating	X	X
high LSG low glazing	Ok	X
High visible transmitted low-e clear	Ok	Ok
Low solar heat gain selective low-e glazing	ok	x

3.1.1.3. Shadings

Shading is one of the most important sustainable strategies because almost all buildings except the ones located the northern countries in the world overheat in the summer and the usual response is to get energy-guzzling air conditioners. Huge increase in energy demand for cooling must be minimized by heat avoidance and passive cooling, and the number one heat avoidance strategy is shading. Although shading of the whole building is beneficial, shading of the windows is crucial. Shading is a solar energy strategy even though it blocks rather than collects solar radiation. For choosing best shading for buildings, orientation is an important parameter. East and west glazing collects more than two times the solar radiation of south windows. Thus, shading of the east and west windows is also more important than the shading of the south windows (Tzempelikos, et al, 2007).

South windows getting more solar radiation contrast with different orientations in the winter time. Accordingly, south windows are extremely desirable from both a shading and passive solar heating perspective. Skylights ought to be avoided because they collect a huge amount of solar radiation in the summer and little in winter. Similarly, east and west windows are not desirable from both heating and cooling perspective (Mahdavi, et al, 2008).

The aggregate solar load comprise of three segments: direct, diffuse and reflected radiation. To anticipate passive solar heating when it is not needed, one should dependably shade window from the direct solar component and usually from the diffuse sky and reflected components. The type, size and location of the shading devices are depend on size of the direct, diffuse and reflected components of the total solar load (Olgyay, et al, 1976).

It seems that shading strategies are in conflict with use of natural light which were talked till now. But the truth is with correct use of shading, it will be possible to use natural lighting with better quality while protecting the building from solar heat gain especially in the overheated periods of the year. It is not possible to give one general principle for amount of shading use, and it is different and depends on the climate and location of the building.

Shadings can be applied in interior spaces or in exterior façades. Usually interior shading devices are movable and exterior shading devices can be both fixed and movable.

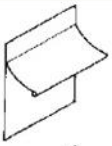
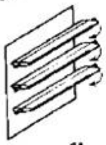
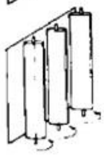
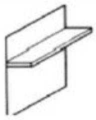
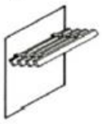
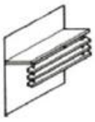
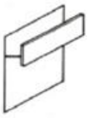
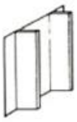
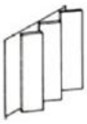
As discussed before, choosing best strategies for shadings is very depend on the orientation. For south façade it is required to use horizontal overhang to penetrate sun radiation in the summer period which is not needed and since in the winter the angle of sun direction is lower it can enter to the building same method can be used for the south east and south west directions also. Usually for north façade oriented shading is not needed, but for hot climates since the sun rise and set from north east and north west it is better to utilize shadings. In these hours of the day sub angel is low so instead of overhang vertical fins are needed (Boyce, et al, 2000).

For two other direction, east and west direction strategies are different. Altitude angle of the sun is so low in these times, so I is required to not use windows on east and west, especially on the west façade or try to minimize usage of the opening. If it is not possible utilizing vertical shading and sometimes combination of vertical and horizontal shading is must.

Another type of the shading is movable shading, it is obvious that movable shading are better than fixed shading devices, since it is possible to move them to the maximum shade during the overheated periods and in opposite get the maximum solar heat gain during the cold periods. Adjustment of these shadings can be so simple or too complex, usually it is possible to adjust them two times a year before the cold period and hot period of the year. The principles for movable shadings are same as the fixed shading devices. (Van Moeseke, et al, 2007).

In table 5, it is showing the different types of the fixed shading, and also discussing about the best orientation for them: (Tzempelikos, et al, 2007).

Table 4: Fixed and movable shadings (Tzempelikos, et al, 2007).

	Descriptive Name	Best Orientation	Comments
	Overhang Awning	South, east, west	Fully adjustable for annual, daily, or hourly conditions Traps hot air Good for view Can be retracted during storms Best buy!
	Overhang Rotating horizontal louvers	South, east, west	Will block some view and winter sun
	Fin Rotating fins	East, west	Much more effective than fixed fins Less restricted view than slanted fixed fins
	Overhang Horizontal panel or awning	South, east, west	Traps hot air Can be loaded by snow and wind Can be slanted
	Overhang Horizontal louvers in horizontal plane	South, east, west	Free air movement Snow or wind load is small Small scale Best buy!
	Overhang Horizontal louvers in vertical plane	South, east, west	Reduces length of overhang View restricted Also available with miniature louvers
	Overhang Vertical panel	South, east, west	Free air movement No snow load View restricted
	Vertical fin	North	Restricts view if used on east and west orientations
	Vertical fin slanted	East, west	Slant toward north in hot climates and south in cold climates Restricts view significantly **Not recommended**
	Eggcrate	East, west	For very hot climates View very restricted Traps hot air **Not recommended**

3.1.1.4. Glare and Daylighting Techniques

Glared is brought on when there are areas of extraordinary brightness contrasted with other darker areas within the field of view. Glare, similar to thermal comfort, is subjective physiological reaction, but it can cause visual discomfort to inhabitants. It can likewise debilitate individual's performance. The human eye can work well over an extensive range of illumination levels, but not if an area of extreme brightness is present in the field of view. Good daylighting design controls glare while giving adequate light for visual performance (Hopkinson, 1972).

There are two methods for measuring glare, the Unifies Glare Rating (UGR). Developed by International Commission on Illumination (CIE) and Visual Comfort Probability (VCP), both of these methods are developed for measuring the artificial lighting glare, but can be used in computer analysis, UGR and VCP can be predicted using the daylighting simulation software radiance (Wienold, et al, 2006).

Quantity goal of natural lighting is to create natural lighting for building during the summer days to reduce usage of the artificial lighting, and also in winter much light to use as solar heating to reduce the heating demand. The quality objectives are the same as electric lighting, and the primary ones are: limit glare, limit veiling reflections, keep away from over the top brightness proportions, and supply genuinely even surrounding brightening all through a space. There are six major objectives which they ought to be accomplished, keeping in mind the end goal to set up the quality lighting:

- To have more amount of light further into the building;
- To decrease the extreme direct glare of unprotected windows and bay skylights;
- To anticipate unreasonable brightness apportion;
- To limit veiling reflections from skylights, clerestory windows, and high windows;
- To diffuse the light by methods for various reflections off the ceiling and walls;

- To utilize the full aesthetic capability of daylighting and sun radiation. (Chauvel, et al, 1982).

Opposite of the artificial lighting, daylighting strategies should be designed and considered from the initial steps of the design. In this process location, form and orientation of the façades are very important, after these, size and types of the fenestrations and also the color of the interior walls are important component which all of them should considered from the first line drawn in design and cannot be added later.

There are some basic strategies related to ordinary windows which are important to note here:

- Windows should located high on the wall and widely distributed;
- Bilateral lighting, it is important to place windows on all walls in all orientations;
- It is important to filter daylighting, it can be by use of natural component such as trees or shading elements;
- Splay the wall. It is important to decrease the contrast between wall and window (Mardalijevic, et al, 2012).

Beside basic strategies which discussed above, there are some advanced methods and strategies, which will be study in the following:

- Light shelves, are the strategies which are becoming more popular these days. Life shelves bring the natural light deeper into the space. Top part of the light shelves above human eye level has a material which can reflect the light into the ceiling and from the roof light can reflected into the space. They can utilize on the south façade instead of simple over hangs;

- Tubular skylights, Duct-like tubes are monetarily accessible with exceptionally reflective, specular inward surfaces that transmit around 50 percent of the outside light through the attic. The measure of light depends to a great extent con the diameter and length. Round tubes are accessible in a scope of sizes from 20 to 60 cm in width, and square tubes are as substantial as 1.2 m2. In spite of the fact that they are a financial approach to add light shafts to one-story, gabled, or flat roofed structures, the light circulation is very little superior to anything that of a roof mounted, fluorescent light. Both the amount and nature of the lighting are enhanced by splaying the roof around the light tube;

- Skylights with dynamic mirrors, it has an rotating mirror which can reflect the sun into the building, and the rotation of the mirror is by using energy from the PV panels of its own;

- Beamed daylighting, a mirror mounted on a heliostat, which is a sun tracking device, mirrors a vertical, concentrated light through the roof irrespective of the sun's position. Since the sun enters the building as a vertical slender beam, it can be effectively used. At the point when substantial heliostats are utilized to light up entire areas of a building, the technique is known as beamed daylighting;

- Prismatic systems, are the tiles which were popular in twenty century. One of the tiles design by Frank Lloyd Right. This tiles are utilized above the windows to reflect he sun into the spaces. Their indoor confronts comprised of triangular grooves that acted like prisms, while their open air faces accompanied different designs (Osterhaus, 2009).

3.1.1.5. Guideline for Optimizing Daylighting

Following table is showing principles for optimizing daylighting.

Table 5: Optimizing Daylighting (Osterhaus, 2009; Mardalijevic, et al, 2012).

Optimizing day lighting		
General principles	Energy efficiency	Top lighting
Integrate day lighting design with the architecture	Use windows with a low U-factors	Use clerestories
	To maximize the quality of day lighting in the winter	Avoid sky lights
Integrated day lighting design with passive solar heating	Increase illuminated	Face clerestories south if there is a significant heating load
	Design for quality day light in regard to glare and brightness ratios to ensure occupant support for day lighting	Opposite situation face it to north
Design the building as a lighting fixture	Use automatic controls electric light	East and west clerestories only if south or north clerestories are impossible
		Use louvers or baffles to diffuse light

Day lighting principles and design decision	
Maximize south windows if winter heating is required	Maximize north windows if winter heating is not required
Avoid east and west windows, if they cannot be avoided use as few as possible and keep them short	Use light shelves except on north façade
Use separate view and day lighting windows. Have day lighting windows high on the wall	Use venetian blind or shades for backup and flexibility
Use open floor plan for maximum light penetration and view	Use glass partitions to allow for borrowed day light
Use light colors on exterior to reflect light into windows and clerestories	Use light colors on the interior to maximize light penetration

3.1.2. Thermal Heat Transfer

This part of the study discusses the creation of an efficient thermal envelope to minimize the heat transfer (heat loss in winter and heat gain in the summer). Heat is lost from a building by transmission, infiltration, and ventilation. Heat is lost by transferring from the ceilings, walls, floors, windows, and doors. Heat flow transferring happens by a mixture of conduction, convection, and radiation. The proportion of each depends predominantly on the specific construction system. The amount of the heat lost from the building's façade is depends on the function of the space, occupant's activities and temperature difference between exterior and interior spaces and in the end thermal resistance of the façade. Hence, by understanding these principles it is possible to decrease heat lost from the building façade by, compact design (minimum area), common or party walls (no temperature difference across walls), and plenty of insulation (large thermal resistance). And in addition heat can penetrate from the joints in structural system and also cracks around the fenestrations. The heat loss because of penetration is an element of the rate of cold air entering the building and the temperature distinction between the indoor and open air (Howell, et al, 2010).

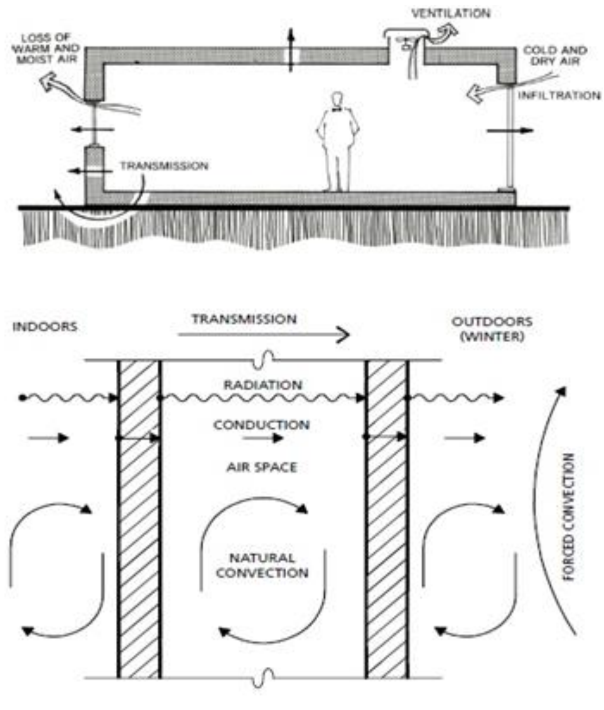


Figure 3: Thermal Heat Transfer (Bergman & Incropera, 2011).

3.1.2.1. Insulation Materials

Fifty years ago utilizing insulation within walls were not a common act, but after 1973 energy crisis, there is no doubt on using insulation material and question now is how much of these material should be used in the building façade. The easy answer to this question can be “the more insulation the better”. Utilizing insulation materials have few benefits for the building’s sustainability, such as:

- It is beneficial in energy use both in summer and winter so accordingly can save the environment;
- Insulation materials are relatively cheap, so by saving energy they help saving money;
- Increasing thermal comfort;
- Insulation materials are very durable;
- It should be taken into consideration that installing this material is much easier during the construction than after that (Al-Homoud, 2005).

There is a calculation related to amount insulation which should be used to be practical. Researches are showing each time that insulation is doubled the heat lost becoming half. It is practical in the first few time (1 to1/2 etc.). But each time doubling the insulation material in costly while it is giving less saving in heat lost (e.g., from 1⁄32 to 1⁄64 to 1⁄128, etc.). More realistic point of view is saying, it should be seen how the cost of the whole building changes as more insulation is used. It is important to see how expenses for mechanical systems for heating and cooling will drop if more insulation material utilized. In some climates by using superinsulation it is possible to eliminate the heating cooling mechanical system and reduce the expenses. In addition, utilizing insulation will secure our buildings in the time that there is a power cut, in this case the temperature of the indoor area drops slowly, and thermal comfort of the habitants is saving (Papadopoulos, et al, 2007). In the following some of the insulation materials will be studied:

- Batts and Blankets are fiberglass, rock wools, cottons, which producing in continue roles or precut by length. They are adjusting the between of the joints and studs. There are high resistance towards fire and moister;

- Loose fill, materials comprise basically of fiberglass, cellulose and extended minerals, for example, perlite and vermiculite. The fiberglass and cellulose sorts are blown into stud spaces and attics. Cellulose is a decent, safe item if appropriately treated with borates to make it fire-retardant and impervious to natural attack. Care must be taken to avert inhalation of the fine particles both amid establishment and a while later. Perlite comprises of lightweight granules that are generally filled stone work wall pits;

- Foamed-in-place, they are mainly made from the plastic. The main exclusion is Air Krete, which is a foamed mineral that has the advantages of acting as a fire stop and of not releasing toxic gases. The plastic foams different enormously because of both the base materials and the foaming agents. Foams can be utilized both during construction after by spraying it into cavities or on surfaces (e.g., basement walls). In all cases, the heal material required to be covered to protect the foam and/or the occupants;

- Boards, usually made from the foamed plastics but some types of this insulation is made from the recycled or waste of organic materials. Boards can also be made of fiberglass and mineral wool. Among board insulation materials, Extruded polystyrene is both more resistant to moisture migration and has a higher R-value than the less expensive, expanded polystyrene (bead board) material. All of the board should be covered to reduce off-gassing and to prevent toxic smoke from being generated during a fire;

- Air Spaces and Radiant Barriers, large plain air spaces are a poor approach to protect. The R-value of an air space of any size is constantly under 1. The ideal size is around 2 cm. For littler air spaces conduction increments, and for bigger ones, convection warm exchange increments. For more thermal resistance, air spaces ought to be loaded with either protection or a radiant barrier (Allen, et al, 2011).

3.1.2.2. Thermal Bridge

A thermal bridge or heat bridge, is a region of an object (regularly a building) which has an essentially higher heat exchange than the surrounding materials bringing about a general decreases in thermal insulation of the object or building. Thermal bridges happen in three ways, through: materials with higher thermal conductivity than the surrounding materials, infiltration of the thermal envelope, and discontinuities or holes in the insulation material (Lee, et al, 2014).

Thermal bridging in buildings decreases energy efficiency and can permit doping moisture and thermal comfort issues. Condensation can bring in indoor air quality issue and building decay. Thermal bridging is averted via careful design applying materials to accomplish a uniform thermal resistance such as thermal breaks and continuous insulation.

Regular heat bridges are result from the utilization of structural sheathing at corners to support the building. Rather, utilize let-in diagonal bracing. At the point when trusses are utilized and the insulation is put along the bottom chords, the web members all penetrate the insulation. When the trusses are made of steel, major heat bridges are created.

Another thermal bridge is the curtain wall when there is no utilization of the thermal breaks and also metal frame of the windows are huge thermal bridge which it is possible to recommend utilization of the thermal breaks or using sustainable woods as a framing to avoiding thermal bridge effect (Larbi, 2005).

In thermal bridge effect, insulation has an important role again, because if there is a small hole in the insulation materials, it can act as a thermal hole. And it is more common since usually there are some holes in insulation material because of the bad craftsmanship and also for piping systems and wires.

And in the end, it is widely common, in architecture design of the façade, for aesthetic point of view, slabs are extending outside. Unfortunately it has a huge effect on the sustainability of the building because this extensions such as concrete cantilevers create a huge thermal bridge (Ge, et al, 2013).

3.1.2.3. Thermal Envelope

Thermal envelope is one of the main elements of a passive or a low energy design. It contains different element but most important parts are walls, roof, windows and doors.

Thermal envelop goal is to intercept the heat going to the open air in the winter and prevent heat enters to the building during the hot periods. Theoretically it is not an expensive act to build a passive building, especially because of the variety of the material. But choosing the correct materials and correct installation is very important.

The total thermal resistance of a wall, roof, or floor construction is just the whole of the resistances of all the elements parts. Declining the total resistance of a wall or roof segment is helpful for comparing choices, for following codes, and for calculating heat loss and heat gain. Many codes, organization literature, and conditions describe the thermal characteristic of a wall or roof by a quantity called the U-coefficient instead of than the total R-value. The U-coefficient is the reciprocal of the aggregate R-value.

Thermal envelop has somehow same principle as water tank, as water tank should keep the water inside and there should not be any hole in it. Thermal envelop should keep the heat inside in winter and vice versa doesn’t let the heat inter in the summer. So there should not be any hole in it, and thermal envelop has to continuous without any break or hole in it (Krope, et al, 2009).

3.1.2.4. Fenestration and Glazing

Fenestrations represent around 30 percent of the heating and cooling load of a building, and they have a huge effect on thermal comfort because of their impact on the mean radiant temperature (MRT).

