# THE USE OF NATURAL LIGHTING THROUGHOUT THE HISTORY: A CONSIDERATION WITHIN THE CONTEXT OF ENVIRONMENTAL, TECHNOLOGICAL, SCIENTIFIC AND SOCIAL DEVELOPMENTS

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AUGUST 2021

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A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED
SCIENCES OF
ÇANKAYA UNIVERSITY

BY
İPEK ŞENGÜL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE
DEGREE OF
MASTER OF SCIENCE
IN
INTERIOR ARCHITECTURE
DEPARTMENT

AUGUST 2021

## ABSTRACT

## THE USE OF NATURAL LIGHTING THROUGHOUT THE HISTORY: A CONSIDERATION WITHIN THE CONTEXT OF ENVIRONMENTAL, TECHNOLOGICAL, SCIENTIFIC AND SOCIAL DEVELOPMENTS

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August 2021, 126 pages

Natural light plays a crucial role in architecture. Through natural light, it is possible to strengthen the interaction between occupants and the building. Throughout history, many civilizations have benefited from the potential provided by natural light. Over time, many design decisions have been developed regarding the use of light indoors. It is possible to mention many factors in the formation of these design decisions. In this study, the indicators that determine the principles of use of light in the historical process are gathered under three fundamental factors. These are environmental factors, engineering and scientific developments, social and cultural factors. In the context of these factors, it has been tried to examine how the methods of admitting daylight into buildings in the historical process. The primary purpose is to examine how daylight was taken into the interior throughout history. Significant developments have been investigated in order to do this review and facilitate the evaluation of the study. In this way, thresholds were determined. Monumental structures on these thresholds were evaluated depending on the determining factors and criteria. It is aimed that this research will provide a basis for natural lighting design in the future. In order to understand the future, the current conditions have been evaluated. Technology, environmental awareness, energy-efficient design, which are influential in shaping natural lighting in today's interiors, have also been discussed.

Inferences made by examining history and today are presented to the audience with summary tables. This study has undertaken to reveal the perspectives we have learned from the past about natural lighting design that will guide the future.

**Keywords:** Natural Light in Architecture, Historical Process, Thresholds, Environmental Factors, Social and Cultural Factors, Scientific and Technological Developments.

# ÖZ

## TARİH BOYUNCA DOĞAL AYDINLATMA KULLANIMI: ÇEVRESEL, TEKNOLOJİK, BİLİMSEL VE SOSYAL GELİŞMELER BAĞLAMINDA BİR DEĞERLENDİRME

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Tez Yöneticisi: Prof. Dr. Gülser ÇELEBİ

Ağustos 2021, 126 sayfa

Doğal ışık mimaride önemli bir rol oynar. Doğal ışık sayesinde insan ve yapı arasındaki etkileşimi güçlendirmek mümkündür. Tarih boyunca birçok medeniyet, doğal ışığın sağladığı potansiyelden yararlanmıştır. Zaman içinde ışığın iç mekandaki kullanımı ile ilgili birçok tasarım kararı geliştirilmiştir. Tasarım kararlarının oluşmasında birçok etkenden söz etmek mümkündür. Çalışmada, tarihsel süreklilik içerisinde ışığın kullanım ilkelerini belirleyen göstergeler üç temel faktör altında toplanmıştır. Bu faktörler çevresel faktörler, mühendislik ve bilimsel alanlardaki gelişmeler, sosyal ve kültürel faktörler olarak sınıflandırılmıştır. Sınıflandırılan bu faktörler bağlamında tarihsel süreçte binalara ışık alma yöntemlerinin nasıl olduğu irdelenmeye çalışılmıştır. Ana amaç ışığın iç mekana tarih boyunca nasıl alındığının irdelenmesidir. İrdelemeyi yapabilmek ve çalışmanın değerlendirilmesini kolaylaştırmak adına önemli gelişmeler araştırılmıştır. Bu şekilde eşikler oluşturulmuştur. Belirlenen bu eşiklerde anıtsal karakterli yapılar belirlenen farktörlere ve kriterlere bağlı olarak değerlendirilmiştir. Bu araştırmanın gelecek dönemlerdeki doğal aydınlatma tasarımına baz oluşturması hedeflenmiştir. Geleceği anlamak için mevcut koşulların değerlendirilmesi yapılmıştır. Günümüz iç mekanlarında doğal aydınlatmanın şekillenmesinde etkili olan teknoloji, çevre bilinci, enerji etkin tasarım gibi konular ayrıca ele alınmıştır. Tarihin ve günümüzün detaylı incelenmesi ile yapılan çıkarımlar özet niteliğindeki tablolar ile okuyucuya sunulmuştur. Bu çalışma doğal aydınlatma tasarımı ile ilgili geçmişten öğrendiğimiz bakış açılarını geleceğe ışık tutacak biçimde ortaya çıkarmayı görev edinmiştir.

