ADAPTING THE QUALITY FUNCTION DEPLOYMENT METHOD TO DESIGN APPROPRIATE BUILDING FACADES

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ABSTRACT

ADAPTING THE QUALITY FUNCTION DEPLOYMENT METHOD TO DESIGN APPROPRIATE BUILDING FACADES

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Advances in technology have changed the lifestyles of most people around the world, thus causing an increase in energy consumption and environmental pollution. Since buildings' facade can play an important role in providing human comfort, decreasing energy consumption, and environmental pollution, facade design should integrate various technologies together by considering construction materials, cost-effectiveness, occupant's requirements, and climatic zones. Considering all of these design parameters together and their complex relationships with each other is not easily achieved by applying conventional design methods. Hence, the Quality Function Deployment (QFD) method, which is based on considering users' needs throughout the design and production phase of industrial products, was studied and the possibility to adapt it to design appropriate building facades was explored.

In this dissertation, a framework, which consists of four phases, was defined by adapting the QFD method. These phases are; Design targets phase, Occupants' requirements phase, Design techniques phase, and Facade design phase. These phases consist of various steps including analysis of 49 case studies, two questionnaire surveys, five Analytic Hierarchy Process (AHP) matrices, and two House of Quality (HoQ) matrices.

To complete these phases, the primary and secondary design targets were determined from a comprehensive literature review and analysis of 49 case studies. Then, this information was used to prepare questions for two dedicated questionnaire surveys regarding the design targets, occupants' requirements, and technical solutions. The surveys were fulfilled by identifying the preferences of occupants regarding their requirements and design targets in the first survey, and preferences of architects about technical solutions and design targets in the second survey. These surveys were conducted with 120 occupants (66 from Turkey & 54 from Iran) and 82 architects (40 from Turkey & 42 from Iran). The data from the questionnaire surveys regarding the primary and secondary design targets were used in five AHP matrices to calculate their priorities. The data from the questionnaire surveys regarding the occupants' requirements and technical solutions were used in the first HoQ matrix to determine the priorities of the technical solutions. In order to calculate the priorities of the appropriate facade systems, output of the first HoQ matrix was transferred to the second HoQ matrix to find their correlation with facade systems determined from the case study buildings. According to the results of the QFD matrices, it is found that adapting QFD method for architectural design improves the design process.

Consequently, the occupants' requirements and architects' opinions regarding the complex design parameters were transferred from one design phase to the other without getting lost to achieve a universally acceptable and appropriate facade design. In conclusion, the QFD framework proposed in this dissertation can be used not only to design appropriate facade systems but also other building components, even entire buildings, by considering user requirements.

Keywords: Quality Function Deployment Method, Solar Facade, Efficient Facade, High-Performance Facade

ÖZ

KALİTE FONKSİYON GÖÇERİMİ METODUNUN UYGUN BİNA CEPHE TASARIMI İÇİN UYARLANMASI

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Teknolojideki gelişmeler, dünyadaki çoğu insanın yaşam tarzını değiştirerek, enerji tüketiminde ve çevre kirliliğinde artışa neden olmuştur. Binaların cephesi, insan konforunun sağlanmasında, enerji tüketiminin ve çevre kirliliğinin azaltılmasında önemli bir rol oynayabileceğinden dolayı, cephe tasarımı için, inşaat malzemeleri, maliyet etkinliği, bina sakinlerinin gereksinimleri ve iklim bölgeleri göz önünde bulundurularak çeşitli teknolojiler bir araya getirilmelidir. Tüm bunları göz önünde bulundurarak, tasarım parametreleri ve birbirleriyle olan karmaşık ilişkileri, geleneksel tasarım yöntemlerini uygulayarak kolayca sağlanamamaktadır. Böylelikle endüstriyel ürünlerin tasarım ve üretim aşaması boyunca kullanıcıların ihtiyaçlarını göz önünde bulundurmaya dayanan Kalite Fonksiyon Göçerimi (Quality Function Deployment - QFD) yöntemi çalışılmış ve bu yöntemin uygun bina cephelerinin tasarımında uyarlama imkanı araştırılmıştır.

Bu tezde QFD yöntemi uyarlanarak dört aşamadan oluşan bir çerçeve tanımlanmıştır. Bu aşamalar; Tasarım hedefleri aşaması, Yolcuların gereksinimleri aşaması, Tasarım teknikleri aşaması ve Cephe tasarım aşamasıdır. Bu aşamalar, 49 vaka analizi, iki anket, beş Analitik Hiyerarşi Süreci (Analytic Hierarcgy Process - AHP) matrisi ve iki Kalite Evi (House of Quality - HoQ) matrisinin analizi dahil olmak üzere çeşitli adımlardan oluşur.

Bu aşamaları tamamlamak için, birincil ve ikincil tasarım hedefleri, kapsamlı bir literatür taraması ve 49 vaka analizi belirlenmiştir. Daha sonra bu bilgiler, tasarım hedefleri, bina sakinlerinin gereksinimleri ve teknik çözümlerle ilgili iki özel anketin sorularını hazırlamak için kullanılmıştır. İlk ankette bina sakinlerinin ihtiyaçları ve tasarım hedefleri ile ilgili tercihleri, ikinci ankette ise mimarların teknik çözümler ve tasarım hedefleri konusundaki tercihleri belirlenerek anketler gerçekleştirilmiştir. Bu anketler 120 bina sakini (Türkiye'den 66, İran'dan 54) ve 82 mimar (Türkiye'den 40, İran'dan 42) ile yapılmıştır. Birincil ve ikincil tasarım hedeflerine ilişkin anketlerinden elde edilen veriler, önceliklerini hesaplamak için beş AHP matrisinde kullanılmıştır. İlk HoQ matrisinde, teknik çözümlerin önceliklerini belirlemek için bina sakinlerinin gereksinimleri ve teknik çözümlerle ilgili anketlerinden elde edilen veriler kullanılmıştır. Uygun cephe sistemlerinin önceliklerini hesaplamak için, ilk QFD matrislerinin sonuçlarına göre, QFD yönteminin mimari tasarıma uyarlanmasının tasarım sürecini geliştirdiği saptanmıştır.

Neticede, karmaşık tasarım parametreleri ile ilgili bina sakinlerinin gereksinimleri ve mimarların görüşleri, evrensel olarak kabul edilebilir ve uygun bir cephe tasarımı elde etmek için saklanarak, bir tasarım aşamasından diğerine aktarılmıştır. Sonuç olarak, bu tezde önerilen QFD çerçevesi, kullanıcı gereksinimleri göz önünde bulundurularak yalnızca uygun cephe sistemlerini tasarlamak için değil aynı zamanda diğer bina bileşenlerini, hatta tüm binaları tasarlamak için de kullanılabilir.

Anahtar Kelimeler: Kalite Fonksiyon Göçerimi Yöntemi, Güneş Cephe, Verimli Cephe, Yüksek Performanslı Cephe

To my parents and my brother who always supported
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ABBREVIATIONS

AHP: Analytic Hierarchy Process

BIPV: Building Integrated Photovoltaic

BIPV/T: Building Integrated Photovoltaic Thermal

BIST: Building Integrated Solar Thermal

BIWT: Building-Integrated Wind Turbines

DEC: Direct Evaporative Coolers

DSF: Double Skin Facade

DQDC: Demanded Quality Deployment Chart

GRP: Glass Reinforced Polyester or polycarbonate

HoQ: House of Quality

IEC: Indirect Evaporative Coolers

PDC: Parts Deployment Chart

PV: Photovoltaic

QCDC: Quality Characteristic Deployment Chart

QFD: Quality Function Deployment

UPVC: Un-Plasticized Polyvinyl Chloride

WWR: Window to Wall Ratio

CHAPTER 1

INTRODUCTION

1.1 Argument

Since their earliest existence, human beings have been looking for ways to achieve comfort in terms of cooling or heating during different seasons. Advances in technology have led to changes in lifestyle, which has resulted in increased energy consumption. Approximately, 76% of all power-plant-generated electricity is used to operate buildings: heating, cooling, lighting, hot water, and the plug load (Lovell, 2010). Using fossil fuel as an energy source of heating in building over the years has brought many problems such as air and water pollution, deforestation, producing greenhouse gases, and toxic emissions that lead to global warming; which is dangerous for humans, animals, and the planet.

External walls play an important role in building energy consumption by affecting cooling and heating energy uses, which decrease the level of energy needed by mechanical systems (Manioglu and Yilmaz, 2006). In other words, the most critical component of the building is its envelope. Hence, a poor facade design leads to higher energy consumption and poor comfort condition; whereas, a well-designed and high-performance skin can improve building energy performance by providing higher quality and reducing the thermal load in the building (Bessoudo, 2008).

Separating an inside environment from an external one is the facade’s primary function , but innovation in the facade systems can achieve some secondary functions as well (Knaack and Klein, 2009). For example, a current approach for ventilation is to get the fresh air directly from outside and treat or preheat it with devices that are part of the facade system, and circulate through the building. In other words, instead of an extended system of ducts, a centrally controlled airflow system is integrated into the facade functions (Knaack and Klein, 2009).

Energy efficient building facades have to be weather tight, resist water penetration to the interior spaces, control air leakage and condensation, and resist wind loads (Brock, 2005). There are several factors, which should be considered in designing proper facades; these are: preventing heat transfer, gaining solar energy in the winter, preventing solar heat-gain in the summer, providing natural light and natural ventilation, being weather tight, and preventing outside noise (Brock, 2005).

Building facades play an essential role in transferring energy between the internal environment and the continuously changing external environment in order to provide the human body's comfort levels (Brock, 2005). Owing to the large area of the facade in most buildings, they are more appropriate for producing energy as well as preventing thermal energy gain or loss. Therefore, architects and engineers try to utilize various technologies to optimize energy consumption and comfort conditions, as well as to use renewable energies instead of fossil fuels. In this regard, different techniques and materials are being investigated in order to use renewable energies for cooling, heating, and lighting systems and their applications to the buildings' facades. Such techniques can be passive or active: in passive facade systems, renewable energies like solar energy are used for heating, cooling directly though the facades without utilizing any mechanical systems; while, in active facade systems, renewable energies are converted to thermal or electrical energies by using mechanical systems.

In order to select appropriate facade systems according to the climatic zone, there are many factors that should be considered to provide human comfort as well as reduce energy consumption and environmental pollution. These factors are cost-effectiveness, suitable facade systems, environmentally friendly materials, energy generation, efficient active and passive techniques. Considering all factors and their relationship with each other in the design process is not easy. Therefore, the Quality Function Deployment (QFD) method, which is being used in the industrial sector to increase production quality, is proposed as a method to design appropriate facades in this dissertation. The QFD method is based on user requirements considered in the whole design process by transferring them from one stage to the other through the QFD matrices. These matrices are Analytic Hierarchy Process (AHP) matrices and House of Quality (HoQ) matrices, in which the priorities of design parameters like design targets, occupants' requirements, technical solutions, and facade systems are calculated to come to appropriate design decisions.

The Quality Function Deployment (QFD) method was developed by Yoji Akao in Japan in 1966 to increase industrial products' design quality. This new method was employed for the first time at Mitsubishi's Kobe shipyard site in 1972 to improve the quality of their products. According to Hauser and Clausing (1988), Toyota transformed into one of the best producers of cars in the world, from being the worst, by using the QFD method. In this method, the customer requirements are the basis for design strategy, which are considered throughout all processes, namely; product design, engineering, and production (Mujalda *et al*., 2015). Maritan (2014) points out that the main strategy of QFD is to concentrate on customer needs in all design stages and transfer them into technical specifications in each stage of the production process in order to have cross-functional management rather than product management. According to Antony and Preece (2002), QFD is a planning technique rather than a quality technique; by focusing on teamwork and making a relationship between current performance and customer satisfaction, QFD creates a clearer view to design. Moubachir and Bouami (2015) state that QFD is a flexible method, which can be used in various engineering fields according to the type of products that have to be manufactured.

Hence, for the first time, the QFD method has been selected to simplify the complex decision-making processes in architectural design and developed further to be used in the production of appropriate facades. In the selected method, the requirements of the building occupants as well as the technological and environmental factors were considered in the design process.

1.2 Aim and Objective

For designing appropriate building facades, it is necessary to consider various parameters such as the climatic and geographical characteristics, durability of the building materials, components and systems, maintenance strategy, glazing area sustainability issues, budget and costing, facade's form and aesthetics, acoustic comfort, thermal comfort, daylight penetration, glare control, solar gain control, ventilation, structural design. In order to integrate all of these parameters into facade design, there are far too many technical solutions, which have to be investigated by the architects and engineers teams; and this is a very difficult and time-consuming task.

Furthermore, during the design process, the impacts of various techniques on each other have also to be determined because selecting any two technical solutions that impact each other negatively can affect the overall performance of the facade. Furthermore, the relationship between different design parameters and technical solutions also plays an important role in the facade's design. Managing the design process by considering all parameters and their relationships with technical solutions is not possible by the conventional design methods.

1.3 Research Objective

This research aims to define a system for designing facades that respond to occupant requirements, save energy, and integrate the use of renewable energy to reduce costs and environmental pollution. However, designing such facades is a very complex and difficult task because it involves making the right decisions regarding countless design variables; hence, another aim was to find a decision-making method that would simplify this complex process.

Therefore, the objective of this research is to adapt the QFD method, which is conventionally utilized in the design and manufacture of consumer products, for designing buildings and their components. The QFD method helps designers make right decisions by considering opinions of occupants and architects to achieve the design targets.

1.4 Research Questions

Four questions have been addressed in this study;

How can we select facade systems that are appropriate to reach the design target?

How can we design appropriate facades without losing sight of the residents' request?

Can we adapt the QFD method from industrial engineering to architecture design?

How can we create a framework by adapting the QFD to design appropriate facades?

1.5 Research Methodology

In order to identify the most effective passive and active facade techniques, which also respond to occupants' requirements, the Quality Function Deployment (QFD) method was selected and adapted in the following manner.

First of all, information and data required for defining the design targets, occupant requirements and technical solutions were obtained by analyzing 49 case study buildings and studying published research papers and reports. Then the importance of them were determined through two questionnaire surveys, which are conducted with architects and occupants. The results of these questionnaire surveys were used in the four phases of the QFD model that are given below.

i. Design targets phase: The aim of this study was to choose the best design option for producing a facade that can improve the building's performance by providing human comfort and decreasing cost as well as assist in decreasing environmental pollution caused by materials and method of construction. These aims were considered as the primary strategic design targets and each primary target was divided into secondary design targets. In order to decide which targets are more important than others, two questionnaire surveys were conducted with occupants and architects. At the end of this phase, the priorities of primary and secondary targets were defined by four Analytic Hierarchy Process (AHP) matrices.

ii. Occupants' requirements phase: In this phase, occupants' requirements were defined with respect to the primary and secondary targets identified in the first phase. Then, the importance of the occupants' requirements was asked through the first questionnaire survey, which also includes questions regarding design targets.

iii. Design techniques phase: After defining innovative and technical solutions for designing appropriate facades, their importance was determined by architects through the second questionnaire survey. The first House of Quality (HoQ) matrix was then made to determine the technical solutions' priorities by using information from both questionnaire surveys.

iv. Facade design phase: In this phase, the options for appropriate facade systems were identified, which were classified into two groups: active and passive facade systems. Then, the priorities of applying these facades were determined in the second HoQ matrix.

1.6 Disposition

This dissertation contains 6 chapters as follows:

Chapter 1 introduces argument, objectives and the methodology of the research.

Chapter 2 describes the literature review.

Chapter 3 presents the materials and methods of research.

Chapter 4 contains the case studies.

Chapter 5 includes the results of the research that are discussed individually.

Chapter 6 contains the conclusion of this dissertation.

CHAPTER 2

LITERATURE REVIEW

This literature review is based on 158 sources on the topics of appropriate buildings' facade. Main concerns in designing appropriate buildings' facade are energy-efficient facade systems, parameters of human comfort requirements, and the methodology which correlates facade systems and human comfort. In this research, facade systems human comfort requirements and Quality Function Deployment (QFD) are discussed thoroughly in following three sections.

2.1 Building Facade Systems and Technologies

Knaack and Klein (2009) state that separating an inside environment from an external one is the primary function of a facade, but innovation in the facade systems can achieve some secondary purpose. Gilanil, Blanco and De la Fuenta (2017) indicate that building envelopes can protect interior spaces from outside impacts like climate change, humidity, temperature, and pollution.

According to Volp (2018) facade design aims to respond to the occupants' requirements and make them satisfied with the following aspects of the building:

- Aesthetic, because the appearance of facades defines the importance and image of the building.
- Security in terms of structural integrity and control of fire spread.
- Comfort (thermal, visual, acoustic) and indoor air quality.
- Easy and safe maintenance of facades.

- Durability and extension of life expectancy of facades which is affected by types and durability of materials, design details, and fabrication process.

2.1.1 Facade Systems

Aksamija (2013) explains that for designing efficient facades, selecting the right envelop materials and facade systems is essential. For example, highly conductive materials like metal create thermal bridges that affect the thermal resistance of the envelope negatively. Halawa, Ghaffarianhoseini, Ghaffarianhoseini, Trombley, Hassan, Baig, Yusoff, and Ismail (2018) state that facade materials play a considerable role in having energy-efficient buildings and indoor thermal comfort.

Al Thobaiti (2014) points out that efficient building envelop not only protects the interior environment as filters from exterior climatic changes but also it improves energy consumption, daylighting, ventilation, and indoor air quality.

Facade systems depend mainly on the choice of the construction materials such as metals, glass, concrete, plastics, or wood. The advantages and disadvantages of the various systems and materials for designing efficient facades are explained briefly as follows:

a) Metal Walls: Watts (2011) classifies six types of metal walls, namely: sheet metal envelope (copper, lead, zinc, or stainless steel sheets to produce soft and complex geometries), profiled metal cladding (can be curved in one direction to produce unidirectional curved surfaces), composite panels, rainscreens (zinc and copper to produce complex or curved geometries), mesh screens (rigid, flexible in one direction, and fully flexible mesh to produce different visual effects, and transparency), and louvers (metal or glass for weather-resisting screens and solar shading on glazed facades).
b) Glass Walls: According to Bessoudo (2008), glass facades provide transparency between inside and outside and maximum daylight and view. In addition, heat loss and gain through the glazing is reduced significantly by

using high performance glass. Glass facades can be produced using Stick glazing systems (for flexibility, speed of installation, ease of handling and storing (Brock, 2005)), unitized glazing panels (factory assembled for speed of construction in tall buildings (Brock, 2005)), frameless clamped glazing system (to achieve a geometrically complex facade (Rice and Dutton (1995)), bolt-fixed glazing (Button, 1993), and glass block walls (solid for durability and fire-resistance, hollow for thermal and acoustic insulation, Watts (2011)).

c) Concrete Walls: Cast in-situ (using molds or formwork as structural walls with thermal insulation Watts (2011)) and precast panels (load-bearing walls or non-loadbearing cladding panels for speed of building, better quality, and variety of surface finish (Brookes and Meijs, 2008)). According to Watts (2011), loadbearing panels are more popular due to their tight weather structure, thermal mass, high fire resistance, and high acoustic insulation; whereas non-loadbearing cladding panels provide considerable freedom in design.

d) Plastic wall made of Glass Reinforced Polyester (GRP) or polycarbonate and Unplasticized Polyvinyl Chloride (UPVC) (Watts, 2011). GRP is a composite material made from durable resins and glass-fiber, which is fire resistant with high tensile, weather resistant, durable, lightweight and has high thermal insulation, high strength, and high ductility ((Brock, 2005) and (Brookes and Meijs, 2008)) while they are less durable than glass (Watts, 2011). UPVC is used for window frames and external finish of the facades because they have durability, light weight, weather resistance, thermal and sound insulation capability (Watts, 2011).

e) Timber frame walls with cladding are easy to construct but sometimes used only for aesthetical purposes rather than economical or durability purposes (Brock, 2005). While timber boards are used for cladding to construct opaque facades, timber louvers are used to produce semitransparent facades (Watts, 2011).

2.1.2 Facade Technologies

New techniques are being investigated to produce buildings that are more efficient and use renewable energies to reduce carbon footprint. The most abundant and freely available resource is solar energy, which can be harvested through the building envelope and used for providing heating, cooling, electricity and hot water. Such building envelopes are generally referred to as solar facades, and can be classified into two main groups; opaque and transparent or translucent solar facades (Quesada, Rousse, Dutil, Badache and Halle, 2012). Both of these groups may have single or Double Skin Facades (DSF) and may use passive or active systems to maximize the integration of solar energy. However, both are fixed or stationary facades. On the other hand, solar envelopes are undergoing a true revolution and their performance is being improved by adding movement to the facades or their components, in order to respond to the external climatic conditions. Such envelopes, that are also called kinetic facades, either track the sun to gain more energy for the buildings or use movable devices to avoid excessive solar gains (Deljavan and Elias-Ozkan, 2017). Various types of facades, which increase the human comfort of building and reduce energy consumption are explained in the following sections.

2.1.2.1 Passive Techniques

Lopez (2011) defines passive systems as those that use renewable energy for the energy requirement of building without applying active (mechanical) systems. Additionally, renewable energies are converted to thermal by passive technologies in order to use or store (for future use) in the buildings. Loonen, Trčka, Cóstola, and Hensen (2013) believe that designing passive systems for buildings depends on facades' shape, which plays a significant role in getting, storing, and distributing solar and wind energies.

Aelenei, Aelenei, and Vieira (2016) explain that the factors like the amount of solar radiation, outdoor temperature and humidity, direction and velocity of wind, amount of precipitation, and outdoor noise, especially traffic noise in various seasons, influence the designing of efficient facades, which apply passive techniques.

2.1.2.1.1 Double-Skin Facades

Heusler (2001) states that a double-skin facade (DSF) works on a multilayer principle consisting of an external facade, an intermediate space, and an inner sealed or operable facade. Arons (2000) has examined the major objectives of double skin facades in seven headings:

- Energy savings and ecological responsibility
- Natural ventilation
- Cost savings: Double-skin facades are significantly more expensive to install; however, it can reduce the initial construction cost of buildings by reducing heating and cooling loads of the envelope in the long-term.
- Sound reduction
- User control and comfort: By enabling occupants to control light with louvers or shades and control air movement and temperature with operable windows, the interior comfort is enhanced.
- Occupant productivity and contact with the environment increase through the glass wall.
- Security: DSFs increase security by having double layers.

Compagno (2002) and Heusler (2001) classify the double-skin facade into four systems (Figure 2.1): multistory facade or the building-high double-skin facade where the cavity extends over the whole height of the building and ventilation (air intake and extract) occurs via large openings at the top and bottom of the cavity, corridor facades where the cavity is divided horizontally into story-high sections for better acoustics, fire protection, or ventilation reasons, box windows where each unit requires its own air intake and exhaust openings, and shaft-box facades have vertical shafts that link the box windows vertically through bypass openings in order to suck out the air from the box windows into the vertical shafts and exhausted from the top using the stack effect.

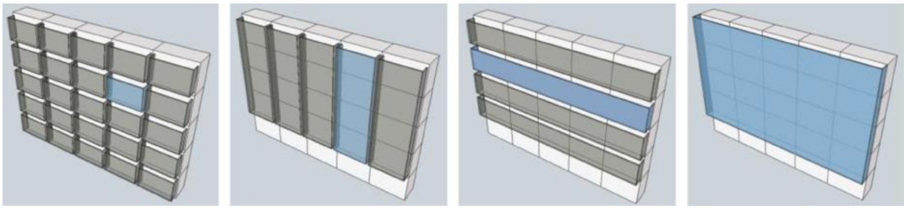


Figure 2.1 Types of double skin facades: Box Window, Shaft-Box Facades, Corridor Facades and Multistory facade (Barbosa and Ip, 2014)

According to Arons (2000), two kinds of operations occur in the DSF systems, which are winter and summer operations. In summer, the heated air of cavity exhausts by stack effect to keep the interior layer's temperature lower for preventing heat transfer to inside the building. Therefore, it decreases energy consumption for cooling of interior spaces. In winter, there are two ways to decrease energy consumption through double skin facades. The first technique is closing the system to prevent air circulation, which acts as a buffer. Therefore, the heat transfer by conductivity, convection, and radiation from inside to outside will be reduced. The second technique is introducing warm air into the cavity from the interior of the building to warm the inner layer of the facade to achieve the same result as the first technique.

Knaack and Klein (2009) explain that the advantage of two glass walls in a DSF is that the exterior wall in DSF can take up wind load and can provide water tightness and acoustic insulation against external noise. While, the interior wall separates inside space from outside and acts as a buffer. According to Fortmeyer and Linn (2014), the extra skin can improve energy efficiency, ventilation quality, insulation of buildings, and reduce cooling demand in summer and heating demand in winter.

Alemdağ and Beyhan (2017) explain that a DSF cavity can have a width from 20 to 200 centimeters, which can be used for maintaining, repairing, and cleaning purposes. Moreover, employing static or movable solar control elements in the cavity prevents the inner layer from overheating. On the other hand, Pomponi, Piroozfar, Southall, Ashton, Farr (2015) suggest having a narrow cavity is better for the stack effect to work. The type of glass, size, and location of sun shading in the cavity, the width of the opening, the operable interior or exterior glass layer, the vent size of the exterior layer, and ventilation systems impact the air temperature and flow in the cavity.

Gratia and De Herde (2007) research shows that the cooling load can be decreased by 23.2% by paying attention to three points: the solar shading position in the cavity, the color of solar shading, and designing opened double-skin facades. The light color blinds in the cavity decrease the cavity temperature significantly.

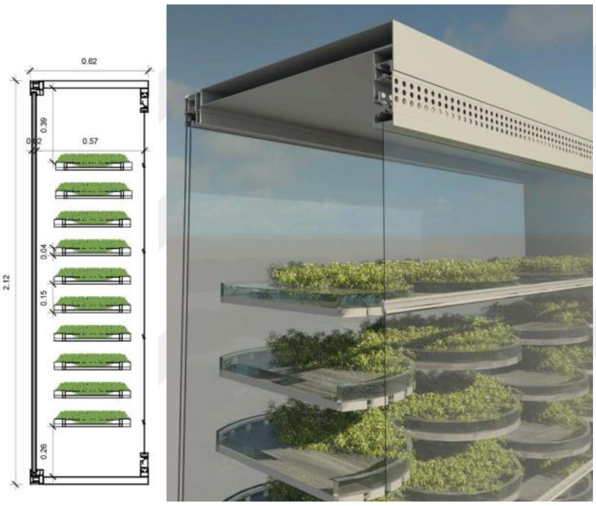


Figure 2.2 Double-skin facade with plant in the cavity to refresh indoor air (Parhizkar *et al*., 2017)

Barbosa and Ip (2014) explain that applying thermal mass in the interior layer of DSF in a hot climate reduces the cooling load of buildings. Moreover, they suggest a low transmittance glass with high absorption for the exterior layer to prevent heat gain. Pomponi *et al*. (2015)'s study indicates that double-skin facades significantly reduce lifecycle of energy consumption and carbon footprint in the renovation of existing building. Parhizkar, Khoraskani, and Tahbaz (2017) propose to grow plants in the DSF cavity (Figure 2.2, above), which can filter indoor air naturally by absorbing CO_2 through photosynthesis. Growing 10 m^2 of Azolla in the cavity can decrease the need for mechanical ventilation by 25.4% for an office with two occupants.

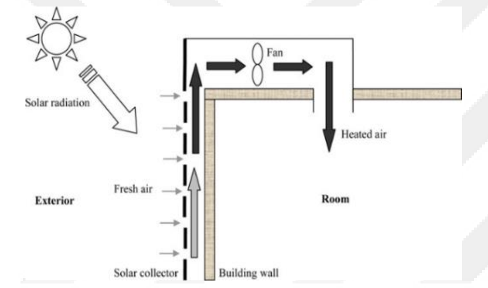
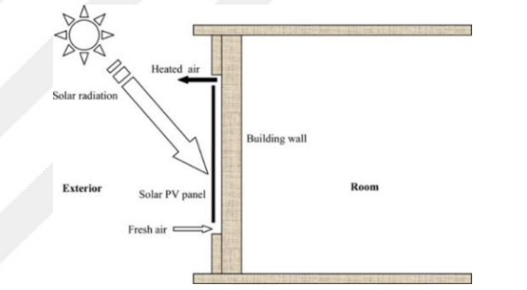
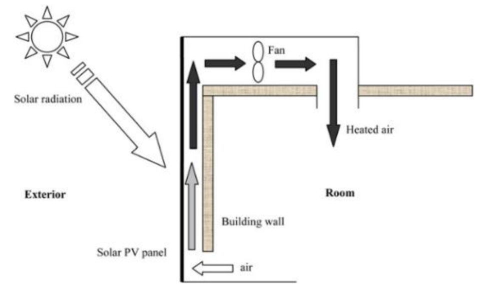
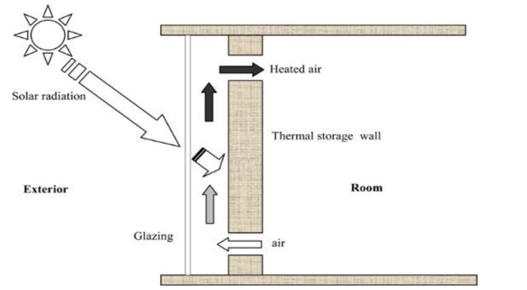
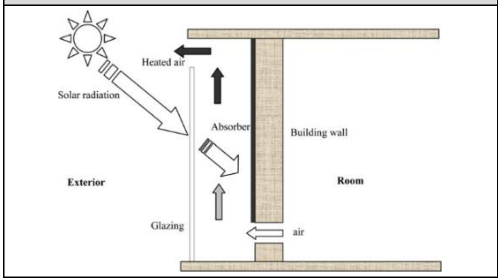
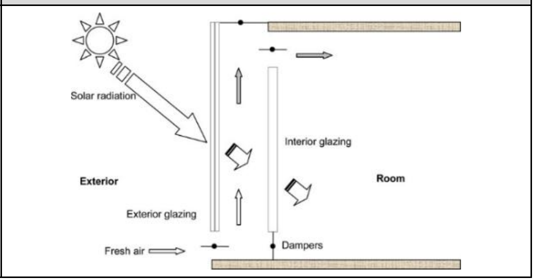
2.1.2.1.2 Solar Facades

According to Quesada *et al*. (2012) "*... solar architecture is undergoing a true revolution because of the development of special facades involved in the processes of heating, ventilation, thermal isolation, shading, electricity generation and lighting of homes: these are called solar facades*." (p.1) Solar facades use radiation from the sun to provide heating, cooling, and hot water in buildings especially in high rise buildings which have larger facade surfaces (Heusler, 2001).

Solar facades are divided into two systems: passive and active (Gevorkian, 2008). In passive or direct systems solar heat is gained and distributed by using the materials' physical or chemical properties. While, in active or indirect systems solar heat collection and distribution are supported mechanically. Quesada *et al.* (2012) give another classification of solar facades based on their opacity, transparency or translucency. According to Quesada *et al*. (2012), opaque solar facades absorb and reflect solar energy instead of directly transferring the solar heat into the buildings. They can either be active facades that produce electrical or thermal energy from solar radiation by utilizing electrical/mechanical equipment, or passive facades that transform the solar radiation into thermal energy for heating, cooling, or ventilation of buildings (Quesada *et al*., 2012). Active opaque facades can be further divided into building integrated solar thermal (BIST) where solar collectors are installed on the facade to produce thermal energy (Table 2.1), building integrated photovoltaic (BIPV) where PV cells/panels are installed on the building envelops (Table 2.1), and building-integrated photovoltaic thermal (BIPV/T) system which is a combination of BIPV and BIST systems thus, producing both electrical energy and air/water heating (Table 2.1). Meanwhile, passive opaque facades can either be used as thermal storage (Trombe) walls which absorb solar heat that can be transferred to the indoor space by radiation or natural convection (Table 2.1), or as a solar chimney wall facing the sun, with glazing mounted on a solid wall so that the heated air in the cavity between the two produces an updraft in the chimney that facilitates natural stack ventilation through the building (Table 2.1).

According to Quesada *et al*. (2012) transparent and translucent solar facades, like opaque solar facades, also absorb and reflects solar radiation and transfer solar heat into the building in an active or passive way. Transparent and translucent active solar facades use mechanical and electrical equipment to transform solar radiation into electrical or thermal energy for buildings. While, transparent and translucent passive solar facades use direct solar energy for heating and ventilation purposes without using any electrical or mechanical equipment (Table 2.1).

Table 2.1 Schematic diagrams of solar facades (Figures taken from Quesada *et al*., 2012)

<table>
<tr><th colspan="2">Schematic Diagrams of Solar Facades</th></tr>
<tr><td>Building-Integrated Solar Thermal (BIST) system</td><td>Building Integrated Photovoltaic (BIPV) system</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Building-Integrated Photovoltaic Thermal (BIPV/T) system</td><td>Thermal Storage Wall</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Solar Chimney wall</td><td>Transparent and Translucent Passive Solar Facades</td></tr>
<tr><td>
</td><td>
</td></tr>
</table>

2.1.2.1.3 Ventilated Facades

Sinclair, Phillips, and Mezhibovski (2009) state that a double-skin facade also is known as a ventilated facade or active curtain wall in which the cavity is ventilated to extract heat gain. As shown in Figure 2.3, the authors classify DSFs into four ventilation strategies namely: mechanically ventilated airflow, mechanically ventilated supply, ventilated exhaust, naturally ventilated. Alemdağ and Beyhan (2017) add another strategy, in which there is no circulation and the cavity acts as a buffer or an insulation layer. Additionally, operable windows on the interior glass wall can be advantageous in tall building because of high wind loads on the facades (Poirazis, 2004) and can improve natural ventilation and nighttime cooling (Fuliotto, 2008).

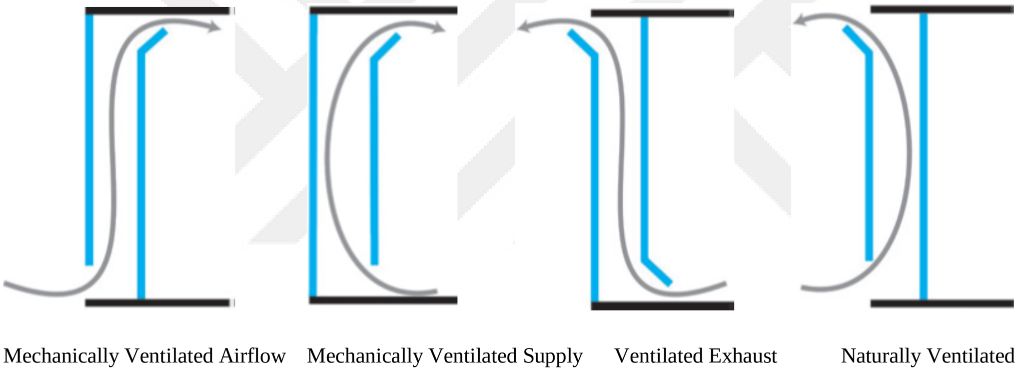


Figure 2.3 Internal and external ventilation conflagrations of DSFs (Sinclair, 2009)

The DSF ventilation system is mostly used in cold climates whereas wind catchers or wind towers are the traditional ventilation systems that are used in hot climates. Bahadori and Dehghani-sanij (2014) explain that the purpose of wind tower (*Baudgeer*) is to create a cooling natural ventilation by exchanging air between inside and outside buildings in regions with a hot and dry or hot and humid climate and strong seasonal winds. The wind tower is built to face the prevailing wind direction and has one, two, four, six, or even eight sides opening on the top, depending on the direction of wind. The inner passage is divided into two, four, six, or eight channels. Figure 2.4 shows the air movement in a typical *Baudgeer*.

According to Bahadori and Dehghani-sanij, (2014) wind towers also act as a chimney at night to exit hot air as fresh air entering the building from windows and doors, which absorbs the heat from the internal surfaces, and this heated air is exhausted through the wind tower passages because of the chimney effect. During the day the wind tower acts as a wind catcher and hot air entering it loses its heat to the walls and surfaces, which had become cooler during the previous night, and flows through the building and escapes through the doors and windows.

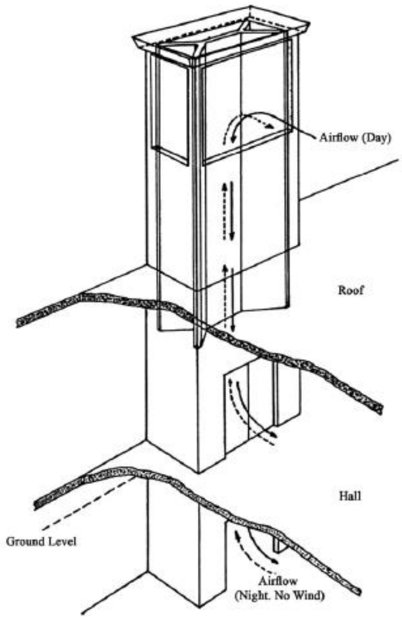


Figure 2.4 A Common wind tower. The airflow is shown by arrows during the day and the night. (Bahadori and Dehghani-sanij, 2014)

2.1.2.1.4 Evaporative Cooling Systems

Amer, Boukhanouf, and Ibrahim (2015) state that evaporative cooling is a process of transferring heat from ambient air to water in evaporative coolers of which there are three types: Direct Evaporative Coolers (DEC) where air and water are in direct contact. Indirect Evaporative Coolers (IEC) where the two fluids are separated by a plate, and a combination of the two systems. Ramkumar and Ragupathy (2015) state that the DEC system (active or passive) is widely used in a dry and hot climate.

According to Pistochini and Modera (2011), active DEC systems consist of evaporative media such as wettable and porous pads, water tank, fan for blowing air through the pads, water distribution system, and recirculation pump. When hot and dry air passes through the wetted pad it becomes moist cooled air because water absorbs the heat from the air to evaporate thus causing a decrease in air temperature and increase in its humidity. The types of pads used in such coolers are shown in Figure 2.5 (Amer *et al.*, 2015).

Figure 2.5 Pads used in active direct evaporative coolers (Amer *et al.*, 2015)

Amer *et al.* (2015) divide the passive DEC system into three types: the *Mashrabiya*, wind tower, and roof ponds. The first two can provide evaporative cooling through facades. A *Mashrabiya* is a wooden screen in front of the window to provide shade and allow breezes to flow inside the building. Fardeheb (2009) explains that if porous earthen water-jugs are added to Mashrabiya, cooling air will be provided for occupants, and they can drink cooled water from these jugs. Al- Fardeheb (2009) suggests that an evaporative cooling system using clay pottery or pipes is a novel approach to have cool air with low water consumption. (Figure 2.6)

Amer *et al*. (2015) explains that there are two types of IECs that are used to decrease the air temperature without changing its humidity: a. the wet-bulb temperature IEC which has a dry passage for the primary air and a wet passage for the secondary air, b. the sub-wet-bulb temperature IEC, which the secondary air flows into the dry passage to become cool before passing through the wet passage in order to have more heat transfer in the dry channel. These two systems can be combined to have a more effective evaporative cooling system.

According to Moshari, Heidarinejad and Fathipour (2016, p 309), the evaporative cooling system is more energy efficient and environmentally friendly than a mechanical vapor compression system but it needs more maintenance and is not suitable for humid regions.

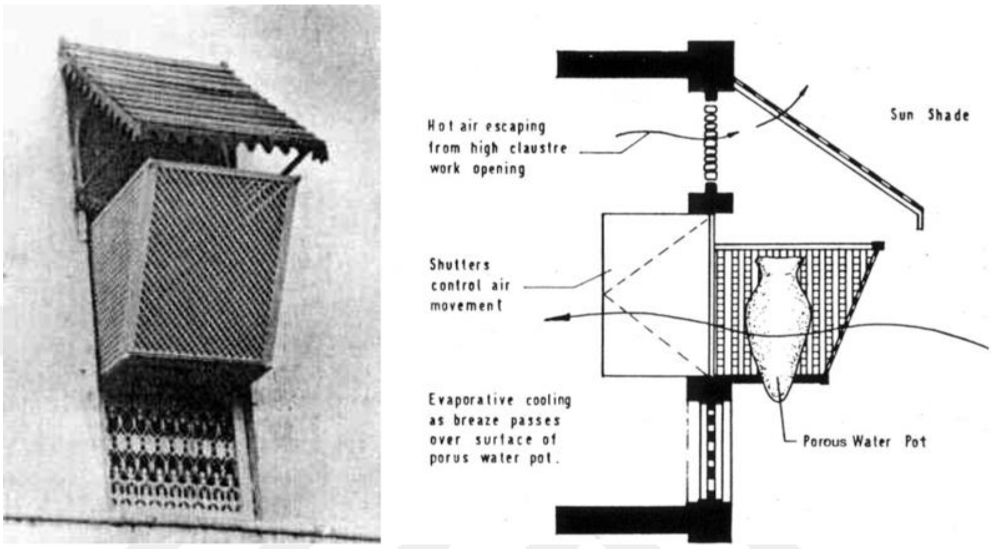


Figure 2.6 Water-jugs are added to Mashrabiya to provide cooling

2.1.2.1.5 Shading Devices

In order to prevent solar heating passively, shading is needed as one of the sustainable strategies to decrease energy consumption significantly. Solar shading systems affect energy consumption for heating, cooling, lighting, and visual comfort (Natural light, View, Glare) (Lechner, 2009; Belliaa, Pedacea, Minichielloa and Pedacea, 2014; and Kirimtat, Chatzikonstantinou and Sariyildiz, 2016). Shading devices should maximize daylight while minimizing energy consumption for cooling (Kirimtat *et al*., 2016). Lechner (2009) states that shading of the whole building can be more useful, but the shading of windows is necessary; while each window orientation needs different shading strategy because of the sun’s moving path. Shading devices can be installed inside, outside, or even within a double glazing or

DSF cavity. The external shading devices not only block the direct solar radiation but also decrease the impact of the reflected and the diffuse components.

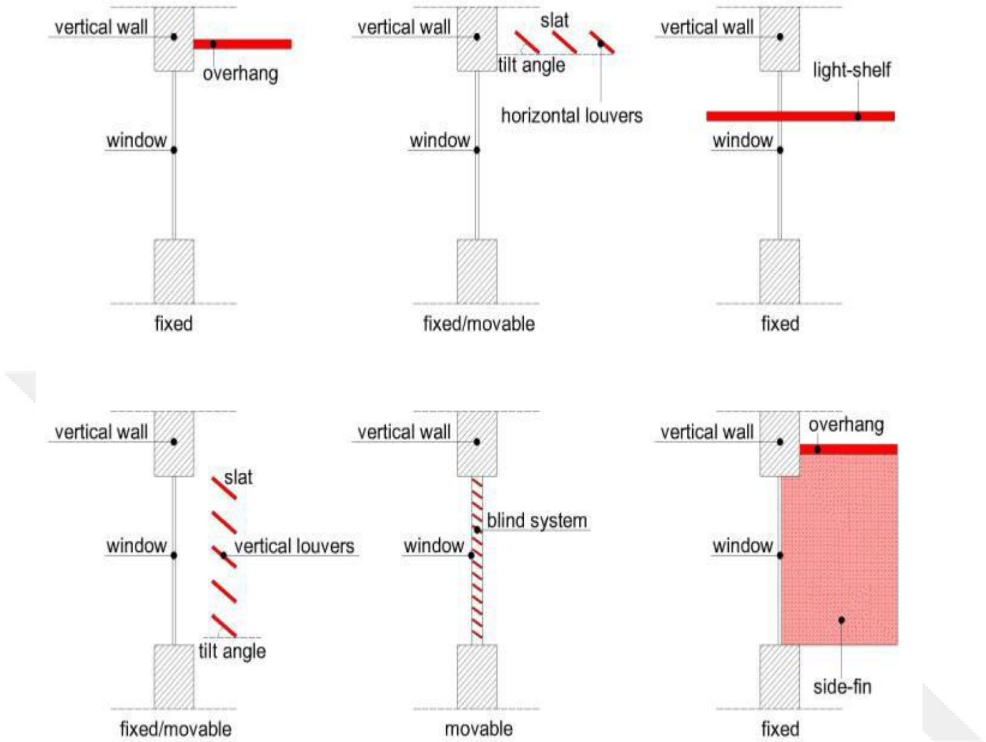


Figure 2.7 Types of shading systems (Belliaa *et al.*, 2014)

Belliaa *et al.* (2014), define different types of fixed and movable shading systems (Figure 2.7, above). Additionally, mention that light shelves type of shading systems are more useful than overhang ones to have more daylight. Although, light shelves are not suggested for north windows they can be combined with overhang types and side fins to reach higher illuminances.

Kirimtat *et al* (2016), Lechner (2009) and Valladares-Rendon, Schmid and Lo (2017) state that external shading devices are more useful than internal ones, and fixed shading systems are more economical than movable ones. A well-designed system can provide a balance between shading, visibility, and daylighting as well as saving energy in the buildings. Figure 2.8 shows the classification of shading devices, according to Valladares-Rendon *et al* (2017). Lechner (2009) and Valladares-

Rendon *et al* (2017) state that horizontal shading devices prevent overheating during hot months while permitting maximum solar heat to enter during cold months. Moreover, they mention that horizontal shading devices are most effective systems on the south, east, and west windows in the summer days.

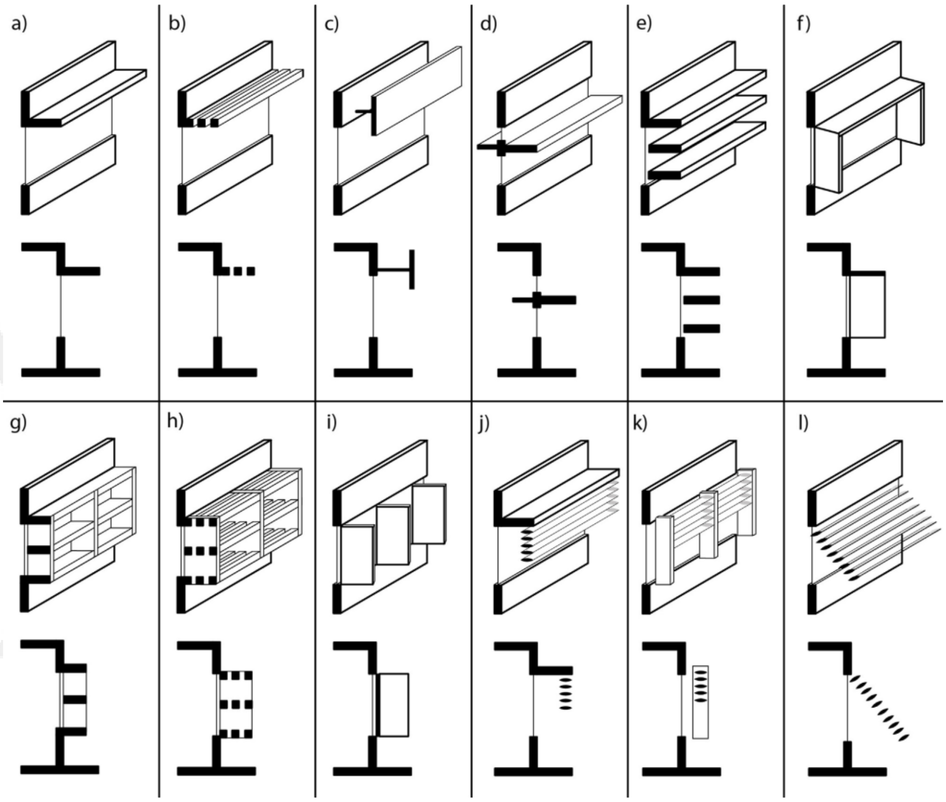


Figure 2.8 Shading devices (Valladares-Rendon *et al.*, 2017)

While overhang systems are better than louvers and fins in providing a complete horizontal view, they will obstruct the high sky. In that case, it is possible to use several small horizontal lovers, which have the same effect as a large overhangs (Figure 2.9) (Lechner, 2009).

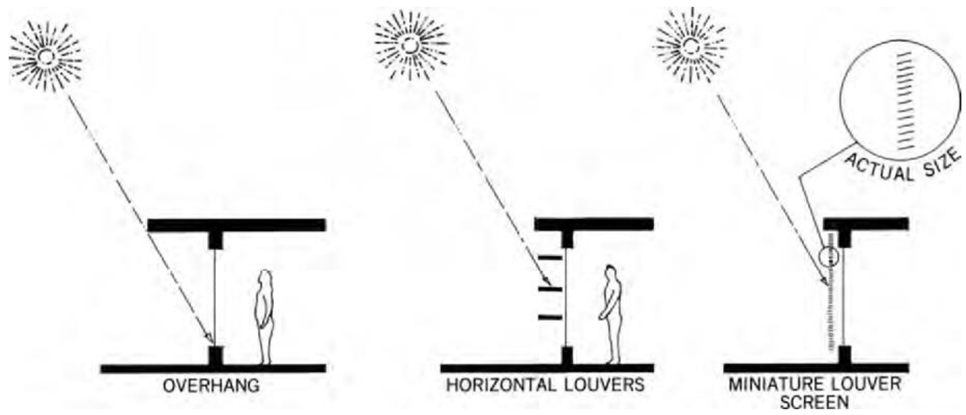


Figure 2.9 Comparing shading devices with different sizes, which have same effect (Lechner, 2009)

The last type of fixed shading device is eggcrate, which is a combination of vertical fins and horizontal overhang (louvers). This shading device is suitable for the west and east windows in hot climates; however, it obstructs the views. In addition, the eggcrate with geometric shapes can are built with marble, metal or wood as illustrated in Figure 2.10.

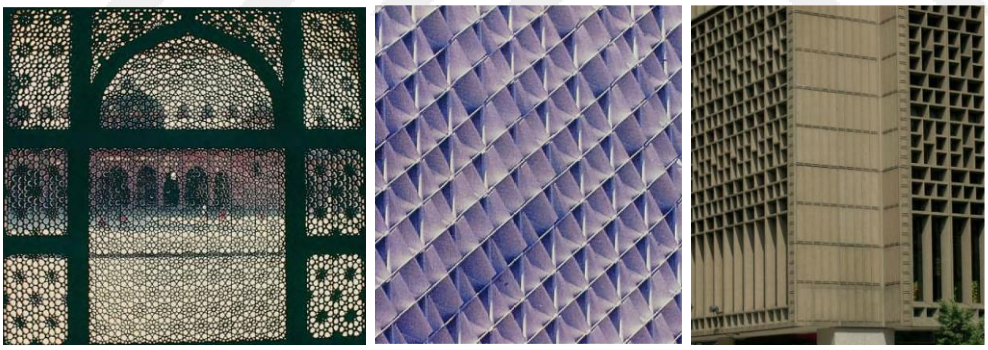


Figure 2.10 Various types of eggcrate by marble, metal and concrete (Lechner, 2009)

Table 2.2 illustrates various fixed shading devices, which are used in different orientations to have maximum efficiency.

Lechner (2009) believes that movable shading devices are more useful than fixed ones because they can respond better to the dynamic nature of solar movement. For example, movable shading devices can block solar radiation during summer, and permit solar radiation inside the building in the winter. The author classifies movable shading devices into five types, which are shown in Table 2.3.

These devices can manually or automatically adjust their angle to block the sun. According to Lechner (2009), movable shading devices need more maintenance. It is need to check and fix wheels or joints in movable shading devices in order to work well.

Table 2.2 Various fixed shading devices in different orientation (Lechner, 2009)

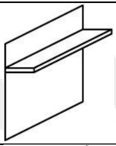
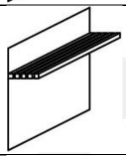
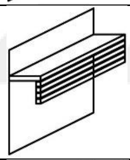
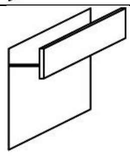
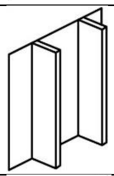
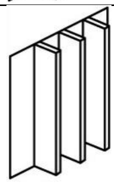
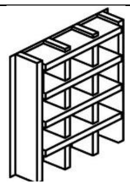
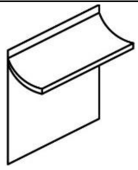
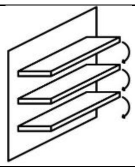
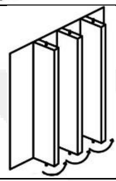
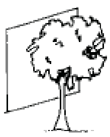
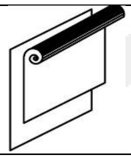
		Descriptive name	Best Orientation	Comments
1		Overhang horizontal panel or awning	South, East, West	Traps hot air can be loaded by snow and wind Can be slanted
2		Overhang horizontal louvers in horizontal plane	South, East, West	Free air movement Snow or wind load is small Small scale Best buy!
3		Overhang horizontal louvers in vertical plane	South, East, West	Reduces length of overhang View restricted Also available with miniature louvers
4		Overhang vertical panel	South, East, West	Free air movement No snow load View restricted
5		Vertical fin	North	Restricts view if used on east and west orientations
6		Vertical fin slanted	East, West	Slant toward north in hot climates and south in cold climates Restricts view significantly Not recommended
7		Eggcrate	East, West	For very hot climates View very restricted Traps hot air Not recommended

Table 2.3 Various movable shading devices in different orientation (Lechner, 2009)

		Descriptive name	Best Orientation	Comments
1		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!
2		Overhang Rotating horizontal louvers	South, East, West	Will block some view and winter sun
3		Fin Rotating fins	East, West	Much more effective than fixed fins Less restricted view than slanted fixed fins
4		Deciduous plants Trees Vines	East, West Southeast, Southwest Northeast Northwest	View restricted but attractive for low-canopy trees Self-cooling Highly recommended
5		Exterior roller shade	East, West Southeast, Southwest Northeast Northwest	Very flexible, from completely open to completely closed View is restricted when shade is used Provides security

2.1.2.1.6 Self-Shading Facades

Lechner (2009) suggests that facades can be designed in such a way that windows always face north or south even when placed on the east and west facades in order to avoid the solar shading problem in the east and west oriented windows. Also, since effective shading devices on west and east windows can restrict the view, it is better to have horizontal windows in the east and west orientation with horizontal movable overhang shading devices; while it is better to design fins for northwest and southwest windows. The facade configuration solutions offered by Lechner (2009) as shown in Figure 2.11 are in effect self-shading facades.

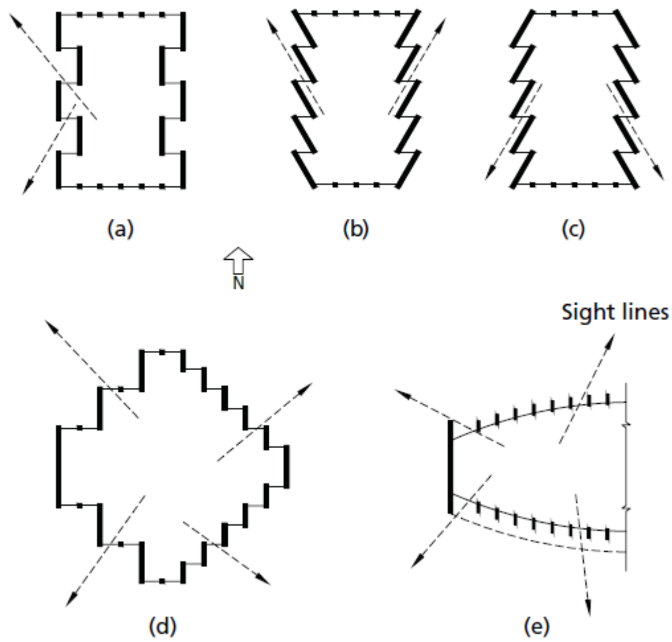


Figure 2.11 The west and south windows, which face north and south (Lechner, 2009)

Valladares-Rendon *et al* (2017, p.461) explain that self-shading facade is a type of facade, which "*decrease the insulation on opaque and glazing elements of the building during a required period.*"

The authors describe various types of self-shading facades, which are designed by considering sun movement angle in different seasons of a year to block radiations in the summer and let them enter the buildings in the winter. Therefore, energy consumption is decreased by designing this type of facade for buildings' envelope. Valladares-Rendon *et al.* (2017) explain that when slope of the facade is increased and combined with other passive systems, energy consumption and insulation demand of envelop will decrease. because by a slight inclination of facade, it is possible to decrease heat gain in the hot months of year. Figure 2.12 shows different types of self-shading facades. The first six types on the top have a simple design and the ones on the bottom have a complex design (Valladares-Rendon *et al.*, 2017).

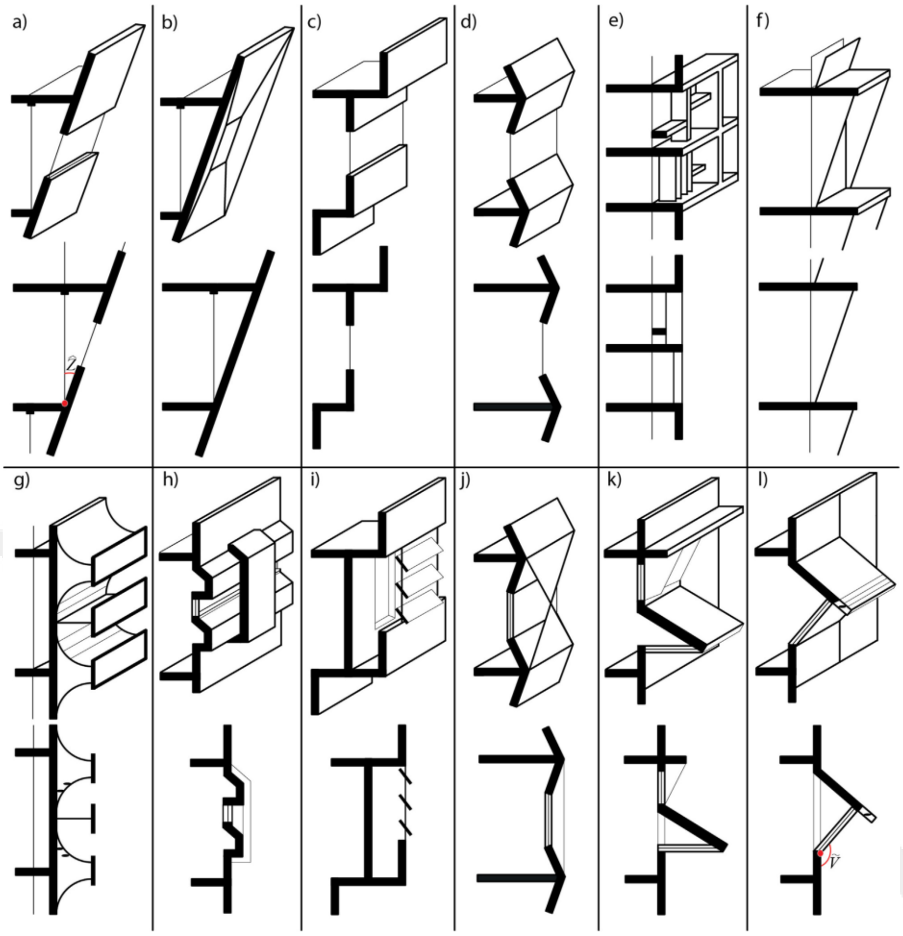


Figure 2.12 Self-shading facades (Valladares-Rendon *et al.*, 2017)

(a) Tilted flat with a rectangular opening, (b) Tilted with texture and square opening, (c) Step with a rectangular opening, (d) Waterfall with a rectangular opening, (e) Filled egg-crate with mini enclosure and full glazing, (f) Zig-zag balconies with full glazing, (g) Horizontal outer panels with louvers and full glazing, (h) Waves with horizontal opening, (i) Step with tilted panels and vertical opening, (j) Waterfall with triangle panels and rectangular opening, (k) Skylight cantilever with tilted shark panels, (l) Skylight cantilever with tilted louver.

2.1.2.1.7 Vegetated Facades

According to Hopkins and Goodwin (2011) the solution to global urban problems of increasing temperature, heat island effect, and carbon emissions is to use vegetation on the building envelopes which includes using vegetated roofs or walls with green climbers or green panels on the facade.

Green facades are classified into traditional green facades and double skin green facade by Besir and Cuce (2018). The former uses self-climbing plants, which have roots in the ground and climb on the surfaces by attaching themselves onto the facade thus, causing significant surface damage (Hopkins and Goodwin, 2011). Figure 2.13 shows the green facade of the historical Northern Club in the USA, which consists of two layers and a cavity between them in order to protect the exterior wall from damages.

Figure 2.13 Virginia Creeper Clad building facade of the Northern Club provides color, shading, and habitat for numerous nesting feral pigeons (Hopkins and Goodwin, 201)

According to Pérez, Coma, Martorell and Cabeza (2014), a double skin green system acts like a ventilated facade, which enhances the thermal performance of the green wall, and it can be constructed with wired, modular trellises, and meshes in order to support climbing plants.

Another type of green facade is the Living wall (green panels on facade), which uses pre-vegetated panels made from plastic, steel, polystyrene, or synthetic fabric installed on the structure of the facade (Hopkins and Goodwin, 2011). In comparison with green facades, green walls need more maintenance in irrigation and fertilizing. Besir and Cuce (2018) classify living walls into two types: continuous and modular systems. The former uses geotextile membrane as a growing media instead of soil, while the latter uses panels and pocket-shaped planters that makes it possible to replace dead plants (Charoenkit and Yiemwattana, 2016) (Figure 2.14).

Figure 2.14 Six-storey tall green wall by architect Jose Maria Chofre, constructed with modular cubic containers, sandwiched between two metal grids.

Hunter, Williams, Rayner, Aye, Hes and Livesley (2014) state that the plants on the wall cool it down by absorbing solar radiation, reflecting solar radiation, providing evapotranspiration cooling, providing thermal insulation by the cavity which depends on the distance of vertical plants from the exterior building wall, and reduction of the wind speed on the wall surface. Susorova, Angulo, Bahrami and Stephens (2013) state that plants help to reduce the temperature of the exterior wall as well as the surroundings, which results in reducing cooling loads and the heat island effect in hot seasons. Integrating plants with high density (Figure 2.15) help decreasing cooling loads as well as reduce the wind flow around the facade and the wind loads (Ottelé, Perini, Fraaij, Haas and Raiteri, 2011). On the other hand, green walls in the south and east orientation generate more cooling effect as compared to the west orientation while there is no cooling effect in the north. Also, the effect of transpiration for providing cooling is more than the effect of thermal insulation and shading in a vertical vegetated wall (Jim, 2015).

Yoshimil and Altan (2011) state that vertical vegetated walls filter contamination from the air (dust, pollen, toxic gases) and provide fresh air for interior spaces to enhance the indoor air quality and decrease energy consumption and carbon emission. (Besir and Cuce, 2018).

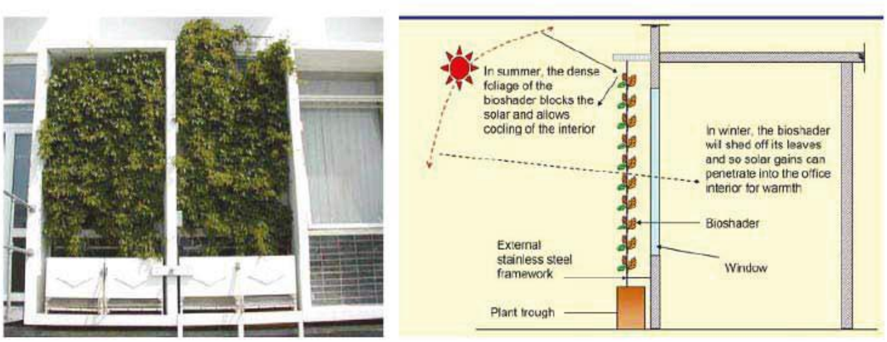


Figure 2.15 The Bioshader experiment (Sheweka and Mohamed, 2012)

Andrews and Rottle (2017) propose three types of movable green walls to prevent solar radiation in the summer by considering the sun’s position. Also, these walls provide insulation to decrease energy consumption for cooling (Figure 2.16). The sliding green wall shown in Figure 2.17 is integrated on the facade of a building in the Washington University in Seattle, which is accessible from balconies for maintenance purposes.

Pérez *et al*. (2014) state that the performance of vertical green walls is affected by the construction system for placing of plants, climate zone for selecting appropriate plant species (evergreen/deciduous, shrub/climbing plants), and the mechanisms of operation (the cooling effect, the shade effect, the insulation effect, and the wind barrier effect). The author also points out that a vertical green wall reduces the noise level because plants reflect the sound by their elements such as leaves, twigs, branches, and trunks. They absorb the sound and convert their energy to heat. Also, the soil of plants can reduce the sound level.

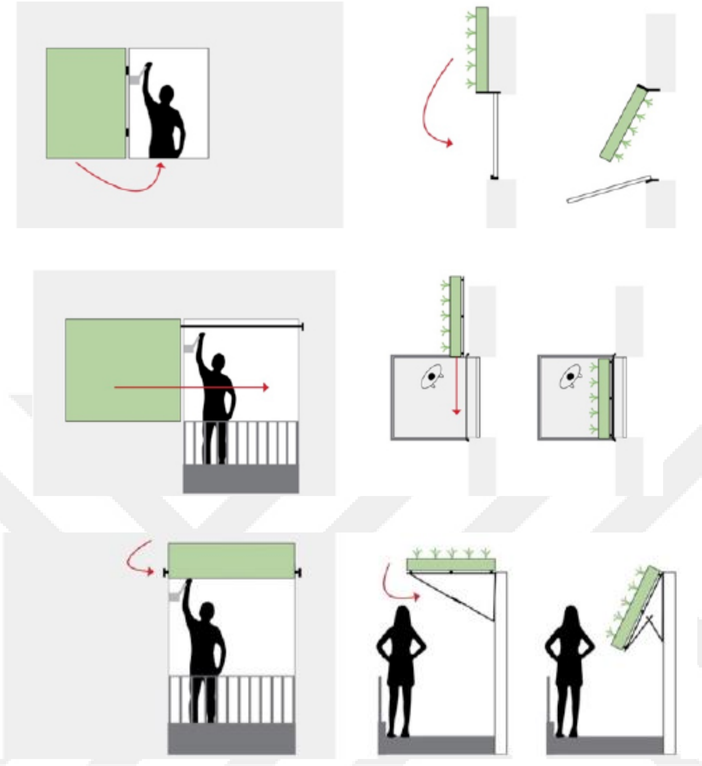


Figure 2.16 Types of movable green walls:

(top) Hinged green window wall (middle) Sliding Balcony Door Green Wall and (bottom) Folding Green Brise-Soleil (Andrews and Rottle, 2017)

Figure 2.17 View of living wall in Washington University in Seattle (Andrews and Rottle, 2017)

2.1.2.2 Active Techniques

The freely available renewable energy sources such as sun, wind, or ground source can be integrated into buildings by using mechanical systems. According to Gevorkian (2008) when mechanical systems are used for collecting sun radiation, storing heat, or distributing heat; the systems are called active systems.

2.1.2.2.1 Active Pipe-Embedded Building Envelope

Jun-long, Qiu-yuan, and Xin-hua (2012, p1663) explain that by utilizing water pipe in the structure of the exterior wall, it is possible to transfer heat and cool of circulating water inside the structure directly. As Jun-long *et al.* (2012) described, heat transferring by active pipe-embedded can be unsteady due to changeable outdoor and indoor air temperature and humidity.

For this purpose, Jun-long *et al.* (2012) design the active pipe-embedded exterior wall, consisting of two bricklayers with 120 mm in thickness and concrete layer between them with 40mm thick. In this prototype water pipe with a 20mm diameter is positioned in the concert layer. The pipes material should allow heat transferring as well as being durable. The research conducted by Jun-long *et al.* (2012) shows that energy is saved significantly by using a pipe-embedded wall. According to them, the pipe size and water temperature considerable effect on the thermal performance considerably in this system.