Although double glazing is about twice as good as single glazing in prevent heat flow, it is still just around one-ninth as useful as an ordinary insulated stud wall. Indeed, even with a low-e coating, a double- glazed window has an R-value of 3, which is still just one-sixth as good as a standard wall. Nevertheless, on south windows, that outcomes in a heat gain during the whole winter, in light of the fact that the passive solar heating during the day overstep the heat loss at night (Heschong, 1999).

The old way of thinking about minimizing the glazed area to prevent the heat lost is not correct any more, since high performance glazed are developed, and this development enable building to have glazed façade specially on the southern façade. It is interesting to know that changing window glazing from R-2 to R-4 has the same effect on heat lost amount as changing walls from R-19 to R-100. And it is because glazing the south, east and west, not only effect on heat lost but also effect the solar heat gain of the building. Thus, an opaque wall should have an R-value of 100 to have the same amount of heat loss as some windows with an R-value of 4.

The benefit of the window R-value and also wall R-value is very depended on the orientation and climate situations. But even in this case, it is almost everywhere with any climate condition, south glazing because having most solar gain is performing better than super insulated opaque walls. But it is not same for east and west orientation, for these to orientation, well insulated walls can perform same as the high R-value window. Thus, windows don't need a similar R-value as walls in order to abstain from being holes in the thermal envelope in the winter, and in the summer, shading is more essential than thermal resistance (Reynolds, et al, 1996).

It should be note that, glazing itself has no thermal resistance, and air spaces, the surface air films, and low-e coatings are the elements which help it to be thermal resistance. Single glazing which is the worst glazing, has no air space but still have slightly insulating stagnant air films which that exist at the time that air arrives in contact with a building façade. The air space can be fill by different gasses but its resistance increase if gasses such as argon, krypton, or xenon be used in it.

Thermal resistance of the windows depends on the two component, glazing and frames. In the huge glazed façades it is glazing area which is losing heat, but in the smaller windows frame has a critical role. Usually frames are made of wood, fiberglass or metal. Wood frames has a good thermal resistance and also fiberglass have low conductance. But in opposite and as mentioned before, metal frames can be used only if thermal break is utilized. In double or triple glazing, heat is mainly lost from the edge spaces, and that's why it is recommended to use thermal breaks (Jaber, et al, 2011).

Because nowadays, there are many different types of low-e coatings available, glazing ought to be specified by both its R-value and its solar heat gain coefficient (SHGC). Hence, the glazing specified would different with building type and climate. It would likewise be "tuned" in that it would change with orientation in any one building. When all is said in done, the higher the R-value of glazing (i.e., the more layers of glass) the lower the sun oriented transmission, which is tragic on the grounds that in cold climate both high R value and high sunlight are craved on south fenestration.

Following table can gives the information needed related to thermal heat lost and sustainable façade design (Manz, et al, 2006).

Table 6: Thermal heat transfer (Manz, et al, 2006; Jaber, et al, 2011).

Thermal heat transfer		
Thermal bridge and glazing		* Insulation materials
Types	Consideration	Types
Structure sheeting is corners	Let-in diagonal bracings	Batts and blankets
Curtain walls	Thermal breaks	Loose fill
	Double/triple glazing	
Metal window frame	Thermal breaks	Foamed-in-place
	Use sustainable wood	
* Insulations	No hole in insulation	Boards
Concrete cantilever in façade	Better to not be used	Air space and radiant barriers

3.1.3. Air Leakage

Air leakage which is additionally called infiltration, is the movement of air inadvertently from the outside to inside space, for the most part it is going on from the cracks in the building façade, or by using the doors. Infiltration bringing humid air of the summer to the building, and on winter moist indoor air moving to the cold façade cavity. In any cases, this buildup can happen in structure, bringing in mold. Infiltration can occur by wind, stack effect and mechanical equipment. Any time that wind make infiltration on one side of the building, exfiltration is happening in the other side. Stack effect is going on when hot air is moving toward the higher levels in building. This effect can be occur in both summer and winter, yet since the temperature contrast amongst indoor and outdoor is significantly more in winter time, then this effect is happening in this period more frequently. Hot air is lighter so it goes to upper levels of the building and by ventilation opening, can discover its way to outside, and cold air infiltrate from the open windows. Therefore, this effect usually create infiltration on the lower part of the building and exfiltration on the upper part (Epstein, et al, 2006).

3.1.3.1. Envelope Airtightness

Facade airtightness can be described as the resistance to inner or outward air leakage through accidental leakage in the building facade. This air leakage is driven by differential weights over the building facade because of the joined effects of stack, outside wind and mechanical ventilation systems.

Airtightness is the essential building trait that effects infiltration (the uncontrolled inward leakage of outside air from cracks, interstices or other unintentional openings of a building, brought on by pressure impacts of the wind as well as stack effect). An airtight building has different beneficial outcomes when joined with an appropriate ventilation framework (even if it is natural, mechanical, or hybrid): (Sandbeg, et al, 2005).

- The capacity of the heating and cooling devices will be smaller and also heat lost will be less, thus, the heating bills will be lower;
- Performance of the ventilation system will be improved;
- Since moisture is trapped in cavities, amount of the mold and rot will be reduced.

In the following parts of building façade usually leakage is happening:

- Connection among walls and other walls or walls and floors;
- Connection among window frames and walls;
- Electrical equipment;
- Doors and other wall infiltrations (Sherman, et al, 2006).

3.1.3.2. Air Barrier and Vapor Barrier

Air barrier is any part or combination of parts, which diminish the movement of air from a building. Air barriers control airflow amongst unconditioned and conditioned spaces. Air barriers are planned to contradict contrast in air pressure amongst indoor and open air. They can be located anyplace in the building. Air barriers must be nonstop over the entire building.

- Utilization of air barrier minimize the infiltration and water penetration;
- Windows and doors should be utilized by considering the weather stripping;
- It is recommended to use revolving door for the entrance;
- It is recommended to consider utilizing a heat exchanger ventilation system rather than infiltration in order to maintain indoor air quality.

Vapor invasion is some way or another same as air leakage. Vapor is water in its vaporous state. It is bit of air, making up around 1% to 4% of the air in most tenable areas. The measure of vapor that air can hold rely on air temperature, hotter air having the capacity to hold more vapor than colder air. Relative humidity, measure the amount of vapor in air rate of the greatest measure of vapor that the air, at a particular temperature, can hold. An essential point about vapor is the manner by which it moves from an outside wall. Air is conveying the vapor, be that as it may it moves from higher density to lower density air through which this procedure is called diffusion (Quirouette, 1985).

Vapor is critical for façade design since it is conveyed via air then it follows that some vapor is unavoidably entering the exterior wall. The problem happens when the vapor-bearing air experience a material that is colder than the air. When the air cools, its ability for conveying vapor is lessen. On the off chance that the air chill enough, the vapor condenses into water. This called the dew-point temperature or dew point. On the off chance that the vapor gathers inside the wall, the subsequent water can soak materials. That water may make a situation that advances the growth of mold. Which can seriously affect the building's inhabitants and their wellbeing. Sustainable facades are designed so that vapor buildup will occur in area in the divider where the water can deplete to the outside (Moras, 2001).

Vapor barriers lessen the movement of moisture and vapor diffusion through the building. The amount of water vapor going through materials is measured in perms, with one perm equivalent to grain of water vapor per hour, per square foot, per inch of mercury. They are assembled into three classes:

I. Class I (vapor impermeable): materials with permeance of 0.1 perm or less such as sheet polyethylene;
II. Class II (vapor semi-impermeable): materials with permeance between 0.1 and 1.0 perm such as Kraft-faced fiberglass;
III. Class III (vapor semi-permeable) materials with permeance between 1.0 and 10 perms such as latex.

Air barriers confine the infiltration of air through walls, which vapor barriers restrict the movement of moisture. Some air barriers may likewise oppose vapor diffusion. In which case they act as both air and vapor barriers. Impermeable vapor barriers can likewise work as air barriers. Their position inside the wall get together relies on upon the climate type. For instance in colder climates, the vapor barrier is typically put within the inside (warm) surface of the insulation. In hot or warm climates, particularly in humid subzones, the vapor barrier is usually on the exterior side of the insulation.

In mixed climates, there is no prepared response for position of vapor barriers. Prevailing temperature and humidity conditions, both inside and outside the building, ought to be considered. There should never be two vapor barriers inside a wall, as this could trap moisture and not permit it to deplete or vanish (Purcell, et al, 1991).

3.1.3.3. Natural Ventilation

As of not long ago, ventilation was the real cooling technique all through the world. It is vital to note that there are two different ventilation techniques. Although they cannot be used in a meantime, they can be utilized at different times of the year. Comfort ventilation acquires in outdoor air, both during the day and at night. The air is then passed directly over people to increase evaporative cooling on the skin. In this case thermal comfort might be accomplished. The daytime air is really warming the building. Night-flush cooling is very different. With this procedure, cool night air is acquainted with flush out the heat of the building, while amid the day almost no outside air is brought inside so that the heat gain to the building is minimized. During the day, the mass of the moderately cool structure goes about as a heat sink for the indoor air and the general population inside (Brager, et al, 2000).

To design effectively for ventilation in the summer or for wind protection in the winter, the accompanying standards and principles of airflow ought to be understood:

- Purpose behind the flow of air. Air flows either due to characteristic convection flows, got on by differences temperature, or accordingly of differences in pressure;

- Types of airflow. There are four fundamental sorts of airflow: laminar, separated, turbulent, and eddy currents. Showing the four sorts by methods of lines speaking to air streams. These charts are like what one would find in a wind-tunnel test utilizing smoke streams. Air flow changes from laminar to turbulent when it experiences sharp obstruction, for example, buildings. Eddy streams are round airflow instigated by laminar air flows;

- Inertia. Since air has some mass, moving air has a tendency to go in a straight line. At the point when compelled to alter direction, air streams will take curves however never right angles;

- Conservation of air. Since air is neither made nor devastated at the building site, the air moving toward a building must equivalent the air leaving the building. Along these lines, lines representing airstreams ought to be drawn as nonstop;

- As air hits the windward side of a building, it packs and makes positive pressure. In the meantime, air is sucked far from the leeward side, making negative pressure Air redirected around the sides will by and large likewise make negative pressure. Take note of that these pressures are not consistently conveyed. The sort of pressure made over the rooftop relies on upon the slope of the rooftop .These pressured regions around the building decide how wind streams through the building. It ought to likewise be noticed that these high- and low-pressure zones are not spots of calm but rather of wind stream as turbulence and eddy currents. Take note of how these streams turn around the airflow in specific areas. For effortlessness' purpose, turbulence and eddy currents are not appeared on all graphs;

- Bernoulli Effect. In the Bernoulli Effect, an expansion in the speed of a liquid abatements its static pressure. As a result of this wonder, there is negative pressure at the development of a venturi tube. A cross segment of a plane wing resembles half a venture tube. A gabled rooftop is additionally similar to a half a venturi tube. In this manner, air will be drained out of any opening close to the edge. The effect can be made much more grounded by designing rooftop openings to resemble full venturi tubes. There is another phenomenon at work here. The speed of air increments quickly with height over the ground. Along these lines, the pressure at the edge of a rooftop will be lower than that of windows at ground level. Thus, even without the assistance of the geometry of a venture tube, the Bernoulli Effect will (Santamouris, et al, 2006).

Table 8 is the summary of the outcomes from the part 3.3 Air leakage.

Table 7: Air leakage and energy efficient façade (Santamouris, et al, 2006; Brager, et al, 2000; Sherman, et al, 2006).

Air leakage Types				
Junction of wall		Junction of windows	Electrical equipment	Access doors
Air leakage principles				
Air barrier	Vapor barrier	Envelop airtightness	Natural ventilation	
Minimizing infiltration	Vapor impermeable	Lowe heating bills	Air flow types	Laminar
				Separated
				Turbulent
				Turbulent eddy current
Windows with excellent weather stripping	Vapor semi-impermeable	Better ventilation	Inertia	
Revolving or vestibule entrance doors	Vapor semi-permeable	Reduce mold	Conservation of air	
Heat exchange ventilation system		Increased thermal comfort	High and low pressure area	
			Bernoulli effect	

3.2. Classification of Energy Efficient Façade Types

The space made inside the walls now needed to satisfy requests and functions concerning utilization and comfort. With a specific end goal to finish this, the local conditions and the users' necessities must be built up in more detail, controlled and the satisfied by methods of sustainable construction.

The technical arrangement becomes out of the context of materials, construction, jointing, succession of creation, and furthermore the requests, in addition to other interior and external physical impacts and conditions. The exterior of building therefor mirror the technological advance of an area and consequently a considerable piece of the separate local culture.

The ruling for a specific material, for instance, is based not absolutely in light of the loads and stresses coming from internal or outside activities, yet is made rather with respect for the rules identified with the production procedure of particular building façade. Here, it is not just the individual use necessities that decide the type of the façade. Rather, these prerequisites should dependably be considered in conjunction with the questions of jointing, the technique for construction, and consequently the specialized acknowledgment within a general system of construction, the authenticity of the materials and the geometrical order, in particular in this field, the profession ability of the architects in their part as ace builder must be seen. They alone, know about every one of the connections and the numerous relationships inside and between the composition of the architecture and the rationale of the construction (Eren, et al, 2013).

There are two primary contrasts between the sorts of facades that can be found in building, one is opaque facade and another is glazed facade. The real distinction is that the glazed facade is portrayed by being situated in the gaps or openings of the façade of a building by methods for which the visual associations between the outside condition and the inside spaces are produced. In the meantime it is related to glass that is it fundamental material that is translucent and permits the visual association, the warmth input and natural lighting. In this manner, it is one of the materials that permit more energy trade. This kind of facade is made out of various layers of glazing material (diverse glass sorts), gasses or fiers noticeable all around crevice as a thermal insulation, and sun protection application. In the opposite hand there are opaque facades, general explanation about opaque facades can be that, they are made of different kinds of materials and they don’t have transparency by itself but they keep the openings inside them. But facades types, opaque facades and glazed façade, plus double skin façade which is the advanced and new technology in façade design will be explain widely in the following pages (Mateas, et al, 2005).

3.2.1. Opaque Building Façade

There are two main differences between the types of façades that can be found in buildings, one is opaque façade and another is glazed façade.

Opaque facade is made out of materials not translucent, for the most part contains the structural piece of the building, and supports the glazing façade. This sort might be made out of at least one materials and more, and can oblige different physical procedures at once, as the insulation and thermal inertia (Magrini, et al, 2014).

3.2.1.1. Opaque Façade Construction Systems

The initial step of the classification is to articulate the two fundamental sorts of construction frameworks. Having along these lines the opaque facade system of Mono-layer and Multi-Layer.

The Mono-layer comprises of a solitary material which needs to react to the necessities of comfort, energy exchange and structural support. More often than not, they are facades of materials inception from stone, which base their execution in means of energy exchange in the limit of thermal inertia that this material might possibly have. Considering the mass, thickness and thermal transmittance of the same (e.g.: mud, stone, and so forth.). The normal U-value of these sorts of materials is between 2.8 to 2 W/m2-K, since stone materials neglect to have thermal transmittance (U esteem).

The Multi-layer system comprises of a few particular layers of various materials; every material have a particular function on the execution of the opaque façade, this function can be structural, aesthetic or sustainable. The materials that create the Multi-layer construction frameworks can be very varied, however as a rule it is conceivable to discover no less than one layer that is structural support and the layer that follows the aesthetic function. At that point, having other conceivable layer that concent to thermal insulation, thermal inertia, control of sunlight radiation, and so on., contingent upon which setup is been designed "Fig 06". Having U values that diverse relying upon the materials that frame the façade, the span are from 3.7 to 0.35 W/m2-K. (Herzog, et al, 2004).

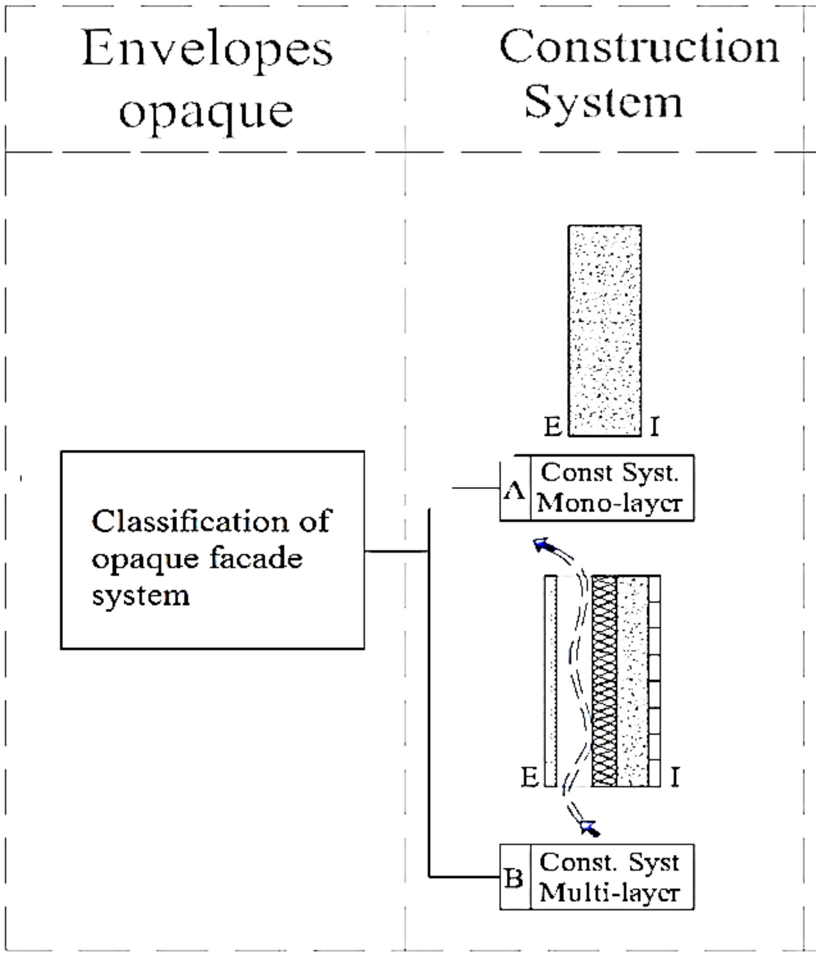


Figure 4: Construction Types of Opaque Façades (Herzog, et al, 2004).

3.2.1.2. Classification of Façade System and the Adoptability to Climate

Having concentrated on this classification critical parameters were figured out. These parameters talk about the conduct of every vertical opaque facade framework to the area climate and capacity to adjust to it, and in addition scopes of estimations of transmittance (U esteem) that each sort has, contemplating the materials that create it.