**Anahtar Kelimeler:** Mimaride Doğal Işık, Tarihsel Süreç, Eşikler, Çevresel Faktörler, Sosyal ve Kültürel Faktörler, Bilimsel ve Teknolojik Gelişmeler.

**ACKNOWLEDGEMENTS**

I would like to express my sincere gratitude to my supervisor Prof. Dr. Gülser ÇELEBİ, and my co-supervisor Dr. Mine YAZICIOĞLU, who give supports during the process of this study, for their valuable contributions. Without their encouragement, support, guidance, and tolerance, this thesis would never have been completed.

I express my special gratitude to Bülent ALTAY, who helped me develop my professional manners throughout my undergraduate life.

Also, I would like to thank Assoc. Prof. Dr. İdil AYÇAM and Asst. Prof. Dr. Güler Ufuk DEMİRBAŞ for their valuable comments and contributions.

I would also like to thank my dear friends Zeynep, Burcu, Gizem, and Murat for their support in all circumstances.

Finally, I express my deepest gratitude to my dear parents Hülya ŞENGÜL and Sebahattin ŞENGÜL, who have overcome all the difficulties with me and supported me all my life. I would not have gotten to where I am today without their precious support and love. I would also like to thank other members of my lovely family member Bora, Özge, and Gülce ŞENGÜL for being with me throughout the process.

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## LIST OF ABBREVIATIONS AND SYMBOLS

**DF** Daylight Factor

**CIE** International Commission on Illumination

**IES** Illuminating Engineering Society

**SC** Sky Component

**ERC** External Reflected Component

**IRC** Internal Reflected Component

**SI Unit** International System of Units

**DA** Daylight Autonomy

**cDA** Continuous Daylight Autonomy

**sDA** Spatial Daylight Autonomy

**UDI** Useful Daylight Illuminance

**ASE** Annual Sun Exposure

**DSP** Daylight Saturation Percentage

# CHAPTER I

# INTRODUCTION

Spaces exist through architecture, and our spatial awareness is created mainly through our visual senses. Our visual sense is also activated by an artificial or natural light source. Although artificial light sources are used effectively today, our oldest and primary light source is the Sun. Natural light, which is the basic need for the adaptation of the human body, is also essential in forming our architectural perception. In this respect, the light coming from the Sun, which is the primary source of life, is one of the critical parameters in architecture.

Through light, it is possible to strengthen the interaction between humans and buildings. It allows us to define and perceive colors, surfaces, forms, textures, and our position. While responding to our physiological and psychological needs, it also forms a primary resource for sustainable architecture. Guzowski also mentions that the occupants' mood is negatively affected due to the lack of daylight in the space and states that daylight is important to the experience of time, space, and environment. (Guzowski, 1999). For such reasons, it is known that the lighting design in any place is of vital importance for the users and the environment.

Since we have adapted to modern life, we spend most of our time indoors. We perceive the outside world through windows or spaces in the building envelope. The quality and quantity of these spaces in the building envelope are directly related to natural light. In this respect, the effect of spaces together with natural light in the formation of the unique identity of the spaces is undeniable. In other words, light can transform spatial context depending on how it is used and where it comes from.

Functional and semantic innovations in the space can also be created with natural light. While getting daylight in some places is the primary purpose, daylight is completely avoided in some areas. Therefore, many design decisions regarding the use of light in space have been developed over time. It is possible to state that there are many actors in the formation of these design decisions. These effects are technological developments, climatic data, geography, cultures, lifestyles, and religions.

In this study, the use of light in space will be examined in the historical process. It will be tried to reveal which factors the use of natural lighting develops. It is known that the use of natural light produces depending on specific factors, but when the literature is searched, it is seen that all of them are unorganized. In this thesis, a natural light reading will be done in the historical process over these factors, which are classified as *Environmental Factors, Engineering and Scientific Developments, Social and Cultural Factors*. At the same time, studies will be made on the *natural lighting typology*. All these examinations will be tried to be made on the outstanding examples in specific periods. These examples are generally monumental structures. This is because the structures that best reflect societies' lifestyles, technological skills, and social and cultural values throughout history are monumental buildings.