Albanese, Robinson, Brehob, and Sharp (2012) believe that the heat pipe system, compared with the passive solar systems, provides more energy for heating in various climates even in cloudy winter days. Ibrahim, Wurtz, Biwole and Achard (2014) recommend using solar energy in the north facade by transferring solar heating of south orientation by employing vertical pipe-embedded structure. For this purpose, they design pipe-embedded wall loop systems for exterior walls, which is shown in Figure 2.18. The exterior walls can be concert or brick with covering by silica aerogels as insulation material. As shown in Figure 2.18, in south facade pipes is located on the insulation material and in north facade pipe is positioned between the insulation material and wall as a serpentine form in order to transfer heat to the inside of building in north orientation. The pipe, which is located in the middle of the insulation, passes through the east exterior wall to reach the north wall, and it comes back to the south wall by passing through the west wall.

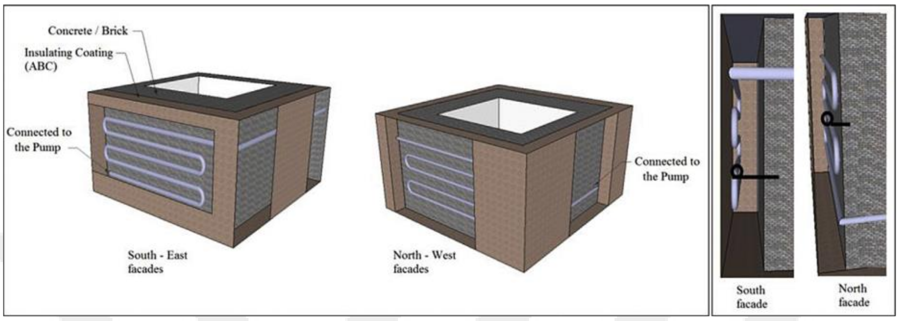


Figure 2.18 Active water pipe-embedded wall loop system (Ibrahim *et al*., 2014)

Moreover, by employing this system, heat losses reduce through the north facade about 88%, 30%-50%, 16%-20% in the Mediterranean climate, Oceanic and the lower Semi-Continental climates, upper Semi-Continental climate respectively (Ibrahim *et al.*, 2014).

Zhang, Shen, Tang, Yang, Xia, Hong, Wang, Wu, Yong Shi, Xu and Liu (2015) define Building Integrated Solar Thermal (BIST) as a multifunctional energy facade that can be applied for producing space heating and hot water supply as well as employed in the mechanical system of building as an energy source. In this system, solar radiation is absorbed and transferred by the working fluid, which can be air, hydraulic, phase change materials (PCM). Zhang *et al*. (2015) recommend various schematics for the air-based BIST system for the exterior wall (Figure 2.19, above).

Zhang *et al*. (2015) explain that the BIST system can be applied in various parts of building facades like wall, window, balcony, or roof-based envelop as shown in Table 2.4.

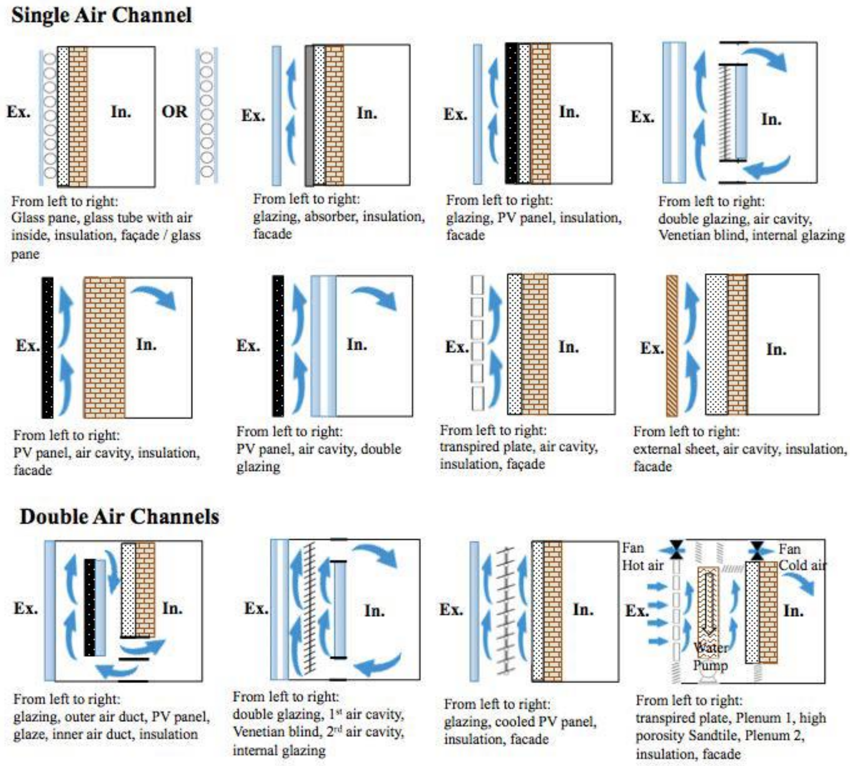
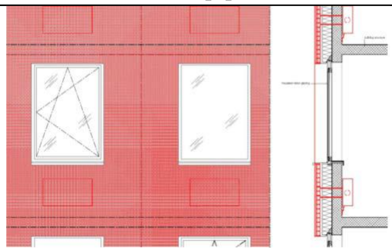
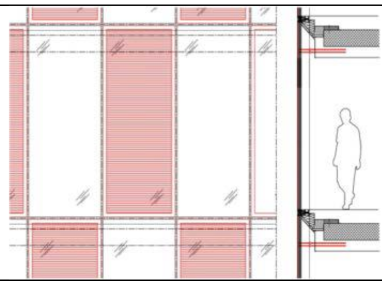
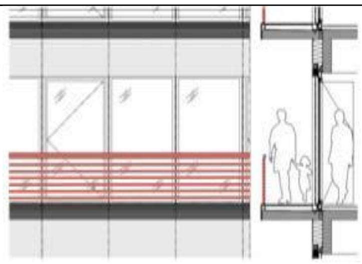
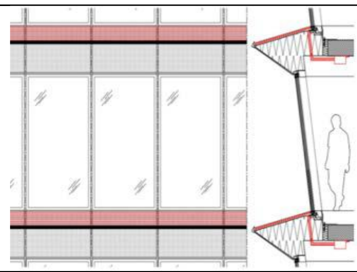


Figure 2.19 Schematics of different air based BIST structure (Zhang *et al.*, 2015)

Table 2.4 The position of Building Integrated Solar Thermal systems on the facade (adapted from Zhang *et al*. 2015)

Envelop part	Window based
	
Balcony/sun shaded based	Roof based
	

2.1.2.2.2 Solar Collectors

As Laughton (2010) explains, solar collectors absorb solar radiation and convert them into thermal energy. The author classifies solar collectors into two main groups based on transition materials; air-based and liquid-based. He believes that air-based collectors, in comparison with liquid-based ones, have advantages due to air does not freeze like water, furthermore small leaks do not make significant problems.

Suman, Khan and Pathak (2015) say that according to researches, the collector performance level is related to three factors: heat transfer coefficient between the working fluid and absorber part, the material of absorber and its coating, the thermal conductivity level of working fluid.

Suman *et al*. (2015) classify solar collectors into three groups; non-tracking, one-axis tracking, and two-axes tracking. De Winter (1990) describe that in this type of collector, whole surface of collector is designed to absorb solar radiations. Unlike tracking collectors, non-tracing collectors are fixed. According to De Winter (1990), non-tracking collector are used for the purpose of water and space heating in the building while tracking ones are employed for producing electric in industrial sections. Suman *et al*. (2015) categorize non-tracking collectors into four groups that are illustrated in Table 2.5.

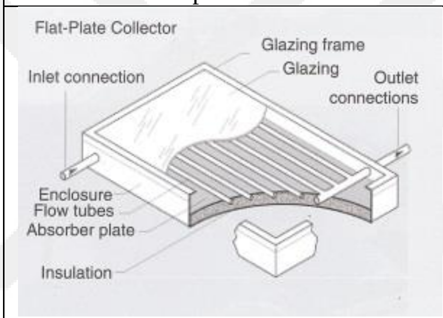
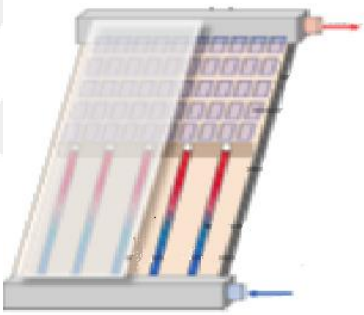
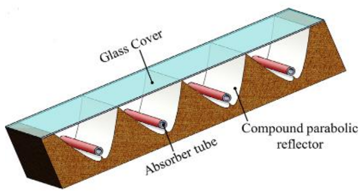
As shown in Table 2.5, a flat plate collector is covered by the glass, so the dust on the glazing part can decrease the performance level of the collector. Hence, maintenance and cleaning the flat plate collector is a very important issue in producing more thermal energy. (Suman *et al*. 2015)

De Winter (1990) and Thorpe (2011) agree that evacuated collectors are very effective in reducing heat loss through conduction and convection; thus, evacuated collectors can reach higher temperatures compared with flat plate collectors. Laughton (2010) explains that evacuated collectors perform well in cold climates because they withdraw the energy from the sunlight and because the circular profile of the tube is always perpendicular to the sun allowing constant energy collection.

Suman *et al*. (2015) say that thermal hybrid photovoltaic is a mixed system, which consist of photovoltaic cells and collector in order to generate electricity and provide domestic hot water as illustrated in Table 2.5. The fluid in the tube can be air, water, or phase change materials. In addition, using “silica/water Nano-fluid” in collector can increase the performance of collector according to Suman *et al*. (2015).

Thorpe (2011) believes that integrating solar thermal collectors on facades not only can be an effective solution to control and prevent overheating in the buildings but also can generate thermal energy for heating and cooling purposes.

Table 2.5 Classification of solar non-tracking collector. Figures taken from Suman *et al*. (2015)

<table>
<tr><td rowspan="4">Non-tracking</td><td>Flat plate collector</td><td>Hybrid photovoltaic</td></tr>
<tr><td>
</td><td></td></tr>
<tr><td>Evacuated tube collector</td><td>Compound parabolic collector</td></tr>
<tr><td></td><td>
</td></tr>
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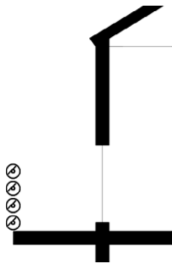
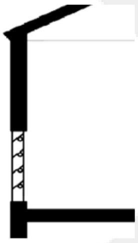
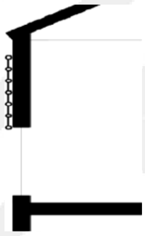
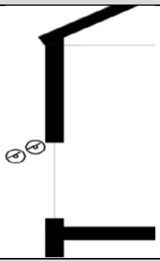
O’Hegarty, Kinnane, and McCormack (2016) explain that various solar collectors can be placed in different facades. They suggest some places in the facades to install the solar collectors that show in Table 2.6.

Table 2.6 Solar thermal facade types (Figures taken from O'Hegarty *et al*. 2016)

Flat plate collector (Opaque facade area)		Evacuated tube collectors (Balcony)	
	 Winkler Solar, 2015		 Schweizer Energie, 2015
Advantages - Range of colors - Geometric flexibility - Material offsetting - Inherent flat surface	Disadvantages - Access difficulties - Connection difficulties - Performance reduction	Advantages - Adjustable absorber inclination - Material offsetting - Multi-functional	Disadvantages - Connection difficulties
Flat plate collector/ Evacuated tube collectors (Transparent facade area)		**Unglazed collector (Opaque facade area)**	
	 Robin Sun, 2015		 Energie Solarie, 2015
Advantages - Disguised in facade - Multi-functional	Disadvantages - Access difficulties - Connection difficulties - Performance reduction	Advantages - Range of color - Cost - Ease of fabrication - Inherent flat surfaces	Disadvantages - Performance reduction
Evacuated tube collectors (Louver)		**Flat plate collector (Gutter)**	
	Advantages - Adjustable absorber inclination - Multi-functional Disadvantages - Access difficulties - Connection difficulties		Advantages - Disguised - Multi-functional Disadvantages - Access difficulties - Connection difficulties
Massive solar thermal collector (Opaque facade area)		**Flat plate collector (Balcony)**	
	Advantages - Cost - Disguised - Inherent flat surface - Material offsetting - Storage benefits Disadvantages - Access difficulties - Connection difficulties - Performance reduction		Advantages - Inherent flat surface - Material off setting - Multi-functional Disadvantages - Connection difficulties - Performance reduction

Blind as Solar Collector: Lopez (2011, p134) designs Venetian blind solar thermal collector (VBSTC) on the facade. According to Lopez (2011), the blind slats are the essential component of the blind collector. The material of slat should be durable and should absorb solar radiation as much as possible. He suggests copper for madding slats because in compere with gold and silver, copper has a high thermal conductivity level and low price. He says that aluminum can be in second place after copper. He convinces that slats' coating plays an important role in the absorption of more radiation at high temperatures. He convinces that the slats should be stable enough to bear their weights without deformation and move without vibration. The last version of the slats designed by Lopez (2011) is shown in Figure 2.20.

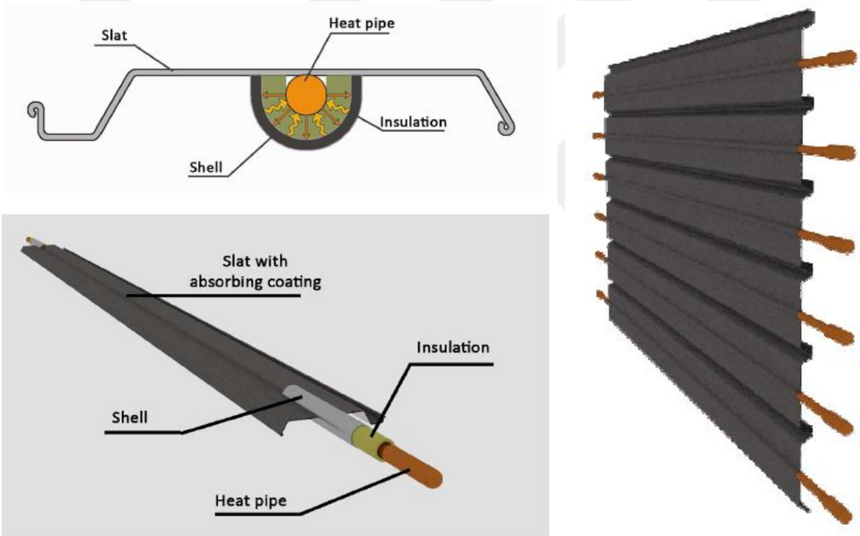


Figure 2.20 Venetian blind solar thermal collector (Lopez, 2011)

The VBSTC can be fixed and movable. Movable blind tracks the sun's position to gain more radiation and improve daylight levels in building spaces according to Lopez (2011).

Velasco, García, Guardo, Fontanals and Egusquiza (2017) designed and analyzed a double-skin facade with a Venetian blind collector in the cavity. The sample facade is designed as a one-story facade with a 4 x 6 x 0.28 dimension. Velasco *et al*. (2017) explain that the slats absorb solar radiations, which heat water steam circulating in the building. In order to increase the absorption of solar radiation, the black surfaces are designed for the solar collector.

Moreover, the slats are angled 45º to prevent glare and absorb more radiation, as illustrated in Figure 2.21. Velasco *et al*. (2017) say that the harvesting energy is used for domestic hot water, heating in the winter. Also, it can be used for cooling by employing mechanical systems. It is concluded from analyzing that the mentioned systems decrease the energy consumption of buildings as well as the building's carbon footprint.

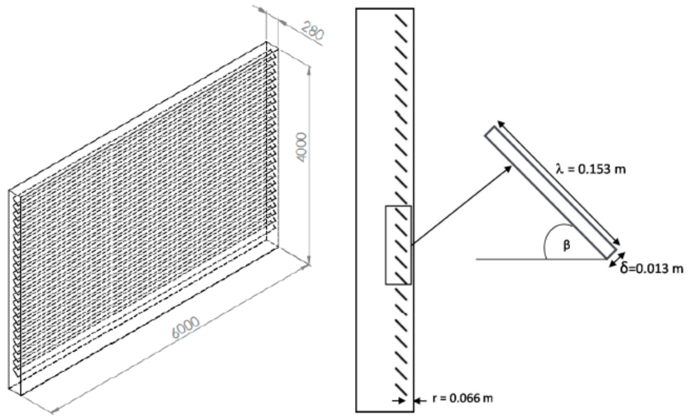


Figure 2.21 Double-skin facade with venetian blind collector
(Velasco *et al*., 2017)

In appendix G, Zhang *et al*. (2015) introduce some projects, which employ various solar thermal collectors on their facades.

2.1.2.2.3 Photovoltaic Panels

Gevorkian (2008) defines photovoltaic as a material that produces electricity directly from sunlight. Hankins (2010) states that PV panels can be installed on buildings facades in all climatic zone. The important point is that to have a 90-degree angle between the sun's rays and the panels' surface. Unlike the hot and cloudy days, cold and clear days rise power production. According to Hankins (2010), in hot climates, the PV output is reduced when the temperature of PV modules goes above 25°C. Therefore, it is better to use a space between the structure and PV modules for ventilation in a hot climate, which is not less than 15cm.

Gevorkian (2008) and Thorpe (2011) mention the advantages and disadvantages of PV panels, which are explained as follows:

Advantages of Photovoltaic:

- PV panels use endless solar energy to generate electricity without leaving any waste in the environment.
- PV panels work for a long time without making problems.
- PV Panels is resistant to various weather condition without needing continuous maintenance.
- PV panels have a modular system so they can be enlarged when more energy needs.
- PV panels can be installed where energy is needed without needing network cables.

Disadvantages of Photovoltaic

- The Performance of PV panels decreases by overheating. Hence having spaces behind them for ventilation could be a useful solution (Agathokleous and Kalogirou, 2016)
- Surface pollution is another problem in reducing the performance of PV panels.
- The cost of PV panels and their installation is high
- At night, energy production is stopped.

According to Thorpe (2011), PV panels can be installed on the building's facade with a slope to take maximum solar radiation. The angle between solar radiation and the surfaces where photovoltaic panels are installed should be calculated according to climate zoon and seasons.

PV panels can be installed on facades by employing various techniques that are explained below:

Photovoltaic curtain wall facade system: Robert and Guariento (2009) explain that PV modules can cover the entire facade surface as curtain wall systems, which are two types according to the fabrication and installation; the stick system is erected on-site, and the unitized system is prefabricated in the factory. He also states that the curtain wall facades can be transparent, semi-transparent, or opaque glazed with the benefits, such as daylighting.

Photovoltaic on double-skin Facade System: Peng, Lu, and Yang (2013) design a semi-transparent photovoltaic double-skin facade to generate energy and provide natural ventilation for the building, shown in Figure 2.22. The exterior layer is made of double tempered glasses with silicon solar cells between them. The horizontal movable lovers are on the top and bottom part of the exterior layer on each floor, opened or closed according to climate change in various seasons to have suitable natural ventilation. Also, to enhance facade performance, the operable windows are designed for the interior layer of the DSF. They point out that photovoltaic cells absorb a high percentage of solar radiation, the transmission of solar radiation into the interior spaces (heat gain) decreases, which reduces the cooling load in hot seasons. According to research conducted by Peng *et al*. (2013), photovoltaic double-skin facade uses 50 percent less electricity in comparison with convention glazing facades in Berkeley (Figure 2.22).

Kang, Hwang, and Kim (2012) design a double-skin facade with horizontal photovoltaic blinds, inclined to 75 degrees to increase electricity production. According to them, the ventilated double-skin facade enhances solar cells' efficiency to generate electricity by 8.3 percent compared with the close double-skin facade.

Photovoltaic on Rain Screen Cladding System: Figure 2.23 indicates the details of the rain screen cladding system that is appropriate for PV integration. In this system, the ventilation cavity helps decrease the PV panels' temperature and increases their performance (Thomas and Fordham, 2001). Figure 2.24 shows detail of a rain screen panel with an integrated PV module.

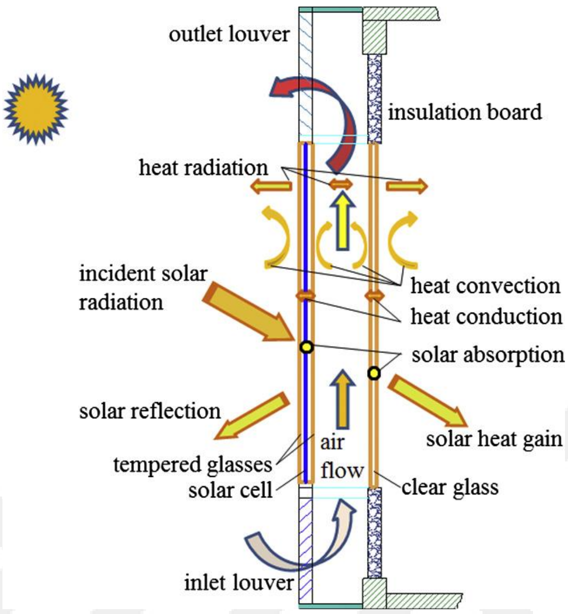


Figure 2.22 Section of photovoltaic double-skin facade designed by Peng *et al*. (2013)

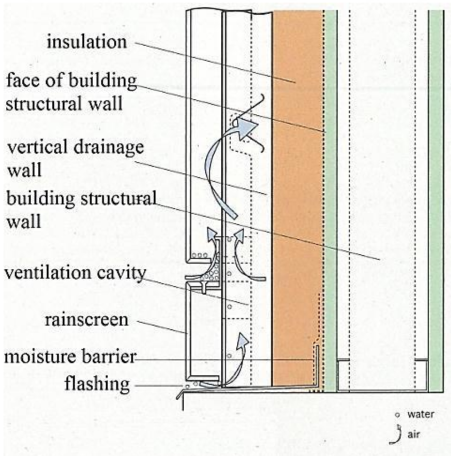


Figure 2.23 Vertical section through a typical horizontal joint detail in a drained and back-ventilated metal rainscreen (Robert and Guariento, 2009)

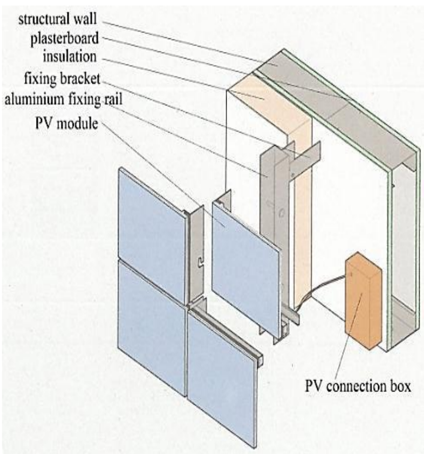


Figure 2.24 Detail of a rainscreen panel integrated with PV module showing electrical connections (Robert and Guariento, 2009)

Photovoltaic as Shading Systems: Robert and Guariento (2009) say that to control daylight, PV modules can be used as a shading element to decrease solar gain and generate electricity at the same time. PV shading systems are two types; movable system and fixed system. The movable system is more efficient and expensive than the fixed system. Jayathissa, Luzzatto, Schmidli, Hofer, Nagy, and Schlueter (2017) believe that the movable photovoltaic facade can decrease the cooling load in hot seasons as well as decrease the heating load in the cold season by adaptive itself to the climate change automatically.

Mandalaki, Zervas, Tsoutsos, and Vazakas (2012) simulate the thirteen types of shading devices with solar cells on their surfaces in south orientation by software Energy Plus in order to find the efficient type in Chania and Athens. The result of their study shows that surrounding shading with PV cells are the most energy-efficient system. The other efficient solar shading systems with PV cells in both locations are canopy inclined single, canopy inclined double, and brise-soleil full facade, respectively, according to Mandalaki *et al*. (2012).

Nagy, Svetozarevic, Jayathissa, Begle, Hofer, Lydon, Willmann, and Schlueter (2016) design an adaptive photovoltaic facade in the south facade of the House of Natural Resources shown in Figure 2.25 to decrease energy consumption by shading on the facade and generation electricity in the Zurich region.

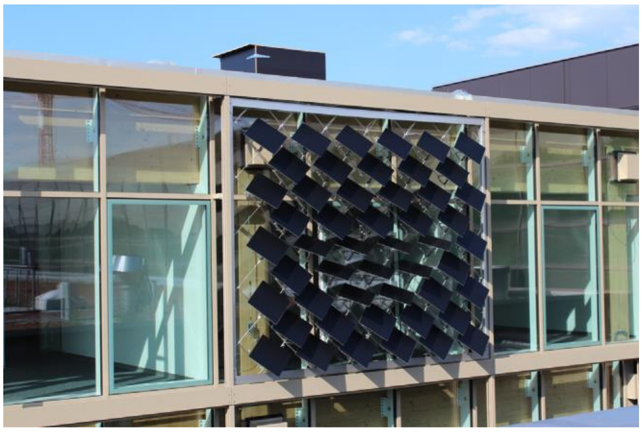


Figure 2.25 Adaptive photovoltaic unit for south facade of House of Natural Resources (Nagy *et al*., 2016)

2.1.2.2.4 Building-Integrated Wind Turbines (BIWT)

Bobrova (2015) believes that using wind energy by structural building to generate electricity is one of the developed areas in a technology-driven world. Bošnjaković (2013) explains that engineers integrate wind turbines on the top part of the building because, with height, the wind speed rises.

Pearl River Tower, located in Guangzhou, Castle House, located in London, and the Bahrain World Trade Center located in Bahrain, is the full-scale building examples that applied the BIWT system. (See Figure 2.26 and Figure 2.27) Despite unsolved vibration and noise problems in these buildings, the BIWT system is highly efficient because of the large turbines. According to Bošnjaković (2013), integrated wind turbines in these buildings can generate 15% of buildings' total energy requirement. Park *et al*. (2015) explain that the place and weight of turbines should be considered to calculate these kinds of the buildings design. (Park *et al*., 2015)

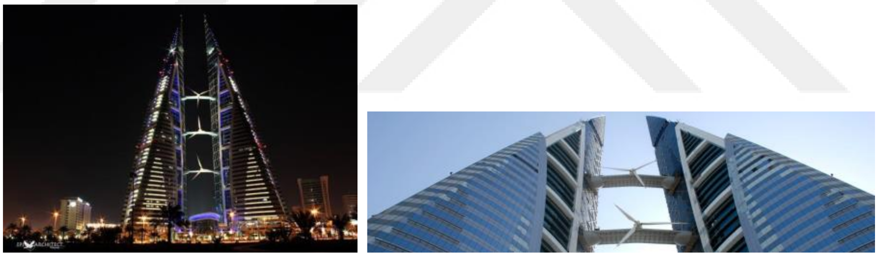


Figure 2.26 world Trade Center located in Bahrain (Bobrova, 2015) and Bošnjaković (2013)

Figure 2.27 Castle House in London (Bobrova, 2015)

According to Park *et al*. (2015) and Bošnjaković (2013), one large turbine or a few ones can be installed in three positions of the high-rise buildings; on the roof, between two building, and inside a hole, as shown in Figure 2.28a. In addition, small-sized turbines can be installed on the facades and roof, which is more economical and conventional in comparison with large ones (Figure 2.28b).

Park *et al*. (2015) design one unite, which repeats horizontally or vertically on the building facades in order to fill empty places of facades. Each unit consists of a rotor and a guide vane, as shown in Figure 2.29. As Park *et al*. (2015, p.11849) explained, "*Modularization enables the system to be easily applied to various types of existing buildings and makes it convenient for the system to be attached and detached*."

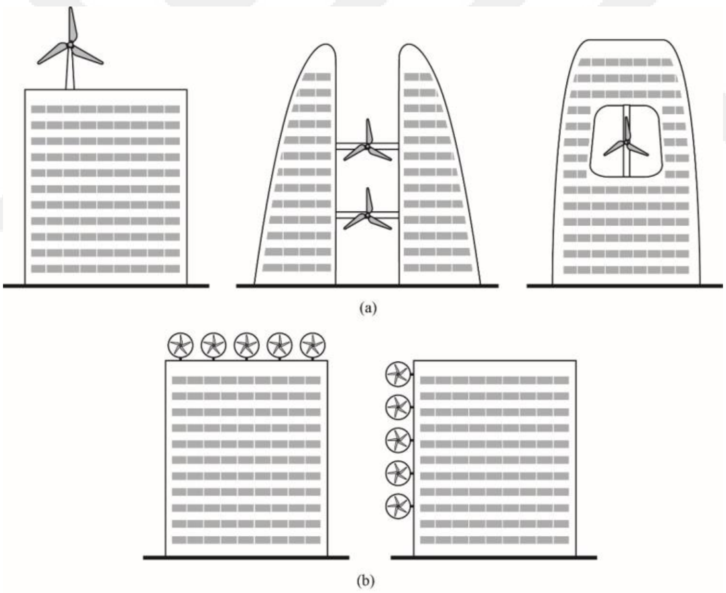


Figure 2.28 Building-integrated wind turbines systems (Park *et al*., 2015)

As Park, Jung, Lee, and Park (2015, p 11849) said, according to velocity or pressure of wind, guide vanes' angle is changed to optimize rotors' operation. In addition, the wind characteristic around each building depends on its form and its neighboring structure. Therefore, the guide vanes play an essential role in enhancing rotor efficiency by collecting the incoming wind and raising its speed.

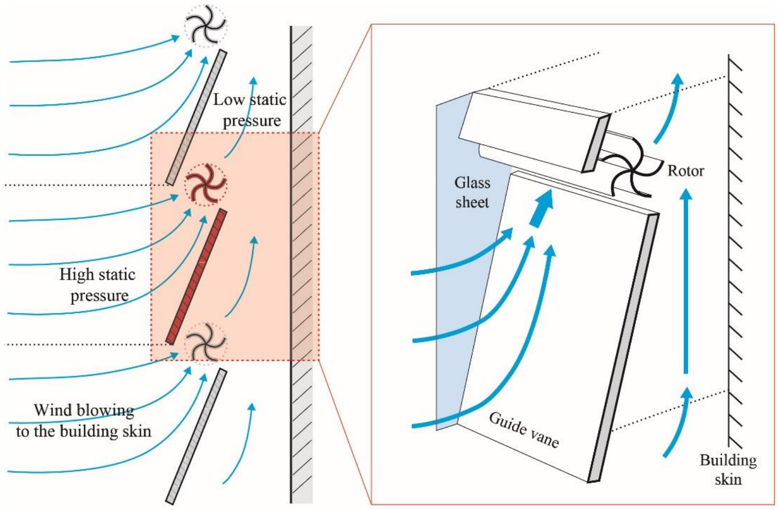


Figure 2.29 Schematic diagram for BIWT system proposed by Park *et al*. (2015)

As Bošnjaković (2013, p.3) described, the requirement for designing efficient wind turbines are;

- "*Good performance in complex winds,*
- *Safe operation in the urban environment,*
- *Low noise level,*
- *Simple, rugged design,*
- *Minimized maintenance,*
- *Aesthetic appearance*."

2.1.2.2.5 Intelligent Building Skins

El Sheikh (2011) and Al Thobaiti (2014) convince that before advanced technology, buildings are designed by using a passive system to enhance space's performance in respect of energy efficiency, which can be a foundation for implementing today's technologies in the intelligent-responsive building. They give the example of an Egyptian Mashrabiyya, one of the successful examples of this kind of facade to deal with thermal and daylighting (Figure 2.30).

Figure 2.30 Egyptian Mashrabiyya from indoor and outdoor facade
(El Sheikh, 2011)

Moreover, operable windows were designed for some special Mashrabiyya, which provides natural ventilation to enhance thermal comfort. Loonen *et al*. (2013) explain that the Arab World Institute in Paris was built according to Mashrabiyya technic as an intelligent skin by Jean Nouvel.

According to Al Thobaiti (2014), the intelligent building skins comprise dynamic elements or surfaces on the facades, which can respond to environmental changes daily or seasonally to decrease buildings' energy consumption and improve the buildings' efficiency. Smart materials, sensors, movable elements, automated features, and control systems are based on designing intelligent building skins.

Bakker, Hoes-van Oeffelen, Loonen, and Hensen (2014) convince that intelligent facades play an essential role in decreasing energy consumption for heating, cooling, lighting, and ventilation as well as improving indoor environmental quality such as thermal comfort, visual comfort, view to outside, indoor air quality, discomfort glare. Loonen, Rico-Martinez, Favoino, Brzezicki, Menezo, Ferla, and Aelenei (2015) convince that it is possible to provide controllable thermal mass and insulation, energy harvesting, radiant heat exchange, humidity control, and solar shading by smart facades. Barozzi, Lienhard, Zanelli, and Monticelli (2016) and Loonen *et al*.

(2013) classify intelligent system in two control systems: Extrinsic control system and Intrinsic control

Extrinsic control system (Kinetic Facades): This system consists of sensors, control systems, and adaptable systems or elements. The sensor records environmental changes, and occupants react (as signals), then this information is sent to control systems, which defines the motion of elements or adaptable systems. Fortmeyer and Linn (2014) define Kinetic facades as energy movers to transfer energy where it is needed or remove from where it is not needed. Ahmad, Abel-Rahman, and Ali, (2015) say that kinetic facades can automatically adapt their shape, form, orientation, or openings to respond to environmental parameters like temperature, humidity, wind.

İlerisoyl and Başeğmez (2018) state that kinetic systems can be categorized based on the material used, movement type, or building element types. İlerisoyl and Başeğmez (2018) focus on movements' mechanism and classify their motions into four types; rotating, sliding, folding, and opening-closing, Retractable scissor. Each of the mentioned motion can be used in various construction forms to design different buildings' components. İlerisoyl and Başeğmez (2018) explain that materials are applied according to the motion type and categorized into rigid and deformable.

Elkhayat (2014) and Megahed (2017) recommend utilizing lightweight, efficient, and flexible materials to structure movable elements. Megahed (2017) suggests that it is better to design easily manufactured and shipped kinetic elements, which can be modular. The simple detail of movable elements makes it possible to install them in various places in a short time. Furthermore, he explains that the maintenance of kinetic facades is very important in the function of them. Therefore, simple design and resistant materials allow them to have smooth movable with low maintenance. Also, Megahed (2017) believes that one crucial point in designing kinetic surfaces is using recyclable and non-polluting materials to decrease the environmental pollution.

According to Formentini and Lenci (2018) and Ahmad *et al*. (2015), movable facades are very expensive. Therefore, they prefer having movable shading devices on facades, which follow sun and control energy consumption for cooling in the summer and heating in the winter. Tzempelikos, Athienitis, and Karava (2007) state that utilizing movable shading devices on the facade is one of the significant solutions to reduce energy consumption for lighting, cooling, and heating. Formentini and Lenci (2018) introduce some of the movable solar shading products for exterior walls like roller shutters, coating glass slats, sun awnings, vertical roller blinds, louvers, and vertical and horizontal solar fins. Elkhayat (2014) says that having control systems is necessary for having automatic movable elements on the facades. Control systems manage all component movement in order to be more efficient.

Kim, Jeon, and Kim (2017) introduce a kinetic layering system that various movable layers create various patterns moment by moving them in a different direction. The route layers' elements can be a circle or triangle. The elements of various layers can be positioned overlap of each other or top of each other.

Intrinsic control: These systems are known as self-adjusting, self-powering, self-actuating systems, which respond directly to climate change like solar radiation, environmental temperature, and relative humidity, wind speed and direction, and CO2-level, without using any energy. Smart materials can be an excellent example of central control systems. Megahed (2017) says that molecules of smart materials are capable of processing their environment and then changing their appearance, shape, or function to respond to their environment. He believes that architects can design adaptive surfaces by knowing about the behavior of smart materials. These materials have various responsibilities such as color change, transformation/deformation, topology or texture change, and permeability. According to Volp (2018), smarts materials change their properties such as mechanical, electrical, chemical, optical, magnetic, or thermal to adapt to environmental change. Loonen *et al*. (2013, p.487) explain that smart materials with various properties like "*anti-bacterial, anti-graffiti, fire-proof, scratch-proof, self-cleaning or abrasion-resistant*" can be used in the construction of building facades.

Fiorito, Sauchell, Arroyo, Pesenti, Imperadori, Masera, and Ranzi (2016) classify smart materials into two categories:

a. Shape change materials: They change their shape when the right stimulus present.

b. Shape memory materials: Volp (2018) describes that the group of mentioned materials remember their original forms to return the original shape.

Fiorito *et al*. (2016) say that shape memory polymers are used widely in buildings as smart materials recently, thanks to lower prices compared with other kinds of smart materials and their high biocompatibility. Santina (2018) explains that shape memory polymer changes its shape in high temperature, and it backs to the first (rigid) form at low temperature as a smart material. According to him, there is another kind of polymer, which has thermochromatic properties. This kind changes its color as well as its shape when the temperature increases.

Loonen *et al*. (2015) describe eight concepts for intelligent facades according to their goals in Table 2.7. In designing the most intelligent building facades, achieving two or several goals of Table 2.7 is mentioned.

Table 2.7 Concept for intelligent facades (Adapted from Loonen *et al*., 2015)

Goal purpose	Responsive function	Operation	Technologies (materials & systems)	Response time	Spatial scale	Visibility	Degree of adaptability
Thermal comfort	Prevent, Reject, Admit or Modulate (store, distribute) solar gains, and conductive, convective and long-wave radiant heat flux	Intrinsic	Shading	Second	Building material	No	On-off
		Extrinsic	Insulation	Minutes	Facade element	Low	Gradual
			Switchable glazing	Hours	Wall	High	
			PCM	Day-night	Fenestration		
Indoor air quality	Controlled porosity for exchange and filtering of outside air		Solar tubes	Seasons	Roof		
			BIPV and solar thermal systems	Years	Whole building		
			Shape memory alloys	Decades			
Visual performance (illuminance, glare, view)	Prevent, Reject, Admit or Redirect visible light		Facade openings				
Acoustic quality	Prevent, Reject, Admit or Redirect sound pressure		Kinetic systems				
			Radiant glazing				
Energy generation	Collect and convert wind energy and sunlight into electricity and thermal energy						
Personal Control	User interaction and adaptation to individual needs						

2.2 Design Requirement of Appropriate Facades

Aksamija (2013) explains that one of the most important contributors to the buildings' comfort parameters and the energy consumption is facade types. In addition, Moghtadernrjad (2013) believes that it is better to reduce environmental pollution and energy consumption in designing building facades. Tam, Le, and Wang (2018) note that decreasing the cost of construction and maintenance and providing human comfort in designing appropriate buildings' facades are significant factors.

2.2.1 Human Comfort

According to Leaman (1995) and Newsham, Brand, Donnelly, Veitch, Aries, and Charles (2009), the resident's satisfaction can be affected by the indoor environment's quality. Lovell (2010) and Kubba (2010) believe that human comfort and indoor environmental quality do not only relate to the quantitative measures of temperature and humidity. They convince that indoor air quality, light levels, acoustics, noise pollution, as well as the ability to control over building systems, access views, connection to nature, building envelopes, and finishing materials are significant issues, which should be taken accounted in designing and construction of buildings. Aelenei *et al.* (2016) show the relationships between human comfort, exterior factors, and facade requirement in Figure 2.31 to design efficient facades buildings.

Zanon, Callegaro, and Albatici (2019) say that Indoor Environment Quality (IEQ) is the main indicator of inside the building's inside condition, which is defined by four factors; indoor air quality, thermal comfort, visual comfort, and acoustical comfort.

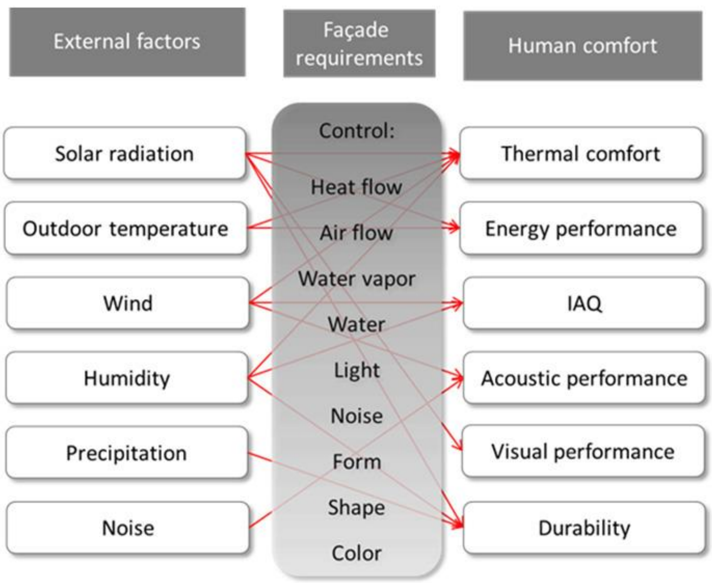


Figure 2.31 Relationship between human comfort, exterior factors and facade requirement (Aelenei *et al.*, 2016)

2.2.1.1 Indoor Air Quality

Jomehzadeh, Nejat, Calautit, Yusof, Zaki, Hughes, and Yazid (2017) says that one of the five tops of environmental health risks is interior air pollution. He explains that indoor air quality is important because most people spend 80%-90% of their time in indoor environments to work, study. As Paul, Sree, and Aglan (2010) said, outdoor air, the number of residents (CO2 rate), buildings' function (house, school, theatre), building location, and buildings' ventilation systems affect indoor air quality. Furthermore, Demirel, Özden, Dögerogly and Gaga (2014) explain that carbonyl compounds such as PVC or linoleum for the floor, cleaning products, personal care products, perfumes, glues, paints, and some construction materials are the source of indoor air pollution.

The definition of acceptable indoor air quality in ASHRAE standards 62 (2019, p.3) is; "*air toward which a substantial majority of occupants express no dissatisfaction with respect to odor and sensory irritation and in which there are not likely to be contaminants at concentrations that are known to pose a health risk.*" According to ASHRAE standard 62 (2019), fresh air is an important factor in designing the buildings, which can be provided by natural ventilation or air filtering systems. In addition, air change (ventilation) value should be minimum 15 cfm/person (7.5 L/s/person). Zhao, Liu, and Ren (2018) command to increase it to 10 L/s/person in most buildings types (ASHRAE standard 62, 2019). Todd (2001) explains that nowadays, natural ventilation is considered more thanks to decreasing energy costs and respecting the environment by reducing fossil fuel use.

Aflaki, Mahyuddin, Al-Cheikh Mahmoud, and Baharum (2015) explain that inside and outside of the air pressure differences cause the cool air flowing through the facades' windows horizontally. They classify mentioned airflow patterns, which affect the residences directly, into three types of ventilation; cross-ventilation (two openings in various facades), single-side ventilation (from one opening), and double-side ventilation (two openings in one facade). Aflaki *et al.* (2015) and Hansanuwat (2010) believe that the size, form, position, and orientation of apertures and the window to wall ratio of exterior wall effect natural ventilation performance. The openings can be in the form of windows, vents, or grills (louvers) on the facades. Zhao *et al*. (2018) say that having natural ventilation is not possible in some cities because of outdoor air pollution. Hence, it is necessary to seal the building envelop and use mechanical indoor air cleaning systems.

Aflaki *et al.* (2015) state that the other technique (indirect) for having natural ventilation is based on the stack effect and wind force used in vernacular architecture in a hot climate. The stack effect is based on temperature difference that it causes warm air flowing upper part to exhaust. They believe that in a hot climate, cross ventilation cannot be useful because there is no temperature difference between inside and outside the building. Todd (2001) suggests designing ventilation shafts (ducts), wind tower (wind catcher), and vertical chimney in building facades as excellent techniques for having fresh air in interior spaces by using stack effect

Koukkouli, Panayiotou, Gelegenis and Kalogirou (2010) state that one of the best and useful techniques in the summer for changing air and removing heat from the mass of interior space, which is stored during the day, is nighttime ventilation. Moreover, for nighttime ventilation, it is possible to use cross ventilation or stack ventilation type.

Poirazis (2004) and Compagno (2002) explain that one of the methods for having fresh air inside of the buildings is designing double-skin facades. Double skin facades not only provide fresh air by natural ventilation but also protect buildings from the influences of the weather and air pollution. Therefore, designing double skin facade for high-rise buildings or ones situated in the vicinity of busy roads can increase indoor air quality. Parhizkar *et al.* (2017) convince that employing green facades for building causes reduction of Co2 rate in indoor spaces, which improves indoor air quality.

2.2.1.2 Thermal Comfort

Mohamed (2014) explains that thermal comfort plays a vital role in the assessment of building performance and energy consumption. According to ASHRAE standard 55 (2017), the definition of thermal comfort is "*that condition of mind which expresses satisfaction with the thermal environment*." Moreover, it is explained that for achieving acceptable thermal comfort, six factors should be considered; metabolic rate, clothing insulation, air temperature, radiant temperature, airspeed, and humidity. Metabolic rate and clothing insulation are characteristics of the users, which are not considered in this study. On the other hand, comfortable temperatures in winter and summer, reasonable humidity, and reasonable airspeed assist in having thermal comfort in the indoor environment that they will be considered in designing buildings facades in this study.

Quesada *et al*. (2012) say that there are various active and passive techniques for gaining solar heat and preventing heat losses to achieve comfort temperature. The active systems are using solar collectors for space heating and providing hot water, installing photovoltaic cells on the facade for generating electricity, and integrating water pipes embedded systems on the facade as a new heating technique in the buildings (Quesada *et al*. (2012), Jun-long *et al.* (2012) and Albanese *et al.* (2012)).

According to Aflaki *et al.* (2015), Hatamipour and Abedi (2008), Tam *et al*. (2018), the passive strategies for preventing heat gain and providing cooling through the building facades in hot seasons can be:

- Utilizing shading elements on facade,
- Designing buildings in the best orientation,
- Optimizing the "window to wall ratio" (Ghosh and Neogi, 2018)
- Improving form and direction of windows,
- Using suitable facades' materials,
- Utilizing light color materials for facades, (Vernacular Mediterranean architectures) (Volp, 2018)

- Using insulation and thermal mass for external walls,
- Applying vegetation around the buildings or on the facades.
- Designing deep balcony with louver screen on the facade, (Vernacular Iranian architectures, the balconies, known as “Shenashir” in Bushehr), (Hatamipour and Abedi, 2008)
- Applying evaporative system on the facades for providing cooling, (Knaack, Klein, Bilow, and Auer (2007) and Amer *et al.* (2015))
- Using tinted glass for opining on the facade, (Aksamija, 2013)
- Utilizing insulated glass (double-glazed and triple-glazed) for opening, (Aksamija, 2013)

Lopez (2011) explains that passively gaining solar energy can be done in three ways; direct solar gain, indirect solar gain, and isolated solar gain. In the direct system, roof, wall, and ceiling of building spaces collect and absorb solar radiations during the day and the absorbed thermal energy release to space during the night. However, in indirect systems, solar radiation is absorbed by thermal mass at day, and it is released to space at night. In an isolated solar gain system, the solar radiation collects by glazing space in front of the exterior wall, and collected heat is brought to the building spaces by convective flow through the bottom and top vents of the exterior thermal wall.

According to Aflaki *et al.* (2015), Hatamipour and Abedi (2008), and Tam *et al.* (2018), for having comfortable temperature in cold season below strategies can be useful,

- Designing buildings in the best orientation,
- Optimizing the “window to wall ratio” (Ghosh and Neogi, 2018)
- Improving form and direction of windows,
- Using suitable facades’ materials,
- Using insulation for exterior walls,
- Designing thermal mass for exterior walls to gather and store solar radiation, (Quesada *et al*., 2012)

- Utilizing insulated glass (double-glazed and triple-glazed) for opening, (Aksamija, 2013)

Aflaki *et al.* (2015) believe that natural ventilation can be the best method to have thermal comfort in the hot season and have a humidity comfort level in the interior spaces. As Paul *et al*. (2010) explained, if air relative humidity increases, the moisture would enhance, which causes mold and bacteria growth, infestation by insects, building components deterioration, and finally, various health problems for occupants.

2.2.1.3 Visual Comfort

As Edwards and Torcellini (2002) said, different light types provide various spectrums, which affect humans psychologically and physiologically. The spectrum of natural light is the best spectrum for eyes. A comparison between natural light and artificial light shows that natural light positively affects human health, like improving mood, increasing morale, decreasing fatigue, and reducing eyestrain. (Belok, Rabea, Hanafi, and El Bastawissi, 2019) Edwards and Torcellini (2002) refer to Dr. Ott (1997) to explain that daylight is a nutrient for metabolic processes like water and food. The light absorbed by the eyes, which influence body temperature, mood, sleep, tumor development, and puberty onset, controls the hormone melatonin production. Edwards and Torcellini (2002) said that, if the level of daylight is insufficient, the buildings' residents will have health problems like headaches, eyestrain. In addition, the primary psychological factor from natural light is having outside view as a living environment. Also, having mountains, rivers, sea, or other natural environmental increases positive psychological benefits **(**Edwards and Torcellini, 2002).

Fabi, Andersen, and Corgnati (2016) classify external factors for having a good quality of natural light into two parameters; physical environmental factors and contextual factors. According to Fabi *et al*. (2016), physical environment factors are the sun and its position, lighting level, daylight penetration, illuminance uniformity, luminance contrasts and distributions, glare, climate, and sky conditions. Contextual factors are the time of day, building design, shading devices, occupants' position, and lighting control.

According to Belok *et al*. (2019), Zelenay, Perepelitza, and Lehrer (2011), in order to have appropriate daylight in the building, two parameters should be considered in designing of building facades; Amount of daylight access and glare prevention.

Carlucci, Causone, De Rosa, and Pagliano (2015, p.6) define glare as "*the sensation produced by luminance within the visual field that is sufficiently greater than the luminance to which the eyes are adapted to cause annoyance, discomfort or loss in visual performance and visibility*."

According to Poirazis (2004), Zelenay *et al*. (2011), Carlucci *et al*. (2015), Moazzeni and Ghiabaklou (2016), Belok *et al*. (2019), there are several s strategies to have appropriate daylight in the building and prevent glare, which are proposed below:

- Utilizing suitable blinds or shading devices in the right position, which blocks glare, helps occupants have visual comfort. The shading elements can be fixed or movable, automatic, or manual.
- Optimizing opening on the facades
- Designing self-shading facades, which have unique geometry with an inclined or curved surface to provide maximum daylight penetration and prevent glare,
- Using light light-colored and reflective surface for shading elements to redirect daylight deeper into space,
- Designing light shelves to reduce glare and increase the depth of light penetration and daylight distribution uniformly.

2.2.1.4 Acoustic Comfort

Peters, Smith, and Hollins (2011) define acoustic as the science of sound. The sound is a wave motion, which can pass through the gases, liquids, and solids. Unpleasant, unwanted, and load sounds are called noise. Caniato, Bettarello, Schmid, and Fausti (2016) say that noise disturbance has been raised in the last years. The source of noise can be traffic (in the first place), music (clubs, pubs, discotheques in the weekend), people speaking, and noisy external machinery like HVAC systems. Ginn (1978) categorize source of noises into two groups; the first source generate sound into the air directly like voice or loudspeakers, which is called airborne sound, and second source act or impact on the building structure by vibrating equipment, which is called impact sound, like noisy plumbing installations, footsteps, and slamming doors. (Figure 2-103)

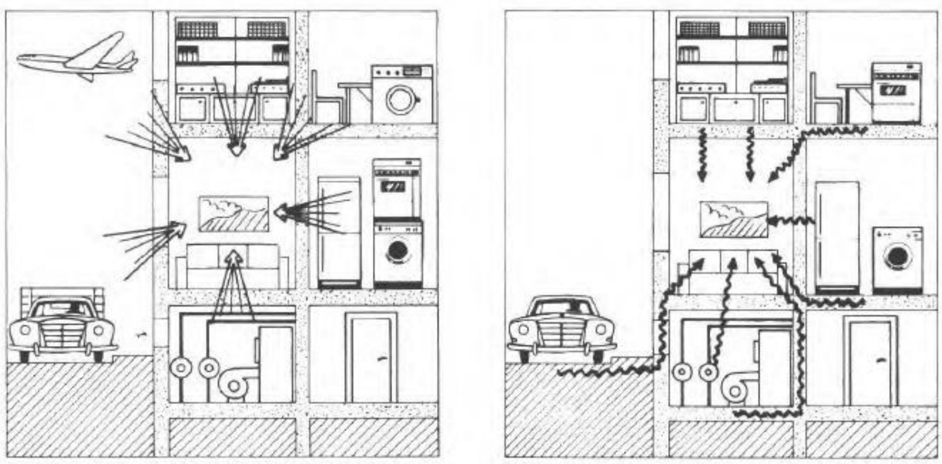


Figure 2.32 The left photo shows the source of noise in air base transferring and right photo shows the sources which impact on the building structure (Ginn, 1978)

Ginn (1978) classify insulations according to sound source into two types: airborne sound insulations and impact sound insulations. In the first type, part of the sound can be absorbed by the wall, and the rest will pass through the walls. The wall materials, wall construction, wall weight, and sound frequency define the percentage of transmitted sound. It is to say; the massive wall makes difficult sound passing through it. Hence, by using sound insulation materials in the wall, it is possible to decrease sound transmission.

Ginn (1978) propose some strategies to decrease outside noise thorough building facades in order to have acoustic comfort;

- Using materials with low stiffness and a high mass in the exterior wall,
- Designing double layer wall with applying the absorbent material like glass fiber or mineral wool as a thin layer (3 cm) in the cavity.
- Utilizing sealed doors and opening in the exterior wall (Long, 2014)
- Using fixed windows in noisy areas
- Utilizing double or triple glazed windows, (Long, 2014)
- Applying a layer of sound insulation or air gap in the exterior wall.
- Utilizing
- Designing vegetated wall as a passive insulation system, (Azkorra, Pérez, Coma, Cabeza, Bures, Álvaro, and Erkoreka, 2015)

Poirazis (2004) convinces that the double-skin facade and the number of openings can be critical for the sound insulation concerning the internal and the external noise pollution. According to Poirazis, (2004), if the building is located in a heavily polluted area with high external noise levels, then a multi stories double-skin facade type is often suggested. The outer layer does not have any openings to avoid noise transmission (from outdoors to indoors).

2.2.2 Decreasing Cost

According to Lovell (2010), construction of building envelops cost is about 35 percent of the construction budget of buildings. As Tam *et al*., (2018) say, designing and erecting sustainable building facades are more expensive than conventional building facades. However, the construction of sustainable facades can be useful in decreasing energy consumption, decreasing maintenance costs, and improving occupants’ comfort and indoor environmental quality.

2.2.2.1 Decreasing Cost of Energy Consumption through Facade Design

According to Gültekin and Alparslan (2011), building sectors utilize around 30%-40% of total energy use, which results in global warming. Shan (2016) reference to DOE (2011) to state the building sectors utilized a large amount of energy (around 40% of total energy) in the United States, which affects the environment.

Halawa *et al.*, (2018) point out that the facade is the main part of building envelopes, which play an essential role in energy saving by passive and active methods employed on the facades.

As Thalfeldt, Pikas, Kurnitski, and Voll (2013) explained, facade performance regarding energy consumption depends on types of windows, opaque component, and shading elements. The crucial factors in designing facades are the window to wall ratio on the facades, windows' area, windows' types (double or triple glazing), properties of window and glazing, shading devices, and thickness of thermal insulation for exterior wall, which affects the cost of energy consumption.

Du, Huang, and Jones (2019) state that one way to reduce energy consumption is energy production from renewable energy. They define six types of resources, which can be used for generation energies: hydropower (water energy), biomass, ocean energy (tide and wave), geothermal, wind, solar. Among the mentioned renewable energy sources, wind and solar energy can be harvested by devices integrated on the facades. Du *et al*. (2019) explain that generate electricity and heat from solar power are done using collectors, photovoltaic panels, or combinations of them. Besides, by using turbines, it is possible to generate electricity from wind power. Hansanuwat (2010) suggests kinetic facade systems in order to generate more energy by tracking the sun position or wind direction.

2.2.2.2 Decreasing Cost of Facade Maintenance/Cleaning

Flores-Colen and de Brito (2010) explain that decay starts as soon as the construction finish. According to Moghtadernejad (2013), local environmental exposure, moisture, freeze-thaw cycles, and chemical (air pollution) can cause facade deterioration. As Flores-Colen and de Brito (2010, p.1718) said, there are some reasons, which cause of building fail: "*faulty design, faulty construction, faulty maintenance, faulty materials, and faulty use*". They divide faulty maintenance into two parts: incorrect maintenance, and usually, no maintenance during building life.

Flores-Colen and de Brito (2010) have three types of maintenance analysis in their study:

- Preventive maintenance: the facades' component control regularly to decrease non-plan works. Therefore, the cost of maintenance for unexpected problems will decrease.
- Predictive maintenance: The facade component performance problems are predicted before becoming worse to decrease the cost of repairing.
- Reactive maintenance: it is related to unexpected problems in the facade, which should be repaired by extra cost.

According to the Building and Construction Authority, Singapore (2017), it is crucial to consider facade maintenance in the designing phase. It means that the facades should be accessible for cleaning, maintenance, repairing, and inspection. If the facades are not accessible, installing access provision for complex facades and high-rise buildings after construction will be very expensive. In designing facades access systems, four factors should be taken into account; providing a safe workplace, accessing every part of facades for cleaning and repairing, optimizing a number of access systems, and decreasing the cost of installing access systems. Moghtadernejad (2013) and Flores-Colen and de Brito (2010) explain that it is better to use durable materials for all facade components to reduce material deterioration and facade maintenance costs to a minimum.

Lee, Ryu, and Lee (n.d) suggest using automatic robot systems instead of conventional rope and gondola for maintenance and cleaning of high rise building because the old systems cause increasing the rate of accidents, which lead to death. Furthermore, using automatic robot systems decrease the cost of facades maintenance.

Using a self-cleaning glass or coating on the facades can be the best solution for reducing maintenance costs and decreasing facade deterioration by air pollution. For example, by spring titanium dioxide (self-cleaning material) on the facade as a final finishing, the facade will not need cleaning. (Andaloro, Mazzucchelli, Lucchini, and Pedeferri, 2016) and (Volp, 2018)

2.2.2.3 Decreasing Cost of Facade Construction

Karaman, Ekici, Cubukcuoglu, Koyunbaba, Kahraman (n.d) say that facades require a huge amount of materials in the construction of buildings, which are noticed by architects and engineers in designing steps to decrease the cost. Therefore, using affordable and local materials as well as designing affordable systems in construction can affect cost reduction. Karaman *et al*. (n.d) explain that it is better to optimize the size of windows by considering daylight performance because large glass areas require more budget compared with opaque areas.

Andrade, Harada, and Shimada (2017), Li, Lu, Wang, Huang, Chen, and Wang (2018), and Du *et al*. (2019) explain that building envelop is one of the most significant parts that can be designed modular and prefabricated to decrease installation costs. They also believe that prefabricated modular facades construction not only decreases cost but also reduces construction time and decreases the number of laborers by easy installation. Andrade, Harada, and Shimada (2017) say that the facade's complex surface can be drawn and analyzed by software and sent to automated machinery for production. The optimization of panels or tiles regarding the cost is called rationalization. The size, materials, forms, and placement of the panels directly affect their fabrication and construction cost and facades' final shape.

2.2.3 Decreasing Environmental Pollution

Muralikrishna and Manickam (2017, p.1) believe that "*Generally, environmental pollution takes place when the environment cannot process and neutralize harmful by-products of human activities in due course without any structural or functional damage to its system.*" They say that the factors that increase environmental pollution are population growth, technological development, increasing energy consumption in the cities for building and industrial sectors. Liu , Zhang, and Liu (2017) suggest two ways to deal with man-made pollution. The first way is preventing pollution from coming into the environment. The second way is cleaning pollution if it comes.

Muralikrishna and Manickam (2017) and Liu *et al.* (2017) classify environmental pollution into four groups: water pollution, air pollution, and soil pollution, noise pollution (physical pollution). Moreover, Mizon (2002) and Lyytimäki and Rinne (2013) note that artificial light at night cause light pollution. Hence, Environmental pollution can be classified into five main groups; air pollution, water pollution, soil pollution, light pollution, noise pollution.

2.2.3.1 Decreasing Soil Pollution

According to Liu *et al.* (2017), soil pollution sources by humans are deforestation and soil wastes, which are generated by industrial sectors and the consumption process. They believe that it is possible to remove soil pollution from the environment by refusing, replacing, reducing, reusing, or recycling of materials.

Gültekin and Alparslan (2011) believe that the buildings influence the environment from construction time to demolition time. According to them, minimizing energy consumption, using renewable energy, utilizing recyclable, reusable, and local materials in designing of buildings are very important parameters to decrease environmental pollution.

As Aksamija (2013) said, the selection of materials, which have a minimum impact on the environment, for the building construction is one of the critical factors in the designing step. According to Gültekin and Alparslan (2011), construction of the building produces large amounts of various materials that it is not possible to recycle all of them. Therefore, using healthy materials instead of industrial materials, which include poisonous substances, are suggested. Healthy and natural materials, which can be recycled and reused, like wood, stone, straw, clay, are suitable materials for buildings construction (Gültekin and Alparslan, 2011).

Moreover, the embodied energy also can the base of choosing construction material. The amount of energy, which need for extracting, processing, transporting, installing, and recycling or disposing of the materials, is called embodied energy. (Aksamija, 2013)

2.2.3.2 Decreasing Air Pollution and Global Warming

European Environment Agency (2019), the sources of air pollution are:

- Burning of fossil fuel for the generation of electricity, heating of buildings.
- Industrial sector,
- Waste treatment,
- Natural sources like volcanic,

Tam *et al.* (2018) and Webb, Aye, and Green (2018) say that for decreasing air pollution and having fresh air for the world’s residents, it is important to decrease fossil fuel by using efficient mechanical systems and applying passive and active systems, which use renewable energy. In addition, using materials with low embodied energy can be useful in decreasing air pollution. Knaack *et al*. (2007) believe that increasing global warming and greenhouse gas emissions because of air pollution result in erecting the energy-efficient building and using renewable energy in the buildings.

Kaegi, Ulrich, Sinnet, Vonbank, Wichser, Zuleeg, Simmler, Brunner, Vonmont, Burkhardt, and Boller (2008) explain that using synthetic TiO2 nanoparticle in most productions and construction materials like paints of exterior facades cause emission, which pollutes the air. Also, some gloves and finishing material cause environmental pollution because of their emission. Therefore, applying non-toxic raw material in producing construction materials assists in decreasing environmental pollution.

2.2.3.3 Decreasing Light Pollution

Mizon (2002) and Lyytimäki and Rinne (2013) explain that artificial light at night causes light pollution that prevents to see stars. Lechner and Arns (2013) state that the main source of light pollutions is road and street lighting, commercial lighting, decorative outdoor lights, and urban areas lighting, lighting from inside, and outside the buildings. According to Mizon (2002), light pollution affects human health, wildlife, plants, environmental degradation, such as glare, sky glow, and intrusion. Moreover, light pollution causes increased energy consumption, which means a waste of energy. Mizon (2002) has a suggestion for architects to reduce decorative lights of buildings' envelops and use shading elements to decrease light pollution.

2.3 Quality Function Deployment

One of the methods for increasing the design quality of products in most industries is Quality Function Deployment (QFD) method that was developed by Yoji Akao in Japan in 1966 and employed for the first time at Mitsubishi's Kobe shipyard site in 1972 for improving the quality of products. According to Hauser and Clausing (1988), by considering customer needs, Toyota became one of the best in the world by using the QFD method, from being the worst.

According to the QFD developer Akao (1990), it is a technique for achieving; a) customer satisfaction by developing the design quality, b) Considering user requirements as the design targets throughout the manufacturing process. He believes that the QFD method is a customer-oriented method that transfers user requests into the design process and quality targets.

Caetano and Amaral (2011) state that the QFD method is a method to fill the gap between customer needs and given technology. In this method, customer requirements are the basis for design strategy and are considered throughout all processes, which are product designing, engineering, and production (Mujalda, Verma, Modi, and Balsara, 2015). According to Antony and Preece (2002), the QFD method is a planning technique rather than a quality technique. By focusing on teamwork and making the relationship between current performance and customer satisfaction, the QFD method creates a clearer design view.

Moubachir and Bouami (2015) state that the QFD method is a flexible method used in various engineering fields according to the type of products that have to be manufactured. Akao (1990) has explained that the QFD method can be used in industrial processes, the construction industry, the service sector, and software deployment. The QFD method was applied by Armacost, Componation, Mullens, and Swart (1994) for the production of exterior structural wall panels. On the other hand, Serpell and Wagner (1997) used the QFD method for designing the building's internal layout. In addition, in their construction projects, the QFD method have been used to get better results for the quality of construction.

Like any other method, Quality Function Deployment also has strong and weak points. From the literature review, the following strong points of the QFD method have been identified:

- Companies manufacture products by considering customer requirements, which helps them to have compromises between products and customers. Therefore, the profits of producers/companies can increase if they can answer/fulfill customer needs (Chien and Su, 2003).
- Analysis of market, customer requirements, and competitors are enhanced by applying the QFD method (Maritan, 2014).

- All departments of production factories like sales, engineering, quality control, and manufacturing departments are involved in the QFD method for the manufacturing process (Maritan, 2014). According to Hauser and Clausing 1988, the QFD method breaks down functional barriers and supports teamwork. It emphasizes multifunctional contribution and teamwork rather than having one leader or manager achieve company goals (Antony and Preece, 2002).
- "*It emphasizes on the visibility of information, which is gathered from several points of view: capability of meeting requirements from the customer's point of view, technical capabilities from a company point of view, and level of competitiveness from a market point of view*" (Antony and Preece, 2002, p.76).
- The QFD method decreases the time spent on production by clarifying checkpoints in each step, which leads to better project planning (Maritan, 2014). The problems decrease because they are identified in early steps by the QFD team (Antony and Preece, 2002).
- Customer satisfaction will increase because the team focuses on their need (Antony and Preece, 2002).

In addition to the above mentioned strong points, the following weak points have been listed by some authors.

- Gathering data from the market and consumers appears to be difficult. Choosing the method of collecting requirements of the customer and giving value to them is an important part of the QFD method, which is complicated (Xie, Tan, and Goh, 2003).
- Sometimes customers do not express their requirements and expectations clearly. The other problem is the dynamic nature of user requirements. Therefore, choosing the right method for gathering data from users plays an essential role in the QFD method because this method is based on users' needs (Maritan, 2014).

- It is crucial to consider the structure of company operations and the QFD method's structure and create harmony between the two; otherwise, problems arise (Maritan, 2014).
- Using only the quality matrices in the QFD method can be misleading if the whole process of the QFD method is not considered. Therefore, it is essential to understand how to integrate the matrices in the method (Maritan, 2014).
- Analysis of large dimension matrices is complicated. Lowe and Ridgway's (2000) have suggested limiting matrices' dimensions to a maximum of 8 lines and 8 columns.
- More concentration is needed to put correct and real information as input data in the QFD matrices because they relate to each other. If there is a problem in the first one, the problem is transferred to the following matrices (Gargione, n.d).

2.3.1 Framework of Maritan

Maritan (2014) has summarized the Quality Function Deployment method as follows:

- Achieving excellence of product quality by evaluating users' requirements as the main goal.
- Employing mathematical calculations in the QFD method makes it an objective method.
- The QFD method follows various steps, including the market and customer analyses to design, technological processes, and production.
- There is a correlation between non-homogeneous contexts like customer requirements and product characteristics in the QFD matrices, which help to have better results in each step of the manufacturing process.
- This method links each company's function to the design process.

- The QFD method follows a complete pathway that helps each workgroup to decide and act clearly.
- The QFD method breaks down complex problems into small ones using an orderly structure, which is simple to solve.

Maritan (2014) defines a framework by using the Quality Function Deployment method, which has two goals: a practical approach and educational clarity. This framework has seven phases and 12 matrices (Figure 2.33). The seven proposed phases of the framework are Strategy, Customer, Product Characteristics, Functions and Mechanisms, Innovation, Parts, Costs and Production process, and Reliability. The mentioned phases are described in detail as following:

(a). The Strategy Deployment Phase is based on answering the following four questions:

- What are the strategies for new product development that the producer is looking for?
- What are the core competencies regarding the producer's strengths?
- Who are the customers of the new product?
- Who will complete these phases?