As to adaptability of the façade to the location climate, it can be noticed that the Multi-layer construction frameworks are more adaptable than the Mono-layer, on the grounds that, there are made out of different materials permitting responding to changes in the climate, which can make more of sustainability .

In the meantime, it is conceivable to presume that the joining of the thermal inertia bolsters the sustainable execution of the building when situated in temperate and warm climates, particularly on the off chance that it has discernible contrasts amongst day and night temperatures, however is not all that suggested for cold climates (Loonen, et al, 2013).

Then again, adding thermal insulation on building's facade enhances the execution of the structures that are situated in cold climate zones, particularly cold climates where you have bring down the temperatures the vast majority of the year, since structures should be secured against the cool and it means energy exchange should be blocked.

Adding an air hole can help the building which are located in warm climates, particularly tropical and also desert like weathers, where consistently high temperatures been discovered. In the meantime it can help buildings situated on temperate climate zones where it is conceivable to see high temperatures in the summer period. This happens on the grounds that, the air chamber has an ability to brings down the temperature of the air inside the building and also ventilated the façade, restoring the air in the chamber, bringing down the contrast between the temperatures outside and inside and at the same can brings down the energy exchange (Kasinalis, et al, 2014).

3.2.2. Glazing Building Façade (Curtain Walls)

There is a main difference between opaque façade and glazed façade, which that is the glazed facade is portrayed by being situated in the gaps or openings of the façade of a building by methods for which the visual associations between the outside condition and the inside spaces are produced. In the meantime it is related to glass that is it fundamental material that is translucent and permits the visual association, the warmth input and natural lighting. In this manner, it is one of the materials that permit more energy trade. This kind of facade is made out of various layers of glazing material (diverse glass sorts), gasses or fiers noticeable all around crevice as a thermal insulation, and sun protection application.

Glazed facades or curtain walls are lightweight façade systems, typically framed with aluminum expulsions connected to the building's essential structure. Curtain walls don't convey structures loads, other than wind fellows and their own dead load. There are three noteworthy segments of drapery dividers: mullions, vision glass and laso spandrel area. The strategies for creation and establishment of curtain walls characterize them as either stick or unitized frameworks (Arias, 2011).

3.2.2.1. Classification of Glazed Facades According to Installation and Fabrication

Stick frameworks comprise of segments (mullions, glass and spandrel boards) that are introduced on the building structure piece by piece to shape the building facade. Stick-system curtain walls can be additionally separated by the technique for glazing and coating. Interior systems permit vision glass to be introduced into the curtain wall openings from the inside of the building. Outside glazing framework, conversely, can be coated just from the outside. Outside glazing is ordinarily utilized for low-rise buildings with simple access to the building's exterior.

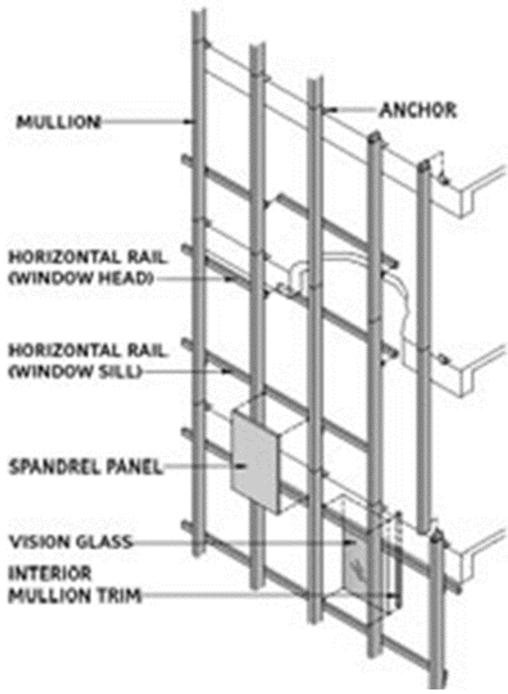


Figure 5: Stick-System Curtain Wall Installation and Fabrication (Paterson, 2011).

Unitized system collected and glazed as modular pieces in the factories. The modular units are ordinarily one vision wide part and maybe a couple stories high. Establishment of unitized framework normally speedier than that of stick frameworks, requiring less field work, in light of the fact that the segments are preassembled. Since assembly of the framework happens essentially in controlled manufacturing factories conditions, the quality control and at the same time performance of unitized framework are superior to stick frameworks (Paterson, 2011).

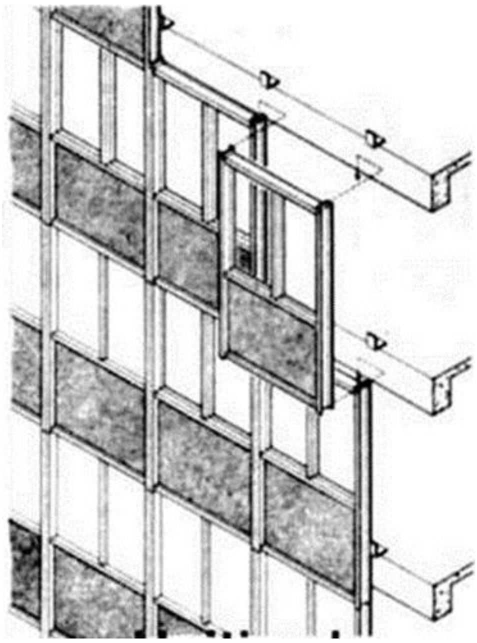


Figure 6: Unitized System Curtain Wall Installation and Fabrication (Paterson, 2011).

3.2.2.2. Performance of Glazed Façade (Curtain Wall)

Thermal performance of the glazed facades or curtain walls congregations relies on upon the plan and association of individual parts such as mullions, also glazing units and spandrel units, attachment part and in the end perimeter closures. Since aluminum has high thermal conductivity, aluminum mullions are normally inclined to exchange heat and also cold through the assembly. To improve the thermal performance of mentioned material which is aluminum mullions, thermal breaks can be joined into their design. Thermal break comprise of low-conductivity materials, for example, urethane and also neoprene elastic, or polyester-fortified nylon, which isolate the mullion's external and in contact with interior metal. A less coasty and also less successful, variety is thermally enhanced mullions, which likewise have thermal break material isolating outside and inside expulsion parts, however have fastener or different components that span the thermal break. As a result of the metal to metal contact at the latches, cold or hot temperatures can exchange through thermally enhanced mullions (No, et al, 2005).

The kind of glazing can essentially influence a curtain wall's performance. However clear vision glass might be attractive for day lighting and at the same time views, and building appearance, it perform ineffectively with respect to insulation or shading. Be that as it may, there are number of approaches to enhance the performance of the vision-glasses. To begin with, the glass itself can be necessarily tinted. Intensely tinted glass can obstruct a considerable measure of direct daylight. Unfortunately, tinted glass additionally blocks sunshine and views. A solitary lite of glass without difference in the type of the glazing gives no insulation. Subsequently, tinted glass is generally the most low cost however minimum compelling method for enhancing glass performance.

Insulating glass units utilizing two liters of glass isolated by a dried up air space can altogether enhance glazing performance. Since one of the characteristics of the air is being poor conductor of the heat, so for sure double-glazing insulating has much more better performance compare to single lite of glass. Advance performance can be accomplished by including another lite of glass. Triple-glazing units perform superior compare to double-glazing ones, in any case, the incremental change is not as much as while going from dingle glazing to double glazing. A coast benefit analysis is expected to decide whether the extra coast for triple glazing is advocated by the expanded performance. Some other material, for example, argon gas or straightforward silica aerogel, can be utilized as a part of lieu of the air between the lites of glass to enhance the insulating characteristics of the glazing units (Skarpness, et al, 2003).

Opaque parts of a curtain walls incorporate spandrels. A spandrel is a not a vertical but horizontal band of opaque curtain wall among strips of glass. In general spandrels are more effective insulation segment of the curtain walls, so if the area of usage of them increased in the facade, the performance of the facade will be improved also. There are four sorts of spandrels: solid, back-covered glass and also it is possible to name glazed shadow boxes and in the end louvers.

An assortment of solid materials can be utilized for spandrel parts, the most widely recognized material is metal panels or metal boards. The boards can have necessary insulation or it is possible to have insulation separated layer behind them (Ting, 2006).

3.2.3. Double Skin Façade

A standout amongst the most imperative techniques for energy saving in a building is via designing its facade in a very careful way. A double skin façade is ideally one of the best alternatives in dealing with the connection between the outside and the inside spaces. It additionally gives some building adaptability to the design. As of late it has gotten much consideration instead of the all the more ordinarily curtain walls. This is a direct result of its capacity to proficiently lessen energy use and along these lines saves cost. The measure of energy saved relies on upon the weather and the design selections. The design of the DSF includes choices on geometric parameters, glass choice and also other factors such as load created by wind, shading, daylighting, and also economic effects on maintenance and so on (Kalyanova, 2008).

In 1990s, the main concern relating to the global warming and the expanding interest for higher quality building supports the architects and engineers to search for new systems as arrangements, together with clear and natural well-disposed energy to be utilized as an option source of energy for lighting at the same time ventilation and of course air-conditions of the buildings.

Double skin facade or in shorter way DFS are utilized to improve the thermal energy performance of buildings with high amount of glazed area. It is made of an external glazed facade offsetting from an inward glazing incorporated into a curtain wall. It generally a controllable shading system placed in the cavity between the two glazing frameworks (Chan, et al, 2009).

According to Safer, Webszyn & Raux 2005:

> Double-skin facade is a special type of envelope, where a second skin, usually a transparent glazing, is placed in front of a regular building facade. The air space in between, called the channel, can be rather important (up to 0.8–1.0 m). In general the channel is ventilated (naturally, mechanically, or using a hybrid system) in order to diminish overheating problems in summer and to contribute to energy savings in winter *(p.64).*

And also stated that:

> Double-skin facade is composed of an external facade, an intermediate space and an inner facade. The outer facade layer (glazing) provides protection against the weather and improved acoustic insulation against external noise. An adjustable sunshade device, such as blinds, is usually installed in the intermediate space to protect the internal rooms from high cooling loads caused by insulation *(p.85).*

The main drawback of double skin facade is that it is said to be more costly than the conventional single glass façade. In any case, it is broadly concurred by numerous specialists that double skin facade (DSF) is more financially effective over the longer period. This is on the grounds that, it is durable and more long lasting when compared with the single glass façade. Furthermore, it gives different advantages that can't be found in single glass facade. One of it is that double skin facade makes spaces more comfortable and eco-friendly which additionally decreases maintenance costs as it saved the building's energy assets (Poirazis, 2004).

There are numerous approaches to classify diverse sorts of a double skin façade. The most widely recognized method for classifying distinctive sorts of the framework was made by Oesterle et al. Actually, Oesterle's definition is utilized by all analysts to order the system. Along these lines it is normal to utilize their classification in this thesis. Oesterle et al. recognize four unique systems that are grouped by the sort of form the intermediate space is divided into and as indicated by the desired ventilation work. The classification includes: Box window type and Shaft – box façade and it is possible to name Corridor façade and Multi story façade (Ahmed, et al, 2016).

3.2.3.1 Box Window

The box window was the primary sort of a double skin façade presented in the building construction. The internal leaf of the system is an internal opening window and the external leaf is a solitary glazed skin. In the outside skin, there is an opening that permits natural air to flow into the cavity. This permits ventilation for both the intermediate space and at the same time provide ventilation for interior rooms. The type of the framework can either be separated on the horizontal level along the building structure, with vertical divisions, or for every window separately (Zollner, et al, 2002). Oesterle, describe the usage and the general functions as:

> Bow-type windows are commonly used in situations where there are high external noise levels and there special requirements are made in respect if the sound insulation between adjoining rooms. This is also the only form of construction that provides these functions in facades with conventional rectangular openings *(p.74).*

Oesterle are generally intrigued by the acoustic advantages of the double skin façade. Box type windows are likewise usually utilized for retrofitting buildings to enhance their performance. It is moderately simple to apply this kind of a double skin façade to old buildings (Zollner, et al, 2002).

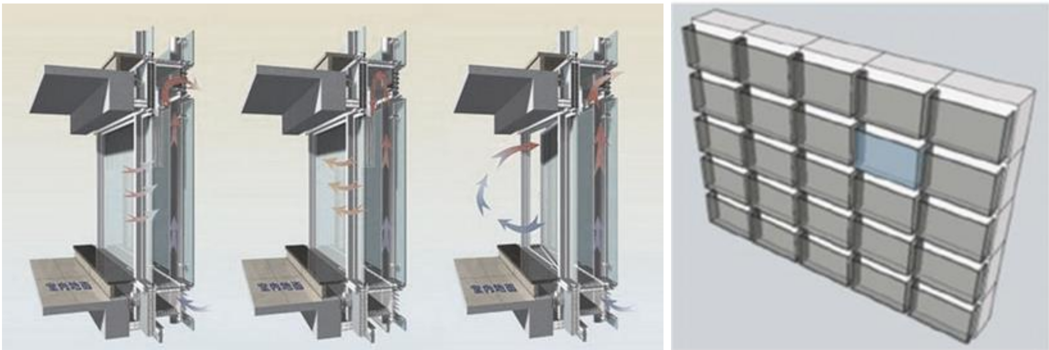


Figure 7: Box Window Double Skin Façade (Ahmed, et al, 2016).

3.2.3.2 Shaft – Box Facades

The shaft – box sort is a framework in based of the explained system which is box type window. It was produced by the Alco Company and the thought is to build up a more complex framework that will use the stack influence by reaping solar radiation. The framework comprises of box type windows on a horizontal level separated on the building and vertical shaft portions. The horizontal partition box type windows are associated with the vertical sections on each story by unique openings. The stack impacts used in the vertical fragment draw air from the box type windows and make wind stream in the entire façade. Once in a while a mechanical wind stream framework is likewise intergraded into this framework to help with the air flow (Wong, et al, 2008). Oesterle et al. describe the usage and the general functions as:

> Shaft-box facades require fewer openings in the external skin, since it is possible to exploit the stronger thermal uplift within the stack. This also has a positive effect in terms of insulation against external noise. Since, in practice, the height of the stack is necessarily limited, this form of construction is best suited to lower-rise buildings. An aerodynamic adjustment will be necessary of all the box windows connected to a particular shaft are to be ventilated to an equal degree *(p. 103).*

The vertical part of this framework can be arranged anyplace in the façade. Oesterle et al. express that there are a few confinements to how high a building with a double skin façade can be because of stack impacts. They are expecting that the double skin façade is just ventilated naturally, yet these confinements can be overcome by adding a mechanical ventilation framework to control the wind stream mostly (Wong, et al, 2008).

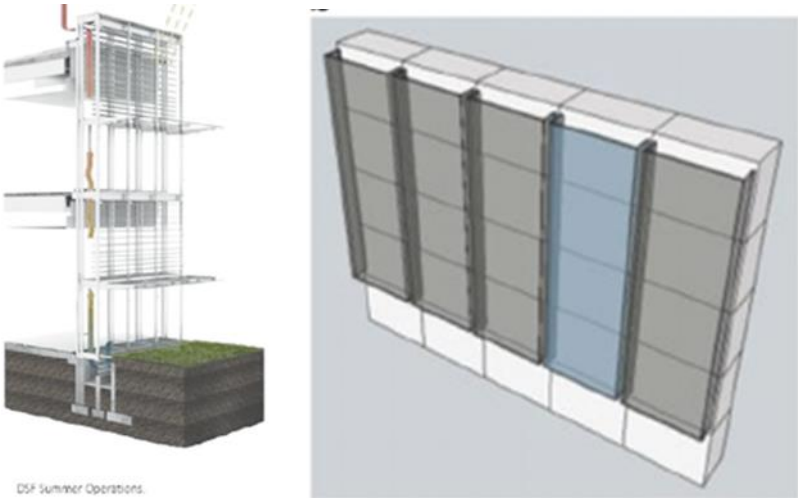


Figure 8: Shaft – box Double Skin Façade (Ahmed, et al, 2016).

3.2.3.3 Corridor Facades

The third framework grouping made by Oesterle et al. is the corridor façade. The corridor façade is just separated horizontally by each floor so the cavity is open along the horizontal length of the building. The only terminations are perhaps at the corners where at times there is a huge contrast in air pressure. The ventilation system can be vary, it can natural or mechanical. In mechanically ventilated frameworks there is a mechanism on every division that controls the wind stream, generally known as "fish head". Again Oesterle describe the usage and the general functions as:

“The air-intake and extract openings in the external façade layer should be situated near the floor and the ceiling. They are usually laid out in staggered form from bay to bay to prevent vitiated air extracted on one floor entering the space on the floor immediately above. Where a corridor façade constructed is used, the individual spatial segments between the skins will almost always be adjoined by number of rooms.”

One of the points of interest for corridor facades over the other two specified is that corridor facade don't constrain the building height. Notwithstanding they don't use the stack impacts as much as a shaft – box window in light of the fact that the interlace impacts will be ended on each floor (Azarbayjani, 2011).

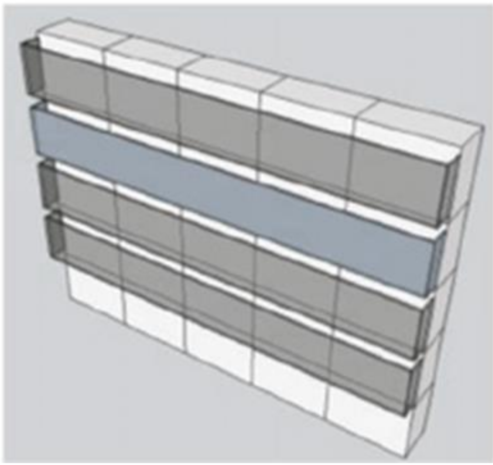


Figure 9: Corridor Double Skin Façade (Ahmed, et al, 2016).

3.2.3.4 Multistory Façade

The last kind of double skin façade is named multistory façade. This sort of framework uses diverse way to deal with the functions and structure. The frameworks in not partitioned horizontally, and even there are some cases which in them it is not seperated at all. In a way might possible to say that it joins the typology of both discussed types which are the corridor façade and the shaft – box. The air intake is near the base and the top to enhance the stack impacts all through the framework (Barbosa, et al, 2014).

> Multistory facades are especially suitable where external noise levels are very high, since this type of construction does not necessarily require openings distributed over its height. As a rule, the rooms behind multistory facades have to be mechanically ventilated, and the façade can be used as a joint air duct for this purpose *(p. 93).*

There are a few situations where the multistory facade framework has discarded a portion of the ventilation of building. It is very regular that the framework is utilized as an addition to the building. That makes it conceivable to decrease the heap on the service frameworks of the building (Barbosa, et al, 2014).

