Role of Façade Elements in Daylight Control for Improving the Quality of Indoor Environment

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ABSTRACT

The issue of maximum utilization of natural light is of a great importance in modern architecture. Natural light is proven to play major roles not only in the overall quality of indoor environment, but also in minimizing energy consumption, and helping physical/psychological health of occupants. However, modern mass constructions struggle with lack of space, windows and access to sunlight. Contemporary architecture, specifically in developing countries relies on artificial lighting rather than daylighting. As a matter of fact, daylight utilization can be assumed as a concept with two contradictory sides. In one perspective, daylight utilization enhances the quality of indoor environment and decreases energy consumption for artificial lighting; but alternatively, direct sunlight particularly in hot climates leads to glare, visual and thermal discomfort. These issues can be addressed by innovative daylight utilization and control strategies as well as lessons learnt from traditional architecture.

This study aims at identifying daylighting strategies and more specifically facade elements for daylight utilization and control. To fulfill this aim, the merits of daylight utilization in architecture are firstly analyzed. It is shown that efficient daylight utilization and control significantly improves the quality of indoor environment from different aspects. Having highlighted these aspects, facade elements for daylight utilization and control are described. Then, case studies in Iranian traditional and contemporary architecture are investigated to identify how different façade elements and their arrangements for daylighting in residential buildings contribute to the quality of indoor environment. Iranian traditional architecture is well known for its sustainability and therefore three traditional cases are picked from hot climate regions in Iran as illustrative cases. The contemporary case studies are featured residential buildings with innovative designs. The results of the case studies uncover valuable clues about how façade elements and design strategies for daylighting enhances the quality of indoor environment. Finally, recommendations for daylighting are given for the designers to integrate lessons learnt from traditional architecture in modern designs.

Keywords: Daylight utilization, Daylight control, Facade elements, Indoor Environment, Iranian contemporary architecture, Iranian traditional architecture.

ÖZ

Doğal ışığın azami kullanılması konusu modern mimaride büyük önem taşıyor. Doğal ışığın, sadece iç ortamın genel kalitesinde değil, aynı zamanda enerji tüketimini en aza indirmede ve kullanıcının fiziksel / psikolojik sağlığına yardımcı olmasında da önemli roller oynadığı kanıtlanmıştır. Bununla birlikte, modern yapılar alan eksikliği, pencereler ve güneş ışığına erişim ile mücadele etmektedir. Çağdaş mimarlık, özellikle gelişmekte olan ülkelerde gün ışığından ziyade yapay aydınlatmaya dayanır. Nitekim, gün ışığı kullanımı iki çelişkili yanı olan bir kavram olarak kabul edilebilir. Bir bakış açısıyla, gün ışığı kullanımı iç mekan ortamının kalitesini arttırır ve yapay aydınlatma için enerji talebini azaltır; ancak diğer taraftan, özellikle sıcak iklimlerde doğrudan güneş ışığı parlama, görsel ve ısısal rahatsızlığa yol açar. Bu konular yenilikçi gün ışığı kullanımı ve kontrol stratejileri ile geleneksel mimariden alınan dersler ile ele alınabilir.

Bu çalışma, günışığı stratejileri ve daha özel olarak gün ışığı kullanımı ve kontrolü için cephe elemanlarının tespit edilmesini amaçlamaktadır. Bu amacı gerçekleştirmek için öncelikle mimaride gün ışığı kullanımının yararları analiz edilir. Etkin gün ışığı kullanımı ve kontrolünün, iç ortamın kalitesini farklı yönlerden önemli ölçüde iyileştirdiği gösterilmiştir. Bu özellikleri vurguladıktan sonra, gün ışığı kullanımı ve kontrolü için cephe ve çatı elemanları açıklanmaktadır. Daha sonra, İran'ın yerel ve çağdaş mimarisindeki örneklarin incelemeleri, farklı cephe elemanlarının ve konut yapılarında günışığı düzenlemelerinin iç mekan kalitesine nasıl katkıda bulunduğunu tespit etmek için incelenmiştir. İran yerel mimarisi sürdürülebilirliği ile ünlüdür ve bu nedenle İran'daki sıcak iklim bölgelerinden üç yerel örneği olarak seçilmiştir. Çağdaş çalışmaları, ise, yenilikçi tasarımlara sahip konut binaları ile donatılmıştır. Örnek incelemelerinin sonuçları, cephe elemanlarının ve günışığı aydınlatması için tasarım stratejilerinin iç ortamın kalitesini nasıl artırdığı hakkında değerli ipuçlarını ortaya koymaktadır. Son olarak, tasarımcılara yerel mimariden öğrenilen dersleri modern tasarımlara dahil etmeleri için günışığına yönelik tavsiyeler verilmiştir.

Anahtar Kelimeler: Günışığı kullanımı, Gün ışığı kontrolü, Cephe elemanları, İç Ortam, İran çağdaş mimarisi, İran yerel mimarisi.

TO MY FAMILY

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INTRODUCTION

1.1 Problem Statement

The rising trend towards urbanization and the need to supply urban occupants with as much space as possible led to high-rise buildings in which natural light influx was overlooked as many other major economic priorities such as increased employee productivity had to be taken into account. On the other hand, modern lifestyle has resulted in people spending most part of each day indoors. Therefore, indoor environment quality has a strong effect, not only on comfort and productivity, but also on personal health of occupants. Therefore, well-performing facade elements like walls, windows and glazing systems is essential to reduce the impact of changing outdoor temperature on the quality of indoor environment. Sunlight however, exists during the year no matter how the temperature of air outside the building changes. To maintain a proper temperature in indoor spaces, solar radiation is to be blocked in summer time and allowed in actively in winter time. A typical window lets the maximum use of solar heat gain in cold season, but it would increase the risk of energy burden for ventilation and cooling in hot season. Generally speaking-excluding innovative designs in contemporary architecture-building facade is not capable of being changed in response to season. Hence, solar radiation should basically be controlled by means of daylighting subsystems mounted on the façade such as blinds.

Besides, daylight can aid artificial lighting reducing energy demand for lighting indoor environment. Therefore, specific consideration should be taken when designing facade and fenestration to assure the admission of proper amount of daylight into the indoor environment. In fact, the amount of daylight influx in indoor spaces should be manipulated to enhance visual comfort. Visual comfort guaranties proper lighting condition by means of daylight utilization and control as well as artificial lighting. Daylight control is vital to avoid glare and direct solar radiation for occupants. Glare causes visual discomfort, which directly degrades the comfort level of indoor environment. Appropriate selection and design of facade elements for daylight utilization and control leads to improved lighting condition in indoor environment as well as energy saving.

1.2 Aim of the Research

In this study, a more detailed consideration will be taken to address the issues of daylight utilization and control by means of façade elements. Then, an overview of a number of approaches for developing buildings' façades with daylight control devices and elements to enhance the lighting condition of indoor environment will be presented. Different types and combinations of openings, glazing systems and solar shading devices will be discussed. Therefore, the main objectives of this study will include:

1. To highlight the advantages of daylighting in building design
2. To explain how daylight utilization and control is planned at the design phase
3. To describe the effect of daylighting in quality of indoor environment
4. To explain façade elements and design strategies for daylighting
5. To identify how facade elements and design strategies created comfortable indoor environment in residential buildings in Iranian traditional architecture

6. To study Iranian contemporary architecture in globally-recognized residential buildings in terms of facade elements for daylighting
7. To give recommendations for building designers to improve quality of indoor environment in terms of daylighting.

1.3 Methodology

Observation and comparative study is the methodology used in this thesis. In the first phase of this study, the significance of daylighting in improving quality of indoor environment is explained. Different aspects of daylighting in architectural concept are investigated. Other benefits of daylight such as health benefits and energy saving are also briefly mentioned. In the second phase, factors such as availability of sunlight, construction site, building type and other issues related to daylight utilization and control are studied to explain planning strategies at design phase. The third phase of the study introduces facade elements for daylighting and describes their characteristics. In the case study phase, three houses in Iranian traditional architecture and three residential buildings in Iranian traditional architecture are considered to explore the components and strategies for effective daylighting while providing visual and thermal comfort. The principles are further discussed in terms of inventive designs by investigating three well-known cases of Iranian contemporary architecture. Analysis of the characteristics of contemporary architecture and integration of traditional strategies for daylighting reveals insightful facts about designing facade layouts which satisfy the conditions of a pleasant daylit indoor environment.

1.4 Contributions

In this study, facade elements for daylighting are studied in terms of quality of indoor environment. Although daylight utilization and control in architecture have been addressed in a wealth of literature considering sustainability, thermal comfort and energy efficiency, the effect of facade design for daylight control and consequently the contribution of daylighting in improved quality of indoor environment were not inspected. This study contributes to the literature by highlighting the architectural aspects of daylight utilization in architecture. Basically, a comprehensive study in the context of facade design for daylight utilization and control which considers characteristics of Iranian architecture in both traditional and innovative contemporary buildings was not conducted.

1.5 Thesis Structure

This thesis is organized as follows. In the Chapter 2, significance of daylight utilization in architecture is explained. The very critical question of "why daylight" is answered by describing architectural aspects of daylight utilization as well as its benefits for health and energy efficiency. Chapter 3 is related to planning for daylight utilization and control at the design phase. Facade elements and their role in effective utilization of daylight and controlling sunlight to provide a high quality indoor space are discussed in Chapter 4. Chapter 5 represents the case studies of Iranian traditional and contemporary architecture and compares these designs. Finally, in Chapter 6, the results of comparisons are discussed and the thesis is concluded.

Chapter 2

IMPORTANCE OF DAYLIGHTING IN BUILDING DESIGN

2.1 Introduction

Through the history of architecture, daylight has always played a crucial role in building design (Michael and Heracleous 2017). The effectually daylit houses, mosques and grand bazaars in Iranian traditional architecture are of the very examples of focusing on daylighting in building design. Daylighting has both visual and non-visual benefits for occupants. Visual contribution of daylight is defined in the context of visual comfort in quality of indoor environment. Daylight enhances the visual quality of indoor environment as it enhances lighting condition and adds aesthetical features by changing the perception of the space. In addition to its visual assets in enhancing lighting comfort, daylight has some non-visual advantages. Physical and mental health of occupants are strongly connected to daylighting condition (Tzempelikos 2017). Furthermore, daylighting is known as component of sustainable architecture for energy efficiency (Ihm, Nemri, and Krarti 2009).

2.2 History of Daylighting in Building Design

Daylight in the Old Stone Age was the sign of difference between day and night for cavemen. As the residential advanced, the simple openings and window-like components are added to houses built from wood and stone for daylighting and ventilation. The history of early crude windows is bound with the history of architecture so is the history of daylighting and mechanisms for letting sunlight lit indoor area (Kischkoweit-Lopin 2002; Littlefair 2000). Windows continue to be the key design element for daylight utilization in private residential buildings, cathedrals, and churches in eighteen centuries in Europe (Baker 2013). Oily paper sheets, mica panes and thin marble stabs, are the material used in early windows. It should be noted that although the window and opening has been developing since early caves, the most remarkable change did not take place until the technology for producing glass for windows was developed (Baker 2013). Thus, it is not exaggerating when it is said “the history of evolution of windows in architecture is defined by the history of glass” (Kurkjian and Prindle 2005).

During Medieval Era in Anglo-Saxon wooden houses, windows were nothing but holes on the walls letting the light and air in. They used animal skins to cover windows for insulating indoor space from outdoor. Windows in the form of mullions made of pebble or lumber began to appear after Norman Conquest (Baker 2013). Back then, most of buildings were made of stone and although glass was available, only rich could afford it and for ordinary people, animal horn was used to make thin sheets as a replacement for glass (Baker 2013; Kurkjian and Prindle 2005).

The history of glass goes back to Egypt at around 3000 BC where glass was used for decoration. In Roman era, hand-blown panes of glass were fixed into frames made of bronze to fit into window holes. In mediaeval period, manufacturing procedure of small panes of glass started and windows with glass became more popular. The glass produced during that period is known as crown glass. Crown glass was manufactured by reheating and spinning a flattened bubble of glass. The dome-shaped glass was then cut into small pieces to fill the window frames. A critical change is actually happened at 17th Century in England where manufacturers produced larger pieces of glass formed into plates. By the end of 1700s, the typical windows with vertical sashes which could be slid for opening were prevalent. In Victorian period and during industrialization, more efficient manufacturing procedure was planned for glass manufacturing. The cylinder method was used to fabricate large panes glass fitting into large window frames (Kurkjian and Prindle 2005). In this period, gothic designs and oriel windows became a norm in Europe (Baker 2013). In Middle East, latticed windows of small glass were prevalent in 17th century. Iranian colorful windows and transparent doors covering a large area on the facade are examples of these windows. Figure 2.1 shows a configuration of Orosi (window with wooden frame opened horizintally) and chand-dari (multiple doors with glazing) in an Iranian traditional house (Nabavi *et al.* 2013).

Figure 2.1: Orosi and 5-dari in Iranian traditional architecture (Nabavi *et al*. 2013)

The modern notion of daylight utilization in building developed with the introduction of modern glazing and window design in architecture. Health and energy benefits of sunlight are the mostly emphasized matters associated with inclusion of daylighting in architecture. The major source for lighting the buildings was daylight supplemented by artificial lighting until 1940s (Baker 2013; Maghsoudi Nia *et al*. 2015). Within a short period of time, artificial lighting took the key role for satisfying lighting needs of occupants (Littlefair 2000). For almost 20 years starting from 1945s, cheap electrical energy as well as fluorescent lights was used in buildings ventilated by mechanical air-conditioning systems. In densely constructed urban areas of cities during industrialization, pollution and noise resulted in fewer openings and even sealed windows. Daylight then lost its role as the key lighting element for buildings.

However, this era was short lived for daylighting. In fact, energy crisis in 1970s and global awareness about CO_2 emission were the factors encouraging building designers to reconsider natural lighting and passive ventilation (Ruck, 2000). Essentially, these factors were the motivations for utilizing daylight in building design. At early stages, daylighting meant for reducing the energy demand of artificial lighting (Ihm *et al.*, 2009). However, in early 1980s, health benefits of daylight for human body and occupants' mental health came into the focus. Researches highlighted the effect of daylight on people's productivity and it was argued that this effect sometimes is even more noticeable than energy saving benefits. These advantages related to daylight utilization in indoor environment have been the very interest of scholars in 1990s (Roche *et al.*, 2000; Boubekri *et al.*, 2014).

After noticing the importance of daylighting, several designers tried to maximized daylight utilization in the buildings achieving high amounts of light influx in indoor spaces as they were over-excited about daylighting. This approach led to superfluous solar radiation, glare, thermal gain and thus discomfort. It also eliminated the energy efficiency of daylighting by increasing the load for cooling and ventilation (M.Saradj 2014). Currently, both occupants and designers are conscious about the merits of daylighting in enhancing quality of indoor environment, energy efficiency, and health.

2.3 Role of Daylighting in Quality of Indoor Environment

Enhanced environmental quality can improve the quality of life of the occupants (Abdul Mujeebu 2019). Indoor environment is affected by several factors including indoor air quality, thermal condition, lighting, acoustics, water quality, ergonomics, and electromagnetic radiation as depicted in Figure 2.2. Hence, the notion "indoor environmental quality" (IEQ) fundamentally represents a concept that covers a diverse range of sub-domains identifying the quality of human life inside a building.

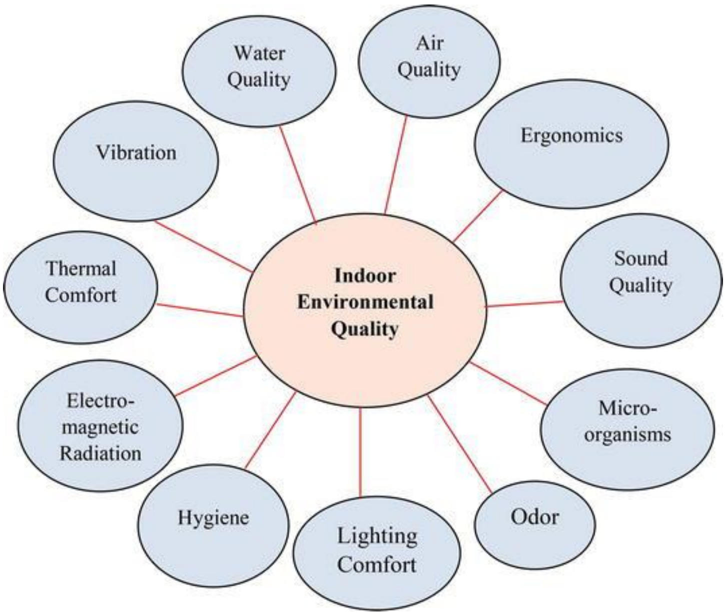


Figure 2.2: Components of Indoor Environment Quality (Abdul Mujeebu, 2019)

In this study, lighting comfort as an antecedent of IEQ is considered. The other sub-dimensions are not in fact the concern of this thesis. Lighting condition in crucial for visual comfort which at the first glance is related to both artificial and natural lighting. Visual quality of indoor environment is improved by daylight utilization. Considering that modern lifestyles can result in people spending more than 80% of each day indoors, contemporary architects are required to concentrate more on efficient natural lighting though.

Natural lighting is consistent with human vision system. Its specific characteristics also contribute to creation of visually pleasant indoor space. Enhanced daylighting systems yield improved quality of indoor environment due to this characteristic (Shin *et al.*, 2013; Tzempelikos, 2017; Hosseini *et al.*, 2018).

It is worth mentioning that in this section, pros of daylighting are discussed under the assumption that issues related to daylighting such as control strategies to overcome glare, design of fenestration to provision of privacy and thermal comfort-related problems are already addressed. These issues of daylighting will be discussed in Chapter 3.

The parameters used for visual comfort's assessment in widely used indoor environment assessment tools (BREEAM, LEED, SBTool and CASBEE) are listed in Table 2. Although the assessment tools cover the issue of visual comfort as a whole, emphasis is given on daylighting–related factors**.** The tools used for daylighting analysis vary in their philosophy, approach and structure as show in Table 2.1. Therefore, the presentation of their main features is an inseparable part of the analysis regarding the consideration of visual comfort related parameters in the assessments they conduct (Giarma *et al*., 2017).