Maritan (2014) has formulated three matrices to answer these questions in order to complete the strategy phase. These three matrices are:

- Analytic Hierarchy Process (AHP) matrix to define the priority of strategic targets,
- QFD correlation matrix to calculate the priority of the core competencies,
- Preplan matrix to identify the priority of the main customer segment.

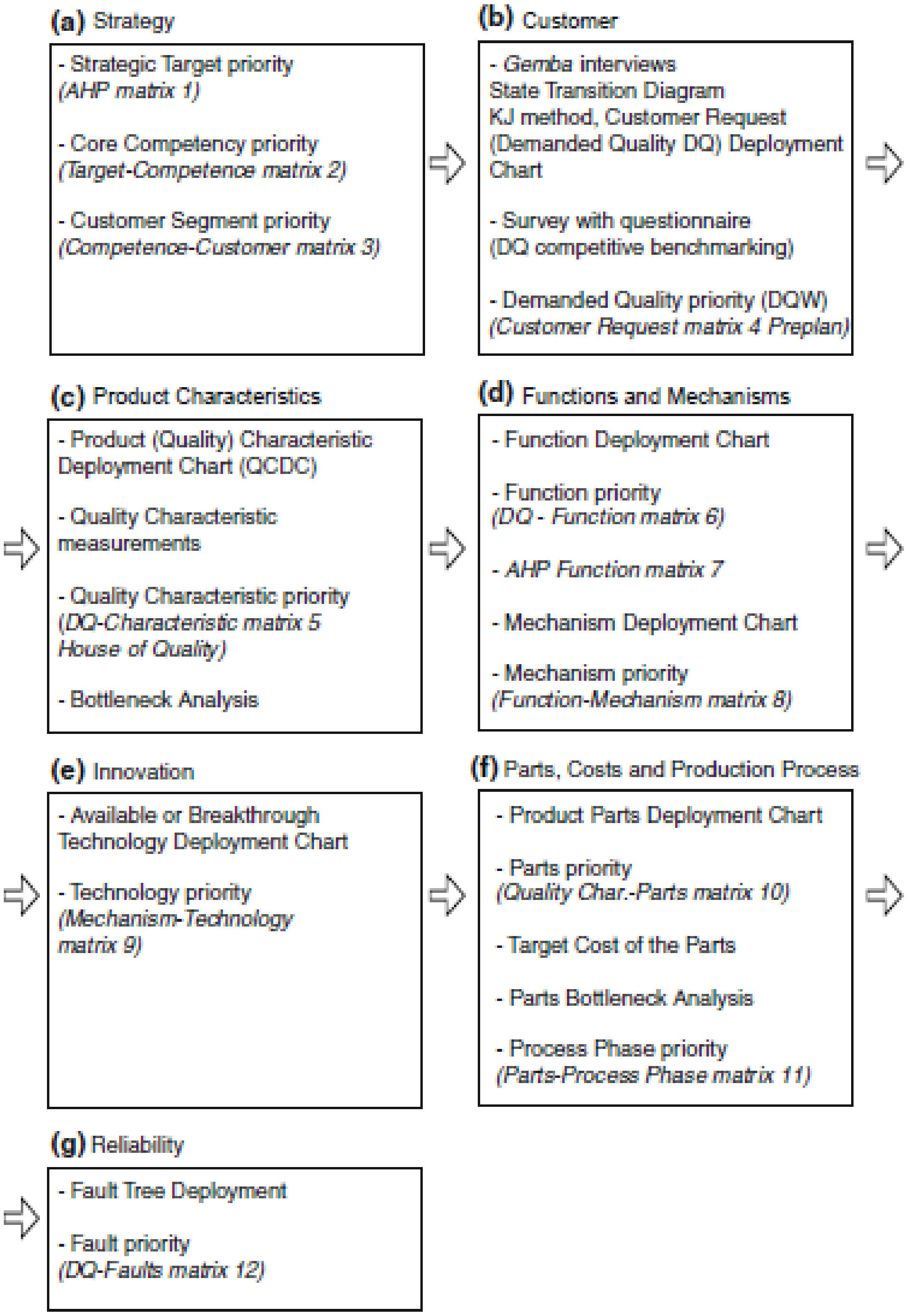


Figure 2.33 The proposed framework with 7 phases and 12 matrices: Strategy Customer, Product Characteristics, Functions and Mechanisms, Innovation, Parts, Costs and Production process, and Reliability (Maritan, 2014)

According to Maritan (2014, p.39), the QFD team starts the work with a brainstorming meeting in order to discuss various ideas about “the strategic subject matters” and fill out the above mentioned “strategic matrices”.

After brainstorming, four to a maximum of ten targets are inserted in the rows, as well as the columns of the strategic target matrix (Figure 2.34). Then their comparative importance is given numerically in the matrix body to determine the targets’ priorities by calculating normalized assessment.

AHP STRATEGIC TARGET MATRIX 1

1 = the row is equally important as the column
3 = slightly more important
5 = more important
7 = much more important
9 = very much more important
0,33 = slightly less important
0,20 = less important
0,14 = much less important
0,11 = very much less important

			STRATEGIC TARGETS									
			A	B	C	D	*a*	*b*	*c*	*d*		
			Reinforcement of the market share	Relaunch of the brand	Increase turnover	Reduce the time to market	*Normalised assessment*				Absolute weight	**Strategic target priority**
STRATEGIC TARGET DEPLOYMENT	1	Reinforcement of the market share	1.00	0.20	5.00	3.00	*0.15*	*0.12*	*0.31*	*0.41*	0.99	**24.87%**
	2	Relaunch of the brand	5.00	1.00	7.00	3.00	*0.77*	*0.60*	*0.44*	*0.41*	2.21	**55.28%**
	3	Increase turnover	0.20	0.14	1.00	0.33	*0.03*	*0.08*	*0.06*	*0.05*	0.22	**5.55%**
	4	Reduce the time to market	0.33	0.33	3.00	1.00	*0.05*	*0.20*	*0.19*	*0.14*	0.57	**14.30%**
		Total	6.53	1.67	16.00	7.33	*1.00*	*1.00*	*1.00*	*1.00*	4.00	100.00%

Figure 2.34 Royal AHP Strategic Targets matrix 1 (Maritan, 2014)

The second matrix (Figure 2.35) is used to calculate the core competencies’ priority, which is the organization’s or company’s strengths. Maritan (2014, p.45) states that according to Prahalad and Hamel (1990), there are three characteristics for core competency: It allows for potential access to a wide variety of markets; it increases benefits perceived by the customer, and it is difficult for the competitors to imitate. Four to ten competencies should be listed in exact and descriptive sentences.

In the second matrix, the strategic targets come from the previous matrix to the left side column of the core competency matrix, and the strategic target weights are inserted into the next column. On the top row, core competencies are listed. Then the correlations between the strategic targets and core competencies are entered for each cell, and lastly, the weights of competencies are calculated and shown in a histogram. (Maritan, 2014) According to the author, This second phase is very interesting for decision-makers, the top management of a company, the owner-manager of a small office, the staff of an organization or a self-employed person.

STRATEGIC TARGET - CORE COMPETENCY MATRIX 2								
⊙ : STRONG CORRELATION ⦸ : MEDIUM CORRELATION ∴ : WEAK CORRELATION			CORE COMPETENCY DEPLOYMENT					
			A	B	C	D	E	
STRATEGIC TARGET DEPLOYMENT		Target priority	We know our customers	Widespread distribution network	Technical experience and specific bicycle know-how	Good financial capacity	Good market share for classic bikes	Total
1	Reinforcement of the market share	24.87%	⦸	∴		⦸	∴	
2	Relaunch of the brand	55.28%	⊙	⦸		⊙	⦸	
3	Increase in turnover	5.55%	∴	∴		∴		
4	Reduce the time to market	14.30%		∴	⊙	∴		
		Absolute weight	5.78	2.11	1.29	5.92	1.91	17.00
		Core competency priority	**33.99%**	**12.39%**	**7.57%**	**34.83%**	**11.22%**	100.00

Figure 2.35 Royal Strategic Target-Core Competency matrix 2 (Maritan, 2014)

The third matrix of the strategy phase is called the Customer Segment Priority. In this part, the main customer segment should be identified by the QFD team. Maritan (2014) explains that the standard customer types are defined by marketing research institutes, who can be customers, retail companies, and other companies.

Maritan (2014, p.49) suggests a way to define customers by creating a chart, which has six columns called “Customer Segment Table.” This table helps the team to identify the customer by asking five questions. The questions are “*Who (who will use the product or the service), What (what they will be used for), When (when on what occasion), Where (where they will be used), Why (for which reason), How (how the service or the product will be used)*” (Maritan, 2014, p.49).

Maritan (2014) states that, like previous matrices, it is better to limit the number of segments to avoid complex calculations. The left column of the matrix will be a list of core competencies and their weight, and the top row is for a list of customers. According to Maritan (2014), defining the impact of internal competencies on customer type is very important in this step. Finally, the result of the correlation between core competencies and customer segments as the absolute weight is made into a histogram to present the exact result (Figure 2.36).

CORE COMPETENCY - CUSTOMER SEGMENT MATRIX 3

⊙ : strong correlation
⊘ : medium correlation
∴ : weak correlation

	CORE COMPETENCY DEPLOYMENT	Core competency priority	Customer 1A Specialised retailer	2B Large scale retail trade	3C Adult end user	4D Young end user	Total
A	We know our customers	33.99%	⊙		⊙	∴	
B	Widespread distribution network	12.39%	⊙	∴	⊘	⊘	
C	Technical experience and specific bicycle know-how	7.57%	⊘	∴	⊘	∴	
D	Good financial capacity	34.83%	⊙	⊘	⊘	⊘	
E	Good market share for classic bikes	11.22%	⊙	∴	⊙	∴	
		Absolute weight	7.54	1.24	4.70	1.83	15.32
		Customer segment priority	**49.20%**	**8.13%**	**30.71%**	**11.96%**	100.00%

Figure 2.36 Royal Core competency-Customer Segment matrix 3 (Maritan, 2014)

(b). Customer Analysis Phase has four steps: "*Questionnaire survey, Gemba interviews (open answer interview), KJ brainstorming (called after its creator Jiro Kawakita), Customer Requests, and Demanded Quality priority*" (Maritan, 2014, p.36). "*Gemba is a Japanese word, which means the place where truth is known, the actual place... the crime scene... QFD Gemba analysis is made up of open answer interviews, addressed to customers or potential customers ... to give his opinion, make suggestions, criticize, and judge the product or service, and make a comparison with the competitors*" (Maritan, 2014, p.51). The author suggests asking the following four questions to help the teams to know their customers and their requirements:

- From where can the teams obtain information about their customers?

- How to create the questionnaire and managed the interview with the users?
- How to organize the raw information which is obtained from customers?
- How to rank the priority of customer requirements?

In order to clarify customer requirements, Maritan (2014, p.51) suggests "Gemba" analysis as the first step. The team selects a small group of customers (10 to 15) to have these open answer interviews in the place where the product is used to have their critical opinion and judgment or even their comparison with several producers. Mazur (1996) points out that the Gemba method offers qualitative analysis instead of quantitative analysis before the product development despite the traditional method. After obtaining information like needs, requests, desires, and expectations of customers from the Gemba method, the brainstorming meeting is started according to the Jiro Kawakita (KJ) method to organize and select the ideas and information from the interviews. These inputs are then used in the "Demanded Quality Deployment Chart (DQDC)" to help prepare a user satisfaction questionnaire sent to a large group of customers. The average scores obtained from the questionnaires are inserted in the customer request matrix (also called the preplan or quality plan matrix) to evaluate customer requirements and determine "... *the importance of customer expectations, competitors' benchmarking and sales issues*" (Maritan, 2014, p.65). For this reason, the result of the QFD questionnaire should be quantitative or based on numerical rating scales. Maritan (2014) emphasizes that the following important points should be considered in preparing the questionnaire.

- It should be in understandable language, and the questions and questionnaires must not be too long (Maritan, 2014). Give short instructions on how to answer the questions (Rattazzi, 1990).
- In the QFD questionnaire, the survey aims should be explained with complete transparency because the customer's opinion is important in the QFD method to understand the strong and weak points about the product (Maritan, 2014).

- Make a group of questions for the same subject. The general questions should be before specific ones, and it is better to place the complex question in the intermediate position (Rattazzi, 1990).
- Write interesting and non-aggressive questions at the start of the questionnaire in order to begin a good collaboration with the interviewee (Goode and Hatt, 1952). While it is better to write aggressive questions at the end (Rattazzi, 1990).

According to Maritan's fame work, the fourth step of customer analysis is making a preplan matrix by getting numerical data from the questionnaire in order to quantify customer requirements with a weight (Figure 2.37).

a. On the right side of the matrix, the requirements of the customers are placed.
b. The second column belongs to the degree of importance given by the customers in the questionnaire, which are called "degree of importance."
c. The third, fourth, and fifth columns relate to the assessment of customers about the product and the competitor's products. These three columns can be under the name of "benchmarking" or "competitive analysis."
d. The next column is "quality plan" or "assessment target," which is calculated by the QFD team for each customer requirement.
e. In the next column, the ratio between preplan and average assessment of our product is shown for each customer requirement. This column is called "rate of improvement".
f. On the right column of the rate of improvement, the sale point column is located that top management identifies it. Three symbols are used for sale point:

   ʘ = Score 1.5 for strong sales point.

   Ө = Score 1.2 for medium sales point.

   No symbol for that demand quality means that it is not considered as a sales point.
g. The following equation calculates the absolute weight.

$$\text{Absolute Weight} = \text{Degree of Importance} \times \text{Rate of Improvement} \times \text{Sales Point}$$

h. In the next column, like other matrices of the QFD, the percentage of absolute weight will be calculated.

	CUSTOMER REQUESTS MATRIX 4 (PREPLAN)								
		BENCHMARKING			PLAN			WEIGHT	
CUSTOMER REQUEST (DEMANDED QUALITY) DEPLOYMENT CHART	DEGREE OF IMPORTANCE	Royal	Competitor A	Competitor B	ASSESSMENT TARGET (Quality Plan)	RATE OF IMPROVEMENT	⊙=1.5 ⊘=1.2 SALES POINT	ABSOLUTE WEIGHT	***CUSTOMER REQUEST PRIORITY DQW (%)***
Feeling of refinement and classic style	4.8	4.0	4.0	4.0	4.5	↗ 1.13	⊙	8.10	***11.16%***
Saving time in assembling	4.0	2.5	3.0	3.5	4.0	↗ 1.60		6.40	***8.82%***
Riding a status symbol	4.8	4.7	4.0	4.4	4.7	→ 1.00	⊙	7.20	***9.92%***
Make an investment for the future	4.7	3.1	4.7	3.3	5.0	↗ 1.61	⊘	9.10	***12.54%***
Absence of back stress	3.2	4.1	4.3	3.5	4.8	↗ 1.17		3.75	***5.16%***
Regular progression in braking	4.6	3.1	4.5	3.7	5.0	↗ 1.61	⊘	8.90	***12.27%***
Feeling of silence while riding	3.8	2.7	3.0	3.6	4.1	↗ 1.52		5.77	***7.95%***
Feeling of fluidity while pedalling	3.5	3.2	4.0	3.0	4.5	↗ 1.41		4.92	***6.78%***
Need for sports style	2.0	2.0	3.0	2.7	3.5	↗ 1.75		3.50	***4.82%***
I feel different from the other cyclists	4.1	2.5	3.0	2.5	3.5	↗ 1.40	⊙	8.61	***11.87%***
Feeling of craftsmanship	4.8	2.3	3.0	3.0	3.5	↗ 0.88	⊙	6.30	***8.68%***
							Total	72.55	100%

Figure 2.37 Royal Customer Requests matrix 4 named Preplan (Maritan, 2014)

According to Maritan (2014), at the end, the result of matrix will be presented in a histogram to understand better.

(c). Product Characteristics Phase consists of the Product (Quality) Characteristic Deployment Chart (QCDC), Quality Characteristic measurements, Quality Characteristic priority (*House of Quality),* Bottleneck Analysis (Maritan, 2014).

Maritan (2014) states that quality characteristics describe their physical features and the outcome of tests and trials. The characteristics should be measurable. Additionally, they should be defined by a list of the alternatives, which respond to the customer requirement. Maritan (2014, p.87) explains that in this phase, technical people of the team come to the fore to translate "*psychological expectations into technical objects.*"

According to Maritan (2014), in this step, the KJ method is used again to define quality characteristics by the technical team. Maritan (2014) explains that the quality features are categorized in a hierarchical structure maximum in three levels as a Quality Characteristic Deployment Chart (QCDC).

Determining value for each characteristic is necessary to make them measurable, which is possible by measurement testing or technical knowledge (Maritan, 2014).

According to Maritan (2014), the third step of the product characteristic phase is making the House of Quality matrix (Figure 2.38). The headings of the HoQ matrix come from QCDC, and the right column comes from the fourth matrix of the previous phase, which is called the customer requests matrix. Maritan (2014) explains that the result of the HoQ matrix is quality characteristic priority.

CUSTOMER REQUEST – CHARACTERISTIC MATRIX 5 (HOUSE OF QUALITY)

		CHARACTERISTIC DEPLOYMENT													
		Comfort				Customisation			Service and after sales				Safety		
CUSTOMER REQUEST (DEMANDED QUALITY) DEPLOYMENT	Customer request priority (DQW)	Braking noise level	Chain noise level	Hub noise level	Bicycle weight	Available colours	Accessories	Component labelling	Bike setting	Paintwork durability test	Warranty	Product delivery time	Lighting efficiency	Braking distance	
Feeling of refinement and classic style	11.16%	∴	⊘	⊘		∴	⊙	⊙			⊘		∴		
Saving time in assembling	8.82%				⊘				⊙		∴	⊘			
Riding a status symbol	9.92%	⊘	⊘	⊘	∴	∴	⊙	⊙	∴	⊘	⊙		⊘	⊘	
Make an investment for the future	12.54%						⊘	∴		⊙	⊙				
Absence of back stress	5.16%				⊘		∴							∴	
Regular progression in braking	12.27%	⊙	∴	∴	∴				∴					⊙	
Feeling of silence while riding	7.95%	⊘	⊙	⊙										∴	
Feeling of fluidity while pedalling	6.78%		⊙	⊘	⊘				⊘						
Need for sports style	4.82%	⊘			⊙		⊘	∴					⊘	⊘	
I feel different from the other cyclists	11.67%	∴	∴	∴		⊙	⊙	⊙		∴	⊘				
Feeling of craftsmanship	8.68%						∴	⊙	∴		∴				
Technical benchmarking	Unit of measurement	dB	dB	dB	kg	no. colours	no. access.	no. compon.	min	hours	years	days	metres	metres	
	Royal	50	37	46	17	1	7	5	45	48	2	10	12	4	
	Competitor A	40	39	40	15	3	10	3	25	48	3	15	13	3	
	Competitor B	36	43	40	16.5	2	15	5	25	48	3	15	12	4	
	Technical Targets	36	35	38	15	3	20	7	25	72	5	7	15	3	
	Difficulty (1=very easy , 5=very difficult)	4	2	1	3	2	2	3.5	4	5	4	3	2	2	Total
	Absolute weight	2.02	2.20	1.79	1.28	1.28	3.63	3.92	1.31	1.54	2.89	0.26	0.55	1.68	24.35
	Characteristic Priority (QCW)	*8.28%*	*9.04%*	*7.37%*	*5.25%*	*5.25%*	*14.89%*	*16.10%*	*5.36%*	*6.34%*	*11.86%*	*1.05%*	*2.28%*	*6.89%*	100.00%

Figure 2.38 Royal House of Quality matrix 5 (Maritan, 2014)

Maritan (2014) states that the last step of third phase is "*the technical benchmarking and Bottleneck Analysis.*" For this step, the team estimated the difficulty of reaching the technical target of quality features by considering the management and technical aspects. Maritan (2014, p.92) explains that the difficulty evaluation is assessed by using a 5-point Likert Scale ranging from "*1 = very easy to 5 = very difficult*".

According to Maritan (2014, p.93), For Bottleneck Analysis, the QFD team makes "*bi-dimensional mapping of the characteristics*" by using "*estimated Difficulty in reaching to specific target*" on Y-axis and "*Characteristic weighted*" on X-axis. The diagram, shown in Figure 2.39, is divided into four quadrants: Easy-High priority, Easy-Low priority, Difficult-Low priority, and Difficult-High priority.

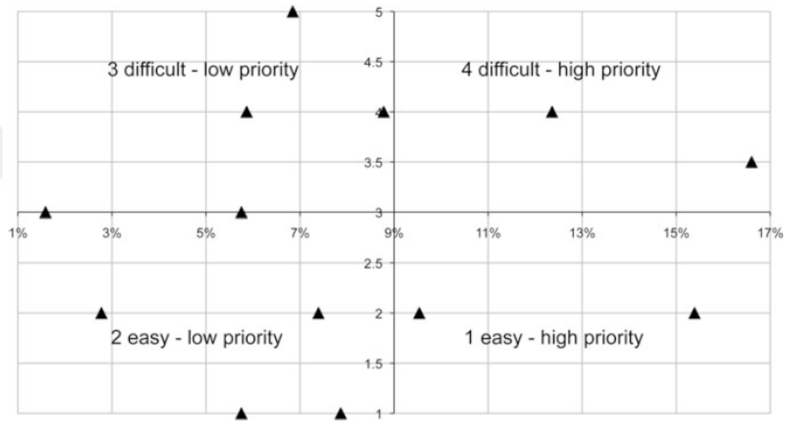


Figure 2.39 Product Characteristic bottleneck analysis (Maritan, 2014)

(d). Functions and Mechanisms Phase is a very important phase in the QFD method because the basic functions of the product or service, which are not mentioned by the customer, will be filled in by the technical team. This phase contains five steps:

- Function Deployment Chart is made using the KJ method, which will be used in the sixth matrix.
- Function priority (DQ - Function matrix 6) in which the correlation between customer requirement and function deployment will be calculated to determine the weight of Product Function (Figure 2.40).
- AHP Function matrix 7 is prepared to correlate product functions among themselves (Figure 2.41).
- Mechanism Deployment Chart

- “Mechanism priority (Function-Mechanism matrix 8)” (Figure 2.42).

Maritan (2014, p.96) points out that the fifth and sixth matrix should present a similar result in the “*list for the items with higher scores*.” He says that if there are significant differences between their results, it is better to recheck the calculation procedure. In the end, the priority of function will be shown in a histogram.

CUSTOMER REQUEST – FUNCTION MATRIX 6											
		FUNCTION DEPLOYMENT									
		It moves people and objects									
		It moves people							It carries objects		
		It runs on the road		It lights the road	It protects rider		It gives comfort		It carries objects		
CUSTOMER REQUEST (DEMANDED QUALITY) DEPLOYMENT	Customer request priority (DQW)	It steers front wheel	It moves rear wheel	It lights the road	It rings the bell	It brakes	It serves as seating for cyclist	It keeps cyclist clean	It carries objects		
Feeling of refinement and classic style	11.16%				∴	⊘		⊘	⊘		
Saving time in assembling	8.82%	∴	∴			⊘					
Riding a status symbol	9.92%			⊘	∴	∴	⊘	⊘	∴		
Make an investment for the future	12.54%								∴		
Absence of back stress	5.16%		∴				⊙				
Regular progression in braking	12.27%					⊙					
Feeling of silence while riding	7.95%	∴	⊙			⊙	∴				
Feeling of fluidity while pedalling	6.78%		⊙				∴		∴		
Need for sports style	4.82%		∴			∴					
I feel different from the other cyclists	11.87%				⊘	⊙		⊘	∴		
Feeling of craftsmanship	8.68%									Total	
	Absolute weight	0.17	1.51	0.30	0.57	3.64	0.91	0.99	0.75	8.83	
	Function Priority	*1.90%*	*17.16%*	*3.37%*	*6.42%*	*41.19%*	*10.31%*	*11.20%*	*8.45%*	100.00%	

Figure 2.40 Royal Function-Customer Request matrix 6 (Maritan, 2014)

Maritan (2014) explains that the seventh matrix (Figure 2.41) is created to correlate Product Functions with themselves by using AHP to identify the most important ones. Like the first matrix of Maritan’s framework. The result of the seventh matrix will be presented in the histogram.

The next step is defining the Mechanism Deployment Chart by using the KJ method. Maritan (2014) believes that mechanisms development and their priority are helpful in making a decision about “*where to work harder on innovation,*” which assists in finding new technical solutions.

AHP FUNCTION MATRIX N. 7

1 = the row is equally important as the column
3 = slightly more important
5 = more important
7 = much more important
9 = very much more important
0,33 = slightly less important
0,20 = less important
0,14 = much less important
0,11 = very much less important

FUNCTION DEPLOYMENT		FUNCTIONS: 1 It steers front wheel	2 It moves rear wheel	3 It lights the road	4 It rings the bell	5 It brakes	6 It serves as seating for cyclist	7 It keeps cyclist clean	8 It carries objects	*Normalised assessment* 1	2	3	4	5	6	7	8	Absolute weight	FUNCTION AHP PRIORITY (%)
1	It steers front wheel	1.00	0.20	5.00	7.00	1.00	5.00	7.00	5.00	*0.13*	*0.07*	*0.20*	*0.21*	*0.26*	*0.30*	*0.21*	*0.15*	1.52	**19.04%**
2	It moves rear wheel	5.00	1.00	7.00	9.00	1.00	5.00	7.00	7.00	*0.63*	*0.34*	*0.28*	*0.26*	*0.26*	*0.30*	*0.21*	*0.21*	2.50	**31.30%**
3	It lights the road	0.20	0.14	1.00	3.00	0.14	0.33	3.00	1.00	*0.03*	*0.05*	*0.04*	*0.09*	*0.04*	*0.02*	*0.09*	*0.03*	0.38	**4.73%**
4	It rings the bell	0.14	0.11	0.33	1.00	0.20	0.20	1.00	0.33	*0.02*	*0.04*	*0.01*	*0.03*	*0.05*	*0.01*	*0.03*	*0.01*	0.20	**2.53%**
5	It brakes	1.00	1.00	7.00	5.00	1.00	5.00	7.00	7.00	*0.13*	*0.34*	*0.28*	*0.15*	*0.26*	*0.30*	*0.21*	*0.21*	1.88	**23.49%**
6	It serves as seating for cyclist	0.20	0.20	3.00	5.00	0.20	1.00	7.00	9.00	*0.03*	*0.07*	*0.12*	*0.15*	*0.05*	*0.06*	*0.21*	*0.27*	0.95	**11.93%**
7	It keeps cyclist clean	0.14	0.14	0.33	1.00	0.14	0.14	1.00	3.00	*0.02*	*0.05*	*0.01*	*0.03*	*0.04*	*0.01*	*0.03*	*0.09*	0.27	**3.42%**
8	It carries objects	0.20	0.14	1.00	3.00	0.14	0.11	0.33	1.00	*0.03*	*0.05*	*0.04*	*0.09*	*0.04*	*0.01*	*0.01*	*0.03*	0.29	**3.56%**
	Total	7.88	2.93	24.66	34.00	3.82	16.78	33.33	33.33	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	*1.00*	8.00	100.00%

Figure 2.41 Royal Function AHP matrix 7 (Maritan, 2014)

He states that it is not needed to be in detail in this phase. The mechanisms are defined as macro-systems to carry out identified functions. Then function mechanisms matrix (8th matrix), shown in Figure 2.42, will be created (Maritan, 2014).

FUNCTION - MECHANISM MATRIX 8

FUNCTION DEPLOYMENT	Function priority	MECHANISM DEPLOYMENT: Steering mechanism	Transmission mechanism	Lighting mechanism	Saddle and frame system	Braking system	Dirt protection mechanism	Carriage system	
It steers front wheel	1.90%	⊙			∴				
It moves rear wheel	17.16%		⊙		∴	∴	⊘		
It lights the road	3.37%	⊘		⊙	∴				
It rings the bell	6.42%				⊘				
It brakes	41.19%		∴		⊘	⊙			
It serves as seating for cyclist	10.31%		⊘		⊙		∴		
It keeps cyclist clean	11.20%		⊙		∴		⊙		
It carries objects	8.45%							⊙	Total
	Absolute weight	0.27	3.27	0.30	2.69	3.88	1.63	0.76	12.81
	Mechanism priority	***2.13%***	***25.56%***	***2.37%***	***21.02%***	***30.28%***	***12.70%***	***5.94%***	100.00%

Figure 2.42 Royal Function-Mechanism matrix 8 (Maritan, 2014)

(e). Product Innovation Phase is related to prioritizing technologies to solve bottlenecks by considering available, underdeveloped, or completely new technologies. According to Maritan (2014), in some cases, the available technology is not enough, and radical innovation like a technological breakthrough is needed. After defining the technology, a Mechanism-Technology matrix (9 th matrix) is made by using Functions priority and Customer Requests priority, shown in Figure 2.43. The result of 9th matrix is defining the priority of technologies and weighting technologies for each mechanism. (Maritan, 2014, P104).

MECHANISM – TECHNOLOGY MATRIX 9									
		TECHNOLOGY DEPLOYMENT							
MECHANISM	Mechanism priority	Led lights	Disc brakes	Light frame (aluminium, titanium?)	Rear hub gear	New paintwork process	Front suspension fork	Bag hooks instead of rack	
Steering mechanism	2.13%			⊘			⊙		
Transmission mechanism	25.56%		∴		⊙		∴		
Lighting mechanism	2.37%	⊙							
Saddle and frame system	21.02%			⊙		⊘	∴	∴	
Braking system	30.28%		⊙		∴				
Dirt protection mechanism	12.70%				⊘	∴		⊘	
Carriage system	5.94%			⊘				⊙	Total
	Absolute weight	0.21	2.98	2.13	2.98	0.76	0.66	1.13	10.85
	TecHnology priority	***1.97%***	***27.47%***	***19.66%***	***27.50%***	***6.98%***	***6.05%***	***10.37%***	100.00%

Figure 2.43 Royal Mechanism-technology matrix 9 (Maritan, 2014)

(e). Parts, Costs, and Production Process Phase utilize data from mechanisms, new technologies, and characteristics by adapting the KJ method to create the "Parts Deployment Chart (PDC)." Then the 10th matrix is prepared by getting data from PDC (Figure 2.44). This matrix will be large if the product components are analyzed in detail. Maritan (2014) suggests dividing the work into a sub-system in order to avoid large matrices. The left column's inputs are the priorities of Characteristic Deployment, which are from 5th matrix (House of Quality), and inputs of the top row are from 9th matrix, which are priorities of Technology Deployment.

The next step of this phase is cost analysis, which is made by answering the two questions: "*How can the cost of a product be subdivided?*" and "*What costs arise from the parts of the product being produced in-house or purchased?*"

The target prices can be determined by analyzing the market and competitors. If the difference between the Parts Target Cost and Parts Value (δ) given at the bottom of 10th matrix is $\delta > 0$, it means that investing more money for improvement Part is possible, which result in verifying customer requirement or technologies; but if $\delta < 0$ it means that the target cost is lower than production cost, which is considered a bottleneck when the component has a high relative weight.

CHARACTERISTICS - PARTS (SUBSYSTEMS) MATRIX 10											
		PARTS DEPLOYMENT									
QUALITY (PRODUCT) CHARACTERISTICS DEPLOYMENT	Product characteristic priority	Handlebars	Led lights	Disc brake system and levers	Saddle	Aluminium frame	Hub gear and chain	Chain-guard and mudguards	Rack	Wheel	
Braking noise level	8.28%			⊙						⊙	
Chain noise level	9.04%						⊙	⊘			
Hub noise level	7.37%						⊙			⊙	
Bicycle weight	5.25%	∴	∴			⊙		⊘	⊘	⊙	
Available colours	5.25%				∴	⊙		⊘	∴	∴	
Accessories	14.89%	∴	⊘		∴			∴	⊙		
Component labelling	16.10%	⊙			⊙	⊙		⊙		∴	
Bike setting	5.36%		∴	⊙	∴		⊙			∴	
Paintwork durability test	6.34%	∴				⊙		⊙	⊘		
Warranty	11.86%	∴	∴	⊘	∴	∴	⊘	∴	∴	∴	
Product delivery time	1.09%			⊘		⊘		⊘			
Lighting efficiency	2.28%		⊙								
Braking distance	6.89%			⊙						∴	Total
	Absolute weight	1.71	0.88	2.24	1.82	3.12	2.31	2.91	1.86	2.34	19.18
	PARTS PRIORITY	*8.94%*	*4.57%*	*11.66%*	*9.50%*	*16.25%*	*12.07%*	*15.15%*	*9.69%*	*12.17%*	100.00%
	Parts target cost	€ 53.62	€ 27.41	€ 69.95	€ 57.02	€ 97.49	€ 72.40	€ 90.92	€ 58.15	€ 73.05	€ 600.00
	Parts valued cost	€ 45.00	€ 25.00	€ 90.00	€ 50.00	€ 130.00	€ 55.00	€ 50.00	€ 60.00	€ 95.00	€ 600.00
	Delta	€ 8.62	€ 2.41	-€ 20.05	€ 7.02	-€ 32.51	€ 17.40	€ 40.92	-€ 1.85	-€ 21.95	€ 0.00

Figure 2.44 Royal CharacteristicParts matrix 10 (Maritan, 2014)

Maritan (2014) suggests making bi-dimensional mapping for better analysis. Bi-dimensional mapping is shown in Figure 2.45, which has four parts:

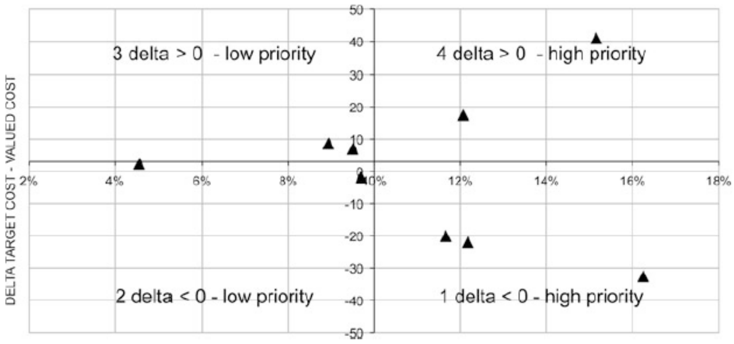


Figure 2.45 Product Characteristic bottleneck analysis (Maritan, 2014)

- Negative δ and high importance are in the first section showing that there are bottlenecks. It means that the parts values are too high, and it is necessary to find a way to decrease them.
- Negative δ and low importance parts are in the second section, which presents that the target costs are lower than production costs. It means that the part cost should be decreased.
- Positive δ and low importance components are shown in third section.
- Positive δ and high importance components are illustrated in the fourth section, which presents that the target costs are higher than the parts values. It means that more money will be invested.

The last step of the product development planning phase is the production process. In this step, 11th matrix is created by data from the result of 10th matrix (Figure 2.46). According to Maritan (2014), the 11th matrix presents the correlation between product parts and production processes, obtained from the Phase Deployment Chart.

(f). Reliability Phase consists of deployment and calculation of Faults' priority, which depends on Parts planning and its effects on customer satisfaction and Customer Requests. Maritan (2014) suggests making a Fault Deployment Chart, called the Fault Tree. This chart shows all the defects and faults that can occur during the process and sort out them in a hierarchical structure.

The next step is creating the12th matrix to weigh the product faults and their effect on customer requirements (Figure 2.47).

PARTS - PROCESS PHASE MATRIX 11											
		PROCESS PHASE DEPLOYMENT									
PARTS DEPLOYMENT	Parts priority	Graphics	Fork insertion on frame and handlebar	Hub gear on frame assembly	Cable Housing	Fitting of brakes	Wheel assembly on frame	Fitting of Chain-guard and mudguards	Fitting of lights	Saddle and accessories	
Handlebars	8.94%	⊘	⊙		⊘	⊘				∴	
Led lights	4.57%								⊙		
Disc brake system and levers	11.66%				⊙	⊙	∴				
Saddle	9.50%	∴								⊙	
Aluminium frame	16.25%	⊙	⊙		⊘		∴	⊘	⊘		
Hub gear and chain	12.07%			⊙	⊙		∴				
Chain-guard and mudguards	15.15%	⊙		⊘				⊙	⊘		
Rack	9.69%	∴							⊙	⊙	
Wheel	12.17%	⊘		⊙		⊙	⊙				Total
Absolute weight		3.65	2.27	2.64	2.89	2.41	1.50	1.85	2.23	1.82	21.25
PARTS PRIORITY		***17.19%***	***10.67%***	***12.41%***	***13.61%***	***11.36%***	***7.04%***	***8.71%***	***10.47%***	***8.55%***	100.00%

Figure 2.46 Royal Parts-Process phase matrix 11 (Maritan, 2014)

CUSTOMER REQUEST - PRODUCT FAULT MATRIX N. 12									
		FAULT DEPLOYMENT (TREE)							
		It does not move		It lights up the road badly		It does not brake		Rust	
CUSTOMER REQUEST DEPLOYMENT	Customer request priority	Jerky cycling	Blocked pedals	No light	Intermittent light	Intermittent braking	Braking not fluid	Rust	
Feeling of refinement and classic style	11.16%			∴	⊘			⊙	
Saving time in assembling	8.82%	∴				∴	∴		
Riding a status symbol	9.92%				⊘		⊘	⊙	
Make an investment for the future	12.54%							⊙	
Absence of back stress	5.16%	∴				∴			
Regular progression in braking	12.27%					⊙	⊘		
Feeling of silence while riding	7.95%	⊙	∴						
Feeling of fluidity while pedalling	6.78%	⊙	⊘						
Need for sports style	4.82%					∴	∴	∴	
I feel different from the other cyclists	11.87%							∴	
Feeling of craftsmanship	8.68%	⊘	⊘					⊘	Total
Absolute weight		1.73	0.54	0.11	0.63	1.29	0.80	3.45	8.56
Faults priority		***20.16%***	***6.35%***	***1.30%***	***7.39%***	***15.09%***	***9.37%***	***40.33%***	100.00%

Figure 2.47 Royal Customer Request-fault matrix 12 (Maritan, 2014)

The 12th matrix, called the request-fault matrix, presents the correlation of Demand Quality, placed in the left column, and Faults Deployment on the top row. Like other matrices, the result of this matrix will also be shown in a histogram.

2.3.2 Quality Function Deployment Phases

According to Moubachir and Bouami (2015), the Quality Function Deployment method follows several phases of product quality deployment combined with other design tools. The first and central phase is the correlation between customer requirements and design specification in a matrix, which is called the House of Quality. According to the type and requirement of projects, several phases can follow in product quality deployment, in matrix form. Akao (1990) has described four phases of deployment for achieving optimal results, namely; quality deployment, technology deployment, cost deployment, and reliability deployment. According to Pahl, Beitz, Feldhusen, and Grote (2007), four phases of the QFD method are product planning, product development, process planning, and production planning. On the other hand, Lin and Pekkarinen (2011) propose three phases: service, process, and activity. While Hauser and Clausing (1988) have defined four phases for the QFD method, namely, House of Quality, Parts Deployment, Process Planning, and Production Planning. Maritan (2014), on the other hand, classifies four phases for the Quality Function Deployment as follows:

- Product concept phase: this phase consists of defining the target of production, anticipating user requirements, and initial process feasibility.
- Product plan phase: in this phase, the product function is achieving through several steps: choosing a key component and mechanical prototype, process feasibility, mock-up, target costs, styling, and identifying the priority of technical tradeoffs.
- Product design phase: this phase consists of several steps: detailed and component design, making the detailed prototype, and testing.

- Process design phase: there are two steps in this phase: pilot manufacturing line and pilot vehicle.

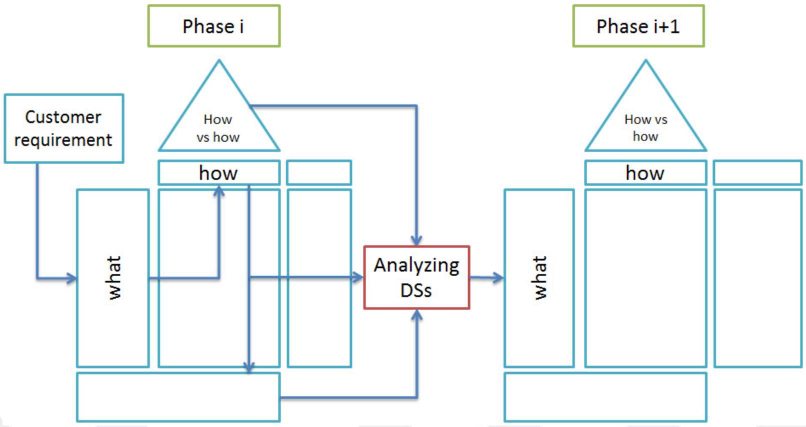


Figure 2.48 Transition between the QFD phases. Source: Moubachir, Bouami, (2015).

According to Moubachir and Bouami (2015), there is one matrix for each phase of the QFD method that is used to define the correlation between two different attributes, the "whats" and "hows," at that phase (Figure 2.48, above). For the calculation of each matrix, the "hows" are put in the top part of the matrix, while the "whats" are inserted into the left column of the matrix (Figure 2.49). Defining both "whats" and "hows" is necessary for the first matrix; after that, the "hows" columns of the first matrix become the "whats" rows of the second matrix, and this process continues to the third and the fourth matrices, as shown in Figure 2.49. In other words, as stated by Sohn and Ju (2015), "*the definition of WHAT and HOW change with each stage, and the framework of QFD is defined by a hierarchical matrix structure in order to guide action in various stages*."

Maritan (2014) has explained that although the QFD method consists of four phases, it is possible to extend the number of levels that are needed.

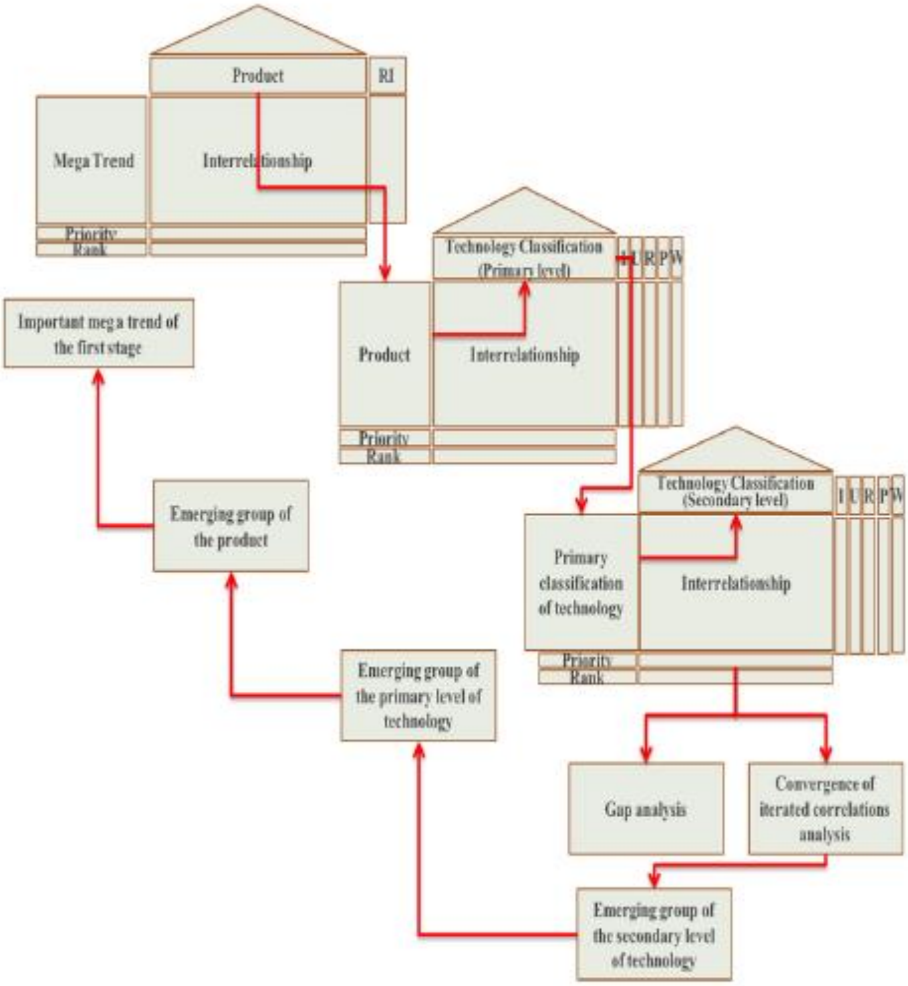


Figure 2.49 Proposed hierarchical QFD framework (Sohn and Ju, 2015)

2.3.3 Definition, Structure, and Building of House of Quality

The House of Quality (HoQ) is so called because it resembles a house with walls, floors, and a pitched roof. It has also become the symbol, the main tool, and the first phase in the QFD process (Akao and Mazur, 2003; Moubachir and Bouami, 2015; and Mujalda *et al.*, 2015). The HoQ matrix combines two charts into a two-dimensional matrix to indicate the correlation between customer needs and product quality characteristics (Ungvari, 1991).

Yang, Yang, Qian, and Kraslawski (2015) state that the HoQ matrix is a way to meet customer requirements with the manufacturing process of the products by considering the impact of user voices (whats), technical features (hows), and the influence of the market on the product quality. The HoQ matrices' results help establish the priorities of customer requirements and determine deficiencies in the production techniques by qualitative and quantitative analyses. The authors point out that "*This information can then be used in selection, adjustment, modification and optimization of the initial plan, thus enabling customer needs to be better satisfied and greater competitiveness to be achieved*." (Yang *et al.*, 2015, p.232)

Yang *et al*. (2015) have presented the structure of the House of Quality matrix (Figure 2.50) as having walls, floor, and roof around the relationship matrix that indicates the relationship between Customer needs (What) and Technical characteristic (How). The left wall is divided into two parts: customer needs (listed in their own words) and the importance of their needs (weighted on a scale of 5). The ceiling of the HoQ matrix is for technical characteristics, which are defined by the QFD team according to their importance to meet the customer needs. The roof of the HoQ matrix is called the correlation matrix, which presents the connections between the technical features. The right wall of the HoQ matrix is called the quality planning matrix (customer assessment matrix), which is used to assess the competitiveness of the product from the customers' point of view. The floor of the HoQ matrix contains the technical evaluation part based on the importance of technical features and technical evaluation of the product.

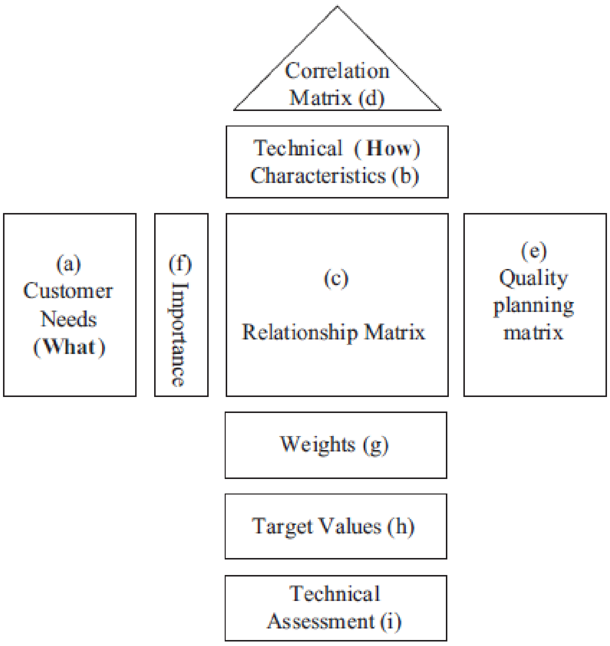


Figure 2.50 Outline of the House of Quality (Yang *et al.*, 2015)

As illustrated in Figure 2.51, conversion of customer requirement into technical characteristics through the process of creating the House of Quality matrix is carried out in the six steps: the determination of Customer Needs, Quality-planning Matrix, Technical Characteristics, Relationship Matrix, Correlation Matrix, and Technical Assessment Matrix (Yang *et al.*, 2015). These steps are explained in the following paragraphs.

(a). Determination of Customer Needs, which are shown as CNi (i = 1, 2, …, m) in Figure 2.51, is the first step towards making the HoQ matrix. According to Yang *et al*. (2015), Ungvari (1991), Antony and Preece (2002), and Moubachir and Bouami (2015), the customer needs can be determined through questionnaires, interviews, observation. Additionally, the needs/requirements can be categorized into three groups: expected, desired, and exciting or unanticipated (Ungvari, 1991; Kano, Seraku, Takahashi, and Tsuji, 1984; and Antony and Preece, 2002).

(b). Determination of the Quality-Planning Matrix is based on eight elements K1 and P1 to P7 (Figure 2.51) : (Yang *et al*., 2015) that are defined as follows K_i is the weight of customer needs on a scale of 1 to 5, which can be defined by the Analytic Hierarchy Process. P1 is the customer satisfaction level with the production, and P2 is the customer satisfaction level with the competitors' products (a scale of 1 to 5). P3 is the target for user need satisfaction that is achieved by "*balancing the weight of the user needs, the results of evaluation of the competitor's products and analysis of the technical difficulty of changing technical parameters*." P4 shows improvement ratio of the customer needs, which is calculated as: $P_{4i} = P_{3i}/P_{1i}$(Where i is the i th customer requirement). P5 shows as a ranking parameter that is used to identify the important customer requirements. Additionally, P6 is customer requirement correction weights and it is calculated as; $P_{6i} = K_i \times P_{4i} \times P_{5i}$. P7 is the relative correction weight of customer requests, which is calculated as; $P_{7i} = P_{6i}/\sum_{i=1}^{m} P_{6i}$ (Yang *et al*, 2015).

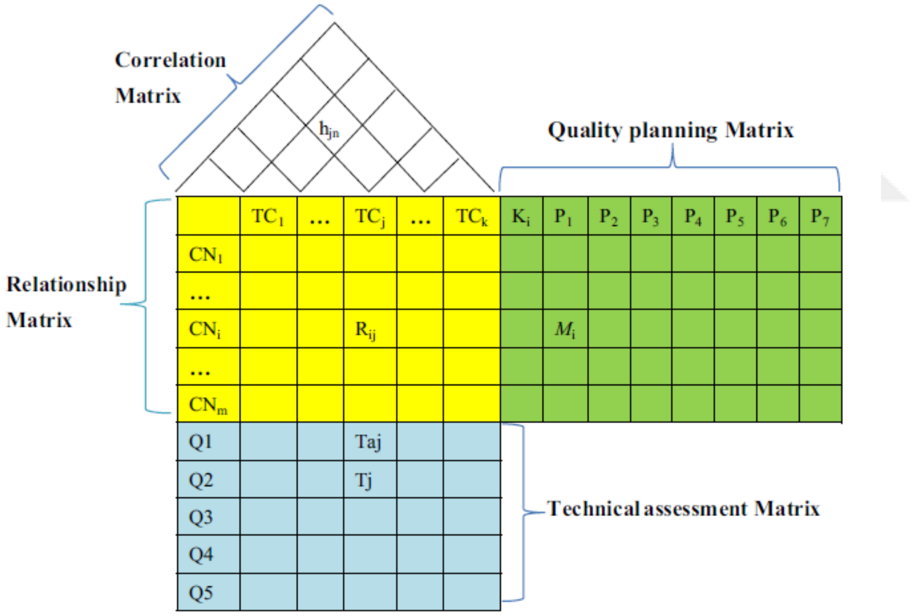


Figure 2.51 Refined structure of the House of Quality. (Yang *et al.*, 2015)

(c). Determination of Technical Characteristics, which is defined as the product description in measurable technical terms by engineers. Technical characteristics affect the customer needs (Hauser and Clausing, 1988) and are listed in the "how" region of matrix (Moubachir and Bouami, 2015 and Yang *et al.*, 2015). These technical characteristics should fulfill the following conditions; meet customer requirements, be relevant, be measurable, and be general significance. Antony and Preece (2002) believe that an important step in the QFD method is how to translate the voice of the customer to the technical language without distorting of customer needs.

(d). Determination of the Relationship Matrix involves the correlation between each of user needs (“whats”) and each of the technical characteristics (“hows”) with symbols (Figure 2.51). The symbols express the degree of correlation: Strong correlation (●), Medium correlation (○), weak correlation (Δ), and zero correlation (empty cell). Antony and Preece (2002) use traditional system to assign the values of 9, 3, 1 respectively for strong, medium, and weak relationships. No symbol in cells means that there is no correlation between user requirements and technical characteristics (Yang *et al*., 2015). The relationship between technical features and customer needs is calculated by multiplying the importance of the “what” to the customer as a percentage (the weight of customer needed to be calculated as a percentage in a separate column) with the strength of the relationship (the value of degrees are 0, 1, 3, 9 in (Gudmundsson, 2013).

(e). Determination of the Correlation Matrix as the roof of the HoQ matrix creates a triangular shape with cells containing some specific symbols that illustrate the relationship between each technical characteristic with the others (Figure 2.51). For negative correlation, “-” sign is used, which means increasing one technical characteristic causes decreasing in the other one. For positive correlation, “+” is used, which means that both characteristics decrease and increase simultaneously. A blank space is used to show that there is no relationship between the two characteristics. To clarify the impact of one characteristic on the other one, Gudmundsson (2013) replaces the symbols with alphabets as follow: “NN” indicates a strong negative relationship; “N” is a negative relationship; “P” is a positive relationship; “PP” shows a strong positive relationship (Moubachir and Bouami, 2015; Antony and Preece, 2002).

(f). Determination of the Technical Assessment Matrix at the bottom region of the HoQ matrix consists of five rows. These rows are the relative importance weight, the target performance of the technical characteristic, the technical assessment of the product, and the technical assessment of the competitor’s product, which are called Q1, Q2, Q3, Q4, and Q5 (Figure 2.51).

This part can also be called the “how much” region, which is divided into three lines, according to Moubachir and Bouami (2015). In the first line, the value of technical characteristics (how much) is established. In the second line, the range of acceptance is written for each characteristic. And in the third line, the score of each technical characteristic is entered (Moubachir and Bouami, 2015).

CHAPTER 3

MATERIALS AND METHODS

In this dissertation, a framework with four phases was considered as a model to design appropriate facade systems by adapting the Quality Function Deployment (QFD) framework proposed by Maritan (2014) (given in section 2.3.1). Different steps were determined for these four phases. The first step was defining primary and secondary targets, occupants’ requirements, technical solutions, and facade systems by analyzing 49 case studies and studying published research papers and reports. The second step was determining preferences of occupants and architects regarding the mentioned parameters through the two questionnaire surveys. The third step was calculating priorities of the parameters by applying the Analytic Hierarchy Process (AHP) and House of Quality (HoQ) matrices. In this chapter, the requirement for four phases of the QFD method, which were analysis of case studies and questionnaire surveys, are explained. Additionally, the application of the case study analysis’ and questions surveys’ results in the framework of this study, which used the QFD method, are clarified.

This chapter presents the materials used, and the methodology followed in conducting the mentioned steps. The Material section describes the three constituents of the research process: the case studies, the questionnaires, and the QFD model. While the Methodology section explains the research in detail in terms of compilation of the data on case studies through literature review, conducting the questionnaire survey and analyzing data, and adapting the QFD framework for architectural design.

3.1 Materials

The materials required to conduct this study in order to apply the QFD method to facade design were 49 case studies, two types of questionnaire surveys conducted in three languages in two countries, and two types of matrices. These are described in the following sub-sections.

3.1.1 Case Studies on Facade Design

In order to obtain information and data regarding characteristics and features necessary in designing building facades with low energy consumption, various types of buildings and their facades were studied from publications, websites, and thesis. It was seen that for different facade types, different techniques could be employed to provide human comfort, decrease energy consumption, and optimize the cost of construction and maintenance. Among these case study buildings, 49 high-performance facades were selected to study for this dissertation. The selection was based on the application of new techniques that employ renewable energies like solar, wind, and geothermal energy via passive and active facade systems. Furthermore, the facades designed by employing several techniques together were preferred to be analyzed in this research.

The selected 49 case study buildings present in a separate chapter (Chapter 4) with sufficient details to understand their construction techniques and sustainability measures; and other relevant information regarding their design teams (architects, structural, mechanical, and electrical engineers), location, climate zone, project year, status, building type, constructed area, and the number of stories.

3.1.2 Questionnaire Surveys for Defining Occupant Requirements and Technical Solutions

Two kinds of questionnaire surveys in three languages (English, Persian, and Turkish) were conducted in both Iran and Turkey for this research. The first one, which consists of 24 questions, was asked from 120 occupants (66 Turkish and 54 Iranian) of various buildings for defining their requirements and importance. The second type with 65 questions was answered by 82 architects (40 Turkish and 42 Iranian) to identify the importance of various techniques in designing appropriate and low energy building facades. On the whole, responses from 202 participants were used as the database in this research. It is noted that the aim of this dissertation is introducing the QFD method as a design method. Hence, the type and number of participants in the questionnaire surveys were not crucial because these surveys in this study were done only to show how the surveys' results were used in the QFD method. While, the type and number of surveys' participants in designing the real project, by adapting the QFD method, should be considered according to the project study.

In the survey carried out with the occupants, three questions about their age, gender, and professions were answered. Then questions regarding design targets and occupants' requirements were answered to determine their preferences. The second questionnaire survey consisted of questions regarding the architects' preferences for design targets and their technical solutions.

Three groups of questions were designed for both surveys. In the first group, questions that were meant to identify the targets for designing facades with low energy consumption were included. In the second group, the importance of the occupants' requirements was identified through questions. In the third group, questions regarding the preferences for active and passive facade techniques and applicable renewable energy systems were asked from architects.

Four questions regarding the primary and secondary targets for designing appropriate building facades were asked in both surveys. The primary targets' importance was defined by answering the first question; while the other three questions were asked to identify the importance of secondary targets. It should be noted here that there is a 5th question regarding preference for renewable energy integration into facades, in the questionnaire for architects (Appendix A2, question 5). These questions were designed in the format of tables where three or four targets were compared two by two, as shown in Table 3.1.

Table 3.1 Format of questions regarding preference of one target over the other that were included in the first group in both occupants' and architects surveys

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
First Target	Second Target				
First Target	Third Target				
Second Target	Third Target				

The format of the subsequent questions regarding the occupants' requirements and facades techniques was based on selecting the relevant answer out of six choices. The first five ones are based on a five-level Likert scale from "Very important/useful" to "Not very important/useful" while responders were also given the option to choose "Do Not Know". Table 3.2 illustrates the format of answers to such questions in this survey. There were 17 questions asked in this manner in the occupants' survey and 60 questions in the architects' survey.

Table 3.2 Format of Likert scale rating type question in both surveys

	Very important/ very useful	Important/ useful	Neutral	Not important/Not useful	Not very important/Not very useful	Do not know
Question						

3.1.3 QFD Model

For designing efficient facades, many factors should be considered. These factors are primary and secondary targets, occupants' requirements, and active and passive efficient facade techniques. The importance and priority of each group play a critical role at the facade designing stage. Hence, for the definition of targets and occupants' requirement priorities, the correlation between occupants' requirements and technical solutions to select suitable facade systems, the QFD framework proposed by Maritan (2014) (Section 2.3.1) was adapted.

Maritan's framework is designed for companies, which would like to improve the quality of their products in order to increase their sales, and it consists of seven phases. These phases are related to the company's strategic priorities, customer requirements, product characteristics, functions and mechanisms, innovation parts, costs and production process, and reliability.

Since the research aim is to provide a framework to guide the design of appropriate facades, the last three phases of Maritan's framework, related to the production phase, have not been utilized. On the other hand, the first four phases have also been altered slightly to adapt to the architectural design process. Hence, the framework of this study consists of the following four phases:

i. Design targets phase: this phase consists of the identification of the strategic design targets, the design of the questions related to the targets for the questionnaire survey, and the calculation of priorities of the strategic targets by using the AHP matrices.
ii. Occupants' requirements phase: the identification of the occupants' requirements and the design of the questions related to these requirements for the first questionnaire survey are aim of this phase.
iii. Design techniques phase: this phase consists of the identification of the technical solutions, the design of the questions related to these techniques for

the second questionnaire survey, and creating the first HoQ matrix to determine the technical solution priorities.

iv. Facade design phase: in this phase, the facade systems were identified to be used in the second HoQ matrix to determine their priorities.

3.2 Methods

The research method consists of three steps to fulfill the four phases of this study's proposed framework. In the first step, a thorough literature review and analysis of 49 case studies were conducted to determine design targets, occupants' requirements, technical solutions, and facade systems. In the second step, two questionnaire surveys were designed and conducted with occupants and architects. In the third step, the results obtained from surveys were used in the QFD matrices to defined their priorities. This chapter presents these three steps in three sections.

3.2.1 Case Studies on Facade Design

At first, 49 buildings were selected as the case studies, which are summarized in chapter 4, from the point of view of facade technologies, type of building and its size, location, climatic zone, year of construction, and the design team (architects, engineers). The sources of information were publications, websites, and graduate research theses.

After summarizing the information regarding these buildings and studying their facades in detail, their facade systems and the applied techniques and solutions in these buildings were listed according to the information gained from the literature review of this study. The facade systems of these buildings are shown in the flowchart in Figure 5.1. The techniques and solutions were applied in case studies' facades were classified into four groups according to the opening characteristics, construction materials, facade components, and energy generation systems. This classification is given in the flowchart in Figure 5.2. In addition, occupants' requirements met in these buildings are presented in the flow chart in Figure 5.3.

All information considered important for this study was then summarized in a table (Table 5.1) to show which facade systems, which techniques, are employed in which building's facades; and, also, to identify the most popular/utilized solutions that are more effective in providing comfort and energy in these buildings. These technical solutions were subsequently used in designing the questionnaire survey for the architects.

3.2.2 Questionnaire Surveys

Two types of questionnaire surveys were prepared and conducted for use in this research. One of them was to be answered by building occupants in order to know their requirements, while architects answered the second one to define their preference regarding facade techniques. Invitation to participate in both surveys was sent by sharing the questionnaires' links with prospective responders via email or WhatsApp. For this purpose, the JotForm website was employed to conduct both types of questionnaire surveys; both questionnaire surveys were uploaded on the JotForm website in three languages; English, Turkish, and Persian. The website gives us the possibility to select one of the three languages to answer. Since Persian is a right-to-left language while English and Turkish are left-to-right languages, for each survey, there were two links; first, the link was defined in two languages; English and Turkish, so participants could select their language, and the second link was defined in the Persian language. Moreover, JotForm made it easy to gather and use the data as it could be copied to an excel file, which was used for making diagrams and matrices.

The participants of the first survey belonged to various groups having different occupations in Iran and turkey. The first survey participants were not selected according to a plan, but the questionnaires were handed out to people who were the researcher encountered in the university, dormitories, banks, etc. to be filled by them.

Hence, the target population were defined as a random sample. Since some participants did not have reliable internet connections, printouts of the questionnaires were provided to them; and data from their responses were transferred to Jotform later by the researcher herself. It is noted that when the participants were filling the questionnaire, the researcher was available to answer their questions if they needed explanations.

Moreover, the participants of the second survey were architects with at least ten years of work experience in consulting architectural offices in Iran and Turkey. In order to do surveys, the researcher met the architects and waited until they filled the questionnaire for giving them an explanation if needed. When the meeting was not possible, the researcher was available to answer the architects by communication tools like Skype and Zoom.

For designing the questions, the information from the literature review and case studies was used. However, first, the responders (the occupants) of questionnaire A1 (Appendix A) were asked to answer three questions about their gender, age, and job. The rest of the surveys' questions were about design targets, occupants' requirements, and technical solutions. Middle East Technical University's human research ethics committee approved the questionnaires done in this dissertation with protocol number 339 ODTÜ. (Appendix H)

Data on personal information (Appendix A, Questionnaires A1) were not presented here. Also, data on questions 34 and 65 (Appendix A, Questionnaires A2) about light tubes and decorative lighting were not used.

3.2.2.1 Designing Questions for Primary and Secondary Targets

As explained in the literature review in Section 0, improving the building's performance by providing human comfort and decreasing cost, as well as decreasing the environmental pollution caused by construction activities, play a crucial role in designing environmentally appropriate building facades. Hence, this research's primary targets regarding the facade's design are improving human comfort, decreasing cost, and decreasing environmental pollution. In order to determine the importance of the primary targets according to occupants' and architects' opinions, their preferences were asked from both groups by the fourth and first questions in Questionnaires A1 and A2, respectively (Appendix A). In order to obtain clarity of data and remove any discrepancies from the answers to questions about the primary targets, further questions were designed to identify the respondents' opinions regarding the secondary targets under each primary target. The secondary targets of the study were determined by referring to design requirement of appropriate facades section in the literature review, as follows:

i. Human comfort: facades can control the air quality, temperature, daylight, and noise of interior spaces in various seasons, which bring satisfaction to the residents regarding their comfort. Hence, improving indoor air quality, thermal, visual, and acoustic comfort as the secondary targets helps achieve residents' comfort through the facades (Section 2.2.1). The importance of the secondary targets for human comfort was determined by the fifth and second questions in Questionnaires A1 and A2 (Appendix A), respectively, from the occupants' and architects' responses.

ii. Decreasing cost: the secondary targets for decreasing costs through the building facades are decreasing construction cost, decreasing cleaning and maintenance cost, and decreasing energy consumption cost by improving facades design. These factors were explained in Section2.2.2, in the literature review. The secondary targets' importance for reducing costs was determined by the sixth and third questions in Questionnaires A1 and A2 (Appendix A), respectively, by the occupants' and architects' responses.

iii. Decreasing Environment pollution: the five kinds of pollution that impact human health, plants, wildlife, and especially the environment are air, soil, water, light, and noise pollution. According to the literature review (Section 2.2.3), the types of pollutions that can be decreased through a successful facade design are air, soil, and light pollution. Hence, the importance of decreasing these three types of pollutions were identified by the opinions of occupants and architects in both A1 and A2 Questionnaire surveys (question seven and four in Questionnaire A1 and A2, respectively).

Finally, the answers to the questions regarding primary and secondary design targets, by formatting given in Table 3.1, are considered in the calculations of the AHP Strategic Targets matrices in the first phase of this research.

3.2.2.2 Designing Questions for the Occupant Requirements

In order to design questions regarding the requirements of buildings' residents, it is necessary to clarify their requests according to the literature review and case studies (Chapters 2 and 4). Table 3.3 shows the relationship between the targets and occupants' requirements. This table consists of three main columns: primary targets, secondary targets, and occupants' requirements.

Table 3.3 Defining occupant's requirement according to main and secondary targets.

Primary Targets	Secondary Targets	Occupants' Requirement
Human Comfort	Indoor Air Quality	Appropriate air change (natural ventilation during day and night)
		Fresh air
	Thermal Comfort	Comfortable Temperature in Winter
		Comfortable Temperature in Summer
	Visual Comfort	Day Light
		Prevent glare
	Acoustic Comfort	Prevent or reduction outside noise
Decreasing Cost	Reducing Energy Consumption	Passive Systems
		Active systems (Energy production from Renewable Energy)
	Decreasing Maintenance Cost	Appropriate materials
		Having simple systems or components
		Accessibility to facades for cleaning and maintenance
	Decreasing Construction Cost	Applying affordable material or systems
		Decreasing installation cost
Decreasing Environmental Pollution	Decreasing soil pollution	Designing for deconstruction and decreasing waste
	Decreasing air pollution	Decreasing using fossil fuels for HVAC systems in the building
		Using low emission materials in the facades construction

With the purpose of acquiring occupants' opinions about their requirements and the importance of each requirement to them (Table 3.3), questions were asked in the format given in Table 3.2. The answers to 17 questions in Questionnaire A1 (Appendix A) rate the importance or usefulness of each requirement.