To conclude, in this article, the criteria to be considered while designing today's buildings in terms of daylight use and their importance will be tried to be revealed. It is thought that this study will be beneficial both in terms of quality and quantity for the buildings to be designed in the future and for the improvement of existing buildings.

## 1.1. PROBLEM STATEMENT

The research began by asking some questions. The research questions are as follows:

- Which developments and events throughout the history of humanity have caused or prevented the penetration of daylight into space? (Thresholds)
- What kind of parameters has an effective role in the use of natural light in buildings? (Factors that Affect Natural Light)
- How did people admit daylight into interior space throughout history? (Typological Approach)
- What kind of changes in the future are expected regarding natural lighting in the interior?

Studies conducted to find answers to these questions have revealed unidirectionality in the literature. While some studies have evaluated the use of natural light within the framework of sustainability, some have examined it under the influence of cultures and religions; While discussing the effect of some building elements, some studies examined inputs such as climate and weather. As can be seen, previous studies have tried to evaluate the information according to a single dynamic. However, natural light design is a multi-disciplinary process.

All the factors that should be considered together in the design process are disorganized in the literature. It has been seen that the resources it gathers together are limited and insufficient. Studies evaluated with a single input contradict the multidimensionality of the use of natural light in buildings. While presenting the problem, this gap in the literature was taken into consideration.

## 1.2. AIM AND SCOPE OF THE RESEARCH

Within the scope of the thesis, how people use daylight throughout history will be analyzed according to the determined criteria. The study began to take shape by examining the literature and reading various articles, books, and articles. Typological approaches have been searched for factors affecting natural light, developments in the historical process, taking the light into the space, through collecting relevant information. The inputs of the study were created with this information obtained by examining the sources.

Specific methods and techniques are essential in classifying this information and making it easier to read history. Karasar supports this by saying that all of the information gathered in the research should ultimately be in the form of classified information. (Karasar, 1981). Since an examination will be carried out in historical continuity in the study, the information obtained from the literature should be classified systematically. As can be seen, it is not possible to evaluate the entire history by adhering to a single criterion while reading. Therefore, some *thresholds* have been created to facilitate the evaluation of the study. It is helpful to establish thresholds to simplify the process when studies covering a long period of time are made. In this study, information was needed about how the thresholds are formed, and this information will be tried to be revealed with tables.

In summary, *where the mentioned thresholds are* is one of the main aims of the thesis. It is important to clearly explain the reason for the process changes to understand the subject in depth. As a second purpose, *examining the lighting typologies used in these thresholds in the historical process* can be shown. Thirdly, it is to determine *which factors are more effective on these thresholds in the historical* *process*. In other words, it will be revealed how to read the natural lighting in these thresholds in the context of the determining criteria.

The thesis will provide a collective resource for researchers on the subject, such as a *"handbook"* on how natural lighting has been handled at certain thresholds in historical continuity. It will also be helpful for future studies. With the help of the results, it is possible to contribute to today's and future buildings' natural lighting design process.

## 1.3. STRUCTURE OF THE THESIS

The thesis consists of six main sections: “Introduction”, “Literature Review in terms of Natural Lighting Concepts and Data Analysis On Historical Development”, “The Historical Analysis and Assessment On the Factors That Affect Thresholds”, “Evaluation of Using Natural Lighting in Contemporary Approach”, “Results and Discussion” and “Conclusion”.

In the first chapter, the aim and scope of the study, research questions, and what is wanted to be revealed are explained.

The second chapter revealed the definition of natural light, physical and semantic characters of natural light. At the same time, it stated the factors affecting the use of natural light by showing historical references. Lighting typologies that have been used throughout history and today are also given in this section.

In the third chapter, evaluations were made according to the thresholds and criteria determined by the data collected from the previous section. These evaluations are presented to the audience in tables so that the subject can be perceived easily. These tables showing the use of natural lighting in buildings have provided summary information to the literature throughout the process.

The fourth chapter has been discussed what kind of parameters are effective in indoor lighting in today's conditions. It has been tried to reveal what kind of factors and systems will be effective in the future in terms of natural lighting application.

In the fifth chapter, revealed evaluations were collected through tables and the results were discussed.

In the last part, inferences related to the subject were tried to be revealed.