Table 2.1: Daylighting-related factors for visual comfort in well-known environment assessment tools (Giarma *et al.*, 2017)

BREEAM	LEED	CASBEE	SBTool
1. Glare Control 2. Daylighting 3. View out 4. Internal and external lighting levels, zoning and control	1. Interior lighting 2. Daylight 3. Quality views	1. Daylight 2. Anti-glare measures 3. Illuminance level 4. Lighting controllability 5. Perceived spaciousness and access to view (in sub-item "Amenity", of the item "Service Ability")	1. Appropriate daylighting in primary occupancy areas 2. Control of glare from daylighting. 3. Appropriate illumination levels and quality of lighting in non-residential occupancies. 4. Controllability (including several criteria with regard to the degree of control for lighting systems) 5. Access to exterior views from interior

BREEAM (Building Research Establishment Environmental Assessment Methodology), the oldest method for the assessment of buildings' environmental performance, was initially published in 1990 by Building Research Establishment, UK. Currently BREEAM can be used for the assessment of buildings of various uses (residential, office buildings, hospitals, schools, etc.) at various stages of their lifecycles. In fact, there are available several schemes, each one of which can be used for different cases (Giarma *et al.*, 2017).

LEED (Leadership in Energy and Environmental Design) has been developed in U.S.A. by U.S. Green Building Council (USGBC). It is a very widely used system for the rating of buildings environmental performance. The different LEED schemes can be used for the assessment of buildings of various uses at all phases of development. LEED can be applied, with the appropriate adjustments, in various regions of the world (Giarma *et al.*, 2017).

CASBEE (Comprehensive Assessment System for Built Environment Efficiency) has been developed in Japan. It can be used for new buildings, existing buildings and buildings under refurbishment (different versions of the tool-in this paper the examined version is CASBE for New Construction4 (the data for offices are taken into consideration)). It covers several building uses; also, a CASBEE tool has been developed for the assessment of urban districts (CASBEE for Urban Development) and another one for cities (CASBEE for cities) (Giarma *et al*., 2017).

SBTool5 (Sustainable Building Tool), which is the evolvement of GBTool (Green Building Tool), has been developed by iiSBE (international initiative for a Sustainable Built Environment). It is the computational tool of the Sustainable Building method, which is constantly developing with the contribution of several organizations, institutions and researchers around the world. SBTool is a generic framework that can be used for the assessment of buildings of various uses at various phases of their lifecycles (design, construction, operation) (Giarma *et al*., 2017).

2.3.1 Daylighting and Visual Comfort

It has been stated that human has been evolved by living in harmony with sunlight and its heat. For thousands of years, human race has been in contact with variations in daylight patterns through the days, seasons (Thornthwaite *et al*. 1954). In fact, daylight provides a better lighting environment than artificial lighting such as cool white or energy-efficient fluorescent electrical light sources because daylight most closely matches the visual response that, through evolution, humans have come through (Tzempelikos 2017). Regardless of all the advances in artificial lighting technology, daylight is still known as the “real color” for human vision system.

Although the daylight color is not constant as it is affected by the changes of sunlight patterns and the sky, it is the baseline for arbitrating the pleasant color of lighting in architecture.

Daylight was integrated in the design of old stores and bazars by means of opening at the roof to show off and display the goods for sale (Klassen 2006). Nowadays, daylight plays a major role in designing display buildings such as museums, shops, and art galleries as architects have noticed the rank of natural light in visual comfort. Today, although locally introduced artificial light is still an essential lighting strategy to display the items in such buildings; the visual comfort revenues of daylight utilization have encouraged the architects to endow the natural light for general lighting.

In residential buildings, daylighting has also been emphasized. Iranian traditional houses feature spaces with different illumination conditions based on functionality. In contemporary architecture, visual comfort by daylighting has gone beyond designing differently daylit spaces. Daylighting condition can be controlled by occupants by manipulating the arrangement of design elements to fulfil their needs. Innovative systems and dynamic facades allow the occupants experience different scenarios of daylighting, resulting in visual comfort and satisfaction.

2.3.2 Daylighting and Visual Perception

Lighting quality is not only related to high quality lighting condition for visual comfort, but it also depends on the visual features of interior spaces. Daylight utilization changes the perception of the space. Unlike artificial lighting, daylight accounts for unique visual aesthetics of the building such as view from inside out, variety of lighting, and visual aesthetics. In Iranian traditional and contemporary buildings, specific attention has been paid to these visual characteristics of indoor environment by means of daylight utilization and control.

2.3.2.1 Variety of Daylight

On the other hand, one of the most prominent characteristics of daylight is its variety. Compared to artificial lights which provide an almost unchanged lighting condition, daylight has the capacity to move and change infinitely. Integrating daylighting design elements provides the architects with the chance to capture these changes for creating dynamic interior space. Daylight utilization lets this variety come into the interior space and benefit occupants (Tzempelikos 2017).

The impression of this variety for occupants is two-fold i.e. adding dynamic aesthetics to indoor experience as well as consistency with human physiology. Human body is naturally adapted to the changes in sunlight patterns both visually and physically and thus it needs to practice this natural cycle. It has been argued that light changes from the first rays of sun in the morning until it gets dark are vital for human's vision (Thornthwaite *et al.* 1954). More precisely, the human's eyes photochemical system requires a renewal process which occurs by practicing adaptation to sunlight. As the lighting patterns of indoor space are altered with sun, the visual process is practiced by the occupants.

In addition to the physiological merit of daylight variation, daylit interior spaces are constantly changing when compared to static artificially-lit spaces. Figure 2.3 shows lighting condition in a modern building in day and night. Although artificial lighting illuminates the indoor space, daylight allows for variety. It allows the occupants experience a continually changing space which alters with time in a natural pace.

Figure 2.3: Variation of lighting in a modern residential building from morning to evening (TDC Office, 2012)

In the spaces fully-lit using artificial light, the occupants always experience the same lighting arrangement and are completely unaware of outside weather condition. Daylighting however, creates an indoor space which is not only varies during the day, but it considerably associated to the conditions of weather. There is no doubt that the experience occupants of a daylit building have in a glare sunny day is entirely different from the experience they have in a rainy day. The lighting condition of interior space is constantly changed by the dynamic configuration of the building with respect to sun. The variation created by daylighting is a unique characteristic which lets the inhabitant be aware of these changes outdoors while living in a visually pleasant environment indoor

2.3.2.2 Light, Shadow and Color Motifs of Daylight

Daylight illuminates the interior space from outside and accordingly, design elements used for daylight utilization and control can be deliberated in a decorative fashion to create colors and patterns from daylight. Colored glass of latticed windows in Iranian traditional architecture is the most well-known example of this pleasant play with daylight in architecture. In Iranian traditional buildings, in addition to toning the interior spaces with colored shafts of sunlight, the patterns of light and shadow created when rays of daylight pass through the latticed openings enhanced the aesthetics of interior design (Maghsoudi Nia *et al*. 2015).

Figure 2.4: Integrating sunlight patterns in indoor space design in traditional (left) and contemporary (right) architecture (CVDB Arquitectos, 2016; Ekhlassi and Rafati, 2015)

Different levels of transparency and arrangement of openings are some of design motifs used by traditional and contemporary architects for daylighting which enhance the visual pleasure ability of interior spaces. Two examples of these aesthetic aspects of daylight are given in Figure 2.4. The right-hand side photo shows the colorful patterns created by daylight in Iranian traditional architecture. The photo is taken from the interior space of the Pink Mosque (The Nasir al-Mulk Mosque) in Shiraz, Iran (Ekhlassi and Rafati 2015). The left-hand side photo belongs to Megalithic Museum designed by design firm CVDB architects in Mora, Portugal. Comparing these two photos from past and today reveals the implication of daylight effects for aesthetic aspects of building design.

2.3.2.3 View Out from Inside

Even though view is not generally recognized as a contributing factor to lighting conditions, it is an exceptional factor in adding visual pleasure to building design. View is the visual communication between indoor and outdoor environment. The view out form inside gives information about outdoor environment, plays role in visual comfort and aesthetics and enhances occupants' physiological well-being (Ulrich 1979). View out from indoor during the day is a product of daylight. It is sunlight that lights on the neighborhood area and allows the occupants of the buildings see the outside world through the windows. The view out provides the occupants with information about outdoor environment. Occupants would be aware of time, sky, weather condition and seasons by having a sight to outdoor space. Without a view to outside, occupants would be completely oblivious about the natural surroundings of the building which causes discomfort. Another asset of view is related to its effects on occupants' physiological health.

A stunning view across natural countryside scenes such as a lake or a river is an entirely different experience compared to a blank view or in cities, gardens, parks, and pools can be the focus of view out shown in Figure 2.5. The photo shows the magnificent view from veranda to the central courtyard in an Iranian traditional house (Nabavi *et al*. 2013). The importance of view in physiological health is highlighted in a research conducted in a hospital. Research has revealed that patients hospitalized in rooms with a pleasant view through the window are more likely to recover early when compared to patients stay in rooms without a view. These findings argue that the view contributes to mental health and improves the physical health accordingly (Ulrich 1979).

Additionally, view provides a center of visual comfort in distant space. People who spend long hours inside the buildings suffer from visual fatigue (Smith 1979). In other words, human’s eyes need to be adapted to eyesight located in some distance and re-adapted again to indoor space.

Based on these facts about view, special attention should be paid to the view through windows when designing a building. In fact, building type, construction site and neighboring outdoor space define the quality of view. Height of building also imposes limitations for creating the most informative and pleasant view out. In high rise buildings, at higher levels a view across the sky may be found while at lower levels the windows look over surroundings.

In some large building facilities such as commercial complexes, the lack of view to sunlit outdoor is compensated by creating the view out across some internal parts of the building. This strategy is satisfies the need for visual rest but without daylight the view lacks variation, and it is not informative about the natural exterior environment. It is worth mentioning that regardless of the limitations and considerations, anywhere that a sunlit view is available, it is strongly recommended to be integrated in window design (Ruck 2000).

Figure 2.5: View out from indoor in Iranian traditional architecture (Nabavi *et al*. 2013)

2.3.2.4 Symbolic Role of Daylighting Elements

The use of daylighting elements can be symbolic, for instance, the type used by Anglican Church symbolizes church. Symbolism can be added to the design both on exterior facade and interior spaces. It is worth mentioning that although symbolic and aesthetic role of daylighting elements may seem of the less prominence than its functionality in daylight utilization, control and ventilation, these aspects have not been overlooked by architects through the history. A typical example is the Boxmoor (Figure 2.6), where Christian cross is quite conspicuous. Skylights in Iranian traditional architecture are another examples of the symbolism of daylighting. Skylights resemble the concept of unity and an opening to the sky where Muslims believed as the place of heaven. Figure 2.6 shows two examples of symbolism using daylighting elements.

Figure 2.6: Symbolism aspects of daylighting design in traditional architecture (Baker 2013; Ekhlassi and Rafati 2015)

2.4 Health and Well-being Benefits of Daylighting

Daylighting contributes to human health in different aspects. It is not only related to effect of sunlight on human body, but also includes the psychological merits of visual comfort and visual characteristics of daylit environment. The studies on benefits of daylight for occupants' health are enormous (Leslie 2003; Michael and Heracleous 2017; Ulrich 1979).

Health benefits of sunlight for human body and the physical health problems related to lack of it have been highlighted in a wealth of studies. For instance, inadequate exposure to sunlight is known as one of the risk factors for vitamin D deficiency (Wacker and Holick 2013). Sunlight deficiency is also associated with as very common disorder known as SAD (seasonal affected disorder) (Graw *et al.* 1999). SAD is a type of depression disorder associated with low levels of sunlight in fall and winter seasons. Deficient daylighting in buildings worsens the symptoms and increases the risk of this disorder.

Resident's productivity is also highly linked with daylight condition in the building. It has been proved by The Centre for Building Performance and Diagnostics (CBPD) that people's productivity increases between 0.7% to 23% in a high quality day0lit environment. The study was conducted on twelve cases worldwide claiming also that annual energy use for artificial lighting is reduced by up to 80% (Clements-Croome 2006). Michael and Heracleous (2017) have shown that in daylit classrooms, students perform better in exams and have less disciplinary issues compared to artificially-lit classrooms. Retail sales and book usage are other factors proved to be increased by daylight utilization in firms and libraries respectively (Araji, Boubekri, and Chalfoun 2007).

The effect of natural light on occupants' psychological health has been highlighted by behavioral and mental health researchers. Sunlight helps decreasing the symptoms of some mental disorders such as bipolar depression (Benedetti *et al*. 2001). The health benefits of natural light/windows in hospital patient recovery rooms have been a given fact for half a century. There is strong evidence that daylight can be extremely beneficial to patients as well as staff in healthcare settings (Ulrich 1979).

Several studies have evaluated the effects of changes in lighting condition on performance of occupants in different groups of buildings and proposed a prediction model of performance as a function of various indoor environmental factors (Shin, *et al.*, 2013; Tzempelikos, 2017). In workplaces, offices, coffees and shops where the indoor environment is properly daylit, people prefer to stay more since they enjoy the environment and experience visual comfort. Leslie (2003) has found a positive relationship between the level of satisfaction with the workplace environment and daylight utilization in office buildings. Therefore, daylight utilization is critical in designing a user-friendly lighting system and ignoring it leads to serious circumstances.

2.5 Daylighting and Energy Saving

Moreover, daylighting decreases energy consumption for artificial lighting and increases energy efficiency. Lighting is responsible for approximately 30% to 50% of energy consumption in commercial buildings. For residential buildings, the global lighting electricity use in 2005 was estimated by the Energy Information Administration (EIA) to be 811 TW h which is 18.3% of residential electricity consumption (Ihm *et al*. 2009).

The energy load for artificial lighting highly varies across countries and even different cities in a specific country. For instance, in the United States, approximately 279 billion kW h of electricity were used for artificial lighting by the residential sector and the commercial sector according to estimations made by EIA in 2016. This was about 10% of the total electricity consumed by both of these sectors and about 7% of total U.S. electricity consumption. Residential lighting consumption was about 129 billion and the commercial sector, which includes commercial and institutional buildings, and street and highway lighting, consumed about 150 billion kW h for lighting (EIA, 2017). In Iran, 30% of the total residential electricity consumption (in the year 2012), is linked to artificial lighting which is almost 12% higher than the global average (Chaharsooghi, *et al.*, 2015). Therefore, lighting is one of the most important areas where significant savings energy consumption is possible by efficient utilization of daylight in indoor environment.

A remarkable amount of energy can be saved by panning efficient daylighting while management thermal gain. Electric lighting energy use can be reduced by 25-50% with advanced light sources, design strategies and controls, and by 75% with the addition of daylighting (Ihm *et al*. 2009). During the period from sunrise to sunset natural light can be the main source of lighting supported by artificial lighting.

Daylight was the major lighting source providing comfortably-lit indoor environment during the day in traditional architecture. It should be noted that in the past, energy efficiency for lighting was not a concern, but the impact of maximum daylighting on thermal comfort was the main consideration. Specifically, in Iranian traditional architecture in hot climate, fascinating design elements and strategies are exploited. On the other hand, energy efficiency is of a special importance in contemporary architecture. Nowadays, building designers need to consider a set of factors related to energy use when planning for daylight utilization. More precisely, maximum daylight utilization and minimum heat gain in hot season are to be practiced simultaneously for energy efficiency.

2.6 Summary

In general, daylighting benefits the buildings in both visual and non-visual aspects. Visual effects of daylighting contribute to quality of indoor environment by enhancing visual comfort and adding visual characteristics to interior space. Non-visual effects of daylighting are related to occupants' well-being and energy saving.

Sunlight is bound with the evolution of human race and benefits of sunlight for physical health are enormous. In addition, architectures can manipulate indoor space by means of daylight features such as variety, light, shadow, color and view out from inside. These features add aesthetics, dynamics to indoor space and make the indoor environment more visually pleasant. The natural day-night cycle and the variation created by sunlight patterns contribute to psychological health and comfort. Hence, daylighting definitely enhances the quality of indoor environment if it is well-planned at the design phase and appropriate elements are used.

Health and well-being are also affected by daylight. Both physical and mental health of occupants have been proved to be enhanced in effectually daylit indoor spaces. Productivity and performance of people are increased by daylighting as well. Daylighting decreases energy demand for artificial lighting and is essential for energy efficiency of buildings.

The main concern of this study is quality of indoor environment and neither well-being nor energy saving. Therefore factors related to visual comfort and visual characteristics of daylighting are considered as the important measures for evaluating daylighting. In addition, since the methodology is based on literature review and case studies, only descriptive criteria of the aforementioned well-known assessment tools are considered for assessing daylight utilization and control in indoor environment. Accordingly, related descriptive criteria are merged for four assessment tools and summarized in Table 2.2. These criteria are used for evaluating daylighting in the case studies.

Table 2.2: Descriptive criteria considered for daylighting (Giarma *et al.*, 2017)

Criteria	**Issue examined**	**Main axes of the compliance criteria**	**Type of criteria**
Visual comfort	Glare Control	Avoidance of glare through either the building form and layout and/or building design measures	Descriptive (e.g. use of compliant shading devices)
	Appropriate illumination levels and quality of lighting	Ensuring the provision of adequate illumination levels and lighting quality and of task lighting support capability	Descriptive (ambient illumination, zoning, etc.)
	Perceived spaciousness and access to view	Provision of adequate view, so that the occupants acquire a visual connection with the outside	Descriptive (windows, views, visual quality, distance of exterior objects)
Visual aesthetics	Motifs, colors, variations and quality of the view out	Provision of a pleasant visual indoor space using light, shadow, colors and cultural motifs, view to the natural environment	Descriptive (e.g. colored glass, view to garden and pool, etc.)

Chapter 3

PLANNING FOR DAYLIGHTING AT DESIGN PHASE

3.1 Introduction

In order for the buildings to benefit from daylight, designers need to incorporate daylighting systems into the design at the very early stage of planning. Daylight utilization and control without considering factors such as construction site characteristics, building type, climate conditions, and privacy etc. triggers issues for occupants and degrades the quality of indoor environment.

The very first reference book which has highlighted the importance of planning for daylighting in architecture was Vitruvius's book series (Baker 2013). Daylight utilization and control was firstly studied by him from quantitative and qualitative point of view. Vitruvius put emphasize on the prominence of selecting a healthy construction site for a building and by that he means a site which allows a decent provision of sunlight to interior spaces.