3.2.2.3 Designing Questions for the Technical Solutions

Questions related to technical solutions in the second Questionnaire survey A2 (Appendix A) were answered by the architects to define their opinions about the importance of various passive and active facade techniques. For designing questions regarding the facade techniques, information on active and passive systems that can be used on the facades in traditional and contemporary architecture was taken from the literature review and the case studies (Chapters 2 and 4).

As explained earlier, this study's main aim is to consider occupants' requirements and find solutions for them to achieve the facade design targets. For each primary target, a separate table was made to present various passive and active techniques

that fulfill the occupants' requirements for achieving "human comfort", "reducing cost," and "decreasing environmental pollution" (Table 3.4, Table 3.5, and

Table 3.6, respectively). These tables consist of four columns, which present the secondary targets, occupants' requirements, main techniques, and sub-techniques. It should be noted that each technique in column 4 can be a solution that respond to one or more requirements of the occupants that are listed in the previously mentioned three tables. The techniques or solutions that help us achieve human comfort in designing efficient facades are shown in Table 3.4. In Table 3.5, occupants' requirements and the technical solutions to fulfill the targets to decrease costs are presented. In order to decrease environmental pollution through facades, there are various solutions and techniques that respond to the occupants' requests.

Table 3.6 illustrates the mentioned techniques gathered from the literature and case studies.

Table 3.4 Technical solutions for achieving Human Comfort target

Secondary target	Occupant Requirement	Techniques (solutions)	Sub-Techniques (sub-solutions)
Indoor Air Quality	Appropriate air change	Natural Ventilation (ventilation through openings in facade)	Installing operable windows (Single-side ventilation)
			Installing operable windows (Double-side ventilation)
			Installing vents (grills) on the facade
		Natural Ventilation (ventilation through the stack effect,)	Designing ventilated ducts on the facade
	Fresh air	Filtering System	Designing vegetal filter on the facade
			Designing filter layer on the facade
Thermal Comfort	Comfortable Temperature in Winter	Solar energy for heating in Winter	Designing water pipe embedded wall
			Gathering and storing solar radiation (solar places-closed balconies)
		Prevent heat loses	Optimizing “window to wall ratio” in designing of the facade
			Designing thermal mass for exterior wall
			Using airtight openings (windows/doors)
			Using insulated glass (triple-glazed window)
			Using appropriate thermal insulation for exterior wall
			Using opening in the appropriate direction to get more solar radiation
	Comfortable Temperature in Summer	Cooling passive systems	Designing evaporative cooling systems by pipe on the facade
			Having natural ventilation (which was explained in first part)
		Prevent heat gain	Optimizing “window to wall ratio” in designing of the facade
			Using insulated glass (triple-glazed window)
			Using appropriate thermal insulation
			Appling tinted (colored) glass
			Installing shading devices (exterior, interior, in cavity)
			Designing balcony as a shading element
			Appling light color materials
			Providing vegetation on the facade to prevent heat gain
	Air movement to exit heated air	Natural ventilation (day and night) was explained at the first part	
		Natural ventilation by stack effect was explained at the first part	
Visual Comfort	Day Light	Catching optimum daylight	Optimizing “window to wall ratio”
			Employing light shelves
			Employing light tubes
	Prevent glare	Shading devices	Translucent panels (louver, punched, mesh, Perforated material) as shading devices for optimizing day light
			Employing movable shading devices for optimizing day light
			Appling tinted (colored) glass
Acoustic Comfort	Prevent or reduction outside noise	Soundproofing facade	Designing airtight opening (damping) to block outside noise
			Using insulated glass (triple glazed or laminate glass)
			Using appropriate sound insulation on the facade to prevent flanking
			Designing double layer wall
			Providing vegetation on the facade to decrease sound transition

Table 3.5 Occupants' requirements and technical solutions for Reducing Cost

Secondary targets	Occupants Requirement	Techniques (Solution)	Sub-Techniques (Sub-Solution)
Reducing Energy Consumption	Passive Systems	Passive systems listed in Table 3.4	
	Active systems (Energy production from Renewable Energy)	Solar Energy	Integrating photovoltaic panel on the facades for generation electricity
			Integrating solar collector on facade for space heating
			Integrating solar collector on facade for hot water supply
		Wind Energy	Integrating Turbine on facade for generation electricity
		Geothermal Energy	Integrating geothermal heating by installing pipes in the exterior walls
			Integrating geothermal cooling by installing pipes in the exterior walls
Decreasing Maintenance Cost	Materials	Low maintenance materials	Employing self-cleaning coating or opaque materials
			Employing self-cleaning glass
			Employing durable materials (long lasting)
	Appropriate systems or components	Designing low maintenance systems (static, kinetic) for facades' components	
	Accessibility to facades	Employing automatic robots	
		Access to facades by designing suitable systems	
Decreasing Construction Cost	Materials	Optimizing "window to wall ratio" in order to decreasing glass area	
		Choosing local materials	
		Choosing affordable materials	
	Decreasing installation cost	Using modular panels (optimum size)	
		Using prefabricated panels	

Table 3.6 Occupants' requirements and Technical solutions for decreasing environment pollution

Secondary targets	Occupants Requirement	Techniques (solution)	Sub-Techniques (sub-solution)
Decreasing soil pollution	Designing for deconstruction and decreasing waste of construction	Choosing nontoxic glues	
		Choosing nontoxic finishing materials	
		Choosing nontoxic paint	
		Reusability	Using reusable materials or systems
		Recyclability	Using recyclable materials
	Decreasing use of cleaning materials	Employing self-cleaning coating or opaque materials	
		Employing self-cleaning glass	
Decreasing air pollution	Decreasing fossil fuel	Passive systems were explained in Table 3.4	
		Active systems (generation energy from renewable sources) were explained in Table 3.5	
	Decreasing emission	Choosing nontoxic materials	

The suggested active and passive facade techniques in Table 3.4, Table 3.5, and Table 3.6 were used to design the technical questions directed to the architects in the second questionnaire (Appendix A, Questionnaires A2). Hence, 60 technical questions were designed in the format shown in Table 3.2 to determine their importance/usefulness according to the architects' ratings.

3.2.2.4 Using Data from Questionnaire Surveys in HoQ Matrices

Two HoQ matrices were prepared; the first HoQ matrix was used to determine the priorities of the technical solution by the correlation between occupants' requirements and the technical solutions; the second HoQ matrix was used to determine the priorities of facade systems by the correlation between the technical solutions and the facade systems.

In order to use the data from the two questionnaire surveys in the HoQ matrices, it is necessary to weigh the rated importance of each requirement and technical solution. As mentioned before, the requirements and solutions were rated from the most positive to the most negative on a five-point Likert scale, which is the rating system used in an HoQ matrix. Therefore, the coefficients for the choices: "Very Important" (VImp), "Important" (Imp), "Neutral" (Neu), "Not Important" (NImp), "Not Very Important" (NVImp) are 5,4,3,2,1 respectively. The coefficient of "Do not know" choice is zero. For weighting answers of each question, the number of "VImp", "Imp", "Neu", "NImp", or "NVImp" answers given by the responders were used in the following equation:

$$weight\ of\ answer = \frac{((5\times\ VImp) + (4\times\ Imp) + (3\times\ Neu) + (2\times\ NImp) + (1\ \times\ NVImp))}{total\ \text{number of}\ answers}$$

At first, the responses of the first questionnaire were evaluated and weighted for their importance/usefulness. These weights are also called the occupants request priority, and their calculated percentages (on total weight) are called the percentage of request priority in the first HoQ matrix. These data are used to calculate the priorities of technical solutions.

The 60 questions in the second questionnaire were further divided into eight groups having the same design concerns. These groups are; achieving a high level of indoor air quality, thermal comfort in winter, thermal comfort in summer, visual comfort, acoustic comfort, energy generation from renewable sources, decreasing construction and maintenance cost, and decreasing environmental pollution (Appendix A, Questionnaires A2). Some of the technical solutions were asked in more than one group in the second questionnaire survey responded by the architects because they can be effective for more than one purpose. For example, “optimizing Window to Wall Ratio” (WWR) can be an effective way to reduce heat transfer in the summer or winter as well as decrease daylight and construction costs. So it was asked in more than one group.

The second questionnaire survey responses were also weighted like those in the first one, using the same equation (given above). However, for weighting a repeated technique, like WWR, as explained in the previous paragraph, the mean value of all the answers (4 in this case) was considered. The weight of each technical solution was then converted into a percentage of the total weights.

In order to use the technical solutions in the first HoQ matrix, these techniques were reclassified according to their applications; and as noted above, after combining the questions for the same techniques, the 60 questions were reduced to 41 and were redistributed in four groups; openings in facade, construction materials, facade components, and energy generation.

In the first HoQ matrix, the occupants’ requirements were listed in the first column, and their respective weights and percentages calculated from the questionnaire responses were inserted into the next two columns; while the technical solutions were written in the header row of the HoQ matrix and their weights and percentages were listed above the column headers.

In the second HoQ matrix, the technical solutions were listed in the first column, and the priorities of these solutions that were calculated in the last rows of the first HoQ matrix as weights and percentages, were listed in the next column; while the facade systems were listed in the header row of the second HoQ matrix.

3.2.3 Application of QFD

In this part, the framework of the study is given, which consists of four phases: Design targets phase, Occupants requirement phase, Design techniques phase, and Facade design phase. In the first phase, five AHP strategic target matrices were prepared; the first matrix was to define the priorities of primary design targets, and the rests were for defining the priorities of secondary targets for human comfort, reducing costs, reducing pollution, and renewable energy integration. In the second phase, the importance of occupants' requirements is defined through the first questionnaire. In the third phase, the data from the first and second questionnaires are used in the first HoQ matrix to define the priorities of technical solutions. In the fourth phase, information from the third phase is used to prepare the second HoQ matrix to determine the priorities of facade systems.

3.2.3.1 Design Targets Phase

In this phase, firstly, the strategic design targets for designing appropriate facades were defined as primary and secondary targets according to the information given in Section 0. Secondly, questions number four to seven in the first questionnaire and number one to five in the second questionnaire regarding the design targets were formulated according to the method given in Section 3.2.2.1. Thirdly, the questionnaire surveys were conducted among building occupants and architects to know their preferences for the identified targets (responses of participants are shown in Appendix B). Fourthly, the AHP matrix was used to make the Strategic Target matrices define targets' priorities using the data from the questionnaire surveys.

Thus, four AHP matrices were created to define the primary and secondary design targets' priorities according to the combined responses of occupants and architects (Appendix A, questions 4 to 7 in Questionnaire A1 and questions 1 to 4 in Questionnaire A2) (Table 3.7 to Table 3.10). The fifth AHP matrix, shown in Table 3.11, was created to define renewable energy sources' priorities for energy generation in the buildings according to the responses to question.5 in the second questionnaire survey (Appendix A, Questionnaire A2).

Table 3.7 First AHP strategic target matrix for determining the priorities of the three primary targets (Human Comfort, Decreasing Costs, and Decreasing Environmental Pollution)

<table>
<tr><th colspan="11">AHP PRIMARY STRATEGIC TARGET MATRIX 1</th></tr>
<tr><td colspan="3" rowspan="3">1= the row is equally important as the column
3= slightly more important
5= more important
7= much more important
9= very much more important
0.33= slightly less important
0.20= less important
0.14=much less important
0.11= very much less important</td><td colspan="6">Targets</td><td rowspan="3">Absolute Weight</td><td rowspan="3">Targets Priority</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>a</td><td>b</td><td>c</td></tr>
<tr><td>Human Comfort</td><td>Decreasing Cost</td><td>Decreasing Environmental Pollutio</td><td colspan="3">Normalized Assessment</td></tr>
<tr><td rowspan="3">Targets</td><td>1</td><td>Human Comfort</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>2</td><td>Decreasing Cost</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>Decreasing Environmental Pollution</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="3">Total</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

The answers to the fifth question of the second questionnaire survey (Appendix A, Questionnaire A2) regarding the comparison of renewable energies by architects were also inserted into the AHP matrix. The priorities of solar, wind, water, and geothermal energies in designing a suitable facade were defined by calculating the fifth AHP matrix, illustrated in Table 3.11.

Table 3.8 Second AHP strategic target matrix for determining the priorities of the first set of secondary targets (for Human Comfort)

AHP SECONDARY STRATEGIC TARGET MATRIX 2: HUMAN COMFORT												
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets								Absolute Weight	Targets Priority
			A	B	C	D	a	b	c	d		
			Indoor Air Quality	Thermal Comfort	Visual Comfort	Acoustic Comfort	Normalized Assessment					
Targets	1	Indoor Air Quality										
	2	Thermal Comfort										
	3	Visual Comfort										
	4	Acoustic Comfort										
		Total										

Table 3.9 Third AHP strategic target matrix for determining the priorities of the second set of secondary targets (for Decreasing Cost)

AHP SECONDARY STRATEGIC TARGET MATRIX 3: DECREASING COST										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing cost of energy consumption through facade desig	Decreasing cost of facade maintenance/cleaning	Decreasing cost of facade construction	Normalized Assessment				
Targets	1	Decreasing cost of energy consumption through facade design								
	2	Decreasing cost of facade maintenance/cleaning								
	3	Decreasing cost of facade construction								
		Total								

Table 3.10 Fourth AHP strategic target matrix for determining the priorities of the third set of secondary targets (for Decreasing Environmental Pollution).

AHP SECONDARY STRATEGIC TARGET MATRIX 4: DECREASING ENVIRONMENTAL POLLUTION										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing air pollutio	Decreasing soil pollution	Decreasing light pollution	Normalized Assessment				
Targets	1	Decreasing air pollution								
	2	Decreasing soil pollution								
	3	Decreasing light pollution								
		Total								

Table 3.11 Fifth AHP matrix for determining the priorities of renewable energies in designing the appropriate facade.

AHP RENEWABLE ENERGY MATRIX 5											
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important		A	B	C	D	a	b	c	d	Absolute Weight	Renewable Energies Priority
		Solar energy	Wind energy	Water energy	Geothermal	Normalized Assessment					
1	Solar energy										
2	Wind energy										
3	Water energy										
4	Geothermal										

To calculate the AHP matrices, at first, the primary (or secondary) targets that are obtained from questionnaire surveys are listed as variables in both the rows (rows 1, 2, 3, ...) and the columns (columns A, B, C, ...). Then the targets are rated according to the importance of one over the other by comparing each target in the rows with each target in the columns, and the degree of importance is noted in the intersecting cell on a scale of 9; this scale is given in the top-left cell of the AHP matrix. If the variable in the row and column are equally important, the value in the cell is given as 1, which is the case when the target variable in the row is the same as that in the column. The rest of the values on the rating scale are: “very much less important=0.11”, “much less important=0.14”, “less important=0.2”, “slightly less important=0.33”, equally important =1”, “slightly more important=3”, “more important=5”, “much more important=7”, and “very much more important=9.”

In the questionnaire surveys, the primary and secondary targets were compared in pairs (A & B, A & C, and B &C), and the importance of one over the other were indicated in one of the three ways, A>B, A=B, and A<B, a fourth possibility was to select “Do not know”. The relevant preference data is given in Tables B1 to B5 in Appendix B. Since the AHP matrix is based on a scale of 9, the data from these questions had to be translated into the AHP scale.

The data given in Appendix B shows the percentages of people who selected "A more important than B" (A>B), "A and B are equally important" (A=B), "B more important than A" (A<B) and "Do not know" options, when comparing two targets (A&B). In order to understand which target was preferred over the other and to what degree, $(A > B) - (A < B)$ was calculated. It should be noted that the data for equal importance (A=B) and "Do not know" were irrelevant in this comparison. This difference was then rescaled according to the AHP matrix scale as shown in Table 3.12 below.

Table 3.12 Degree of importance between two targets.

	The row is equally important as the column	Slightly more important	More important	Much more important	Very much more important	Slightly less important	Less important	Much less important	Very much less important
Result of (A>B) % - (A<B) %	0	+ (0% - 25%)	+ (26% - 50%)	+ (51% - 75%)	+ (76% - 100%)	- (0% - 25%)	- (26% - 50%)	- (51% - 75%)	- (76% - 100%)
Degree of importance	1	3	5	7	9	0.33	0.2	0.14	0.11

For example, when comparing the two design targets Human Comfort (A) and Decreasing Cost (B), 95 out of 202 (47%) people selected A>B, 89 out of 202 (44%) selected A=B, 14 out of 202 (6.9%) selected B>A, and 4 out of 202 (2%) said "Do not know" (data is taken from Table B1-3 in Appendix B). Hence, the difference between those who preferred Human Comfort (A) and those who preferred Decreasing Cost (B) can be calculated as $(A > B) - (A < B) = 47\% - 6.9\% = 40.1\%$. This percentage difference lies within the range of 26% to 50% (Table 3.12), which is denoted as "more important" and corresponds to 5 on a scale of 9 in the AHP matrix.

After inserting the rescaled values of the importance of row items over column items into columns A, B, C in the AHP matrix, the normalized assessment is calculated and shown in columns a, b, and c. The normalized assessment values are a ratio of the cell value in the targets column (A, B, C, ...) to the sum of values in that column.

Each target's absolute weight is the sum of the normalized assessment values in columns a, b, c, ..., while the target priority is the percentages of absolute weight. These values help us to prioritize the design targets.

In order to clarify the calculation method of the AHP matrix, the calculation of the first AHP strategic target matrix is shown in Table 3.13.

Table 3.13 Calculation of first AHP strategic target matrix as an example.

AHP PRIMARY STRATEGIC TARGET MATRIX 1 (Occupants & Architects)										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Human Comfort	Decreasing Cost	Decreasing Environmental Pollutio	Normalized Assessment				
Targets	1	Human Comfort	1.00	5.00	0.33	1/4.2=0.24	5/11=0.45	0.33/1.53= 0.22	0.24+0.45+ 0.22=0.91	0.91*100/3= 30.28
	2	Decreasing Cost	0.20	1.00	0.20	2/4.2=0.05	1/11=0.1	0.20/1.53= 0.13	0.05+0.1+ 0.13=0.28	0.28*100/3= 8.97
	3	Decreasing Environmental Pollution	3.00	5.00	1.00	3/4.2=0.71	5/11=0.45	1/1.53= 0.65	0.71+0.45+ 0.65=1.81	1.81*100/3= 60.75
Total			4.20	11.00	1.53	0.24+0.05+ 0.71=1	0.45+0.1+0 .45=1	0.22+0.13+ 0.65=1	1+1+1=3	30.28+8.97+ 60.75=100

Finally, the results of each AHP matrix were presented in a chart to show the priority of targets. As a result of the calculations shown in Table 3.13, we can see that "decreasing environmental pollution" is the most important design target, followed by providing "human comfort"; and "decreasing cost" is of the least importance.

3.2.3.2 Occupants' Requirements Phase

In this phase, firstly, the occupants' requirements were defined by making a table according to the information given in Section 3.2.2.2. Secondly, the questionnaire survey was designed according to the requirement of occupants (Appendix A, Questionnaire A1). Thirdly, the survey was conducted among the building occupants. Fourthly, the importance ratings of occupants' requirements were weighted, and their percentages were calculated (Appendix C) according to the method given in Section 3.2.2.4, in order to insert them into the first HoQ matrix (Table 3.15).

3.2.3.3 Design Techniques Phase

In this phase, the priorities of technical solutions were identified in order to select the appropriate techniques to design a building facade. There are five steps in the design techniques phase that are described as follows.

The first step of this phase is defining the technical solutions to design appropriate building facades by applying and analyzing information from the literature review and the 49 case studies according to the method described in Section 3.2.1. The second step is designing questionnaire surveys about technical solutions (Appendix A, Questionnaire A2) by making the tables of technical solutions (Table 3.4, Table 3.5, and Table 3.6), and using the method given in Section 3.2.2.3. The third step is conducting the second questionnaire survey by rating the technical solutions' questions and weighing them (raw and derived data are given in Appendix D). The fourth step is creating the first HoQ matrix for identifying the priorities of the technical solutions. The fifth step is making a chart from the HoQ matrix result in order to illustrate the technical priority.

In the first HoQ matrix, the occupants' requirements and their weighted answers, taken from the first questionnaire survey, were placed in the first and second columns. The percentage of weighted answers were given in the third column. The technical solutions from the second questionnaire survey were placed on the first header row of the matrix, while the second and third header rows illustrated the weight of the techniques and their percentages, respectively (Table 3.15).

The correlation between the occupants' requirements and technical solutions was defined in the matrix body. The correlations between requirements and techniques were expressed by using symbols: strong (Ꙩ), medium (□), weak (Δ), or empty cell for no correlation; while the corresponding numerical values for the strength of the relationship were 9, 3, 1, and 0, respectively. After defining the correlation, the priority of the technical solution was calculated by multiplying the percentage weight of the occupant's requirement (column 3) by the strength of the correlation between the two, as shown in Table 3.14.

Then, each technical solution's absolute weight was calculated by adding all the values in its column and illustrated in the second last row. The percentage of the absolute weight was calculated and given in the last row of the HoQ matrix, which represented the technical solution's priority.

The positive and negative effects of the correlation between the technical solutions themselves were represented by "+" and "-" sign, respectively, in the HoQ matrix roof. If the cell is empty, there was no correlation between the pair of technical solutions.

The calculation of the first column of the first HoQ matrix is explained as an example in Table 3.14 to clarify the calculation method.

Table 3.14 The calculation method of the House of Quality matrix

Θ = Strong Correlation = 9 □ = Medium Correlation = 3 Δ = Weak Correlation = 1		Occupants Request Priority (Weight of answers)	Percentage of priority	Opening in Facades	
Occupant Requiremnets				Operable windows	Weight of Operable windows
Human comfort	Natural ventilaton for day (air changing)	4.6	6.38	Θ	9*6.38=57.42
	Natural ventilaton for night (air changing)	3.8	5.27	Θ	9*5.27=47.43
	Fresh air (air changing)	4.2	5.83	Θ	9*5.83=52.43
	Appropriate temperature in winter	4.7	6.52	□	3*6.52=19.56
	Appropriate temperature in summer	4.6	6.38	Θ	9*6.38=57.42
	Decreasing day light	4.6	6.38		0*6.38=0
	Preventing glare	3.7	5.13		0*5.13=0
	Having outside view from interior spaces	4.2	5.83		0*5.83=0
	Preventing outside noise	4.6	6.38		0*6.38=0
Decreasing cost	Decreasing cost of energy by using renewable energy	4.6	6.38	Δ	1*6.38=6.38
	Decreasing maintenance cost having access to facade	4.1	5.69	Θ	9*5.69=51.18
	Decreasing maintenance cost by having simple systems or components for facade	4	5.55	Θ	9*5.55=49.93
	Decreasing construction cost by applying affordable material or systems	3.7	5.13	Θ	9*5.13=46.19
	Decreasing cost of installation in facade construction	3.6	4.99	Δ	1*4.99=4.99
Decreasing environmental pollution	Decrease air pollution caused by the consumption of fossil fuels to have fresh air	4.5	6.24	Θ	9*6.24=56.17
	Decrease emission (from toxic materials) from facade materials to have fresh air	4.4	6.1		0*6.6.1=0
	Decrease soil pollution by designing for deconstruction and decreasing waste	4.2	5.83		0*5.83=0
	Absolute Weight of Techniques	72.1	100	449.1	
	Percentage of Absolute Weight			3.9	

3.2.3.4 Facade Design Phase

The priorities of the appropriate facade systems are defined in this phase in the following steps.

In the first step, the second HoQ matrix was made by applying the result of the first HoQ matrix and appropriate facade systems (Section 5.1.1). The technical solutions and their percentages of absolute weights obtained from the first HoQ matrix were inserted into the first and second columns. The facade systems presented in Section 5.1.1 were placed in the top row. According to Figure 5.1, there are two main groups for facade systems, namely active and passive. Each of these systems was classified into seven systems. Therefore, fourteen facade systems were placed in the header row.

In the second step, the correlations between the facade systems and technical solutions were defined by considering the data from case study buildings, presented in Table 5.1 and bar chart in Figure 5.4.

In the third step, the second HoQ matrix was calculated like the first one in order to determine the priorities of facade systems.

In the fourth step, the relationship between the facade systems was defined on the roof of the second HoQ matrix to show their impact on each other. The second HoQ's roof helps us to design a mixed facade system by considering their relationship.

In the fifth step, facade systems' priorities obtained from the second HoQ matrix were presented in a bar chart. The second HoQ that was applied in this study is presented in Table 3.16.

Table 3.15 First House of Quality matrix for defining the technique priorities

Θ = Strong Correlation
□ = Medium Correlation
Δ = Weak Correlation

					Opening in Facades (9)									Construction Materials (13)													Facade Component (14)														Generation energy (5)				
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
			Occupants Request Priority	Percentage of priority	Operable windows	Vents (grills) on the facades	Insulated glass for opening	Tinted (colored) glass	Air tightness of opening	Optimize window to wall ratio	Opening orientation	Low maintenance self-cleaning glass	Light shelves	Light color materials	Low maintenance opaque materials	Durable materials	Local materials	Affordable materials or systems	Reusable materials	Recyclable materials	Nontoxic finishing	Nontoxic glues	Nontoxic paint	Thermal insulation	Sound insulation	Thermal mass for exterior wall	Exterior shading devices	Interior shading devices	Shading devices in the cavity of double skin	Ducts / Chimney wall on the facades	Air filtration on the facade	Modular prefabricated panels for the facades	Plantation on the facade	Solar spaces on the facades	Water pipe embedded on the facades	Water evaporative system on the facades	Low maintenance systems for the	Automatic robots for cleaning of the facades	Balconies for the facades	Double layer exterior wall	Photovoltaic panels on the facades	Solar collector on the facade for space	Solar collector on the facade for hot water	Wind turbine on facade	Geothermal energy through wall cavity
					4.7	3.2	4.2	3.5	4.5	4	3.9	4.4	3.9	2.8	4.3	4.7	4.4	4.1	3.9	4.3	4.4	4.2	4.4	4.7	4.5	4.2	4.4	3.8	3.3	3.3	3.8	3.7	3.3	3.9	3.3	3.1	3.9	3.6	3.8	4.6	4.2	3.3	3.3	2.6	2.7
		Occupant Requiremnets			2.95	2.01	2.64	2.2	2.83	2.51	2.45	2.77	2.45	1.76	2.7	2.95	2.77	2.58	2.45	2.7	2.77	2.64	2.77	2.95	2.83	2.64	2.77	2.39	2.07	2.07	2.39	2.33	2.07	2.45	2.07	1.95	2.45	2.26	2.39	2.89	2.64	2.07	2.07	1.63	1.7
Human comfort	1	Natural ventilaton for day (air changing)	4.6	6.4																																									
	2	Natural ventilaton for night (air changing)	3.8	5.3																																									
	3	Fresh air	4.2	5.8																																									
	4	Appropriate temperature in winter	4.7	6.5																																									
	5	Appropriate temperature in summer	4.6	6.4																																									
	6	Increasing day light	4.6	6.4																																									
	7	Preventing glare	3.7	5.1																																									
	8	Having outside view from interior spaces	4.2	5.8																																									
	9	Preventing outside noise	4.6	6.4																																									
Decreasing cost	10	Decreasing cost of energy by using renewable energy	4.6	6.4																																									
	11	Decreasing maintenance cost by having access to facade	4.1	5.7																																									
	12	Decreasing maintenance cost by having simple systems or components for facade	4	5.5																																									
	13	Decreasing construction cost by applying affordable material or systems	3.7	5.1																																									
	14	Decreasing cost of installation in facade construction	3.6	5																																									
Decreasing environmental pollution	15	Decrease air pollution caused by the consumption of fossil fuels to have fresh	4.5	6.2																																									
	16	Decrease emission (from toxic materials) from facade materials to have fresh air	4.4	6.1																																									
	17	Decrease soil pollution by designing for deconstruction and decreasing waste	4.2	5.8																																									
		Absolute Weight		100																																									
		Percentage of Absolute Weight																																											

Table 3.16 Second House of quality matrix for identifying priorities of facade systems

ϴ = Strong Correlation
□ = Medium Correlation
Δ = Weak Correlation

		Technical Solutions	Percentage of Technical Solutions priority	Facades with Passive Systems							Facades with Active Systems							
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	
				Double skin façade	Solar façade	Ventilated Facade	Facade with evaporative cooling	Facade with Fixed shading devices	Self-shading facade	Vegetated façade	Facade with movable shading devices	Movable façade	Rotating building	Facade with Smart material	Solar energy integrated facade	Wind energy integrated facade	Geothermal energy	
Opening in Facades	1	Operable windows																
	2	Vents (grills) on the facades																
	3	Insulated glass for opening																
	4	Tinted (colored) glass																
	5	Air tightness of opening																
	6	Optimize window to wall ratio																
	7	Opening orientation																
	8	Low maintenance self-cleaning glass																
	9	Light shelves																
Construction Materials	10	Light color materials																
	11	Low maintenance opaque materials																
	12	Durable materials																
	13	Local materials																
	14	Affordable materials or systems																
	15	Reusable materials																
	16	Recyclable materials																
	17	Nontoxic finishing																
	18	Nontoxic glues																
	19	Nontoxic paint																
	20	Thermal insulation																
	21	Sound insulation																
	22	Thermal mass for exterior wall																
Facade Component	23	Exterior shading devices																
	24	Interior shading devices																
	25	Shading devices in the cavity of double skin facades																
	26	Ducts / Chimney wall on the facades																
	27	Air filtration on the façade																
	28	Modular prefabricated panels for the facades																
	29	Plantation on the facade																
	30	Solar spaces on the facades																
	31	Water pipe embedded on the facades																
	32	Water evaporative system on the facades																
	33	Low maintenance systems for the facades																
	34	Automatic robots for cleaning of the facades																
	35	Balconies for the facades																
	36	Double layer exterior wall																
Energy Generati	37	Photovoltaic panels on the facades																
	38	Solar collector on the facade for space heating																
	39	Solar collector on the facade for hot water																
	40	Wind turbine on facade																
	41	Geothermal energy through wall cavity																Total
		Absolute Weight																
		Percentage of Absolute Weight																

CHAPTER 4

CASE STUDIES

New technologies and materials have made innovative facade designs increasingly possible for different climatic regions and different building typologies. Hence, many high-performance buildings with sustainable, adaptive, and responsive facades are coming up around the world, which are unique in their design. In this study, forty-nine high-performance buildings were selected to analyze (Deljavan and Ozkan, 2017).

The mentioned high performance buildings are introduced below:

1. US Census Bureau Headquarters
Architects: SOM (Skidmore, Owings & Merrill LLP) (http://www.som.com/) Structural Engineers: SOM (Skidmore, Owings & Merrill LLP) Mechanical & Electrical Engineers: SOM (Skidmore, Owings & Merrill LLP) Location: Suitland, MD 20746, USA Climate Zone: Humid Subtropical Climate, Cfa Status: Constructed Project Year: 2007 Building Type: Office Building Area: 139,355 m^2 building with a 92,903 m^2 structured parking garage Number of Stories: 8-story https://www.youtube.com/watch?v=YFELRzS3wxk
   

- To decrease solar glare, a brise-soleil, which deflects sun radiations as a sun breaker on the facade, is designed wavy shape from sustainable wood,
- To increase daylight and view, a narrow floor-plate is designed for building,
- To reduce energy consumption, a green roof with a walking path and energy-efficient mechanical systems are employed,
- To maximize daylight, the facades of the courtyard are designed by glasses,
- To increase natural light, the building has an open office plan designed.

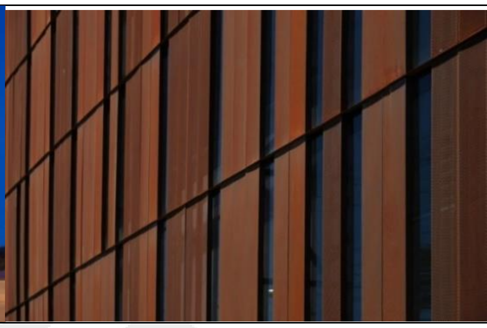
2. Santa Monica Civic Center Parking Structure

Architects: Moore Ruble Yudell Architects & Planners (http://www.moorerubleyudell.com/)
Location: Santa Monica, California, USA
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed
Project Year: 2008
Building Type: Parking Garage
Area: 27,758 m^{2} - structure includes 900 parking spaces
Number of Stories: 6 floors above ground, 2 floors below ground
Client: Kingdom of Saudi-Arabia
LEED-Certified
https://vimeo.com/10467834

- To generate energy, photovoltaic panels are installed on the roof and three facades of the buildings,
- To decrease environmental pollution, recycled materials are used in construction,
- To decrease heating and cooling load, low glazing facades are designed,
- To reduce consumption energy for artificial lighting, multicolor glass panels are installed on the facades to enter natural light into interior spaces and to allow natural ventilation for the building,
- To generate electricity, photovoltaic panels are installed on the roof.

3. Building Block Social Nestle Graneros

Architects: GH+A / Guillermo Hevia
Location: Graneros, O’Higgins, Chile
Climate Zone: Semi arid Climate, Bsk
Status: Constructed
Project Year: 2009
Building Type: Office Building
Area: 2,800 m^2
Number of Stories: 3-story

- To decrease energy consumption, designing passive (evaporative system, natural ventilation, daylight) and active systems by employing renewable resources are considered as the main strategy in this building to protect the environment,
- To decrease cooling load, two skins facades are designed in order to create vertical ducts for natural ventilation by evaporative cooling, which comes from water ponds in front of the building in hot seasons,
- To prevent glare, second skin as a perforated corten steel panels are separated from the building and wrap the building, which acts as shading elements,
- To decrease facades maintenance, corten steel is used as second skins because corten steel oxides in a short time and create a thin layer to protect itself and to have tonality (brown, orange) by changing daylight.
- To prevent glare and optimize inside daylight, black glass are used on the facade.

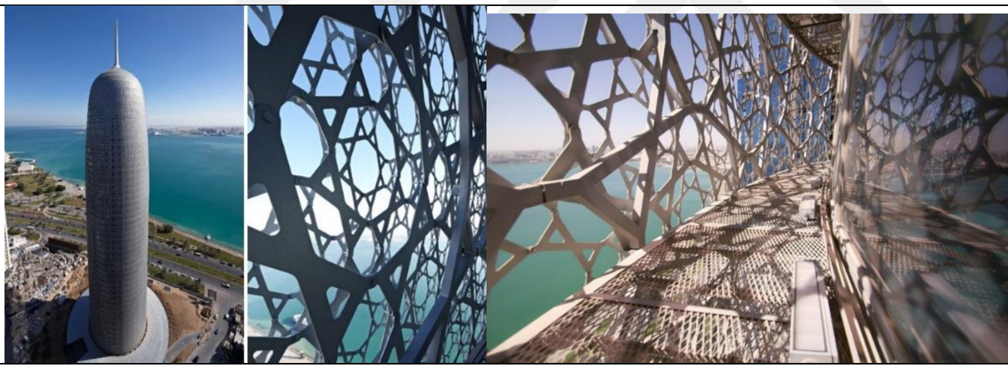
4. 3M Italia S.P.A Headquarters

Architects: Mario Cucinella
Location: Pioltello, Milan, Italy
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed
Project Year: 2010
Building Type: Office Building
Area: 10,300 m2
Number of Stories: 5-story

- To decrease the cooling load in the hot seasons, the series of terraces are designed in south orientation on each floor to provide shaded. In other words, the terraces are like environmental buffer spaces to protect interior spaces from climate extremes in hot and cold seasons,
- To increase daylight in the interior spaces, two open sky courtyards are designed.
- To optimize energy consumption, insulated glasses are employed on the facades.
- To produce energy from the sun, photovoltaic panels are installed on the roof and the east, west, and north facades as shading systems.

5. Burj Doha

Architects: Jean Nouvel (http://www.jeannouvel.com/)
Location: Doha, Qatar
Climate Zone: Hot Desert Climate, Bwh
Status: Constructed
Project Year: 2011
Building Type: Office Building
Area: 110,000 m^2 (45 m in diameter)
Number of Stories: 46 floors above ground, 3 floors below ground
https://www.youtube.com/watch?v=T9ciCzTQkLw



- To protect the building from high temperatures and high wind (with desert sands), the tower is covered by a metal mesh, which is designed like “mashrabiya.” The mashrabiya is a screen, which is used in vernacular architectures to provide passive cooling in hot seasons,
- To optimize daylight entrance to the building and to decrease cooling loads, the density of metal mesh is different in various orientations: on the north, south, east, and west, opacity is 25%, 40%, 60%, 60% respectively.
- To reduce solar gain, the inner layer of facades is designed by slightly reflective glass.
- To prevent solar gain, interior solar blinds are used,
- To make maintenance of facades easy, a walkway is designed between the steel mesh screen and interior glass facade on each floor of the tower..

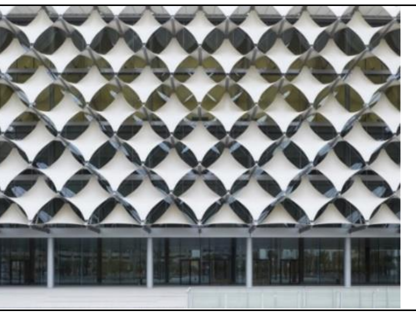
6. Hanwha Headquarter Remodelling

Architects: UN Studio (http://www.unstudio.com/)
Location: Seoul, South Korea
Climate Zone: Humid Continental Climate, Dwa
Status: Constructed (renew)
Project Year: 1980 completed 2013 renovation
Building Type: Office Building
Area: Building surface 57,696 m^2
Number of Stories: 30-story
http://www.designboom.com/architecture/unstudio-hanwha-headquarters-seoul-24-4-2014/
http://www.archello.com/en/project/hanwha-headquarter-office-tower-seoul
https://www.dezeen.com/2014/04/30/hanwha-hq-seoul-unstudio-dynamic-facade/

- To optimize natural light entrance in interior spaces and decrease energy consumption, the facade is designed by various bands of opaque panels and insulated glass with aluminum frames. In other words, the facades are designed as self-shading facades with various panels' forms (different geometry) regarding facades' orientation and sun radiations angular to allow or to block solar radiations Facade with Fixed shading elements.
- To generate electricity, the photovoltaic cells are installed in upper portion of panels in south and south east facades. To harvest maximum energy, it is better to angle the photovoltaic cells on the panels to receive direct sun radiations
- To decrease cooling and heating loads, the window to wall ratio is 55%.

7. King Fahad National Library

Architects: Gerber Architekten (https://www.gerberarchitekten.de/)
Location: Riyadh, Kingdom of Saudi Arabia
Climate Zone: Hot Desert Climate, Bwh
Status: Constructed (renew)
Project Year: 2002, 2014
Building Type: Library
Area: -
Number of Stories: 5-story
https://www.youtube.com/watch?v=MenAPMC8U-M

https://www.youtube.com/watch?v=_8BbXkND-tA
 
• To decrease cooling loads, the old building facades are covered by layers as sunshades, which are made of textile awnings supported by tensile-stressed steel cable structure. • To maximize daylight penetration and to have outside and inside view, sunshades have unique forms as shown in the picture, and textile awning is made of translucent material. • The form of second layers allow having natural ventilation, which results in reducing cooling load and increasing thermal comfort. • The facade glows at night like a white cube as a lighthouse for the city.
8. New Kuwait University Sabah AL-Salem University, College of Education
Architects: Perkins+Will (http://perkinswill.com/) Location: Shidadiyah, Kuwait Climate Zone: Hot Desert Climate, Bwh Status: Constructed Project Year: 2014 Building Type: Educational Building Area: 59,458 m2 Number of Stories: 5-story LEED Gold rating in 2014 https://www.youtube.com/watch?v=UTxllO0VprM

• To maximize both view and daylight penetration and to minimize heat gain and glare, self-shading skin is designed for building, which can deal with “swings in temperature (from 5ºC to 60ºC) and relative humidity (from 5% to 85%).”

- To reduce heat gain and glare and also to maximize daylight by diffusing it into the interior spaces, shading fins are made of two tempered laminated glass and a ceramic frit between them.
- To decrease the load of facade structure and construct it speedily, the opaque panels on the facade are very light and thin, which made of "Glass-Fiber-Reinforced Concrete (GFRC)".
- To reduce the cooling load, the insulated glasses are used on the facade,
- The operable windows are installed on the east and west facades to decrease energy consumption for cooling and provide natural ventilation.
- To minimize heat transfer from both side of the facade, insulation materials are used behind the GFRC panels.
- This building's self-shading skin prevents 82% of solar heat gain, which results in decreasing 21% of energy consumption.
- To provide optimizable shading, the depth of exterior skin varies in a different orientation and various height. For instance, it is more in-depth at the top of the facade and narrower at the bottom.

9. South Australian Health

Architects: Woods Bagot (http://www.woodsbagot.com/)
Location: Adelaide SA, Australia
Climate Zone: Mediterranean Climate, Csa
Status: Constructed
Project Year: 2014
Building Type: Health and Medical Research
Area: 25,000 m2
Number of Stories: 7 floors above ground, 3 floors below ground
LEED Gold rating
https://www.youtube.com/watch?v=cpPpFCGy6aI

- Facade orientation is considered to maximize daylight entrance.
- To decrease heat gain and glare as well as to provide maximum natural light and view, a triangulated dia-grid facade as a self-shading facade is designed. It is based on a steel dia-grid as the main structure and an external aluminum suite.

- To optimum daylight and thermal comfort, each panel’s geometry is designed according to the solar radiation and its orientation. Furthermore, the depth of fins varies in order to block or allow solar radiation entrance, which is designed by the computer program.
- To maximize thermal comfort, insulated glasses are used on the facades’ panels.
- To construct facades speedy and quickly, the facade is built by prefabricated panels.

10. Juvelen- a new landmark in Uppsala (Uppsala Travel Centre Contest)

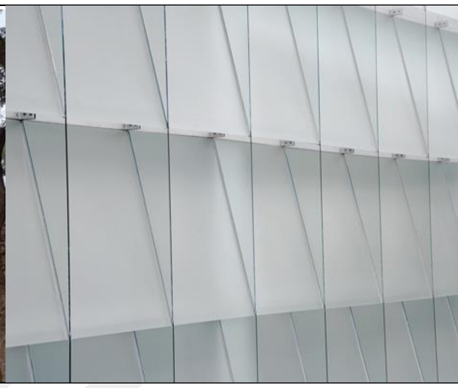
Architects: Utopia Arkitekter (http://www.utopia.se/en)
Location: Uppsala Resecentrum, Sweden
Climate Zone: Humid Continental Climate, Dfb
Status: Conceptual
Project Year: 2013-2018
Building Type: Travel Center, Fitness Center, Restaurant
Area: 10,000 m^2
Number of Stories: 6-story
Client: Skanska
LEED Platinum rate.


- The facade structure base in this building is several large rectangles according to the building’s structural system. Differently inclined diagonals are installed on the rectangle’s structure to make complex forms, which are made of various triangles with different sizes and shapes. Then windows or opaque panels (blank metal-colored concrete panels) as shading elements or photovoltaic panels are installed in the triangles.
- To optimize thermal comfort and daylight entrance, the panels have different depths in various orientations.

11. Habitat Items Leon

Architects: SHINE Architecture **&** TA arquitectura (http://shinearchitecture.com/)
Location: Leon, Mexico
Climate Zone: Humid Subtropical Climate, Cwa
Status: Constructed
Project Year: 2012

Building Type: Educational Building
Area: 1,180 m^2
Number of Stories: 2-story
https://vimeo.com/68869639
https://sketchfab.com/models/4e4e569bf59540ff91fba0fc6443c6c5
http://shinearchitecture.com/projects/2/talleresdiseno/
https://www.dezeen.com/2012/11/27/habitat-talleres-de-diseno-by-shine-architecture-and-ta-arquitectura/

- To have thermal, visual, and acoustic comfort in the hot and dry climatic condition of Leon (summer temperature is 38°C and relative humidity is 10%) in this building, architects decide to employ passive systems.
- To decrease heat gain, glass “flakes” panels are used on the facades. Glass “flakes” panels diffuse daylight inside the building. Furthermore, glass “flakes” properties can change according to orientation from translucent to transparent.
- To provide natural ventilation, the glass “flakes” panels are inclined to create a gap between panels.
- To provide more natural ventilation and increase natural light, an atrium with a vent on the top and roof light is designed. Roof light employs glass “flakes” panels to diffuse daylight.
- To create shade, the wooden circulation passage is designed, which joints two floors from the outside.

12. Rey Juan Carlos Hospital

Architects: Rafael De La-Hoz (http://www.rafaeldelahoz.com/)
Location: Madrid, Spain
Climate Zone: Mediterranean climate, Csa
Status: Constructed
Project Year: 2012
Building Type: Hospital
Area: 24,923.20 m^2
Number of Stories: 9-story
https://www.youtube.com/watch?v=sUazlAII2dQ

- To decrease environmental pollution, renewable energy systems and green materials are used in this building.
- A large rectangular structure is designed as a base of building with two circular towers.
- To provide natural ventilation, the skylights with vents are designed on the roof of two towers.
- o optimize daylight entrance, have the outside view from inside, and improve natural ventilation, two towers have two skins; the outer skin consists of white ceramic frits panels with circle windows, which is supported by stainless-steel structure.
- To increase thermal comfort, the green roof is designed for the building.

13. John and Frances Angelos Law Center

Architects: Behnisch Architekten, Ayers Saint Gross(http://behnisch.com/ , http://asg-architects.com/)
Location: Baltimore, USA
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed
Project Year: 2013
Building Type: Educational Building
Area: 17,873 m^2
Number of Stories: 12-story
Client: University of Baltimore
https://www.youtube.com/watch?v=MF83Ue4nd88
http://www.aiatopten.org/node/379

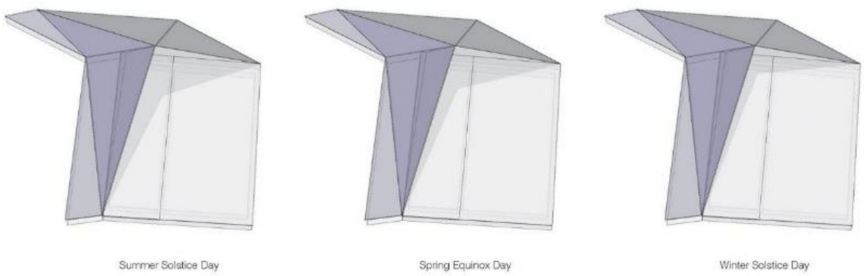
- The building consists of three L-shaped volumes, which are connected by narrow atrium "green stalk" in interior spaces. Each volume has its function, which affects the designing of its facade.
- The facades of volume with classrooms and offices function are designed by aluminum panels and punched windows with transparent glass (operable and fixed windows). The operable windows provide natural ventilation for classrooms and offices. All glass areas are shaded automatically from the exterior by Venetian blinds, which block or allow solar radiation entrance according to weather conditions. Moreover, a

frameless glass screen wall, which is supported by bracket from the exterior wall, protect blinds from high winds.

- The facades of the library volume are glazed aluminum panels as a curtain wall. To prevent solar gain, 70% of the wall is covered by ceramic frit “*one-half of each panel is fully fritted, and a half-floor height is covered by gradient frit pattern*.” The top of the glazing wall is transparent to allow daylight penetration. To provide natural ventilation, the operable vents are designed on the panels.
- The facades of the atrium is a glazed curtain wall, which is supported by a steel frame. On each floor, natural ventilation into the atrium is provided by operable windows, and heated air is exhausted by low-velocity fans from the atrium. To prevent heat gain, fixed louvers are installed on the outside of facades.
- The operable windows of all offices, classrooms, and library are controlled by occupants locally. However, the operable windows of the atrium are controlled by the building automation system.

14. Soho Hailun Plaza

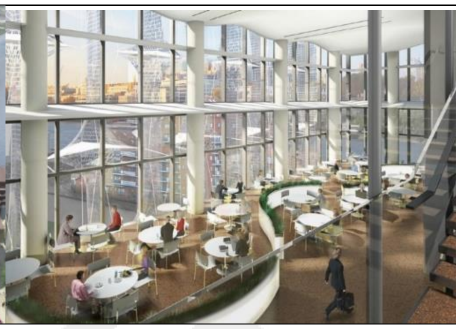
Architects: UN studio (http://www.unstudio.com/) Location: Shanghai, China Climate Zone: Humid Subtropical Climate, Cfa Status: Conceptual Project Year: 2016 Building Type: Office Building Area: - Number of Stories: 33-story	



- The facades of Soho Hailun Plaza are self-shading facades, which consist of various prefabricated panels with the function of shading screen and window.
- Each wall panel consists of 311 components in eleven forms designed according to the orientation and sun radiation angle.

15. Embassy of the United States

Architects: Kieran Timberlake (http://www.kierantimberlake.com/)
Location: London, England
Climate Zone: Oceanic Climate, Cfb
Status: Conceptual
Project Year: 2017
Building Type: Embassy Building
Area: -
Number of Stories: 12-story



- The building is designed as a crystalline (transparent) cube.
- To prevent heat gain and glare and to maximize natural light, the "multiple-layer-laminated" glass (the outer layer is made of ETFE (ethylene tetrafluoroethylene)) are employed on the facades of the Embassy of the United States.
- To generate electricity, the entire roof of the building is covered by crystalline and thin-film photovoltaics. Furthermore, the EFTFE layer of facades includes photovoltaic cells, which catch solar radiation in order to prevent them from penetrating inside.
- To increase interior spaces' thermal comfort, "*facade optimized to shade interiors from east, west and south sun while admitting daylight and framing large open view portals to the outside*."

16. Sony City Osaki

Architects: Nikken Sekkei (http://www.nikken.co.jp/en/)
Location: Tokyo, Japan
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed
Project Year: 2011
Building Type: Office Building
Number of Stories: 25-story

- To provide natural ventilation, the building is designed as a narrow rectangle, located against the prevailing wind. However, the form allows the breeze from TOKYO Bay to flow inside of the building.
- The stairways and elevators are designed on the western side to block solar radiation on the west facade.
- Solar panels as shading devices are installed on the south facade to generate electricity and block heat gain.
- To decreasing the cooling load, the evaporative system is employed on the facade of this building. For this purpose, terracotta louvers with titanium oxide (TiO_2) cover (to prevent mold and moss), which pass the rainwater, are installed on the eastern facade. By evaporating water in the louvers, the temperature of louvers surface decrees, which result in cooling ambient. In order to prevent freezing water in the winter, it is better to design louvers with a certain thickness and the symmetrical form. These kinds of facades are called BIOSKIN.
- The rainwater is gathered from the roof and stored in the tank, which is located in the basement. Then it is filtered and pumped up to use in BIOSKIN of each floor.
- The BIOSKIN system is a traditional Japanese system known as "Sudare". In "Sudare", thin bamboo is used instead of terracotta louvers.
- BIOSKIN system not only decreasing cooling load but also decreasing outdoor temperature.

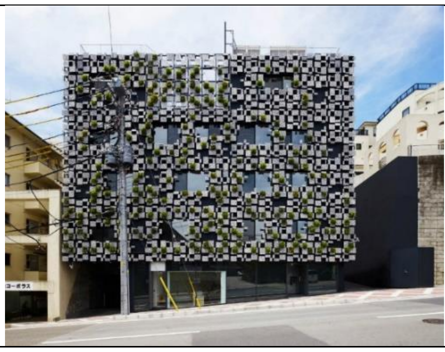
17. Hospital Manuel Gea Gonzales

Architects: Facade designer: Berlin-based Elegant Embellishments (http://www.elegantembellishments.net/)
Location: Mexico City, Mexico
Climate Zone: Subtropical Highland Climate, Cwb
Status: Constructed
Project Year: 1992 completed 2013 renovation
Building Type: Hospital
Area: 2,500 m^2 facade
Number of Stories: 5-story
https://www.youtube.com/watch?v=cyBL2OaYh54
http://www.medicaldaily.com/mexico-city-hospital-eats-pollution-torre-de-especialidades-features-innovate-facade-tiling-265942
https://www.youtube.com/watch?v=Z34sFb7VXNw

https://www.youtube.com/watch?v=BTr9ZPiqBo4

Architects: Facade designer: Berlin-based Elegant Embellishments (http://www.elegantembellishments.net/) Location: Mexico City, Mexico Climate Zone: Subtropical Highland Climate, Cwb Status: Constructed Project Year: 1992 completed 2013 renovation Building Type: Hospital Area: 2,500 m^2 facade Number of Stories: 5-story https://www.youtube.com/watch?v=cyBL2OaYh54 http://www.medicaldaily.com/mexico-city-hospital-eats-pollution-torre-de-especialidades-features-innovate-facade-tiling-265942 https://www.youtube.com/watch?v=Z34sFb7VXNw https://www.youtube.com/watch?v=BTr9ZPiqBo4
• Five hundred titanium dioxide blocks supported by a metal structure are installed as a second skin of the existing building To filter air pollution in Mexico City (one of the most polluted cities). Titanium dioxide has “anti-microbial and photocatalytic” properties. It means that when blocks receive solar radiation (UV rays), it neutralizes and breaks the toxins and smog. • The blocks are formed to get maximum sun radiations in order to filter more polluted air that entrances into the building. Moreover, the blocks filter sunlight and decrease the temperature of interior spaces. • The installation of the blocks is not complicated. They are assembled on the ground then installed on the vertical metal structure. • To maintenance the blocks, it is necessary to keep them white by spraying regularly. The lifetime of blocks is about 5-10 years.
18. Green Cast
Architects: Kengo Kuma & Associates (http://kkaa.co.jp/) Structural Engineers: Makino Structural Design Location: Odawara-shi, Kanagawa prefecture, Japan Climate Zone: Humid Subtropical Climate, Cfa Status: Constructed Project Year: 2011

Building Type: Multipurpose building which consists of a shop, a clinic, offices, and a private residence
Area: 1052 m^2
Number of Stories: 4 floors above ground, 1 floor below ground




- The aluminum die-cast panels cover the exterior wall as a secondary facade to prevent heat gain in hot seasons. However, the green walls allow having daylight and natural ventilation in interior spaces.
- Each block is made of 3 to 6 aluminum panels, and all equipment like watering hoses and downpipe are installed between the panels and exterior wall.

19. Yishun Community Hospital

Architects: GENSLER (http://www.gensler.com/)
Location: Yishun, Singapore
Climate Zone: Tropical Rainforest Climate, Af
Status: Constructed
Project Year: 2012
Building Type: Hospital
Area: -
Number of Stories: 12 floors above ground, 3 floors below ground
https://www.youtube.com/watch?v=36pVi1MBmv8

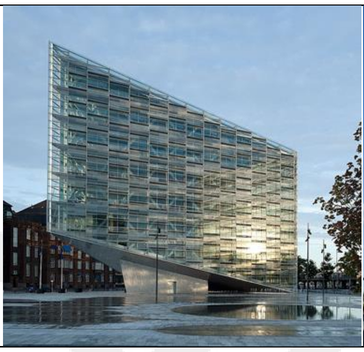

- To respond to the warm and humid weather of Singapore, natural ventilation, daylight penetration. are considered design strategies.
- To make shade and decrease the cooling load, deep overhangs and wide verandas are designed for this building.
- Low thermal conducting and lightweight materials like wood are used for the construction of this building.

- To optimize view and have natural ventilation, the movable lovers are installed on the facades, which block unwanted solar radiation.

20. Unilever Haus

Architects: Behnisch Architekten (http://behnisch.com/)
Location: Hamburg, Germany
Climate Zone: Oceanic Climate, Cfb
Status: Constructed
Project Year: 2009
Building Type: Office Building
Area: 37.997 m^2
Number of Stories: 6-story
Client: Strandkai 1 Projekt GmbH
Gold Eco Label from Hafen City
https://www.youtube.com/watch?v=H5WAgzTc2tE
https://www.youtube.com/watch?v=4SkSy6vBWiE


- To decrease cooling, hating loads and to optimize natural light, the designer team consider double-skin facade with the opening at the bottom and top for Unilever Haus, (cavity is between 1 meter to 1.8 meters).
- Ethylene Tetra Fluoro Ethylene (ETFE), as a high tech material, is used instead of glass in the double-skin facade's outer skin, which can protect the building from the wind as well as allow daylight penetration.
- ETFE is based on plastic, and it has resistance properties to electrical, chemical, high-energy radiation, and a wide temperature range.
- Thermally activated reinforced concrete is used for the construction of the ceiling in order to cool the space.
- Large windows are designed for maximizing natural light in the atrium.
- Blinds are designed in the cavity of the double-skin facade to prevent heat gain.
- In order to have fresh air in interior space, a hybrid air handling system is used. It means the coming air is passed through various filters before reaching inside of the buildings.
- Recyclable materials are used in the building's construction to minimize adverse effects during the construction, during the occupation, and even during future demolition.

21. The Crystal and the Cloud
Architects: Schmidt Hammer Lassen Architects Location: Copenhagen, Denmark Climate Zone: Oceanic Climate, Cfb Status: Constructed Project Year: 2010 Building Type: Office Building Area: 6,850 m^2 Number of Stories: 7-story
 
• Two atriums are designed to maximize natural light in the building. • To prevent heat gain, the double-glazing panels and multi-faceted glass, which reflects daylight, are used on the facade. • Natural ventilation through the double facade is designed to cool interior spaces at night. The heated air is exhausted from the atrium, which decreases internal temperatures. • The facade consists of two-layer glasses to improve thermal comfort. Insulated glasses are employed for the inner layer, and the outer glazing system is a subtle silk print, which prevents solar radiation from coming to inside by reflection. • The energy consumption is reduced by 25 percent in this building.
22. Manitoba Hydro Place
Architects: KPMB- Architects (http://www.kpmbarchitects.com/) Location: Manitoba, Canada Climate Zone: Subarctic Climate, Dfc Status: Constructed Project Year: 2010 Building Type: Office Building Area: - Number of Stories: 22-story https://www.youtube.com/watch?v=xBze3kgjL-s https://www.youtube.com/watch?v=1PTgMtamJ6Q https://www.youtube.com/watch?v=DGk2gHcyxjQ https://www.youtube.com/watch?v=CE0POHOWyp4 https://www.youtube.com/watch?v=DdgSGxIp61g

https://www.youtube.com/watch?v=xXUhWlUswBk

- To improve natural ventilation, the design team considers A-shape for this building because of wind direction.
- A double-skin facade with a story-high and 1.3 meters depth in the western and eastern sides of the building is designed to improve natural ventilation. The facades' inner layer is made of single glazing, whereas the outer layer is made of insulated glass. In the hot seasons, the end of the eastern and western of the double-skin facade is opened to drive out the heated air. The inner layer has operable windows, which are controlled manually. Sixteen window vents (insulated glass) on the west facade and fourteen window vents (insulated glass) per floor on the east are located in front of each column. The size of vents are 1 meter by 2 meter.
- The solar chimney is located at the north tip, which exhausts the heated air.
- Six gardens by three-story height are considered at the north end, and the three six-story atriums are designed at the south end, which provides humidification by using water features for the building.

23. Council House

Architects: DesignInc (http://www.designinc.com.au/)
Location: Melbourne VIC, Australia
Climate Zone: Oceanic Climate, Cfb
Status: Constructed
Project Year: 2006
Building Type: Office Building
Area: 12,526 m^2
Number of Stories: 9 floors above ground, 1 floor below ground
http://www.melbourne.vic.gov.au/building-and-development/sustainable-building/council-house-2/Pages/council-house-2.aspx
https://www.youtube.com/watch?v=vJV0wnbAZ6M
https://www.youtube.com/watch?v=N1CkwnqrYrE

- To decrease energy consumption in this building, three strategies are applied; improving efficiency of mechanical systems, recycling methods in order to prevent environmental pollution, generation electricity from renewable sources.
- Five shower towers made of lightweight fabric with 1.4 meters in diameter are installed on the facade. The showers get air from the street and cool it by evaporation. Then the cool air is sent to three tanks, in which there are 10000 small balls made from stainless steel and filled by a salt suspension as a Phase Change Material (PCM). The water coming from cooling systems will be pre-cooled by mentioned balls and will be resent to the systems. "*Testing shows that these towers reduce temperature about 4-13 degrees Celsius from the top of the tower to the bottom of the tower*."
- For having night purging, the windows on the south and north facades are opened automatically in order to drive out heated air from concrete ceilings by cross-ventilation to the six ducts in the north facade to exhaust by stack effect from the building. On top of ducts, six turbines are installed to generate electricity. The windows are closed automatically in a rainy and windy situation or when the outside temperature is higher than the temperature of the concrete ceiling.
- Light shelves are designed to maximize daylight, which brings indirect natural illumination into the building.
- Solar shadings are installed on the north, west, and east facades of the building. The south facade is blocked by shading elements completely during office hours. There are used perforated material as solar shading on the east facade, which also acts as a thermal chimney for natural ventilation. The recycled timber louvers are covered the west facade to optimize view and daylight penetration and to protect the facade from the harsh western sun. According to sun radiation, the lovers are opened and closed automatically.

- To prevent glare and reduce heat gain, the vertical garden with nine stories high, which continue on the two sides of balconies on the installed mesh, is designed in 1.6 meters depth and 2.2 meters height.
- As a result, 85%, 85%, 95% reduction in electricity consumption, gas consumption, and carbon emission produce respectably.

24. Surry Hills Library and Community Centre

Architects: FJMT (https://fjmtstudio.com/index.php)
Location: New South Wales, Australia
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed
Project Year: 2009
Building Type: Library
Area: 898 m^2
Number of Stories: 3 floors above ground, 1 floor below ground
https://www.youtube.com/watch?v=W7b3iuDs1Ow
https://www.youtube.com/watch?v=hdkzIY3vikY

- To decrease heat gain and glare, large vertical timber-veneer- clad louvers cover the west glazing facade, which tracks the sun automatically by getting signals from the buildings' management control system.
- On the north facade, a double-skin facade with bamboo plants in the cavity is designed in order to have natural ventilation and filter the coming air into the building.
- On the south facade, the thermal wall and atrium are designed to decrease cooling and heating loads. The atrium consists of a series of triangular shapes with various plants in order to have a passive cool system and filter incoming air. Air is drowned to the atrium from the top; then, it is filtered by plants and sent to the underground thermal labyrinth to cool by geothermal in order to use in interior spaces.
- Durable and sustainable materials are used in the construction of the building.

25. KFW Westerkade

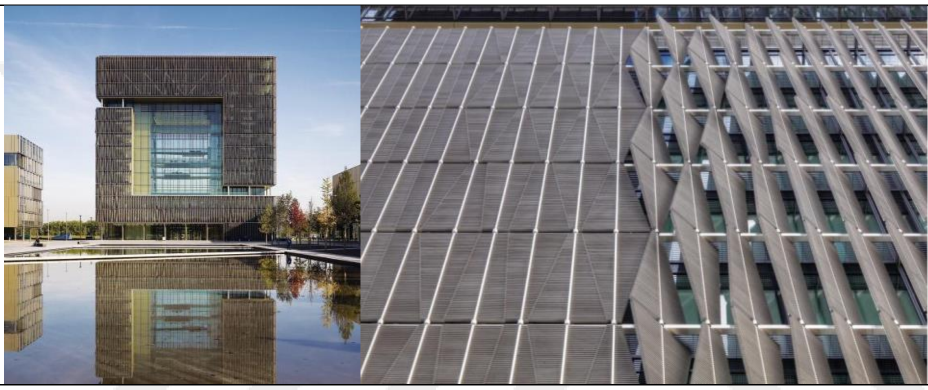
Architects: Sauerbruch Hutton (http://sauerbruchhutton.de/)
Location: Frankfurt, Germany
Climate Zone: Oceanic Climate, Cfb
Status: Constructed

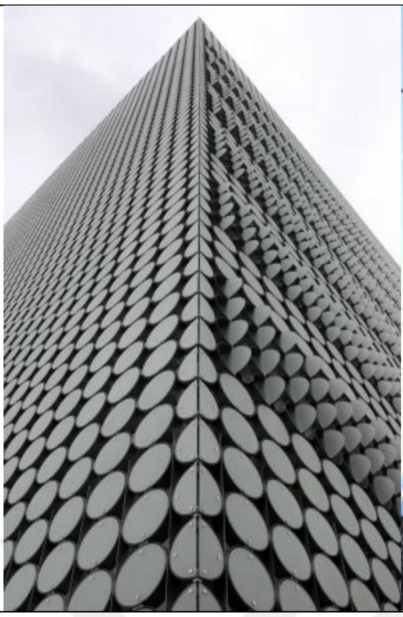
Project Year: 2010
Building Type: Office Building
Area: 39,000 m2
Number of Stories: 14-story
It was awarded “Best Tall Building in the World 2011” by the Council of Tall Buildings and Urban Habitat, Chicago (CTBUH).
https://www.youtube.com/watch?v=zDlivGsFgbI
https://www.youtube.com/watch?v=6_xJQEN-4sk

- This building consumes less than 100 kWh/m2 annually, making it the most energy-efficient office building around the world.
- The main three strategies in designing this building are employing activated slabs, natural ventilation, and geothermal energy to optimize thermal comfort.
- To have natural ventilation, the facades of the building are double-skin facades with a 70 cm cavity. The inner layer consists of fixed insulated aluminum frames, in which operable windows with double-glazed argon-filled are installed. The colored ventilation flaps and the glazing panels are an outer layer. The flaps color is different in various orientation “*red flaps on the west facade, green flaps on the north facade, and blue flaps on the south facade*.” Some of the flaps are openable for the purpose of ventilation, and some of them are fixed as acoustic insulation. The flaps are opened and closed automatically in order to control the constant temperature and pressure of the cavity. The outer skin can be opened by managing the system of building in the summer to prevent overheating.
- To cool the building in the summer by geothermal, the outside air is drawn into the ventilation tubes in the foundation slab. Then the air is cooled underground and sent to the ventilation system.

26. Q1 Thyseen Krupp Quarter

Architects: JSWD Architekten, Chaix & Morel et Associés (http://www.jswd-architekten.de/ , http://www.chaixetmorel.com/en/aacma/p1/)
Location: Essen, Germany
Climate Zone: Oceanic Climate, Cfb

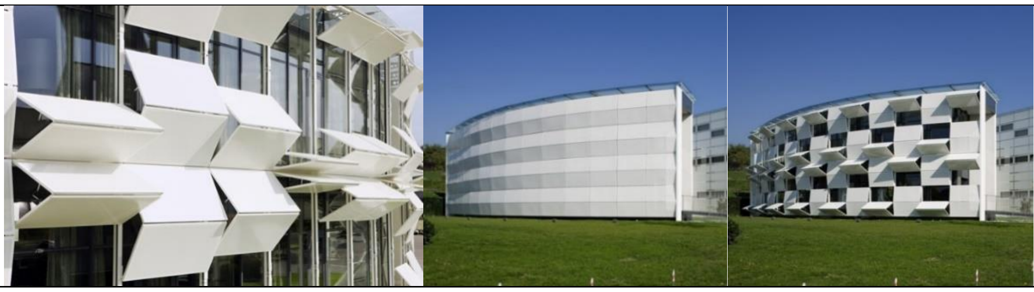
Status: Constructed Project Year: 2010 Building Type: Office Building Area: - Number of Stories: 14-story (54-meter high) Client: ThyssenKrupp AG, ThyssenKrupp Real Estate GmbH The Q1 building has been awarded a gold certificate by the German Society for Sustainable Building (DGNB). The building has also received the BDA Essen award, the "2012 German Steel Construction Award" and one of the "LEAF Awards", in addition to others. https://www.youtube.com/watch?v=j7txNiJDkqU&index=2&list=PLL6ecP8xcVERrDINwBkh5baT93CS-btxs

• The main facade consists of two L-shape volumes, and the rectangle glass surface for the atrium with ten stories high. • The atrium is designed to provide fresh air for the office rooms arranged around the atrium. • The movable shading elements, which consist of 400 stainless louvers, are designed to minimize overheating in the hot seasons. The shading elements track the sun's path automatically. • To maximize daylight and view and to decrease glare and heat gain, the vertical sun shading with triangular, square, and trapezoidal shapes, which consist of louvers, are designed for the main facade.
27. Rmit Design Hub
Architects: Sean Godsell and Peddle Thorp Architects Location: RMIT University, Melbourne, Australia Climate Zone: Oceanic Climate, Cfb Status: Constructed Project Year: 2012 Building Type: Educational Building Area: 13,000 m^2 Number of Stories: 9-story https://www.youtube.com/watch?v=xDyeATq5GBY https://www.youtube.com/watch?v=A3xeudIhtTk



- The shading elements in circular “disks” form with 600 mm diameter are covered the entire building as a second facade layer of the existing building. The disks are made of sandblasted glass with horizontal or vertical aluminum axel, which is fixed in a galvanized steel cylinder with a slightly greater diameter on a horizontal or vertical axel. The disks open to 90° horizontally in the north and south orientation and vertically in the west and east orientation automatically to track sun radiation, which is controlled by the management system of the building. Also, they have closed in windy days also automatically.
- On each floor for maintenance purposes, it is possible to access the disks by a walkway.
- By using galvanized steel and sandblasted glass on the facades, the requirement for maintenance decrease in minimum. Galvanized steel is affordable material in comparison with others.