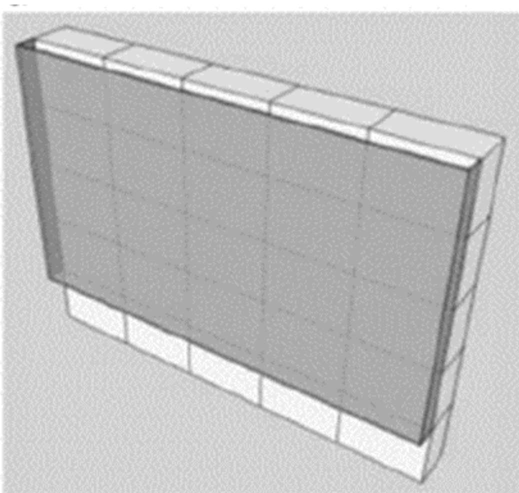


Figure 10: Multistory Double Skin Façade (Ahmed, et al, 2016).

3.3. Materials of Energy Efficient Façade

Since the center of the nineteenth century, development in building structures, form and function has depended on advances in building sciences, materials and technologies. New or enhanced building materials have offered extraordinary opportunities for advancement on innovation in architecture and design. Progresses in metallurgy have permitted steel and aluminum to be economical choices for building facade. Raised floors for ventilation and wiring, initially created for computer rooms and in general for equipment spaces, and now usually utilized as a part of an assortment of inhabitances. The mix of lighter-weight materials, new innovation and a perpetually increasing emphasis on adjusting low construction coasts with high performance has prompted the improvement of the curtain walls as a standout amongst the most proficient and moderate cladding arrangements (Guinn, 2010).

Late improvements in façade technologies are taking after three general trends. The first is in small-scale techniques: coatings, thin films, advanced glazing technologies and also it is possible to mention advanced materials development to enhance façade performance at the small scale level. The second in toward large-scale, for example, double skin facade. The third pattern is the expanded integration of energy-generation segments into the building skin. With each of these patterns, the functional performance objectives are the same: isolating the indoor and outdoor condition, relieving unfriendly outside natural impacts, and keeping up inward inhabitant comfort conditions with least energy utilization (Crawley, et al, 1999).

- ETFE, is a Teflon-coated fluoropolymer material blown or expelled to shape huge sheets. ETFE is impervious to corruption by ultraviolet (UV) light and environmental pollution. To address distinctive utilize conditions, it can be produced as single-ply sheet or two or triple-ply air-filled "pillows". ETFE is low in maintenance coast, recyclable and it is much lighter in weight compare to glass. In itself, as a solitary sheet material, ETFE has extremely poor thermal and acoustic performance and ought not to be utilized as a part of façade applications. . Nonetheless, in the two and triple-ply designs it has amazing thermal properties, and it has only one reason, the reason is the air which is trapped between the layers of this material and can act as an insulation. The air-filled pillows are kept up at steady air pressure with respect to wind load by pumps giving the skin a chance to alter in light of the varying loads. ETFE is not fabric and can't be utilized as a self-supporting tensile structure. Rather, the pressurized air holds the pillows in place. A furthermore structure, as a rule comprising of aluminum extrusions, steel bars, or steel cables, is expected to support the pillow (Cardoso, et al, 2007).

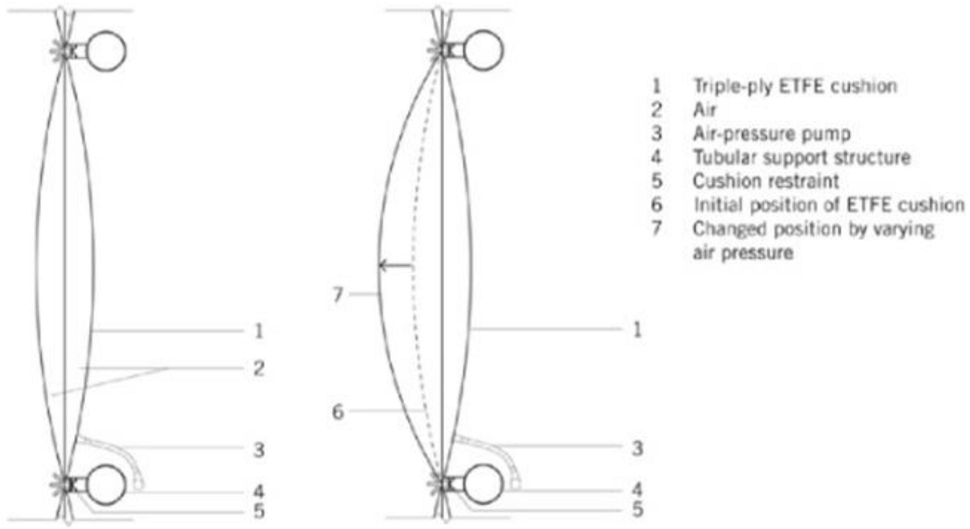


Figure 11: Triple-Ply Air Filled ETFE Pillows with a Supporting Structure (Cardoso, Et Al, 2007).

- Aerogels, are manufactured solids that comprise totally of air. They have the least density among every known solids. On account of their low density, aerogels very low thermal conductivity, and along these lines are thought for applications where high thermal insulation is required. Commercial glazing items utilizing aerogel supplements are available. In some of these items, the aerogel in incorporated with polycarbonate sheets to shape a translucent cladding material. In others, silica aerogel in normal shape fills the space between glass lites of insulation unit, or inside the cavities of channel glass. Aerogel is hydrophobic and noncombustible, with great acoustic properties. Thermal resistance of aerogel-filled glazing, with U-values between 0.57W/m2-k and 1.00W/m2-k is better than that of standard insulation glazing units, which infrequently accomplished U-values under 1.43 W/m2-k. Silica aerogel is translucent, making it a fantastic approach to bring sun light into the spaces. Be that as it may, this translucence makes it not proper option for vision glass (Buratti, et al, 2012);

- Vacuum Insulated Glazing Units, This material give enhanced thermal resistance contrasted with standard air-or gas-filled insulated glazing segments. These units utilize a vacuum between two lites of glass to raise assembly's thermal resistance. There is for all intents and purposes no conduction or convection of heat exchange. With little heat exchange from conduction, convection or radiation, vacuum insulated glazing units can accomplish U-estimations or let's say U-values under 0.57 E/m2-k. The vacuum between the two lites of glass spots them under negative pressure and can pull them toward each other. In order to make it work, a grid of spacers is set between the lites. These spacers, are created by material with low conductivity, and are separated a few inches from each other in both directions. are commonly thin, making them perfect where superior glazing needs to installed in existing frames- a situation same for building retrofit projects (Tenpierik, et al, 2007).

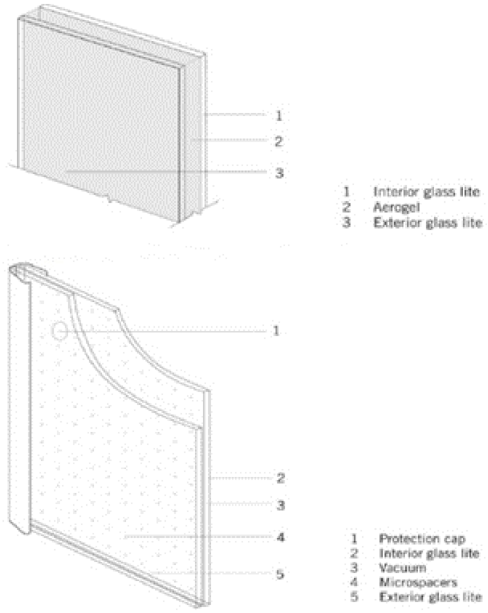


Figure 12: Vacume Insulation Glazing Unite (Tenpierik, et al, 2007).

Smart Materials, Living organism's forms can adopt to changing conditions in the environment. Advancement in physical and material sciences have prompted improvement of smart materials that reacting to variable outside and inside acoustical, lighting, and ecological conditions.

There are different sorts of smart materials: shape memory, alloys also fiber optic sensors, electrically initiated materials and it is possible to name phase change materials, self-cleaning materials and photovoltaic. Some of these smart materials are relevant for facades and are economically and commercially accessible. There incorporate façade coordinated photovoltaic, electrochromic glass, self-cleaning materials also stage change materials and fiber optic.

Other mentioned materials are still developing, or not appropriate to facade. For instance piezoelectric materials, which deliver electricity from applied pressure, have little application for facade. Thermoelectric materials, which change temperature to electricity power and the other way around, are accessible, however their utilization for façade is still in the examination stage (Addington, et al, 2005).

- Electrochromic glass fuses a film that changes its opacity when electrical voltage is connected. For instance, clear electrochromic glass has the ability to change itself to dark tint. The glass can keep up that tinted shade without extra power. To give back the glass to its straightforward state, voltage is connected once more (Sakoske, 2007);

- Suspended particle device (SPD) glass comprise of a thin film of fluid crystal suspended in transparent conductive material and overlaid between two layers of glass. By applying voltage, the measure of light going through the glass can be controlled. In SPD's typical nonelectrified express, these fluid crystals are arbitrarily arranged, light is scattered between the crystals to give the glass a translucent appearance. At the point when the voltage is connected, the crystal particles adjust. Permitting light to go through the material and make it transparent. SPD glass in normally utilized for security control in interior spaces, the time required to switch amongst translucent and transparent states is practically momentary. However the impact on energy investment funds are not noteworthy and this innovation in not prescribed application for building façade (Reece, 2007).

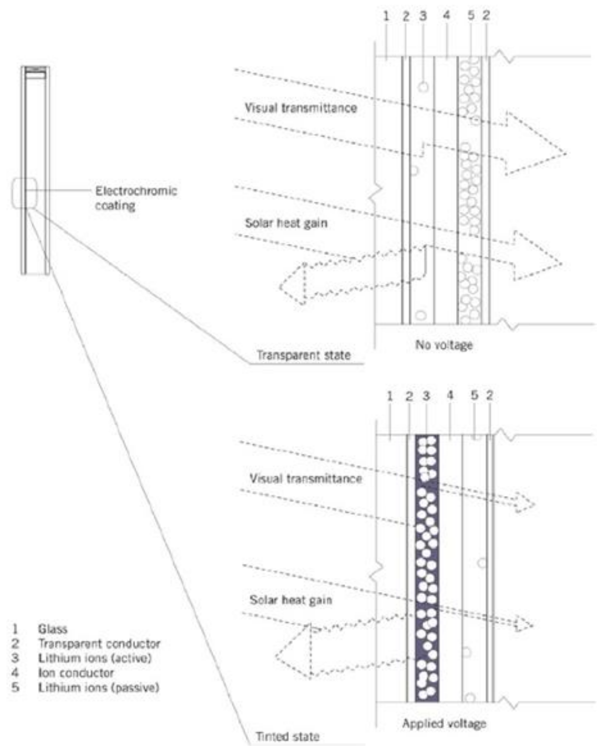


Figure 13: Suspended Particle Device (Albert, et al, 2003).

- Self-cleaning glass regularly utilizes a thin film of titanium dioxide on the outside surface as a photocatalytic covering. Photocatalysts are intensifies that utilization the UV bands of daylight to make a chemical response. At the point when presented to daylight, the titanium oxide triggers a strong oxidation prepare that convert noxious organic and inorganic substances into innocuous compounds. The self-cleaning process on glass includes two phases. In the photocatalytic organize, natural dirt breaks when the glass is exposed to daylight. Next, in the hydrophilic stage, rain washes the soil and dirt from the glass by getting the loose particles. This is a compelling method for keeping glass clean without high coast for maintenance. Self-cleaning is not restricted to glass. Titanium dioxide can be mixed and applied to different sorts of materials, for example, concrete, to give the self-cleaning impact (Licciulli, et al, 2002);

- Phase change materials (PCMs) are solid at room temperature, yet melt at higher temperature, engrossing and putting away heat in the process. PCMs are either natural or inorganic. At the point when PCMs are joined into the building façade, they can retain high outside temperature during the day and disseminate the warmth to the inside during the evening. PCM items, are producing such as triple-insulated glazing units (IGUs) with incorporated PCM, are accessible (Zalba, et al, 2003);

- Photocoltaic (PV) glass coordinates crystalline solar cells or amorphouse this films that produce energy from light. With PV glass, the PVs are incorporated into covered or doubled glazed units. There are two general sorts of PV glass: semitransparent and opaque. Semitransparent PV glass is more like patterned ceramic frit, permitting to some light to infiltrate through the glass. Opaque PV glass utilizes solid PVs. furthermore, is suitable for spandrels and other no vision ranges of the façade (Notton, et al, 2005).

Table 8: Characteristics of Energy Efficiency Facade

Thermal heat transfer		
Thermal bridge and glazing		* Insulation materials
Types	Consideration	Types
Structure sheeting is corners	Let-in diagonal bracings	Batts and blankets
Curtain walls	Thermal breaks Double/triple glazing	Loose fill
Metal window frame	Use sustainable wood	Foamed-in-place
* Insulations	No hole in insulation	Boards
Concrete cantilever in façade	Better to not be used	Air space and radiant barriers

Fenestration and glazing characteristics							
Fenestration and orientation considerations					Glazing		
General considerations for fenestration	Not more than 20% of the floor				Transparency types	Solar heat gain	Natural lighting
	Movable shading is needed				Clear	ok	X
General considerations for orientations	North	Projection outdoor windowsill			Tinted	X	Ok
	south	Light shelves (shorter than east and west			Heat absorbing	X	Ok
	East and west	Extra deep light shelf	louver	Ribbon windows	Reflective	x	Ok
					Spectrally selective	Ok	x
Orientations	Fenestration Types				Glazing types	Solar heat gain	Natural lighting
	Windows	Sky lighting	Clerestories		Low-e glazing	Ok	Ok
North façade	x	x	x		Spectrally selective low e coating	X	X
South façade	Maximum	Minimum of usage	Maximum of usage		high LSG low glazing	Ok	X
East and west façade	Minimum	Minimum of usage	Maximum of usage		High visible transmitted low-e clear	Ok	Ok
					Low solar heat gain selective low-e glazing	ok	x

Optimizing day lighting		
General principles	Energy efficiency	Top lighting
Integrate day lighting design with the architecture	Use windows with a low U-factors	Use clerestories
	To maximize the quality of day lighting in the winter	Avoid sky lights
Integrated day lighting design with passive solar heating	Increase illuminated	Face clerestories south if there is a significant heating load
	Design for quality day light in regard to glare and brightness ratios to ensure occupant support for day lighting	Opposite situation face it to north
Design the building as a lighting fixture	Use automatic controls electric light	East and west clerestories only if south or north clerestories are impossible
		Use louvers or baffles to diffuse light

Day lighting principles and design decision	
Maximize south windows if winter heating is required	Maximize north windows if winter heating is not required
Avoid east and west windows, if they cannot be avoided use as few as possible and keep them short	Use light shelves except on north façade
Use separate view and day lighting windows. Have day lighting windows high on the wall	Use venetian blind or shades for backup and flexibility
Use open floor plan for maximum light penetration and view	Use glass partitions to allow for borrowed day light
Use light colors on exterior to reflect light into windows and clerestories	Use light colors on the interior to maximize light penetration

Air leakage Types			
Junction of wall	Junction of windows	Electrical equipment	Access doors

Air leakage principles				
Air barrier	Vapor barrier	Envelop airtightness	Natural ventilation	
Minimizing infiltration	Vapor impermeable	Lowe heating bills	Air flow types	Laminar
				Separated
				Turbulent
				Turbulent eddy current
Windows with excellent weather stripping	Vapor semi-impermeable	Better ventilation	Inertia	
Revolving or vestibule entrance doors	Vapor semi-permeable	Reduce mold	Conservation of air	
Heat exchange ventilation system		Increased thermal comfort	High and low pressure area	
			Bernoulli effect	

Shading devices and orientation consideration	
Shading types	Best orientation
Fixed shading	
Overhang horizontal panel	South
Overhang horizontal louver	South
Overhang horizontal louver in vertical panel	South/east/west
Overhang vertical panel	South/east/west
Vertical fin	North
Vertical fin slanted	East/west
Eggorate	East/west
Movable shading	
Overhang awning	South
Overhang rotation horizontal louver	South
Fin rotating fin	East/west
Exterior roller shade	East/west

Façade types	
Opaque façade	Mono layer
	Multi layer
Curtain walls	Single glazed
	Double glazed
	High performance
	Triple glazed
Double skin façade	Box window
	Shaft-box façade
	Corridor façade
	Multistory façade

Materials for sustainable façade	
ETFT	
Vacuumed insulation units	
Aerogel	
Smart materials	Self cleaning glass
	Phase change
	PV glass
	Suspended particle device

3.4. Climate Consideration for Energy Efficient Façade Design

When the study is related to energy efficiency, one of the most important factors which should be considered during the design process is climate. And considering climate while designing is not a new way of design but it is the age old idea of the design as Vitruvius saying. Architects should adopt climate to their designs because both buildings and users are experiencing it in their daily life.

Architects which are dealing with energy efficiency and want to design energy efficient façade, besides considering the requirements of the project they should understand the characteristic of the site location and climate. In this case architects can design the sustainable façade which help the building to reduce amount of the energy use. Thus, understanding and applying the climate guideline is important in designing the sustainable façade since the strategies and criteria which are working for a sustainable façade in hot climate are different than a sustainable façade design for a cold, or temperate climate (Krishan, 2001).

3.4.1 Climate Classification and Types

Climate including the different factors and it is the average of them. These factors are the temperature, humidity, amount of rainfall, wind and etc. which are calculating during the long time, sometimes climate data are calculating and coming from thirty and more years.

For understanding the climate, there are different strategies and methods to study and classifying the climate. One of the methods for classifying the climate is ASHRAE climate classification. In this method of classification, in general climates classify within six groups. And each one divided into smaller groups. Following, table 11 is showing the ASHRAE characteristic (Briggs, et al, 2003).

Table 9: ASHRAE Climate Classification System (Briggs, et al, 2003).

ZONE NUMBERS	ASHRAE CLIMATE CLASSIFICATION	SUB-ZONES
1	**Very Hot**	**Humid**
		Dry
2	**Hot**	**Humid**
		Dry
3	**Warm**	**Humid**
		Dry
		Marine
4	**Mixed**	**Humid**
		Dry
		Marine
5	**Cool**	**Humid**
		Dry
		Marine
6	**Cold**	**Humid**
		Dry
7	**Very Cold**	-
8	**Subarctic**	-

ASHRAE climate classification because of the subgroups and more detail looks difficult to use even if it can classify all climates worldwide. In the following table countries divided according to the zone numbers in the table in above.

Table 10: International Countries According to ASHRAE Climate Classification (Briggs, et al, 2003).