Planning a satisfactory daylit environment demands collaborations among many professionals including planners, architectures, interior designers and even heating and cooling specialists (Ruck 2000). In this section, design considerations for integrating maximum daylighting in planning the buildings are reviewed. In order to plan for daylighting at design phase availability of sunlight, obstruction and the type of the building should be taken into account.

Table 3.1 shows design goals of daylighting and related conditions (Webb 2006). Visual comfort and visual characteristics of daylighting are the most important objectives of daylighting in improved quality of indoor spaces. In order to achieve this objectives climate condition and site and location of the building should be considered (Webb 2006). In addition, characteristics of the design plan such as presence of semi-open (veranda) and open (courtyard) spaces, function of the building (e.g. residential, educational, office) affect the fenestration design and overall daylighting system. Provision of privacy is another criteria to be taken into account when planning for daylighting.

Table 3.1: Design goals of daylighting and related conditions (Webb 2006)

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

3.2 Planning for Daylighting Based on Climate Conditions

Climate condition affects daylight availability and temperature. These conditions identify the maximum and minimum amount of daylight and sunlight heat which can enter into the building. In order to understand the situation, the designer should study availability of daylight and the climate condition the façade would be exposed to.

3.2.1 Availability of Sunlight

Natural light is provided to the buildings using the sunlight luminance from the sky. Therefore, climate condition is one of the factors which determines how much sunlight is available on construction site. Regardless of the local area the construction site is located in, each local region features a specific climate which is the key factor in determining how many sunny days exist during the year.

In hot and arid climates sunlight is constantly available during the whole year in the clear sky. Winters have cold nights and temper days in this regions and maximum daylighting is demanded. On the other hand, in summer time daylight control and ventilation for decreasing thermal gain in indoor spaces is of great importance (Nabavi *et al*. 2013).

For hot and humid climates such as tropics, winters are temper and sunlight is almost available during the years. Daylighting conditions in these areas are similar to hot and arid climates without need to have concern about cold winters. Proper ventilation should be incorporated in the design while planning for daylighting to direct the heat and humidity out (M.Saradj 2014).

In mix climates with distinct summer and winter, sunlight availability changes profoundly during the year from hot season to cold season. In these regions, more efficient daylighting systems are needed to exploit enough daylight in cloudy sky in the winter time and control the extra sunlight in the summer time (Shan 2014).

Cold and mountainous climates feature very cold winters and temper summers. Long periods of time, the sky is covered with clouds and access to sunlight is limited. Appropriate daylight utilization is more important in these areas than daylight control (Shan 2014).

3.2.2 Temperature

Temperature and climate conditions are closely related. The aim of the designer who plans daylighting at initial design phase is to attain the best performance for the planned building type. Performance of daylighting should be estimated using simulations or physical measurement. Any specific daylighting element or strategy which is assumed to improve the quality should be considered in the model before planning to be integrated in the design. Furthermore, the ration of openings to indoor space is to be observed and checked. It should be noted that majority of simulating and modeling approaches for estimating daylighting design ignore thermal computations (Tzempelikos and Athienitis 2007). However, as daylighting and thermal strategies are closely related, thermal strategy should be taken into account simultaneously with daylighting strategy during the initial design phase according to type of the building.

Maximum daylighting may be a proper plan for cold winters in mixed climates but it would result in thermal discomfort in summer and increases the thermal load. On the other hand, if daylight is minimized for decreasing energy consumption for cooling system in summer, in winter time quality of lighting would degrade (Tzempelikos 2017).

Considerations about temperature at design phase are not isolated from climate conditions nor from thermal comfort considerations. Cold seasons needs more sunlight heat and hot seasons require less. At the design phase, fenestration is planned to address these considerations. Glazing and openings cause thermal loss in winter time and thermal gain in summer time. In planning for window to wall ratio, glazing area and shading systems, temperature should not be ignored (Tzempelikos and Athienitis 2007).

3.3 Planning for Daylighting Based on Site and Location Conditions

Site and location conditions determine potentials and limitation for daylight utilization and control. Building orientation, fenestration design, and façade design without taken these considerations into account would result in poor daylight utilization and control.

3.3.1 Latitude

Daylight intensity and patterns are determined in the first step by the geographical location of the building i.e. the latitude of the construction site. These conditions define the level of availability of sunlight in the planed building. Without precise estimation of operational condition of façade elements, a designer is not able to plan effective daylighting strategies.

For instance, at low latitudes and tropical regions, sunlight is available almost all year long. Daylight levels are high at these areas and thus the main concern for the designers is to restrict the amount of sunlight to avoid thermal gain. In other word, façade elements and design strategies in tropics mainly focus on daylighting using the natural light reflected from the ground and the sunlight from lower sky. This way, indoor environment is prevented from being overheat. On the contrary, cold and hot seasons are distinct at low latitudes. In these areas, the appropriate design allows for maximum use of sunlight especially in cold seasons when the sun is low in the sky. Unlike high latitudes where high parts of sky are to be obstructed, daylight is redirected into interior space from the brightest parts of the sky at low latitudes. At high latitude regions, on the other hand the duration of sunlight in a day is shorter when compared to low latitudes.

In addition, climate conditions and surrounding landscapes should be taken into account when façade elements are designed for daylighting (Ruck 2000). For instance, given two cities at the same latitude, availability of sunlight in buildings located in a flat city would be different from the one located in a valley between the mountains. On the other hand, building orientation also contributes to availability of sunlight in the building. Based on orientation, alternative design emphasis is demanded. Regarding sunlight availability and façade design, studying traditional architecture provides insightful information about proper design strategies aligned with climate.

3.3.2 Exterior Obstructions of Sunlight on Site

No matter how much of sunlight is available at the geographical region, there are always obstructions blocking some levels of it. Hence, in addition to latitude and climate conditions, the construction site is needed to be studied considering potential blockades of daylight. Obstructions include neighboring buildings, trees and other greenery which profoundly affect availability of daylight illuminating the façade (Hamzah and Lau 2016). Obstruction is a complicated notion in architecture as it is not only related to the availability of daylight but also linked with a wide range of considerations and regulations. In each local zone, regulations limit the height and the size of the buildings. Safety is another issue because some rules impose a minimum distance between buildings to protect them from spreading fire. Note that these considerations are not the subject matter of this study.

On the other hand, legislation the respect for allowing neighboring buildings access proper amount of daylight makes it compulsory for the planners to design buildings paying attention to neighboring buildings right for daylight. These regulations were firstly drafted in 1792 in U.S. and gradually in other countries (Ruck 2000). Since then, the rules and regulations have been modified all around the world but still any design must be within the limitation of the regional construction rules not to play the role of a major obstruction for daylighting surrounding buildings. Consequently, architects are obliged to take into account two major issues when designing a building: the obstructions in the neighborhood which limit availability of daylight and the obstruction their design would cause for neighboring buildings.

3.3.3 Building Typology

Another crucial factor to be considered when planning daylighting is the type of the building. Although explaining variety of buildings is far beyond the patience of this study, regular constrains of urban design have resulted in a limited number of popular design schemes. The typical building types can be broadly categorized into residential (such as houses), commercials (such as offices), educational (such as schools), civic (such as museums) and transport (such as airports). Each type comprises several sub-types each necessitates a special daylighting strategy (Veitch 2006). For instance, residential buildings include detach houses, semi-detached houses, multi-story family houses, apartments and residential complexes.

For each building type, daylighting quality differs and is to be planned in view of construction site characteristics, limitations and location (Ruck 2000; Veitch 2006). For complex designs where floor area comprises different zones, daylight is an architectural element. Special care should be taken to properly daylight different indoor zones. For these cases such as schools and office buildings, daylighting is a very crucial architectural element. Hence, during design phase, several parameters related to quality of daylighting should be studies. Wrong estimation of luminance distribution, results in poor daylit zones and decreases the quality of indoor environment.

3.4 Planning for Daylighting based on Provision of Privacy

Provision of privacy in architecture is defined mainly in the cultural context of an urban community. The level of privacy required for each building also in an antecedent of type of building. Fundamentally, residential buildings are amongst the buildings with maximum call for privacy (Baker 2013; Giovannini *et al*. 2015). Daylighting on the other hand, encourages several transparent openings on facade and thus a view from outside to indoor spaces. The introverted houses in Iranian traditional architecture are the very example of entirely-private indoor spaces where daylighting is addressed by central courtyards and open spaces surrounded by high walls.

Atria and courtyard are technically assumed as distinct architectural elements. These elements create private or semi-private spaces to enhance daylighting, ventilation and thermal comfort. Atrium takes its etymological root from inner courtyards of Roman architecture (Baker 2013). Meaning to admit daylight and allow for ventilation to the surrounding indoor space, the word atrium has expanded in dimensions as described as an interior daylit space having two or more walls on its sides and letting daylight in from the top. The roof is glazed using of transparent/translucent materials. It allows the natural light come into the indoor spaces through the glazed or sometimes semi-open non-glazed opening to the sky. It can be considered as either the advanced version of the dome or vault permitting daylight into the central areas of magnificent houses or a sky-lit private open space to allow for more openings without privacy concerns. Modern atrium have basically a glazed skylight on the roof which thinly reduces the daylight, keeps occupants informed about the weather and sky condition, contributs to ventilation and minimizes the need for ventilation, heating and cooling.

Inner courtyards in Iranian traditional architecture are elements added to the design for daylighting, ventilation, visual comfort and privacy. Featured houses in Iranian traditional architecture had multiple courtyards which let the designer arrange fenestration on multiple facades while privacy was provided to occupants (Maghsoudi Nia *et al*. 2015).

The remedy of inner courtyard and atria is not a feasible solution in contemporary mass construction. In contemporary architecture, provision of privacy should be seriously taken into account in the design phase otherwise meeting the need of full privacy involves the “net curtain” solution; in a case it is necessary. Some translucent materials allow for adequate daylight, but break the internal image view from outside. This is inconsequential in day time as the outside light surpasses that in within and no demerit exists in employing the distributing elements on the openings (Tzempelikos 2017).

3.5 Summary

Daylight utilization and control is a matter of concern at the early stage of building design. While facade elements play the key role in daylighting, characteristics of other design elements influence the arrangement and configuration of windows and solar shading systems. The architects and design groups are required to see the whole picture in order to be able to successfully utilize and control daylight. Planning for daylight design and strategy is thus part of the initial design phase. Several factors such as availability of sunlight, obstruction and building type are of importance. At the design phase, appropriate arrangement of windows, shading, skylight, and glazing to be integrated into the buildings are planned to assure proper amount of daylight is allowed into interior space without negatively effecting thermal comfort. Provision of privacy to occupants of the building is of course another concern. In general, a comfortable indoor environment in terms of daylighting is the result of the balance among all needs, limits and potentials.

Chapter 4

FAÇADE ELEMNTS FOR DAYLIGH UTILIZATION AND CONTROL

4.1 Introduction

Buildings are exposed to solar radiation and natural light at different intensities throughout the day, which requires techniques to manage light conditions in a space to create a high quality indoor environment. Controlling natural light becomes very challenging when several elements are considered simultaneously, e.g. minimizing heat gain, while maximizing daylight, yet considering the problems of glare.

In fact, delivering appropriate amount of daylight into indoor spaces as well as aesthetics is prominence when designing building façades. Daylight should be controlled to efficiently illuminate indoor environment without causing visual and thermal discomfort. Visual discomfort is caused by glare a phenomenon which is of a great concern nowadays as most modern buildings are equipped with electric devices to work with. Thermal discomfort created by daylighting is another issue to be addressed specially in hot climates. Traditional architecture exemplifies sophisticated facade designs for daylight utilization and control.

In addition, daylight is well known as an approach to decrease energy consumption for electrical lighting and even heating in cold season. In contemporary architecture, most designers and lighting engineers may recommend a correct window-to-wall ratio from the standpoint of energy efficiency although the owners of buildings and occupants typically prefer to have a spacious open area. More precisely, a perfect façade must guarantee an expansive openness and reduce the amount of solar heat gain in hot season while exploiting maximum daylight in cold season. It is also worth mentioning that unlike traditional architecture, limitations on construction area and land-use have to be considered in contemporary architecture while planning for daylight utilization. Building spacious open spaces and atria is not always possible specifically in hyper cities with dense construction of high-rise buildings.

Daylight utilization and control in a building is determined in the first step by fenestration i.e. the design, construction and arrangement of openings in a building. Windows, shading elements, and skylights have been always taking part in the history of daylighting no matter how advances in construction material, and glazing have changed design characteristics. On the other hand, innovative daylighting approaches have been developed in recent years to bring more daylight into indoor environment of buildings. Bearing these facts in mind, in addition to the facade elements in daylighting and their role in improving quality of indoor environment, skylights, and innovative designs are also needed to be considered when daylighting in building design is studied.

Accordingly, fenestration, glazing and every arrangement of openings for daylighting is to be planned carefully at design phase according to the needs of occupants. Today, advanced daylighting elements facilitate building of high quality daylit indoor environment but these elements and the associated strategies are to be incorporated into the design procedure of the buildings.

Construction, design and arrangement of openings in a building are central errands of fenestration in building design. An architect considers several factors and design characteristics when planning for fenestration in a building and efficient daylighting is one the key objectives. Facade elements for utilization and management of daylight basically include windows on walls and solar shading elements.

Table 4.1 represents the fenestration and glazing characteristics for proper daylihgting in the buildings. Several considerations to be taken for arrangement of windows, skylights and celersteroris on the facade are described in the table. In this study, windows, and skylights are considered as the major facade elements for daylight utilization. Fixed and movable shading elements are also necessary for controlling daylight. Glazing of different transparency levels have different solar heat gain and allows for natural lighting.

4.2 Windows

The window is an opening in a wall of a building enhancing light and mainly air to the inside. Windows are in two core categories: (1) the window set on building's walls and (2) the opening to the sky into the roof also known as skylights. Hence, windows in this section refers to facade windows.

The idea of small panes of glass inside latticed windows of wood, stone or bronze was very common in traditional architecture of Europe and Middle East. Specifically, in Iranian traditional architecture, tall latticed window-doors with colorful glass are frequently observed. The design of the window is very pertinent not just because of the aesthetic values but also because of the major roles it plays in the quality of indoor environment. As will be demonstrated in the case studies, with the huge rise in ‘passive’ buildings, the window takes the leading part in daylighting development in contemporary architecture, a development that has been in a continuous flux.

Table 4.1: Fenestration and Glazing Characteristics (Hutchins, 1998)

Fenestration and glazing characteristics

Fenestration and orientation considerations

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

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

Glazing

Transparency types	Solar heat gain	Natural lighting
Clear	ok	X
Tinted	X	Ok
Heat absorbing	X	Ok
Reflective	X	Ok
Spectrally selective	Ok	x
Glazing types	**Solar heat gain**	**Natural lighting**
Low-e glazing	Ok	Ok
Spectrally selective low e coating	X	X
high LSG low glazing	Ok	X
High visible transmitted low-e clear	Ok	Ok
Low solar heat gain selective low-e glazing	ok	x

4.2.1 Window Objectives

For instance, in the aspect of technology, the ‘interactive’ window designed by the architects in Studio E and industrialized to a real-world platform by a manufacturer known as Colt indicates a synergic approach to the building environmental control. Notably, this platform does not request the necessity for glasses of high technology known as high tech glass but using cheap clear windows. The objectives of the window design include:

1. To provide daylight

2. To maximize the benefits of daylighting system
3. Provision of sound insulation for normal circumstances.
4. To account for thermal insulation.
5. To provide ventilation without creating draughts

The attributes of window enable individual control by occupants, and this is an important feature in measuring user satisfaction, as it often suits the environmental requirements. This is a clear demonstration of exemplary leadership by architecture in satisfying the needs of indoor environment. Lastly, the essentialities of windows are described thus (Philips 2004):

1. Windows are crucial elements in building design because they contribute to change, color, sunlight, modeling, view and orientation.
2. With the necessity for energy efficiency in architecture, window design leads in the direction of high-technology design, where the issues of direct sunlight, glare ventilation, solar gain, pollution and noise are jointly resolved.
3. Developments in windows now make air-conditioning optional.
4. There exists a meeting point between providing of maximum visual comfort and considering environmental condition in a building, and the world should accept the reality of environmental issues such as green gas emissions and global warming.

4.2.2 Window Configuration and Arrangement

To fulfill previously mentioned objectives, different window configurations have been invented. Vertical windows became notable in 14th century but its glorious period was 18th century through the development of Georgian window (Philips 2004). Vertical windows are tall windows divided by masonry at intervals. It has become a very preferred architectural feature as it quickly comes to the view of visitors, and architects consider it very vital. A logical case as it is in the Iranian traditional architecture when the window extended the entire length of the external wall lighting the entire deep indoor space. Other examples are transparent doors, multiple openings arranged vertically and horizontally to utilize and control daylight in hot climates on central plateau of Iran. This is seeking for a technique to overcome the need of vertical requirement of the window. Another example is which requires another window at the lower level on top of door openings for adequate daylight. To demonstrate the variations in window characteristics, frequent window configuration and designs in Iranian traditional architecture are shown in Figure 4.1.

Figure 4.1: Different window arrangements in Iranian traditional architecture (Nabavi *et al.*, 2013)

The illustrations of the buildings in Figure 4.2 along embankment in London show three contemporary styles to fenestration. Notably, all the buildings in the figure are of the 20th century. The one on the left-hand side displays very traditional detached windows, the one in the middle reveals an evolving horizontal window, where the expressed floors receive particular attention. The building on the right reveals further development on window, where the window becomes an extension of the external attachment for a full glass façade. However, all the buildings portray just architectural fashion, and unrevealing of daylight success.

Figure 4.2: Three different styles of fenestration in contemporary architecture on London's Embankment (Baker 2013)

The Georgian window developed in the 18th century was one of the best choices because it had good qualities like admitting unadulterated daylight, providing ventilation in hot season; and capable of being regulated by shutters, as well as providing some sort of security. However, it gave less attention to thermal insulation, perhaps because thermal gain from solar radiation and the possibility of visual discomfort because of glare were unimportant at that time. Going forward, window development has evolved, ranging from the standard vertical or horizontal windows on the walls of majorly residences, to the windows often found in modern buildings. Nonetheless, the Georgian window offers certain instructions yet to be learnt today, mostly as regards the subtlety of the detailing. These lessons are (Baker 2013):

1. The modern method of production leaves the wooden pieces utilized for dividing the parts of an opening of the timber area too heavy, thereby partially or completely blocking the view out from inside, particularly where the eyesight lines of the ones inside meet.