28. Kiefer Technic Showroom

Architects: Ernst Giselbrecht +Partner (http://giselbrecht.at/)
Location: Austria
Climate Zone: Humid Continental Climate, Dfb
Status: Constructed
Project Year: 2010
Building Type: Office Building
Area: -
Number of Stories: 2-story
https://www.youtube.com/watch?v=rAn4ldWjw2w


• To increase thermal comfort and daylight penetration, "*a dynamic facade system of electrically driven folding elements made of perforated aluminum*" is designed for Kiefer Technic Showroom. The facade changes its appearance each hour automatically according to the sun position. Also, the system allows users to control their spaces manually. • To the maintenance of the system, protruding bridges are considered on the facade. • The building management system controls the system.
29. CJ Cheiljedang Research and Development center
Architects: Yazdani Studio (http://www.cannondesign.com/yazdanistudio/) Location: Seul, Korea Climate Zone: Humid Continental Climate, Dwa Status: Constructed Project Year: 2014 Building Type: Office Building Area: - Number of Stories: 15-story https://www.youtube.com/watch?v=nbcf-NzJpr0

• To minimize solar gain and glare, and maximize daylight, dynamic wraparound steel perforated skins as sun shading is designed for these three buildings. The dynamic skin is folded in on itself based on scissor actuators automatically to create shade according to sun position. A unit consists of three ribbons, which are located on every floor. The windows can be covered entirely by second skin or not. The zig-zag motion allows the skin to move independently. It means, one side of the building can be covered by steel skin to block the sun radiations, whereas the other side is entirely open for getting daylight. • Perforated steel panels allow having daylight always during the day.

30. Mercella Niehoff School of Nursing
Architects: Solomon Cordwell Buenz (http://www.scb.com/) Location: Chicago, USA Climate Zone: Humid Continental Climate, Dfa Status: Constructed Project Year: 2012 Building Type: School Area: 5,574 m^2 Number of Stories: 4-story

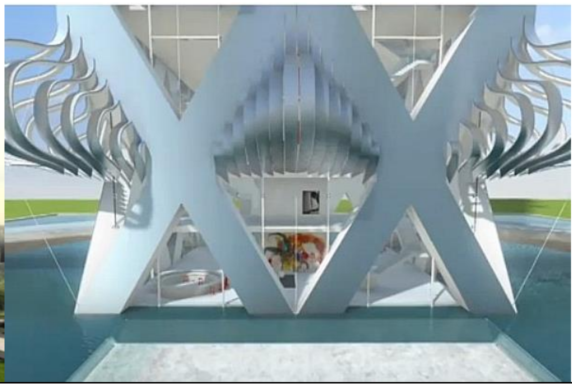
• The aluminum fixed sunshades are designed for the south facades to decrease heat gain and prevent glare. Besides, exterior rolling shades are installed on the west elevation. Rolling shades act automatically according to the sun’s position and weather conditions like wind speed, humidity, and temperatures. Furthermore, by using triple-glazed on the facade, heat gain reduces by 90 percent. • The two solar chimneys are designed in two sides of the south facade to provide natural ventilation. Also, operable windows on south and north facades automatically provide cross ventilation according to the building management control system. In individual offices, occupants can close or open windows by themselves; however, the natural ventilation in public spaces is automatically controlled by the building management system. On the ground floor, the cross-ventilation strategy is employed; however, in other stories, air comes from the north facade to the inside of the building and exits from louvers located top of the chimney wall by stack effect strategy. The building has natural ventilation for 120 days in a year. • To gain heat in the winter, the solar chimneys act reverse. The air draws from the top of the solar chimney; then, it is preheated to send into the interior spaces. This way decrease energy consumption in the winter by 5-10 percent.
31. Al Bahar Towers
Architects: Aedas Architects (http://www.aedas.com/en) Location: Abu Dhabi, United Arab Emirates Climate Zone: Hot Desert Climate, Bwh

Status: Constructed
Project Year: 2012
Building Type: Office Building
Area: -
Number of Stories: 29-story
https://www.youtube.com/watch?v=t5tLY9lyxI4
https://www.youtube.com/watch?v=BSEVoFi9MpQ
https://www.youtube.com/watch?v=kIL8KrPKi24

- A dynamic shading system as a second skin is designed for Al Bahar Towers To minimize cooling load in hot seasons. The annual cooling lodes reduce by 35 percent, and overall energy consumption has a 15 percent reduction.
- To maximize daylight and minimize heat gain and glare, the inner skins of towers are constructed by a glass curtain wall, and outer skins are made of translucent fiberglass (with 20% visibility). The dynamic skins consist of several units. Each unit composes of three Y shape arms and six individually frames covered by fiberglass. Each unit can be in five positions between entirely open or closed according to the sun position automatically. The gap between tow skins is 2 meters, which can be used for maintenance purpose.

32. Kinetower (Kinetura)

Architects: Barbara van Biervliet and Xaveer Claerhout
Location: Belgium,Stakendijik
Climate Zone: Temperate oceanic climate, Cfb
Status: Conceptual
Project Year: 2006
Building Type:
Area: -
Number of Stories: -
http://www.claerhout-vanbiervliet.com/#/en/about%2Dus/
https://vimeo.com/29937130
http://v.youku.com/v_show/id_XMjUxNTQzMzE2.html

- To maximize daylight and minimize heat gain and glare, the smart material is used for designing of Kinetower' facades. "*The smart materials can transform from a flexible state to rigid and vice versa*" to respond to the environment, especially solar heat and temperature. This transformation is called "Metamorphism." Smart materials' transformation property can be used in designing interior spaces, facades, and lighting-fixture.

33. Abu Dhabi Central Market

Architects: Foster + Partners (http://www.fosterandpartners.com/)
Location: Abu Dhabi - United Arab Emirates
Climate Zone: Hot Desert Climate, Bwh
Status: Constructed
Project Year: 2014
Building Type: Shop Center
Area: 689416.0 m^2
Number of Stories: 3-story
Façade Consultant: Arup (http://www.arup.com/)


- The roof and the exterior walls of this building are constructed by sliding perforated panels in order to provide natural ventilation in the hot and drying climate. By moving panels, it is possible to maximize natural ventilation in a different direction. In hot seasons, the panels are opened to prevent overheating, and in cold seasons, the panels of the exterior wall and roof are closed.

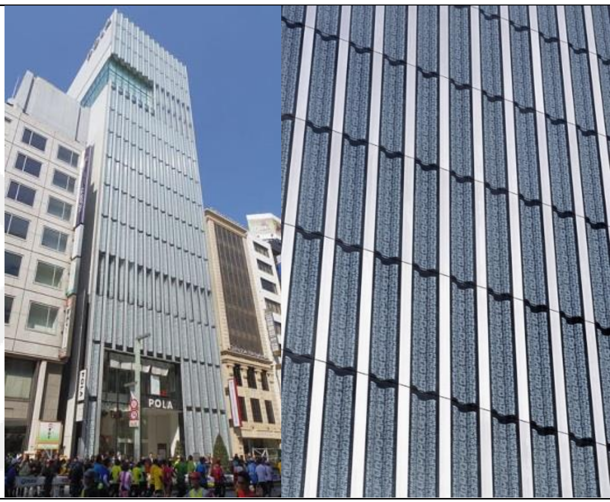
34. Richard J. Klarchek Information Commons

Architects: Solomon Cordwell Buenz
Location: N Sheridan Rd, Chicago, Illinois, EEUU
Climate Zone: Humid Continental Climate, Dfa
Status: Constructed
Project Year: 2007
Building Type: Library
Area: 6,410 m^2
Number of Stories: 4-story
The building is LEED Silver certified


- Each facade of this building has its characteristic.
- The west facade is designed as a double-skin facade To provide natural ventilation in the building during a year. The outer skin is “a cable net glass wall,” and the inner skin is a fixed system by the insulated glass. The gap between the two skins is 91.5 cm. Furthermore, the double-skin facade’s cavity as a sealed place can act as thermal and acoustic insulation. On the top of the facade, the glass parapet with vents not only exhausts the heated air by stack effect but also maintains transparency for the facade.
- To prevent excessive heat and glare and maximize daylight, the movable blind, which tracks the sun, is located in the cavity.
- The east facade is designed by a double glass wall with roller blinds, which automatically block direct solar radiation by 92 percent. The open pattern of roller blind allows daylight penetration.
- Two rows of vents with 76.2 cm high are located in the east facade to provide fresh air for interior spaces.
- When the vents on the east facade and the opening of the interior skin of the west facade are open, cross ventilation is provided in the building.
- For glazed facades of this building, insulated glass (argon filled and low-iron) is used.
- The south and north facades are blocked by seminar rooms and service cores.

35. POLA, Ginza

Architects: Yasuda Atelier, Nikken Sekkei (http://www.yasudaatelier.com/ , http://www.nikken.co.jp/en/
Location: Tokyo, Japan
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed
Project Year: 2009
Building Type: Commercial Building
Area: -
Number of Stories: 14 Floors
https://www.youtube.com/watch?v=dJLkHabokik



- A double-skin facade with movable sun shading is designed for building facade to have thermal comfort in summer and winter. There are windows at the top and bottom of the facade. In the summer, by the opening of windows at the bottom and top, heated air is exhausted by the chimney effect. In winter, heated air in the cavity of double skin facade works as thermal and acoustic insulation. The windows are opened and closed automatically according to the inside and outside temperature, which is controlled by the management system of the building. This double skin system decrease energy consumption for HVAC system of the building by 30 percent. Also, a double-skin facade protects the building from the wind.
- To reduce heat gain glare and to maximize daylight penetration, 185 curved acrylic panels (1 by 3 meters) with a shutter mechanism, which works track sun position automatically, are located in the cavity of the double-skin facade. Moreover, the translucent panels allow us to have a clear view even when they are closed.

36. Vivian and Seymour Milstein Family Heart

Architects: Pei Cobb Freed & Partners (http://www.pcf-p.com/)
Location: New York, USA

Climate Zone: Humid Subtropical Climate, Cfa Status: Constructed Project Year: 2010 Building Type: Hospital Area: 11,613 m^2 Number of Stories: 6 floors above ground, 2 floors below ground Received LEED Gold certification https://www.youtube.com/watch?v=7k4IYKHEw2c

• The curved double-skin facade with movable panels in the cavity as climate wall is designed for the facade of Vivian, and Seymour Milstein Family Heart o increase the thermal comfort of interior spaces. The cavity is 76.2 cm, which has catwalks made of open steel grates on each floor for maintenance purposes. The cavity is a perfect solution for having natural ventilation in the summer by opening the bottom and top vents, and it can be an insulation buffer in the winter by closing the mentioned vents. Insulated tend glasses are utilized for the climate wall. The kinetic panels, which are made of fabric louvers, move according to the sun's position to maximize daylight penetration and prevent heat gain. • The atrium with 21 meters height, which connects the existing building to new ones by encasing glass bridges, is located behind the climate wall.
37. Gemini Haus
Architects: Roland Mösl (http://www.pege.org/), Planetary Engineering Group Earth (PEGE) Location: Weiz, Austria Climate Zone: Warm-summer humid continental climate, Dfb Status: Constructed Project Year: Proposed 1991, Construction time 2001 Building Type: Part of the Styria County Energy Exhibition Area: - Number of Stories: 2-story Won a prize at the prestigious World Exhibition of Innovation

- The main strategy for the construction of Gemini Haus is generating electricity from solar energy, decreasing fusil fuel consumption as an energy source, and reducing air pollution.
- The second curved skin, which consists of photovoltaic panels (150 m2), rotates around the cylindrical building to catch more radiations to maximize electricity generation.
- Insulation is considered for the exterior wall of this building to prevent heat gain and heat loss.

38. Sliding House by DRMM

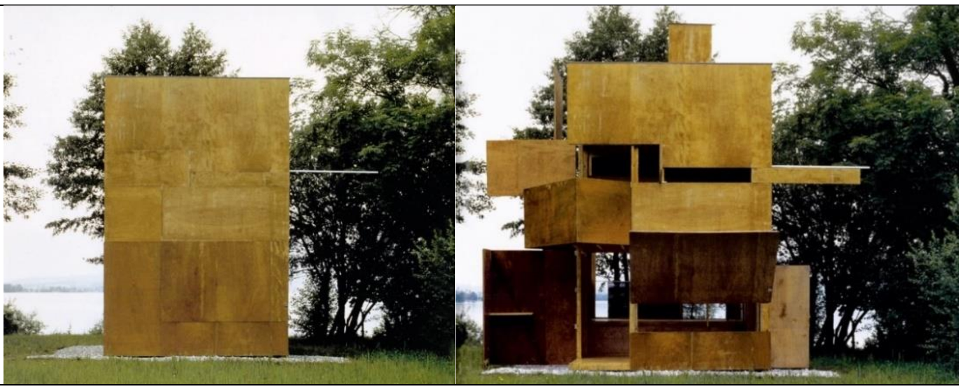
Architects: dRMM; Alex de Rijke, Joana Pestana Lages Goncalves
Location: Suffolk, England
Climate Zone: Oceanic Climate, Cfb
Status: Constructed
Project Year: begun 2006, completed 2009
Building Type: House, Residential
Area: 200 m^2
Number of Stories: 2-story
Engineer: Michael Hadi Associates, Rutger Snoek, David Williams
Mechanical engineer: DJW Consulting Limited
Electrical engineer: Robert Hart Electrical Engineering
Client: Ross & Sally Russell


- To increase visual and thermal comfort in the summer and winter, the kinetic cover with 28m length is moving (sliding) top of the three-building with 5.8 m width and 7.2 m height. The exterior walls and roof of the main building are constructed by the glass. Red stain larch and black stain larch are used for the construction of the garage. The sliding house is covered or uncovered in 6 minutes to respond to the environmental changes such as rain, storm. daily and yearly in order to have natural light, view, and solar heat in the winter and have shading in the summer. It is possible to half covered glass houses also, which depend on the position of the sun or other environmental issues. The kinetic cover moves by the power of four motors, which are installed into the walls. Each motor has its batteries, which are charged by solar panels.

- To construct easily, except groundworks, internal joinery fixtures, and external surfaces, the other parts of the building were made in a factory as prefabricated elements to install in the construction site.

39. GucklHupf

Architects: Hans Peter Wörndl
Location: Vienna, Austria (Mondsee, Austria)
Climate Zone: Oceanic Climate, Cfb
Status: constructed
Project Year: 1993
Building Type: Recreation House
Area: 48 m^2
Number of Stories: two and one half levels
Mechanical engineer:
Electrical engineer:
Client: Mondsee's summer festival
Climate: Marine West Coast Climate
Material of interest: Wood
https://www.tumblr.com/search/gucklhupf
https://www.amazon.com/GucklHupf-Hans-P-W%C3%B6rndl/dp/3775705759



- To respond to residents' need, the building facades, which is constructed as a part of a festival, are continually changing.
- Most parts of the building can move, raise, fold, or extend by a novel system of stainless steel cable and hinges in order to give various shapes for the building.

40. M-vironments by Micheal Jantzen
Architects: Micheal Jantzen (http://www.michaeljantzen.com/Welcome.html) Location: Valencia, Spain Climate Zone: Cold semi-arid climate, Status: Constructed Project Year: 1999 designing, 2001 constructed Building Type: Houses, Office facilities and Pavilions Area: - Number of Stories: 1-Story https://www.youtube.com/watch?v=rtxvQ29X6eo

• M-vironments system, as a conceptual designing, has interchangeable and transformable structures. The mentioned structure can have a different function with various sizes. The system consists of rectangular panels, which are made of steel frames with thin concrete composite sheets. The structure can be self-sufficient by using renewable energy for the motion of panels and frames, which are used in the structure system of M-vironments. The panels and frames can be disassembled in order to make a different shape. Each panel can fold into or out of the structure, which results in having various shapes for different functions such as sun shading, places for sleep or sit. Some of these panels are used as windows or doors. Some of the panels move to respond to environmental changes like rain or wind. • M-vironments systems can be independent energy systems by employing photovoltaic panels or wind power. Moreover, by changing the shape, natural ventilation will be improved.
41. Dynamic Tower, Rotating Tower
Architects: David Fisher Location: Dubai, United Arab Emirates Climate Zone: Hot Desert Climate, Bwh Status: Conceptual Project Year: Proposed 2008, Construction Start 2009, Completion 2020

Building Type: Offices (1-20), Luxury Hotel (21-35), Apartments (36-70), luxury Villas (71-80) Area: around 111500 m^2, (Apartments area: 124 m^2, Villas area: 1,200 m^2 with own parking space). Number of Stories: 80 Stories, 420 meters tall. Structural Engineer: Leslie E. Robertson Associates Structural Material: Concrete http://www.dynamicarchitecture.net/ https://www.youtube.com/watch?v=iY0Uuyf8Xhw https://www.youtube.com/watch?v=q4kMQzgiytA https://www.youtube.com/watch?v=FmCn_XyO7Cs https://www.youtube.com/watch?v=roVL89E1RIs https://www.youtube.com/watch?v=Ah3qcUJGZxM https://www.youtube.com/watch?v=JKE_U_wcKgU https://www.youtube.com/watch?v=rI72Ce4jLrA https://www.youtube.com/watch?v=Bq-QUkE1DGM https://www.youtube.com/watch?v=xOhjgLKSzW0 https://www.youtube.com/watch?v=j-OzdXmydDE https://www.youtube.com/watch?v=U777-tKSt_0 https://www.youtube.com/watch?v=6h1PRHdhYv8

• To accelerate the construction speed of Dynamic Tower by 30 percent in compere with a typical skyscraper, the tower's central core is built by reinforced concrete than the rest parts (about 90 percent) are installed on a central core as prefabricated elements. • The prefabricated system also decreases the cost of construction by decreasing the number of workers and construction time. • Each floor can be rotated independently by its occupants' control with 6 meters in one-minute speed. It takes 180 minutes to have complete rotation. By independent rotation, the tower's form is constantly changing. • The rotating tower is environmentally friendly and energy self-sufficient by generation energy. To generate electricity between each rotating floor, 79 wind turbines and photovoltaic panels are installed. The tower generates not only its own energy but also extra energy for the city's grid.

As it is calculated, each turbine can produce 1,200,000 kWh of energy under Dubai’s normal wind condition.

42. Wind Shaped Pavilion By Michael Jantzen

Architects: Michael Jantzen (http://www.michaeljantzenstudio.com/home.html)
Location: Frankfurt am Main, German
Climate Zone: Oceanic Climate, Cfb
Status: Conceptual
Project Year: -
Building Type: Public or Private Pavilion
Area: -
Number of Stories: 6-story

- Wind power is used to generate electricity for Wind Shaped Pavilion to have a self-sufficient building.
- The building is designed by the six segments made of lightweight fabric, which are arranged around a central open frame. Each segment rotates independently by wind power. The rotation of segments not only generates electrical energy for its night time illumination but also alters the shape of the building. Furthermore, the rotation of segments also can be according to residents in order to have a nicer view. The shape of the building constantly changes because of wind blow.

43. Heliotrop (Vauban, Freiburg), (Offenburg), (Hilpoltstein)

Architects: Rolf Disch,(http://www.rolfdisch.de/index.php?p=home&pid=2&L=1&host=2)
Location: Freiburg im Breisgau, German - Offenburg, German- Bavaria, German
Climate Zone: Oceanic Climate, Cfb
Status: Constructed
Project Year: 1994, 1994, 1995
Building Type: Private Home, Visitor’s Center and Showroom, Dental Laboratory
Area: -
Number of Stories: 3-story
German Sustainability Award in 2008,
Japanese PEN-Magazine Creativity Award in 2007–08,
Wuppertal Energy and Environment Prize in 2005,
Global Energy Award in 2003,
European Solar Prize in 2002,
Photovoltaic Architecture Prize Baden-Württemberg in 2001.
https://www.youtube.com/watch?v=5tlW0N1ltHQ

- To increase daylight and decrease energy consumption for lighting, cooling, and heating, Heliotrop is designed as self-sustaining by rotating 360° according to sun position.
- Prefabricated wooden panels as recyclable materials are used to construct this building. A central column supports the building's rotating structure with 14.5 m high and 2.9m diameter, made of glue-laminated timber.
- Two insulation kinds are used in exterior walls (tripled-paned thermal insulated glass and highly thermally insulated) for choosing the right side in various seasons by rotating of building to gain heat or prevent solar heat. For example, by facing the triple-glazed windows to the sun, the interior spaces will have maximum natural light and heat gain during cold seasons.
- To generate more electricity, 54 m2 photovoltaic panels, which are called sun sail, are installed on the roof that they track the sun automatically by rotating in two axes horizontally and vertically. The sun sail moves independently from the building rotation, which increases the generation of energy by 30 to 40 percent.
- The balconies with tube collectors (34.5m2) as railings are designed around the building to provide hot water for domestic need and space heating. Also, balconies act as sun shading to prevent heat gain and glare.
- A geothermal exchange system is employed To cool the interior spaces.
- Excessive energy around five or six times more than building energy requirement is generated by Heliotrop, which supplies to the grid but draws from the grid when solar power is not sufficient to operate.

44. Suite Vollard

Architects: Bruno de Franco
Location: Curitiba, Paraná, Brazil
Climate Zone: Subtropical Highland Climate, Cwb
Status: Constructed
Project Year: 2001
Building Type: Residential
Area: Each apartment 270 m^2 , surrounded by 30 m^2 balcony
Number of Stories: Floors (above ground) 15, Floors (below ground) 2, 50 m high
Structural Material: Concrete, Reinforced, Glass, Steel
Constructor: Moro Construções Civis LTDA, and Fritz Georg Gehbauer
https://www.youtube.com/watch?v=sUUT0Wnh3nY
https://www.youtube.com/watch?v=ybX2sjtPOg8
https://www.youtube.com/watch?v=u731zoP8WUY&t=75s

https://prezi.com/h4v26mcx_oei/the-suite-vollard/
http://www.slideshare.net/DiasKoshumbekov1/suitevollardpresentation-ah



- To increase thermal comfort and visual comfort, Suite Vollard is designed as a rotating tower. Each floor rotates 360 degrees in two directions (clockwise or counter-clockwise) around the central core in one hour independently and smoothly without any noise. The occupants can control the speed, direction, and timing of rotation via a touch screen. Moreover, the power for rotation is deficient; it is like the power required to run a washing machine.
- The central fixed core is used for areas, which require mechanical and electrical services like kitchens, toilets, and bathrooms. Furthermore, the balcony surrounds each floor to make shade.
- The circular tower's facade is made of double colored glass with different color like blue, gold, and tinted silver to optimize daylight.
- To minimize energy consumption for heating, cooling, and natural light, building track the sun in various seasons in order to be in the right position to gain heat or prevent solar heat.
- The building is constructed durability without any component repairing for 30 years to decrease maintenance costs. Also, the lifetime of mechanical systems is forecasted between seven and eleven years by the constructor.
- To maintenance the movable parts, there is easy access under each floor.

45. Rotating Dome Home

Architects: Patric Marsili
Location: Brittany, France and New York, USA
Climate Zone: Temperate Oceanic Climate, Cfb, Humid Subtropical Climate, Cfa
Status: constructed
Project Year: 1988, 1999
Building Type: House
Area: - , 215 m^2
Number of Stories: two stories
Client: - , Shiva Vencat
Structural Material:
https://www.youtube.com/watch?v=fz7utI74c1M
https://www.youtube.com/watch?v=v79fSKmg9B8

https://www.youtube.com/watch?v=nwlgkNEhA0Q
https://www.youtube.com/watch?v=AKDzm-_IrWo
https://www.youtube.com/watch?v=Nwv7sW1Ollw
https://www.youtube.com/watch?v=WoKddOirtPI&t=65s
https://www.youtube.com/watch?v=gQUsh-zYso8
https://www.youtube.com/watch?v=iAyA1oWXeNc
https://www.youtube.com/watch?v=XBbfFpmwcx0

- The dome form can be an efficient form of decreasing the surface area of facades and roofs to respond to the weather condition. The dome shape allows the building to resist winds of up to 174mph (280kph) and hurricanes. Also, the dome form can resist an earthquake up to an eight on the Richter.
- The rotating dome home is constructed based on a concrete platform, which supports the central wooden pillar. A central wooden pillar supports the prefabricated wooden elements of the dome.
- To decrease environmental pollution, for construction of dome home, recyclable materials like spruce (durable and flexible) as beams, red cedar as roof, spruce, and bamboo as floor and cork or pulped wood as insulation (located inside the wall) are used.
- The dome house rotates 360 degrees smoothly with a small motor by remote control.
- To provide thermal, visual comfort and ventilation, one way is designing a rotating building, which can be positioned on the right side in various seasons to get or prevent solar heat.
- Vertical windows are designed for building with shutter, which is used in heavy rains to prevent making a sound because of the sloped glass.
- To decrease energy consumption and air pollution, the photovoltaic panels on the dome can be useful.

46. Everingham Rotating House

Architects: Luke Everingham
Location: Wingham, Australia
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed, designed 2002
Project Year: March 2006
Building Type: House
Area: 24-metre diameter octagon
Number of Stories: 2-story

Client: Luke Everingham
Structural Material: Glass and Steel
https://www.youtube.com/watch?v=Qp_n8-Y7YCM
https://www.youtube.com/watch?v=tNHt0QNSHHE
https://vimeo.com/160830186
https://prezi.com/bxc8ehoxqbkq/everingham-rotating-house/

- Everingham Rotating House with 360 º (within a 180º retainer) rotation is designed as an octagonal shape with 24 m diameter, which is surrounded by 3m veranda with a wooden floor on a circular disc. The direction and speed of rotation are controlled or programmed by the occupants. The building can rotate 360 degrees between 30- 120 minutes at various speeds. In this building, the central service core also rotates by the rest of the building.
- The building is positioned in the right direction by rotation at various times of a day or a year to optimize natural ventilation, thermal and visual comfort.
- The building is constructed by durable materials to decrease maintenance costs..
- Geothermal energy is used for heating to decrease energy consumption in winter. The plastic pipe with 120 m length is located 2 m depth underground, where the temperature is 22ºC, to heat the building with the air in the pipe by drawing into interior spaces.

47. Rotating Home by Johnstone

Architects: Al Johnstone
Location: Southern California, USA
Climate Zone: Humid Subtropical Climate, Cfa
Status: Constructed
Project Year: 2000 - 2003
Building Type: Residential, House
Area: 475 m^2
Number of Stories: 2-Story
Structural Material: Steel-Reinforced Concrete, Glass Wall
https://www.youtube.com/watch?v=Kji1Us6s9z8

- The rotating home in cylinder form is designed in two stories with a stationary floor as a garage (ground floor) and a rotating floor (second floor) with 360-degree rotation. The speed and direction of rotation can be controlled by occupants. The building can have one rotation in 30 minutes or in 24 hours with 1 1/2 –horsepower motor. The building is constructed by reinforced concrete with a glass facade. The two floors are connected by a central elevator. The entrance of the building is located on the ground floor.
- A swivel device is designed in the central elevator shaft o to have an uninterrupted flow of water, gas, and other utilities. The swivel acts as a transfer station between the fixed water pipe, sewage, and natural gas pipes and complementary pipes, which are attached to the rotating part of the building.
- Around 11 m2 areas are employed to install photovoltaic panels on the roof to generate electricity.
- In the case of fire, the building roof will be flooded with water.

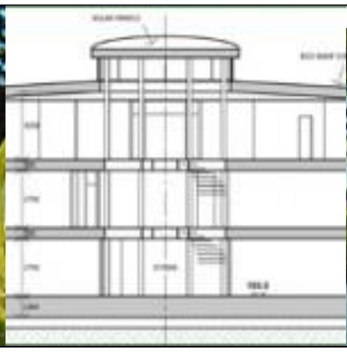
48. 55° Dubai – Time Residences

Architects: Glenn Howell Architects (http://glennhowells.co.uk/), P & T Architects & Engineers Ltd.
Location: Dubai, United Arab Emirates
Climate Zone: Hot Desert Climate, BWh
Status: Conceptual
Project Year: 2008 to 2010
Building Type: Residential apartments or Holiday Apartments (200 apartments)
Area: -
Number of Stories: 30 stories (122.99m)
https://www.youtube.com/watch?v=uoE8S04c81M
https://www.youtube.com/watch?v=9okngHfMLrA

- The tower rotates 360 degrees in seven days using solar energy during the day and stored solar energy during the night to improve natural ventilation, daylight.

49. Rotating Ecohome – The Dumble Project

Architects: Robin Hamilton
Location: Snelston, England
Climate Zone: Oceanic Climate, Cfb
Status: Constructed
Project Year: 2010
Building Type: Residential, House
Area: 930 m2
Number of Stories: Four Stories
https://www.youtube.com/watch?v=IlJvQK5xZ68

- To decrease the cost of energy in the building, the designer of this building considered three strategies; providing energy for the daily requirement of the building, storing energy for later building requirements, selling excess energy to the grid.
- Wind turbines are integrated on the roof and on the upper part of the exterior wall to generate energy. The employed turbine is designed for getting maximize energy even at low wind speed conditions.

- Moving photovoltaic panels are installed on the roof of the building to generate energy. The moving panels can adjust themselves in angle and direction to the sun in order to generate maximum electricity.
- Geothermal heating is used to provide hot water for domestic use.
- To decrease environmental pollution and energy consumption, a multi-fuel stove, which burns paper, wood, is used in the living room. The heat from multi-fuel stove and flue gases is recycled in the machine room, where is located at the back of the building, for use as heating energy. The machine room is designed to control equipment and systems like heat exchanging.
- Recycling techniques like recycling waste and greywater and collecting rainwater are employed to enhance the building's energy efficiency.
- Heated or cold air from the machine room flow inside the wall's ducts to provide heating or cooling according to the seasons.
- To have passive heating and cooling, the double-glazed atrium, which gains a large amount of solar energy, is designed. The gained heat is sent to the machine room for distribution or storing.
- The electricity generated by renewable energy is converted into mains voltage electricity to use in the building.
- If the outside weather is not suitable, the machine room will control the heating and cooling of interior spaces, and when the outside weather is comfortable, the natural ventilation will be allowed by air flowing from the ground floor into the atrium and other spaces of the building.

CHAPTER 5

RESULT AND DISCUSSION

This chapter presents the results of the three steps of this research on how to design appropriate facades that fulfill the requirements of the building occupants and achieve the design targets using the most applicable technical solutions. The first Section 5.1 gives an analysis of the information summarized from the 49 case studies. The Second 5.2 evaluates the data obtained from the 202 forms filled for the two questionnaires. The third Section 0 presents the application of the QFD method.

5.1 Case Studies

One of the challenges in designing building facades is to evaluate which systems or techniques can be effective in decreasing energy consumption and environmental pollutions as well as improving human comfort. As explained in the material section, 49 efficient buildings were selected to analyze their facade systems and technologies that make them efficient in responding to occupant's requirements. The information regarding case studies was gathered from various sources such as papers, thesis, and websites. Then the lists of the facade systems, techniques, and occupants' requirements that were used in these buildings to provide human comfort were made. In other words, these buildings were analyzed according to their facade systems, the technical solutions, and the human comfort requirements, which were categorized in flowcharts for brevity and clarity.

5.1.1 Facade Systems

The facade systems of 49 buildings were classified into two main groups: passive and active systems. As shown in Figure 5.1, the systems working passively without using mechanical systems were placed in the passive systems group. The active systems were categorized into two groups; Intelligent facades and Integrated energy systems. Each of them has its sub-group that is presented in Figure 5.1 as a flowchart.

The six buildings of the analyzed case studies were designed as conceptual projects that introduce new technological ideas. The facades of Kinetower (Chapter 4, No. 32) were designed using smart material, which transforms from a flexible state to rigid and vice versa according to environmental conditions. GucklHupf (Chapter 4, No.39) and M-vironments (Chapter 4, No. 40) have interchangeable and transformable structures in their facades. These two buildings' facades consist of movable panels with various motion (sliding, folding, rotating) to alter their appearances according to environmental changes. Dynamic Tower (Chapter 4, No. 41) is a rotating tower with 80 stories. Each floor of this tower rotates independently. So, its appearance changes continuously. The sixth conceptual building is the Wind Shaped Pavilion. This building is designed by using light materials to rotate with wind energy in order to generate electrical energy.

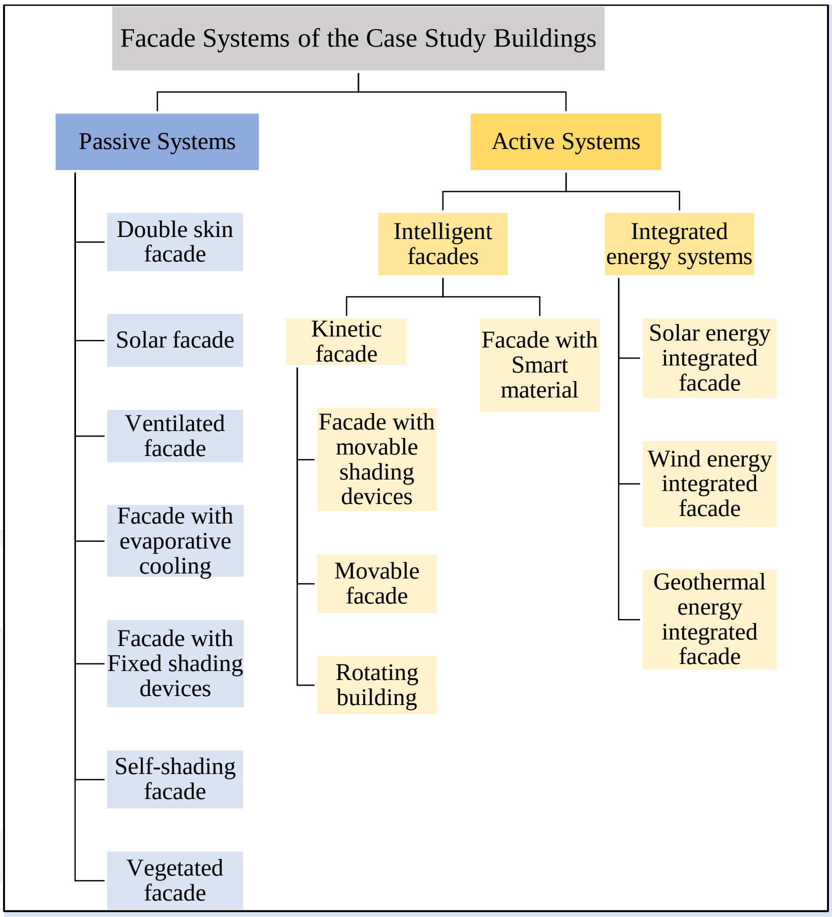


Figure 5.1 Types of facade systems identified from the 49 case studies

5.1.2 Technical Solutions

In order to make a list of the technical solutions, a few technologies that were expensive and complex have been left out; the rest are given in Table 5.1. For example, shower towers and ducts with turbines on top of them that were used in Council House (Chapter 4, No.23) are not listed.

The technical solutions identified from the case studies, shown in Figure 5.2, were categorized into four groups as given below:

- Openings in facade: the characteristic of the opening and type of glazing were placed in this category.

- Construction materials: the types of materials used in the construction of facades were listed under the category of construction materials.
- Facade components: this category consists of technologies used in facade components in the construction.
- Energy generation: the techniques that were applied in facades to generate energies were in this category.

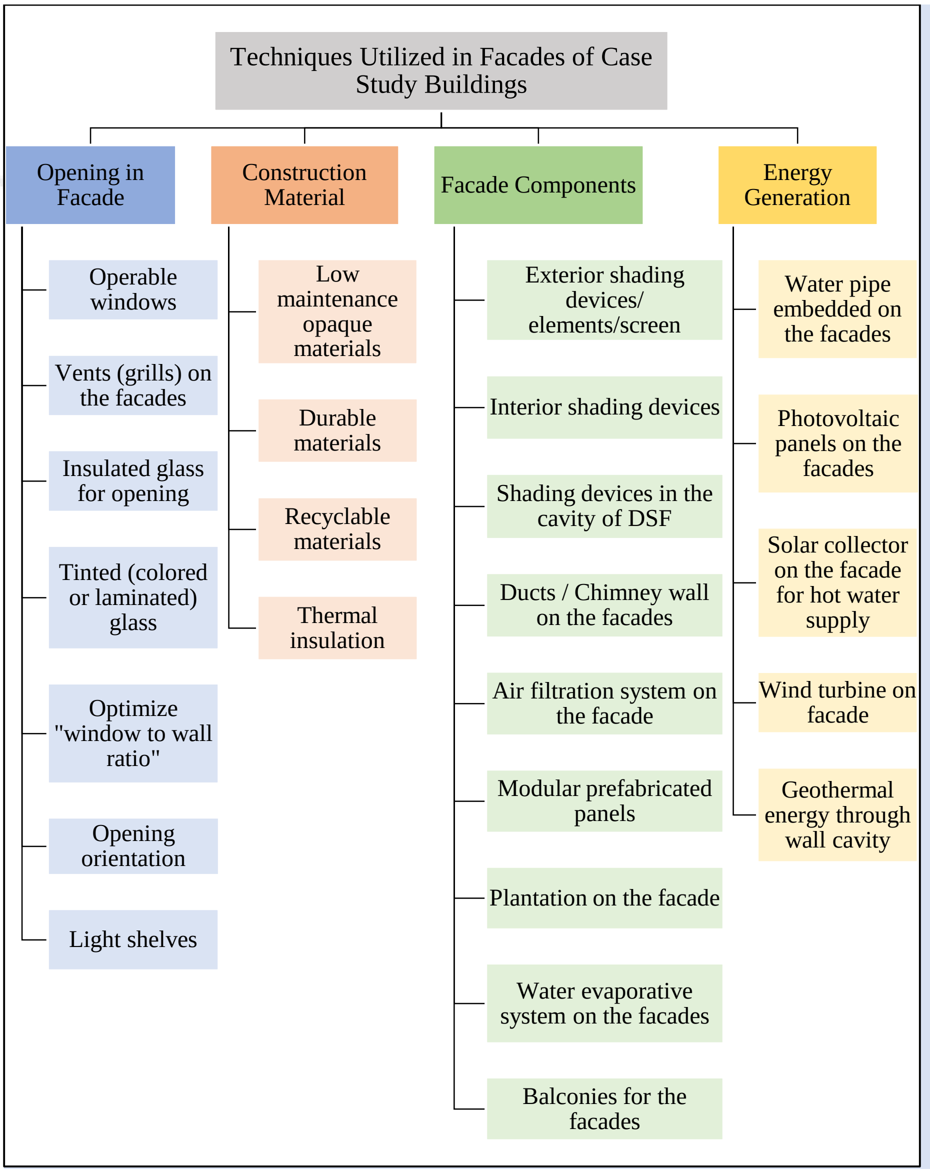


Figure 5.2 Classification of technical solutions used in the facades of the 49 case study buildings

5.1.3 Occupant Requirements

In this part, attention has been paid to how the facades have responded to the occupants’ requirements. The occupants’ requirements that have been met in these buildings were categorized in Figure 5.3. These requirements were listed under three groups of primary targets: human comfort, decreasing cost, and decreasing environmental pollution.

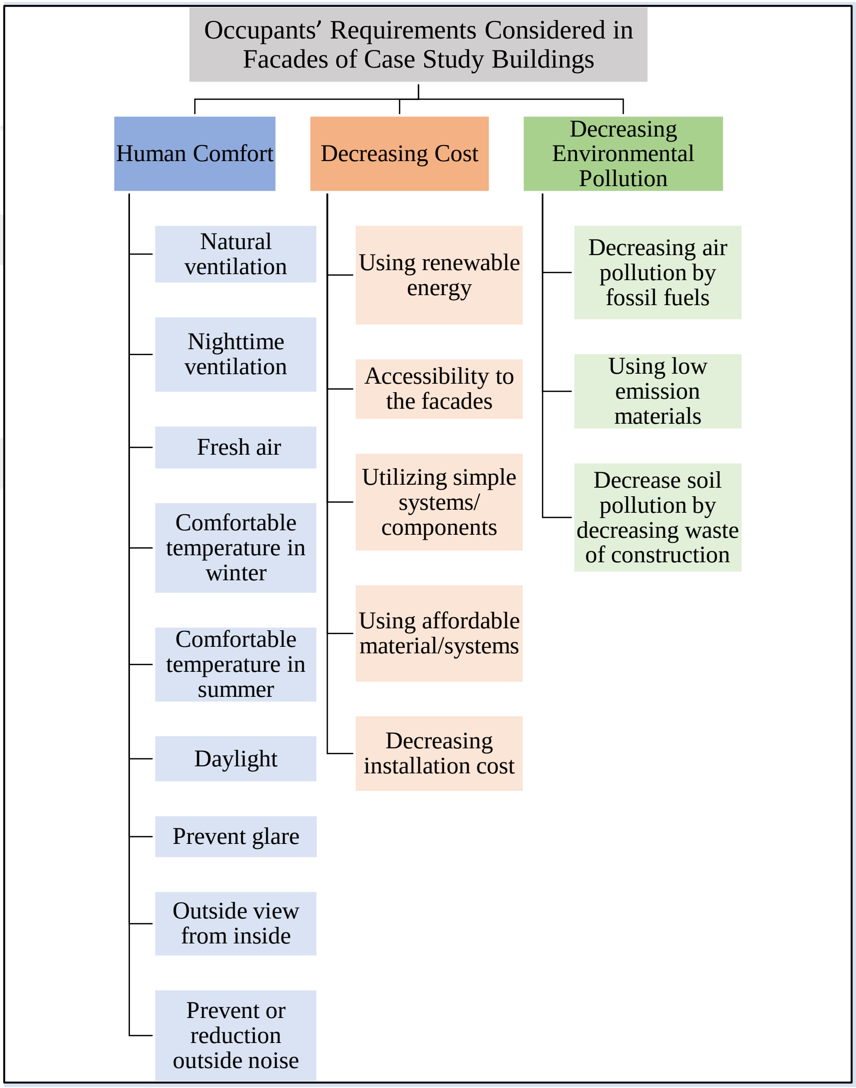


Figure 5.3 Categorization of occupants’ needs that were targeted in the 49 case studies

Table 5.1 Employed techniques in 49 buildings to have efficient buildings regarding energy consumption

		Operable windows	Vents (grills) on the facades	Insulated glass for opening	Tinted (colored) glass	Optimizing WWR	Opening Orientation	Light shelves	Low maintenance materials	Durable materials	Recyclable materials	Thermal insulation	Exterior shading elements	Interior shading elements	Shading devices in the cavity of DSF	Chimney wall on the facade	Air filtration system on the facade	Modular prefabricated panels for the facades	Plantation on the facade	Water evaporative system on the facades	Balconies for the facades	Water pipe embedded on the facades	Photovoltaic panels on the facades	Solar collector on the facade for hot water	Wind turbine on the facade	Geothermal energy through wall cavity	Facade with movable shading devices	Movable facade	Rotating building	Facade with Smart material	Solar energy integrated facade	Wind energy integrated facade	Geothermal energy integrated facade	Double skin facade	Solar facade	Ventilated facade	Facade with evaporative cooling	Facade with fixed shading devices/ elements	Self-shading facade	Vegetated facade	Natural ventilation	Nighttime ventilation	Fresh air without mechanical systems	Comfortable temperature in winter	Comfortable temperature in summer	Day light	Prevent glare	Outside view from inside	Prevent or reduction outside noise	Using renewable energy	Accessibility to the facade	Simple systems/components	Affordable material/systems	Decreasing installation cost	Decrease air pollution by fossil fuels	Low emission materials	Decrease soil pollution by decreasing waste of
1	US Census Bureau Headquarters					✔					✔		✔																																	✔	✔	✔									
2	Santa Monica Civic Center Parking Struct	✔				✔				✔	✔		✔										✔				✔				✔										✔					✔				✔	✔	✔					
3	Building Block Social Nestle Graneros				✔	✔			✔	✔			✔			✔				✔																✔					✔		✔		✔	✔	✔	✔				✔			✔		
4	3M Italia S.P.A Headquarters	✔		✔							✔		✔								✔		✔								✔				✔									✔	✔	✔	✔	✔		✔	✔	✔			✔		
5	Burj Doha				✔	✔				✔	✔		✔	✔																								✔							✔	✔	✔				✔						
6	Hanwha Headquarter Remodelling	✔		✔		✔				✔	✔		✔					✔					✔								✔								✔							✔	✔	✔		✔				✔	✔		
7	King Fahad National Library	✔				✔							✔					✔																				✔			✔				✔	✔	✔	✔						✔	✔	✔	
8	New Kuwait University Sabah AL-Salem	✔		✔	✔	✔						✔	✔					✔																					✔		✔			✔	✔	✔	✔	✔						✔			
9	South Australian Health	✔		✔		✔	✔						✔					✔																					✔					✔	✔	✔	✔	✔						✔	✔		
10	Juvelen- a new landmark in Uppsala	✔				✔	✔																✔								✔								✔					✔	✔	✔	✔	✔		✔					✔		
11	Habitat Items Leon		✔		✔	✔							✔					✔																		✔			✔		✔	✔			✔		✔	✔	✔		✔	✔		✔	✔		
12	Rey Juan Carlos Hospital	✔			✔	✔					✔		✔					✔					✔								✔							✔			✔				✔	✔	✔	✔		✔				✔	✔		
13	John and Frances Angelos Law Center	✔	✔		✔	✔							✔														✔											✔			✔				✔	✔	✔	✔							✔		
14	Soho Hailun Plaza	✔				✔	✔						✔					✔					✔								✔								✔		✔			✔	✔	✔	✔	✔		✔				✔	✔		
15	Embassy of the United States			✔	✔									✔				✔					✔								✔				✔										✔	✔	✔	✔		✔				✔	✔		
16	Sony City Osaki	✔				✔	✔						✔					✔		✔			✔								✔						✔				✔	✔	✔		✔	✔	✔	✔		✔	✔			✔	✔		
17	Hospital Manuel Gea Gonzales	✔				✔							✔				✔	✔												✔												✔			✔	✔	✔						✔			
18	Green Cast	✔				✔											✔	✔	✔																					✔	✔		✔		✔	✔	✔	✔			✔			✔	✔		
19	Yishun Community Hospital	✔				✔					✔		✔				✔		✔		✔																			✔	✔		✔		✔	✔	✔	✔			✔				✔		
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27	Rmit Design Hub	✔			✔	✔			✔	✔			✔					✔									✔														✔					✔	✔	✔			✔						
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29	CJ Cheiljedang Research & Develop. center	✔				✔							✔					✔									✔														✔				✔	✔	✔	✔									
30	Mercella Niehoff School of Nursing	✔		✔									✔	✔		✔											✔									✔					✔			✔	✔	✔	✔	✔								✔	
31	Al Bahar Towers	✔				✔							✔					✔									✔																			✔	✔	✔			✔						
32	Kinetower (Kinetura)					✔												✔												✔														✔	✔	✔	✔	✔									
33	Abu Dhabi Central Market												✔					✔									✔														✔					✔	✔	✔									
34	Richard J. Klarchek Information Commons	✔	✔	✔		✔							✔		✔			✔									✔							✔							✔			✔	✔	✔	✔	✔	✔		✔				✔		
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36	Vivian and Seymour Milstein Family Heart		✔	✔	✔										✔			✔									✔							✔							✔			✔	✔	✔	✔	✔	✔		✔				✔		
37	Gemini Haus	✔		✔								✔											✔					✔			✔										✔			✔	✔	✔	✔	✔		✔					✔		
38	Sliding House by DRMM	✔		✔		✔					✔							✔										✔																✔	✔	✔	✔	✔							✔		
39	GucklHupf										✔																	✔													✔					✔	✔										
40	M-vironments by Micheal Jantzen	✔									✔												✔		✔			✔			✔	✔									✔			✔	✔	✔	✔	✔		✔							
41	Dynamic Tower, Rotating Tower					✔												✔					✔		✔				✔		✔	✔													✔	✔	✔	✔		✔				✔			
42	Wind Shaped Pavilion By Michael Jantzen																	✔							✔				✔			✔																		✔							
43	Heliotrop	✔		✔		✔					✔	✔									✔		✔	✔					✔		✔										✔			✔	✔	✔	✔	✔		✔	✔				✔		
44	Suite Vollard	✔		✔	✔	✔			✔	✔								✔			✔								✔												✔			✔	✔	✔	✔	✔			✔	✔			✔		
45	Rotating Dome Home	✔		✔						✔	✔	✔	✔					✔					✔						✔		✔										✔			✔	✔	✔	✔	✔		✔	✔				✔		
46	Everingham Rotating House	✔				✔				✔											✔					✔			✔				✔								✔			✔	✔	✔	✔	✔		✔					✔		
47	Rotating Home by Johnstone				✔	✔															✔								✔												✔			✔	✔	✔	✔	✔			✔				✔		
48	55° Dubai – Time Residences					✔												✔			✔								✔																	✔	✔										
49	Rotating Ecohome – The Dumble Project	✔		✔		✔					✔	✔									✔	✔	✔		✔	✔			✔		✔	✔	✔								✔			✔	✔	✔	✔	✔		✔			✔		✔		
	FREQUENCY	36	6	18	13	38	6	1	3	10	16	6	27	3	4	4	7	31	5	2	9	2	15	1	5	4	15	4	9	2	15	5	4	8	2	4	2	4	6	4	34	4	9	25	38	47	45	43	9	19	21	5	1	15	30	4	

5.1.4 Utilization Frequency of Facade Systems, Technical Solutions, and Occupant Requirement in Case Studies

As a result of this study, 14 facade systems, 25 technical solutions, and 16 occupant requirements, which were considered in the construction of case studies buildings, were listed in Table 5.1. This Table shows which facade systems, techniques, and requirements were used to design and construct each building facade. The numbers in the last row of the Table 5.1 show the total number of buildings that contained the item listed in the related columns with regard to the facade systems, technical solutions, and occupant requirements. This shows us which of them have been applied the most among the 49 buildings.

As shown in Figure 5.4, 14 facades of case studies have movable shading devices, which track the sun to decrease cooling load and prevent glare. Solar energy integrated facade is another important facade system, which was applied in 15 building facades. Rotating building as an innovative solution was utilized in nine buildings to maximize daylight, natural ventilation, thermal comfort in summer and winter.

Moreover, double skin facades were used in eight buildings as a useful system in winter and summer. Smart materials were utilized in the construction of two building facades only. One of these buildings is the conceptual design for Kinetower (Chapter 4, No. 32), and the other building that used smart materials to filter the air is Hospital Manuel Gea Gonzales (Chapter 4, No.17).

Facades with evaporative cooling were applied in the facades of only two case study buildings; Sony City Osaki (Chapter 4, No. 16), and Council House (Chapter 4, No. 23). However, the techniques that were used in these two buildings are completely different. One of them (Sony City Osaki) has used pipes on the facades, and the other one (Council House) has used shower towers on the facade.

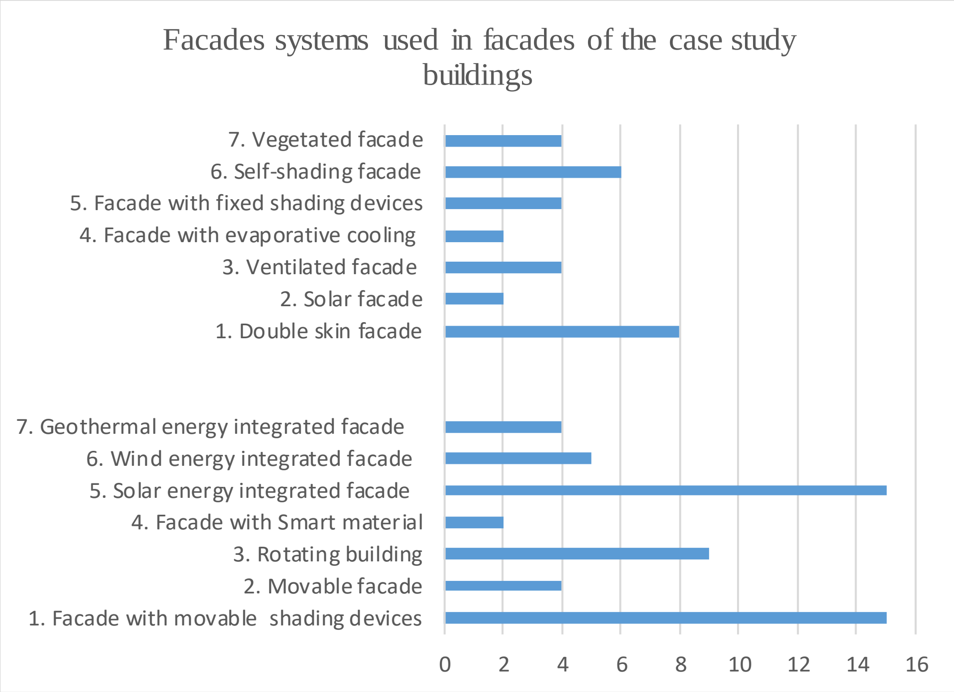


Figure 5.4 Frequency of facade systems identified in the 49 case study buildings (top systems are passive and bottom are active systems)

Figure 5.5 shows the techniques and their use frequency in case study buildings. The technical solution called "Optimizing the window to wall ratio" has been used in 38 buildings out of 49 with the highest magnitude. In 36 facades, operable windows were installed, which is the second most frequently used solution. The third most used technical solution is applying prefabricated and modular panels, which were utilized in the construction of 34 facades. The fourth most popular technique is integrating external shading devices applied in the facades of 27 buildings.

Moreover, using insulated glass, recyclable materials, tinted (colored) glass in the construction of 18, 16, and 13 facades, respectively, are other important techniques that help design an energy-efficient facade. The installation of photovoltaic panels on 15 facades shows the importance of generating electricity by utilizing solar energy. On the other hand, light shelves and solar collectors were used in just one building facade. Although none of the case study buildings were seen with solar collectors, it does not mean that this technique is not useful. Additional 15 buildings are presented in Appendix G, which use solar collectors on their facades.

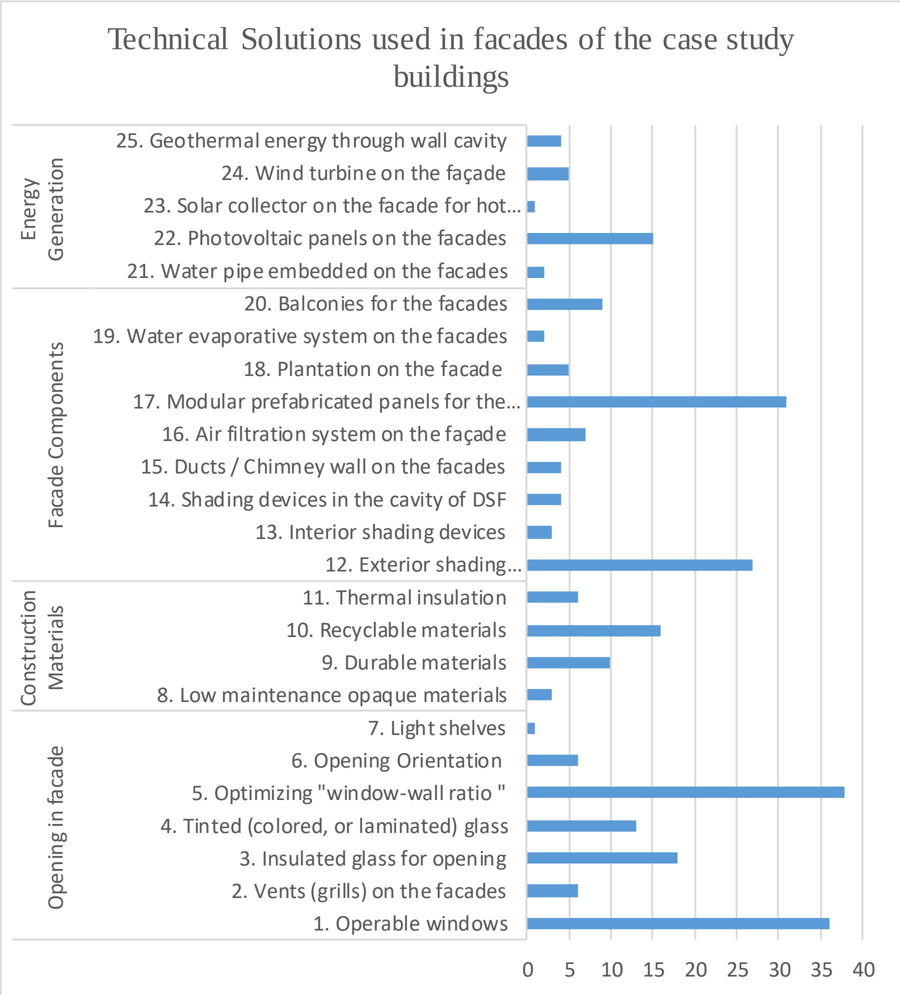


Figure 5.5 Frequency of technical solutions used in facades of the case study buildings

The bar chart in Figure 5.6 shows the requirements of occupants considered in the case study buildings. In this chart, we see that providing daylight, preventing glare, and having outside views are occupants' requirements fulfilled in 47, 45, and 43 buildings, respectively, through facade design. These three factors are related to facades' openings that are paid attention to in the construction of most facades by optimizing the "window to wall ratio" and having operable windows. Offering comfortable temperature in summer and natural ventilation in 38 and 34 buildings, respectively, shows that designing movable shading devices as a facade system is useful in providing satisfaction. The passive and active techniques were used in 30 buildings to decrease air pollutions caused by fossil fuels. Using an affordable system was mentioned only in one building. Also, night-time ventilation and utilizing low emission materials in facades were provided in four buildings.

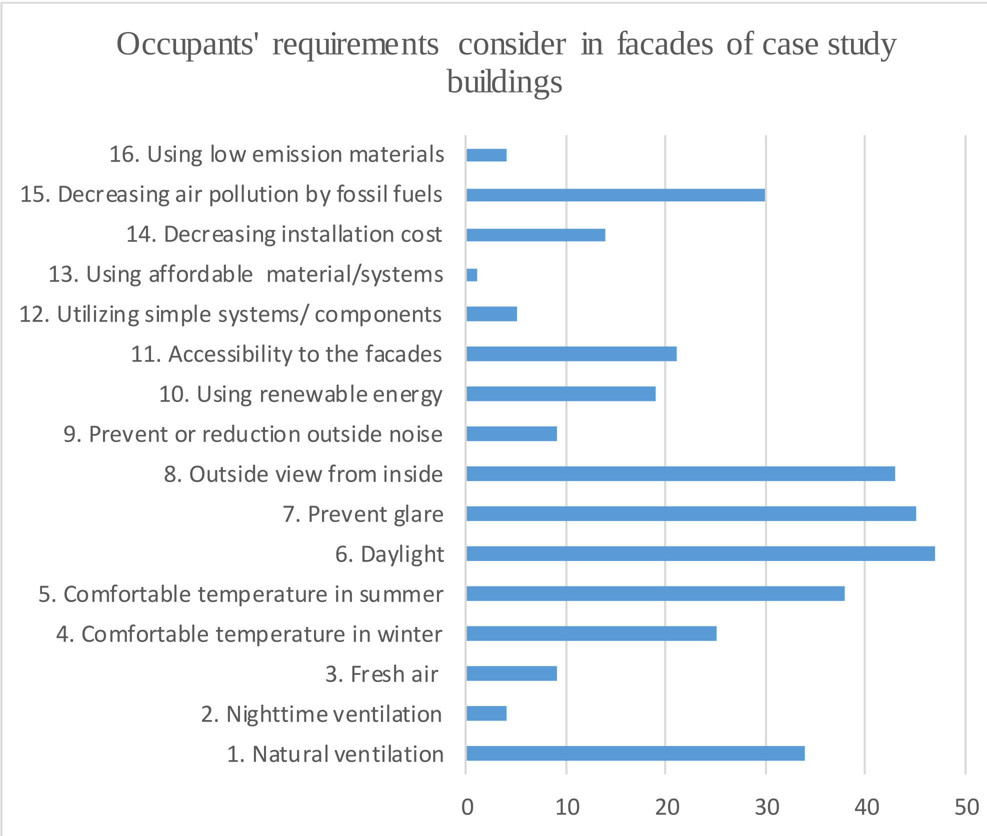


Figure 5.6 Frequency of occupant's requirements considered in the facades of 49 case study buildings

5.2 Questionnaire Surveys

In this section, the results of two questionnaire surveys will be discussed in three parts; responses to target questions, responses to occupants' requirements, and responses to questions on technical solutions.

5.2.1 Responses to Target Questions

The importance of primary and secondary targets was acquired from 202 participants, both designers (42 Iranian and 40 Turkish) and occupants (54 Iranian and 66 Turkish). As explained in Section 3.2.2.1, one question regarding the primary targets and three questions regarding the secondary targets were designed in both questionnaire surveys, shown in appendix A (question 4 to 7 in Questionnaire A1 and questions 1 to 4 in Questionnaire A2).

According to Section 3.1.2 in Table 3.1, the three or four targets were compared two by two in each question to determine the participants' preference. As explained in Section 3.2.2.1, three targets, including improving human comfort, decreasing cost, and decreasing environmental pollution, were compared in the questions regarding the primary targets. Furthermore, four targets were compared with each other in the first set of secondary targets questions. These targets were indoor air quality, thermal comfort, visual comfort, and acoustic comfort. The targets compared in the second set of secondary targets were decreasing cost of energy consumption through facade design, decreasing cost of facade construction, and decreasing cost of facade maintenance/cleaning. In the third set of secondary targets questions, decreasing air pollution, decreasing soil pollution, and decreasing light pollution were compared. Identifying the importance of secondary targets helped determine the facade systems and technologies that can be useful in designing efficient facades by reducing energy consumption. Additionally, the architects' preferences in integrating various renewable energy sources into the facade design was asked in the fifth question of the second questionnaire. (Appendix A, Questionnaire A2).

The results of the questionnaire survey regarding the primary and secondary targets are shown in Appendix B. According to these results, the bar charts were prepared to present the percentage of answers by participants' preferences (Figure 5.7, Figure 5.8, Figure 5.9).

The preferences of participants regarding the primary targets are shown in Figure 5.7. According to their answers about the comparison of human comfort and decreasing cost (first chart in Figure 5.7), 43% of Iranian architects, 50% of Turkish architects, 41% of Iranian occupants, and 44% of Turkish occupants declared that human comfort and decreasing cost are equally important. Also, 50% of Iranian architects, 35% of Turkish architects, 55% of Iranian occupants, and 44% of Turkish occupants believed that human comfort is more important than decreasing cost. On the other hand, 13% of Turkish architects preferred decreasing costs in comparison with human comfort. These data show that human comfort and decreasing cost are equally important for most participates.

Moreover, 49% of architects and 60% of occupants believed that human comfort and decreasing environmental pollution are equally important, according to the second chart in Figure 5.7. While the third chart shows that decreasing environmental pollution was preferred in comparison to decreasing cost by most participants (53% of architects and 56% of occupants). Slight differences in design targets' preference indicate that all three targets are of equal importance to the participants. Data from these responses were used in the AHP matrix to determine the priorities of three primary targets.

In Figure 5.8, the occupants' and architects' preferences are presented regarding the parameters of the human comfort target. The first chart of Figure 5.8 shows that air quality and thermal comfort are equally important (61% of participants). The second chart presents that thermal comfort and daylight importance is the same (59% of participants). The third chart illustrates that 45% of participants believed that thermal comfort is more important than acoustic comfort. In addition, 43% of the participants were convinced that thermal comfort and acoustic comfort are equally important.

In Figure 5.8, the fourth chart shows that air quality is as important as daylight according to 52% of the participants' opinions. As shown in the fifth chart, 57% of Iranian and Turkish architects and 68% of Turkish occupants believed that air quality is more important than acoustic comfort, while 48% of Iranian occupants declared both are equally important. In the sixth chart of Figure 5.8, Turkish occupants (64%) and Iranian architects (55%) preferred daylight compared to acoustic comfort, while 50% of Iranian occupants and 55% of Turkish architects believed that daylight is as important as acoustic comfort.

Figure 5.9 shows the priority of the second and third sets of secondary targets defined by architects and occupants from the two countries (Iranian and Turkish). The first and second charts present that decreasing cost of energy consumption is more important than decreasing the cost of maintenance and the cost of construction according to 61% and 57% of participants' opinions, respectively. In the fourth chart, around 40% of participants were convinced that decreasing the cost of maintenance and the cost of construction are equally important. While, 32% of participants believed that decreasing the cost of maintenance is important than the decreasing cost of construction.

The fourth chart shows that decreasing air pollution is as important as decreasing soil pollution according to 57% of the participants. Finally, as illustrated in the fifth and sixth charts, decreasing air and soil pollutions are more important than decreasing light pollution according to 69% and 72% of the participants, respectively.

The priorities of using renewable energies through the facade design for generating electricity are presented in Figure 5.10. According to Turkish and Iranian architects, solar energy (around 71% - 84%) is the most important renewable source to apply to the facades for electricity production in comparison with other energy sources. The second, third, and fourth places belong to the wind (24% - 33%), geothermal (17% - 32%), and hydro- energies (4% - 15%)

Question: Which parameter is more important for designing facades? Please select the appropriate answer according to your opinion/experience.

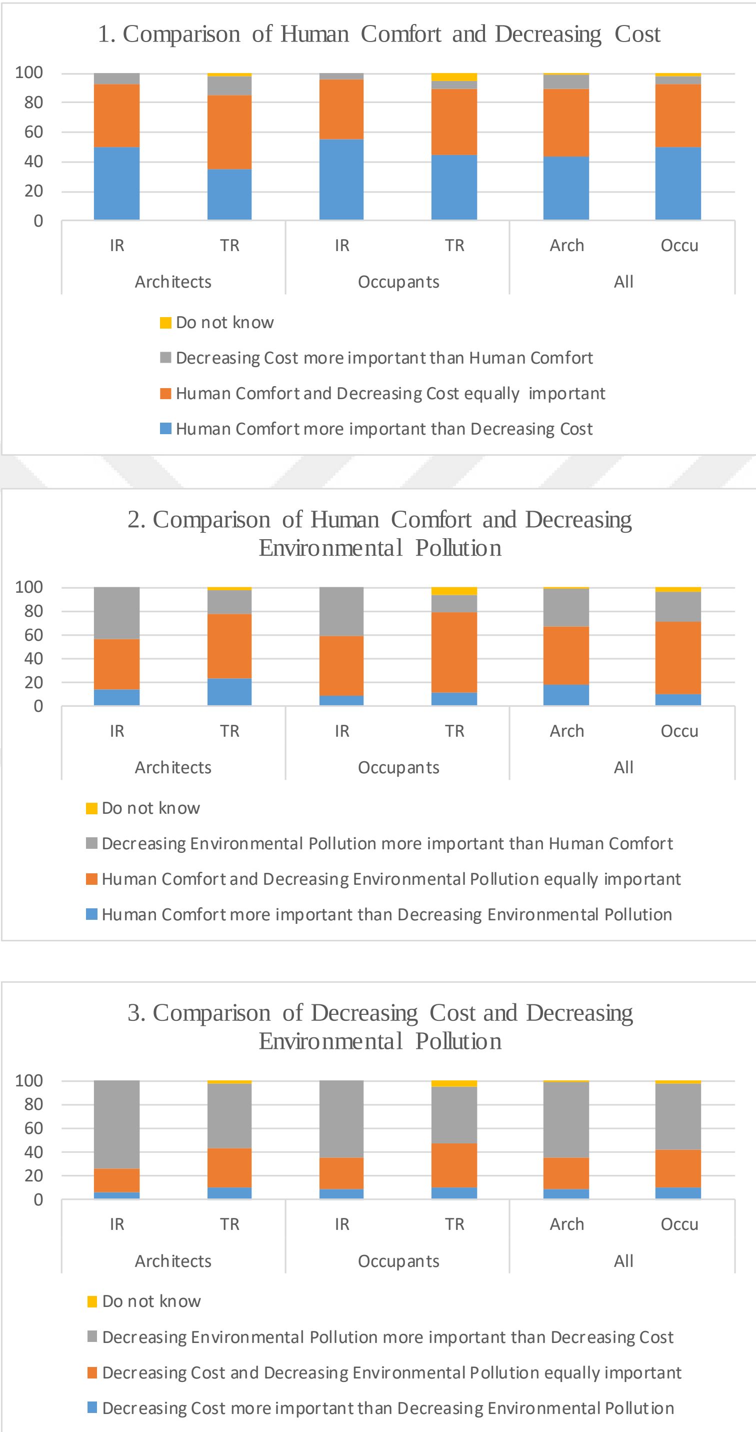


Figure 5.7 Participants’ preferences regarding primary targets

Question: Which parameter is more important to provide better indoor environment? Please select the appropriate one according to your opinion/experience.