Country	City	Zone
Argentina	Buenos Aires/Ezeiza	3
	Cordoba	3
	Tucuman/Pozo	2
Australia	Adelaide (SA)	4
	Alice Springs (NT)	2
	Brisbane (AL)	2
	Darwin Airport (NT)	1
	Perth/Guildford (WA)	3
	Sydney/KSmith (NSW)	3
Azores (Terceira)	Lajes	3
Bahamas	Nassau	1
Belgium	Brussels Airport	5
Bermuda	St George/Kindley	2
Bolivia	La Paz/El Alto	5
Brazil	Belem	1
	Brasilia	2
	Fortaleza	1
	Porto Alegre	2
	Recife/Curado	1
	Rio de Janeiro	1
	Salvador/Ondina	1
	Sao Paulo	2
Bulgaria	Sofia	5
Chili	Concepcion	4
	Punta Arenas/Chabunco	6
	Santiago/Pedahuel	4
China	Shanghai	3
Cuba	Guantanamo Bay NAS (Ote)	1
Cyprus	Akrotiri	3
	Larnaca	3
	Paphos	3
Czech Republic	Prague/Libus	
Dominican Republic	Santo Domingo	
Egypt	Cairo	
	Luxor	
Finland	Helinski/Seutula	
France	Lyon/Satolas	4
	Marseille	4
	Nantes	4
	Nice	4
	Paris/Le Bourget	4
	Strasbourg	5
Germany	Berlin/Schoenfeld	5
	Hamburg	5
	Hannover	5
	Mannheim	5
Greece	Souda (Crete)	3
	Thessalonika/Mikra	4
Greenland	Narssarssuaq	7
Hungary	Budapest/Lorinc	5
Iceland	Reykjavik	7
India	Ahmedabad	1
	Bangalore	1
	Bombay/Santa Bruz	1
	Calcutta/Dum Dum	1
	Madras	1
	Nagpur Sonegaon	1
	New Delhi/Safdarjung	1
Indonesia	Djakarta/Halimperda (Java)	1
	Kupang Penfui (Sunda Island)	1
	Makassar (Celebes)	1
	Medan (Sumatra)	1
	Palembang (Sumatra)	1
	Surabaga Perak (Java)	1
Ireland	Dublin Airport	5
	Shannon Airport	4
Israel	Jerusalem	3
	Tel Aviv Port	2
Italy	Milano/Linate	4
	Napoli/Capodichino	4
	Roma/Fiumicion	4
Jamaica	Kingston/Manley	1
	Montego Bay/Sangster	1
Japan	Fukaura	5
	Sapporo	5
	Tokyo	3
Jordan	Amman	3
Kenya	Nairobi Airport	3
Korea	Pyonggang	5
	Seoul	4
Malaysia	Kuala Lumpur	1
	Penang/Bayan Lepas	1
Netherlands	Amsterdam/Schiphol	5
New Zealand	Auckland Airport	
	Christchurch	
	Wellington	
Norway	Bergen/Florida	5
	Oslo/Fornebu	6
Pakistan	Karachi Airport	1
Papua New Guinea	Port Moresby	1
Paraguay	Asuncion/Stroessner	1
Peru	LimaCallao/Chavez	2
	San Juan de Marcona	2
	Talara	2
Philippines	Manila Airport (Luzon)	1
Poland	Krakow/Balice	5
Romania	Bucuresti/Bancasa	5
Russia	Kaliningrad (E. Prussia)	5
	Krasnoiarsk	7
	Moscow Observatory	6
	Petropavlovsk	7
	RostovNaDonu	5
	Vladivostok	6
	Volgograd	6
Saudia Arabia	Dhahran	1
	Riyadh	1
Senegal	Kakar/Yoff	1
Singapore	Singapore/Changi	1
South Africa	Cape Town/D F Malan	4
	Johannesburg	4
	Pretoria	3
Spain	Barcelona	4
	Madrid	4
	Valencia/Manises	3
Sweden	Stockholm/Arlanda	6
Switzerland	Zurich	5
Syria	Damascus Airport	3
Taiwan	Tainan	1
	Taipei	2
Tanzania	Dares Salaam	1
Thailand	Bangkok	1
Tunisia	Tunis/El Auoina	3
Turkey	Adana	3
	Ankara/Etimesgut	4
	Istanbul/Yesilkoy	4
United Kingdom	Birmingham (England)	5
	Edinburgh (Scotland)	5
	Glasgow Airport (Scotland)	5
	London/Heathrow (England)	4
Uruguay	Montevideo/Carrasco	3
Venezuela	Caracas/Maiquetia	1
Vietnam	Hanoi/Gialam	1
	Saigon (Ho Chi Minh)	1

But for this study, still ASHRAE climate classification in used, since it is the main one of climate classification. But for making it more easy to use for design and architecture filed, only main groups of this classification will be use and subgroups and also very hot, very cold and subarctic climates are eliminated. So for this study cold, mixed, hot and warm climate zones were studied.

3.4.2 Climate Based Design Approach for Sustainable Façade Design

Among all building elements façades are the main elements of the building which affect amount of the energy consumption of the building and also affect users comfort. For being environmental friendly and at the same time create comfortable atmosphere for users, façade should meet many criteria. Façade should create a view and bring natural light and natural ventilation into the building while carrying its own dead load and also resisting wind load. Façade should gain solar radiation and in some times of the year should shade and protect interior spaces from solar heat gain.

For achieving all these goals architects must understand the external environment characteristic, and mainly they should understand climate issues. As mentioned in previous chapters, factors such as orientation, solar radiation gain, ventilation and etc. affecting users comfort and energy consumption of the building, and these factors are directly related and decision about them is depending on the climate characteristic of the site location.

Thus, it became understandable that design for different locations needs understanding of climate factors and characteristics in order to choose the suitable design strategies. So for designing a sustainable façade following factors should be considered by including the climate characteristics.

- Orientation of the building façades: since it is on the effect of solar radiation;
- Shading controls;
- Natural ventilation: since it effects cooling load and air quality;
- Natural lighting: in order to reduce energy use of artificial lightings.

For choosing mentioned strategies to design a sustainable façade, it is must to consider climate condition to reduce the impacts of the façade and energy use of the building. Table 12 is giving a general and initial idea about how climate can affect design decision making. In the following chapter this topic will be explain widely according to ASHRAE climate classification (Olgyay, 2015).

Table 11: Design Strategies for Sustainable Façade by Climate Consideration (Olgyay, 2015).

Climate type	Design strategies for sustainable façade
Cold climate	Solar collection and passive heating: collection of solar heat through the building façade. Heat storage: storage of the heat in the mass of the wall Daylighting: use of natural light sources and increasing glazing areas of the façade, use of high performance glass, and use of light shelves to redirect light into interior spaces.
Hot climate	Solar control: protection of the façade from direct solar radiation through self-shading methods or shading devices. Reduction of external heat gain: protection from solar heat gain by infiltration or conduction.
	Cooling: use of natural ventilation where environmental characteristics and building function permit. Daylight: use of natural light sources while minimizing solar heat gain through use of shading devices and light shelves.
Tropical and temperate	Solar control: protection of façade from direct solar radiation (shading) during warm seasons. Solar collection and passive heating: solar collection during cold seasons. Daylighting: use of natural light sources and increasing glazed area of the façade with shading devices.

3.5 Chapter Summary

In this chapter characteristics of the energy efficient façades were studies, they grouped mainly into three, solar heat gain and lighting, thermal heat transfer and air leakage. Each of these groups studied in detail. And in the second part types and materials of the energy efficient façades were studies. So by end of this chapter wide understanding from behavior of the sustainable façades and their types were appeared. Table 10, in the next page, is giving all information in this chapter in one kind of check list. This table is showing general characteristics of sustainable façades. And they cannot applied in all location. Thus, in the coming chapter, one important factor in sustainability will be studied, this factor is climate. Next chapter can gives an understanding related to characteristic of climate zones. And later by adding climate factor to the table 10, final check list which are practical for each climate zone will be find (chapter 6).

And also in this chapter climate classification which is going to be used in this study were introduced and its characteristics were mentioned in table 11 By understanding climate classification and importance of climate in design decisions and the table 10 which came from the study of sustainable façades characteristics in beginning of this chapter, it is possible to add the climate factor to sustainable façade design characteristics and come up with best suggestion for designing sustainable façades for different locations worldwide with different climate zones.

In following chapter, the final check list for designing sustainable façade according to the climate classifications will be explained. Thus, this check list can able architects to find the best strategies for designing sustainable façade for any location in world.

Chapter 4

GUIDELINES FOR DESIGNING ENERGY EFFICIENT FAÇADE BY CLIMATE CONSIDERATION

A building design is the result of innumerable decisions, and the success of the final design depends on which alternatives are chosen at every step of the design process. However, because the most important decisions are made at the front end of the schematic design stage. Even if all of the relevant knowledge has been acquired, it is still a major challenge to know what applies to a specific project and at what point in the design process a particular decision should be made. A checklist can be a guide for the designer about what important options are available for the heating, cooling, and lighting of buildings. To achieve a sustainable integrated design, it is important that the best alternative is chosen at the accurate step in design process. The single best example of how a particular decision has a major impact on many future decisions and the success of the final design is the choice of orientation. Only the correct choice will allow for high-performance passive solar, shading, and day lighting, and for their successful integration.

4.1. Energy Efficient Façade for Hot Climates

It is possible to categorize an area in hot climate zone if the high temperature difference between night and day with high summer day time temperature (32-36 ^{o}C) and high solar radiation. In this climate zone most of the year weather is hot and dry, there are few days with raining which usually it is extreme and storm is appearing. In desert and extreme dry parts the difference in temperature between day and night is high. In such climate, the main issue is thermal comfort of the users, and a building can be sustainable if firstly it is thermal resistance and can protect users from high temperature difference in between outside the inside building.

Main issue for designing a façade in such climate zone is that the solar heat gain is not required, so direct sun light can be a problem, and can cause the cooling cost for users and make the buildings far from the sustainability. And at the same time, for sure providing natural lighting is an important fact for users. The other important issue is having natural ventilation which can help the cooling of the building.

Beside the initial thinking while designing a building in such climate zone, such as choosing the correct and suitable site location which is done by considering prevailing wind and also possibility of having neighboring buildings and vegetation to provide shading for the building, there are other considerations which were widely discussed in the previous chapters, such as the type of the transparency and glazing, amount of fenestration and suitable types of it, and very important part of façade design which is shading.

In general it should be mention that, best type of glazing for such climate zone is high light to solar gain ration glazing and lower R-value. Having the less amount of window on west and east. And using correct types of shading.

From the façade types double skin façade technique is very use full for hot and dry climate zone especially the ones which are increasing the natural ventilation like box window or etc. in the other hand material utilization is an important factor in sustainable façade design. Materials such as phase change materials which are categorized in smart materials are very useful for hot and dry climates. These type of materials can adopt themselves with climatic issues and can help the building in reducing energy consumption which in this climate zone is mainly for cooling.

If other types of the façade is chosen to be applied such as curtain wall, it is very important to choose the correct glazing. For curtain walls it is required to use double glazing or triple glazing which because of the gas between the layers, they are more thermal resistant and can help the sustainability of the building. The other important factor is insulation, insulation should be applied without any hole or crack in it and it is suggested to not use the cantilever concrete in the façade design of the buildings in this climate zone, because this part of façade can work as an thermal bridge and it cause the thermal lost and in continuation effect the general sustainability of the building.

In the following table (table 14) all design criteria which were discussed before are considered, and by considering the characteristic of the hot and dry climate, best options for designing the sustainable façade in hot and dry climate were gathered. This table will work as a check list if any architect wants to design a sustainable building in hot and dry climate zone, and gives the opportunity to find out best methods, materials and etc.

Table 12: Checklist for Designing Energy Efficient Façade in Hot Climate Zone.

CLIMATE ZONEC	HOT AND DRY CLIMATE
CLIMATE CHARACTERISTICS	- Sever lack of precipitation annual evaporation exceeds annual precipitation - Subtropical deserts with average temperature greater than 180c - Low latitudes 0-10 degree of central Africa, north and east parts of Australia. - Protection of the façade from direct solar radiation with shading devices - Reduction of external heat gain.
DESIGN CRITERIA AND DESIGN STRATEGIES FOR SUSTAINABLE FAÇADE DESIGN	
IMPORTANT NOTE	IN HOT AND DRY CLIMATE SOLAR HEAT GAIN IS NOT REQUIRED BUT GAINING NATURAL LIGHTING IS NEEDED

ORIENTATION	AXIES	Building along and **east-west** axes.
	CONSIDERATION	**Prevailing wind** should be considered
SITE SELECTION CONSIDERATION	Shading in summer by buildings and vegetation such as tress and etc.	
FORM	Limiting the depth of the building.	
GLARE	Utilizing louver with south facing clerestories.	
AIR BARRIER	Minimizing infiltration	

FENESTRATION AND DAYLIGHTING			
IMPORTANT NOTE		Fenestrations should not be more than 20% of the floor area, because solar heat gain is not required.	
TYPES		**CONSIDRATION**	
WINDOWS	✓	Max. on south façade min. on west	
CLERESTORIES	-	If winter heat is needed	
SKYLIGHINTG	X	Not suitable	
ATRIUM	✓	Locating on north façade	
LIGHTTUBE	✓	Require for small core areas.	

GLAZING AND **TRASPARENCY**

- High light –to-solar gain ration glazing
- Lower R-value

TYPES	**Solar heat gain**	**lighting**	**Suitable for hot climate**	
Clear	✓	X	X	
Heat absorbing	X	✓	✓	
Tinted	X	✓	✓	Because of the reflection of sun (sunny days)
Reflective	X	✓	-	Heat gain is not needed
Spectrally selective	✓	X	X	
Single glazing	✓	✓	X	
Conventional glazing	✓	✓	-	It is fine if moveable shading is considered.

MATERIALS		
ETFT	Poor thermal performance	X
Vacuum insulation glazing units	give enhanced thermal resistance	✓
Aerogel	very low thermal conductivity and insulation is needed	X
Smart materials	The once which are good in thermal resistance or can adopt with hot climates are very useful such as phase change materials	✓

GLAZING

TYPES	Solar heat	lighting	Suitable for hot climate	
Low-e glazing	✓	✓	X	Heat is not needed
Spectrally selective low-e coating	X	X	X	Lighting level is low
High LSG low glazing	X	✓	✓	
High visible transmitted low-e clear	✓	✓	✓	Shading is needed
Low solar heat gain selective low-e glazing	X	✓	✓	

SHADING

TYPES	Usage for hot climate		Orientation
Overhang/awning	X	Trap hot air	South/east/west
Overhang/Louver	✓	Free air movement	South/east/west
Overhang/Horizontal louver in vertical panel	✓	Free air movement	South/east/west
Overhang/vertical plane	✓	Free air movement	South/east/west
Vertical fin	-	-	North
Vertical fin slanted	X	- Slant towards north - Not recommended cause restricting the view.	East/west
Eggcrate	X	For very hot climate Not recommended cause restricting the view.	East/west
Overhang awning	X	Trap Hot air	South/east/west
Overhang horizontal rotating louver	✓	Blocking sun	South/east/west
Fin rotating fins	✓	Slant towards north More effective than fix one.	East/west

FAÇADES

TYPES		Suitable for hot climate	
Opaque	Multi layer	✓	
	Mono layer	X	
Glazed (Curtain wall)	Single	X	
	Double	✓	
	High performance	✓	
	Triple	✓	
Double skin facade	Box windows	Good ventilation	✓
	Shaft box	Stack effect	✓
	Corridor façade		✓
	Multi story façade	Decrease the ventilation	✓

THERMAL HEAT TRANSFER

Façade type: curtain wall	Thermal break and double/triple glazing
Structure	Diagonal bracing
Fenestration (metal windows)	Thermal break and sustainable wood
Insulation	There should not be hole in it.
Concrete cantilever	Not suitable.

4.2. Energy Efficient Façade for Cold Climates

For designing an energy efficient façade it is important for architects to have understanding from the climate characteristics and having a wide view towards sustainable design criteria. By understanding two mentioned group of knowledge it will be possible to design sustainable buildings.

For cold climate in contrast by hot climate, solar heat gain is very important, most of the energy consumption in such climates, is heating energy so solar heat gain can reduce it.

In cold climates it is better to have higher ration of windows to wall in this case it is possible to gain maximum solar radiation and it can serve both peruses, heating and natural lighting of the building. But at the same it should be considered that, having more glazing façade can increase the heat transfer between interior space and exterior space for controlling this fact, it is important to use double or triple glazing which the space between layers are filled by gases so this thermal transfer will be reduce.

And other important factor is correct use of shading, for example there is no need to use eggcrate shading and also at the same time it is better to consider the snowfall in such climate zones, thus, usage of overhang is not required because of the load of snow.

For material usage again smart materials are very useful for self-cleaning and also phase change materials which can adopt with thermal situation. For cold climate high thermal resistance is important, thus, vacuum insulation glazing unit is useful.

Table 15, can work as a check list, which can gives the opportunity to design sustainable façade for cold climate zone.

Table 13: Checklist for Designing Energy Efficient Façade in Cold Climate Zone.

CLIMATE ZONEC	COLD CLIMATE
CLIMATE CHARACTERISTICS	- Collection of the solar heat through the building façade is very important. - Storage of the heat in the mass of the wall is required - Use of natural light sources and increasing glazing areas of the façade, use of high performance glass, and use of light shelves to redirect light into interior spaces.

DESIGN CRITERIA AND DESIGN STRATEGIES FOR SUSTAINABLE FAÇADE DESIGN

IMPORTANT NOTE	IN COLD CLIMATE SOLAR HEAT GAIN IS VERY IMPORTANT AND ALSO AT THE SAME TIME GAINING NATURAL LIGHTING IS NEEDED. HIGH WINDOW TO WALL RATION IS NEEDED.

ORIENTATION	AXIES	Building along and **east-west** axes.
	CONSIDERATION	**Prevailing wind** should be considered
SITE SELECTION CONSIDERATION	Winter solar access should be considered for choosing the site location.	
FORM	Limiting the depth of the building.	
FENESTRATION AND DAYLIGHTING	IMPORTANT NOTE	Ration of the window to wall should be high and also its better to have windows high on the wall to gain more solar radiation.

TYPES		CONSIDRATION
WINDOWS	✓	Max. on south façade min. on west
CLERESTORIES	✓	For winter heat
SKYLIGHINTG	X	Not suitable
ATRIUM	✓	Locating on south façade
LIGHTTUBE	✓	Require for small core areas.

GLARE	Utilizing louver with south facing clerestories.