2. In the cases where glazing bars should be employed, they are often too heavy thereby creating unwarranted shadows and reducing the available daylight, whereas the Georgian window makes room for lighter size, giving room for more daylight.

3. The outline of expanded sides between the walls and the window openings, which balances the window's vividness seen against the brightness of the interior, has been ignored. This lesson from mediaeval churches is still applicable in contemporary architecture, although the usage of slope to cover the security cover ups may no longer be necessary. It should be noted that the thermal merits and acoustic capacity of contemporary windows introducing double glazing should not be forgotten.

Admittedly, many of the windows discussed set into wall intervals either horizontally or vertically, with their accompanying benefits, especially on determining daylight entrance. It is however noteworthy that wall-to-wall window is necessary for modern buildings. And this needs structural particularizing. Taking for instance, horizontal divisions may be needed; hence the glazing can cover the facade between the ceiling and the ceiling level or spandrel. The architect should also take note of the meeting point of the window with the wall at the right angle. This is to avoid a conflict of brightness. Again, it may be needed to break up the elevation of the building by introducing structural element and articulating the perimeter of façade. In this, the wide horizontal windows between the vertical axes might be handled like the splays of traditional building. The essence of taking cognizance of window elevation, especially when it relates to orientation of facades, is to provide solutions to any exposure in case solar shading and protection from glare are needed.

4.2.3 Window Glazing

Architects are expected to take view into cognizance when designing a building, fenestration, arrangement of windows and their details. Some of the most beautiful windows were those in Britain in 18th century where the sophistry of glazing bar, ensuring that daylight was captured; was taken into much consideration. This has become less necessary in the present day architecture since here is no limit for the glass size. In fact, glazing can be stretched in such a large area to let fully transparent facade.

Now, there are many different glazing types for windows. Therefore, it is pertinent for the architect together with the services and lighting specialist to consider performance specification. These specifications include but not limited to alignment of the window, its thermal characteristics, acoustic features, and the capacity solar shading. The main function of the window- entrance of daylight; and introduction of the view to outside must also be included. Again, ventilation enabling of the window should be considered, and that determines whether it should be fixed or open.

When a glazing type reduces the impression of daylight and to a high extent, darken both interior and the exterior view, the view from outside towards the building would automatically make the façade look dark. It is human nature to appreciate the natural environment, but sometimes, certain modifications turn out disappointing. Oftentimes, residential buildings have dark glass applied to the façade and this makes the interior dull. The three basic categories of glazing are given below (Philips, 2004).

1. **Clear glazing:** This type of glazing is a thick glass which can be single or double glass. Having more sheets and increasing the thickness result in diminishing daylight. However, the impression of the exterior color is perceived to be natural. Clear glass allows for high daylight transmission as well as high solar radiation. This has resulted in the development of high-tech glasses manufactured to lessen the thermal gain of sunlight, and consequent loss of daylight transmission.

2. **Tinted glass:** This appears in two forms: first, when the clear glass is highly modified to create radiant thermal diffusion features; so, the thicker the glass is, the poorer the diffusion of sunlight would be, and the higher the sunlight radiant heat can be controlled. Additionally, glazing covered with meticulously fine layers of specific material (metallic oxides) reduces the heat from the building. These coatings are done on the inside of the layer of glass, alongside other sheets in a concealed double-glazed piece, purposely for safety. When this is done, it is exposed to destruction. The coated glasses are often intended to transmit natural light and therefore appear clear. They also do not block the view, but very costly. So, the specification should be on demand. Care should however be taken in using this glass to avoid glare to other buildings or motorists because of their high reflectiveness.

3. **Miscellaneous glazing:** Different types of glazing are grouped here because they can hardly be fussed in one category. They include wired glass, patterned glass, and laminated glasses. Each of these categories are explained in the following.

4. **Patterned glass:** This kind of glazing is a variant of semi-molten glass, basically used for decorative propose. It is hardly used for windows because their capacity for light transmission is modifiable.

5. **Wired glass**: The manufacturing of this glass involves sandwiching of wire mesh within the breadth of the glass. It is mainly exploited for security situations.

6. **Laminated glasses:** This has similar manufacturing process for enclosing sheets of laminate plastic between planes of glass. It also has security applications. It is

used in museums where exhibits are exposed to daylight, and to control the entry of UV light.

7. **Glass blocks**: These were common in 1930s. It has thermal attributes given the hollow appearance of the blocks. It is still in vogue till date as it introduces daylight into new buildings, once openings are provided.

8. **High tech glazing**: This is a microcosm of many types, the most advanced are the photovoltaics, which are designed to enable the glass generate electricity itself through radiation on south facing exposures. It can be used to reduce the energy needed for artificial lighting. UK government for instance is investing heavily for the development of this method. Two other notable types of high tech glass are one, the photochromic glasses, which respond to environmental stimulus, and two, the electrochromic glasses which indirectly respond, when electrical current switch change their visual and thermal features. These two forms lack economic viability and they are still in developmental stages. When choosing glazing, it is important to consider cost and efficiency.

4.3 Solar Shading

Many types of solar shading exist, each with its merits and demerits. The architect should therefore be conscious of the criteria required in determining the nature of shading needed for the building. The major reasons why shading is required in the design are as follow (Tzempelikos 2017):

1. It minimizes the effect of thermal gain from sunlight radiation
2. It reduces glare caused by direct sunlight radiation through windows
3. It enhances privacy

Minimizing heat gain from the sun: The need for this is often seasonal, because there are times in the year that heat gain becomes necessary. Heat gain is higher on South facing exposures. As the solar heat gain gets into the building enclosure though the facade, it is hard to control the heat as it is stopped by the shading system in the first place, so the external system becomes preferable. In choosing the external shading, one should not forget the problem of structural suitability and the requirement for regular cleaning

Reduction of glare from direct sunlight: Glare can occur in different ways by reflection from outside sources, from direct view of the sun, or items in the building. Unlike heat gain, glare can easily be controlled from the inside of the building using internal shading elements.

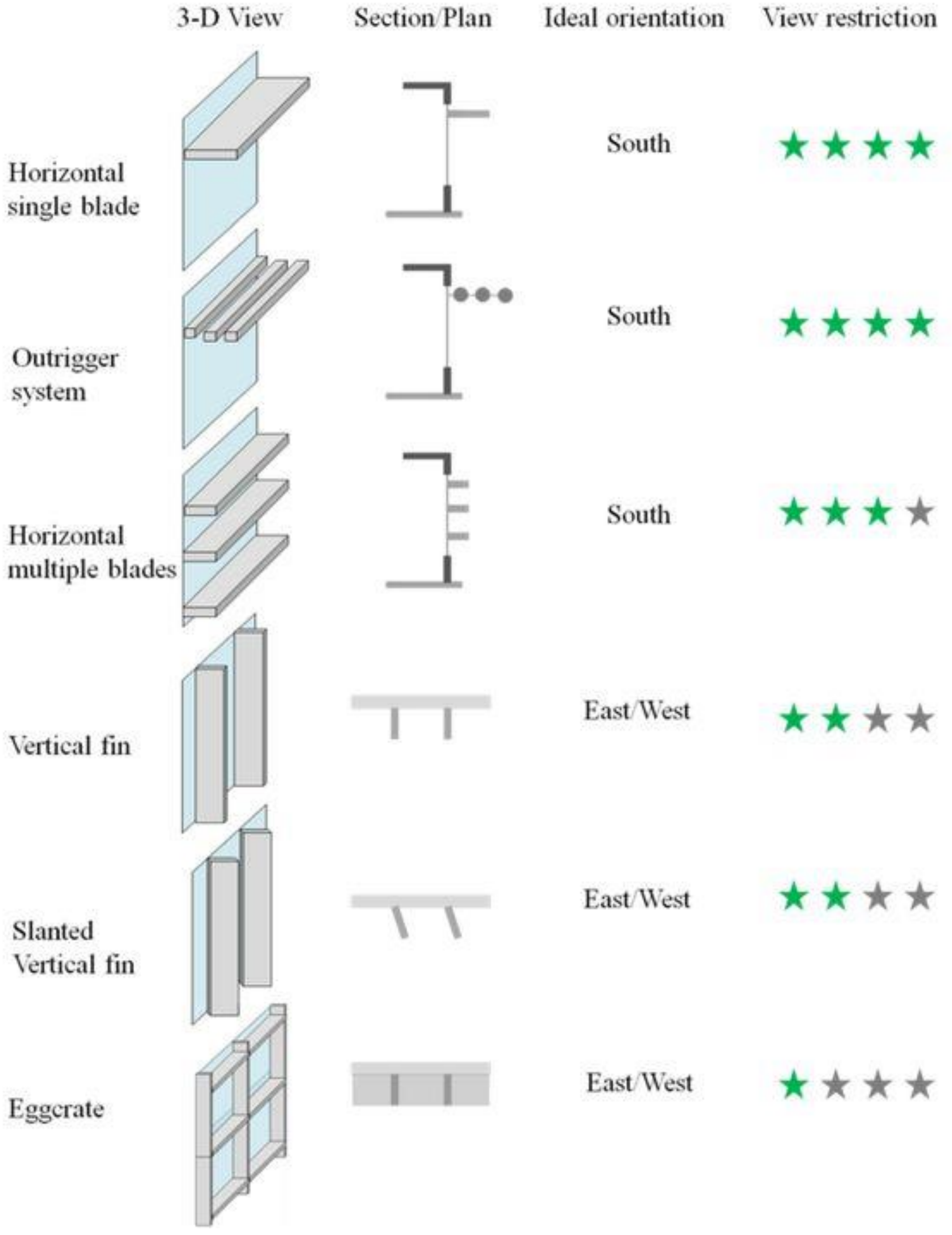
Enhancement of privacy: Internal shading devices mainly function as elements to block the view in from outside. This is of more importance in contemporary architecture as the lack of inner courtyards forces the designers to place windows on the facade facing streets.

4.3.1 External Shading

External shading systems include light shelves, overhangs and canopies, shutters, fixed and movable louvers, deep window reveals, vertical fins, egg crate baffles, and roller blinds. In choosing any method here, the most critical factor to consider is the viability of the hardware involved. In addition, the architect might also need to check the exterior appearance of the building. As much as it is needful to control the solar heat gain by manipulating it before entering the building, methods of external shading methods can be vulnerable. Other types of external shading are, awnings light, continental shutters, and the external roller blinds. To ensure cost effectiveness, comparison should be made with internal shading. Again, the architect needs to consider the visual appearance, which is, viewing it from the elevation before deciding.

Another type of blind is the vertical hung louver blind. Here the slats can be rotated, and so it offers flexibility, privacy and low cost for domestic use especially when joined with roller blind. Different glazing can be used to control the heat gain of sunlight and there are many options for this. First, the low emissivity glazing has thermal properties of the glass that can function for solar control. A major merit for this is that it admits higher levels of daylight than the original tinted version, and as a result controls heat loss. Second, the prismatic glazing has also proved very effective. These small panels of prismatic glazing are attached to high level skylights, to allow the entrance of daylight, redirecting the sunlight to the ceiling space or completely excluding it. Lastly, there are high tech glazing (already mentioned under glazing available for window). They include, electronic and liquid crystal glazing (which can darken when electric current is applied), photochromic glass (a kind of glass which turns darker in response to sunlight radiation) and the thermo-chromic glass (with adaptive transmission value in response to heat). It should be noted that these later developments are not in the mainstream, and so are unlikely to stand the test of time.

Table 4.2: Fixed and movable solar shadings (Tzempelikos and Athienitis 2007)



4.3.2 Internal Shading

This type is considered not very efficient because the heat generated is already within the building and may be difficult to extract. So, windows are often considered more preferable. However, the advantage of the internal shading over the external one is that it is less vulnerable and easier to maintain. Hence the solar gain may not be controlled very well from the inside, additional method can be adopted. For instance the use of curtains with reflective lining can be used in residential building. A more flexible form of control is the venetian blind, which has the advantage of its adjustability to allow for adequate daylight entry.

This excellent tool had been predicted not to stand the test of time; nonetheless, it is still thriving in providing efficient glare control. It is motorized and can be integrated with the panes of glass to prevent damaging. Another merit of the venetian blind is that the surface design of the horizontal slats can be varied to meet the individual requirements of the building. More so, venetian can be easily upturned when sunlight control is not needed. The issue however is when this element dropped; it remains in a closed position. Proper management would enhance maximum utility. The venetian blind has the potential to keep thriving.

4.4 Skylights

Skylights are architectural designs that permit daylight to enter from above through glazed opening in the roof, protecting the interior from wind. The traditional skylights were conceived as ordinary openings on the center of vault to allow daylight. In Iranian traditional architecture, skylights symbolize spiritual concepts such as unity and heaven. Going forward, by the 19th century, there were improvements to allow fully glazed barrel vaults or glazed domes to be placed on the roof of building remote from the side walls and the facade windows. This pattern still exists in the 20th century buildings such as in residential buildings, museums and shopping malls. Figure 4.3 shows an example of employing skylight for daylighting an art museum where design characteristics does not allow for facade windows. The layers of glazing are deliberately contrived to control glare, and protect indoor environment from undesired climate conditions (Ruck 2000).

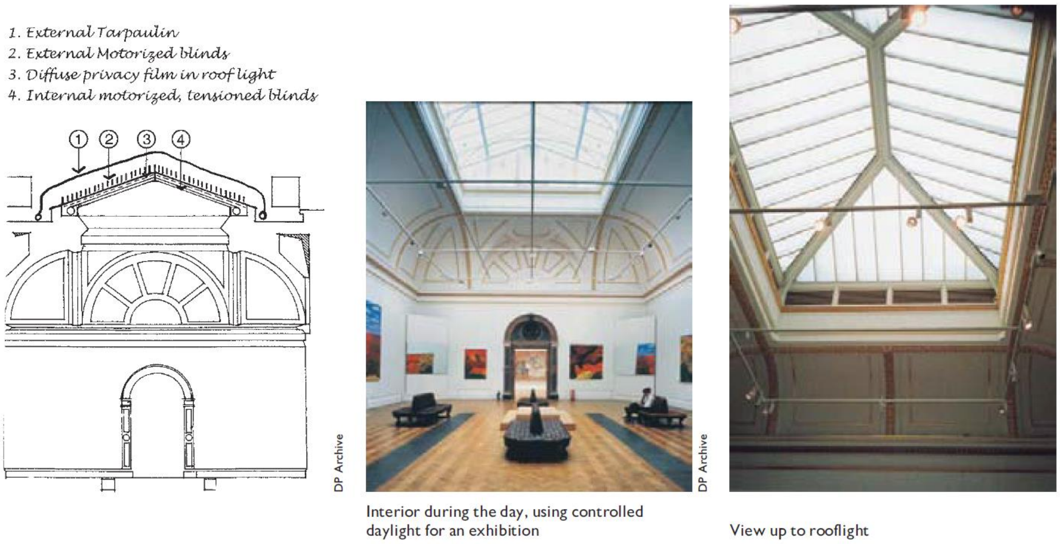


Figure 4.3: Using skylight for daylighting in an art gallery, the layers of roof opening (left), daylit interior space (middle), and the view to skylight (right) (Ruck, 2000)

To understand the level of innovations in the skylights in contemporary architecture, museums and exhibitions can be considered. Variety in the shapes and sizes of skylight, glazing and decorative elements developed to introduce daylighting from the roof appear in these buildings. By 20th century, the use of skylight was mainly peculiar to industrial buildings. There are different types of skylights in building design ranging from simple openings in passageways on traditional architecture to fully glazed skylights in newly-developed forms on roof in modern architecture.

Skylight can be designed for either clear or cloudy skies. But most significant of the strategies is how they deal with direct sunlight. Solar shading is a concern for daylighting except on the north-oriented facades. It is important to consider solar shading and glare protection in the design process as different functions. Solar shading is a thermal function that mainly protects from direct sunlight, while glare protection is a visual function that moderates high luminance in the visual field. Glare protection system not only addresses direct sunlight but also skylight and reflected sunlight.

In cloudy conditions, diffuse light strategies aim to distribute skylight to the interior in the absence of direct sun. Given this case, windows and skylights are designed to allow daylight into the room under the cloudy sky conditions. In a sunny condition, the openings on the wall are weak points causing overheating and glare. Systems that provide sun shading and glare protection are therefore very essential. Depending on the design strategy, different shading systems that transmit either diffused skylight or direct sunlight may be used. Another way of enhancing daylight is simply applying an architectural measure like reflective sills. But window design is notable as a major influence as regards performance in cloudy situations.

These strategies diffuse light in climatic conditions where skies are predominant and consistently addressing direct sunlight. Shading of direct sunlight is part of the constant operating mode of this strategy. It does not need low sized openings for daylight levels of overcast skies, since shading systems that allow the window to depend mainly on diffuse skylight can be used.

Here, direct sunlight is so bright that the amount of incident sunlight falling on a small aperture is enough to provide adequate daylight levels in spacious interior. When sunshine probability is high, beam daylighting strategies would be required. Since sunlight is a parallel source, direct sunlight can be easily guided and piped, thereby requiring optical system for direct light guiding and light transport systems. It is important to combine apertures designed for beam daylight with other view openings since the apertures do not provide outside view. And beam daylighting only needs small apertures. So, view opening can be an added strategy when the approach targets cloudy skies.

4.5 Innovative Systems

Newly-developed devices, materials and adaptive facades are well-known innovative systems for daylight utilization and control. These systems mainly seek to improve the capabilities of conventional daylighting technique to direct daylight by using new optical materials, elements and devices, such as overhangs, light shelves, blinds, screens, and light filters). These advanced daylighting systems facilitate delivering direct daylight into remote and windowless deep spaces in buildings and usually aim to maximize the utilization of the available daylight in indoor environment (Giovannini *et al*. 2015).

Inventive glazing technologies with enhanced thermal insulation capability allows for more glazing area and thus lets more daylight come into indoor space while preventing transmission of much solar heat. Adaptive facades with capability to adjust their characteristics with user, environment and object have also attracted the interest of pioneer architects of in recent years.

The objective innovative daylighting systems seek is to improve the distribution of daylight in space and to control direct sunlight. Some of the eminent innovative systems to enhance daylight utilization and daylight control are mirrors, prismatic glazing, and adaptive facades. Among them, adaptive facades have attracted more global attention in recent decade.