## CHAPTER II

## LITERATURE REVIEW IN TERMS OF NATURAL LIGHTING CONCEPTS AND DATA ANALYSIS ON HISTORICAL DEVELOPMENT

### 2.1. THE PHYSICAL CHARACTERISTICS OF NATURAL LIGHT

Light is a type of energy emitted by radiation, and it is part of the electromagnetic spectrum, including infrared, visible light, ultraviolet, X-rays, Gamma Rays, and Radio waves. Our visual system is sensitive to only "visible light," and visible light is a small part of the electromagnetic range. We cannot see other forms of the electromagnetic spectrum. (Definition: Natural Light; Sunlight - Photokonnexion, n.d.). Figure 1 illustrates the electromagnetic spectrum diagram clearly.

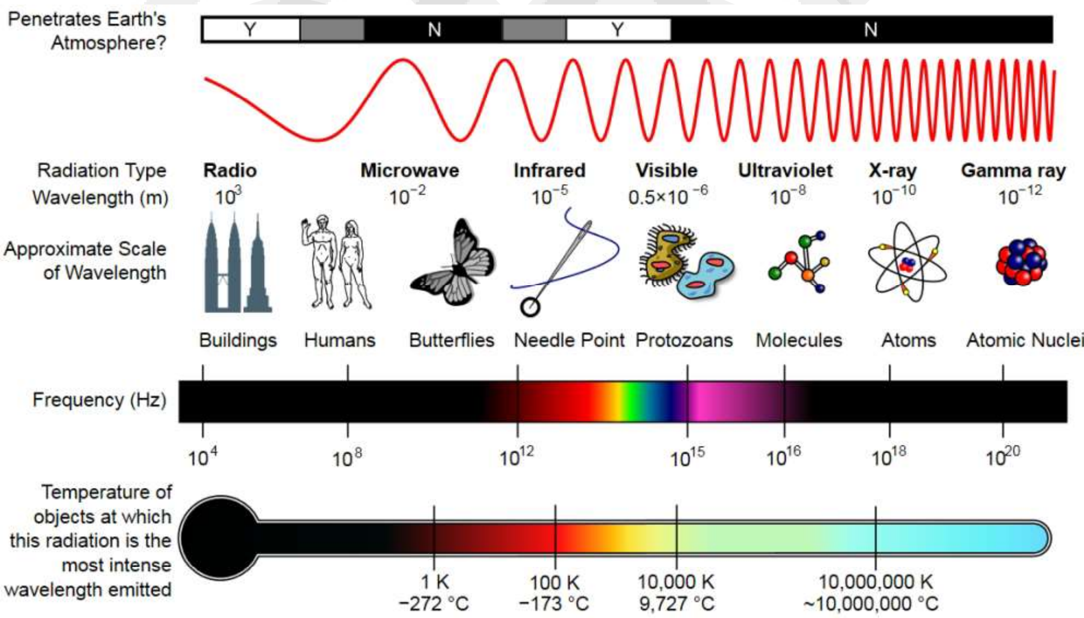



Figure 1. Electromagnetic Spectrum Diagram.
(Url 1)

Through light, we can build and comprehend our environment, which includes forms, shapes, colors, materials, etc. According to Innes, two general types of light make our physical world visible: natural light and artificial light. (Innes, 2012).

Sunlight and daylight create natural light. Sunlight, which includes the entire color spectrum, is defined as light from the sun that is visible. On the other hand, daylight is defined as the light that comes in whenever the sun is above the horizon. It does not matter if daylight is visible or not. (Coles & House, 2007, p. 119)

Natural light, which includes sunlight and daylight, has been the primary light source since the beginning. For example, over 2000 years ago, Marcus Vitruvius Pollio emphasized the importance of daylight and developed architectural rules in this regard. (National Association of Rooflight Manufacture, 2015). Louis Kahn also gives priority to daylight, which he associates directly with the sun. As it is seen, light in architecture, especially daylight is crucial to create space.

### 2.1.1. The Scientific Types of Natural Light

Both directly and indirectly, the light of the sun is our planet's main natural light source. Sunlight reaches the Earth in several ways as direct light from the sun, diffused by the clouds, and reflected light.

Direct sunlight is considered to be the most potent and high-intensity type of point light source. Illuminance approximately 120.000 lux can be produced on the Earth's surface. (National Association of Rooflight Manufacture, 2015). Because of this, there is a risk of excessive heat gain. Also, the risk of glare is high, and there is a quality problem due to the glare. Sky conditions, location, time of the day, and season affect the brightness and quality of direct sunlight. For more efficient use, control of the light should be ensured. Sunlight which is convenient for creating high-contrast images, creates sharp shadows with solid edges. Color Temperature is between 1800-5500 Kelvins. (Warmer Color).