GLAZING AND TRASPARENCY

- High light –to-solar gain ration glazing
- Lower R-value

TYPES	**Solar heat gain**	**lighting**	**Suitable for hot climate**	
Clear	✓	✓	✓	It is good because of gaining solar direction
Heat absorbing	X	✓	X	Not suitable
Tinted	X	✓	X	Not suitable
Reflective	X	✓	-	Heat gain is not needed
Spectrally selective	✓	X	-	Good for heat but not lighting
Single glazing	✓	✓	✓	
Conventional glazing	✓	✓	✓	It is fine if moveable shading is considered.

AIR BARRIER	Minimizing infiltration		
MATERIALS	ETFT	Poor thermal performance	X
	Vacuum insulation glazing units	give enhanced thermal resistance	✓
	Aerogel	very low thermal conductivity and insulation is needed	X
	Smart materials	The once which are good in thermal resistance or can adopt with hot climates are very useful such as phase change materials	✓

NOTE: HIGH R-VALUE WINDOWS IS NEEDED ON NORTH FAÇADE.

GLAZING

TYPES	Solar heat	lighting	Suitable for hot climate	
Low-e glazing	✓	✓	X	Problem is thermal resistance
Spectrally selective low-e coating	X	X	X	Lighting level is low
High LSG low glazing	X	✓	X	Solar heat is needed
High visible transmitted low-e clear	✓	✓	✓	Shading is needed
High solar heat gain selective low-e glazing	✓	✓	✓	

SHADING

TYPES	Usage for hot climate		Orientation
Overhang/awning	X	Snow load on it.	South/east/west
Overhang/Louver	✓	Free air movement	South/east/west
Overhang/Horizontal louver in vertical panel	✓	Free air movement	South/east/west
Overhang/vertical plane	✓	Free air movement	South/east/west
Vertical fin	-	-	North
Vertical fin slanted	X	- Slant towards south - Not recommended cause restricting the view.	East/west
Eggcrate	X	It is more useful for very hot climates.	East/west
Overhang awning	✓	Trap Hot air	South/east/west
Overhang horizontal rotating louver	X	Blocking sun	South/east/west
Fin rotating fins	✓	Slant towards south More effective than fix one.	East/west

FAÇADES

TYPES		Suitable for hot climate	
Opaque	Multi layer	✓	
	Mono layer	X	
Glazed (Curtain wall)	Single	X	
	Double	✓	
	High performance	✓	
	Triple	✓	
Double skin facade	Box windows	Good ventilation	✓
	Shaft box	Stack effect	✓
	Corridor façade		✓
	Multi story façade	Decrease the ventilation	✓

THERMAL HEAT TRANSFER

Façade type: curtain wall	Thermal break and double/triple glazing
Structure	Diagonal bracing
Fenestration (metal windows)	Thermal break and sustainable wood
Insulation	There should not be hole in it.
Concrete cantilever	Not suitable.

4.3. Energy Efficient Façade for Mixed Climates

Mixed climate zones are cold in winter and hot in summer, it means they have different seasons, and for designing façade both characteristic for cold and hot periods should be considered. Temperature of this climate zone is different from 25 to 35 degree is summer period and 10-15 in winter. And this degree is lower at night time sometimes lower than zero.

For this climate zone gaining solar heat is important during the winter months and building should be protected from solar heat gain during the summer period. Utilization of the correct shading is very important, usage of movable shadings is required.

Using the double or triple glazing should be considered for all climate zones, single glazing is not required for any climate zone, and it is not beneficial for energy consumption of the building. For mixed climate zone usage of the smart materials should be one of the considerations especially phase change materials which can adopt themselves to the climate change which is happening in the temperate climate zones.
Among façade types again double skin façade can have best performance in terms of the energy saving and sustainability issues for the buildings in temperate climate zone. Table 16 it is possible to find all the criteria which should be considered in designing sustainable façade for buildings by considering the characteristic of the temperate climate, best options for designing the sustainable façade in hot and dry climate were gathered.

Table 14: Checklist for Designing Energy Efficient Façade in Mixed Climate Zone.

CLIMATE ZONEC	TEMPRATE CLIMATE
CLIMATE CHARACTERISTICS	-
DESIGN CRITERIA AND DESIGN STRATEGIES FOR SUSTAINABLE FAÇADE DESIGN	
IMPORTANT NOTE	IN COLD CLIMATE SOLAR HEAT GAIN IS VERY IMPORTANT AND ALSO AT THE SAME TIME GAINING NATURAL LIGHTING IS NEEDED. HIGH WINDOW TO WALL RATION IS NEEDED.

ORIENTATION	AXIES	Building along and **east-west** axes.			
	CONSIDERATION	**Prevailing wind** should be considered			
SITE SELECTION CONSIDERATION	Winter solar access should be considered for choosing the site location.				
FORM	Limiting the depth of the building.				
FENESTRATION AND DAYLIGHTING	IMPORTANT NOTE	Ration of the window to wall should be high and also its better to have windows high on the wall to gain more solar radiation.			
	TYPES	**CONSIDRATION**			
	WINDOWS	✓	Max. on south façade min. on west		
	CLERESTORIES	✓	For winter heat		
	SKYLIGHINTG	X	Not suitable		
	ATRIUM	✓	Locating on south façade		
	LIGHTTUBE	✓	Require for small core areas.		
GLARE	Utilizing louver with south facing clerestories.				
GLAZING AND **TRASPARENCY**	- High light –to-solar gain ration glazing - Lower R-value				
	TYPES	**Solar heat gain**	**lighting**	**Suitable for hot climate**	
	Clear	✓	✓	✓	It is good because of gaining solar direction
	Heat absorbing	X	✓	X	Not suitable
	Tinted	X	✓	X	Not suitable
	Reflective	X	✓	-	Heat gain is not needed
	Spectrally selective	✓	X	-	Good for heat but not lighting
	Single glazing	✓	✓	✓	
	Conventional glazing	✓	✓	✓	It is fine if moveable shading is considered.
AIR BARRIER	Minimizing infiltration				
MATERIALS	ETFT	Poor thermal performance	X		
	Vacuum insulation glazing units	give enhanced thermal resistance	✓		
	Aerogel	very low thermal conductivity and insulation is needed	X		
	Smart materials	The once which are good in thermal resistance or can adopt with hot climates are very useful such as phase change materials	✓		

NOTE:	HIGH R-VALUE WINDOWS IS NEEDED ON NORTH FAÇADE.				
GLAZING	TYPES	Solar heat	lighting	Suitable for hot climate	
	Low-e glazing	✓	✓	X	Problem is thermal resistance
	Spectrally selective low-e coating	X	X	X	Lighting level is low
	High LSG low glazing	X	✓	X	Solar heat is needed
	High visible transmitted low-e clear	✓	✓	✓	Shading is needed
	High solar heat gain selective low-e glazing	✓	✓	✓	
SHADING	TYPES	Usage for hot climate		Orientation	
	Overhang/awning	X	Snow load on it.	South/east/west	
	Overhang/Louver	✓	Free air movement	South/east/west	
	Overhang/Horizontal louver in vertical panel	✓	Free air movement	South/east/west	
	Overhang/vertical plane	✓	Free air movement	South/east/west	
	Vertical fin	-	-	North	
	Vertical fin slanted	X	- Slant towards south - Not recommended cause restricting the view.	East/west	
	Eggcrate	X	It is more useful for very hot climates.	East/west	
	Overhang awning	✓	Trap Hot air	South/east/west	
	Overhang horizontal rotating louver	X	Blocking sun	South/east/west	
	Fin rotating fins	✓	Slant towards south More effective than fix one.	East/west	
FAÇADES	TYPES		Suitable for hot climate		
	Opaque	Multi layer	✓		
		Mono layer	X		
	Glazed (Curtain wall)	Single	X		
		Double	✓		
		High performance	✓		
		Triple	✓		
	Double skin facade	Box windows	Good ventilation	✓	
		Shaft box	Stack effect	✓	
		Corridor façade		✓	
		Multi story façade	Decrease the ventilation	✓	
THERMAL HEAT TRANSFER	Façade type: curtain wall	Thermal break and double/triple glazing			
	Structure	Diagonal bracing			
	Fenestration (metal windows)	Thermal break and sustainable wood			
	Insulation	There should not be hole in it.			
	Concrete cantilever	Not suitable.			

4.4. Energy Efficient Façade for Warm Climates

Being warm and humid is the characteristic of warm climate zone. In ASHRAE climate classification warm is named as non-arid climate, mainly it has two season which are dry season or wet season, mainly the temperature of this climate zone is between 32-22 degree and in less temperature it is going lower than 18 degree. So mainly it has warm to hot temperature and it is humid.

For countries which are located in 5-10 degree latitude warm climate is occur. For designing a sustainable building or designing energy efficient façade for warm climate zone, by knowing the characteristics of this climate, which are hot and humid it is known that ventilation is an important factor in design. Mainly because of the hot temperature solar heat gain is not required. In this manner utilizing correct shadings is very important. Shadings should protect building from solar heat but at the same time give the opportunity of air movement in order to create natural ventilation such as horizontal louvers or vertical planes. For the glazing it is require to use double or triple glazing but low solar heat gain.

Double skin façade is a required façade type for this climate, but as mentioned before natural ventilation should be in mind. So double skin facades such as box window is more practical that the one which is limiting the natural ventilation such as multi story façade type.

Table 17 gathered all information which is needed to be checked for designing sustainable façade for tropical climate such as materials, façade types, glazing, transparency and et

Table 15: Checklist for Designing Energy Efficient Façade in Mixed Climate Zone.

CLIMATE ZONEC	TROPICAL CLIMATE
CLIMATE CHARACTERISTICS	- Not arid climate throughout the entire year. - Temperature warm to hot and moistening the entire year - Tropical rainforest is hot. - Summer months are hot, wet and humid and uncomfortable while the drier months can be quite pleasant.

DESIGN CRITERIA AND DESIGN STRATEGIES FOR SUSTAINABLE FAÇADE DESIGN

IMPORTANT NOTE	FOR THIS CLIMATE ZONE DIRECT AND INDIRECT EVAPORATING COOLING, VENTILATION ARE VERY IMPORTANT.

ORIENTATION	AXIES	Building along and **east-west** axes.
	CONSIDERATION	**Prevailing wind** should be considered
SITE SELECTION CONSIDERATION	Catching the natural ventilation.	
FORM	Limiting the depth of the building.	
FENESTRATION AND DAYLIGHTING	IMPORTANT NOTE	Fenestrations should not be since most of the year it is hot, high percentage of fenestration for solar heat gain is not needed.

TYPES		**CONSIDRATION**
WINDOWS	✓	Max. on south façade min. on west
CLERESTORIES	✓	Winter heat for evaporation
SKYLIGHINTG	X	Not suitable
ATRIUM	✓	Locating on north façade
LIGHTTUBE	✓	Require for small core areas.

GLARE	Utilizing louver with south facing clerestories.

GLAZING AND TRASPARENCY

- High light –to-solar gain ration glazing
- Lower R-value

TYPES	**Solar heat gain**	**lighting**	**Suitable for hot climate**	
Clear	✓	✓	X	Solar heat gain is not required
Heat absorbing	X	✓	✓	
Tinted	X	✓	✓	
Reflective	X	✓	✓	
Spectrally selective	✓	X	X	
Single glazing	✓	✓	✓	With required shadings.
Conventional glazing	✓	✓	-	It is fine if moveable shading is considered.

AIR BARRIER	Minimizing infiltration

MATERIALS

ETFT	Poor thermal performance	X
Vacuum insulation glazing units	give enhanced thermal resistance	✓
Aerogel	very low thermal conductivity and insulation is needed	X
Smart materials	Phase change materials. Self cleaning	✓

GLAZING

TYPES	Solar heat	lighting	Suitable for hot climate	
Low-e glazing	✓	✓	X	Heat is not needed
Spectrally selective low-e coating	X	X	X	Lighting level is low
High LSG low glazing	X	✓	✓	
High visible transmitted low-e clear	✓	✓	✓	Shading is needed
High solar heat gain selective low-e glazing	X	✓	✓	

SHADING

TYPES	Usage for hot climate		Orientation
Overhang/awning	✓		South/east/west
Overhang/Louver	✓	**Free air movement**	South/east/west
Overhang/Horizontal louver in vertical panel	✓	**Free air movement**	South/east/west
Overhang/vertical plane	✓	**Free air movement**	South/east/west
Vertical fin	-	-	North
Vertical fin slanted	X	- Slant towards north - Not recommended cause restricting the view.	East/west
Eggcrate	X	Not recommended cause restricting the view.	East/west
Overhang awning	✓		South/east/west
Overhang horizontal rotating louver	✓	Blocking sun	South/east/west
Fin rotating fins	✓	Slant towards north More effective than fix one.	East/west

FAÇADES

TYPES		Suitable for hot climate	
Opaque	Multi layer	✓	
	Mono layer	X	
Glazed (Curtain wall)	Single	X	
	Double	✓	
	High performance	✓	
	Triple	✓	
Double skin facade	Box windows	**Good ventilation**	✓
	Shaft box	Stack effect	✓
	Corridor façade		✓
	Multi story façade	Decrease the ventilation	X

THERMAL HEAT TRANSFER

Façade type: curtain wall	Thermal break and double/triple glazing
Structure	Diagonal bracing
Fenestration (metal windows)	Thermal break and sustainable wood
Insulation	There should not be hole in it.
Concrete cantilever	Not suitable.

Chapter 5

Case Study: Building Analysis of the Architect, Norman Foster in Terms of Energy Efficient Façade Design

As clarified in past sections there are a few standards, strategies and materials in designing energy efficient façade. The building façade controls the collaboration between the building and its outside condition by right off out the undesirable outer condition components and in this manner influencing the amount and rate of asset utilization and environmental deterioration by the working keeping in mind the end goal to manage the inside condition. The idea of building façade as the principal line of defense in the passive systems utilized towards accomplishing energy efficient building. Passive system can embraced to give natural lighting, natural ventilation and heating and cooling in the building.

Of course there are many examples of energy efficient façade for high rise buildings around the world, but this study focused on buildings, designed by Norman Foster "who his and his company (Foster+ partners) is famous because of the high-tech architecture, Foster + Partners is a standout amongst the most creative architecture and coordinated design practices on the planet. In the course of recent decades the practice has spearheaded a sustainable way to deal with architecture through a strikingly extensive variety of work, from urban strategies, airports, cultural buildings, workplaces and working environments to private houses." (Davies, 1988).

In following pages, this research gives a summery background about the architect Norman Foster and afterward some of his acclaimed buildings are analyzed according to principles in design of energy efficient façades which is explained in previous chapters. Building assessment chart is characterized by giving general data about the name, place, production year and general description of building and examination as indicated by sustainability issue. The content and assessment are bolstered by photographs of the building and furthermore plans, sections and 3D modelling of the building for better comprehension of the ideas regarding sustainability and sustainable façade design.

As explained above, it is necessary to give short summery about architect Norman Foster and his way of looking at buildings.

Norman Foster born in First June 1935. He is a British architect whose organization and company of Foster + Partners keeps up a global design rehearse popular for high tech design and architecture. In his era and generation, he is one of the most prolific British architects. He won the Pritzker Architecture Prize, which is refer as the Nobel Prize of architecture in 1999.Furthermore, he could win Prince of Austria Award and also AIA Gold Medal in 2009 and 1994.

He did his study in University of Manchester's school of architecture and city planning in 1956 and could graduate in 1961. He attended to Yale school of architecture with wining the Henry Fellowship and earned his Master degree. He had the opportunity to meet Richard Roger in Yale University which they both with two sisters Georgie and Wendy Cheesman established an architectural practice as Team 4, in this group of four only Georgie (later Wolton) had passed RIBA exams. Their team could get a good reputation very quick especially for the high-tech design. It was in 1967 and after broke up of the Team 4 which Foster and Wendy Cheesman set up the Foster association and this company later changed its name to Foster and Partners. In this company from 1968, Norman Foster was cooperating and worked with American architect Richard Buckminster Fuller until 1983 when Fuller passed away. Foster and Fuller work on many projects together which their works became important in field of design by having environment sensitivity approach.

In Foster + Partners, nowadays he is working with engineers to use computer systems. They focus on essential physical laws, for example, convection. They have created efficient buildings like the Swiss Re London headquarters (Sudjic, 2010).

In following parts selected buildings and the selection reasons will be explained and then buildings will be analyzed according to the sustainability principles.

5.1 Selection Criteria

When the topic is come to the energy efficiency one of the important issues which effect the study, and architects have to consider during the design process is climate. In this part first of all climate classification will be shown and according to that four countries with different climate zones were chosen as case study locations. For having energy efficient building different principles should apply to the buildings in different climates and it is the reason that make the climate zones more important for designing The building and specially façade of the building which is the first element of the building that is in touch with the exterior conditions.

Mentioned countries in the table 18 are in different climate zones and from these countries one of the Norman Fosters high-rise mixed used buildings were chosen, to analyze according to the principles for sustainable façade design. In total four buildings will be analyze in this study and in the end one main table will be prepared which can give a perspective for designing sustainable façade by considering the climate conditions in different climate zones.

Table 16: Climate description for chosen counties (By Author)

Climate classification	Countries	Description
Mixed	Germany(Frankfurt) 	Germany's climate is moderate and has generally no longer periods of cold or hot weather.
Warm	Malaysia (Kuala Lumpur) 	Malaysia is located in the equatorial region, and has a tropical rainforest climate. Located near the equator, Malaysia's climate is categorized as equatorial, being hot and humid throughout the year.
Hot	United Arab Emirate(Dubai) 	The climate of the UAE generally Dry, very hot and very sunny. The hottest months are July and August, when average maximum temperatures reach above 50 °C
Cold	Russia (Moscow) 	Russia and Siberia between the Scandinavian Peninsula and the Pacific Ocean has a cold and subarctic climate with extremely severe winters.

The chosen buildings and short description about them is in the following table. After mentioning the selected buildings among all Norman Foster projects, in the next part each building will be analyzed.

- Case one: The Frankfurt Commerzbank Tower (Frankfurt, Germany);
- Case two: Ilham Tower (Malaysia, Kuala Lumpur);
- Case three: The index (UAE, Dubai);
- Case four: the Russia Tower (Russia, Moscow).

All of the chosen building are one of a kind, and they are famous because of their specific design and being the best and first. For example Commerzbank Headquarter is the first ecological building in the world or Russia tower will be the first high rise building which can fully ventilate itself naturally.

Table 17: Chosen Case Studies (By Author).