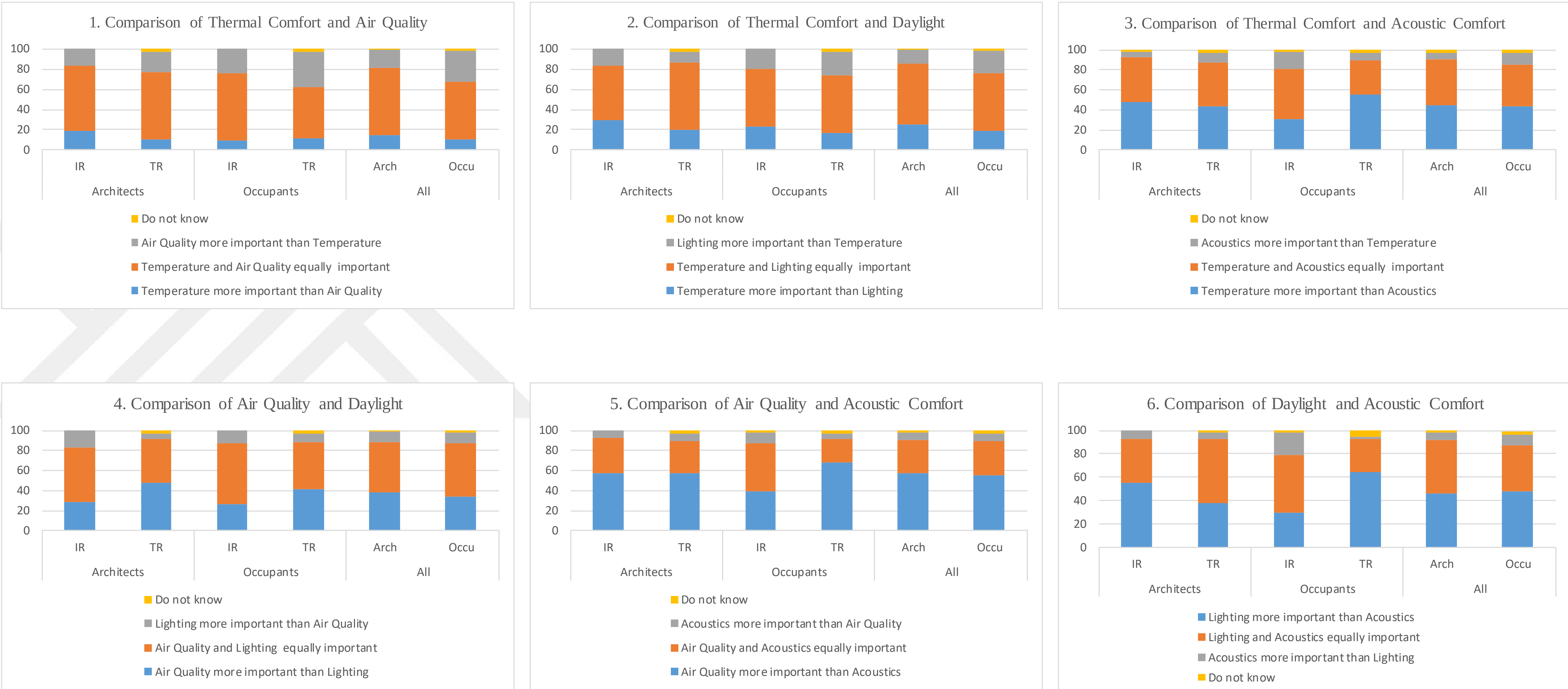


Figure 5.8 Importance of the first set of secondary targets according to participants' preferences

Question: Which parameter is more important in decreasing overall cost of building through facade design? Please select the appropriate answer according to your opinion/experience. (chart 1,2,3)

Question: Which parameter is more important in decreasing environmental pollution through facade design? Please select the appropriate answer according to your opinion/experience. (chart 4,5,6)

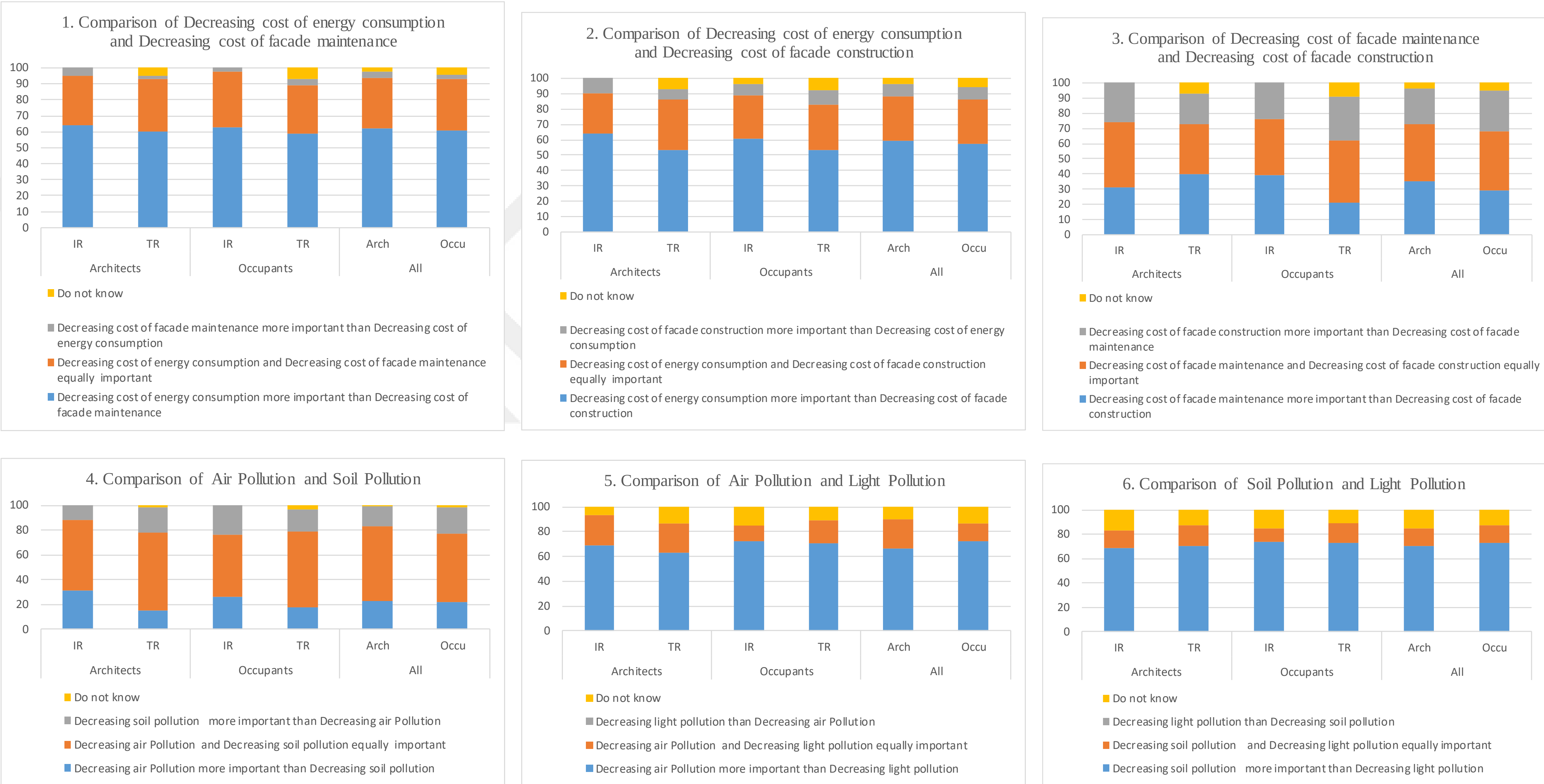


Figure 5.9 Importance of the second and third sets of secondary targets according to participants’ preferences

Question: Which types of renewable resources do you prefer for producing energy through the facade? Please select the appropriate answer according to your opinion/experience.

Figure 5.10 Importance of using renewable energy according to architects’ preferences

5.2.2 Responses to Occupants' Requirements Questions

One of the essential topics in buildings' design is responding to residents' needs to ensure their satisfaction and comfort. In this respect, features leading to residents' satisfaction and comfort have been investigated in 49 case study buildings. Section 3.2.2.2 explained how meeting the occupants' requirements helped us achieve the primary and secondary targets of designing appropriate facades. The 16 parameters that can satisfy occupants were obtained from analyzing the case study buildings (Figure 5.3). One more parameter was added from the literature review, which is soil pollution reduction by decreasing the construction waste. The lists of parameters that provide user satisfaction were formulated as questions to be asked from occupants in the first questionnaire survey.

Figure 5.11 presents the bar charts made by occupants' responses to 17 questions of the first survey regarding their requirements. The answers of occupants to their requirements are presented in Appendix C. According to the chart in Figure 5.11, for Iranian occupants, natural ventilation, daylight, and preventing outside noise were the three most important parameters by 78%, 76%, and 78%, respectively. In contrast, having a comfortable temperature in winter by 78% was the most important parameter for Turkish occupants. Since Iran has its own petroleum and gas production, the price of energy in Iran is much lower than in Turkey. Therefore, Iranian occupants preferred to have more natural ventilation, daylight, and acoustic comfort because energy bills are low in Iran. While for Turkish people having comfortable temperatures in winter without paying more was their first preference. However, decreasing air pollution and using renewable energy sources were another important parameter for both nations by 63% to 70%. The less important parameters for occupants were using simple and affordable systems as well as preventing glare and decreasing installation costs by 18%, 21%, and 16%, shown in the bar chart in Figure 5.11. In order to use information from the first questionnaire survey regarding occupants' requirements in the first HoQ matrix, the responses of occupants to their requirements were weighted. Then their weights were calculated as percentages according to the method described in Section 3.2.2.4.

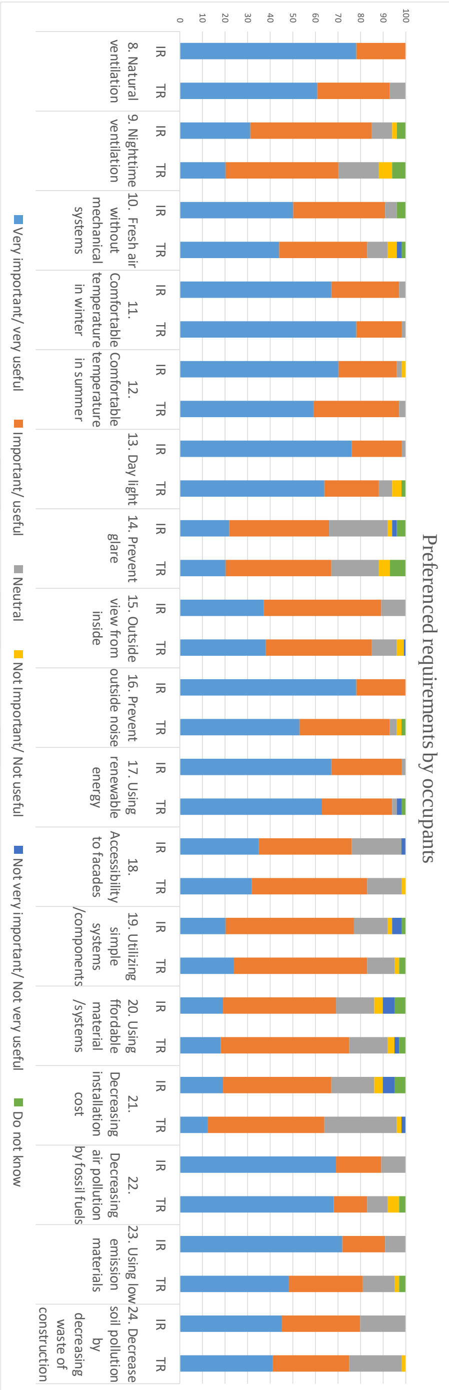


Figure 5.11 Requirements preferences according to responses of Iranian and Turkish occupants

Finally, the occupants' requirements, their weighted preferences, and percentages of weighted answers were presented in the first, second, and third columns of the first HoQ matrix for further calculations.

5.2.3 Responses to Technical Solutions Questions

For designing questions about technical solutions, 41 technologies, which were acquired from the analysis of case studies (Figure 5.2) and literature review, were asked in the second questionnaire survey conducted with the architects. These techniques are categorized into four groups, as given in Figure 5.12.

It should be noted that these 41 solutions were reclassified into eight groups which are Indoor Air Quality, Thermal Comfort (in winter), Thermal Comfort (in summer), Visual Comfort, Acoustic Comfort, Energy Generation (renewable energy), Decreasing Construction and Maintenance Cost, and Decreasing Environmental Pollution. In order to draw the architects' attention to the applications of technical solutions for obtaining various goals, some questions were repeated in several groups, as presented in Appendix A (Questionnaire A2). For example, "window to wall ratio" (WWR) can be an effective parameter in optimizing thermal comfort (both in summer and winter), daylight, and decreasing cost. The responses of architects to questions regarding the technical solutions in the second survey are presented in Appendix D. The results of the second questionnaire survey conducted with architects were presented as bar charts in Figure 5.13 to Figure 5.17 as bar charts. As explained in the method section (Section 3.2.2.4), the second questionnaire's responses were weighted for their importance/usefulness to be put in the first row of the first HoQ. Their percentages were also calculated to be inserted in the second row of the mentioned matrix to help us define the correlation between occupants' requirements and technical solutions. It should be noted that these weighted numbers and their percentages have not been used in the HoQ matrix calculations. They are used only to determine the correlation between the occupants' requirements and technical solutions.

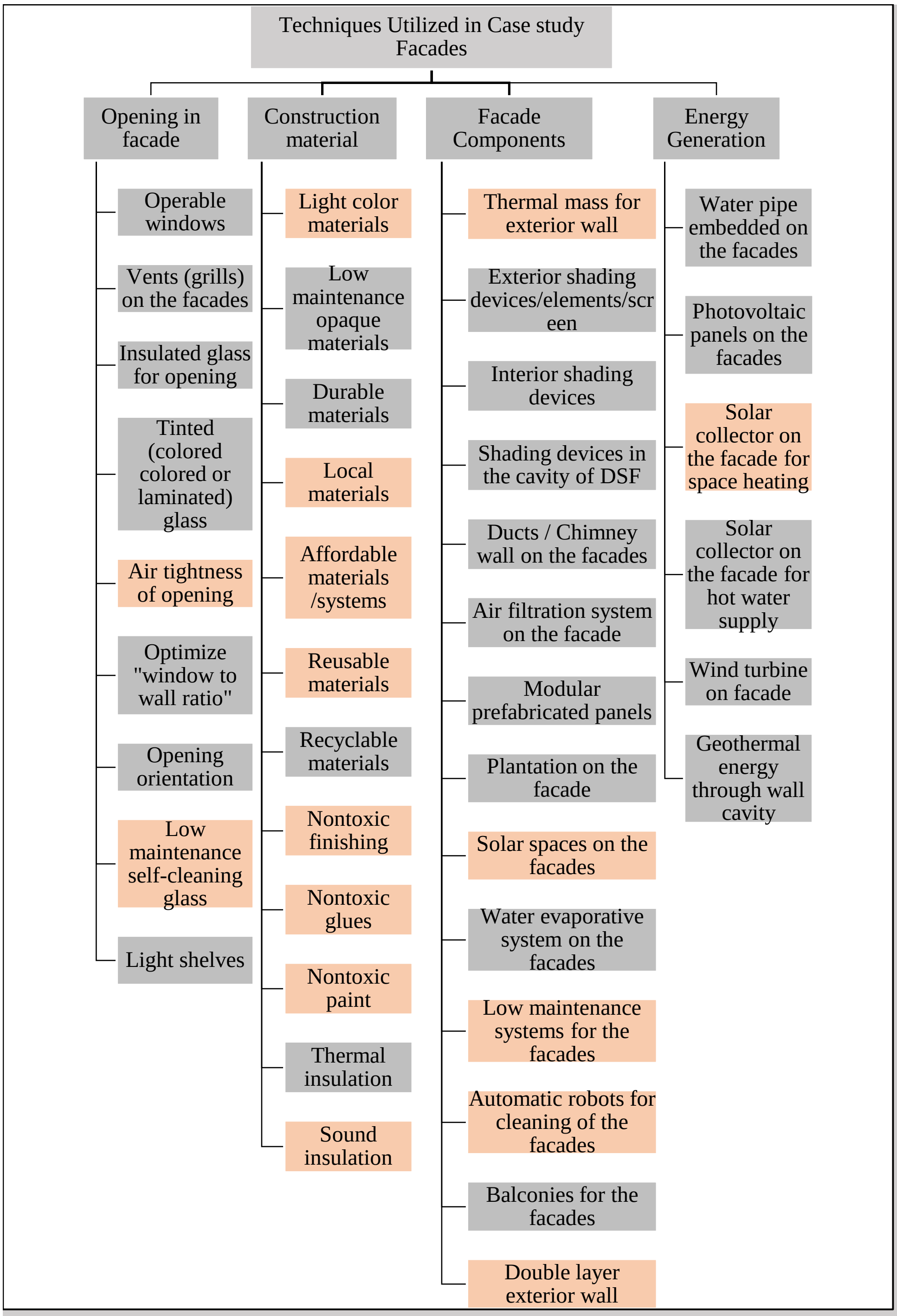


Figure 5.12 The technical solutions included in the second questionnaire survey for architects.

☐ Acquired from the analysis of case studies ☐ Obtained from literature review

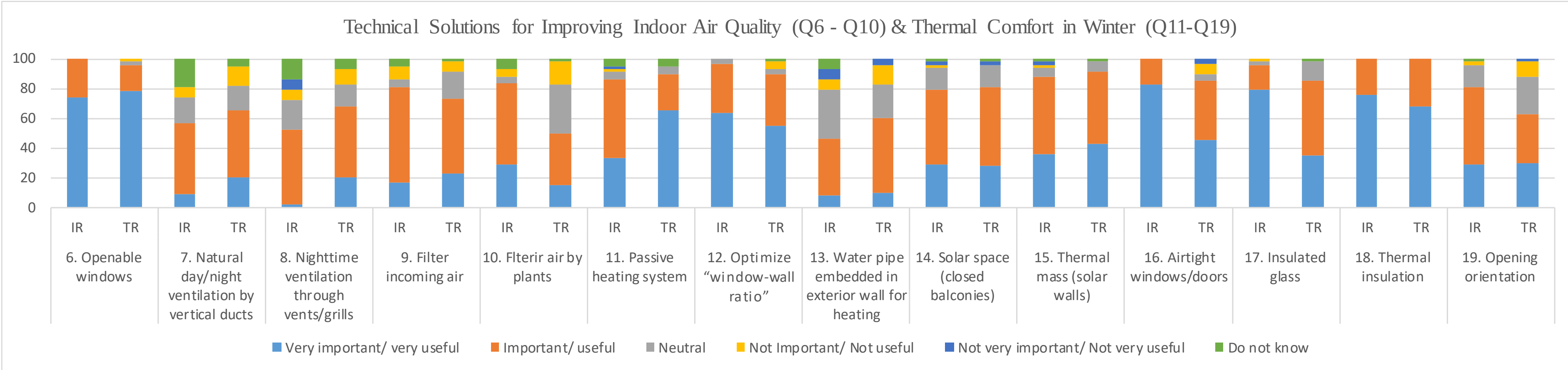


Figure 5.13 Percentages of technical solutions for indoor air quality and thermal comfort in winter according to responses of Iranian and Turkish architects' preferences

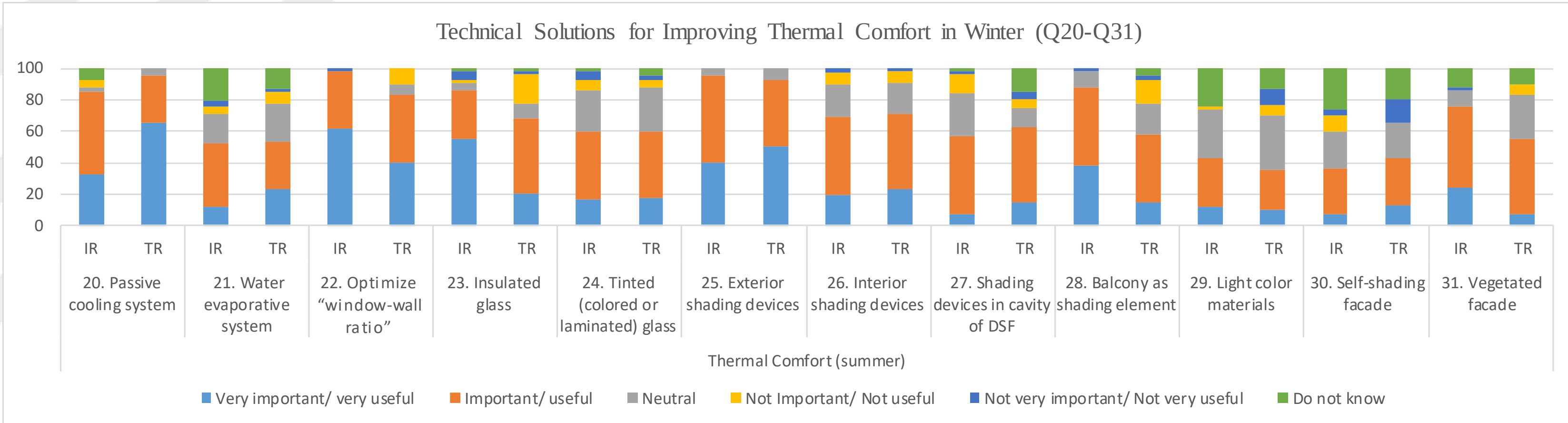


Figure 5.14 Percentages of technical solutions for thermal comfort in summer according to responses of Iranian and Turkish architects' preferences

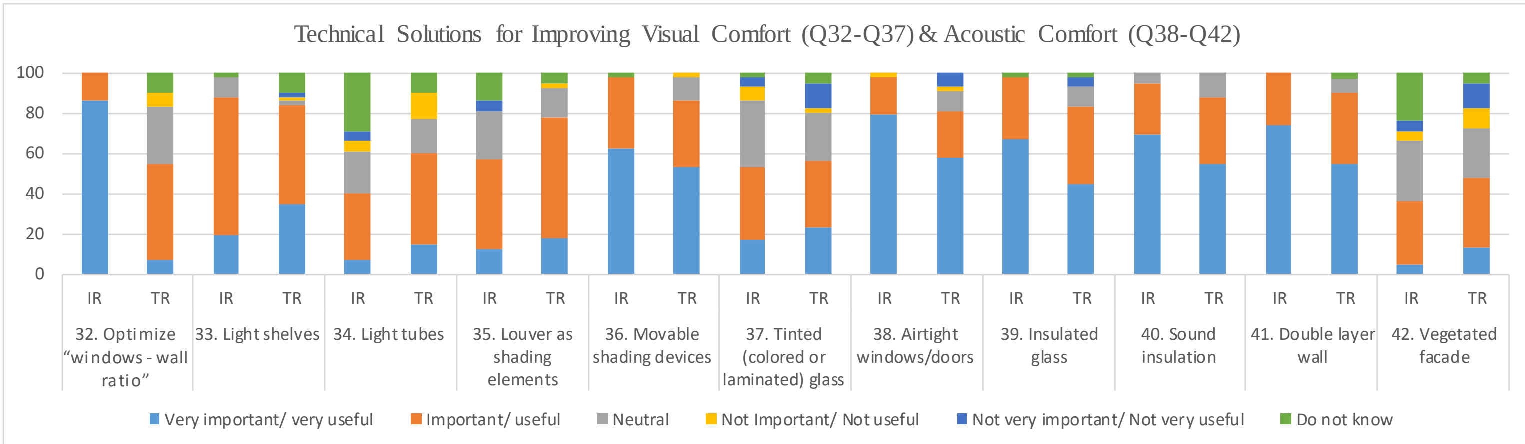


Figure 5.15 Percentages of technical solutions for improving visual and acoustic comforts according to responses of Iranian and Turkish architects' preferences

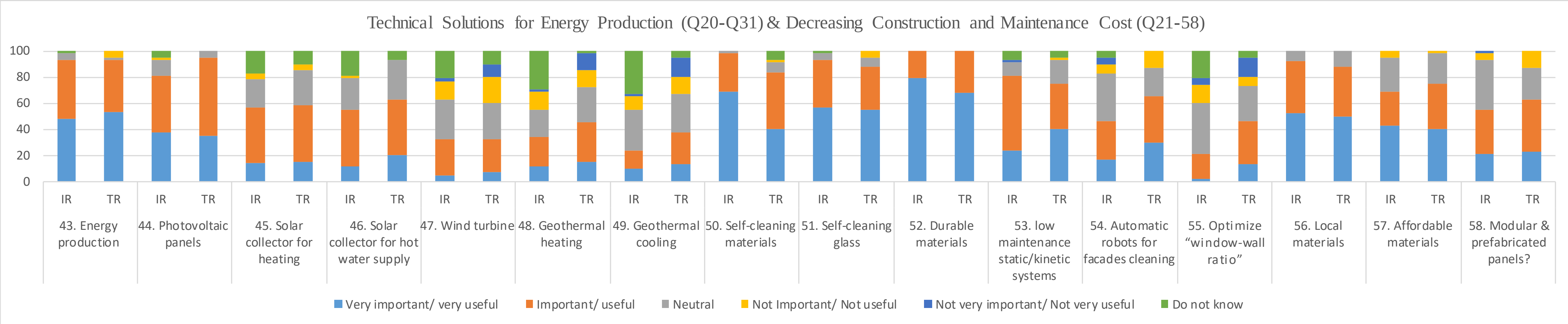


Figure 5.16 Percentages of technical solutions for energy production and decreasing construction and maintenance cost according to responses of Iranian and Turkish architects' preferences

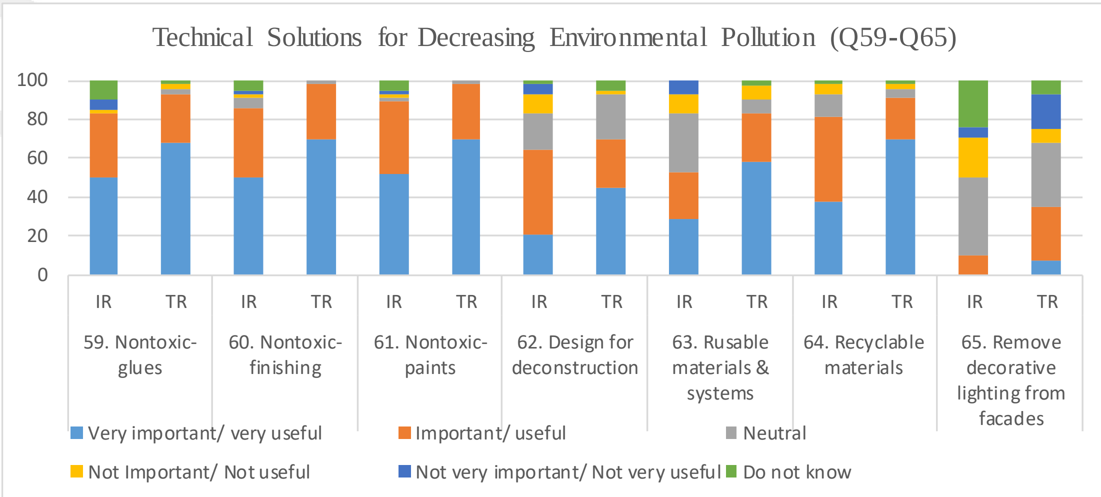


Figure 5.17 Percentages of technical solutions for decreasing environmental pollutions according to responses of Iranian and Turkish architects' preferences

Moreover, the mean values were calculated for repeated questions, as explained in Section 3.2.2.4, in order to be inserted into the first HoQ matrix. Thus, 41 technical solutions from case study buildings and literature review, presented in Figure 5.12, were put in the first HoQ matrix to calculate their priorities.

5.3 QFD Model

The first important point to consider in utilizing the QFD method is to have awareness about the production or design strategy in order to define the targets of projects. For this purpose, experts and engineers have a brainstorming meeting to identify, discuss, and determine the targets. Then, they use the AHP matrix to determine the priorities of the selected targets.

According to the targets, the team formulates questions to determine the users' requirements. As explained before, the main strategy in the QFD method is considering the needs or requirements of users in the design and production of the commodity. For designing questions, again, they have a brainstorming meeting, usually using the KJ method. In this method, each member of the QFD team writes his/her questions or thoughts, then the team members discuss the questions and make a questionnaire. The questionnaire survey results are put in the preplan matrix to be reweighted by considering the manufacturing of the product by other factories. The team has another brainstorming meeting in the same way to define the product characteristics, to be inserted into the HoQ matrix, in order to define their priorities. In this research, the QFD method has been adapted according to the steps in the building facades' design process. In other words, in the proposed method, instead of a QFD team, architects' and occupants' opinions have been taken to identify the primary and secondary design targets for designing appropriate facades. Also, 82 architects were involved in deciding the facade system's design instead of considering the opinion of a QFD team. Therefore, their combined experience has been used with more precision than brainstorming. The other point is about using a preplan matrix; it is suggested to use a preplan matrix to reweight the occupants' requirements according to standards and location. As explained before, the important point is how we can use the QFD method to design facades in this dissertation. Therefore, a certain location is not defined here; and so a preplan matrix becomes redundant, and the occupants' weighted preferences for their requirements have been used directly in the house of quality matrix. In this section, five AHP matrices, which defined the primary and secondary targets' priorities and preferences for renewable resources to be applied in facade systems, are presented to discuss. Also, two HoQ matrices that were calculated in order to determine the priority of technical solutions and facade systems are presented and discussed. The priorities of the mentioned parameters are the data obtained as the output of the QFD matrices.

5.3.1 Targets Matrices

To make AHP strategic targets matrices, it is necessary to calculate how much each target is important more than the others, in each target question, according to the method explained in Section 3.2.3.1. Accordingly, for each group of targets one table was prepared to show the calculation and degree of importance of targets compared two by two, according to both questionnaire surveys' results. Each table consists of four columns. In the first column, the compared targets were inserted. In the second column, the name of participants groups was put. In the third column, the importance of targets was calculated according to the responses, as explained in Section 3.2.3.1. In the fourth column, the importance of targets was determined according to the scale of the AHP matrix (scale of 9). The results of each survey were calculated separately. It means that for comparing two targets, there are three rows. In the first one, the importance was calculated according to the first questionnaire survey conducted with the occupants. In the second row, the importance between two targets was defined by the results of the second questionnaire surveys conducted with architects, and in the third row, the degree of importance between two targets was defined by combining the data from the two surveys.

Table 5.2 illustrates the degree of importance of primary targets by comparing them two by two. Table 5.3, Table 5.4, and Table 5.5 show the degree of importance for three secondary targets group. These tables are made by using responses from participants regarding primary and secondary design targets, as shown in Appendix B. According to the last columns in these tables, the importance of targets in the rows to the columns targets are defined in the body of the AHP matrices.

Table 5.2 Calculating the degree of importance/priority of the three primary targets for occupants and architects separately and combined

		(A>B)-(A<B)	Degree of Importance (priority of targets)
A=Human Comfort B=Decreasing Cost	Occupants	50%-5%= 45%	A is more important than B, (5)
	Architects	43%-10%= 33%	A is more important than B, (5)
	Total	47%-7%= 40%	A is more important than B, (5)
A=Human Comfort B=Decreasing Environmental Pollution	Occupants	11%-26%= -15%	A is slightly less important than B, (0.33)
	Architects	18%-32%= -13%	A is slightly less important than B, (0.33)
	Total	14%-28%= -14%	A is slightly less important than B, (0.33)
A=Decreasing Cost B=Decreasing Environmental Pollution	Occupants	10%-56%= -45%	A is less important than B, (0.2)
	Architects	9%-65%= -56%	A is much less important than B, (0.14)
	Total	9%-59%= -50%	A is less important than B, (0.2)

Table 5.3 Calculating the degree of importance/priority of secondary targets for the primary target of human comfort

		(A>B)-(A<B)	Degree of Importance (priority of targets)
A= Temperature B=Air Quality	Occupants	10%-30%= -20%	A is slightly less important than B, (0.33)
	Architects	15%-18%= -3%	A is slightly less important than B, (0.33)
	Total	12%-25%= -13%	A is slightly less important than B, (0.33)
A= Temperature B=Lighting	Occupants	19%-22%= -3%	A is slightly less important than B, (0.33)
	Architects	24%-13%= 11%	A is slightly more important than B, (3)
	Total	21%-18% =3%	A is slightly less important than B, (0.33)
A= Temperature B=Acoustics	Occupants	44%-12%=32.5%	A is more important than B, (5)
	Architects	45%-7%= 38%	A is more important than B, (5)
	Total	45%-10%= -35%	A is more important than B, (5)
A= Air Quality B=Lighting	Occupants	34%-11%= 23%	A is slightly more important than B, (3)
	Architects	38%-11%= 27%	A is more important than B, (5)
	Total	36%-11%= 25%	A is slightly more important than B, (3)
A= Air Quality B=Acoustics	Occupants	55%-8%= 47%	A is more important than B, (5)
	Architects	57%-7%= 50%	A is more important than B, (5)
	Total	56%-7%= 49%	A is more important than B, (5)
A= Lighting B=Acoustics	Occupants	48%-9%= 39%	A is more important than B, (5)
	Architects	46%-6%= 40%	A is more important than B, (5)
	Total	48%-8%= 40%	A is more important than B, (5)

Table 5.4 Calculating the degree of importance/priority of secondary targets for the primary target of decreasing cost

		(A>B)-(A<B)	Degree of Importance (priority of targets)
A=Decreasing Cost of Energy Consumption through facade design. B=Decreasing Cost of Facade Maintenance /cleaning	Occupants	50%-5%= 45%	A is more important than B, (5)
	Architects	43%-10%= 33%	A is more important than B, (5)
	Total	47%-7%= 40%	A is more important than B, (5)
A=Decreasing cost of energy consumption through facade design B=Decreasing Cost of Facade Construction	Occupants	11%-26%= -15%	A is slightly less important than B, (0.33)
	Architects	18%-32%= -13%	A is slightly less important than B, (0.33)
	Total	14%-28%= -14%	A is slightly less important than B, (0.33)
A=Decreasing cost of facade maintenance /cleaning B=Decreasing cost of facade construction (DCFC)	Occupants	10%-56%= -45%	A is less important than B, (0.2)
	Architects	9%-65%= -56%	A is much less important than B, (0.14)
	Total	9%-59%= -50%	A is less important than B, (02)

Table 5.5 Calculating the degree of importance/priority of secondary targets for the primary target of decreasing environmental pollution

		(A>B)-(A<B)	Degree of Importance (priority of targets)
A=Decreasing air Pollution B=Decreasing soil pollution	Occupants	22%-21%= 1%	A & B are equally important (1)
	Architects	23%-16%= 7%	A is slightly more important than B, (3)
	Total	22%-19%= 3%	A is slightly more important than B, (3)
A=Decreasing air Pollution B=Decreasing light pollution	Occupants	72%-0= 72%	A is much more important than B, (7)
	Architects	66%-0= 66%	A is much more important than B, (7)
	Total	69%-0= 69%	A is much more important than B, (7)
A=Decreasing soil pollution B=Decreasing light pollution	Occupants	73%-0= 73%	A is much more important than B, (7)
	Architects	70%-0= 70%	A is much more important than B, (7)
	Total	72%-0= 72%	A is much more important than B, (7)

The degree of importance of the primary and secondary targets were used in calculations of the AHP strategic targets matrices. In order to determine the occupants' and architects' opinions regarding the priority of targets separately for each targets group, three AHP matrices were calculated. The first and second ones were calculated by using occupants' and architects' responses, individually. In the third one, the priority of targets was defined by using sum of occupants' and architects' responses. Table 5.6 presents the priorities of primary targets for occupants, architects, and both together in the three AHP matrices. Table 5.7, Table 5.8, and Table 5.9 show the priorities of the secondary targets for human comfort, decreasing cost, and decreasing environmental pollutions.

Table 5.6 AHP matrices for defining the priorities of the primary targets.

AHP PRIMARY STRATEGIC TARGET MATRIX 1 (Iranian & Turkish Occupants)

1= the row is equally important as the column
3= slightly more important
5= more important
7= much more important
9= very much more important
0.33= slightly less important
0.20= less important
0.14=much less important
0.11= very much less important

			Targets A	Targets B	Targets C	a	b	c		
			Human Comfort	Decreasing Cost	Decreasing Environmental Pollutio	Normalized Assessment			Absolute Weight	Targets Priority
Targets	1	Human Comfort	1.00	5.00	0.33	0.24	0.45	0.22	0.91	30.28
	2	Decreasing Cost	0.20	1.00	0.20	0.05	0.09	0.13	0.27	8.97
	3	Decreasing Environmental Pollution	3.00	5.00	1.00	0.71	0.45	0.65	1.82	60.75
		Total	4.20	11.00	1.53	1.00	1.00	1.00	3.00	100.00

AHP PRIMARY STRATEGIC TARGET MATRIX 1 (Iranian & Turkish Architects)

1= the row is equally important as the column
3= slightly more important
5= more important
7= much more important
9= very much more important
0.33= slightly less important
0.20= less important
0.14=much less important
0.11= very much less important

			Targets A	Targets B	Targets C	a	b	c		
			Human Comfort	Decreasing Cost	Decreasing Environmental Pollutio	Normalized Assessment			Absolute Weight	Targets Priority
Targets	1	Human Comfort	1.00	5.00	0.33	0.24	0.38	0.22	0.85	28.24
	2	Decreasing Cost	0.20	1.00	0.14	0.05	0.08	0.10	0.22	7.33
	3	Decreasing Environmental Pollution	3.00	7.00	1.00	0.71	0.54	0.68	1.93	64.43
		Total	4.20	13.00	1.47	1.00	1.00	1.00	3.00	100.00

AHP PRIMARY STRATEGIC TARGET MATRIX 1 (Occupants & Architects)

1= the row is equally important as the column
3= slightly more important
5= more important
7= much more important
9= very much more important
0.33= slightly less important
0.20= less important
0.14=much less important
0.11= very much less important

			Targets A	Targets B	Targets C	a	b	c		
			Human Comfort	Decreasing Cost	Decreasing Environmental Pollutio	Normalized Assessment			Absolute Weight	Targets Priority
Targets	1	Human Comfort	1.00	5.00	0.33	0.24	0.45	0.22	0.91	30.28
	2	Decreasing Cost	0.20	1.00	0.20	0.05	0.09	0.13	0.27	8.97
	3	Decreasing Environmental Pollution	3.00	5.00	1.00	0.71	0.45	0.65	1.82	60.75
		Total	4.20	11.00	1.53	1.00	1.00	1.00	3.00	100.00

Table 5.7 AHP matrices for defining the priorities of the secondary targets for human comfort.

AHP SECONDARY STRATEGIC TARGET MATRIX 2: HUMAN COMFORT (Iranian & Turkish Occupants)												
1= the row is equally important as the column			Targets								Absolute Weight	Targets Priority
3= slightly more important			A	B	C	D	a	b	c	d		
5= more important			Indoor Air Quality	Thermal Comfort	Visual Comfort	Acoustic Comfort	Normalized Assessment					
7= much more important												
9= very much more important												
0.33= slightly less important												
0.20= less important												
0.14=much less important												
0.11= very much less important												
Targets	1	Indoor Air Quality	1.00	3.00	3.00	5.00	0.54	0.66	0.42	0.31	1.93	48.23
	2	Thermal Comfort	0.33	1.00	3.00	5.00	0.18	0.22	0.42	0.31	1.13	28.18
	3	Visual Comfort	0.33	0.33	1.00	5.00	0.18	0.07	0.14	0.31	0.70	17.54
	4	Acoustic Comfort	0.20	0.20	0.20	1.00	0.11	0.04	0.03	0.06	0.24	6.05
		Total	1.86	4.53	7.20	16.00	1.00	1.00	1.00	1.00	4.00	100.00

AHP SECONDARY STRATEGIC TARGET MATRIX 2: HUMAN COMFORT (Iranian & Turkish Architects)												
1= the row is equally important as the column			Targets								Absolute Weight	Targets Priority
3= slightly more important			A	B	C	D	a	b	c	d		
5= more important			Indoor Air Quality	Thermal Comfort	Visual Comfort	Acoustic Comfort	Normalized Assessment					
7= much more important												
9= very much more important												
0.33= slightly less important												
0.20= less important												
0.14=much less important												
0.11= very much less important												
Targets	1	Indoor Air Quality	1.00	3.00	5.00	5.00	0.58	0.66	0.54	0.31	2.10	52.41
	2	Thermal Comfort	0.33	1.00	3.00	5.00	0.19	0.22	0.33	0.31	1.05	26.25
	3	Visual Comfort	0.20	0.33	1.00	5.00	0.12	0.07	0.11	0.31	0.61	15.24
	4	Acoustic Comfort	0.20	0.20	0.20	1.00	0.12	0.04	0.02	0.06	0.24	6.10
		Total	1.73	4.53	9.20	16.00	1.00	1.00	1.00	1.00	4.00	100.00

AHP SECONDARY STRATEGIC TARGET MATRIX 2: HUMAN COMFORT (Occupants & Architects)												
1= the row is equally important as the column			Targets								Absolute Weight	Targets Priority
3= slightly more important			A	B	C	D	a	b	c	d		
5= more important			Indoor Air Quality	Thermal Comfort	Visual Comfort	Acoustic Comfort	Normalized Assessment					
7= much more important												
9= very much more important												
0.33= slightly less important												
0.20= less important												
0.14=much less important												
0.11= very much less important												
Targets	1	Indoor Air Quality	1.00	3.00	3.00	5.00	0.54	0.66	0.42	0.31	1.93	48.23
	2	Thermal Comfort	0.33	1.00	3.00	5.00	0.18	0.22	0.42	0.31	1.13	28.18
	3	Visual Comfort	0.33	0.33	1.00	5.00	0.18	0.07	0.14	0.31	0.70	17.54
	4	Acoustic Comfort	0.20	0.20	0.20	1.00	0.11	0.04	0.03	0.06	0.24	6.05
		Total	1.86	4.53	7.20	16.00	1.00	1.00	1.00	1.00	4.00	100.00

Table 5.8 AHP matrices for defining the priorities of the secondary targets for decreasing cost.

AHP SECONDARY STRATEGIC TARGET MATRIX 3: DECREASING COST (Iranian & Turkish Occupants)										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing cost of energy consumption through facade desig	Decreasing cost of facade maintenance/cleaning	Decreasing cost of facade construction	Normalized Assessment				
Targets	1	Decreasing cost of energy consumption through facade design	1.00	7.00	5.00	0.75	0.84	0.56	2.14	71.41
	2	Decreasing cost of facade maintenance/cleaning	0.14	1.00	3.00	0.10	0.12	0.33	0.56	18.60
	3	Decreasing cost of facade construction	0.20	0.33	1.00	0.15	0.04	0.11	0.30	10.00
		Total	1.34	8.33	9.00	1.00	1.00	1.00	3.00	100.00

AHP SECONDARY STRATEGIC TARGET MATRIX 3: DECREASING COST (Iranian & Turkish Architectss)										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing cost of energy consumption through facade desig	Decreasing cost of facade maintenance/cleaning	Decreasing cost of facade construction	Normalized Assessment				
Targets	1	Decreasing cost of energy consumption through facade design	1.00	7.00	5.00	0.75	0.84	0.56	2.14	71.41
	2	Decreasing cost of facade maintenance/cleaning	0.14	1.00	3.00	0.10	0.12	0.33	0.56	18.60
	3	Decreasing cost of facade construction	0.20	0.33	1.00	0.15	0.04	0.11	0.30	10.00
		Total	1.34	8.33	9.00	1.00	1.00	1.00	3.00	100.00

AHP SECONDARY STRATEGIC TARGET MATRIX 3: DECREASING COST (Occupants & Architectss)										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing cost of energy consumption through facade desig	Decreasing cost of facade maintenance/cleaning	Decreasing cost of facade construction	Normalized Assessment				
Targets	1	Decreasing cost of energy consumption through facade design	1.00	7.00	5.00	0.75	0.84	0.56	2.14	71.41
	2	Decreasing cost of facade maintenance/cleaning	0.14	1.00	3.00	0.10	0.12	0.33	0.56	18.60
	3	Decreasing cost of facade construction	0.20	0.33	1.00	0.15	0.04	0.11	0.30	10.00
		Total	1.34	8.33	9.00	1.00	1.00	1.00	3.00	100.00

Table 5.9 AHP matrices for defining the priorities of the secondary targets for decreasing environmental pollution.

AHP SECONDARY STRATEGIC TARGET MATRIX 4: DECREASING ENVIRONMENTAL POLLUTION (Iranian & Turkish Occupants)										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing air pollution	Decreasing soil pollution	Decreasing light pollutio	Normalized Assessment				
Targets	1	Decreasing air pollution	1.00	1.00	7.00	0.47	0.47	0.47	1.40	46.71
	2	Decreasing soil pollution	1.00	1.00	7.00	0.47	0.47	0.47	1.40	46.71
	3	Decreasing light pollution	0.14	0.14	1.00	0.07	0.07	0.07	0.20	6.58
		Total	2.14	2.14	15.00	1.00	1.00	1.00	3.00	100.00

AHP SECONDARY STRATEGIC TARGET MATRIX 4: DECREASING ENVIRONMENTAL POLLUTION (Iranian & Turkish Architects)										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing air pollution	Decreasing soil pollution	Decreasing light pollutio	Normalized Assessment				
Targets	1	Decreasing air pollution	1.00	3.00	7.00	0.68	0.72	0.47	1.87	62.39
	2	Decreasing soil pollution	0.33	1.00	7.00	0.22	0.24	0.47	0.93	31.09
	3	Decreasing light pollution	0.14	0.14	1.00	0.10	0.03	0.07	0.20	6.52
		Total	1.47	4.14	15.00	1.00	1.00	1.00	3.00	100.00

AHP SECONDARY STRATEGIC TARGET MATRIX 4: DECREASING ENVIRONMENTAL POLLUTION (Occupants & Architects)										
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important			Targets						Absolute Weight	Targets Priority
			A	B	C	a	b	c		
			Decreasing air pollution	Decreasing soil pollution	Decreasing light pollutio	Normalized Assessment				
Targets	1	Decreasing air pollution	1.00	3.00	7.00	0.68	0.72	0.47	1.87	62.39
	2	Decreasing soil pollution	0.33	1.00	7.00	0.22	0.24	0.47	0.93	31.09
	3	Decreasing light pollution	0.14	0.14	1.00	0.10	0.03	0.07	0.20	6.52
		Total	1.47	4.14	15.00	1.00	1.00	1.00	3.00	100.00

The priorities of primary and secondary targets as the results of the calculation of the AHP matrices were illustrated in four bar charts (Figure 5.18). The first bar chart illustrates the priority of primary targets, and the other three charts show the priority of secondary targets.

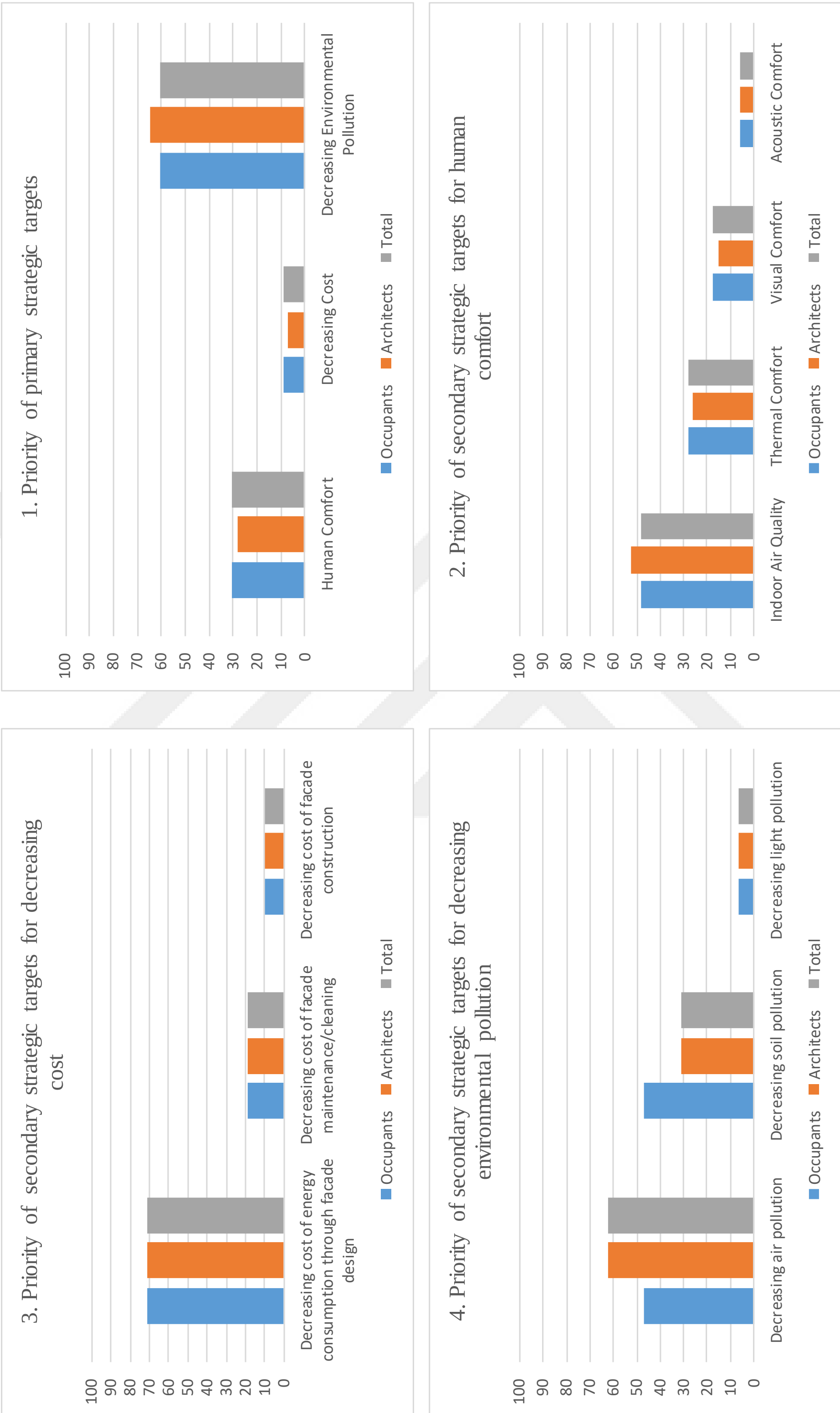


Figure 5.18 Priority of primary and secondary targets of research

As shown in the first chart, decreasing environmental pollution is the first priority of occupants and architects by around 60%. Improving human comfort by 30% is in the second place, and decreasing cost by 10% is in the third place. The important point is that decreasing environmental pollution is in the first place with a big difference compared to improving human comfort and decreasing the cost. In the second chart, improving indoor air quality by around 50%, thermal comfort by around 27%, visual comfort by around 17%, and acoustic comfort by 6% have first, second, third, and fourth priorities. In the third chart, decreasing cost of energy consumption through facade design by 70% is the most important priority to occupants and architects. Decreasing cost of facade maintenance by 20% and decreasing cost of construction by 10% are in the second and third places. In the fourth chart, decreasing light pollution by 6% is the least important to architects and occupants. For architects, decreasing air pollution by 60% is more important than decreasing soil pollution by 30%, while for the occupants, decreasing soil pollution by 47% and decreasing air pollution by 47%. have equal importance.

The results show that there is a close relationship between the first preference of each group of targets. Participants believe that environmental pollution should be considered in designing efficient facades for buildings in order to have fresh air for increasing air quality and decreasing air pollution by reducing of energy consumption (fossil fuels) through the facade.

Therefore, it can be concluded that in order to reduce air pollution and have fresh air, the consumption of fossil fuels should be reduced through active and passive facade designs, which is the target of the dissertation. After defining the research targets, the next step is to decide how to reduce fossil fuel consumption by buildings. One way to reduce fossil fuel consumption is to use renewable energy sources on building facades, as explained in the literature review. To know which renewable energy sources can easily be integrated into the facades, their application on the facades was asked in the second questionnaire survey conducted with architects (Appendix A, Questionnaire A2, question 5). Also, the information about renewable resources and their application was given in the literature review.

To define the priority of renewable energies that can be applied on the facades, Table 5.10 was prepared by using the data from the architects' responses. Then, after calculating the degree of importance for targets in Table 5.10, the AHP renewable energy matrix (Table 5.11) was calculated by using data from Table 5.10.

Table 5.10 Calculating degree of importance/priority of renewable energy for application on the facades

	(A>B)-(A<B)	Degree of Importance (priority of targets)
A= Solar energy B=Wind energy	71%-4%= 67%	A is much more important than B, (7)
A= Solar energy B=Water energy	84%-2%= 82%	A is very much more important than B, (9)
A= Solar energy B=Geothermal	73%-4%= 69%	A is much more important than B, (7)
A= Wind energy B=Water energy	45%-10%= 35%	A is more important than B, (5)
A= Wind energy B=Geothermal	41%-20%= 21%	A is slightly more important than B, (3)
A=Water energy B=Geothermal	15%-32%= -17%	A is slightly more important than B, (3)

The AHP renewable energy matrix, and its results as a bar chart are shown in Table 5.11 and Figure 5.19. As illustrated in this chart, solar energy is in the first place with a huge difference, to be used in the building facades according to the architect's opinion. Wind, water, and geothermal energy are placed in the second, third, and fourth places. It means that for designing efficient facades, the systems and techniques that can convert solar energy into usable energy in the building should be reviewed and the most efficient one should be selected. Hence, various techniques and solutions determined from the 49 case study buildings and the literature review were prioritized according to the questionnaire data from architects. Their opinions were considered in the design process by utilizing the first House of Quality matrix, which will be explained in the next section.

Table 5.11 AHP matrix for defining the priorities of renewable energies in designing of efficient facades.

AHP RENEWABLE ENERGY MATRIX 5											
1= the row is equally important as the column 3= slightly more important 5= more important 7= much more important 9= very much more important 0.33= slightly less important 0.20= less important 0.14=much less important 0.11= very much less important		A Solar energy	B Wind energy	C Water energy	D Geothermal	a Normalized Assessment	b	c	d	Absolute Weight	Renewable Energies Priority
1	Solar energy	1.00	7.00	9.00	7.00	0.72	0.82	0.50	0.62	2.66	66.45
2	Wind energy	0.14	1.00	5.00	3.00	0.10	0.12	0.28	0.26	0.76	19.01
3	Water energy	0.11	0.20	1.00	0.33	0.08	0.02	0.06	0.03	0.19	4.68
4	Geothermal	0.14	0.33	3.00	1.00	0.10	0.04	0.17	0.09	0.39	9.86
		1.39	8.53	18.00	11.33	1.00	1.00	1.00	1.00	4.00	100.00

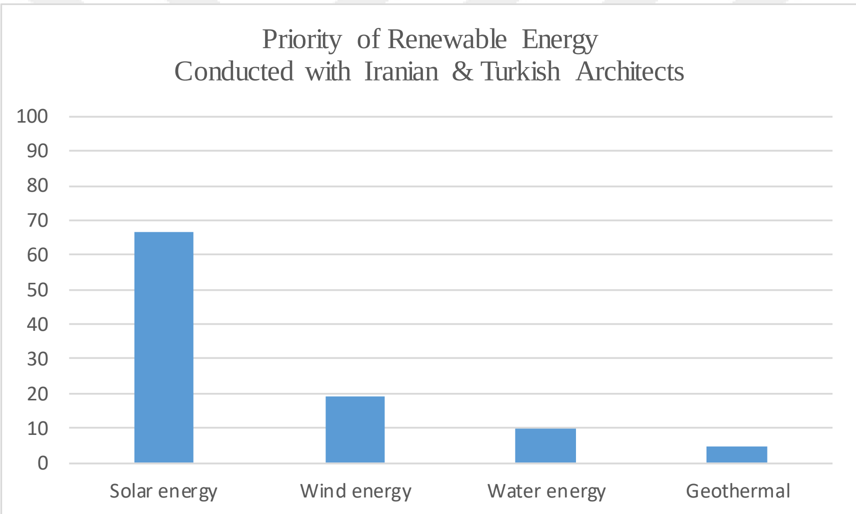


Figure 5.19 Priority of renewable energy

5.3.1 House of Quality Matrices

In this part, the priorities of various techniques and systems used in buildings' facades to make them efficient were defined. For this purpose, two HoQ matrices were created. The first one was made using the data from both questionnaire surveys regarding the occupants' requirements and technical solutions to determine technical solutions' priorities. The second HoQ matrix was created by using the first HoQ matrix results and data from the case studies regarding facade systems to define facade systems' priorities.

The first HoQ matrix is for determining the priorities of the technical solutions. As explained before, the occupants' requirements and technical solutions were rated in two questionnaire surveys. The ratings of responses in both surveys were weighted. The percentages of weighted preferences were calculated according to Section 3.2.2.4, which are shown in Appendix C and D. Then, the weighted preferences and their percentages regarding the occupants' requirements and technical solutions were inserted into the first HoQ matrix, as clarified in Section 3.2.3.3. The correlations between them on a three-point scale: strong (ʘ=9), medium (□=3), and weak (Δ=1)), were defined in the matrix's body. It is important to note that the weighted numbers and their percentages about technical solutions were only utilized in defining the correlation between the requirements and solutions, not in the calculation of the first HoQ matrix.

In the QFD method, the correlations are determined by the QFD team, who knows the products and techniques by having several brainstorming meetings. However, in this study, not only the preferences of 82 architects but also 49 case study buildings and literature review helped us to define the relationship between occupants' requirements and technical solutions, as shown in Table 5.12. For better understanding, the pictures of some techniques are illustrated in Appendix E.

Moreover, the relationships between the technical solutions in the HoQ matrix roof were also determined by considering case studies and information from the literature review and the author's personal experiences, which were done by the QFD team in real projects. For the positive relationship, "+" sign and for the negative relationship "-" sign were used that is given in Table 5.12. Having a positive relationship means that improving one solution affects improving the other ones, which have positive relations with it. On the other hand, having negative relations means that the improvement of one reduces the other's efficiency. For example, as shown in the first matrix roof in Table 5.12, "operable window" has a positive relationship with

12 other technical solutions (optimize window to wall ratio, opening orientation, durable materials, reusable materials, thermal insulation, air filtration system on the facade, modular prefabricated panels for the facades, plantation on the facade, Solar spaces on the facades, evaporative water system on the facades, low maintenance systems for the facades, and balconies for the facades). In contrast, it has a negative relation with four technical solutions (sound insulation, interior shading devices, exterior shading devices, and water pipe embedded on the facades). Each technique's impact on others should be considered in the design process because the negative impacts make the technique weak or useless.

Determining correlation in both parts plays an important role in the design process because, if they are not determined accurately, the technical solutions' priorities would not be realistic and so the design would not be appropriate.

After defining the correlations, the HoQ matrix was calculated, as explained in Table 5.13. The last two rows present the absolute weights of technical solutions and their percentages. In order to see the priorities of technical solutions, it is better to make a bar chart by using percentages of absolute weights, which is shown in Figure 5.20.

The bar chart in Figure 5.20 shows the priorities of technical solutions obtained from the first HoQ matrix. Designing solar spaces on the facades has the highest weighted priority by 5.2%; because this technique is very useful in winter and summer to control the temperature in order to have thermal comfort in the building.

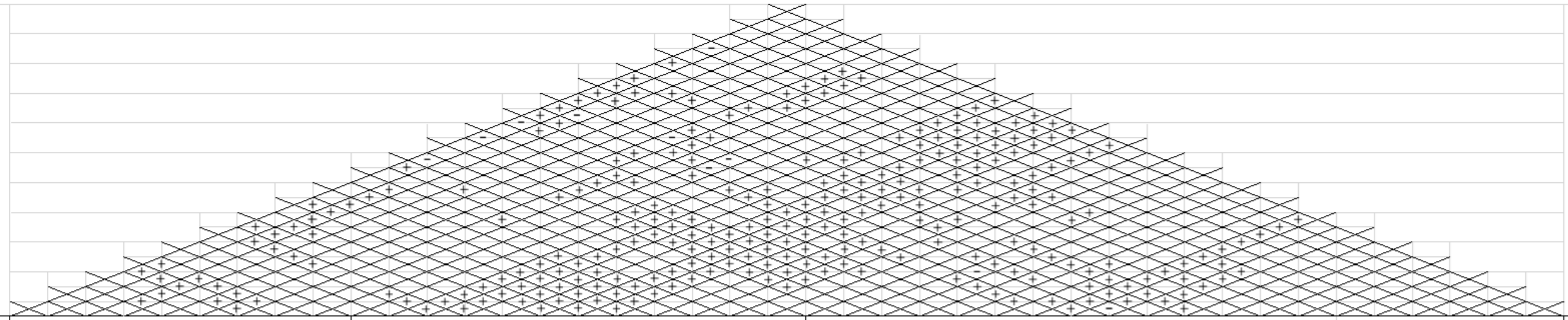
The second place belongs to two techniques; opening orientation and exterior shading devices (by 4.5%). Opening orientation plays an important role in gaining or preventing solar radiation in winter and summer, respectively, which results in decreasing energy consumption for heating or cooling. Also, opening orientation affects natural ventilation by being in the direction of the prevailing winds. Additionally, exterior shading devices are one of the effective solutions to prevent the entry of solar heat. So helps to reduce energy consumption for cooling in the summer.

There are three techniques in the third place: having operable windows on facades, installing interior shading devices, and optimizing window to wall ratio by 3.93%, 3.92%, and 3.88%, respectively. Having operable windows on facades is very useful for natural ventilation that reduces energy consumption for cooling loads. Optimizing the window to wall ratio is one of the effective ways to control gaining or preventing solar radiation in winter and summer as well as daylight to improve human thermal and visual comfort. Interior shading devices can prevent solar radiation, but it is not as useful as exterior ones.

The fourth-place belongs to two techniques: integrating photovoltaic cells by 3.83% and plantation on the facade by 3.78%. Integrating photovoltaic cells on the facade decreases energy (fossil fuel) consumption by generating electricity. The important point is that the amount of energy produced depends on the amount of area in which the solar panels are installed. In addition, the plantation can be a filter to provide fresh air as well as prevent solar heat as a solar shading feature.

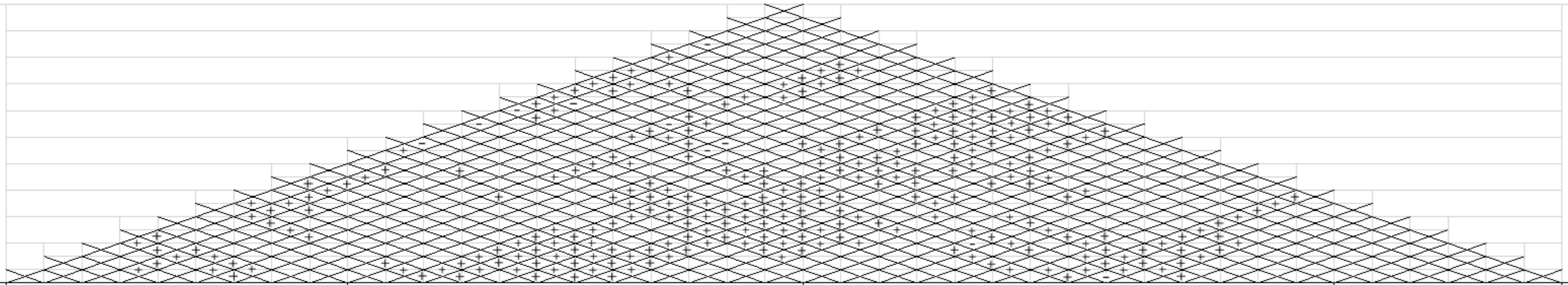
These eight technical solutions are being used in many building facades as the primary solutions to decrease energy consumption. Hence, the calculation of priority by the HoQ matrix helps us select useful solutions as well as consider occupants' requirements and various parameters regarding the design.