Diffused light is determined by the overcast sky and clear sky light conditions. The atmosphere and clouds act as filters. Thus, the blue sky vault provides us diffuse light. For example, whereas the level of diffused light is increased by thin clouds, direct light is decreased. When diffused light is compared with direct sunlight, diffused light might be much softer than direct sunlight. In addition, the diffused sky is used as the primary light source in cloudy climates. There is no excessive heat gain because of the diffuse light, but sometimes there is a problem with light quantity. Depending on the thickness of the cloud coverage and partially cloudy weather conditions, the quality and intensity of the light may change. Fluctuations in distribution and color temperature occur due to the constant transition between direct sunlight and hazy daylight. (Egan & Olgyay, 2002, p. 89). The overcast sky can produce approximately 10.000 lux illuminance levels in winter. On the other hand, the bright overcast day in the summer may produce around 30.000 lux. (*Learn about Daylighting and the Controlled Use of Natural Light*, n.d.). Also, diffused light has a soft low contrast. Color Temperature is between 5500-12000 Kelvins. (Cooler Color).

The reflected light is defined as sunlight or sky light that comes from the surfaces which are horizontal or vertical. From one surface to another, light can quickly reflect. For example, it can be reflected from surrounding structures, floors, glass, water, or anything else. Quality and quantity of light change depending on the characteristics of the surface. In some cases, for example, in regions with lots of buildings, reflected light might be the main factor in reaching daylight into the interior space. Generally, the light reflected from the ground is responsible for 15% or more of the daylight coming to the building. (*Learn about Daylighting and the Controlled Use of Natural Light*, n.d.). In Figure 2, we can see the illustrated summary of natural light sources.

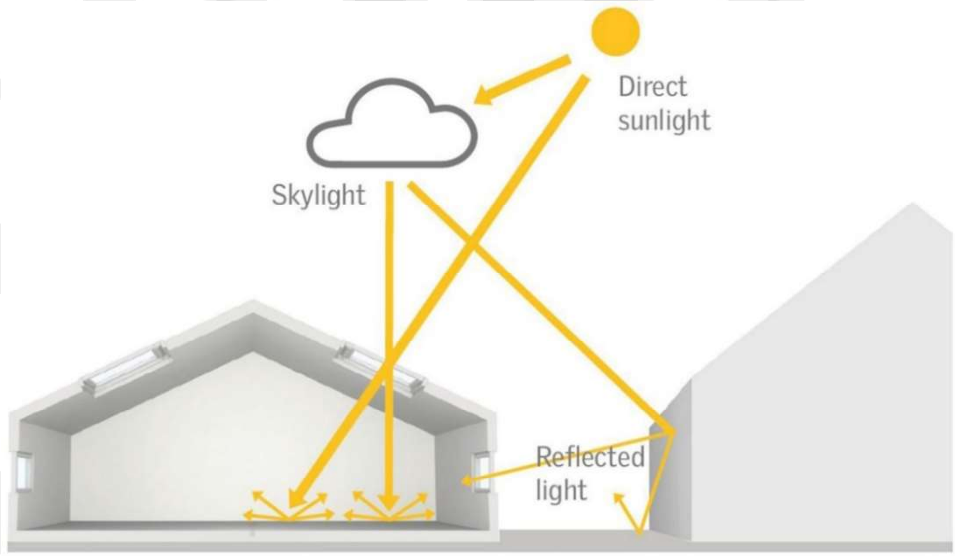



Figure 2. The Types of Natural Light.
(Url 2)

Architects/interior architects benefit from understanding the types of daylight while making design decisions. The use of daylight in design has the potential such as increasing energy savings, improving human health, and giving identity to space.

### 2.1.2. Daylight Metrics

While designing a space integrated with daylight, we should have some questions in mind. Evaluating the best condition for human comfort, providing productivity, minimizing energy use, optimizing pros and cons are some of them. Solving such problems is possible with daylight measurements. For these reasons, daylight metrics have become crucial.

The concept of daylight metrics might be basically defined as the measurement of daylight. We can characterize this concept as a measurement to reveal the potential of natural light in architecture while providing user comfort and energy efficiency in design. Through these metrics, we can create a convenient design solution for façades, windows, skylights, atriums. (Acosta et al., 2019). In summary, it is inevitable to make precise measurements to construct spaces considered from every angle, and the benefit-harm relationship has been optimally resolved. At this point, it is necessary to explain some concepts related to the measurement of light in order to understand the daylight metrics in depth.