Climate	Case Studies	photo
Mixed	Case one: The Frankfurt Commerzbank Headquarter	 
Warm	Case two: Ilham Tower	 
Hot	Case three: The Index	 
Cold	Case four: Russia Tower	 

5.2. Analysis and Results

After choosing buildings which were mentioned in table 19 according to the climate zones, their function (mixed used high-rise buildings) and also architect (Norman Foster) in this part of the study each building will be analyze according to the sustainable façade design criteria which were widely explained in previous chapters. Analysis of the buildings are coming from literature review of the buildings, and by the end one table were prepared for each building by author that is the summery of the analysis and showing the chosen decisions which were done by architect.

5.2.1. Case Study One: The Frankfurt Commerzbank Headquarter

The Commerzbank is the first ecological tower in the world and by having fifty-three stories is the tallest building in Europe. The project investigates the nature of the office condition, growing new ideas for its ecology and working pattern. Key to this idea is a dependence on natural frameworks of lighting and ventilation. Each office is sunlight and has operable windows, enabling the users to control their own particular condition. The outcome for energy consumption levels is half of the formal office towers (Van Meel, 2000).

Figure 14: The Frankfurt Commerzbank Headquarter (Van Meel, 2000).

Commerzbank floor planning is in the Equilateral triangle which has the round corners plus convex sides. Building has a central atrium which floors and also cores of the three corners located around it. Floors of the buildings designed with three wings, which all offices located in two wings and the third wing forms the four story height gardens. The atrium in the center of the building also has the triangular shape and made the transparent impression. The slender appearance of the building is because of the nine gardens and also natural light. A very unique frame construction were used which gives the opportunity to span the gardens even more than 24 meter wide and it is without using the columns (McCallum, 1997).

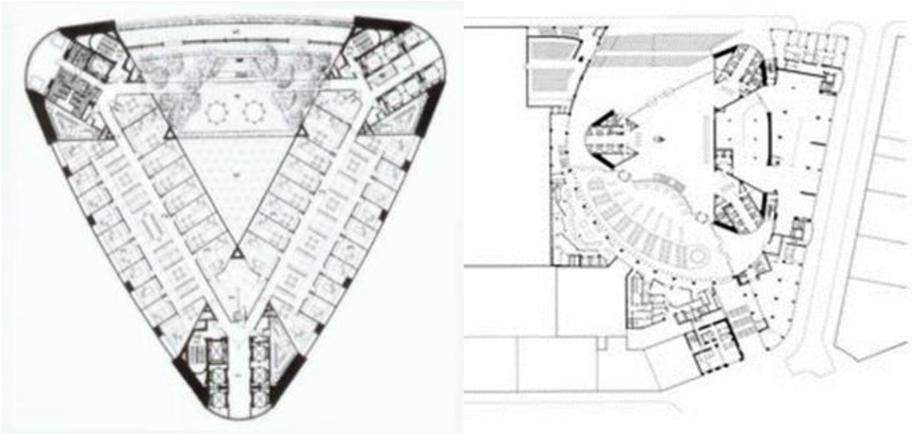


Figure 15: The Frankfurt Commerzbank Headquarter Typical Plan (McCallum, 1997).

Figure 15: The Frankfurt Commerzbank Headquarter Typical Plan (McCallum, 1997).
In order to achieve natural ventilation and also for substantial energy-saving and in design of this building a method was used which even till now is unique and that is two-layered facade. The external skin has slots through which air can enter the cavity between the layers. The windows of the interior facade, even those on the most elevated floors, might be opened, guaranteeing that natural ventilation is conceivable up to the 50th floor. The windows on the atrium side likewise be opened (McCallum, 1997).

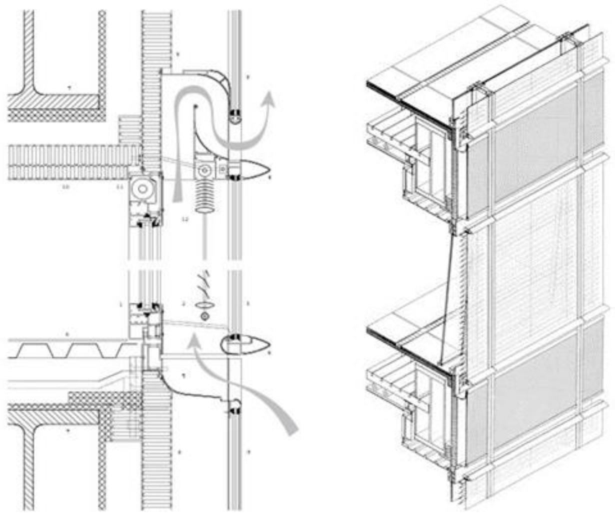


Figure 16: Cavity between the Layers in Façade (McCallum, 1997).

In Commerzbank's design gardens are fundamental elements and they are more and a decoration elements in Norman Foster design. In spiral structure, nine sky gardens ascend the tower – they are facing eastwards, southwards and westwards. Organically, the vegetation shows the geographical orientation. Because of the sky gardens lots of natural light provided for offices. Furthermore, they can be utilized by users for correspondence purposes and for breaks; they make a feeling of openness and frame some portion of the modern arrangement of natural ventilation (Gupta, et al, 2014).

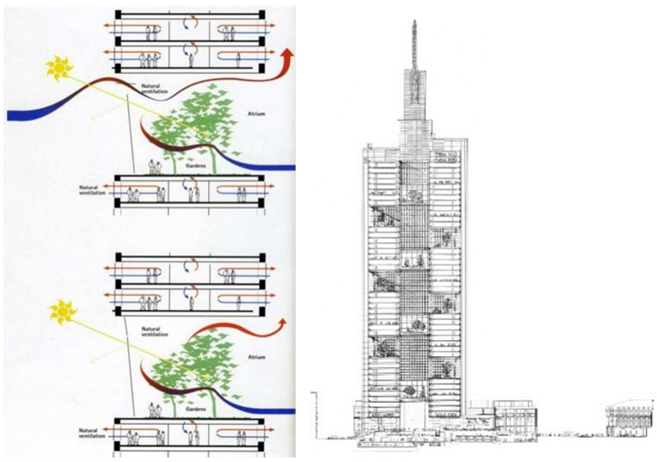


Figure 17: Natural Ventilation and Natural Lighting through Gardens in Façade (Gupta, et al, 2014).

Commerzbank Tower designed in a way which natural ventilation can operate 60% of the year and other 40% of the year in either too cold or too windy. Windows of the tower has automatic system and by this ventilation system can be drop down to 35% and it is in comparison with buildings which are fully mechanic air conditioned buildings (Aktuglu, et al, 2009).

In order to have optimum daylight and ventilation building designed in a way to respond the wind and solar orientation. For achieving the maximum solar radiation and also wind the floor planning and triangular shape of the building and at the same time south-west orientation of the building are very important (Aktuglu, et al, 2009).

5.2.1.1 Results of Case Study One

In this building architect tried to catch the natural ventilation and use daylighting strategies in order to create sustainable building and a building which is brings comfort for the users.

Façade of the building designed in tree layer fixed glass, cavity layer and double glazing hinged windows and cladding type of the building is double skinned aluminum framed curtain wall. This façade system gives the opportunity to building to ventilate itself naturally. Ventilation of the building through cavity were shown in figure 14 on the outer façade slots were designed for improving ventilation.

This building has floor to floor glazing and full height atrium with glass decks every twelve floor. These are the daylighting techniques which were considered by architect and provide natural lighting for office spaces. In the other hand sky gardens were design which are helping both daylighting of the building and works as ventilation system for building.

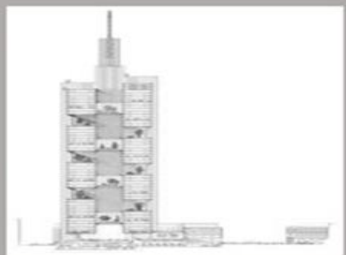
Frankfurt Commerzbank headquarter designed in a way to have passive solar heat gain because of the amount of glazing on the façade and also has stack effect and can ventilate itself and this create passive cooling for the building for most months of the year.

For this building shading strategies that were discussed before were not applied but floor gardens can help the shading of the building.

Following table is the final outcomes from analyzing the Frankfurt Commerzbank Headquarter which is showing by using which techniques and strategies for a high rise building locating in temperate climate zone for façade design, architect could achieve sustainability and users comfort.

Table 18: Result of case study one analysis (Aktuglu, et al, 2009; Gupta, et al, 2014).

CASE STUDY ONE	The Frankfurt Commerzbank Headquarter				
BUILDING INFORMATION	Form	Triangular in shape	Heating and cooling	Passive solar heat gain	
High rise mixed use building	Orientation	South-west direction		Natural ventilation	
				Stack effect	
Climate zone: Temperate	Fenestration And daylight	Windows for inner façade	Shading	Not applied	
		Slot on outer skin		Other consideration	Floor gardens
		Atrium			
Location : Frankfurt Germany	Glazing type	Double glazed operable window.	Façade layers	Fixed glass	
		Outer skin of fixed glass and ventilation cavity		Cavity layer	
				Double glazed hinged window	
Height : 259 meter	Daylighting	Skylights - full height atrium with glass decks every twelve floor	Thermal mass	Not applied	
		Sky gardens			
		Floor to floor glazing			
Area: 125000 square meter	Cladding	Double skinned aluminum framed curtain wall	Thermal envelop	Not applied	



5.2.2. Case Study Two: Ilham Baru Tower

In the heart of Kuala Lumpur the Ilham Baru Tower with 58 story and 275 meter high by having different spaces from living to working located. It is still under the construction but after finishing it will be in a group of tallest mixed use buildings in the city. The challenge in designing such a huge new skyscraper plan was to identify with the vast, urban scale, and additionally in detail, façade is rich and finely tuned to shade the insides and to give top high quality living spaces. The tower's geometry is driven by the requirement for adaptable and flexible, column free spaces to oblige its maximum of function. Its frame is similarly formed by the climate and urban setting – the diamond shaped arrangement increases the living spaces with perspectives of key city points of interest and the facade tilt far from the morning and evening sun to diminish solar gain (Elsayed, 2012).

Figure 18: Ilham Baru Tower (Elsayed, 2012).

The building is set back from the edge of the site and balanced on a slender base to make a tree-lined plaza that goes into the atrium. The coated facades are pulled back to shade the doors of the entrances and make a great entry sequence. The tower additionally highlights enormous, open sky gardens, which are up to 40 meters in height and have continuous city views, made conceivable by the tower's inventive, self-supporting diagrid structure. Office floors are situated in the lower part of the tower, and in the center there is a three-story atrium, and in upper levels there are apartments – there are separated entrances in the ground floor for each two different function from either sides of the tower. In the last levels and in very top penthouses are located which they have view of the KL center (Yusoff, et al, 2014).

Figure 19: Ilham Baru Tower (Yusoff, et al, 2014).

Unified form of the building is because of the stainless steel-clad structure and at the same time triangulated glass panels with shading systems created this powerful form. Shading of the building designed by diagonal brise soleil which there are located on each facade and their orientation is in respond to the sun path and by this method interior spaces are protected from solar heat gain. For reducing the glare opaque frit were applied on the high performance glazing. Structure solution of the building which mentioned before helped the building to reduce material usage and at the same time minimize building's embedded energy (Ha, et al, 2013).

Figure 20: Utilization of Shading and Opaque Frit on High Performance Glazing to Reduce Glare and Solar Heat Gain (Ha, 2013).

5.2.2.1 Results of Case Study Two

As mentioned before Ilham Baru Tower is located in Malaysia which has tropical climate. It was discussed widely before but for reminding having warm to hot temperature with a high humidity. In this climate zone solar heat is not required so shading strategies and glazing is very important.

In this building architect tried to design a façade in a way to achieve tuned façade in order to create shading for the building and also the façade of the building is tilted in a way which it is away from morning and evening sun direction that is helping the interior space to be protected from solar heat gain.

This building has a huge glazed façade and for creating the shading the façade is pulled back. At the same time for achieving ventilation and more natural lighting atrium and sky garden were designed.

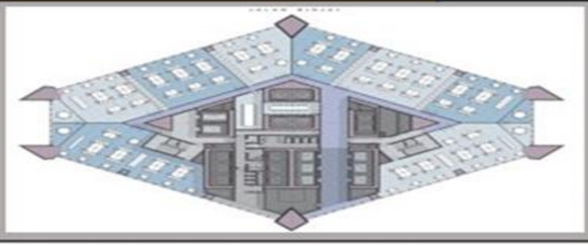
Façade system of the building is stainless steel clad structure with triangular glass and of course shading system. As mentioned before shading is an important factor for tropical climate zone. Diagonal brise soleil which is across all façade and have respond to the sun path protect building interior space from solar heat gain. Because of the sun radiation in this climate zone, glare effect is another issue which architects are facing. For this building architects for solving the glare effect utilized opaque frit which reducing the glare effect. In the other hand glazing type of the building is very important, thermal resistance of the glazing is very important in order to reduce energy consumption of the building, in this building high performance glazing were used in order to respond to this need.

One of the impacts of high rise building is amount of the material which is using, and it effects sustainability of the building. Because of the solutions which were using for façade system and structure of this building minimizing the material required for construction thus, it can effect building embedded energy.

Following table is the final outcomes from analyzing the Ilham Baru Tower which is showing by using which techniques and strategies for a high rise building locating in tropical climate zone for façade design, architect could achieve sustainability and users comfort.

Table 19: Result of case study two analysis
(Ha, 2013l; Yusoff, et al, 2014; Elsayed, 2012).

CASE STUDY TWO	ILHAM BARU TOWER				
BUILDING INFORMATION	Form	Diamond shape plan	Heating and cooling	Center atrium	
High rise mixed use building	Orientation	North- south axe		Natural ventilation	
				Thermal comfort	Interligent glass with articulated shading device
Climate zone: Tropical	Fenestration And daylight	Large glass façade	Shading	Diagonal brise soleil across each façade	
		Slot on sky garden skin		Other consideration	---------
		Atrium			
Location : Kuala lampur, Malaysia	Glazing type	High performance glazing	Façade layers	Triangular glass panel	
				Stainless steel clad structure	
				Double glazed hinged window	
Height : 298 meter	Daylighting and glare	Opaque frit on the high performance glazing to reduce glare	Thermal mass	Not applied	
		Sky gardens			
		Floor to floor glazing			
Area: 8250square meter	Cladding	Stainless steel clad structure	Thermal envelop	Not applied	



5.2.3 Case Study Three: Index Tower

The Index Tower was awarded in 2011 as the "Best Tall Building Middle East and Africa" because this building is a new environmental icon in the region of Middle East by showing the importance of the passive strategies such as orientation, shading devices and also core placement. This building is not only a model of the developing sustainable built environment for Middle East but also for any similar climate zones in the world. In spite of the minimalism in design, the building offers a reassurance on the capacity of modern buildings to draw on the natural qualities of their environment. The persuading trait of the tower is its intelligent integration of space, daylight and shades to limit sun gains. The building adopts an especially interesting strategy at its base, with just its structural fins and cores coming the distance to the ground, but other spaces are all open to the open air and shaded atrium which is cooling down by a large pool. This is a conspicuous difference to the completely closed coated lobby spaces normal of most tall buildings and a further case of The Index's relationship to its local climate which takes into consideration this openness (Parker, et al, 2013).

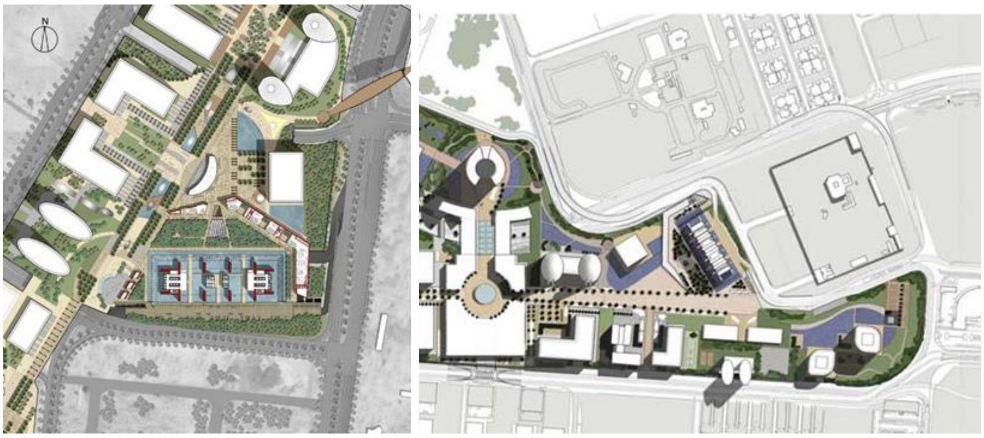


Figure 21: Location of the Index Tower in Site (Parker, et al, 2013).

The Index involves a conspicuous corner site inside the Dubai International Finance Center, a financial district expected to build up Dubai as an investment market, and to give a catalyst to assist financial development in the region. Adjusting a residential, business and social uses all together to bolster the Finance Center and more extensive community, the building speaks to a vertical city quarter with a populace of around 6,000 inhabitants and workers on its 20,000 sq. m site. The Index operate the sustainable worldview of maximizing the environmental benefits of a compact, skyscraper form with an effective design that decreases the requirement for mechanical cooling frameworks and artificial lighting. Oriented east to west, the building is situated at a slant off-grid, it is designed in this way to highlight the metropolitan perspective of Dubai International Finance Center on the north side and the Dubai cityscape on the south. By moving in the opposite direction of the city axis, the building is additionally ready to limits the solar gain; the building's core mass imbrue heat and limits its dependence on mechanical ventilation (Perez Gutierrez, et al, 2014).

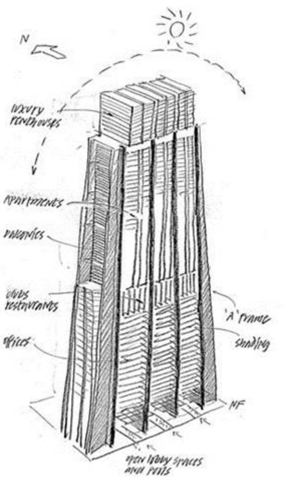


Figure 22: Building Orientation- Oriented on East West axis
(Perez Gutierrez,et al, 2014).

An arrangement of sunshades shelters the insides on the exposed south rise. Entrance facade is from four-story atrium with the tower sitting on a landscape platform, which gives shaded pedestrian through the site. What's more, with having a pool in entrance in light of natural ventilation which the atrium create, passive cooling is given. This orientation of building likewise diminishes solar gain, as the building's core mass imbrue heat and decreases its dependence on mechanical ventilation. Setting the lift core on either side of the building, where they are perfectly obvious externally, guarantees that orientation is clear (Shin, 2013).