4.5.1 Adaptive Façade

This thrives from the concept of adaptation as Darwin proposed. Adaptation can easily be applied in architecture. A building can be likened to human who resists changes to natural environmental forces. A building shell quickly comes to mind when building adaptation is mentioned. The building shell, also known as building skin is the structural enclosure of the building consisting of facades and roof. There are two main types of building shell:

1. **Traditional (non-adaptive, conventional) building shell:** This shell protects the interior from direct environmental factors and manually regulates air pressure with its fenestrations. But the major defect is that it only obeys the environment without adapting it (Giovannini *et al*. 2015). In other words, it is static and does not adapt the variability of changing conditions.

2. **Adaptive building shell:** In a wider view, the term 'adaptation' is used in architecture as relating to the changing morphologies of the architectural artifact. These morphological changes are basically because of the timely changes of evolution of architecture as a social entity, technological initiative and practice (Giovannini *et al*. 2015). In architecture, adaptation is a long process that happens with time and generations.

   The sense with which this study adopts the concept of adaptation is not as it relates to architecture as a whole, but specifically as regards building shell/skin. In this analogy, adaptive building shell (ABS) as a term describes the group of facades and roofs that interact within the sense proposed in the study. "Adaptive architecture is a type of architecture with the potential to alter the physical properties of the building, such as: form, shape, color, texture, acoustic, porosity, etc, in a predetermined manner to adapt to the changing external and internal stimuli, such as temperature, relative humidity, precipitation, wind, sound, solar radiation, Co_2-level, etc; user activities, needs and social contexts." (Schnädelbach and March, 2010)

According to Giovannini *et al.* (2015), adaptive shells are categorized into two main groups: (1) Micro-level, and (2) Macro-level. This implies that adaptive behavior of the shell is either based on a change in properties or behavior at the micro-level or at the macro-level. However, there may be need for combination of both levels. Micro-level adaptation occurs within the material itself, changing the energy state of the material. Macro-level adaptation is quite visible. It is usually referred to as 'kinetic envelopes' since it is often associated with different kinds of motion like folding, sliding, rolling, hinging, etc.

Adaptive building shells are basically designed to respond to (1) environment, (2) users, and (3) objects (Schnädelbach and March 2010). Building shells respond to such environmental factors as daylight, rain, wind and the likes. Such building shells improve the performance of the building by proper daylighting, and less energy consumption. The key driver here is environmental sustainability. It is also possible for a building shell to respond to the needs of the users. For instance, the architectural layout can be changed manually or automatically. Adaptive facade to objects is less common compared to others according to Schnaddelbach (2010). An example for this is where the media façade interacts with the passerby via their mobile phones. A device known as 'plane tracker' decodes radio signal of the plane and gets the occupants informed . (Beaver *et al*. 2007)

Two types of control mechanism responsible for the adaptive behavior of the shell are (1) intrinsic control, and (2) extrinsic control. Building shells with intrinsic control are self-adjusting given that the inherent attribute for adaptive behavior is automatically moved by environmental stimuli. The ones with extrinsic control have three basic elements; sensors, processors and actuators (Loonen *et al*. 2013). According to Negroponte (1975), responsiveness is a matter of intelligence. It is therefore the intelligent system of a building shell that makes it adaptive. Responsiveness can take place through mechanical/digital sensing, control or actuation technology. Whether it is manually or automatically is not much important.

Regarding daylighting adaptive facades are meant to let more or less daylight in indoor environment in response to seasonal changes, sunlight patterns and demanded level of privacy. Movable facades such as the ones designed by Iranian contemporary architects are representative examples. Sharifiha house designed by Nextoffice design group in Tehran features movable sections which change the indoor environment's condition in terms of daylight, heat energy loss, privacy and functionality. Another example is sliding façade of Danial apartment by TDC group. Daylighting and privacy in this building can be controlled by the second layer of façade consisting of materials with three different levels of transparency.

4.5.2 Innovative Glazing

Mirrors: The interaction of light or sunlight with a mirrored surface can be used for reflection; ranging from hand-held mirror (which provides light to the dark recesses of renaissance church), to the fixed mirrored louvres (which direct light upwards the ceiling). Alternatively, there are those which can direct light downward the interior. Specialist solution is required hence it works with motorized tracking.

Prismatic glazing: This uses refraction of light rather than reflection. The method is more applicable to systems of skylight than vertical windows. A typical example is Richard Rogers' redevelopment of Billingsgate fish market to a modern center. It refracts sunlight away, and eliminates glare while allowing daylight to the space below. The only limitation is that it is too expensive.

Light shelves: This is comparatively very cost effective. As mentioned in solar shading, they are used to give a view window below the light shelf, having the light above to reflect to the ceiling to further redistribute the daylight into the room. Although they do not increase the daylight, they assist to extend the light to enhance uniformity. Another merit is that they are less vulnerable to damage, but require periodic cleaning.

4.6 Summary

Fenestration and glazing characteristics of a building are related to thermal comfort, lighting comfort, privacy and energy efficiency of the buildings. Specifically, façade elements including windows, solar shading, skylight and innovative designs are used for daylight utilization and control. These elements has different types and variations and thus proper selection and arrangement of these elements is critical for improving quality of indoor environment in terms of visual comfort. The architect's aim in daylighting is integrating façade elements for minimum glare, direct sunlight and heat gain.

Daylighting benefits the residents the most if high performance daylight utilization and control strategies are applied. In fact, the criteria for visual comfort are determined by the considerations taken in the design phase as already explained. Considering the descriptive criteria of visual comfort, the following considerations are to be taken at the planning phase for daylighting to improve quality of indoor environment.

Table 4.2: Performance critera, planning phase considerations and facade elements for of daylighting (Ruck *et al*., 2000; Giarma *et al*., 2017)

<table>
<tr><th>Criteria</th><th>Issue examined</th><th>Facade elements</th></tr>
<tr><td>Visual comfort</td><td>Glare Control
Appropriate illumination levels and quality of lighting
Perceived spaciousness and access to view</td><td rowspan="3">Window
Size
Placement
Orientation
Glazing
Shading system
Skylights</td></tr>
<tr><td>Visual aesthetics</td><td>Motifs, colors, variations and quality of the view out</td></tr>
<tr><td>Privacy</td><td>Provision of desired privacy</td></tr>
</table>

Chapter 5

CASE STUDY: FACDE ELEMENTS FOR DAYLIGHTING IN IRANIAN TRADITIONAL AND CONTEMPORARY ARCHITECTURE

5.1 Introduction

Architecture and climate have been essentially linked during the history. This link is thus critical in daylighting since availability of sunlight and considerations about thermal comfort are determined mostly by climate. Iran is a country with diverse climate regions ranging from cold and mountainous to hot and humid. However, considering that more than two third of urban areas in Iran are located in hot and arid (semi-arid) regions, Iran climate is described primarily as hot and dry (Mansouri and Kazemian 2014). Therefore, daylighting in Iranian architecture has been challenged by thermal comfort specifically in traditional architecture when today's ventilation systems were not available. The strategies used in Iranian traditional residential buildings are characterized by their success in providing occupants with a daylit comfortable indoor environment.

Although Iranian architecture has been being transformed since ancient time, Iranian contemporary architecture is differently evolved in recent decade. Advances in technology, introducing new materials and interactions with Western communities resulted in tremendous shifts in the architecture of residential buildings. Innovation is now frequently observed in Iranian contemporary architecture. Some of the distinguished contemporary architects in Iran have integrated the main concepts of Iranian traditional architecture in the design to fulfil the needs of occupants while there are others who have been inspired more by innovative techniques. Climate yet is playing its influential role in Iranian contemporary architecture.

In this chapter, six residential buildings in Iran are selected as the case studies. Facade elements for daylighting in Iranian traditional architecture are firstly studied by reviewing and analyzing three residential buildings. The main focus is to identify how façade elements and design strategies in these buildings were planned in harmony with climate condition to enhance quality of indoor environment. Three cases of contemporary residential buildings are then studies. Contemporary case studies are carefully chosen to demonstrate the innovative characteristics of Iranian contemporary architecture and their coherence with climate conditions.

5.2 Case Studies in Iranian Traditional Architecture

The necessity of shaping the light beams is the common aspect of all light utilization systems in Iranian traditional architecture which often led to the creation of bright geometric forms inside the building which resulted by geometrical logic of forms, hierarchy, sequence and arrangement of the openings in building envelope (Nabavi *et al*. 2013). Due to the high intensity of sunlight in most parts of Iran, traditional architects often avoided utilization of direct light into the buildings and made use of several components such as porches, wooden or stone latticed windows, stained and colored glass or skylights. The main function of these elements was to modify the undesirable aspects of sunlight and turn it into a pleasant light. Traditional architecture cases studied in this chapter include Rashidi House, Ameri House and Tabatabaei

House. All these buildings are located in hot climate (either hot and arid or hot and humid) where overheating is the key issue to be addressed in daylighting rather than adequacy of sunlight.

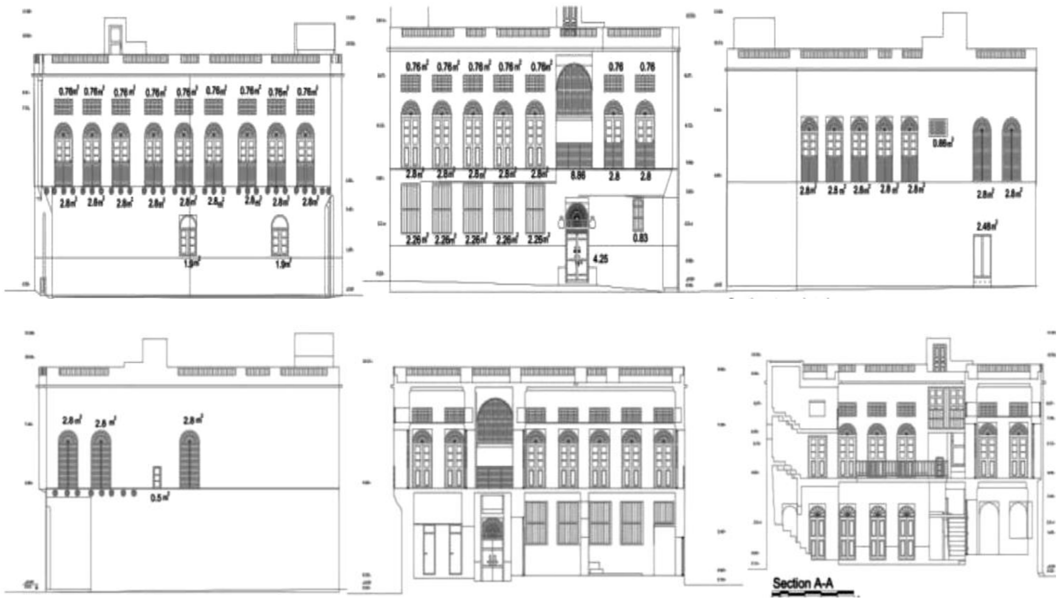
5.2.1 Case Study 1: Rashidy House

Rashidy historical mansion is a residential building in Bushehr city, Iran dated back to Qajar period (1785 to 1925). Although courtyard houses are common in Iranian traditional architecture, Bushehr courtyard houses are discriminative in some aspect. In the hot and arid regions in central parts of Iran, traditional houses are completely introverted so as rooms built around the central open space and the building environment is almost closed to the outside world. In Bushehr city however, traditional courtyard houses are semi-introverted having windows in the upper floors facing the streets (M.Saradj 2014). This strategy of bilateral windows is necessary for maximum use of wind stream for decreasing the heat and alleviating intense humidity. Moreover, unlike traditional houses in hot and arid region, basement is not commonly seen in Bushehr's architecture since underground water streams are close to surface.

5.2.1.1 Technical Information about Rashidy House

Table 5.1 shows the technical information of this building, its facades and sections. Rashidy house is located in Bushehr port city at south-western part of Iran along the Persian Gulf coast. The city had become one of the most important economic and political centres of Iran during Qajar era and accordingly its traditional architecture experienced significant growth and improvement. Bushehr's weather is categorized as hot and humid with hot summers and mild winters. Sunlight is basically available in this region during the whole year. Therefore, daylighting in traditional architecture of the Bushehr city is implemented by paying specific attention to providing proper ventilation and thermal comfort in indoor space.

Table 5.1: Technical Information about Rashidy House (M.Saradj, 2014)

	
Built in	Qajar era
Old function	House
New function	Historical mansion
Located in	Bushehr, Iran
Number of floors	2
Climate	Hot and humid
Sections and facade	
	

5.2.1.2 Daylighting in Rashidy House

From daylighting point of view, daylight control is an issue in such climate since daylight utilization causes thermal discomfort. In this regard, Rashidy house is not only a sophisticated example of evolved architecture of Bushehr city in Qajar ear, but also represents the merits of Iranian traditional architecture in efficient daylight utilization and control. The building is a two story building with a central courtyard. On the ground floor storage rooms, bathroom (hammam), and toilet are built. Kitchen, dining room and living rooms are on the first floor.

Rashidy house is a semi-introverted courtyard house in which ventilation and thermal comfort in indoor space is provided by design solutions like increased height, wide porches around central courtyard, bilateral windows and different design of ground and first floor. Daylight utilization and control is addressed by means of functional façade elements such as tall windows, coloured glass, shenashil (wooden screens), and louvered windows. Facade elements for daylight utilization and control are explained in the following (M.Saradj 2014).

As mentioned before, occupants did not spend much time on the ground floor since living rooms and kitchen are located on the first floor. The rooms on the first floor have high ceilings and several tall windows while on the ground floor there are fewer windows especially across the street. This configuration is in the favour of privacy as well as thermal comfort. In other words, the daylighting variance in this multi-story structure keeps the floor cool, generates temperature difference and air flow. Figure 5.1 illustrates the first and the second floor of Rashidy house. Unlike ground floor, the quality of daylight in the rooms on the first floor is decent as shown in Figure 5.2. Orosi window/doors with clear glass in the middle and stained glass on top let the daylight light the indoor space while controlling the glare. Windows in the middle of walls create a view over the central courtyard and pool. There are some smaller windows close the ceiling with coloured glass to let more light in and to direct the risen hot and humid air out.

Figure 5.1: Arrangement of openings in the ground and first floor of Rashidy house (M.Saradj 2014)

Direct solar radiation is controlled in Rashidy house by using shuttered and louvered windows as shown in Figure 5.3. Moreover, the wide porch around the courtyard on the first floor (refer to Figure 5.1) provides solar shading for the openings facing courtyard on the ground floor. For the windows on the first floor which face the street, the depth of the windows across the street was increased to prohibit direct sunlight as illustrated in Figure 5.4. The depths of the Orosis on the first floor were also adjusted to provide shading.

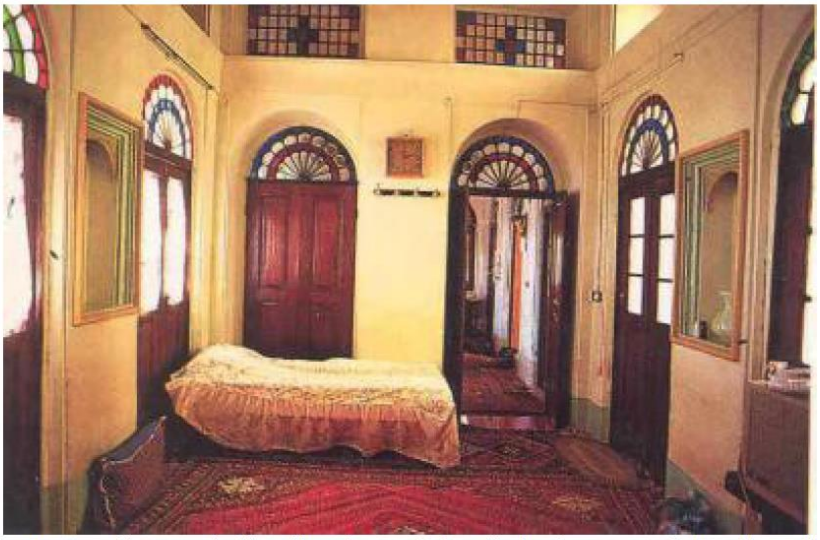


Figure 5.2: High quality daylighting in a room on the first floor of Rashidy house with bilateral windows (M.Saradj 2014)

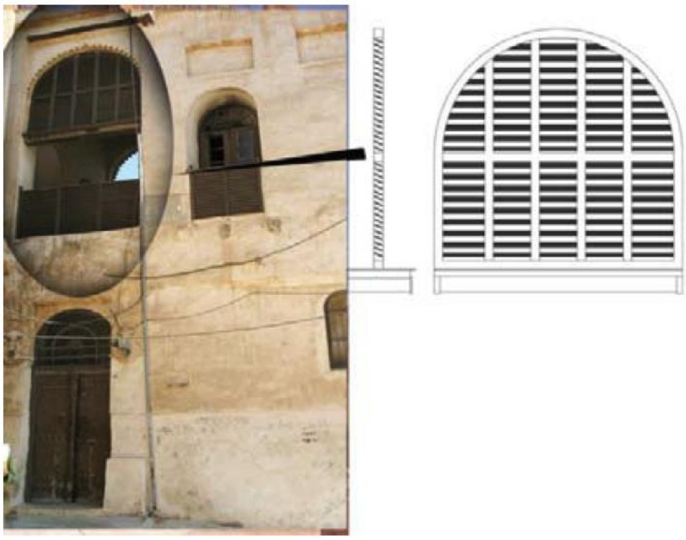


Figure 5.3: Daylight control using shutters and louvers in Rashidy house (M.Saradj 2014)

5.2.1.3 Summary of Case Study 1

The investigations on daylight utilization and control in Rashidy house are summarized in Table 5.2. Facade and design elements for daylighting are listed and the elements used in the building are marked. In addition, considerations which the designers would have taken in planning phase are outlined.