Table 5.12 Defining the correlations between the occupants’ requirement and technical solutions in the body and relationship between the technical solutions on the roof



Θ = Strong Correlation □ = Medium Correlation Δ = Weak Correlation			Occupants Request Priority	Percentage of priority	Opening in Facades (9)									Construction Materials (12)												Facade Component (14)														Energy Generation (6)						
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	
					Operable windows	Vents (grills) on the facades	Insulated glass for opening	Tinted (colored, or laminated) glass	Air tightness of opening	Optimize window to wall ratio	Opening orientation	Low maintenance self-cleaning glass	Light shelves	Light color materials	Low maintenance opaque materials	Durable materials	Local materials	Affordable materials or systems	Reusable materials	Recyclable materials	Nontoxic finishing	Nontoxic glues	Nontoxic paint	Thermal insulation	Sound insulation	Thermal mass for exterior wall	Exterior shading devices/elements/screen	Interior shading devices	Shading devices in the cavity of double skin	Ducts / Chimney wall on the facades	Air filtration system on the facade	Modular prefabricated panels for the facades	Plantation on the facade	Solar spaces on the facades	Water evaporative system on the facades	Low maintenance systems for the facades	Automatic robots for cleaning of the facades	Balconies for the facades	Double layer exterior wall	Water pipe embedded on the facades	Photovoltaic panels on the facades	Solar collector on the facade for space heating	Solar collector on the facade for hot water supply	Wind turbine on facade	Geothermal energy through wall cavity	
					4.7	3.2	4.2	3.5	4.5	4	3.9	4.4	3.9	2.8	4.3	4.7	4.4	4.1	3.9	4.3	4.4	4.2	4.4	4.7	4.5	4.2	4.4	3.8	3.3	3.3	3.8	3.7	3.3	3.9	3.1	3.9	3.6	3.8	4.6	3.3	4.2	3.3	3.3	2.6	2.7	
		Occupant Requiremnets			2.95	2.01	2.64	2.2	2.83	2.51	2.45	2.77	2.45	1.76	2.7	2.95	2.77	2.58	2.45	2.7	2.77	2.64	2.77	2.95	2.83	2.64	2.77	2.39	2.07	2.07	2.39	2.33	2.07	2.45	1.95	2.45	2.26	2.39	2.89	2.07	2.64	2.07	2.07	1.63	1.7	
Human comfort	1	Natural ventilaton for day (air changing)	4.6	6.38	Θ	Θ				□	Θ																Θ	Δ		□	□		□	Θ	□			□						□		
	2	Natural ventilaton for night (air changing)	3.8	5.27	Θ	Θ				□	Θ																□	Δ		Θ	□		□													
	3	Fresh air	4.2	5.83	Θ	Θ				□	Θ										Θ	Θ	Θ				□	Δ		Δ	Θ		Θ	□	Θ											
	4	Appropriate temperature in winter	4.7	6.52	□	□	Θ	□	Θ	Θ	Θ			□										Θ		Θ	Θ	Θ	Θ	□			□	Θ	□			□	Θ	□	Θ	Θ	Θ	□	Θ	
	5	Appropriate temperature in summer	4.6	6.38	Θ	Θ	Θ	□	Θ	Θ	Θ			Θ										Θ		Θ	Θ	Θ	Θ	Θ			Θ	Θ	Θ			Θ	Θ		□			□		
	6	Increasing day light	4.6	6.38				Δ		Θ	Θ		Θ	Θ													Δ	Θ	Δ				Δ	□				Δ								
	7	Preventing glare	3.7	5.13				Θ		Δ	Θ		Θ														Θ	Θ	Θ				□	Θ				□								
	8	Having outside view from interior spaces	4.2	5.83						Θ	Θ																□	Θ	Θ					Θ												
	9	Preventing outside noise	4.6	6.38		□	Θ		Θ	Δ	Δ														Θ	Θ	Δ	□	□				□	□					Θ							
Decreasing cost	10	Decreasing cost of energy by using renewable energy	4.6	6.38	Δ	□	□	□	□	Θ	Θ			Θ										Θ		Θ	□	□	□	Θ			□	Θ	Θ			Δ		Θ	Θ	Θ	Θ	Θ	Θ	
	11	Decreasing maintenance cost by having access to facade	4.1	5.69	Θ					□		Θ			Θ												Θ	Θ	□	□			Θ	Θ	□	Θ	Θ	Θ		□	Θ					
	12	Decreasing maintenance cost by having simple systems or components for facade	4	5.55	Θ	□						Θ	□	□	Θ	Θ											Θ	Θ	□	Θ				Θ	□	Θ	Θ	Θ		□	Θ	□	□	Θ		
	13	Decreasing construction cost by applying affordable material or systems	3.7	5.13	Θ	Θ	Θ	Θ	Θ	Θ		Θ	□		Θ	□	Θ	Θ	Θ	Θ	□	□	□	Θ	Θ	□	Θ	□	Θ	Θ		□	Θ	□	□	Θ	Θ	Θ	Θ	□	Θ	Θ	Θ	Θ	Θ	
	14	Decreasing cost of installation in facade construction	3.6	4.99	Δ	Δ				□			□				□	□	□					□	□		Θ	Δ	Θ	Θ		Θ	Θ	□	Θ		Θ		□	Θ	Θ	Θ	Θ	Θ	Θ	
Decreasing environmental pollution	15	Decrease air pollution caused by the consumption of fossil fuels to have fresh air	4.5	6.24	Θ	Θ				□	□		□	□					□	□				Θ		Θ	□		□	□		Δ	Δ	Θ	Θ			□	Θ	Θ	Θ	Θ	Θ	Θ	Θ	
	16	Decrease emission (from toxic materials) from facade materials to have fresh air	4.4	6.1																				□		□				□	Θ		Θ	□	□			□	Θ	□	Θ	Θ	Θ	Θ	Θ	
	17	Decrease soil pollution by designing for deconstruction and decreasing waste	4.2	5.83								Θ			Θ	Θ			Θ	Θ	Θ	Θ	Θ	Θ	Θ							Θ	Δ			□	□									Total
	Absolute Weight			100																																										
	Percentage of Absolute Weight																																													

Table 5.13 Calculation of the first house of quality for defining the priority of technical sollutions



O = Strong Correlation
□ = Medium Correlation
Δ = Weak Correlation

					Opening in Facades (9)									Construction Materials (12)											
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
			Occupants Request Priority	Percentage of priority	Operable windows	Vents (grills) on the facades	Insulated glass for opening	Tinted (colored, or laminated) glass	Air tightness of opening	Optimize window to wall ratio	Opening orientation	Low maintenance self-cleaning glass	Light shelves	Light color materials	Low maintenance opaque materials	Durable materials	Local materials	Affordable materials or systems	Reusable materials	Recyclable materials	Nontoxic finishing	Nontoxic glues	Nontoxic paint	Thermal insulation	Sound insulation
					4.7	3.2	4.2	3.5	4.5	4	3.9	4.4	3.9	2.8	4.3	4.7	4.4	4.1	3.9	4.3	4.4	4.2	4.4	4.7	4.5
		Occupant Requiremnets			2.95	2.01	2.64	2.2	2.83	2.51	2.45	2.77	2.45	1.76	2.7	2.95	2.77	2.58	2.45	2.7	2.77	2.64	2.77	2.95	2.83
Human comfort	1	Natural ventilaton for day (air changing)	4.6	6.38	57.42	57.42	0	0	0	19.14	57.42	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	2	Natural ventilaton for night (air changing)	3.8	5.27	47.43	47.43	0	0	0	15.81	47.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	3	Fresh air	4.2	5.83	52.43	52.43	0	0	0	17.48	52.43	0	0	0	0	0	0	0	0	0	52.43	52.43	52.43	0	0
	4	Appropriate temperature in winter	4.7	6.52	19.56	19.56	58.67	19.56	58.67	58.67	58.67	0	0	19.56	0	0	0	0	0	0	0	0	0	58.67	0
	5	Appropriate temperature in summer	4.6	6.38	57.42	57.42	57.42	19.14	57.42	57.42	57.42	0	0	57.42	0	0	0	0	0	0	0	0	0	57.42	0
	6	Increasing day light	4.6	6.38	0	0	0	6.38	0	57.42	57.42	0	57.42	57.42	0	0	0	0	0	0	0	0	0	0	0
	7	Preventing glare	3.7	5.13	0	0	0	46.19	0	5.132	46.19	0	46.19	0	0	0	0	0	0	0	0	0	0	0	0
	8	Having outside view from interior spaces	4.2	5.83	0	0	0	0	0	52.43	52.43	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	Preventing outside noise	4.6	6.38	0	19.14	57.42	0	57.42	6.38	6.38	0	0	0	0	0	0	0	0	0	0	0	0	0	57.42
Decreasing cost	10	Decreasing cost of energy by using renewable energy	4.6	6.38	6.38	19.14	19.14	19.14	19.14	57.42	57.42	0	0	57.42	0	0	0	0	0	0	0	0	0	57.42	0
	11	Decreasing maintenance cost by having access to facade	4.1	5.69	51.18	0	0	0	0	17.06	0	51.18	0	0	51.18	0	0	0	0	0	0	0	0	0	0
	12	Decreasing maintenance cost by having simple systems or components for facade	4	5.55	49.93	16.64	0	0	0	0	0	49.93	16.64	16.64	49.93	49.93	0	0	0	0	0	0	0	0	0
	13	Decreasing construction cost by applying affordable material or systems	3.7	5.13	46.19	46.19	46.19	46.19	46.19	46.19	0	46.19	15.4	0	46.19	15.4	46.19	46.19	46.19	46.19	15.4	15.4	15.4	46.19	46.19
	14	Decreasing cost of installation in facade construction	3.6	4.99	4.993	4.993	0	0	0	14.98	0	0	14.98	0	0	0	14.98	14.98	14.98	0	0	0	0	14.98	14.98
Decreasing environmental pollution	15	Decrease air pollution caused by the consumption of fossil fuels to have fresh air	4.5	6.24	56.17	56.17	0	0	0	18.72	18.72	0	18.72	18.72	0	0	0	0	18.72	18.72	0	0	0	56.17	0
	16	Decrease emission (from toxic materials) from facade materials to have fresh air	4.4	6.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18.31	0
	17	Decrease soil pollution by designing for deconstruction and decreasing waste	4.2	5.83	0	0	0	0	0	0	0	52.43	0	0	52.43	52.43	0	0	52.43	52.43	52.43	52.43	52.43	52.43	52.43
		Absolute Weight		100	449.1	396.5	238.8	156.6	238.8	444.2	511.9	199.7	169.3	227.2	199.7	117.8	61.17	61.17	132.3	117.3	120.2	120.2	120.2	361.6	171
		Percentage of Absolute Weight			3.928	3.468	2.089	1.37	2.089	3.886	4.478	1.747	1.481	1.987	1.747	1.03	0.535	0.535	1.157	1.026	1.052	1.052	1.052	3.163	1.496

		Facade Component (14)														Energy Generation (6)						
		22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	
		Thermal mass for exterior wall	Exterior shading devices/elements/screen	Interior shading devices	Shading devices in the cavity of double skin facades	Ducts / Chimney wall on the facades	Air filtration system on the facade	Modular prefabricated panels for the facades	Plantation on the facade	Solar spaces on the facades	Water evaporative system on the facades	Low maintenance systems for the facades	Automatic robots for cleaning of the facades	Balconies for the facades	Double layer exterior wall	Water pipe embedded on the facades	Photovoltaic panels on the facades	Solar collector on the facade for space heating	Solar collector on the facade for hot water supply	Wind turbine on facade	Geothermal energy through wall cavity	
		4.2	4.4	3.8	3.3	3.3	3.8	3.7	3.3	3.9	3.1	3.9	3.6	3.8	4.6	3.3	4.2	3.3	3.3	2.6	2.7	
	Occupant Requiremnets	2.64	2.77	2.39	2.07	2.07	2.39	2.33	2.07	2.45	1.95	2.45	2.26	2.39	2.89	2.07	2.64	2.07	2.07	1.63	1.7	
Human comfort	1 Natural ventilaton for day (air changing)	0	57.42	6.38	0	19.14	19.14	0	19.14	57.42	19.14	0	0	19.14	0	0	0	0	0	19.14	0	
	2 Natural ventilaton for night (air changing)	0	15.81	5.27	0	47.43	15.81	0	15.81	0	0	0	0	0	0	0	0	0	0	0	0	
	3 Fresh air	0	17.48	5.825	0	5.825	52.43	0	52.43	17.48	52.43	0	0	0	0	0	0	0	0	0	0	
	4 Appropriate temperature in winter	58.67	58.67	58.67	58.67	19.56	0	0	19.56	58.67	19.56	0	0	19.56	58.67	19.56	58.67	58.67	58.67	19.56	58.67	
	5 Appropriate temperature in summer	57.42	57.42	57.42	57.42	57.42	0	0	57.42	57.42	57.42	0	0	57.42	57.42	0	19.14	0	0	19.14	0	
	6 Increasing day light	0	6.38	57.42	6.38	0	0	0	6.38	19.14	0	0	0	6.38	0	0	0	0	0	0	0	
	7 Preventing glare	0	46.19	46.19	46.19	0	0	0	15.4	46.19	0	0	0	15.4	0	0	0	0	0	0	0	
	8 Having outside view from interior spaces	0	17.48	52.43	52.43	0	0	0	0	52.43	0	0	0	0	0	0	0	0	0	0	0	
	9 Preventing outside noise	57.42	6.38	19.14	19.14	0	0	0	19.14	19.14	0	0	0	0	57.42	0	0	0	0	0	0	
Decreasing cost	10 Decreasing cost of energy by using renewable energy	57.42	19.14	19.14	19.14	57.42	0	0	19.14	57.42	57.42	0	0	6.38	0	57.42	57.42	57.42	57.42	57.42	57.42	
	11 Decreasing maintenance cost by having access to facade	0	51.18	51.18	17.06	17.06	0	0	51.18	51.18	17.06	51.18	51.18	51.18	0	17.06	51.18	0	0	0	0	
	12 Decreasing maintenance cost by having simple systems or components for facade	0	49.93	49.93	16.64	49.93	0	0	0	49.93	16.64	49.93	49.93	49.93	0	16.64	49.93	16.64	16.64	49.93	0	
	13 Decreasing construction cost by applying affordable material or systems	15.4	46.19	15.4	46.19	46.19	0	15.4	46.19	15.4	15.4	46.19	46.19	46.19	46.19	15.4	46.19	46.19	46.19	46.19	46.19	
	14 Decreasing cost of installation in facade construction	0	44.94	4.993	44.94	44.94	0	44.94	44.94	14.98	44.94	0	44.94	0	14.98	44.94	44.94	44.94	44.94	44.94	44.94	
Decreasing environmental pollution	15 Decrease air pollution caused by the consumption of fossil fuels to have fresh air	56.17	18.72	0	18.72	18.72	0	6.241	6.241	56.17	56.17	0	0	18.72	56.17	56.17	56.17	56.17	56.17	56.17	56.17	
	16 Decrease emission (from toxic materials) from facade materials to have fresh air	18.31	0	0	0	18.31	54.92	0	54.92	18.31	18.31	0	0	18.31	54.92	18.31	54.92	54.92	54.92	54.92	54.92	
	17 Decrease soil pollution by designing for deconstruction and decreasing waste	0	0	0	0	0	0	52.43	5.825	0	0	17.48	17.48	0	0	0	0	0	0	0	0	Total
	Absolute Weight	320.8	513.3	449.4	402.9	401.9	142.3	119	433.7	591.3	374.5	164.8	209.7	308.6	345.8	245.5	438.6	335	335	367.4	318.3	11432.7323
	Percentage of Absolute Weight	2.806	4.49	3.931	3.524	3.516	1.245	1.041	3.794	5.172	3.276	1.441	1.834	2.699	3.024	2.147	3.836	2.93	2.93	3.214	2.784	100

The lowest absolute weight belongs to using local materials and affordable materials. According to the results of the first HoQ matrix, the construction materials are the least important. It means that architects just focused on the techniques in their design, and they do not have enough information about materials. For example, the priorities of using nontoxic materials are 1.1%, even when their prioritized targets are decreasing environmental pollutions. As a result, the house of quality matrix helps us consider all related parameters in the design process.

That is to say, in the first step of the design process, every designer defines goals and limitations, but during the design process, most of these goals and limitations are forgotten. While the HoQ matrix carries our goals or limitations from one to other design steps to be considered in the whole design process.

Then second HoQ matrix was calculated in order to know the priority of facade systems in designing appropriate facades. For this purpose, the technical solutions and their percentage of absolute weights calculated in the first HoQ were transferred to the first and second columns of the second HoQ matrix. On the header row, 14 facade systems were listed, which have been identified by analyzing the 49 building facades (Section 5.1.1).

In this part of the design process, the correlations between the technical solutions and facade systems were defined by information from the literature review, analysis of 49 facades of the case study buildings, and results of 8 questions of the second questionnaire survey.

The second questionnaire survey results (8 questions) about the facade systems were presented as a bar chart in Figure 5.21. According to the bar chart, around 90 % of architects said it is important/very important to use passive systems for cooling and heating buildings. Turkish architects by 65% in comparison with Iranian ones by 35% believe that passive systems are very important. Around 95% of architects from both nations convinced that energy generation through facades is important/very important. Hence, around 90% of architects believe that using renewable resources passively or actively for buildings' energy consumption is important or very important. Also, 90% of architects responded that facades with movable shading devices are useful or very useful in decreasing the energy consumption of buildings. Around 60% of Iranian architects and 80% of Turkish architects said that using perforated materials for designing shading devices can be useful. Around 45% of architects were convinced that constructing self-shading facades are effective in decreasing energy consumption.

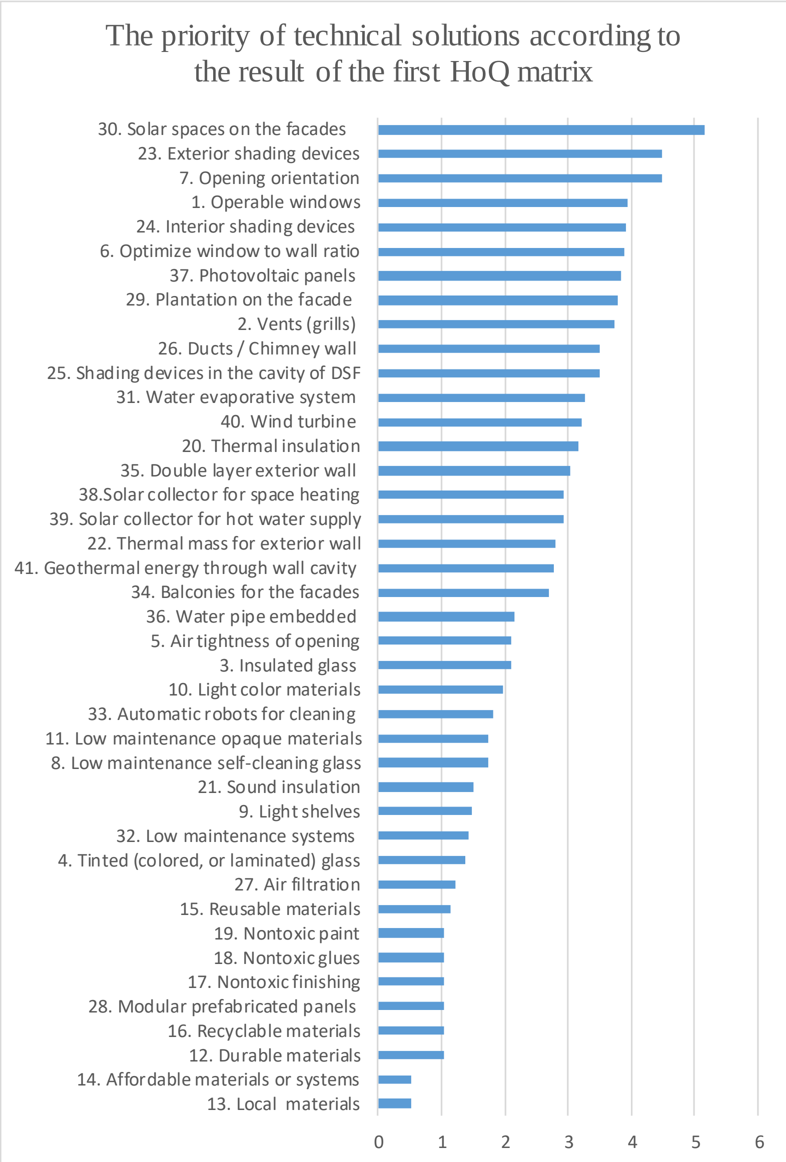


Figure 5.20 Priorities of technical solutions as a result of the first HoQ matrix.

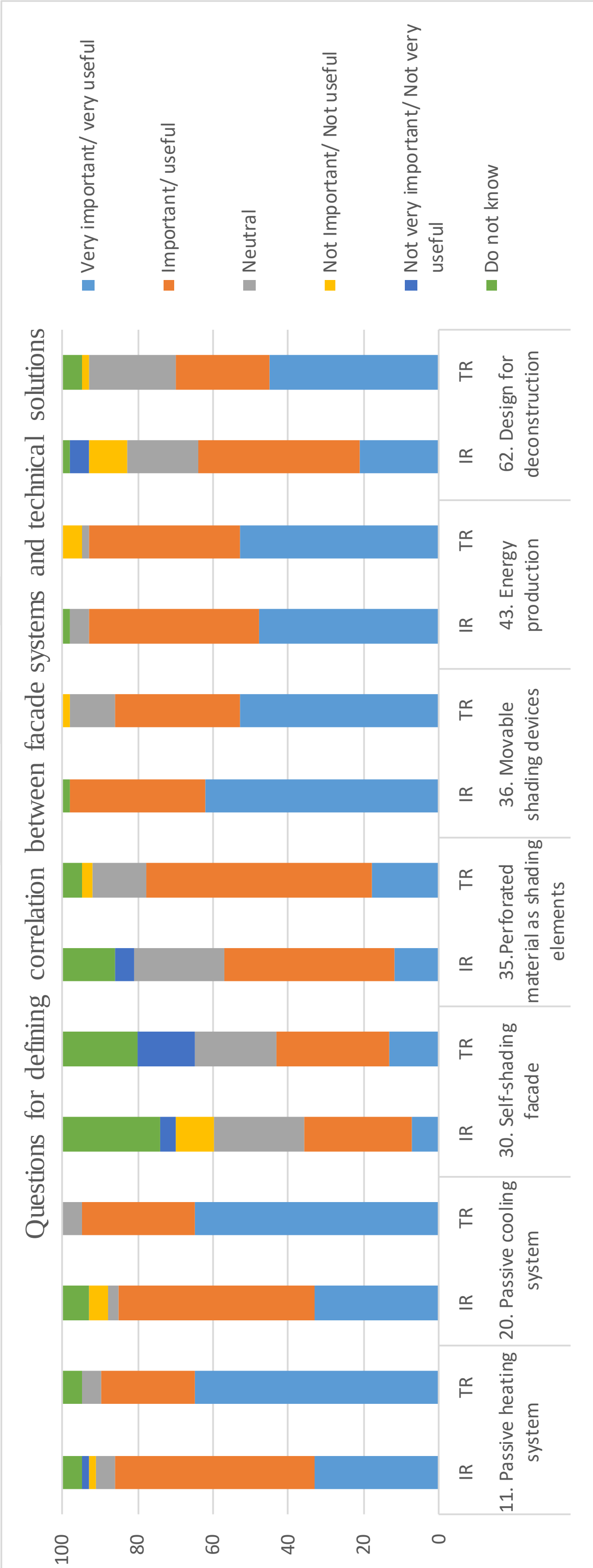
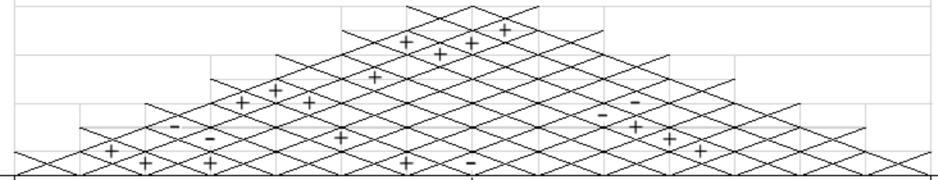


Figure 5.21 Questions regarding the preferences of facade systems by architects

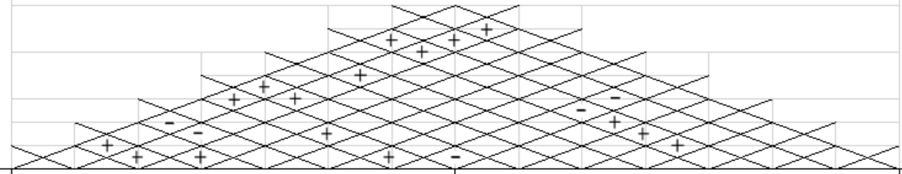
Table 5.14 Defining the corrolations between the technical solutions and facade systems in the body and relationship between the facade systems on the roof



Θ = Strong Correlation
□ = Medium Correlation
Δ = Weak Correlation

				Facades with Passive Systems							Facades with Active Systems							
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	
		Technical Solutions	Percentage of Technical Solutions priority	Double skin facade	Solar facade	Ventilated Facade	Facade with evaporative cooling	Facade with Fixed shading devices	Self-shading facade	Vegetated facade	Facade with movable shading devices	Movable facade	Rotating building	Facade with Smart material	Solar energy integrated facade	Wind energy integrated facade	Geothermal energy integrated facade	
Opening in Facades	1	Operable windows	3.93	□	Θ	Θ	Θ					□	□	□				
	2	Vents (grills) on the facades	3.74	Θ	Θ	Θ	Θ					□	□	□				
	3	Insulated glass for opening	2.09	Θ	Θ									Δ	Θ			
	4	Tinted (colored, or laminated) glass	1.37	□	Θ			Δ			Δ			□	Θ			
	5	Air tightness of opening	2.09	Θ	Θ	Θ	Θ			□						Θ		
	6	Optimize window to wall ratio	3.88	Θ	Θ				□	Θ		□	□		Θ	□	Δ	
	7	Opening orientation	4.47	□	Θ	Θ	□	Θ	Θ	□	Θ	□	□		Θ	□		
	8	Low maintenance self-cleaning glass	1.74	Θ	Θ	Δ				Θ				Θ	Θ			
	9	Light shelves	1.47		Θ	□		□	Δ	□	□	□	□					
Construction Materials	10	Light color materials	1.98					Θ	Δ			Δ	Δ		Δ			
	11	Low maintenance opaque materials	1.74	□	□	Δ	□	Θ	□	□	Θ	Θ	□	Δ	Δ	Δ	Δ	
	12	Durable materials	1.03	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	
	13	Local materials	0.52	□	□	□	□	□	□	□	□	□	□	□	□	□	□	
	14	Affordable materials or systems	0.52	□	□	□	□	□	□	□	□	□	□	□	□	□	□	
	15	Reusable materials	1.15	□	□	□	□	□	□	Δ	□	□	□		Δ	Δ	Δ	
	16	Recyclable materials	1.03	□	□	□	□	□	□		□	□	□					
	17	Nontoxic finishing	1.04	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	
	18	Nontoxic glues	1.04	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	
	19	Nontoxic paint	1.04	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	
	20	Thermal insulation	3.15	□		□		Θ	Θ		Θ	Θ	Θ		□	□	Θ	
	21	Sound insulation	1.5		Δ	Δ		Δ	Δ		Δ	Δ	Δ					
Facade Components	22	Thermal mass for exterior wall	2.81		Θ			Δ	Δ		Δ				□			
	23	Exterior shading devices/elements/screen	4.48	□	Θ	Δ		Θ	Θ	□	Θ	Θ	□					
	24	Interior shading devices	3.92	Θ	Θ			Δ	Δ			□	□					
	25	Shading devices in the cavity of double	3.51	Θ														
	26	Ducts / Chimney wall on the facades	3.51	Θ	Θ	Θ												
	27	Air filtration system on the facade	1.23	□	Δ	Θ	Θ	Δ	Δ	Θ	Δ	Δ	Δ	□				
	28	Modular prefabricated panels for the	1.03	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	
	29	Plantation on the facade	3.78	□				□	□	Θ	Δ	Δ	Δ					
	30	Solar spaces on the facades	5.16	Θ	Θ	Θ					□	□	□		□	□	□	
	31	Water evaporative system on the facades	3.27			Δ	Θ	□			□	□						
	32	Low maintenance systems for the facades	1.43	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	Θ	
	33	Automatic robots for cleaning of the	1.82	Θ	□										Θ			
	34	Balconies for the facades	2.7			□	□	□	□	□	□	□	□	□	□	□	□	
	35	Double layer exterior wall	3.02		□	Θ		□	□		□	□	□		□	□	Θ	
Energy Generation	36	Water pipe embedded on the facades	2.15	□	□		Θ	□	□		□	□			Θ			
	37	Photovoltaic panels on the facades	3.83	Θ	Θ	□		□	Θ		Δ	Θ	□		Θ			
	38	Solar collector on the facade for space	2.93	Θ	Θ	□		□	Θ		Δ	Θ	□		Θ			
	39	Solar collector on the facade for hot water	2.92	Θ	Θ	□		□	Θ		Δ	Θ	□		Θ			
	40	Wind turbine on facade	3.21			□			□							Θ		
	41	Geothermal energy through wall cavity	2.77	□	□				□								Θ	Total
		Absolute Weight	100															
		Percentage of Absolute Weight																

Table 5.15 Calculation of the second house of quality for defining the priority of facade systems



Θ = Strong Correlation
□ = Medium Correlation
Δ = Weak Correlation

		Technical Solutions	Percentage of Technical Solutions priority	Facades with Passive Systems							Facades with Active Systems							
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	
				Double skin facade	Solar facade	Ventilated Facade	Facade with evaporative cooling	Facade with Fixed shading devices	Self-shading facade	Vegetated facade	Facade with movable shading devices	Movable facade	Rotating building	Facade with Smart material	Solar energy integrated facade	Wind energy integrated facade	Geothermal energy integrated facade	
Opening in Facades	1	Operable windows	3.93	11.79	35.37	35.37	35.37	0	0	0	0	11.79	11.79	11.79	0	0	0	
	2	Vents (grills) on the facades	3.74	33.66	33.66	33.66	33.66	0	0	0	0	11.22	11.22	11.22	0	0	0	
	3	Insulated glass for opening	2.09	18.81	18.81	0	0	0	0	0	0	0	0	2.09	18.81	0	0	
	4	Tinted (colored, or laminated) glass	1.37	4.11	12.33	0	0	1.37	0	0	1.37	0	0	4.11	12.33	0	0	
	5	Air tightness of opening	2.09	18.81	18.81	18.81	18.81	0	0	6.27	0	0	0	0	0	18.81	0	
	6	Optimize window to wall ratio	3.88	34.92	34.92	0	0	0	11.64	34.92	0	11.64	11.64	0	34.92	11.64	3.88	
	7	Opening orientation	4.47	13.41	40.23	40.23	13.41	40.23	40.23	13.41	40.23	13.41	13.41	0	40.23	13.41	0	
	8	Low maintenance self-cleaning glass	1.74	15.66	15.66	1.74	0	0	0	15.66	0	0	0	15.66	15.66	0	0	
	9	Light shelves	1.47	0	13.23	4.41	0	4.41	1.47	4.41	4.41	4.41	4.41	0	0	0	0	
Construction Materials	10	Light color materials	1.98	0	0	0	0	17.82	1.98	0	0	1.98	1.98	0	1.98	0	0	
	11	Low maintenance opaque materials	1.74	5.22	5.22	1.74	5.22	15.66	5.22	5.22	15.66	15.66	5.22	1.74	1.74	1.74	1.74	
	12	Durable materials	1.03	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	
	13	Local materials	0.52	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	
	14	Affordable materials or systems	0.52	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.56	
	15	Reusable materials	1.15	3.45	3.45	3.45	3.45	3.45	3.45	1.15	3.45	3.45	3.45	0	1.15	1.15	1.15	
	16	Recyclable materials	1.03	3.09	3.09	3.09	3.09	3.09	3.09	0	3.09	3.09	3.09	0	0	0	0	
	17	Nontoxic finishing	1.04	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	
	18	Nontoxic glues	1.04	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	
	19	Nontoxic paint	1.04	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	9.36	
	20	Thermal insulation	3.15	9.45	0	9.45	0	28.35	28.35	0	28.35	28.35	28.35	0	9.45	9.45	28.35	
	21	Sound insulation	1.5	0	1.5	1.5	0	1.5	1.5	0	1.5	1.5	1.5	0	0	0	0	
Facade Components	22	Thermal mass for exterior wall	2.81	0	25.29	0	0	2.81	2.81	0	2.81	0	0	0	8.43	0	0	
	23	Exterior shading	4.48	13.44	40.32	4.48	0	40.32	40.32	13.44	40.32	40.32	13.44	0	0	0	0	
	24	Interior shading devices	3.92	35.28	35.28	0	0	3.92	3.92	0	0	11.76	11.76	0	0	0	0	
	25	Shading devices in the cavity of double	3.51	31.59	0	0	0	0	0	0	0	0	0	0	0	0	0	
	26	Ducts / Chimney wall on the facades	3.51	31.59	31.59	31.59	0	0	0	0	0	0	0	0	0	0	0	
	27	Air filtration system on the facade	1.23	3.69	1.23	11.07	11.07	1.23	1.23	11.07	1.23	1.23	1.23	3.69	0	0	0	
	28	Modular prefabricated panels for the	1.03	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	9.27	
	29	Plantation on the facade	3.78	11.34	0	0	0	11.34	11.34	34.02	3.78	3.78	3.78	0	0	0	0	
	30	Solar spaces on the facades	5.16	46.44	46.44	46.44	0	0	0	0	15.48	15.48	15.48	0	15.48	15.48	15.48	
	31	Water evaporative system on the	3.27	0	0	3.27	29.43	9.81	0	0	9.81	9.81	0	0	0	0	0	
	32	Low maintenance systems for the	1.43	12.87	12.87	12.87	12.87	12.87	12.87	12.87	12.87	12.87	12.87	12.87	12.87	12.87	12.87	
	33	Automatic robots for cleaning of the	1.82	16.38	5.46	0	0	0	0	0	0	0	0	0	16.38	0	0	
	34	Balconies for the facades	2.7	0	0	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	8.1	
	35	Double layer exterior wall	3.02	0	9.06	27.18	0	9.06	9.06	0	9.06	9.06	9.06	0	9.06	9.06	27.18	
Energy Generation	36	Water pipe embedded on the facades	2.15	6.45	6.45	0	19.35	6.45	6.45	0	6.45	6.45	0	0	19.35	0	0	
	37	Photovoltaic panels on the facades	3.83	34.47	34.47	11.49	0	11.49	34.47	0	3.83	34.47	11.49	0	34.47	0	0	
	38	Solar collector on the facade for space	2.93	26.37	26.37	8.79	0	8.79	26.37	0	2.93	26.37	8.79	0	26.37	0	0	
	39	Solar collector on the facade for hot	2.92	26.28	26.28	8.76	0	8.76	26.28	0	2.92	26.28	8.76	0	26.28	0	0	
	40	Wind turbine on facade	3.21	0	0	9.63	0	0	9.63	0	0	0	0	0	0	28.89	0	
	41	Geothermal energy through wall cavity	2.77	8.31	8.31	0	0	0	8.31	0	0	0	0	0	0	0	24.93	Total
		Absolute Weight	100	526.6	595.4	386.9	243.6	300.6	347.8	210.3	267.4	362.2	250.6	121	362.8	180.3	173.4	4329
		Percentage of Absolute Weight		12.17	13.75	8.937	5.627	6.943	8.035	4.858	6.177	8.367	5.788	2.795	8.381	4.166	4.006	100

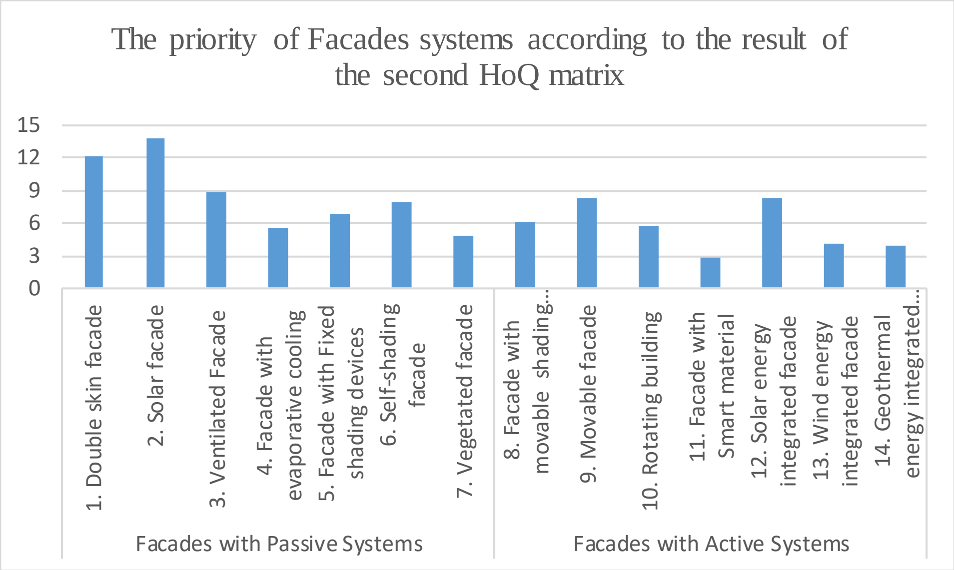


Figure 5.22 Priorities of facade systems as a result of the second HoQ matrix.

Like the previous matrix, correlations between technical solutions and facade systems were defined by a three-point scale: (strong (ʘ=9), medium (□=3), weak (Δ=1)). Table 5.14 shows the correlation between the rows and columns in the second HoQ matrix presented by these signs. Additionally, the positive and negative relationships of facade systems were determined in the roof of the matrix. Then, according to the correlations, the second HoQ matrix was calculated, which is illustrated in Table 5.15.

The result of calculations determined facade systems' priorities, shown in the last row of the second HoQ matrix. These results also are presented as a bar chart in Figure 5.22 in order to be furtherly analyzed.

According to the bar chart in Figure 5.22, solar facade is given the highest importance among other systems, by around 14%. The double skin facade is given the second priority by around 13%. The important point is that both are in the passive facades group because this group's maintenance is not as costly as the active facades group. Also, the construction of active systems is very expensive. The lowest priority belongs to facades with smart materials. Because using smart materials in buildings is in the testing phase and a small number of building facades have used smart materials in their constructions. Also, as mentioned earlier, architects are not very familiar with the materials of construction.

The result shows us three primary targets of the research, which were improving human comfort, decreasing cost, and decreasing environmental pollution have been met by selecting a solar facade as the first priority and double skin facade as the second priority.

CHAPTER 6

CONCLUSION

Various types of active and passive facade systems are being designed, developed, and constructed to improve human comfort as well as decrease energy consumption with the least damage to the environment and nature. Besides, new techniques and solutions are being investigated to produce more efficient facades. Selecting appropriate and efficient facades for the different climatic zones is one of the most challenging design problems. Hence, to select an appropriate facade system that could respond to human comfort, decrease environmental pollution, and decrease the cost of facade maintenance and its construction, the Quality Function Deployment (QFD) method is proposed in this dissertation.

The QFD method has been applied as a decision-making process in designing and manufacturing products by the industrial sector. The basis of this method is to meet the needs of users to sell more products in a marketing competition with other similar products. On the other hand, the priorities of users' requests in all stages of design and production in the QFD method are considered. The important point is that the decisions are made by the QFD team instead of just one person. In comparison, the design process of buildings is completely different. In order to design a building, architects analyze the site and clients requirements and select various construction systems by considering the building standards. Then they select the materials of construction and technical details. If the project is very large, with a big investment, the design team and the clients meet to define their project's goals and limitations. Since the design process sometimes takes almost a year, even if the initial research is documented, it is not considered during the design process. In other words, the initial design targets are forgotten by designers when they try to solve the various design or construction problems. Many factors should be considered in designing appropriate and efficient building facades, which can confuse the architects during the design process. Hence, architects carry out the design process based on their own experiences and tend to ignore the occupants' or clients' requirements. While in this study, by adapting the QFD method, instead of designer's opinion, the experience of 82 architects and 120 occupants were considered by utilizing data from two questionnaire surveys.

In Section 1.4, four research questions were defined in order to be answered in this study. A brief summary of the answers is presented here.

The first question is the method of selecting facade systems that is appropriate to reach the design targets. To fulfill this purpose, the identification of occupants' requirements and technical solutions as well as the correlations between them, were defined by considering design targets, which are present in all steps of the design process in this research.

The second question is considering occupants' requirements in designing appropriate facades. In this dissertation, by using the QFD method for the first time in designing building facades, it becomes possible to consider the occupant's requirements in all steps of the design process through transferring this information from one matrix to another matrix.

The third question is to find an approach to adapt the QFD method from industrial engineering to architectural design. In this research, adapting the QFD method makes it easy to select the best technical solutions and facade systems that meet the occupants' requirements to design an appropriate facade system.

The last question is to find a way to create a framework by adapting the QFD method to design appropriate facades. In order to answer the fourth research question, the framework of the design process (Figure 6.1) was created by adapting the QFD framework proposed by Maritan (2014).

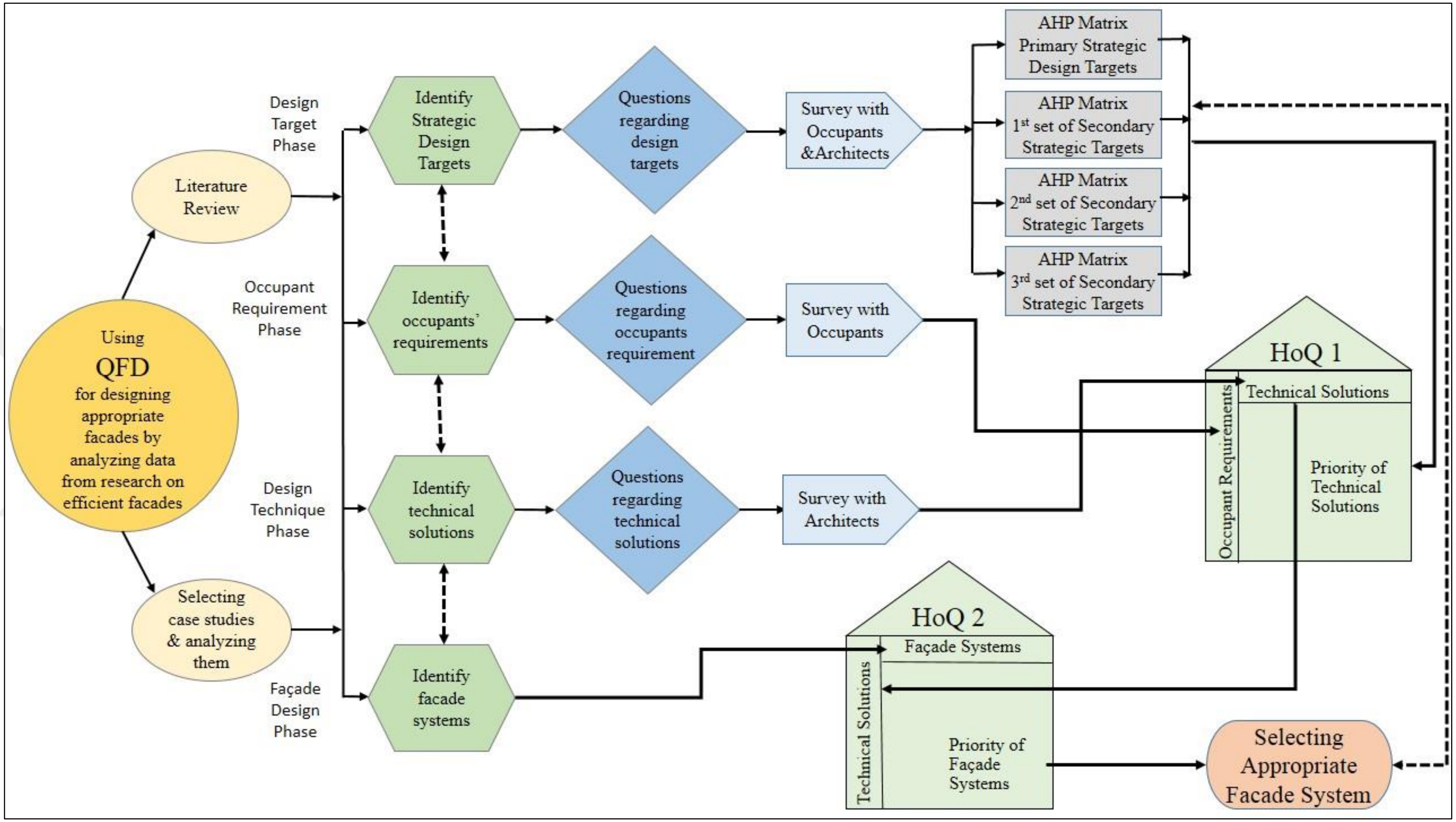


Figure 6.1 Framework of design process for selecting the required systems needed to design appropriate facades

According to the results of this research that was conducted to formulate a framework for designing appropriate facades by utilizing the QFD method (Figure 6.1), the following suggestions are offered to improve each step of the design phase:

i. Design targets phase: There are two methods to define the strategic design targets and their importance in actual projects. The first method is to have a brainstorming meeting with the QFD team, including architects, mechanical, electrical, construction engineers, and project owners, to determine the targets and their importance. The second method is to have a questionnaire conducted with the potential occupants to determine their preferences regarding the design targets, which are defined by the QFD team in the brainstorming meetings. After defining the targets and their importance through the mentioned methods, the strategic targets' priorities are calculated by the AHP matrices.

ii. Occupants' requirements phase: In order to identify the occupants' requirements, there are three methods. The first method is defining occupants' requirements by the QFD team through a brainstorming meeting. The second method is to get the occupants' opinions regarding their requirements, which are identified by the QFD team during their brainstorming meetings, by conducting a questionnaire survey. A third method used in this research is to identify occupants' requirements through a review of other researches related to occupants' behavior or post-occupancy evaluations in similar buildings.

iii. Design techniques phase: In real projects, it is difficult to have questionnaire surveys answered by a large number of architects for each project. Hence, it is suggested that each member of the QFD team searches and studies new techniques and solutions that have been used in other notable real or conceptual projects. These techniques should then be shared in the brainstorming meetings with other QFD team members in order to select the most appropriate techniques. The priorities of the selected technical solutions are determined by making the first HoQ matrix.

In this research, a very large matrix was prepared to prioritize four groups of techniques at the same time, including openings in facades, construction materials, facade components, and energy generation. However, it recommended to make a separate HoQ matrix for each technical solution group and then select those with the highest priorities from each matrix to include in the next phase.

iv. Facade design phase: As suggested in the previous phases, it is better to define the facade systems by the QFD team and then make the second HoQ matrix to determine their priorities.

The framework that was created in this dissertation by adapting the QFD method, can be used as a model for designing various buildings, especially large scale projects in consulting engineering offices. Additionally, it is possible to use the mentioned QFD model in academic researches. In this dissertation, only four phases are specified for the design decision process, however other phases can be added using the HoQ matrices for each stage until the project's construction is completed.

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APPENDICES

A. Questionnaires

A1: Questionnaire Regarding Occupants' Requirements (English)

This study is about the designing of building facades, which is being conducted by Nastaran Deljavan, a Ph.D. student in the Building Science Graduate Program, Department of Architecture at Middle East Technical University (METU) in Turkey. In this study, the main aim is to propose a novel approach for designing efficient facades by using solar energy. For achieving this aim, the Quality Function Deployment (QFD) method will be used, which increases design quality. The basis of the design strategy of the QFD method is the user requirement, which will be considered in all steps of the design process. The framework of this study consists of four phases by using the QFD method. These phases are:

- Design Targets phase,
- User requirements phase,
- Design techniques phase,
- Facade design phase.

Each phase has several steps, which consist of the Analytic Hierarchy process (AHP) matrices, correlation matrices and house of quality, charts, and questionnaire surveys. In order to obtain data required for this study, we will use two questionnaires, which will be sent to building residents and architects. The data gathered through the questionnaire survey will be utilized only for the doctoral research mentioned herein.

Nastaran Deljavan

Ph.D student in Building Science Program in Architecture Department, at Middle East Technical University, Turkey

E-mail: deljavan.nastaran@metu.edu.tr

1. Gender; Male Female

2. What is your age group?

Less than 20 20-29 30-39 40-49 Above 50

3. What is your occupation? ………………………………………….

4. Which parameter is more important for designing facades? Please select the appropriate answer according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Human Comfort	Decreasing Cost				
Human Comfort	Decreasing Environmental Pollution				
Decreasing Cost	Decreasing Environmental Pollution				

5. Which parameter is more important to provide better indoor environment? Please select the appropriate one according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Temperature	Air Quality				
Temperature	Lighting				
Temperature	Acoustics				
Air Quality	Lighting				
Air Quality	Acoustics				
Lighting	Acoustics				

6. Which parameter is more important in decreasing overall cost of building through facade design? Please select the appropriate answer according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Decreasing cost of energy consumption through facade design	Decreasing cost of facade maintenance/cleaning				
Decreasing cost of energy consumption through facade design	Decreasing cost of facade construction				
Decreasing cost of facade maintenance/cleaning	Decreasing cost of facade construction				

7. Which parameter is more important in decreasing environmental pollution through facade design? Please select the appropriate answer according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Decreasing air Pollution	Decreasing soil pollution				
Decreasing air Pollution	Decreasing light pollution				
Decreasing soil pollution	Decreasing light pollution				

8 to 24: Please select the appropriate answer according to your opinion/experience.

	Very importa nt/very useful	Impo rtant/ usefu l	Neutral	Not importa nt/Not useful	Not very import ant/No t very useful	Do not know
8. How important is it to have natural ventilation in the building?						
9. How important is it to have nighttime ventilation to get cooler outside air?						
10. How important is it to have fresh air in the building without mechanical systems?						
11. How important is it to have comfortable temperature in winter?						
12. How important is it to have comfortable temperature in summer?						

13. How important is it to have day light in the building?						
14. How important is it to prevent glare (large amount of reflected light)?						
15. How important is it to have outside view from inside of the building?						
16. How important is it to prevent outside noise from entering the building?						
17. How important is it to reduce energy consumption by using renewable energy (solar, wind, water, and geothermal energy)?						
18. How useful is it to decrease maintenance cost of facade by having access to it?						
19. How useful is it to decrease maintenance cost of facade by having simple systems or components?						
20. How important is it to decrease construction cost of the facade by applying affordable material or systems?						
21. How useful is it to decrease cost of installation in the facade construction?						
22. How important is it to decrease air pollution caused by the consumption of fossil fuels to have fresh air?						
23. How important is it to use low emission materials (toxic materials) to have fresh air?						
24. How important is it to decrease soil pollution by designing for deconstruction and decreasing waste of construction?						

A1: Questionnaire Regarding Occupants' Requirements (Turkish)

Bu çalışma, ODTÜ'de Yapı Bilimleri Yüksek Lisans Programı, Mimarlık Bölümü'nde doktora öğrencisi Nastaran Deljavan tarafından yürütülen bina cephelerinin tasarımı hakkındadır. Bu çalışmada, güneş enerjisi ile verimli cepheler tasarlamak için yeni bir yaklaşım önermek esastır. Bu amaca ulaşmak için, tasarım kalitesini artıran Kalite Fonksiyon Göçerimi yöntemi kullanılacaktır. Kalite Fonksiyon Göçerimi yönteminin stratejisinin temeli, tasarım sürecinin tüm adımlarında dikkate alınacak olan kullanıcı gereksinimidir; bu nedenle, anket araştırmasına ihtiyaç duyulacaktır.

Bu çalışma kapsamında, Kalite Fonksiyon Göçerimi yöntemi dört aşamadan oluşmaktadır. Bu aşamalar:

- Tasarim Hedefleri Aşaması,
- Kullanici Gereksinimleri Aşaması,
- Tasarim Teknikleri Aşaması,
- Cephe Tasarimi Aşaması,

Her aşamada, Analitik Hiyerarşi süreci (AHP) matrisleri, korelasyon matrisleri ve kalite evi, grafikler ve anketlerinden oluşan birkaç adım vardır.

Bu çalışmaya gerekli verileri elde etmek için, bina sakinlerine ve mimarlara gönderilecek iki anket kullanacağız. Anket aracılığıyla toplanan verileri sadece burada belirtilen doktora araştırması için kullanılacaktır.

Nastaran Deljavan

ODTÜ'de Yapı Bilimleri Yüksek Lisans Programı, Mimarlık Bölümü'nde doktora öğrencisi

E-mail: deljavan.nastaran@metu.edu.tr

1. Cinsiyet;

Erkek Kadın

2. Yaşınız aşağıdaki gruplardan hangisine girmektedir?

20 den az 20-29 30-39 40-49 50 den fazla

3. Mesleğiniz nedir? ………………………………………….

4. Cephe tasarlamak için hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Kullanıcı konforu	Toplam İnşaat Maliyetini Düşürmesi				
Kullanıcı konforu	Çevre Kirliliğinin Azaltılması				
Toplam İnşaat Maliyetini Düşürmesi	Çevre Kirliliğinin Azaltılması				

5. Bina içinde daha iyi bir ortam sağlamak için hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun olanı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Sıcaklık	Hava kalitesi				
Sıcaklık	Aydınlatma				
Sıcaklık	Akustik				
Hava kalitesi	Aydınlatma				
Hava kalitesi	Akustik				
Aydınlatma	Akustik				

6. Cephe tasarımı ile toplam inşaat maliyetini düşürmede hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Cephe tasarımı sayesinde enerji tüketim maliyetini azaltmak	Cephe bakım / temizlik maliyetinin düşürülmesi				
Cephe tasarımı sayesinde enerji tüketim maliyetini azaltmak	Cephe ilk yapım maliyetinin düşürülmesi				
Cephe bakım / temizlik maliyetinin düşürülmesi	Cephe ilk yapım maliyetinin düşürülmesi				

7. Cephe tasarımı ile çevre kirliğin düşürmede hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Hava kirliğin azaltmak	Toprak kirliğin azaltmak				
Hava kirliğin azaltmak	Aydınlık kirliğin azaltmak				
Toprak kirliğin azaltmak	Aydınlık kirliğin azaltmak				

Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

	Çok önemli / Çok yararlı	Önemli / Yararlı	Nötr	Önemsiz / Yararsız	Çok önemsiz / Çok yararsız	Fikrim yok
8. Binada doğal havalandırma yapılması ne kadar önemli olur?						

9. Dışarıdaki serin havanın içeri alınması için gece havalandırması ne kadar önemli olur?						
10. Binalarda mekanik havalandırma sistemleri kullanmadan temiz hava sağlamak ne kadar yararlı olur?						
11. Kış aylarında binada uygun sıcaklığa sahip olmak ne kadar önemli olur?						
12. Yaz aylarında binada uygun sıcaklığa sahip olmak ne kadar önemli olur?						
13. Binanın yapay ışıklandırma kullanmadan gün ışığı ile aydınlatılması ne kadar önemli olur?						
14. Parlamayı önlemek (çok yansıyan ışık) ne kadar önemli olur?						
15. Binanın içinden dışarıyı görmek ne kadar önemli olur?						
16. Dışarıdaki gürültünün binaya girmesini önlemek ne kadar önemli olur?						
17. Yenilenebilir enerji (güneş, rüzgar su,ve jeotermal enerjisi) Kullanarak enerji tüketimini azaltmak ne kadar önemli olur?						
18. Cepheye erişerek cephenin bakım maliyetini azaltmak ne kadar önemli olur?						
19. Basit sistemlere veya basit bileşenlere uygulayarak cephenin maliyetini azaltmak ne kadar önemli olur?						

20. Uygun fiyatlı malzeme veya sistemler uygulayarak cephenin inşaat maliyetini azaltmak ne kadar önemli olur?						
21. Cephe inşaatında montaj maliyetini azaltmak ne kadar yararlı olur?						
22. Fosil yakıtların tüketiminden kaynaklanan hava kirliliğini azaltmak ne kadar önemli olur?						
23. Cephe inşaatında düşük emisyonlu malzemeler kullanmak ne kadar önemli olur?						
24. Toprak kirliliğini azaltmak için cephe elemanlarının sökülüp başka yerde yeniden kullanabilmesi ve atık miktarını azaltıması ne kadar önemli olur?						

A1: Questionnaire Regarding Occupants’ Requirements (Persian)

این مطالعه درمورد طراحی نمای ساختمانهای مسکونی بلند مرتبه توسط نسترن دلجوان، دانشجوی دکتری در رشته تکنولوژی ساخت زیر شاخه دپارتمان معماری دانشگاه فنی خاورمیانه در ترکیه انجام می گیرد. هدف اصلی این مطالعه ارائه یک روش جدید برای طراحی نماهای ساختمان با استفاده از انرژی خورشیدی است. برای دستیابی به این هدف و افزایش کیفیت طراحی از روش گسترش کارکرد کیفیت استفاده خواهد شد. مبنای روش نامبرده بر پایه نیاز کاربران می باشد که در تمام مراحل تحقیق تا طراحی در نظر گرفته خواهد شد.

این مطالعه در چهار مرحله با استفاده از روش گسترش کارکرد کیفیت صورت گرفته خواهد شد. مراحل مذکود عبارتند از:

- مرحله تعیین اهداف
- مرحله تعیین نیاز کاربران
- مرحله تعیین تکنیک های طراحی
- مرحله طراحی نما

هر مرحله شامل چندین زیر مرحله است که ماتریسهای تحلیلی، نمودارها و پرسشنامه ها را شامل می شود. جهت به دست آوردن اطلاعات مورد نیاز، دو نوع پرسشنامه که پاسخ دهندگان آنها ساکنان ساختمانها و معماران هستند آماده شده است. اطلاعات جمع آوری شده از طریق پرسشنامه فقط برای تحقیقات دکترای مذکور مورد استفاده قرار خواهد گرفت.

نسترن دلجوان

دانشجوی دکترای رشته علم ساختمان در دپارتمان معماری دانشگاه فنی خاورمیانه، ترکیه

ایمیل: deljavan.nastaran@metu.edu.tr

1. جنسیت؛

مرد زن

2. گروه سنی شما چیست؟

کمتر از 20 سال 29-20 30-39 40-49 بالای 50 سال

3. شغل شما چیست؟ ....

4. کدام پارامتر برای طراحی نماهای ساختمانها مهم تر است؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

پارامترها		پارامتر الف مهمتر از پارامتر ب است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر ب مهمتر از پارامتر الف است	نمی دانم
الف	ب				
آسایش (راحتی) انسان	کاهش هزینه				
آسایش (راحتی) انسان	کاهش آلودگی محیط زیست				
کاهش هزینه	کاهش آلودگی محیط زیست				

5. کدام پارامتر برای بهبود کیفیت محیط داخلی ساختمان بهتر است؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

پارامترها		پارامتر الف مهمتر از پارامتر ب است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر ب مهمتر از پارامتر الف است	نمی دانم
الف	ب				
دمای مطلوب	کیفیت هوای داخل ساختمان				
دمای مطلوب	روشنایی				
دمای مطلوب	جلوگیری از ورد صدای بیرون				
کیفیت هوا داخل ساختمان	روشنایی				
کیفیت هوا داخل ساختمان	جلوگیری از ورد صدای بیرون				
روشنایی	جلوگیری از ورد صدای بیرون				

6. کدام پارامتر در کاهش هزینه کلی ساختمان از طریق طراحی مناسب مهم تر است؟ لطفا با توجه به نظر/ تجربه خود، گزینه مناسب را انتخاب کنید.

نمی دانم	پارامتر ب مهمتر از پارامتر الف است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر الف مهمتر از پارامتر ب است	پارامترها	
				ب	الف
				کاهش هزینه نگهداری / تمیز کردن نمای ساختمان	کاهش هزینه مصرف انرژی از طریق طراحی نما
				کاهش هزینه ساخت نما	کاهش هزینه مصرف انرژی از طریق طراحی نما
				کاهش هزینه ساخت نما	کاهش هزینه نگهداری / تمیز کردن نمای ساختمان

7. کدام پارامتر در کاهش آلودگی محیط زیست از طریق طراحی مناسب نما، مهم است؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

نمی دانم	پارامتر ب مهمتر از پارامتر الف است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر الف مهمتر از پارامتر ب است	پارامترها	
				ب	الف
				کاهش آلودگی خاک	کاهش آلودگی هوا
				کاهش آلودگی نور	کاهش آلودگی هوا
				کاهش آلودگی نور	کاهش آلودگی خاک

لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

نمی دانم	خیلی مهم نیست / خیلی مفید نیست	مهم نیست / مفید نیست	خنثی	مهم / مفید	بسیار مهم / بسیار مفید	
						8. داشتن تهویه طبیعی در ساختمان چقدر مهم می باشد؟
						9. تهویه شبانه برای خنک کردن هوای داخل ساختمان چقدر مهم می باشد؟
						10. داشتن هوای تازه در ساختمان بدون سیستم مکانیکی چقدر مهم می باشد؟
						11. داشتن دمای مناسب در زمستان چقدر مهم می باشد؟
						12. داشتن دمای مناسب در تابستان چقدر مهم میباشد؟
						13. داشتن نور طبیعی در ساختمان چقدر مهم می باشد؟

.14 جلوگیری از انعکاس نور آفتاب در فضای داخلی ساخنمان چقدر مهم می باشد؟						
.15 دیدن منظره های خارج، از درون ساختمان چقدر مهم می باشد؟						
.16 جلوگیری از ورود سر و صدای خارجی به ساختمان چقدر مهم می باشد؟						
.17 بکارگیری انرژیهای قابل تجدید در کاهش مصرف انرژی (انرژی خورشید، باد، آب و زمین) در ساختمان چقدر مهم می باشد؟						
.18 داشتن دسترسی به نما در کاهش هزینه های تعمیر و نگهداری نما چقدر مهم می باشد؟						
.19 بکارگیری سیستمها ودیتایلهای ساده در کاهش هزینه های تعمیر و نگهداری نما چقدر مهم می باشد؟						
.20 بکارگیری مصالح و یا سیستم های مقرون به صرفه در کاهش هزینه های ساخت نمای ساختمان چقدر مهم می باشد؟						
.21 کاهش هزینه نصب در ساخت نمای ساختمان چقدر مفید می باشد؟						
.22 کاهش آلودگی هوای ناشی از مصرف سوخت های فسیلی چقدر مهم می باشد؟						
.23 بکارگیری مصالح کم آلاینده درنما برای داشتن هوای تازه چقدر مفید می باشد؟						
.24 استفاده مجدد از المانهای نما در طراحی ساختمانهای دیگر چقدر مفید است؟						

A2: Questionnaire Regarding Technical Solutions (English)

This study is about the designing of building facades, which is being conducted by Nastaran Deljavan, a Ph.D. student in the Building Science Graduate Program, Department of Architecture at Middle East Technical University (METU) in Turkey. In this study, the main aim is to propose a novel approach for designing efficient facades by using solar energy. For achieving this aim, the Quality Function Deployment (QFD) method will be used, which increases design quality. The basis of the design strategy of the QFD method is the user requirement, which will be considered in all steps of the design process. The framework of this study consists of four phases by using the QFD method. These phases are:

- Design Targets phase,
- User requirements phase,
- Design techniques phase,
- Facade design phase.

Each phase has several steps, which consist of the Analytic Hierarchy process (AHP) matrices, correlation matrices and house of quality, charts, and questionnaire surveys. In order to obtain data required for this study, we will use two questionnaires, which will be sent to building residents and architects. The data gathered through the questionnaire survey will be utilized only for the doctoral research mentioned herein.

Nastaran Deljavan

Ph.D student in Building Science Program in Architecture Department, at Middle East Technical University, Turkey

E-mail: deljavan.nastaran@metu.edu.tr

1. Which parameter is more important for designing efficient facades? Please select the appropriate answer according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Human Comfort	Decreasing Cost				
Human Comfort	Decreasing Environmental Pollution				
Decreasing Cost	Decreasing Environmental Pollution				

2. Which parameter is more important to provide better indoor environment? Please select the appropriate one according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Temperature	Air Quality				
Temperature	Lighting				
Temperature	Acoustics				
Air Quality	Lighting				
Air Quality	Acoustics				
Lighting	Acoustics				

3. Which parameter is more important in decreasing overall cost of building through facade design? Please select the appropriate answer according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Decreasing cost of energy consumption through facade design	Decreasing cost of facade maintenance/cleaning				
Decreasing cost of energy consumption through facade design	Decreasing cost of facade construction				
Decreasing cost of facade maintenance/cleaning	Decreasing cost of facade construction				

4. Which parameter is more important in decreasing environmental pollution through facade design? Please select the appropriate answer according to your opinion/experience.

Parameters		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Decreasing air Pollution	Decreasing soil pollution				
Decreasing air Pollution	Decreasing light pollution				
Decreasing soil pollution	Decreasing light pollution				

5. Which types of renewable resources do you prefer for producing energy through the facade? Please select the appropriate answer according to your opinion/experience.

Renewable resources		A more important than B	A and B equally important	B more important than A	Do not know
A	B				
Solar energy	Wind energy				
Solar energy	Water energy				
Solar energy	Geothermal				
Wind energy	Water energy				
Wind energy	Geothermal				
Water energy	Geothermal				

Please select the appropriate answer according to your opinion/experience.

	Very importa nt/very useful	Impor tant/ useful	Neutral	Not importa nt/ Not useful	Not very importa nt/ Not very useful	Do not know
Indoor Air Quality						
6. How useful is it to have openable windows for natural ventilation (day or night)?						
7. How useful is it to have natural ventilation (day or night) through vertical ducts on the facade?						
8. How useful is it to have natural ventilation (day or night) through vents (grills) on the facade?						

9. How useful is it to filter incoming air through the facade?						
10. How useful is it to design facades with plants for filtering the air to have better air quality?						
Thermal Comfort in Winter						
11. How useful is it to employ passive heating system in the building?						
12. How useful is it to optimize “window to wall ratio” to gain more solar energy?						
13. How useful is it to have water pipe embedded for exterior wall to heat interior spaces and have hot water supply?						
14. How useful is it to design solar space (closed balconies) on the facade for heating?						
15. How useful is it to design thermal mass (solar walls) on the facade for space heating?						
16. How useful is it to have airtight openings (windows/doors) to prevent heat loss through the facade?						
17. How useful is it to have insulated glass for openings (triple glazed or laminate glass) to prevent heat transfer through the facade?						
18. How useful is it to have thermal insulation in designing of facade for preventing heat loss/heat gain?						
19. How useful to design opening in appropriate direction to get more solar radiation?						
Thermal Comfort in Summer						
20. How useful is it to employ passive cooling system in the building?						
21. How useful is it to integrate water evaporative systems (water clay pipes) on the facade for cooling?						
22. How useful is it to optimize “window to wall ratio” to prevent solar heat gain?						
23. How useful is it to have insulated glass for windows (triple glazed or laminate glass) to prevent heat transfer through the facade?						
24. How useful is it to have tinted (colored) glass for providing thermal comfort?						
25. How useful is it to have exterior shading devices on the facades to block excessive sun light?						

26. How useful is it to have interior shading devices on the facades to block excessive sun light?						
27. How useful is it to have shading devices in cavity of double skin facade to block excessive sun light?						
28. How useful is it to have a balcony as a shading element on the facade?						
29. How useful is it to have light color materials on the facades for prevent heat gain by reflection?						
30. How useful is it to design self-shading facades to prevent heat gain?						
31. How useful is it to have vegetated facades to prevent heat gain?						
Visual Comfort						
32. How useful is it to optimize "windows - wall ratio" to have more day light and view?						
33. How useful is it to design light shelves to have more daylight in the building?						
34. How useful is it to integrate light tubes to have more daylight in the building?						
35. How useful is it to design perforated material (punched, mesh,) for shading elements to prevent glare?						
36. How useful is it to have movable shading devices on the facades?						
37. How useful is it to use tinted (colored) glass to have visual comfort?						
Acoustic Comfort						
38. How useful is it to have airtight windows/doors (damping) to block outside noise?						
39. How useful is it to use insulated glass for openings (triple glazed or laminate glass) to block outside noise?						
40. How useful is it to use sound insulation in designing of facade?						
41. How useful is it to design double layer wall for blocking outside noise?						
42. How useful is it to have vegetated facades to decrease sound transition?						
Energy Generation from Renewable Sources						
43. How useful is it to produce energy through the facades?						
44. How useful is it to integrate Photovoltaic panels on the facades for producing electricity from solar energy?						

45. How useful is it to integrate solar collector on the facade for space heating?						
46. How useful is it to integrate solar collector on the facade for having hot water supply?						
47. How useful is it to integrate wind turbine on the facades for producing electricity?						
48. How useful is it to integrate geothermal heating by using pipe in the exterior wall?						
49. How useful is it to integrate geothermal cooling by using pipe in the exterior wall?						
Decreasing Construction and Maintenance Cost						
50. How important is it to use low maintenance opaque materials/self-cleaning materials on the facade?						
51. How useful is it to have low maintenance/ self-cleaning glass on the facade?						
52. How important is it to use durable materials (long lasting) on the facade?						
53. How important is it to design low maintenance systems (static or kinetic) on the facades?						
54. How useful is it to employ automatic robots for facades cleaning for decreasing maintenance cost?						
55. How useful is it to optimize “window to wall ratio” in order to decrease glass area for reducing cost?						
56. How important is it to use local materials on the facades?						
57. How important is it to use affordable materials on the facades?						
58. How useful is it to decrease cost of installation in the facade construction by employing modular and prefabricated panels?						
Decreasing Environmental Pollution						
59. How important is it to use nontoxic glues in construction of the facade?						
60. How important is it to use nontoxic finishing in construction of the facade?						
61. How important is it to use nontoxic paints in construction of the facade?						

62. How important is it to design for deconstruction?						
63. How important is it to use reusable materials and systems in construction?						
64. How important is it to use recyclable materials in construction?						
65. How important is it to remove decorative lighting from building facades for decreasing light pollution?						