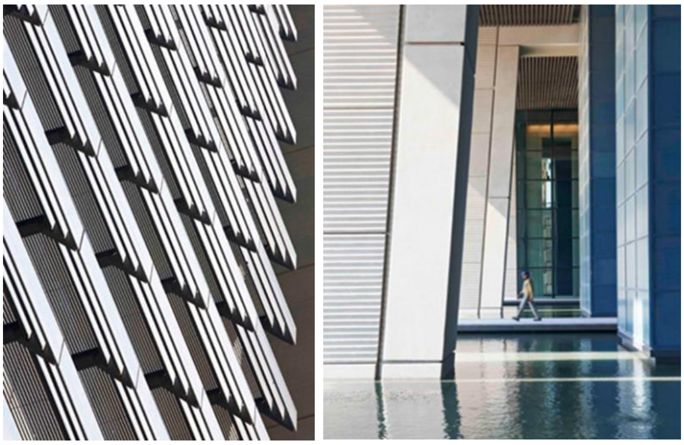


Figure 23: Shading Detail and Atrium in Entrance Façade (Shin, 2013).

The environmental strategy is dynamic and incorporated with the tower's architectural design: the open atrium at the base of the building consolidates shading with an expansive water feature in order to make a cool microclimate; every apartment have the ability for naturally ventilated; and vast glazing ranges on the workplace floors maximize natural light, however are controlled by external shading in the spaces that there is high solar gain (Shin, 2013).

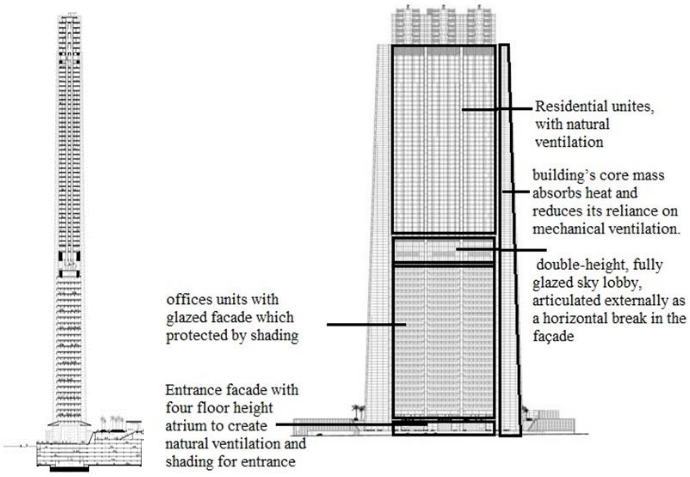


Figure 24: Core in East and West Side and Building Façade Arrangement
(Shin, 2013).

5.2.3.1 Results of Case Study Three

Designing in dry and hot climate zone needs specific considerations, in these climates zone as discussed widely before solar radiation is high but at the same time solar heat gain is not required. It is important to catch the natural lighting for the interior spaces but not solar heat thus, shading and having natural ventilation which can help cooling is an important factor for designing sustainable façade in hot and dry climates.

Index tower which is locating in Dubai UAE, is constructed in one of the hot and dry climate countries. This building as mentioned before is one of the best examples for providing passive strategies for cooling, ventilating and shading the building.

For designing this building orientation were chosen very carefully in order to answer the needs of the design in this region.

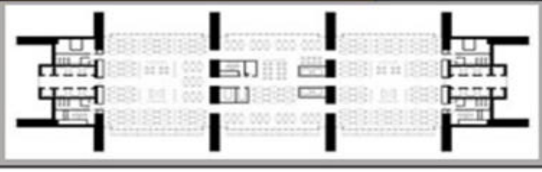
This building designed in a way to have a core in the center which coming all the way to the ground level, this core helping building to absorb the solar heat and also, lift cores are located in each side of the building one reason to catch the correct and required orientation and in the other hand to act as a thermal mass and absorb be solar heat.

An atrium designed for this building in order to provide natural lighting for spaces and also by having spaces which are opening towards this shaded atrium it is possible to achieve ventilation for interior spaces. For having cool temperature some pools were designed so they can cool the air while ventilating in the building.

As mentioned in this design two factors were very important one the orientation of the building to reduce the needs of the building for mechanical cooling and artificial lighting and the core masses which are absorbing the heat and can help the ventilation. All glazed façade of the building which is high performance glazing and high light to solar heat gain are protected by use of shadings. For entrance façade of the building four floor high atrium were designed which helps the natural ventilation and shading. Following table is the final outcomes from analyzing the Index Tower which is showing by using which techniques and strategies for a high rise building locating in hot and dry climate zone for façade design, architect could achieve sustainability and users comfort.

Table 20: Result of case study three analysis
(Shin, 2013; Perez Gutierrez,et al, 2014; Parker, et al, 2013).

CASE STUDY TWO	INDEX TOWER				
BUILDING INFORMATION	Form	Rectangular plan with slender profile shape	Heating and cooling	Natural ventilation and passive cooling	Center atrium
High rise mixed use building	Orientation	East-west axe			Operable windows toward atrium
				Passive cooling	Core mass
Climate zone: Hot and dry	Fenestration And daylight	Large glass façade	Shading	Shading for the southern façade	
		Glazed sky lobby		Other consideration	Atrium in entrance façade
		Atrium			
Location : Dubai, UAE	Glazing type	High performance glazing- High light to heat gain glazing	Façade layers	Glazed façade	
				Double skin façade for southern façade	
				Double height glazed sky lobby	
Height : 326 meter	Daylighting and glare	Glazed façade	Thermal mass	Core mass for absorbing the heat	
		Atrium			
Area: 20000 square meter	Cladding	High light to heat gain glazing façade with shading devices	Thermal envelop	Not applied	



5.2.4 Case Study Four: Russia Tower

Russia Tower is located in Moscow City, it is close to the landmarks of the city for example it is located in 5.5 km of Red Square. This tower is still under the construction and after the finishing it will be the mixed+ use building with capacity of 25,000 people, it will include offices, a hotel apartments and also shopping. There will be a private garden for apartments. It will have 600 meter high which includes 118 floors. The specific thing about this building is, it will be the tallest naturally ventilated building in the world and of course one of the best examples in Europe. Proceeding with topics initially investigated in the Tokyo Millennium Tower, the project augments the practice's examination concerning the nature of the tall building, taking structure, nature and urban rationale to another level (Halvorson, et al, 2007).

Figure 25: Russia tower (Halvorson, et al, 2007).

In view of a profoundly productive geometry gotten from a triangular plan with an open "green" spine, the building's essential structure contains three "arms" that decrease as they rise. They make a slender pyramidal shape that accomplishes the greatest stability with the minimum structure and permits the best appropriation of space. Residential and hotel accommodation are located in the higher floors they are modular units which can be arranged exclusively. apartments advantage from fresh air and at the same time natural light, with double or even triple height volume which they can have access to the sky gardens. At the summit, an open review deck with bistros and bars makes an attractive new fascination for guests and occupants, while an ice-rink and shops add diversity to life in the road level (Pagonis, et al, 2000).

Figure 26: Plan Organization of the Russia Tower (Pagonis, et al, 2000).

Figure 27: Urban Location of the Russia Tower (Pagonis, et al, 2000).

The environmental strategy bridles a scope of passive techniques and controls. Strategically, mixed-use functions offers a solid beginning stage, permitting energy adjust for the duration of the day as people move amongst office and home. Fundamentally, the tower's increase profile makes shallow floor plates that boost daylight infiltration and increment the potential for natural ventilation. Building has triple glazing and also high performance facade which help the tower to reduce amount of heat loss. For helping the building energy need photovoltaic panels were used. Recycling of the energy can decrease the heating demand up to 20 per cent. For supplying the fresh water, snow and rain water saving can cut the water consumption for toilets almost the third. From sustainability point of view, Russia tower can offer the new and unique solutions bot socially and environmentally (Harvorson, 2009).

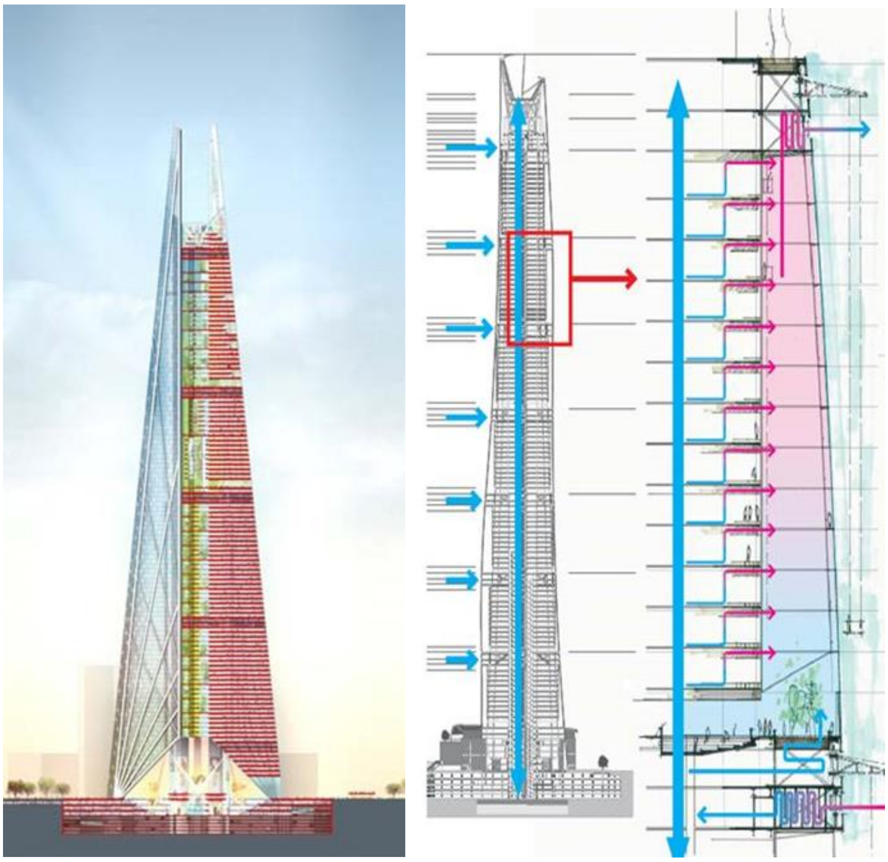


Figure 28: Russia Tower Natural Ventilation System (Harvorson, 2009).

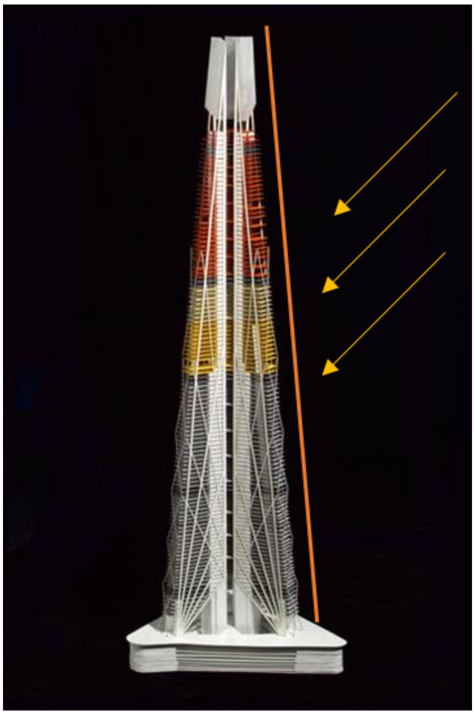


Figure 29: Tilted Façade of the Russia Tower in order to Catch Maximum Sun Direction (Harvorson, 2009).

5.2.4.1 Results of Case Study Four

Constructing a building is cold climate zones require specific design considerations according to the characteristics of the climate zone which were mentioned before. In cold climate zone catching solar heat gain is very important. In Russia tower also this was considered.

Russia tower construction is stopped because of the financial problems, but if it finish it will be the tallest and first building with is ventilating naturally.

For achieving main goals for designing this building which were gaining solar heat, natural lighting a natural ventilation, some passive strategies were applied.

First of all the tilt in the façade and floor planning of the building gives the opportunity to the building to gain maximum solar radiation which can serve both peruses, first to gain maximum natural lighting and secondly for solar heat gain.

The shallow shape of the façade and also the void in center of the building which end up with the sky garden helps the ventilation of the building, in this case all units can benefit the air movement and ventilate the spaces naturally.

Façade of the building is glazed façade, and glazing type of is triple glazing high performance façade and this type of the glazing help the building to keep the solar heat gain inside the building and reduce the loss of the energy. For the upper stories which are apartments and hotel cantilever balconies were designed which can cause of heat lost and act as thermal bridge.

Following table is the final outcomes from analyzing the Russia Tower which is showing by using which techniques and strategies for a high rise building locating in cold climate zone for façade design, architect could achieve sustainability and users comfort.

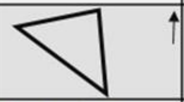
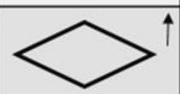
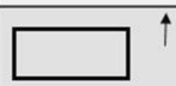
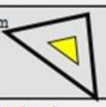
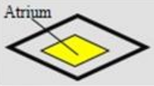
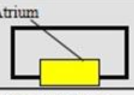
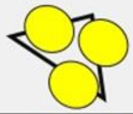
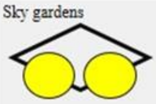
Table 21: Result of Case Study Four Analysis (Harvorson, 2009; Pagonis, et al, 2000; Halvorson, et al, 2007).

CASE STUDY TWO	Russia Tower				
BUILDING INFORMATION	Form	Triangular plan, primary structure comprises three arms	Heating and cooling	Natural ventilation and passive cooling	Central void
High rise mixed use building	Orientation	South east axe			Sky gardens
					Tilted façade
					High performance glazing
Climate zone: Cold	Fenestration And daylight	Large glass façade	Shading	Other consideration	Sky gardens
		Sky garden			
		Central void			
Location : Moscow, Russia	Glazing type	Triple glazing, high performance	Façade layers	Glazed façade	
				Sky gardens	
Height : 600 meter	Daylighting and glare	Glazed façade	Thermal mass		
		Sky garden			
Area: 50000 square meter	Cladding	Glazed façade	Thermal envelop	Cantilever balconies	
			Photovoltaic supply the building's energy needs and feed electricity back into the city grid Snow and rain water harvesting is expected to cut fresh water consumption for toilets by a third		

5.3 Comparison of Case Studies

In following table it is possible to compare all four case studies in terms of all criteria which were discussed in previous chapters.

Table 22: Comparison of Case Studies
(Harvorson, 2009; Pagonis, et al, 2000; Halvorson, et al, 2007; Shin, 2013; Perez Gutierrez,et al, 2014; Parker, et al, 2013; Yusoff, et al, 2014).

Case studies	Commerzbank headquarter (Germany)	Ilham Tower (Malaysia)	Index Tower (UAE)	Russia Tower (Russia)
Height and square meter	259m/125000 sqm	298m/8250 sqm	326m/20000sqm	600m/50000sqm
Climate Zones	Mixed climate	Warm climate	Hot climate	Cold climate
Form				
Fenestration and Glazing	Windows for inner façade	Large glass façades	Large glass façades	Large glazing façade
	Slot on outer skin	Slot on sky garden skin	Glazed sky lobby	Sky gardens
	Atrium	Atrium	Atrium	Void in the middle
	Atrium 	Atrium 	Atrium 	
Glazing Types	Double glazed	High performance glazing	High performance glazing, high light to heat gain glazing	Triple glazing, high performance
Day lighting	Sky lights (atrium)	Opaque frit on the high performance glazing	Glazed façade	Glazed façade
	Sky gardens (all orientations in different floors)	Sky gardens		Sky garden
	Floor to floor glazing	Floor to floor glazing	Atrium	
	Sky gardens 	Sky gardens 	No sky gardens	Sky gardens 
Cladding	Double skin aluminum framed curtain wall	Stainless steel clad structure	High light to heat gain glazing façade with shading devices	Double skin façade
Shading	Not applied	Diagonal brise soleil across	Shadings applied on south façade	Not applied
Heating/ cooling and ventilation	Passive solar heat gain	central atrium helps for natural ventilation	Central atrium for natural ventilation	Central void and sky garden for natural ventilation
	Natural ventilation by stack effect		Core masses for passive cooling	Tilted façade for catching maximum solar radiation for passive heating
Thermal mass	Not applied	Not applied	Core mass for absorbing the heat	Core next to the sky garden
				

Chapter 7

CONCLUSION

Nowadays, in current era, both in global and local scale sustainability is one of the most important concerns. And it is the reason to try to decrease the impacts of human activities on the environment while trying to increase the life quality. Besides understanding the importance of energy crisis, climate change is another challenge. Both of the mentioned concerns, are critical factors which should considered in the building design.

It is important to keep in mind that annually population growth is around two per cent and by needs of improving the living quality, energy demand is getting more and more. And this energy demand according to expectations will be ten times more in the 2050. In the other hand, mentioned population growth increase the demands for buildings also, and it is the time which high rise buildings which can have huge capacity to inhabit people becoming important. Thus, finding alternatives to use energy resources more efficient is unavoidable. High rise buildings have an ability because of their vast amount of the façade for using sustainable resources. And they can be user friendly and offer a healthy and comfortable atmosphere for users.

Therefore, in order to find new methods, this study tried to analyze methods, design decisions and materials for face of the high rise buildings which can reduce the energy consumption of high rise buildings by providing natural lighting, natural ventilation and passive heating/cooling in comparison to use of fossil fuels for mentioned purposes.

This study started with hypothesis which is standing on a point of view which passive strategies decisions in first steps of design and use of suitable materials can decrease the energy demand of high rise buildings.

However, there is no enough attention paid on this topic. In order to fill this gap, this research has reviewed the design methods decisions, principles and materials in designing the façade of high rise buildings. Furthermore, case studies which are the successful examples designed by Norman Foster for sustainable high rise buildings helped better understanding on this topic.

Next step after introducing the importance of the subject, the study reviewed the subject theoretically to understand the sustainability in chapter three principles, methods, materials for designing sustainable façade were studied through literature review. In the fourth chapter factor of the climate which is important in designing sustainable buildings were studied. Afterwards, from outcomes of chapter three and four the main result of this study which are the checklist for designing sustainable façade according to the climate characteristics and conditions were drawn.

As mentioned previously, for better understanding of the subject, successful examples designed by Norman Foster in different countries which different climate characteristics were analyzed. All cases were analyzed by design strategies and material usage (glazing and opaque materials) which outcome of each one were summarized in the table 19 to 22. All cases designed with different strategies adopted to climate characteristics in order to decrease the energy consumption by providing the natural lighting, natural ventilation and passive heating/cooling strategies.

Finally, this study is showing the point of view for architects, in order to think about sustainability from the first lines in their design. Architects are the ones which can control the energy consumption of their buildings by their decisions, by deciding about strategies and materials to be used in their design. This study can help in this purpose and it can be the first step of the future works.

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