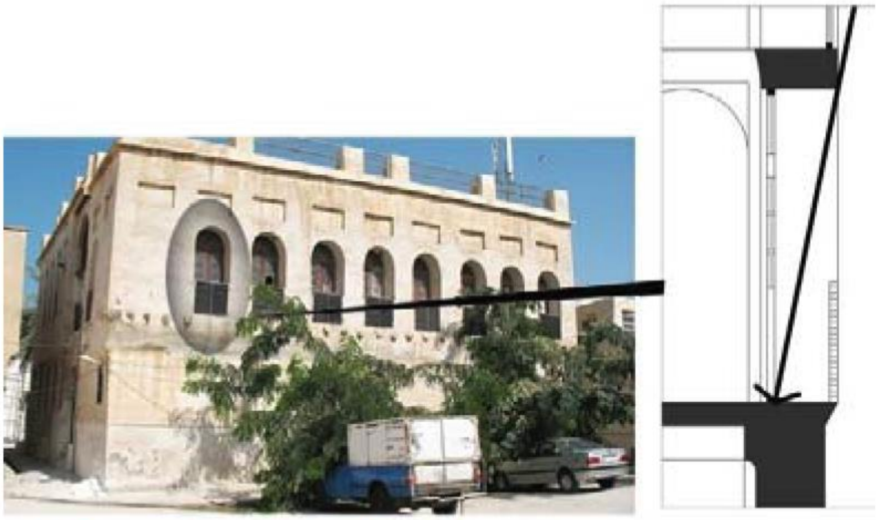


Figure 5.4: Increased depth of windows facing street to control daylight in Rashidy house (M.Saradj 2014)

Table 5.2: Daylighting in Rashidy house (M.Saradj, 2014)

Performance criteria	Facade elements/design
Glare Control	▪ windows with increased depth ▪ shutters and louvers ▪ wide porch on first floor ▪ tinted glazing on high openings
Appropriate illumination levels and quality of lighting	▪ two levels of lighting in first and second floor ▪ bilateral windows ▪ clear glass on low openings
Perceived spaciousness and access to view	▪ view to the courtyard ▪ view to the street from second floor
Aesthetics	▪ colored glazing ▪ wooden latticed windows ▪ view to the pool in the courtyard
Provision of privacy	▪ no opening on the first floor facade facing street ▪ external shading ▪ tinted glazing ▪ most of the openings to the courtyard

5.2.2 Case Study 2: Ameriha House

Ameriha house is a traditional residential building in Kashan, Iran. This city is one of the richest Iranian cities in terms of ancient architectural heritage and archeology. Although the archeological sites near Kashan are as old as human civilization, Kashan received the main attention firstly as a leisure spot for kings of Safavid dynasty. However, the earthquake of 1778 left the city with ruins of its fabulous garden palaces and spacious houses. During Qajar era, the glory of the city was reimbursed having left several exceptional instances of Qajar stunning architecture. These buildings signify the finest aesthetics of Iranian traditional architecture as well as its sustainability and compatibility with climate conditions.

The city of Kashan is located in the central plateau of Iran featuring hot and arid climate. However, the weather in the city is also recognized as mountainous because of its proximity to an all year snow-capped mountain, Karkas. This feature creates a climate with distinct cold and hot seasons. Traditional houses of Kashan were mainly designed with separate compartments for summer and winter, known as "Tabestan-neshin" and "Zemestan-neshin" respectively. Consequently, specific considerations were taken in daylight utilization and control in traditional architecture of Kashan (Mansouri and Kazemian 2014).

5.2.2.1 Technical Information about Ameriha House

The original building of what is called today as Ameriha house was firstly built during Zandieh dynasty. The house was partially destroyed as a result of the earthquake and was completely rebuilt and extended to a large house with seven courtyards and several rooms in Qajar period (Tahbaz *et al*. 2015). The building has two floors and unlike Rashidy house studied in previous section, it has a basement served as storage space and water reservoir (Khazineh). Technical Information about this building is given in Table 5.3. Facade and section of the building around the main courtyard are also shown in the table.

5.2.2.2 Daylighting in Ameriha House

Ameriha house is an introverted building with no windows on the facades across streets or fields outside of the house. To enter the house, people were to pass through a narrow ninety degree corridor for privacy considerations (Figure 5.5). Daylighting in this house is provided by using openings across its several courtyards as well as skylights. The facades facing the courtyards have several tall windows in variety of shapes with colorful glass, transparent multi-doors (Se-dar and Panj-dari) and aperture on the walls (Rozan). Wooden lattices, stained glass, and adding depth to windows are the daylight control elements. Thermal comfort and ventilation strategies were planned specifically for summer residence section and winter residence section. Central pool and garden in addition to wind catchers and roof wells contribute to improved thermal comfort and ventilation.

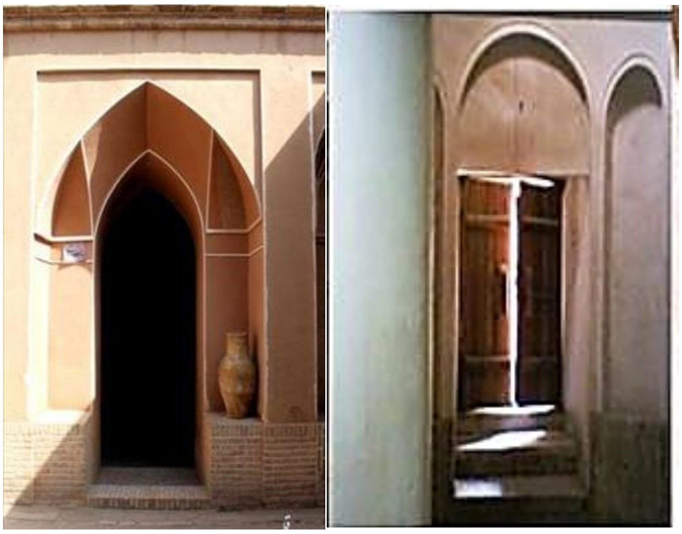
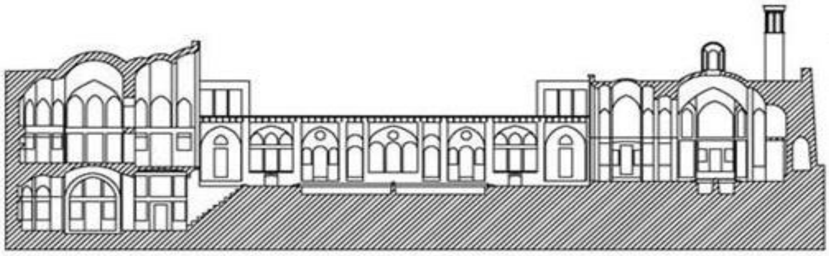


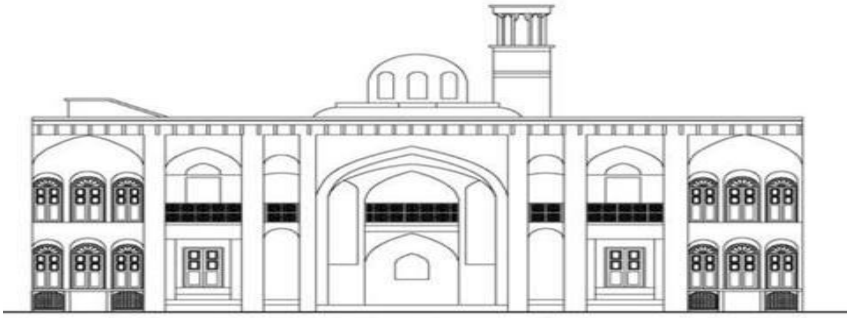
Figure 5.5: Entrance of Ameriha house (Kazemzadeh *et al.*, 2013)

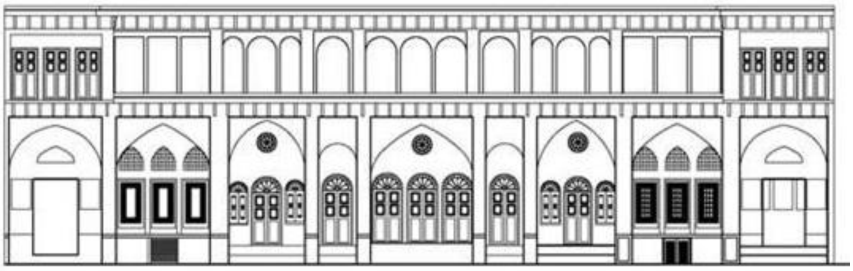
Table 5.3: Technical Information about Ameriha House (Tahbaz *et al*. 2015)

Built in	Qajar era
Old function	House
New function	Boutique hotel
Located in	Kashan, Iran
Number of floors	2 + basement
Climate	Hot and arid

Sections and facade







In Ameriha house, there are totally 85 rooms with different daylighting qualities based on their functionality. High quality homogenous daylighting is presented for the spaces where daily activities were done such as living rooms, meeting rooms (Talar), kitchen and dining rooms. Basement, bathrooms, storage spaces and the rooms used for resting are moderately daylit. An interesting fact about Ameriha house is the gradual change in illumination in the passages between indoor spaces. Illuminated spaces are connected to darker spaces through moderately daylit passages to avoid the disturbance of changing in lighting conditions (Kazemzadeh *et al.*, 2013).

Figure 5.6 shows three differently daylit indoor spaces. Figure 5.6 (a) is of the main hall (Talar-e-ayneh) which functions as a gathering room for events and meetings. This room is highly illuminated and it has a view across the pool and the garden in the main courtyard. In Figure 5.6 (b), a picture of Hozkhaneh is given which is a passage connecting Andarooni (the space specified for family) and Birooni (the space specified for guests and visitors). The lighting condition is moderate in Hozakhaneh. Middle hall (Talar-e-miani) is shown in Figure 5.6 (c). Such spaces are located in the middle segments of the building where there is no sufficient daylight coming in through the openings on the facade. Some sunlight is provided in the middle hall through skylight.

(a) (b) (c)

Figure 5.6: Three differently daylit spaces in Ameriha house. (a) Talar-e-ayneh, (b) Hozkhaneh, (c) Talar-e-miani (Tahbaz *et al*. 2015)

Traditional facade elements are frequently used in Ameriha house. Tall latticed openings glazed with colored glass on top and clear glass on the bottom. In large unilaterally windowed spaces where the depth of the space causes issues for daylighting, high ceilings and two rows of openings exist as shown in Figure 5.7. As seen in the picture, in addition combination of multi-doors and colored glass windows provides a well-daylight indoor environment. Aesthetics aspects of daylighting are also vibrant in indoor spaces via colorful light and view over courtyard. It is worth mentioning that the depth of the windows is related with their height. The taller windows were installed deeper on the facade to decrease glare and heat gain when sun is high.

The strategies for enhancing thermal comfort and ventilation in Ameri house have been carefully designed according to the climate conditions. The house has several wind catchers to provide ventilation and fresh air in summer. In fact, the highest wind catcher in the city belongs to Ameriha house. The sections specified to be used by occupants in summer face west, east or north to reduce thermal gain. The winter sections on the other hand, mainly face south to absorb more sunlight in cold winters of Kashan. Bilateral rooms have openings close to the roof or roof wells to direct the heat outside.

Figure 5.7: Combination of latticed windows and 5-dari (left), combination of Orosi and two doors (right) in Ameriha house (Kazemzadeh *et al.*, 2013)

5.2.2.3 Summary of Case Study 2

The results of study on daylight utilization and control in Rashidy house are briefly outlined in Table 5.4. Similar to previous case stud, facade and design elements are marked and considerations which the designers would have taken in planning phase are noted.

Table 5.4: Daylighting in Ameriha house (Kazemzadeh *et al.*, 2013)

Performance criteria	**Facade elements/design**
Glare Control	▪ windows with increased depth ▪ wooden latticed windows ▪ wooden shutters ▪ colored glazing
Appropriate illumination levels and quality of lighting	▪ three levels of lighting in different spaces ▪ multiple windows/doors ▪ clear glass on shaded openings ▪ skylight in intermediate spaces
Perceived spaciousness and access to view	▪ view to the courtyard ▪ view to the street from second floor
Aesthetics	▪ colored glazing ▪ wooden latticed windows ▪ view to the pool in the courtyard
Provision of privacy	▪ no opening on the facade facing street ▪ external shading ▪ tinted glazing ▪ most of the openings to the courtyard

5.2.3 Case Study 3: Tabatabai House

Tabatabai house is a traditional mansion in the historical city of Kashan built in Qajar era. As stated before, Kashan is located in hot and arid climate zone of central part of Iran but it also features cold winters of mountainous areas because of proximity to a high mountain.

5.2.3.1 Technical Information about Tabatabai House

Classical characteristics of Iranian traditional architecture are glamorously represented in this building. Similar to Ameriha house, there are a number of courtyards and several rooms in Tabatabai house. Totally 50 rooms are arranged around four courtyards in the building. Summer places and winter places are separated. The building is a two-story house with two basements. Wind catchers, roof wells and pools were embedded in the design to offer thermal comfort and ventilation (Nabavi *et al.*, 2013). A brief overview of this building is presented in Table 5.5.

5.2.3.2 Daylighting in Tabatabai House

In terms of daylighting, Ameriha house (reviewed in previous section) and Tabatabai house have several characteristics in common which are recognized as daylighting elements in Iranian traditional architecture such as Orosi, 3-dari and 5-dari glazed with colored glass, skylight and deep windows. However, in Tabatabai house there is more emphasize on a distinguishing shading element when compared to Ameriha house: “Ivan” (veranda). Veranda is a wide covered space connecting interior spaces to the central yard (Hosseini *et al*. 2018).

Table 5.5: Technical Information about Tabatabai House (Nabavi *et al.*, 2013; Hosseini *et al.*, 2018)

Built in	Qajar era
Old function	House
New function	Historical monument
Located in	Kashan, Iran
Number of floors	2 + 2 basements
Climate	Hot and arid

Sections

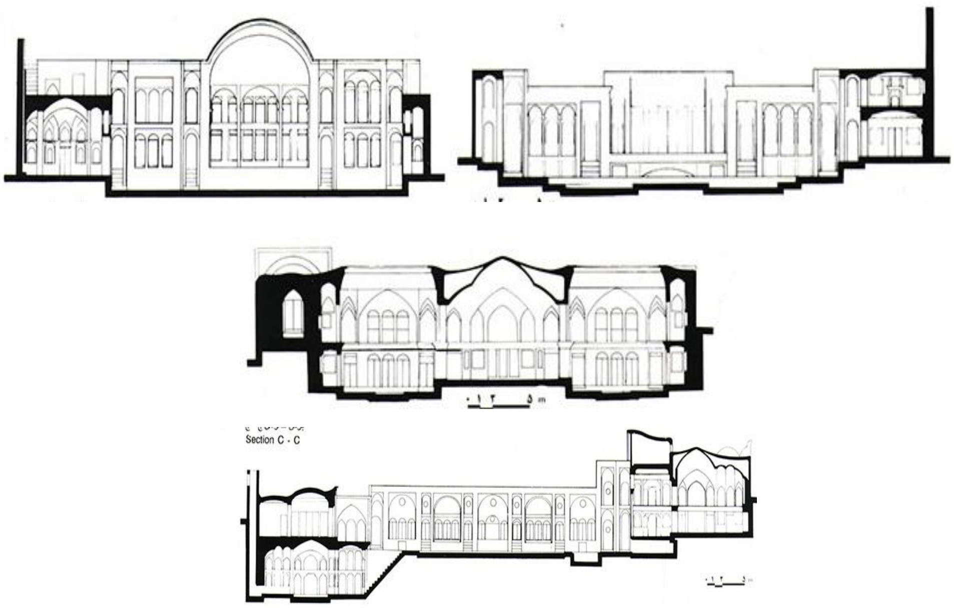
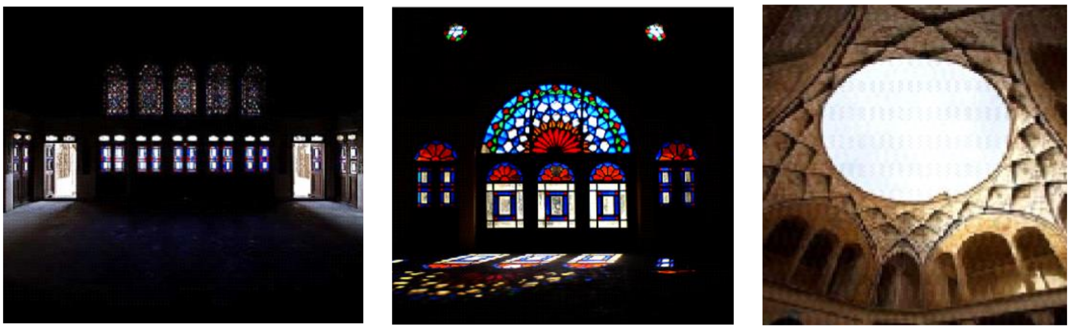


Figure 5.8 shows the view from inside out through veranda in Tabatabai house. Other verandas around the yard can also be seen in the picture. Since veranda is open only from one side, it creates shading and cool air for indoor environment. It is basically designed for the south-facing facade to control the glare and sunlight heat. On other north-facing facade there is no veranda and only the depth of openings is slightly increased to control daylight. Verandas on other facades are not as wide as the main veranda facing south.

Other elements and strategies used for daylight utilization and control are very similar to Ameriha house. Tall latticed windows with stained and colored glass are used to daylight living rooms, kitchen and main halls. On the other hand, passages and spaces connecting major sections are lit by small windows or skylights. In Tabatabai house roof well is also used in the backyard for daylighting and ventilation. Figure 5.9 illustrates the daylight utilization and control elements of Tabatabai house.

Figure 5.8: A view of yard across veranda as a solar shading element in Tabatabi house (Nabavi *et al.*, 2013)



(a) (b) (c)

Figure 5.9: Orosi and 5-dari (a), tall windows (b), skylight (c) in Tabatabai house (Hosseini *et al.*, 2018)

5.2.3.3 Summary of Case Study 3

The results of study on daylight utilization and control in Tabatabai house are briefly outlined in Table 5.4. Similar to Table 5.2, facade and design elements are marked and considerations which the designers would have taken in planning phase are noted.