A2: Questionnaire Regarding Technical Solutions (Turkish)

Bu çalışma, ODTÜ'de Yapı Bilimleri Yüksek Lisans Programı, Mimarlık Bölümü'nde doktora öğrencisi Nastaran Deljavan tarafından yürütülen bina cephelerinin tasarımı hakkındadır. Bu çalışmada, güneş enerjisi ile verimli cepheler tasarlamak için yeni bir yaklaşım önermek esastır. Bu amaca ulaşmak için, tasarım kalitesini artıran Kalite Fonksiyon Göçerimi yöntemi kullanılacaktır. Kalite Fonksiyon Göçerimi yönteminin stratejisinin temeli, tasarım sürecinin tüm adımlarında dikkate alınacak olan kullanıcı gereksinimidir; bu nedenle, anket araştırmasına ihtiyaç duyulacaktır.

Bu çalışma kapsamında, Kalite Fonksiyon Göçerimi yöntemi dört aşamadan oluşmaktadır. Bu aşamalar:

- Tasarim Hedefleri Aşaması,
- Kullanici Gereksinimleri Aşaması,
- Tasarim Teknikleri Aşaması,
- Cephe Tasarimi Aşaması,

Her aşamada, Analitik Hiyerarşi süreci (AHP) matrisleri, korelasyon matrisleri ve kalite evi, grafikler ve anketlerinden oluşan birkaç adım vardır.

Bu çalışmaya gerekli verileri elde etmek için, bina sakinlerine ve mimarlara gönderilecek iki anket kullanacağız. Anket aracılığıyla toplanan verileri sadece burada belirtilen doktora araştırması için kullanılacaktır.

Nastaran Deljavan

ODTÜ'de Yapı Bilimleri Yüksek Lisans Programı, Mimarlık Bölümü'nde doktora öğrencisi

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1. Verimli cephelerini tasarlamak için hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
İnsan konforu	Toplam İnşaat Maliyetini Düşürmesi				
İnsan konforu	Çevre Kirliliğinin Azaltılması				
Toplam İnşaat Maliyetini Düşürmesi	Çevre Kirliliğinin Azaltılması				

2. Bina içinde daha iyi bir ortam sağlamak için hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun olanı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Sıcaklık	Hava kalitesi				
Sıcaklık	Aydınlatma				
Sıcaklık	Akustik				
Hava kalitesi	Aydınlatma				
Hava kalitesi	Akustik				
Aydınlatma	Akustik				

3. Cephe tasarımı ile toplam inşaat maliyetini düşürmede hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Cephe tasarımı sayesinde enerji tüketim maliyetini azaltmak	Cephe bakım / temizlik maliyetinin düşürülmesi				
Cephe tasarımı sayesinde enerji tüketim maliyetini azaltmak	Cephe ilk yapım maliyetinin düşürülmesi				
Cephe bakım / temizlik maliyetinin düşürülmesi	Cephe ilk yapım maliyetinin düşürülmesi				

4. Cephe tasarımı ile çevre kirliğin düşürmede hangi parametre daha önemli olur? Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

Parametreler		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Hava kirliğin azaltmak	Toprak kirliğin azaltmak				
Hava kirliğin azaltmak	Aydınlık kirliğin azaltmak				
Toprak kirliğin azaltmak	Aydınlık kirliğin azaltmak				

5. Cephede enerji üretmek için hangi türden yenilenebilir kaynaklar tercih ediyorsunuz? Lütfen görüşünüze / deneyiminize uygun cevabı seçiniz.

Yenilenebilir kaynaklar		A, B den daha önemli	A ve B eşit derecede önemli	B, A dan daha önemli	Fikrim yok
A	B				
Güneş enerjisi	Rüzgar enerjisi				
Güneş enerjisi	Hidro enerji				
Güneş enerjisi	Jeotermal				
Rüzgar enerjisi	Hidro enerji				
Rüzgar enerjisi	Jeotermal				
Hidro enerji	Jeotermal				

Lütfen görüşünüze / deneyimize uygun cevabı seçiniz.

	Çok önemli / Çok yararlı	Önemli / Yararlı	Nötr	Önemsiz / Yararsız	Çok önemsiz / Çok yararsız	Fikrim yok
İç Ortam Hava Kalitesi						
6. Doğal havalandırma için (gündüz ve gece) açılabilir pencerelerin olması ne kadar yararlı olur?						
7. Cephede düşey kanallardan geçerek havalandırma (gündüz ve gece) yapılması ne kadar yararlı olur?						

8. Dış cephelerde bulunan havalandırma deliklerinden (ızgaralar) gündüz ve gece havalandırmasının yapılması ne kadar yararlı olur?						
9. Cepheden gelen havayı filtrelemek ne kadar yararlı olur?						
10. Dışardan gelen havayı cephedeki bitkiler ile filtrelemek ne kadar yararlı olur?						
Termal Konfor (kış)						
11. Binada pasif ısıtma sistemi kullanmak ne kadar yararlı olur?						
12. Daha fazla güneş enerjisi elde etmek için “pencere-duvar oranını” optimize etmek ne kadar yararlı olur?						
13. Isıtma için dış duvarda su borusu kullanılması ne kadar yararlı olur?						
14. Isıtma için cephede güneş odası (kapalı balkonlar) tasarlamak ne kadar yararlı olur?						
15. Isıtma için cephede termal kütle (güneş duvarları) tasarlamak ne kadar yararlı olur?						
16. Cepheden ısı kaybını önlemek için hava geçirmez pencereler / kapılar kullanmak ne kadar yararlı olur?						
17. Cepheden ısı geçişini önlemek için üç camlı ve ya laminat camlı pencereler kullanmak ne kadar yararlı olur?						
18. Isı kaybını / ısı kazanımını önlemek için cephe tasarımında ısı yalıtımı ne kadar yararlı olur?						
19. Isıtma için dış pencerelerin yönüleri ne kadar önemli olur?						
Termal Konfor (yaz)						
20. Binada pasif soğutma sistemi kullanmak ne kadar yararlı olur?						
21. Su buharlaştırma sistemlerinin (cephelerde kil den yapma su boruları						

kullanılması) soğutma için cepheye entegre edilmesi ne kadar yararlı olur?						
22. Güneş ısısı kazanımını önlemek için “pencere-duvar oranını” optimize etmek ne kadar yararlı olur?						
23. Cepheden ısı geçişini önlemek için üç camlı ve ya laminat camlı pencereler kullanmak ne kadar yararlı olur?						
24. Termal konfor sağlamak için renkli camlar(filmli camlar) kullanmak ne kadar yararlı olur?						
25. Aşırı güneş ışığını engellemek için cephelerde dış gölgeleme cihazlarının kullanılması ne kadar yararlı olur?						
26. Aşırı güneş ışığını engellemek için cephelerde iç gölgeleme cihazlarının kullanılması ne kadar yararlı olur?						
27. Aşırı güneş ışığını engellemek için çift cidarlı cam cephe boşluğunda gölgeleme cihazlarının kullanılması ne kadar yararlı olur?						
28. Cephede gölgelendirme elemanı olarak bir balkon ne kadar yararlı olur?						
29. Yansıtma yoluyla ısı kazanımını önlemek için cephelerde açık renkli malzemelerin kullanılması ne kadar yararlı olur?						
30. Isı kazanımını önlemek için kendinden gölgeli cepheler tasarlamak ne kadar yararlı olur?						
31. Isı kazanımını önlemek için bitkilendirilmiş cepheler tasarlamak ne kadar yararlı olur?						
Görsel Konfor						
32. Gün ışığına daha fazla sahip olmak için “pencere-duvar oranını” optimize etmek ne kadar yararlı olur?						

33. Binada daha fazla gün ışığına sahip olmak için ışık rafı tasarlamak ne kadar yararlı olur?						
34. Binada daha fazla gün ışığına sahip olmak için ışık tüplerini entegre etmek ne kadar yararlı olur?						
35. Parlamayı önlemek için cephelere perfore ızgaraları tasarlamak ne kadar yararlı olur?						
36. Cephelerde hareketli gölgeleme cihazları tasarlamak ne kadar yararlı olur?						
37. Renkli camlar (filmli camlar) görsel konfor için kullanmak ne kadar yararlı olur?						
Akustik Konfor						
38. Dış gürültüyü engellemek için hava geçirmez pencereler / kapılar kullanmak ne kadar yararlı olur?						
39. Dış gürültüyü engellemek için üç camlı pencereler ve ya laminat cam kullanmak ne kadar yararlı olur?						
40. Cephe tasarımında ses yalıtımı kullanmak ne kadar yararlı olur?						
41. Dış gürültüyü engellemek için çift katmanlı duvar tasarlamak ne kadar yararlı olur?						
42. Ses geçişini azaltmak için bitkilendirilmiş cephe tasarlamak ne kadar yararlı olur?						
Enerji Üretimi (yenilenebilir enerji)						
43. Cephelerde enerji üretmek ne kadar yararlı olur?						
44. Fotovoltaik panelleri cephelere güneş enerjisinden elektrik üretmek için entegre etmek ne kadar yararlı olur?						
45. Isıtma için güneş kolektörlerini cepheye entegre etmek ne kadar yararlı olur?						

46. Sıcak su temini için güneş kolektörlerini cepheye entegre etmek ne kadar yararlı olur?						
47. Elektrik üretimi için rüzgar türbinlerinin cephelere entegre edilmesi ne kadar yararlı olur?						
48. Dış duvarda boru kullanarak jeotermal ısıtmayı entegre etmek ne kadar yararlı olur?						
49. Dış duvarda boru kullanarak jeotermal soğutmayı entegre etmek ne kadar yararlı olur?						
İnşaat ve Bakım Maliyetini Düşürmek						
50. Cephede daha az bakım gerektiren opak malzemeler/kendi kendini temizleyen malzemeler kullanmak ne kadar önemli olur?						
51. Cephede daha az bakım gerektiren / kendi kendini temizleyen camlar kullanlması ne kadar yararlı olur?						
52. Cephede dayanıklı malzemeler (uzun ömürlü) kullanmak ne kadar önemli olur?						
53. Cephelerde daha az bakım gerektiren sistemler (statik veya kinetik) kullanmak ne kadar önemli olur?						
54. Bakım maliyetini azaltmak için cephelerin temizliğinde otomatik robotlar kullanmak ne kadar yararlı olur?						
55. Maliyeti azaltmak için cam alanının azaltması amacıyla “pencere-duvar oranını” optimize etmek ne kadar yararlı olur?						
56. Cephelerde yerel malzemeler kullanmak ne kadar önemli olur?						
57. Cephelerde uygun fiyatlı malzemeler kullanmak ne kadar önemli olur?						

58. Cephe inşaatında montaj maliyetin azaltmak için modüler ve prefabrik paneller kullanmak ne kadar yararlı olur?						
Çevre Kirliliğinin Azaltılması						
59. Cephe yapımında toksik olmayan yapıştırıcıların kullanılması ne kadar önemli olur?						
60. Cephe yapımında toksik olmayan malzemelerin kullanılması ne kadar önemli olur?						
61. Cephe inşaatında toksik olmayan boyaların kullanılması ne kadar önemli olur?						
62. Cephe elemanlarının sökülüp başka yerde yeniden kullanabilmesi ne kadar önemli olur?						
63. Yeniden kullanılabilir malzemelerin inşaatta kullanilması ne kadar önemli olur?						
64. İnşaatta geri dönüştürülebilir malzemeler kullanmak ne kadar önemli olur?						
65. Işık kirliliğini azaltmak için bina cephelerinden dekoratif aydınlatmayı kaldırmak ne kadar yararlı olur?						

A2: Questionnaire Regarding Technical Solutions (Persian)

این مطالعه درمورد طراحی نمای ساختمانهای مسکونی بلند مرتبه توسط نسترن دلجوان، دانشجوی دکتری در رشته تکنولوژی ساخت زیر شاخه دپارتمان معماری دانشگاه فنی خاورمیانه در ترکیه انجام می گیرد. هدف اصلی این مطالعه ارائه یک روش جدید برای طراحی نماهای ساختمان با استفاده از انرژی خورشیدی است. برای دستیابی به این هدف و افزایش کیفیت طراحی از روش گسترش کارکرد کیفیت استفاده خواهد شد. مبنای روش نامبرده بر پایه نیاز کاربران می باشد که در تمام مراحل تحقیق تا طراحی در نظر گرفته خواهد شد.

این مطالعه در چهار مرحله با استفاده از روش گسترش کارکرد کیفیت صورت گرفته خواهد شد. مراحل مذکود عبارتند از:

- مرحله تعیین اهداف
- مرحله تعیین نیاز کاربران
- مرحله تعیین تکنیک های طراحی
- مرحله طراحی نما

هر مرحله شامل چندین زیر مرحله است که ماتریسهای تحلیلی، نمودارها و پرسشنامه ها را شامل می شود. جهت به دست آوردن اطلاعات مورد نیاز، دو نوع پرسشنامه که پاسخ دهندگان آنها ساکنان ساختمانها و معماران هستند آماده شده است. اطلاعات جمع آوری شده از طریق پرسشنامه فقط برای تحقیقات دکترای مذکور مورد استفاده قرار خواهد گرفت.

نسترن دلجوان

دانشجوی دکترای رشته علم ساختمان در دپارتمان معماری دانشگاه فنی خاورمیانه، ترکیه

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1. کدام پارامتر برای طراحی نماهای ساختمانها مهم تر است؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

پارامترها		پارامتر الف مهمتر از پارامتر ب است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر ب مهمتر از پارامتر الف است	نمی دانم
الف	ب				
آسایش (راحتی) انسان	کاهش هزینه				
آسایش (راحتی) انسان	کاهش آلودگی محیط زیست				
کاهش هزینه	کاهش آلودگی محیط زیست				

2. کدام پارامتر برای بهبود کیفیت محیط داخلی ساختمان بهتر است؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

پارامترها		پارامتر الف مهمتر از پارامتر ب است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر ب مهمتر از پارامتر الف است	نمی دانم
الف	ب				
دمای مطلوب	کیفیت هوای داخل ساختمان				
دمای مطلوب	روشنایی				
دمای مطلوب	آکوستیک (جلوگیری از ورد صدای بیرون)				
کیفیت هوا داخل ساختمان	روشنایی				
کیفیت هوا داخل ساختمان	آکوستیک (جلوگیری از ورد صدای بیرون)				
روشنایی	آکوستیک (جلوگیری از ورد صدای بیرون)				

3. کدام پارامتر در کاهش هزینه کلی ساختمان از طریق طراحی مناسب نما، مهم است؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

پارامترها		پارامتر الف مهمتر از پارامتر ب است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر ب مهمتر از پارامتر الف است	نمی دانم
الف	ب				
کاهش هزینه مصرف انرژی از طریق طراحی نما	کاهش هزینه نگهداری / تمیز کردن نمای ساختمان				
کاهش هزینه مصرف انرژی از طریق طراحی نما	کاهش هزینه ساخت نما				
کاهش هزینه نگهداری / تمیز کردن نمای ساختمان	کاهش هزینه ساخت نما				

4. کدام پارامتر در کاهش آلودگی محیط زیست از طریق طراحی مناسب نما، مهم است؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

پارامترها		پارامتر الف مهمتر از پارامتر ب است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر ب مهمتر از پارامتر الف است	نمی دانم
الف	ب				
کاهش آلودگی هوا	کاهش آلودگی خاک				
کاهش آلودگی هوا	کاهش آلودگی نور				
کاهش آلودگی خاک	کاهش آلودگی نور				

5. کدام نوع از منابع تجدیدپذیر را برای تولید انرژی از طریق نما ترجیح می دهید؟ لطفا با توجه به نظر / تجربه خود، گزینه مناسب را انتخاب کنید.

پارامترها		پارامتر الف مهمتر از پارامتر ب است	پارامتر الف و ب اهمیت یکسان دارند	پارامتر ب مهمتر از پارامتر الف است	نمی دانم
الف	ب				
انرژی خورشیدی	انرژی باد				
انرژی خورشیدی	انرژی آب				
انرژی خورشیدی	ژئوترمال (انرژی زمین)				
انرژی باد	انرژی آب				
انرژی باد	ژئوترمال (انرژی زمین)				
انرژی آب	ژئوترمال (انرژی زمین)				

لطفا با توجه به نظر / تجربه خود، پاسخ مناسب را انتخاب کنید

	بسیار مهم / بسیار مفید	مهم / مفید	خنثی	مهم نیست / مفید نیست	خیلی مهم نیست / خیلی مفید نیست	نمی دانم
کیفیت هوا در داخل بنا						
6. داشتن پنجره های بازشو جهت تهویه طبیعی (روزانه یا شبانه) چقدر مفید می باشد؟						
7. طراحی داکتهای عمودی در نما جهت تهویه طبیعی (روزانه یا شبانه) چقدر مفید می باشد؟						
8. طراحی روزنه های کوچک در نما جهت تهویه طبیعی (روزانه یا شبانه) چقدر مفید می باشد؟						
9. تصفیه هوای وارد شده از طریق پنجره ها چقدر مفید می باشد؟						

						10. تصفیه هوای وارد شده از طریق گیاهان روی نما چقدر مفید می باشد؟
آسایش حرارتی(زمستان)						
						11. استفاده از سیستم گرمایش پسیو در ساختمان چقدر مفید می باشد؟
						12. بهسازی تناسب پنجره ها به دیوار در طراحی نما جهت جذب بیشتر انرژی خورشید چقدر مفید می باشد؟
						13. تامین گرمایش ساختمان با طراحی سیستم لوله کشی روی نما (با استفاده از انرژی خورشیدی) چقدر مفید می باشد؟
						14. طراحی فضای خورشیدی (سیستم گلخانه یا بالکن سرپوشیده) در نما جهت ذخیره گرمای خورشید چقدر مفید می باشد؟
						15. طراحی دیوار خورشیدی (جرم حرارتی) در نما جهت حفظ گرمایش فضای داخلی چقدر مفید می باشد؟
						16. هوابندی درها و پنجره های نما جهت جلوگیری از هدر رفتن گرما چقدر مفید می باشد؟
						17. استفاده از پنجره های با شیشه سه لایه یا لمینیت شده در نما جهت جلوگیری از هدر رفتن گرما چقدر مفید می باشد؟
						18. استفاده از عایق حرارتی در نما جهت جلوگیری از انتقال گرما چقدر مفید می باشد؟
						19. طراحی پنجره های در جهت مناسب در نما برای بهره وری بیشتراز گرمای خورشید چقدر مفید می باشد؟
آسایش حرارتی(تابستان)						
						20. استفاده از سیستم سرمایش پسیو در ساختمان چقدر مفید می باشد؟
						21. استفاده ازسیستم تبخیر آب (بوسیله نصب لوله های سفالی) درنما جهت تامین سرمایش ساختمان چقدر مفید می باشد؟
						22. بهسازی تناسب پنجره ها به دیوار در طراحی نما جهت جلوگیری از جذب بیشتر انرژی خورشید در تابستان چقدر مفید می باشد؟
						23. استفاده از پنجره های با شیشه سه لایه یا لمینیت شده در

						نما جهت جلوگیری از جذب بیشتر انرژی خورشیدی در تابستان چقدر مفید می باشد؟
						24. استفاده از شیشه های دودی (رنگی) در نما جهت جاوگیری از گرمای بیشتر خورشید در تابستان چقدر مفید می باشد؟
						25. استفاره از سایه بان در نما جهت جلوگیری از نفوذ بیشتر گرمای خورشید در تابستان چقدر مفید می باشد؟
						26. استفاره از سایه بان برای پنجره ها در فضای داخلی جهت جلوگیری از نفوذ بیشتر گرمای خورشید در تابستان چقدر مفید می باشد؟
						27. استفاره از سایه بان در فضای داخلی دیوارهای شیشه ای دو جداره جهت جاوگیری از نفوذ بیشتر گرمای خورشید در تابستان چقدر مفید می باشد؟
						28. طراحی بالکن در نما به عنوان سایه بان چقدر مفید می باشد؟
						29. طراحی نما با مصالح رنگ روشن جهت کاهش جذب گرمای خورشید از طریق انعکاس نور چقدر مفید می باشد؟
						30. طراحی سایه بانهایی که جزی ازهندسه نما هستند جهت کاهش جذب گرمای خورشید چقدر مفید می باشد؟
						31. طراحی نما پوشیده از گیاهان جهت کاهش جذب گرمای خورشید چقدر مفید می باشد؟
آسایش دید						
						32. بهسازی تناسب پنجره ها به دیوار در طراحی نما جهت افزایش نور طبیعی چقدر مفید می باشد؟
						33. طراحی لایت شلو (طراحی پنجره های عمودی نزدیک سقف برای جذب بیشتر نور طبیعی) جهت افزایش نور طبیعی چقدر مفید می باشد؟
						34. طراحی لایت تیوب (استفاده از لوله ها از جنس مصالحی که به شدت نور را منعکس می کنند) در نما چقدر مفید می باشد؟
						35. طراحی پنجره با پانلهای پانچ شده ویا مش جهت جلوگیری از انعکاس نور خورشید چقدر مفید می باشد؟

36. طراحی سایه بانهایی متحرک برای نما جهت کاهش جذب گرمای خورشید چقدر مفید می باشد؟						
37. استفاده از شیشه های دودی (رنگی) در نما جهت راحتی دید چقدر مفید می باشد؟						
آسایش آکوستیک						
38. هوابندی درها و پنجره های نما جهت جلوگیری از صدای بیرون چقدر مفید می باشد؟						
39. استفاده از پنجره با شیشه سه لایه یا لمینیت شده در نما جهت جلوگیری از صدای بیرون چقدر مفید می باشد؟						
40. استفاده از عایق صدا در طراحی نما چقدر مفید می باشد؟						
41. طراحی دو لایه دیوار خارجی جهت جلوگیری از صدای بیرون چقدر مفید می باشد؟						
42. طراحی نما پوشیده از گیاهان جهت جلوگیری از صدای بیرون چقدر مفید می باشد؟						
تولید انرژی (انرژی تجدید پذیر)						
43. تولید انرژی از منابع قابل تجدید از طریق نما چقدر مفید می باشد؟						
44. نصب پانلهای خورشیدی روی نمای ساختمان جهت تولید الکتریسیته چقدر مفید می باشد؟						
45. نصب کولکتورهای خورشیدی روی نمای ساختمان جهت تولید گرما چقدر مفید می باشد؟						
46. نصب کولکتور های خورشیدی روی نمای ساختمان جهت تولید آب گرم چقدر مفید می باشد؟						
47. نصب توربینهای بادی روی نمای ساختمان جهت تولید الکتریسیته چقدر مفید می باشد؟						
48. استفاده از انرژی زمین جهت تولید گرما از طریق نصب لوله های هوا روی نمای ساختمان چقدر مفید می باشد؟						
49. استفاده از انرژی زمین جهت تولید سرما از طریق نصب لوله های هوا روی نمای ساختمان چقدر مفید می باشد؟						
کاهش هزینه ساخت و نگهداری						
50. استفاده از متریالهایی (شفاف و یا غیر شفاف) که کمترین نیاز						

به نگهداری را دارند به عنوان متریال نما چقدر مهم می باشد؟						
51. استفاده از شیشه هایی که خود تمیز شونده هستند به عنوان متریال نما چقدر مفید می باشد؟						
52. استفاده از مصالح با دوام در نمای ساختمان چقدر مهم می باشد؟						
53. استفاده از سیستمهای (ثابت یا متحرک) که کمترین نیاز به نگهداری را دارند به عنوان سیستم نمای ساختمان چقدر مهم می باشد؟						
54. استفاده از رباط اتوماتیک جهت تمیز کردن نما چقدر مفید می باشد؟						
55. بهسازی تناسب پنجره ها به دیوار در طراحی نما جهت کاهش مساحت شیشه به کار رفته برای کاهش هزینه چقدر مفید می باشد؟						
56. استفاده از مصالح محلی در نمای ساختمان چقدر مهم می باشد؟						
57. استفاده از مصالح مقرون به صرفه در نمای ساختمان چقدر مهم می باشد؟						
58. پایین اوردن هزینه نصب نمای ساختمان با به کار گرفتن پانلهای پیش ساخته مودولار چقدر مفید می باشد؟						
کاهش آلودگی محیط زیست						
59. استفاده از چسبهای غیرسمی در ساخت نمای ساختمان چقدر مهم می باشد؟						
60. استفاده از مصالح غیرسمی در ساخت نمای ساختمان چقدر مهم می باشد؟						
61. استفاده از رنگهای غیرسمی در ساخت نمای ساختمان چقدر مهم می باشد؟						
62. استفاده مجدد از المانهای نما در طراحی ساختمانهای دیگر چقدر مهم است؟						
63. طراحی ساختمان با مصالحی که برای بار دوم یا چندم مورد استفاده قرار می گیرند چقدر مهم است؟						
64. طراحی ساختمان با مصالح قابل بازیافت چقدر مهم می باشد؟						
65. حذف روشناییهای دکوراتیو شب از نما جهت کاهش آلودگی نور چقدر مفید می باشد؟						

B. The Answers of First Targets Questions Conducted by Occupants and Architects

B1: Answers for primary targets question

B1-1 OCCUPANTS' ANSWER FOR FIRST TARGET QUESTION (CONDUCTED WITH IRANIAN & TURKISH OCCUPANTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	Tr	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All
Human Comfort	Decreasing Cost	30	56	30	45	60	50	22	41	29	44	51	43	2	3.7	4	6.1	6	5	0	0	3	4.5	3	2.5	54	45	66	55	120
Human Comfort	Decreasing Environmental Pollution	5	9.3	8	12	13	11	27	50	45	68	72	60	22	41	9	14	31	26	0	0	4	6.1	4	3.3	54	45	66	55	120
Decreasing Cost	Decreasing Environmental Pollution	5	9.3	7	11	12	10	14	26	24	36	38	32	35	65	32	48	67	56	0	0	3	4.5	3	2.5	54	45	66	55	120

B1-2 ARCHITECTS' ANSWER FOR FIRST TARGET QUESTION (CONDUCTED WITH IRANIAN & TURKISH ARCHITECTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All
Human Comfort	Decreasing Cost	21	50	14	35	35	43	18	43	20	50	38	46	3	7.1	5	13	8	9.8	0	0	1	2.5	1	1.2	42	51	40	49	82
Human Comfort	Decreasing Environmental Pollution	6	14	9	23	15	18	18	43	22	55	40	49	18	43	8	20	26	32	0	0	1	2.5	1	1.2	42	51	40	49	82
Decreasing Cost	Decreasing Environmental Pollution	3	7.1	4	10	7	8.5	8	19	13	33	21	26	31	74	22	55	53	65	0	0	1	2.5	1	1.2	42	51	40	49	82

B1-3 OCCUPANTS' and ARCHITECTS' ANSWER FOR FIRST TARGET QUESTION (CONDUCTED WITH OCCUPANTS & ARCHITECTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All
Human Comfort	Decreasing Cost	35	43	60	50	95	47	38	46	51	43	89	44	8	9.8	6	5	14	6.9	1	1.2	3	2.5	4	2	82	41	120	59	202
Human Comfort	Decreasing Environmental Pollution	15	18	13	11	28	14	40	49	72	60	112	55	26	32	31	26	57	28	1	1.2	4	3.3	5	2.5	82	41	120	59	202
Decreasing Cost	Decreasing Environmental Pollution	7	8.5	12	10	19	9.4	21	26	38	32	59	29	53	65	67	56	120	59	1	1.2	3	2.5	4	2	82	41	120	59	202

B2: Answers for secondary targets question: Human Comfort

B2-1 OCCUPANTS' ANSWER FOR SECOND TARGET QUESTION: HUMAN COMFORT (CONDUCTED WITH IRANIAN & TURKISH OCCUPANTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total					
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%
Temperature	Air Quality	5	9.3	7	11	12	10	36	67	34	52	70	58	13	24	23	35	36	30	0	0	2	3	2	1.7	54	45	66	55	120	100
Temperature	Lighting	12	22	11	17	23	19	31	57	38	58	69	58	11	20	15	23	26	22	0	0	2	3	2	1.7	54	45	66	55	120	100
Temperature	Acoustics	17	31	36	55	53	44	27	50	23	35	50	42	9	17	5	7.6	14	12	1	1.9	2	3	3	2.5	54	45	66	55	120	100
Air Quality	Lighting	14	26	27	41	41	34	33	61	31	47	64	53	7	13	6	9.1	13	11	0	0	2	3	2	1.7	54	45	66	55	120	100
Air Quality	Acoustics	21	39	45	68	66	55	26	48	16	24	42	35	6	11	3	4.5	9	7.5	1	1.9	2	3	3	2.5	54	45	66	55	120	100
Lighting	Acoustics	16	30	42	64	58	48	27	50	20	30	47	39	10	19	1	1.5	11	9.2	1	1.9	3	4.5	4	3.3	54	45	66	55	120	100

B2-2 ARCHITECTS' ANSWER FOR SECOND TARGET QUESTION: HUMAN COMFORT (CONDUCTED WITH IRANIAN & TURKISH OCCUPANTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All
Temperature	Air Quality	8	19	4	10	12	15	27	64	27	68	54	66	7	17	8	20	15	18	0	0	1	2.5	1	1.2	42	51	40	49	82
Temperature	Lighting	12	29	8	20	20	24	23	55	27	68	50	61	7	17	4	10	11	13	0	0	1	2.5	1	1.2	42	51	40	49	82
Temperature	Acoustics	20	48	17	43	37	45	19	45	18	45	37	45	2	4.8	4	10	6	7.3	1	2.4	1	2.5	2	2.4	42	51	40	49	82
Air Quality	Lighting	12	29	19	48	31	38	23	55	18	45	41	50	7	17	2	5	9	11	0	0	1	2.5	1	1.2	42	51	40	49	82
Air Quality	Acoustics	24	57	23	58	47	57	15	36	13	33	28	34	3	7.1	3	7.5	6	7.3	0	0	1	2.5	1	1.2	42	51	40	49	82
Lighting	Acoustics	23	55	15	38	38	46	16	38	22	55	38	46	3	7.1	2	5	5	6.1	0	0	1	2.5	1	1.2	42	51	40	49	82

B2-3 OCCUPANTS' and ARCHITECTS' ANSWER FOR SECOND TARGET QUESTION: HUMAN COMFORT (CONDUCTED WITH OCCUPANTS & ARCHITECTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All
Temperature	Air Quality	12	15	12	10	24	12	54	66	70	58	124	61	15	18	36	30	51	25	1	1.2	2	1.7	3	1.5	82	41	120	59	202
Temperature	Lighting	20	24	23	19	43	21	50	61	69	58	119	59	11	13	26	22	37	18	1	1.2	2	1.7	3	1.5	82	41	120	59	202
Temperature	Acoustics	37	45	53	44	90	45	37	45	50	42	87	43	6	7.3	14	12	20	9.9	2	2.4	3	2.5	5	2.5	82	41	120	59	202
Air Quality	Lighting	31	38	41	34	72	36	41	50	64	53	105	52	9	11	13	11	22	11	1	1.2	2	1.7	3	1.5	82	41	120	59	202
Air Quality	Acoustics	47	57	66	55	113	56	28	34	42	35	70	35	6	7.3	9	7.5	15	7.4	1	1.2	3	2.5	4	2	82	41	120	59	202
Lighting	Acoustics	38	46	58	48	96	48	38	46	47	39	85	42	5	6.1	11	9.2	16	7.9	1	1.2	4	3.3	5	2.5	82	41	120	59	202

B3: Answers for secondary targets question: Decreasing Cost

B3-1 OCCUPANTS' ANSWER FOR THIRD TARGE QUESTION: DECREASING COST (CONDUCTED WITH IRANIAN & TURKISH OCCUPANTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All
Decreasing cost of energy consumption through facade design	Decreasing cost of facade maintenance /cleaning	34	63	39	59	73	61	19	35	19	29	38	32	1	1.9	3	4.5	4	3.3	0	0	5	7.6	5	4.2	54	45	66	55	120
Decreasing cost of energy consumption through facade design	Decreasing cost of facade construction	33	61	35	53	68	57	15	28	20	30	35	29	4	7.4	6	9.1	10	8.3	2	3.7	5	7.6	7	5.8	54	45	66	55	120
Decreasing cost of facade maintenance /cleaning	Decreasing cost of facade construction	21	39	14	21	35	29	20	37	27	41	47	39	13	24	19	29	32	27	0	0	6	9.1	6	5	54	45	66	55	120

B3-2 ARCHITECTS' ANSWER FOR THIRD TARGE QUESTION: DECREASING COST (CONDUCTED WITH IRANIAN & TURKISH ARCHITECTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All
Decreasing cost of energy consumption through facade design	Decreasing cost of facade maintenance/ cleaning	27	64	24	60	51	62	13	31	13	33	26	32	2	4.8	1	2.5	3	3.7	0	0	2	5	2	2.4	42	51	40	49	82
Decreasing cost of energy consumption through facade design	Decreasing cost of facade construction	27	64	21	53	48	59	11	26	13	33	24	29	4	9.5	3	7.5	7	8.5	0	0	3	7.5	3	3.7	42	51	40	49	82
Decreasing cost of facade maintenance/ cleaning	Decreasing cost of facade construction	13	31	16	40	29	35	18	43	13	33	31	38	11	26	8	20	19	23	0	0	3	7.5	3	3.7	42	51	40	49	82

3-3 OCCUPANTS' and ARCHITECTS' ANSWER FOR THIRD TARGET QUESTION: DECREASING (CONDUCTED WITH OCCUPANTS & ARCHITECTS

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All
Decreasing cost of energy consumption through facade design	Decreasing cost of facade maintenance/ cleaning	51	62	73	61	124	61	26	32	38	32	64	32	3	3.7	4	3.3	7	3.5	2	2.4	5	4.2	7	3.5	82	41	120	59	202
Decreasing cost of energy consumption through facade design	Decreasing cost of facade construction	48	59	68	57	116	57	24	29	35	29	59	29	7	8.5	10	8.3	17	8.4	3	3.7	7	5.8	10	5	82	41	120	59	202
Decreasing cost of facade maintenance/ cleaning	Decreasing cost of facade construction	29	35	35	29	64	32	31	38	47	39	78	39	19	23	32	27	51	25	3	3.7	6	5	9	4.5	82	41	120	59	202

B4: Answers for secondary targets question: Decreasing Environmental Pollution

B4-1 OCCUPANTS' ANSWER FOR FOURTH TARGET QUESTION: DECREASING ENVIRONMENTAL POLLUTION (CONDUCTED WITH IRANIAN & TURKISH OCCUPANTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All
Decreasing air Pollution	Decreasing soil pollution	14	26	12	18	26	22	27	50	40	61	67	56	13	24	12	18	25	21	0	0	2	3	2	1.7	54	45	66	55	120
Decreasing air Pollution	Decreasing light pollution	39	72	47	71	86	72	7	13	12	18	19	16	0	0	0	0	0	0	8	15	7	11	15	13	54	45	66	55	120
Decreasing soil pollution	Decreasing light pollution	40	74	48	73	88	73	6	11	11	17	17	14	0	0	0	0	0	0	8	15	7	11	15	13	54	45	66	55	120

B4-2 ARCHITECTS' ANSWER FOR FOURTH TARGET QUESTION: DECREASING ENVIRONMENTAL POLLUTION (CONDUCTED WITH IRANIAN & TURKISH ARCHITECTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All	All%	IR	IR%	TR	TR%	All
Decreasing air Pollution	Decreasing soil pollution	13	31	6	15	19	23	24	57	25	63	49	60	5	12	8	20	13	16	0	0	1	2.5	1	1.2	42	51	40	49	82
Decreasing air Pollution	Decreasing light pollution	29	69	25	63	54	66	10	24	10	25	20	24	0	0	0	0	0	0	3	7.1	5	13	8	9.8	42	51	40	49	82
Decreasing soil pollution	Decreasing light pollution	29	69	28	70	57	70	6	14	7	18	13	16	0	0	0	0	0	0	7	17	5	13	12	15	42	51	40	49	82

B4-3 OCCUPANTS' and ARCHITECTS' ANSWER FOR FOURTH TARGET QUESTION: DECREASING ENVIRONMENTAL POLLUTION (CONDUCTED WITH OCCUPANTS & ARCHITECTS)

Parameters		A more important than B						A and B equally important						B more important than A						Do not know						Total				
A	B	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All	All %	Arch	Arch %	Oc	Oc %	All
Decreasing air Pollution	Decreasing soil pollution	19	23	26	22	45	22	49	60	67	56	116	57	13	16	25	21	38	19	1	1.2	2	1.7	3	1.5	82	41	120	59	202
Decreasing air Pollution	Decreasing light pollution	54	66	86	72	140	69	20	24	19	16	39	19	0	0	0	0	0	0	8	9.8	15	13	23	11	82	41	120	59	202
Decreasing soil pollution	Decreasing light pollution	57	70	88	73	145	72	13	16	17	14	30	15	0	0	0	0	0	0	12	15	15	13	27	13	82	41	120	59	202

C. Occupants’ answers to their requirement in first questionnaire Survey

	Very important/			Important/ useful			Neutral			Not Important/			Not very important/			Do not know			Total			Weight			
	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	All %
8. How important is it to have natural ventilation in the building?	42	40	82	12	21	33	0	5	5	0	0	0	0	0	0	0	0	0	54	66	120	4.78	4.53	4.64	6.45
9. How important is it to have nighttime ventilation to get cooler outside air?	17	13	30	29	33	62	5	12	17	1	4	5	0	0	0	2	4	6	54	66	120	4.04	3.65	3.83	5.32
10. How important is it to have fresh air in the building without mechanical systems?	27	29	56	22	26	48	3	6	9	0	3	3	0	1	1	2	1	3	54	66	120	4.3	4.15	4.22	5.86
11. How important is it to have appropriate temperature in winter?	36	52	88	16	13	29	2	1	3	0	0	0	0	0	0	0	0	0	54	66	120	4.63	4.77	4.71	6.54
12. How important is it to have appropriate temperature in summer?	38	39	77	14	25	39	1	2	3	1	0	1	0	0	0	0	0	0	54	66	120	4.65	4.56	4.6	6.39
13. How important is it to have day light in the building?	41	42	83	12	16	28	1	4	5	0	3	3	0	0	0	0	1	1	54	66	120	4.74	4.42	4.57	6.35
14. How important is it to prevent glare (large amount of reflected light)?	12	13	25	24	31	55	14	14	28	1	3	4	1	0	1	2	5	7	54	66	120	3.72	3.59	3.65	5.07
15. How important is it to have outside view from inside of the building?	20	25	45	28	31	59	6	7	13	0	2	2	0	1	1	0	0	0	54	66	120	4.26	4.17	4.21	5.85
16. How important is it to prevent outside noise from entering the building?	42	35	77	12	27	39	0	2	2	0	1	1	0	0	0	0	1	1	54	66	120	4.78	4.41	4.58	6.36
17. How important is it to reduce energy consumption by using renewable energy (solar, wind, water, and geothermal energy)?	36	42	78	17	21	38	1	1	2	0	0	0	0	1	1	0	1	1	54	66	120	4.65	4.52	4.58	6.36
18. How useful is it to decrease maintenance cost of facade by having access to it?	19	21	40	22	34	56	12	10	22	0	1	1	1	0	1	0	0	0	54	66	120	4.07	4.14	4.11	5.71
19. How useful is it to decrease maintenance cost of facade by having simple systems or	11	16	27	31	39	70	8	8	16	1	1	2	2	0	2	1	2	3	54	66	120	3.83	3.97	3.91	5.43
20. How important is it to decrease construction cost of the facade by applying	10	12	22	27	38	65	9	11	20	2	2	4	3	1	4	3	2	5	54	66	120	3.56	3.79	3.68	5.12
21. How useful is it to decrease cost of installation in the facade construction?	10	8	18	26	35	61	10	21	31	2	1	3	3	1	4	3	0	3	54	66	120	3.54	3.73	3.64	5.06
22. How important is it to decrease air pollution caused by the consumption of fossil fuels to	37	45	82	11	10	21	6	6	12	0	3	3	0	0	0	0	2	2	54	66	120	4.57	4.38	4.47	6.21
23. How important is it to decrease emission from facade materials (toxic materials) to have	39	32	71	10	22	32	5	9	14	0	1	1	0	0	0	0	2	2	54	66	120	4.63	4.2	4.39	6.1
24. How important is it to decrease soil pollution by designing for deconstruction and	24	27	51	19	23	42	11	15	26	0	1	1	0	0	0	0	0	0	54	66	120	4.24	4.15	4.19	5.83
																								72	100

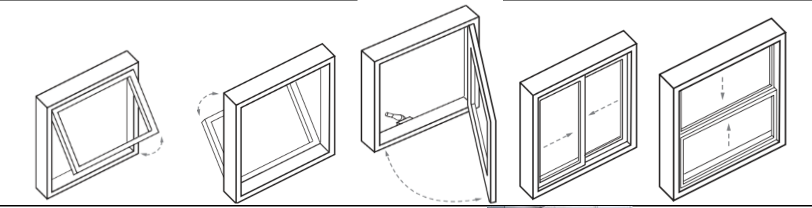
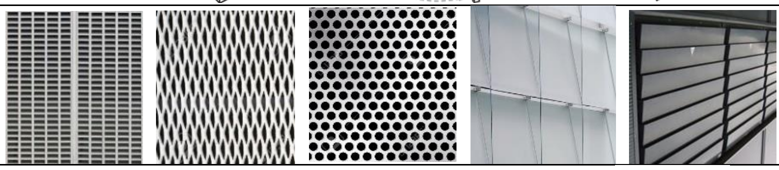
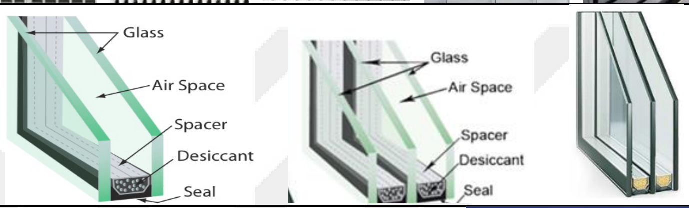
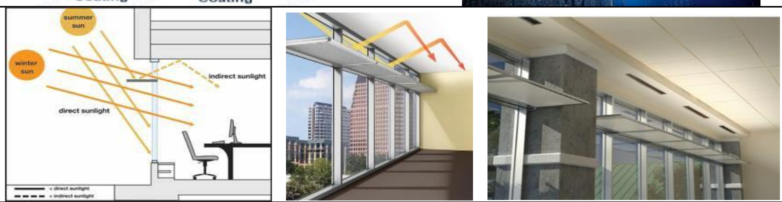
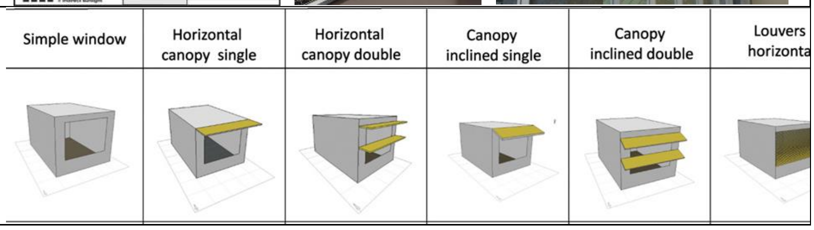
D. Architects' Answers Regarding Technical Solutions in Second Questionnaire Survey

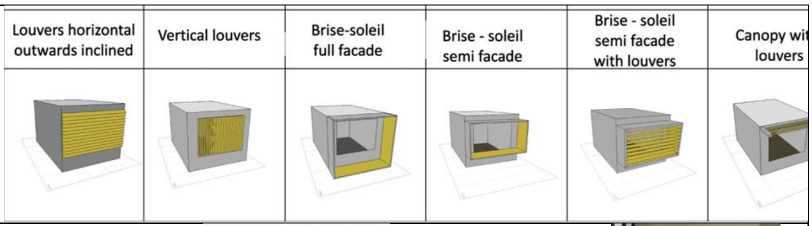
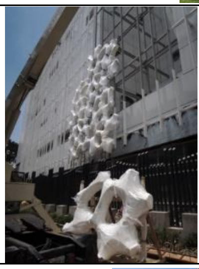
		Very important/			Important/ useful			Neutral			Not Important/			Not very important/			Do not know			Total			Weight			
		IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	All %
Indoor Air Quality	6. How useful is it to have openable windows for natural ventilation (day or night)?	31	31	62	11	7	18	0	1	1	0	1	1	0	0	0	0	0	0	42	40	82	4.74	4.7	4.72	2.06
	7. How useful is it to have natural ventilation (day or night) through vertical ducts on the facade?	4	8	12	20	18	38	7	7	14	3	5	8	0	0	0	8	2	10	42	40	82	3.02	3.58	3.29	1.44
	8. How useful is it to have nighttime ventilation through vents (grills) on the facade?	1	8	9	21	19	40	8	6	14	3	4	7	3	0	3	6	3	9	42	40	82	2.9	3.55	3.22	1.41
	9. How useful is it to filter incoming air through the facade?	7	9	16	27	20	47	2	7	9	4	3	7	0	0	0	2	1	3	42	40	82	3.74	3.8	3.77	1.65
	10. How useful is it to design facades with plants for filtering the air to have better air quality?	12	6	18	23	14	37	2	13	15	2	6	8	0	0	0	3	1	4	42	40	82	3.86	3.43	3.65	1.59
Thermal Comfort (winter)	11. How useful is it to employ passive heating system in the building?	14	26	40	22	10	32	2	2	4	1	0	1	1	0	1	2	2	4	42	40	82	3.98	4.4	4.18	1.83
	12. How useful is it to optimize "window-wall ratio" to gain more solar energy?	27	22	49	14	14	28	1	1	2	0	2	2	0	0	0	0	1	1	42	40	82	4.62	4.33	4.48	1.95
	13. How useful is it to have water pipe embedded for exterior wall to heat interior spaces and have	3	4	7	16	20	36	14	9	23	3	5	8	3	2	5	3	0	3	42	40	82	3.1	3.48	3.28	1.43
	14. How useful is it to design solar space (closed balconies) on the facade for heating?	12	11	23	21	21	42	6	6	12	1	0	1	1	1	2	1	1	2	42	40	82	3.93	3.95	3.94	1.72
	15. How useful is it to design thermal mass (solar walls) on the facade for space heating?	15	17	32	22	19	41	2	3	5	1	0	1	1	0	1	1	1	2	42	40	82	4.1	4.25	4.17	1.82
	16. How useful is it to have airtight openings (windows/doors) to prevent heat loss through the	35	18	53	7	16	23	0	2	2	0	3	3	0	1	1	0	0	0	42	40	82	4.83	4.18	4.51	1.97
	17. How useful is it to have insulated glass for openings (triple glazed or laminate glass) to prevent heat transfer through the facade?	33	14	47	7	20	27	1	5	6	1	0	1	0	0	0	0	1	1	42	40	82	4.71	4.13	4.43	1.93
	18. How useful is it to have thermal insulation in designing of facade for preventing heat loss/heat	32	27	59	10	13	23	0	0	0	0	0	0	0	0	0	0	0	0	42	40	82	4.76	4.68	4.72	2.06
	19. How useful to design opening in appropriate direction to get more solar radiation?	12	12	24	22	13	35	6	10	16	1	4	5	0	1	1	1	0	1	42	40	82	4	3.78	3.89	1.7
Thermal Comfort (summer)	20. How useful is it to employ passive cooling system in the building?	14	26	40	22	12	34	1	2	3	2	0	2	0	0	0	3	0	3	42	40	82	3.93	4.6	4.26	1.86
	21. How useful is it to integrate water evaporative systems (water clay pipes) on the facade for	5	9	14	17	12	29	8	10	18	2	3	5	1	1	2	9	5	14	42	40	82	2.9	3.25	3.07	1.34
	22. How useful is it to optimize "window-wall ratio" to prevent solar heat gain?	26	16	42	15	17	32	0	3	3	0	4	4	1	0	1	0	0	0	42	40	82	4.55	4.13	4.34	1.9
	23. How useful is it to have insulated glass for openings (triple glazed or laminate glass) to prevent heat transfer through the facade?	23	8	31	13	19	32	2	4	6	1	7	8	2	1	3	1	1	2	42	40	82	4.21	3.58	3.9	1.7
	24. How useful is it to have tinted (colored) glass for providing thermal comfort?	7	7	14	18	17	35	11	11	22	3	2	5	2	1	3	1	2	3	42	40	82	3.52	3.53	3.52	1.54
	25. How useful is it to have exterior shading devices on the facades to block excessive sun light?	17	20	37	23	17	40	2	3	5	0	0	0	0	0	0	0	0	0	42	40	82	4.36	4.43	4.39	1.92
	26. How useful is it to have interior shading devices on the facades to block excessive sun light?	8	9	17	21	19	40	9	8	17	3	3	6	1	1	2	0	0	0	42	40	82	3.76	3.8	3.78	1.65
	27. How useful is it to have shading devices in cavity of double skin facade to block excessive sun	3	6	9	21	19	40	11	5	16	5	2	7	1	2	3	1	6	7	42	40	82	3.4	3.18	3.29	1.44
	28. How useful is it to have a balcony as a shading element on the facade?	16	6	22	21	17	38	4	8	12	0	6	6	1	1	2	0	2	2	42	40	82	4.21	3.38	3.8	1.66
	29. How useful is it to have light color materials on the facades for prevent heat gain by reflection?	5	4	9	13	10	23	13	14	27	1	3	4	0	4	4	10	5	15	42	40	82	2.81	2.8	2.8	1.22
	30. How useful is it to design self-shading facades to prevent heat gain?	3	5	8	12	12	24	10	9	19	4	0	4	2	6	8	11	8	19	42	40	82	2.45	2.65	2.55	1.11
	31. How useful is it to have vegetated facades to prevent heat gain?	10	3	13	22	19	41	4	11	15	0	3	3	1	0	1	5	4	9	42	40	82	3.6	3.25	3.43	1.5

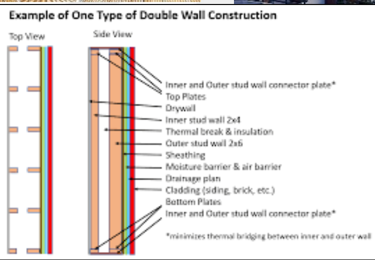
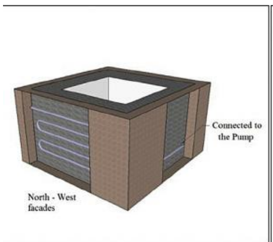
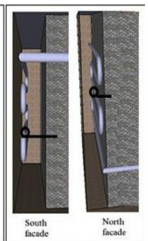
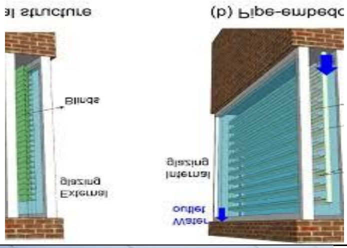
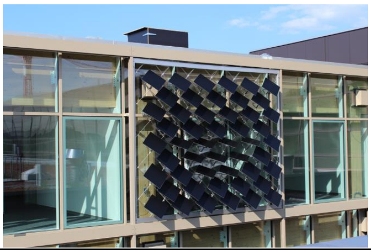
Table D (continued)

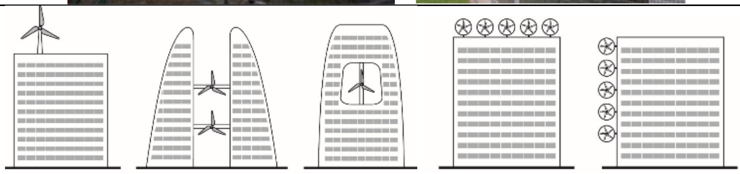
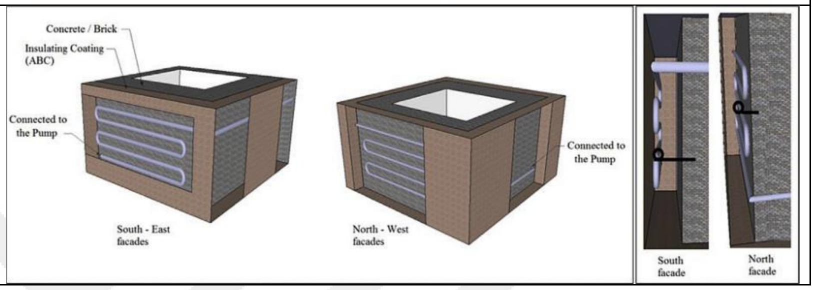
		Very important/			Important/ useful			Neutral			Not Important/			Not very important/			Do not know			Total			Weight			
		IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	IR	TR	All	All %
Visual Comfort	32. How useful is it to optimize “windows - wall ratio” to have more day light and view?	36	31	67	6	8	14	0	1	1	0	0	0	0	0	0	0	0	0	42	40	82	4.86	4.75	4.8	2.1
	33. How useful is it to design light shelves to have more daylight in the building?	8	14	22	29	19	48	4	1	5	0	1	1	0	1	1	1	4	5	42	40	82	4	3.8	3.9	1.7
	34. How useful is it to integrate light tubes to have more daylight in the building?	3	6	9	14	18	32	9	7	16	2	5	7	2	0	2	12	4	16	42	40	82	2.48	3.33	2.89	1.26
	35. How useful is it to design translucent panels (louver, punched, mesh, Perforated material) for shading elements to prevent glare?	5	7	12	19	24	43	10	6	16	0	1	1	2	0	2	6	2	8	42	40	82	3.17	3.78	3.46	1.51
	36. How useful is it to have movable shading devices on the facades?	26	21	47	15	13	28	0	5	5	0	1	1	0	0	0	1	0	1	42	40	82	4.52	4.35	4.44	1.94
	37. How useful is it to use tinted (colored) glass to have visual comfort?	7	9	16	15	13	28	14	10	24	3	1	4	2	5	7	1	2	3	42	40	82	3.45	3.35	3.4	1.49
Acoustic Comfort	38. How useful is it to have airtight windows/doors (damping) to block outside noise?	33	23	56	8	9	17	0	4	4	1	1	2	0	3	3	0	0	0	42	40	82	4.74	4.2	4.48	1.95
	39. How useful is it to use insulated glass for openings (triple glazed or laminate glass) to block	28	18	46	13	15	28	0	4	4	0	0	0	0	2	2	1	1	2	42	40	82	4.57	4.1	4.34	1.9
	40. How useful is it to use sound insulation in designing of facade?	29	22	51	11	13	24	2	5	7	0	0	0	0	0	0	0	0	0	42	40	82	4.64	4.43	4.54	1.98
	41. How useful is it to design double layer wall for blocking outside noise?	31	22	53	11	14	25	0	3	3	0	0	0	0	0	0	0	1	1	42	40	82	4.74	4.38	4.56	1.99
	42. How useful is it to have vegetated facades to decrease sound transition?	2	5	7	13	14	27	13	10	23	2	4	6	2	5	7	10	2	12	42	40	82	2.55	3.1	2.82	1.23
Energy Production (renewable energy)	43. How useful is it to produce energy through the	20	21	41	19	16	35	2	1	3	0	2	2	0	0	0	1	0	1	42	40	82	4.33	4.4	4.37	1.91
	44. How useful is it to integrate Photovoltaic panels on the facades for producing electricity from solar	16	14	30	18	24	42	5	2	7	1	0	1	0	0	0	2	0	2	42	40	82	4.02	4.3	4.16	1.82
	45. How useful is it to integrate solar collector on the facade for space heating?	6	6	12	18	17	35	9	11	20	2	2	4	0	0	0	7	4	11	42	40	82	3.17	3.38	3.27	1.43
	46. How useful is it to integrate solar collector on the facade for hot water supply?	5	8	13	18	17	35	10	12	22	1	0	1	0	0	0	8	3	11	42	40	82	3.07	3.6	3.33	1.45
	47. How useful is it to integrate wind turbine on the facades for producing electricity?	2	3	5	11	10	21	13	11	24	6	8	14	1	4	5	9	4	13	42	40	82	2.52	2.7	2.61	1.14
	48. How useful is it to integrate geothermal heating by using pipe in the exterior wall?	5	6	11	9	12	21	9	11	20	6	5	11	1	5	6	12	1	13	42	40	82	2.4	3.15	2.77	1.21
	49. How useful is it to integrate geothermal cooling by using pipe in the exterior wall?	4	5	9	6	10	16	13	12	25	4	5	9	1	6	7	14	2	16	42	40	82	2.19	2.93	2.55	1.11
Decreasing Construction and Maintenance Cost	50. How important is it to use low maintenance opaque materials/self-cleaning materials on the	29	16	45	12	17	29	1	3	4	0	1	1	0	0	0	0	3	3	42	40	82	4.67	3.98	4.33	1.89
	51. How useful is it to have low maintenance/ self-cleaning glass on the facade?	24	22	46	15	13	28	2	3	5	0	2	2	0	0	0	1	0	1	42	40	82	4.43	4.38	4.4	1.92
	52. How important is it to use durable materials (long lasting) on the facade?	33	27	60	9	13	22	0	0	0	0	0	0	0	0	0	0	0	0	42	40	82	4.79	4.68	4.73	2.07
	53. How important is it to design low maintenance systems (static or kinetic) on the facades?	10	16	26	24	14	38	4	7	11	0	1	1	1	0	1	3	2	5	42	40	82	3.79	3.98	3.88	1.69
	54. How useful is it to useful to employ automatic robots for facades cleaning to decrease	7	12	19	12	14	26	16	9	25	3	5	8	2	0	2	2	0	2	42	40	82	3.31	3.83	3.56	1.56
	55. How useful is it to optimize “window-wall ratio” in order to decrease glass area for reducing cost?	1	5	6	8	13	21	16	11	27	6	3	9	2	6	8	9	2	11	42	40	82	2.36	3.05	2.7	1.18
	56. How important is it to use local materials on the facades?	22	20	42	17	15	32	3	5	8	0	0	0	0	0	0	0	0	0	42	40	82	4.45	4.38	4.41	1.93
	57. How important is it to use affordable materials on the facades?	18	16	34	11	14	25	11	9	20	2	1	3	0	0	0	0	0	0	42	40	82	4.07	4.13	4.1	1.79
	58. How useful is it to decrease cost of installation in the facade construction by employing modular and prefabricated panels?	9	9	18	14	16	30	16	10	26	2	5	7	1	0	1	0	0	0	42	40	82	3.67	3.73	3.7	1.61
Decreasing Environmental Pollution	59. How important is it to use nontoxic glues in construction of the facade?	21	27	48	14	10	24	0	1	1	1	1	2	2	0	2	4	1	5	42	40	82	3.93	4.5	4.21	1.84
	60. How important is it to use nontoxic finishing in construction of the facade?	21	28	49	15	11	26	2	1	3	1	0	1	1	0	1	2	0	2	42	40	82	4.14	4.68	4.4	1.92
	61. How important is it to use nontoxic paints in construction of the facade?	22	28	50	15	11	26	1	1	2	1	0	1	1	0	1	2	0	2	42	40	82	4.19	4.68	4.43	1.93
	62. How important is it to design for deconstruction?	9	18	27	18	10	28	8	9	17	4	1	5	2	0	2	1	2	3	42	40	82	3.6	3.98	3.78	1.65
	63. How important is it to use reusable materials and systems in construction?	12	23	35	10	10	20	13	3	16	4	3	7	3	0	3	0	1	1	42	40	82	3.57	4.25	3.9	1.7
	64. How important is it to use recyclable materials in construction?	16	28	44	18	8	26	5	2	7	2	1	3	0	0	0	1	1	2	42	40	82	4.07	4.5	4.28	1.87
	65. How important is it to remove decorative lighting from building facades for decreasing light	0	3	3	4	11	15	17	13	30	9	3	12	2	7	9	10	3	13	42	40	82	2.07	2.78	2.41	1.05
																									229	100

E. Technical Solutions for Facade Design

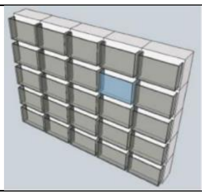
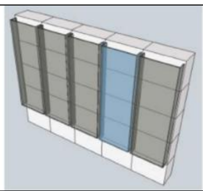
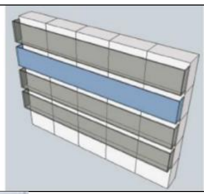
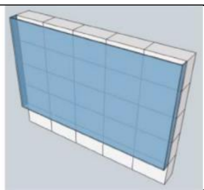
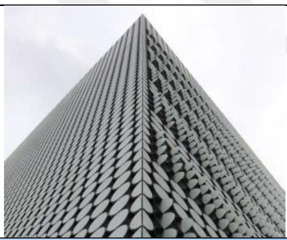
Operable windows	
Vents (grills) on the facades	
Insulated glass for opening	
Tinted (colored, or laminated) glass	
Low maintenance self-cleaning glass	
Light shelves	
Exterior shading devices	

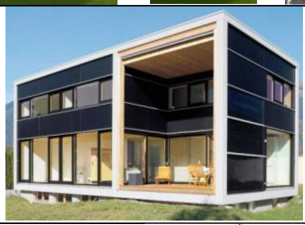
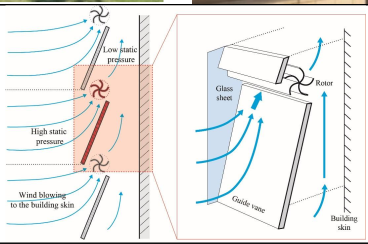
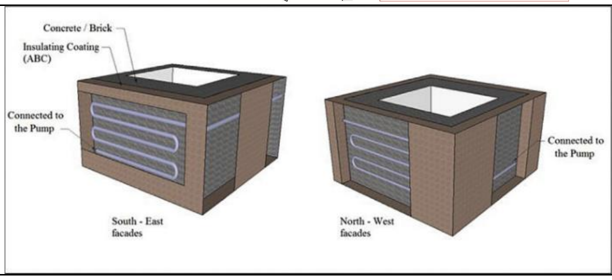
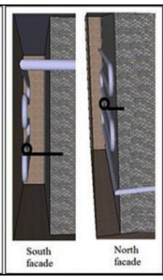
	
Interior shading devices	   
Shading devices in the cavity of double skin facades	 
Ducts / Chimney wall on the facades	 
Air filtration on the facade	  
Plantation on the facade	 

Water evaporative system on the facades	  
Automatic robots for cleaning of the facades	 
Balconies for the facades	 
Double layer exterior wall	
Water pipe embedded on the facades	  
Photovoltaic panels on the facades	 

Solar collector on the facade	
Wind turbine on facade	
Geothermal energy through wall cavity	

F. Facade Thechnologies

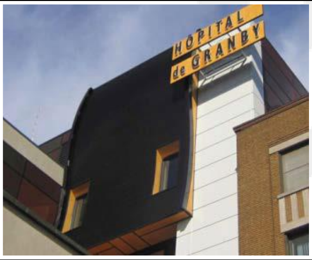
Double skin facade	   
Ventilated Facade	 
Facade with evaporative cooling	  
Facade with Fixed shading devices	 
Self-shading facade	 
Vegetated facade	 

Facade with movable shading devices	 
Movable facade	 
Rotating building	  
Facade with Smart material	   
Solar energy integrated facade	 
Wind energy integrated facade	
Geothermal energy	 

G. Solar Collectors on Facades

Introduction of fifteen buildings that are used solar collectors on their facades. Figures taken from Zhang *et al*. (2015)

No.1: House J, single family house, Nenzing, Austria	No.2: School building in Geis, Switzerland	No.3: Sunny woods, apartment house, Zürich, Switzerland
		
In this building, 12 m2 flat plate solar collectors are installed on the south facades. The size of collectors is designed by considering the modular rhythm of the facade.	The building's south facade has a modular design with 63 m2 solar collectors to provide heating for spaces and hot water supply.	The solar-tube collectors are designed as a translucent baluster for the balcony.
No. 4: KOMBISOL® house, Tyrol, Austria	No. 5: Passive house Caldonazzi, Austria	No. 6: Passive house Rudshagen, Oslo, Norway
		
70 m2 solar thermal system is installed on the facade to provide heating and hot water. The additional energy is saved in the concrete core of the house in the winter.	The south facade of the building consists of 75% windows and 25% solar thermal systems (17 m2), designed to provide hot water and heating for spaces.	The high-performance polymer collector with 19.5 m2 is installed on the south facade to provide domestic hot water and heating for the building (61 kwh/m2 annually).
No. 7: Petersbergenstrasse, Austria	No. 8: Alpiner Stützpunkt Schiestlhaus of the Austria Tourist Club, Austria	No. 9: Retrofitted Office Building in Ljubljana, Slovenia
		
The 50 m2 flat plates solar collectors are installed as a prefabricated second layer wall in 10º southwest orientation for providing hot water and heating.	In this project, the BIST system is installed on the south facade. The generated energy is transferred to three storage tanks with 2000 liter capacity to provide heating.	"*air heating vacuum tube collectors*" and transparent solar collectors are installed as a balustrade on the fifth floor and on the stair wall, respectively, in the existing building's south facade.

No. 10: HQ, AKS DOMA Solartechnik	No. 11: Hotel Jezerka, Czech Republic	No. 12: Environmental Research Station Schneefernerhaus, Germany
		
The building's whole heating requirement is provided by 80 m2 BIST system installed on the south facade. The generated heating is heated spaces through the thermal wall and a floor heating system.	n the south facade of the building, solar collectors are installed as vertical handrails of balconies with 236 m2 or “as flat roofs where vertical collectors would be overloaded by the wind” to provide hot water for the pool and domestic need of the building.	The 100 m2 solar collectors are installed on the existing building’s stone facade to provide hot water and space heating for the building. The hot water flows under the floor and in the radiators to heat spaces.
No. 13: Granby Hospital, Granby (Quebec) / Canada	No. 14: The Bellona Building, Oslo, Norway	No.15: The centre d’exploitation des Routes Nationales, Bursins, Switzerland
		
The 82 m2 based air solar collectors are integrated on the hospital building facade to provide pre-heated fresh air for the interior spaces. This system is one of the efficient systems, which pay back 70% within five years.	The building’s south facade is designed as a self-shading situ concrete facade, which is covered by 240 solar collectors. Using insulated windows and insulation in the wall decreases the air leakage factor and the thermal bridge.	On the south facade of the building, stainless steel unglazed metal collectors are mounted in a large area for providing hot water and floor heating. The weight of a collector is 10 kg/m2, which makes it easy to install.

H. Human Research Ethics Committee Questionnaires Approval

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04 EKİM 2019

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Prof.Dr. Soofia TAHİRA ELİAS ÖZKAN

Danışmanlığını yaptığınız **Nastaran DELJAVAN'ın "Bina Cephelerinin Tasarımında Bütünleşik Kullanıcı Tercihleri ve Enerji Yaklaşımı"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülmüş ve **339 ODTÜ 2019** protokol numarası ile onaylanmıştır.

Saygılarımızla bilgilerinize sunarız.

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Üye

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Üye

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MS	Tabriz Azad University	2002
BS	Tabriz Azad University	1999
High School	Tohid, Tabriz	1994

WORK EXPERIENCE

Academic:

Year	**Place**	**Enrollment**
2008-2011	Azad University, Central Branch	Instructor
2007-2009	Azad University, Shahr-e-rey Branch	Instructor

Industrial:

Year	**Place**	**Enrollment**
09.2013 - 11.2017	Mimor Mimarlık	Project Manager
09.2010 - 02.2012	Emarat-e-Khorshid Consulting Engineering Co.	Project Manager

09.2007 - 09.2010	Urban Development and Revitalization Organization	Project Manager
06.2005 - 09.2007	Nagsh-e-Jahan Pars Consulting Engineering Co.	Project Manager
01.2004 - 06.2005	Secco Iran Factory	Manager of the design department
07.2001 - 06.2004	Ghaflan Sahand Azar Co.	Technical engineer

FOREIGN LANGUAGES

Native Azarbaijani, Fluent Persian, Good English, Good Turkish

PUBLICATIONS

1. Deljavan, N. & Elias-Ozkan, S. T., (2017). Taxonomy of Sustainable, Responsive and Adaptive Facades. PLEA. Vol 3, pp. 3991-3998