Table 5.6: Daylighting in Tabatabai house (Hosseini *et al.*, 2018)

Performance criteria	Facade elements/design
Glare Control	▪ windows with increased depth ▪ wooden latticed windows ▪ wooden shutters ▪ colored glazing
Appropriate illumination levels and quality of lighting	▪ three levels of lighting in different spaces ▪ multiple windows/doors ▪ clear glass on shaded openings
Perceived spaciousness and access to view	▪ view to the courtyard ▪ view to the street from second floor
Aesthetics	▪ colored glazing ▪ wooden latticed windows ▪ view to the pool in the courtyard
Provision of privacy	▪ no opening on the facade facing street ▪ external shading ▪ tinted glazing ▪ most of the openings to the courtyard

5.3 Daylighting in Iranian Contemporary Architecture

Today, increased urbanization in Iranian cities has led to compact development, multi-story buildings with small yards that eclipse open spaces, limiting the access to sunlight and eroding the immediate connection between occupants and natural environment. On the other hand, technology has created new forms of architecture in Iranian contemporary architecture based on intelligent design, and new methods of construction with more considerations about sustainability, natural lighting and improved quality of indoor environment. However, as a result of uneven development in the country, these inventive designs are observed more in the capital city, Tehran than in other parts of Iran. Tehran hosts most of the globally-recognized Iranian contemporary architects and design groups who have received international awards. In this study, three cases of Iranian contemporary architecture located in Tehran city are studied including Sharifiha house, Danial apartment and Nikbakht house.

5.3.1 Case Study 4: Sharifiha House

Located in northern part of Tehran, Sharifiha house is a successful example of kinetic facades with adaptation capability based on outdoor environment and occupants' desires. The building is designed by Iranian architect Alireza Taghaboni in collaboration with Nextoffice architecture firm. Alireza Taghaboni has received both Iranian and Dubai firm awards and also was nominated for World Architecture Festival award in 2014 (Archdaily, 2014).

5.3.1.1 Technical Information about Sharifiha House

Sharifiha house is a 7 story building with two basements serve as pool and fitness facility. Parking space and housekeepers' room are located on the ground floor. The spaces on the first and second floors are designed for public activities, and guests. Family's private spaces are on the third and fourth floor. The building features three mobile spaces which are capable of rotating, shifting and changing positions. This configuration allows occupants alter the spatial organization of indoor environment based on their desires. Technical Information about Sharifiha house is given in Table 5.7.

5.3.1.2 Daylighting in Sharifiha House

Architecture Alireza Taghaboni describes Sharifiha house as a building that "provides a solution to the old problem of having poorly-lighted indoor environment. The house adapts to the functional needs of its users. Depending on whether there is a guest or not, the guest room - on the second floor - can be reconfigured for different purposes (Nejadriahi 2017). Similarly, home offices and breakfast rooms can change the formality of their appearance according to their occupants' desires. There is always the possibility of having different seasonal or lighting scenarios because of this setup." The section diagram, rotation process and the main concept of the three moving parts of Sharifiha house is shown in Figure 5.10.

Daylighting is provided in Sharifiha house by means of tall and wide windows with clear glass. The depth of windows is increased to create solar shading, avoid glare and decrease heat gain in hot seasons. Inside the house, maximum transparency and openness exists to let the daylight reach larger indoor spaces. A partially glass roof is implemented on the roof which functions as skylight for almost all floors through the passageways exist in all floors. These passages provide daylit connections between all floors and indoor spaces. In Figure 5.11 daylight condition in indoor two example indoor spaces is shown. Daylight utilization and control elements such as wide and tall windows, interior blinds, transparent doors, skylight and passageways connecting indoor spaces at each level can be seen in the figure. The basement is lit using the glass bottom of a shallow pool in the small courtyard (Figure 5.10 section diagram).

Table 5.7: Technical Information about Sharifiha House (Archdaily, 2014)

Built in	2013
Function	House
Located in	Darrous, Tehran, Iran
Design firm	Next office
Architect in charge	Alireza Taghaboni
Number of floors	5 + 2 basements
Climate	Semi-arid cool climate

Sections

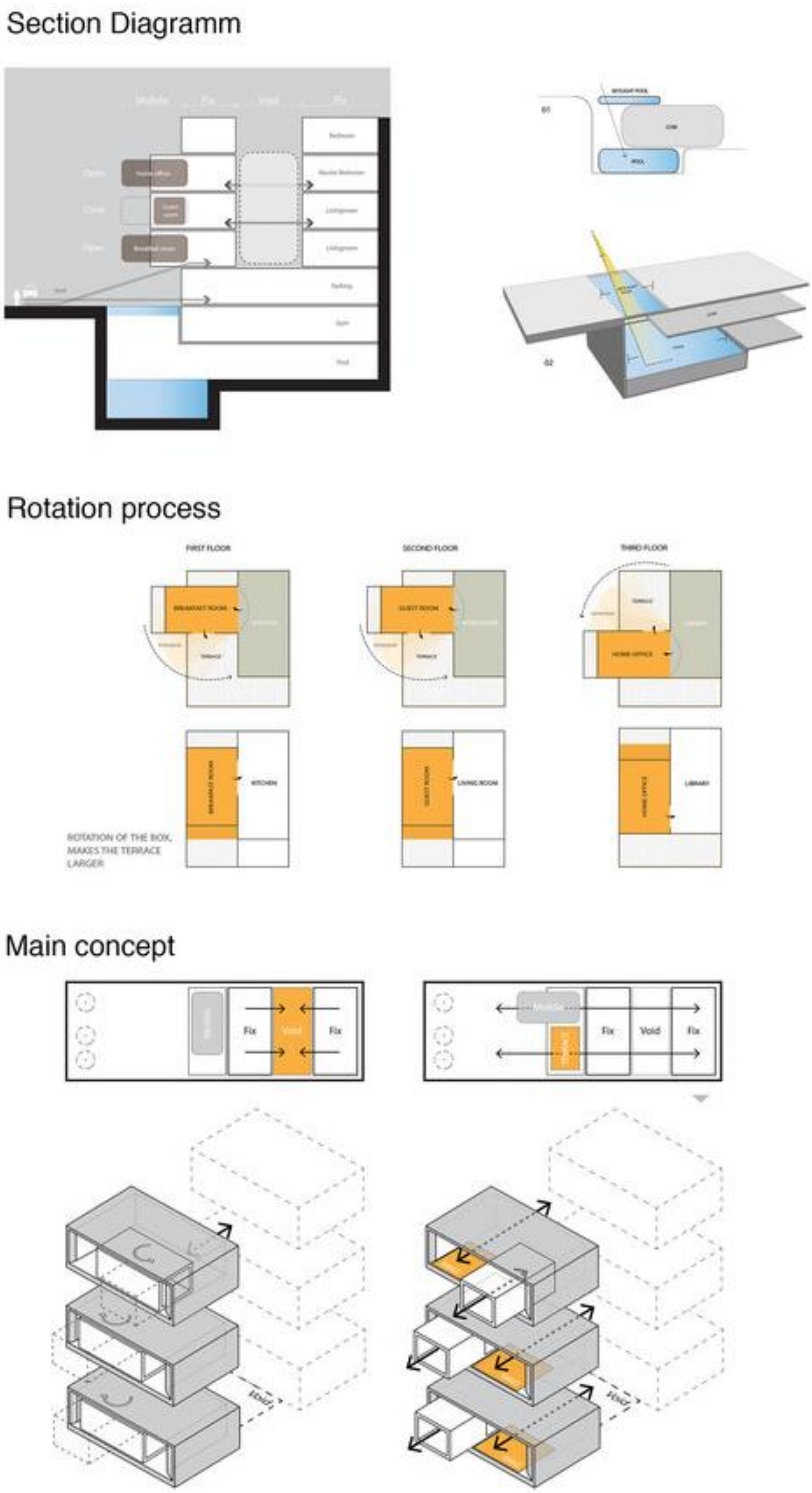
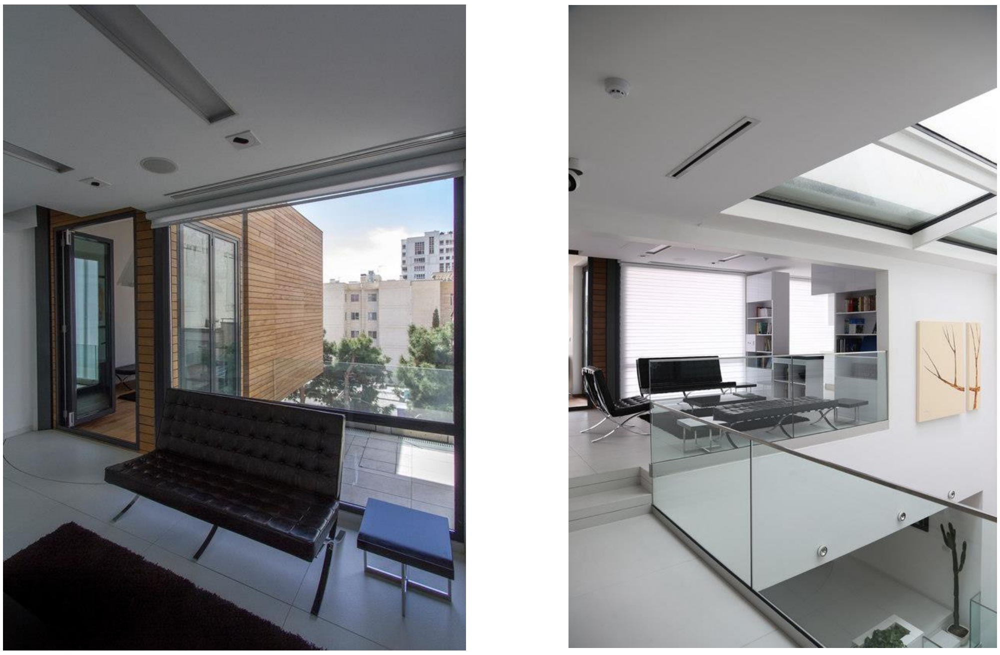


Figure 5.10: Conceptual diagram of moving parts in Sharifiha house (Archdaily 2014)



(a) (b)

Figure 5.11: Daylighting through wide and tall windows, transparent doors (a) and skylight (b) in Sharifiha house (Archdaily, 2014)

The concept of rotating rooms also resembles winter and summer spaces in Iranian traditional architecture. As explained before, occupants migrated between Tabestan-neshin and Zemestan-neshin in Iranian traditional houses in regions with distinct hot and cold seasons. Tehran climate is described as mixed climate with mild spring and falls, cold winters and hot summers. The adapting façade of the building allows occupants change the openings according to the season generating different daylighting scenarios. Two different indoor environments generated with minimum and maximum openings on the façade are shown in Figure 5.12. Minimal openings are achieved when movable rooms are in horizontal position which results in lower levels of daylighting. In winter time, this configuration keeps the indoor space warmer and saves energy. On the other hand, when rooms are in their vertical position, large shaded verandas are created to control daylight in summer.

(a) (b)

Figure 5.12: Façade configurations and daylight condition of indoor environments with minimum (a) and maximum (b) openings (Archdaily, 2014)

5.3.1.3 Summary of Case Study 4

In Table 5.8 the result of the case study on Sharifiha house is briefly presented. The most interesting fact about the building is that the architect has exploited all design elements for daylighting. In addition, two different levels of privacy are provided for occupants.

Table 5.8: Daylighting in Sharifiha house (Archdaily, 2014)

Performance criteria	Facade elements/design
Glare Control	▪ windows with increased depth ▪ vertical shading
Appropriate illumination levels and quality of lighting	▪ tall windows of clear glass ▪ adaptive level of opening ▪ skylight
Perceived spaciousness and access to view	▪ different levels of lighting by moving facade ▪ view to the courtyard ▪ view to the street
Aesthetics	▪ revolving rooms
Provision of privacy	▪ two levels of privacy by moving facade

5.3.2 Case Study 5: Nikbakht House

Nikbakht house, also known as Niavaran Residential Complex is designed by featured Iranian architect Mohammad Reza Nikbakht (Wordarchitecture, 2015). The building is located in a Shemiran district on the northern part of Tehran, Iran. Shemiran district is on the slant of Alborz Mountain where old gardens used to cover a large area. In recent decades, due to urbanism and mass construction plenty of those old trees were cut to free the land for building apartments. On the construction site assigned for Nikbakht house, old buttonwood trees were abundant (approximately 120) most of them having been there for 60 years. The local municipality’s construction office allowed the owner to cut down 45 of those trees. The design firm, Zandigan however, convinced the owner to let-off the deforestation by decreasing the gross area of the plan from 13000 to 1100 square meters. Nikbakht house is an exceptional case in this regard since the unique design approach taken by Mohammed Reza Nikbakht placed priority in conserving those trees. As a result of his incredible work, the architect Mohammad Reza Nikbakht, was nominated by the international community of architects in 2012 and Niavaran residential complex was granted the World Architecture Award (Wordarchitecture, 2015).

5.3.2.1 Technical Information about Nikbakht House

Nikbakht house is a 6 story building with two basements. The five upper floors accommodate 30 residential apartments. On ground floor ceremony hall, manager's office and entrance vestibule are located. The first basement provides space for parking and on the second basement there are gym facilities, swimming pool and spa. Although twisting the building around deep-rooted trees on construction site is the mostly admired feature of Nikbakht house by design community, there are several other architectural characteristics in this building not impeccably spotted by architecture journalists. The building goes beyond typical strategies for planning residential building by integrating drifts of Iranian traditional architecture in the design. In the overall form of the building existing gardens are combined with courtyards, and semi-open spaces without scarifying cultural values, privacy and visual comfort. Technical Information about Nikbakht house is summarized in Table 5.9.

5.3.2.2 Daylighting in Nikbakht House

The conceptual viewpoint of Nikbakht house's architect towards the building site, sociocultural values and the nature in combination with his inspiration from Iranian traditional architecture is expressed in the rich styles and details of building facade, fenestration and daylighting. In Nikbakht house, there are several open and semi-open spaces around the trees as show in the site plan in Figure 5.13. It is clear in the figure how the facade is twisted around the trees and inner courtyards are created.

Table 5.9: Technical Information about Nikbakht House (Wordarchitecture, 2015)

Built in	2011
Function	Residential Complex
Located in	Naivaran, Tehran, Iran
Design firm	Zandigan
Architect in charge	Mohammadreza Nikbakht
Number of floors	6 + 2 basements
Climate	Semi-arid cool climate

3D Model

Figure 5.13: Site plan of Nikbakht house (Wordarchitecture, 2015)

Apartments in this residential complex have a specific form dictated by the curvature of the facade curving around the trees. This creates a larger facade surface compared to typical building designs. The radial design around the vegetation site reminds the motifs of Iranian traditional architecture for better daylighting and ventilation. Figure 5.14 illustrates a central courtyard and the semi-open staircase around it in Nikbakht house. Semi-open staircases provide a pleasant daylit yet shaded and ventilated passageway.

Figure 5.14: Central courtyard and semi-open staircase around it in Nikbakht house (Wordarchitecture, 2015)

In Iranian community, privacy is a critical concern. However, the extraordinary design of Nikabkht house could have resulted in some privacy concerns if there were openings on curved walls around courtyards for daylighting. More precisely, some windows might have a view out to other apartments. The architect has refused to ignore the confidentiality demanded by occupants and there is now opening on the walls facing other apartments. The need for daylight utilization in such cases are met by means of glass blocks instead of openings as shown in Figure 5.15 which let the daylight illuminate interior spaces while blocking the view from other apartments.

Figure 5.15: Glass blocks for daylighting and provision of privacy in Nikbakht house (Wordarchitecture, 2015)

The facade facing street on the other hand, has tall windows and openings with clear glass as shown in Figure 5.16. These walls of the building benefit from onsite trees which provide some shading but in hot summers of Tehran when sunlight heats up the interior space and results in glare, extra solar shading is required. This need is more critical for windows on north-facing facade. On these windows external vertical shades are installed. The shades are continuous patterns of wooden color material to add aesthetics to the facade while providing solar shading. The depth of the windows on northward facade is also increased. Figure 5.17 illustrates the vertical solar shading on the facade and the increased depth of windows.

Figure 5.16: Wide and tall openings with clear glass for daylighting in Nikbakht house (Wordarchitecture, 2015)

Figure 5.17: External solar shading in Nikbakht house (Wordarchitecture, 2015)

5.3.2.3 Summary of Case Study 5

In Table 5.10, results of case study 5, Nikbakht House are shown. It should be noted that while the extraordinary design of the building around the trees makes this building a unique architectural icon, it cannot be assumed as an example of using innovative systems for daylighting. In addition, this building is considered as semi-introverted because there are some inner courtyards in the building similar to private courtyards of Iranian traditional houses and at the same time there are openings on building facade into the street.

Table 5.10: Daylighting in Nikbakht house (Wordarchitecture, 2015)

Performance criteria	Facade elements/design
Glare Control	▪ windows with increased depth ▪ vertical shading
Appropriate illumination levels and quality of lighting	▪ tall windows of clear glass ▪ bilateral openings ▪ semi-open spaces
Perceived spaciousness and access to view	▪ different levels of lighting ▪ view to the multiple courtyard ▪ view to the street
Aesthetics	▪ revolving rooms
Provision of privacy	▪ openings to the courtyard ▪ limited opening on the first floor ▪ glass blocks

5.3.3 Case Study 6: Danial Apartment

Constructed by the design firm TDC Office Danial apartment is located in Tehran downtown. This region of Tehran features very limited area for construction site, as it is in the neighborhood of Tehran grand bazar with narrow streets and dense construction of shopping malls, offices and residential buildings. In addition, the climate condition in this region of Tehran is hotter and has less precipitation compared to the districts on Northern parts where case studies 4 and 5 are located. Danial apartment is designed by Sara Kalantary and Reza Sayadian who consider these limitations and utilize an innovative scheme for designing an exceptional building in the heart of Tehran. This building won Chicago International Architecture Award for this design on 2012. It was also nominated for World Architectural Festival in Housing category in the same year (TDC Office, 2012).

5.3.3.1 Technical Information about Danial Apartment

Danial apartment is a 6 story building constructed in a rectangular shape land of 320 square meters. Each of the 5 floors includes one residential apartment. The basement is assigned for pool, sauna and recreation facilities. Parking space is on the ground floor. The courtyard is very small and the lonely pine tree on construction site has been preserved in the courtyard. The most eye-catching feature of Danial apartment is the design of its facade. An innovative design of transparent, translucent and solid glass which can be manipulated and controlled based on occupants' desires. The story of inspiration for this astonishing facade design is well explained by TDC office:

> "While we were exploring the site for the first time, we saw an isolated pine tree left from a beautiful jungle which used to exist there not very long time ago…That tree was the inspirational idea that came across. A tree has many branches supported clear of the ground by the trunk and below the ground, the roots branches spread out and above the ground, the branches divide into shoots that bear leaves. These three parts (the trunk, roots and leaves) have different textures with different transparencies), this is where the idea of the facade design came from." (TDC Office, 2012).

Figure 5.18 illustrates the facade design idea inspired by tree. Three different levels of transparency and the shape of leaves are perceptively used by the architects. It should be noted that these patterns were not only integrated into the facade design, but also similar motifs were created in interior spaces. The mirror work on the staircase space and the form of the ceiling on entrance lobby perfectly match the patterns on facade of the building. Technical information of Danial apartment are summarized in Table 5.11.

Table 5.11: Technical Information about Danial Apartment (TDC Office, 2012)

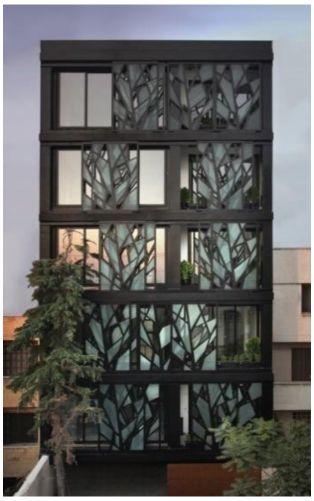
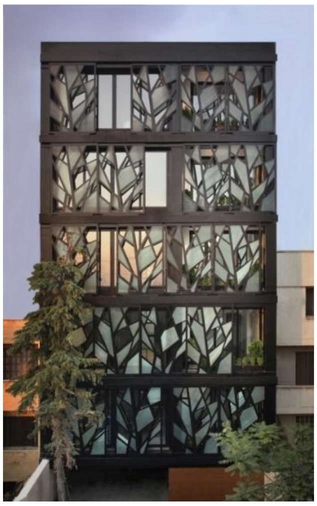
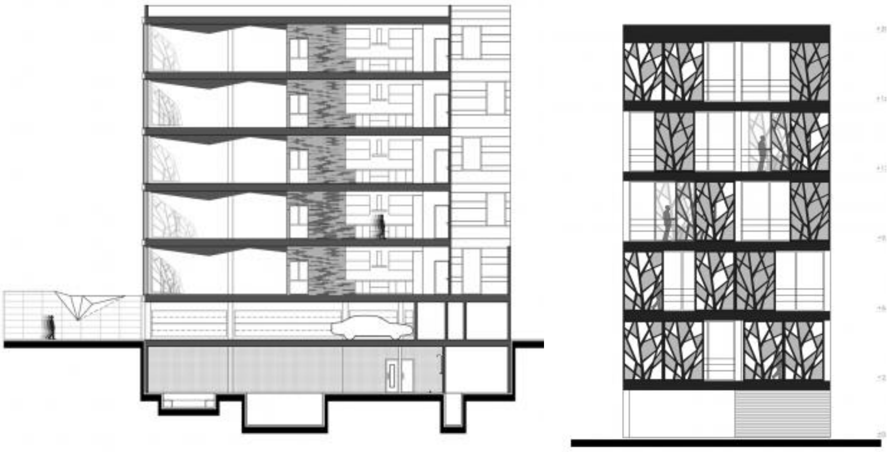
 	
Built in	2012
Function	Residential
Located in	Tehran
Design firm	TDC Office
Architect in charge	Reza Sayadian and Sara Kalantary
Number of floors	6 + 1 Basement
Climate	Semi-arid cool climate
Sections 	

Figure 5.18: Inspiration from different transparency levels and the leave forms of trees used in Danial apartment (TDC Office, 2012)

5.3.3.2 Daylighting in Danial Apartment

Daylight in Danial apartment is mainly utilized and controlled by its innovative facade design. From exterior, the shape of the latticed facade is an abstract concept which resembles the form of tree leaves. From interior, the facade modifies the rays of light in three different ways and as the sunlight angle varies, unique patterns of light and shadow change the lighting condition of interior space. The architects of Danial building describe the building facade as a dynamic facade which plays with light and shadow to create a pleasant indoor environment. They called this the story of zero and infinity and claimed that the working on the balance between the light and the shadow (two opposite elements) functions better than manipulating each of them individually.

This dynamic facade strategy is implemented by means of a double skin facade. On the inner layer, tall and wide windows with clear glass are placed. On the outer layer, the facade of each apartment is covered by 4 movable panels in addition to a void space of the same dimension as panels. These semi-open movable panels are partially covered with translucence glass. The lattice itself is solid and the windows on the inner layer are transparent. On each floor, there are two patterns of glazing for panels which are complementary to each other. When two complementary panels cover each other, minimum daylight comes in. The blank space is for maximum daylighting and by arranging similar panels medium daylighting is achieved. This is how three levels of transparency are formed in Danial building. This variety allows occupants experience a borderless indoor space with different sense of depth. The dynamic facade is entirely adjustable by occupants. All panels can be relocated horizontally from one side of the facade to the other side alongside two rail rows. These movements of semi-transparent panels in addition to two different patterns of glazing give the occupants several choices for configuring the facade and consequently daylighting condition in indoor space. Four different configurations of facade panels and the changes in light and shadow patterns in indoor spaces are shown in Figure 5.19.

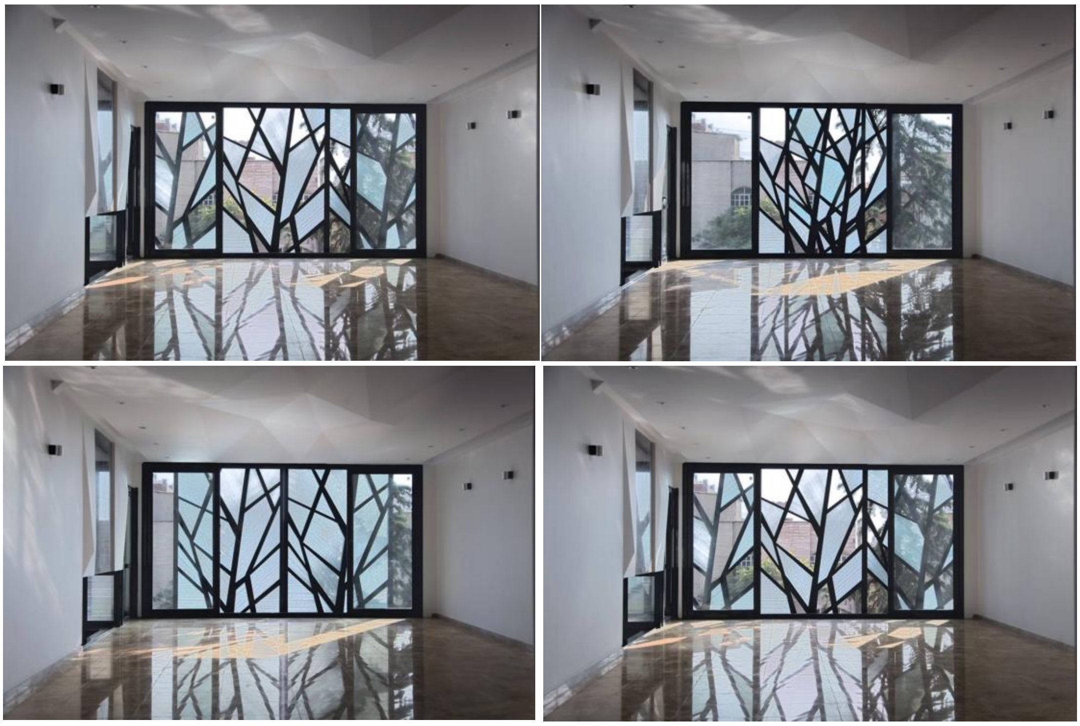


Figure 5.19: Indoor lighting condition for four different configurations of facade in Danial apartment (TDC Office, 2012)

Other strategies for daylighting and solar shading in Danial apartment include increased depth of windows on the inner layer of facade, windows on side walls (patio), and balcony. The balcony on each floor can be semi-open (like veranda) or open based on the arrangement of panels. The view out from inside is partially the pine tree on the small courtyard and mostly the opposing buildings specifically for the 1st, the 2nd and the 3rd floor. The higher floors i.e. 4th and 5th have a view out to the Sorkhe-Hesar Mountain on South of Tehran. Thus, privacy level can be adjusted using movable panels based on inhabitant's desire.

5.3.3.3 Summary of Case Study 6

Daylighting in Danial apartment is briefly described in Table 5.12. The main feature of daylitghting in this building is the movable second layer of the façade with three transparency levels.

Table 5.12: Daylighting in Danial Apartment (TDC Office, 2012)

Performance criteria	Facade elements/design
Glare Control	▪ windows with increased depth ▪ vertical shading ▪ latticed horizontal planes (movable)
Appropriate illumination levels and quality of lighting	▪ tall windows of clear glass ▪ adaptive level of opening ▪ skylight (patio)
Perceived spaciousness and access to view	▪ different levels of lighting by moving planes ▪ view to the courtyard ▪ view to the street ▪ glazing with different transparency levels
Aesthetics	▪ movable latticed planes inspired from trees
Provision of privacy	▪ two levels of privacy by moving planes on the façade ▪ openings to the courtyard

5.4 Summary of Traditional and Contemporary Case Studies in Terms of Facade Elements for Daylighting

Façade elements for daylighting including windows, shading devices, skylights and innovative systems are summarized in Table 5.13 for the case studies. The key function of elements in providing visual comfort, creating motifs, variety in idoor environment and view to the outside are marked. For all cases the visual needs of a comfortable daylit indoor environment are met. Visual comfort, variety, visual motifs and view out are marked accordingly in the table. In can be argue that the cases of traditional architecture provide efficient daylight utilization and control by proper design and arrangement of windows, shading devices and skylights. In contemporary cases, innovative design ideas enhanced daylighting and visual comfort.

Table 5.14 summarizes fenestration and glazing characteristics of the traditional and contemporary case studies. Analysis of design considerations taken in traditional cases and comparing with contemporary cases reveals the following facts about the phases taken by contemporary architects. The motivations from traditional architecture are adapted by contemporary architects to fulfill the needs of residents in terms of visual comfort and privacy.

Table 5.13: Summary of case studies in terms of façade elements and visual functionality [by Author from (M.Saradj, 2003; Tahbaz et al. 2015; Kazemzadeh et al. 2013; abavi et al. 2013; Hosseini et al., 2018; Archdaily, 2014; Wordarchitecture, 2015; TDC Office, 2012)]

Case Study	Façade Elements		Function			
			Visual Comfort	Variety	Motifs	View
Rashidy	Windows	Small windows, Orosi windows, colored glass and clear glass	✓	✓	✓	✓
	Shading Devices	Shenashil (wooden screens), louvered windows, adding depth of windows	✓	×	×	×
	Skylights	-				
	Innovative Systems	-				
Ameriha	Windows	Orosi windows, colorful glass, multi-doors, aperture on the walls	✓	✓	✓	✓
	Shading Devices	Wooden lattices, stained glass, and adding depth to windows	✓	×	×	×
	Skylights	Open	✓			
	Innovative Systems	-				
Tabatabai	Windows	Tall windows, colorful glass, multi-doors, aperture on the walls	✓	✓	✓	✓
	Shading Devices	Ivan, Wooden lattices, stained glass, and adding depth to windows	✓	×	×	✓
	Skylights	Open	✓	×	×	×
	Innovative Systems	-				
Sharifiha	Windows	Tall windows, clear glass	✓	✓		✓
	Shading Devices	Adding depth to windows, balcony	✓	×	×	×
	Skylights	Glazed	✓	×	×	×
	Innovative Systems	Adaptive facade	✓	×	✓	✓
Nikbakht	Windows	Windows of different sizes, clear glass, glass blocks	✓	✓	✓	✓
	Shading Devices	Vertical, balcony	✓	×	×	×
	Skylights	-				
	Innovative Systems	Curved façade around trees	×	×	✓	✓
Danial	Windows	Tall windows, clear glass, tinted glass	✓	✓	✓	✓
	Shading Devices	Moving façade, balcony, Adding depth to windows	✓			
	Skylights	-				
	Innovative Systems	Dynamic facade	✓	✓	✓	✓

Table 5.14: Fenestration and glazing in case studies [by author from (Hutchins, 1998; Tzempelikos and Athienitis 2007)]

Fenestration and glazing in traditional case studies						
Glazing			**Orientation**	**Fenestration Type**		
Transparency types	Solar heat gain	Natural lighting		Windows	Skylight	Clerestories
Clear	✓	✓	North façade	×	×	×
Tinted	×	✓	South façade	✓	×	×
Colorful	×	✓	East and west facade	✓	✓	✓
Fenestration and glazing in contemporary case studies						
Glazing			**Orientation**	**Fenestration Type**		
Transparency types	Solar heat gain	Natural lighting		Windows	Skylight	Clerestories
Clear	✓	✓	North façade	×	×	×
Tinted	×	✓	South façade	✓	×	×
Glass blocks	×	✓	East and west facade	✓	✓	×

5.5 Comparison of Traditional and Contemporary Cases

Analysis of the daylighting in traditional and contemporary cases in terms of façade elements and design considerations reveals some prominent facts about the phases taken by contemporary architects motivated by traditional architecture. The highlights of these facts are as follows.

1. In case 1, Rashidy house privacy considerations are satisfied in a semi-introverted design by placing windows at higher level i.e. no windows on the first floor façade facing street. Similarly in case study 5, Nikbakht house, there is no window on the façade facing street in the first floor.

2. Multiple courtyards in case 2, Amariha house let the interior space being properly daylit while privacy is provided. In Nikbakht house, the innovative architecture

for preserving the trees created multiple courtyards which are deliberately used for daylighting.

3. In cases 2 and 3, Ameriha and Taatabai houses, winter and summer residents are separately designed because of the distinct summer and winter in the region. The moving façade of case 4, Sharifiha house is in fact inspired from this residents as two different levels of daylighting and exposure to outside weather is generated. The minimum level of opening to reduce heat loss in the cold winters of Tehran and the maximum level of opening with shading for summers.

4. In all traditional cases, different levels of transparency is used in the glazing including clear glass, tinted glass and colorful glass. There are two objectives for this: having different indoor spaces with different daylighting conditions as well as aesthetics. In case 6, Danial apartment, the architects utilized different levels of transparency in the second layer of the façade. The design lets the residents change the daylighting condition in indoor environment and it also creates motifs and patterns of light and shadow.

5. Semi open spaces in Nikbakht house resemble veranda shaded areas in Tabatabai house. These design strategy creates smooth transition from outer space with the highest illumination to the inside. Thus the residents experience three levels of daylight illumination while going out from house or entering house.

6. In general, daylighting in contemporary architecture is more challenging when compared to traditional cases because of the limited site area which restricts the courtyard area. Moreover, provision of privacy is an issue because of multistory

buildings and multiple apartments in one building. On the other hand, advanced strategies and elements allow for more innovation in planning, design and construction. The three case studies of contemporary architecture open new horizons to three different ways of innovative architecture.

7. In other word, in traditional architecture there are multiple spaces with different illumination level specified to different activities. Seasonal residential sections also exist in traditional architecture to address the needs as the hot season turns into cols season. In Sharifiha house and Danial apartment, two different strategies are used to change the daylight illumination level of the space according to the needs of residents and seasonal changes.

5.6 Discussion

Façade elements for daylighting are critical in lighting comfort and consequently in improved quality of indoor environment. Proper daylight utilization and control entails deep understanding of functionality of these elements as well as other characteristics of the building and its exterior environment. Fenestration and façade design for daylighting follows some fundamental regulations. However, these regulations do not dictate a unique design pattern for daylight utilization and control. Windows, shading devices and skylights can be formed and organized in several arrangements. Each of these elements has a variety of shapes, dimensions and features.

The six case studies investigated in this thesis revealed that limitations resulting from climate conditions, construction site, privacy concerns and even energy saving critics would not negatively affect the quality of daylighting in indoor environment if the designer impertinently exploits daylighting elements. Both traditional and contemporary case studies provide enough evidence for this claim. In addition, contemporary cases achieve a high quality daylit environment by integrating innovative design strategies with lessons leant from past.

Chapter 6

CONCLUSIONS

In this study, the role of façade elements in daylight utilization and control in terms of improved quality of indoor environment is investigated. In the first stage of the study, importance of daylighting in architecture is discussed. It is argues that daylighting improves the quality of indoor environment, contributes to better health and well-being of occupants and decreases energy consumption for lighting indoor spaces. Quality of indoor environment is in fact a multi-dimensional construct and lighting comfort as one its dimensions is influenced by daylighting. Daylight utilization and control improves quality of indoor environment in visual aspects.

Visual aspects of lighting quality affected by daylighting include visual comfort and visual characteristics of indoor environment. Visual comfort is created by manipulating daylight through daylighting elements and strategy to light indoor spaces with natural light and at the same time minimizing the effects of glare, direct sunlight and thermal discomfort of daylight. Daylighting also accounts for visual characteristics of indoor environment via variety, aesthetics, and view out from inside.

In the second phase of the study, considerations to be taken in design phase for proper daylighting are discussed. Climate conditions influence availability of sunlight and determine temperature outside the building. These factors are important in design phase for daylighting strategies. Construction site characteristics and location are other attributes which a designer should at design phase for daylighting. Latitude of construction region, presence of exterior obstructions of sunlight and building type are the main issues to be deliberated. Privacy concern is another challenge in fenestration and daylighting. Desired privacy level varies based on type of building, cultural values and individual preferences.

The third phase of the study discusses façade elements, their characteristics, different forms and their role in daylighting. Windows, Solar shading and skylights are studies to uncover how each element is used for daylight utilization and control. These elements are extensively used by Iranian traditional and contemporary architectures in a variety of shapes and configurations. I addition, innovative contemporary systems for daylighting including adaptive facades are explained.

Having uncovered the facts about daylighting, design considerations and façade elements for daylight utilization and control, in the final stage of the study, six cases of residential buildings in Iran are inspected. Three case studies are featured houses in hot regions of Iran well-known for their brilliant design and sustainability. The other three cases are globally-recognized residential buildings nominated and awarded for their unique and spectacular designs.

The cases are studied by observation of façade elements, design characteristics and quality of daylighting. Mechanisms for daylight utilization and control are identified and compared. The final conclusion is by integrating traditional schemes of daylighting such as windows of different sizes, multiple openings of different transparency levels, incorporating courtyard, semi-open spaces and skylights in contemporary building, better daylighting can be achieved. Innovative designs used by contemporary architecture are successful because they are inspired by lessons from past which notifies us to respect nature and adapt sustainable buildings. Advanced in construction materials and construction technology facilities the ways towards this goal.

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