According to definitions provided by Innes (Innes, 2012);

*Luminous flux (ø)* is the total amount of light emitted by a light source per unit of time. Lumen (lm) is the SI unit (International System of Units) of luminous flux.

*Lumen (lm)* is the measures of the total amount of visible light produced by a source or coming from the surface to the human eye. If the lumen rating is high, the light sources appear brighter.

*Lux (lx)* is the unit used to describe the amount of light falling on a surface. The lumen per square meter ($lm/m^2$) formula is defined as a Lux (lx). A case reported by Stein et al. (2005) claimed that between 10-20 lx as insufficient, 20-100 lx as ordinary, 100-200 lx as reasonable, 200-400 lx as strong, and more than 400 lx as severe. (Stein et al., 2005).

*The Luminous Intensity* is related to the amount of light obtained per unit area. Candela (cd) is the SI unit of luminous intensity. If the energy of the light is high and the defined surface area on which it falls is small, we can say that the energy of the light is high.

*Illuminance* is the amount of light falling on a surface. Lux (lx) is the SI unit of illuminance.

*Luminance* is the amount of light reflected from a surface to our eyes. Candela (cd) per square meter ($cd/m^2$) is the unit of luminance.

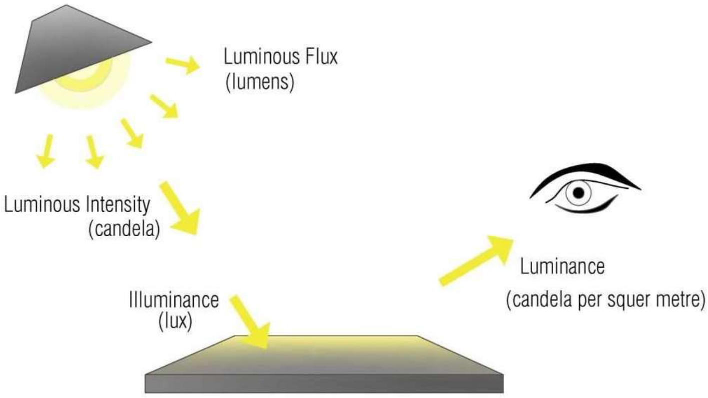
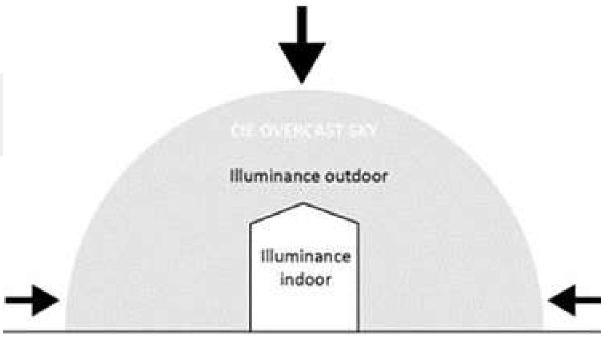



Figure 3. Components of Quantifying Light.
(Url 3)

The purpose of a metric is to predict better or worse performance outcomes and ensure that design decisions are made correctly. More than one metric can be used when evaluating performance. There is no obligation to keep to a single metric. The most valuable metrics are those chosen according to adequate conditions. In order to make the most accurate design decisions, it is necessary to examine the metrics used (daylight factor and new approach arising from need).

#### 2.1.2.1. Daylight Factor

Daylight factor; used to evaluate daylight levels. In the literature, the Daylight factor (DF) tends to be used to refer to the ratio between indoor illuminance and outdoors illuminance under the overcast sky condition, which is determined by International Commission on Illumination (CIE) standard. (Hopkinson, 1963). Usually given as a percentage, this formula is calculated as: (see Figure 4)




$$DF = \frac{Illuminance\ indoor}{Illuminance\ outdoor} \times 100 \quad [\%]$$

Figure 4. Measurement of Daylight Factor.
(Url 4)

The daylight factor consists of three components. These are; sky component (SC), external reflected component (ERC), and internal reflected component (IRC). It is necessary here to clarify exactly what is meant by sky component (SC), external reflected component (ERC), and internal reflected component (IRC). SC encompasses the light that comes from the sky, and it does not include direct sunlight. ERC is a term that refers to light reflected from exterior surfaces or obstructs like façades. In contrast, IRC is defined as the light reflected from interior surfaces or obstructs such as ceilings, furniture, interior walls (Arpacıoğlu, 2010, pp. 70–71) as demonstrated in Figure 5. It would not be wrong to define the daylight factor as the sum of the (SC), (ERC), and (IRC).

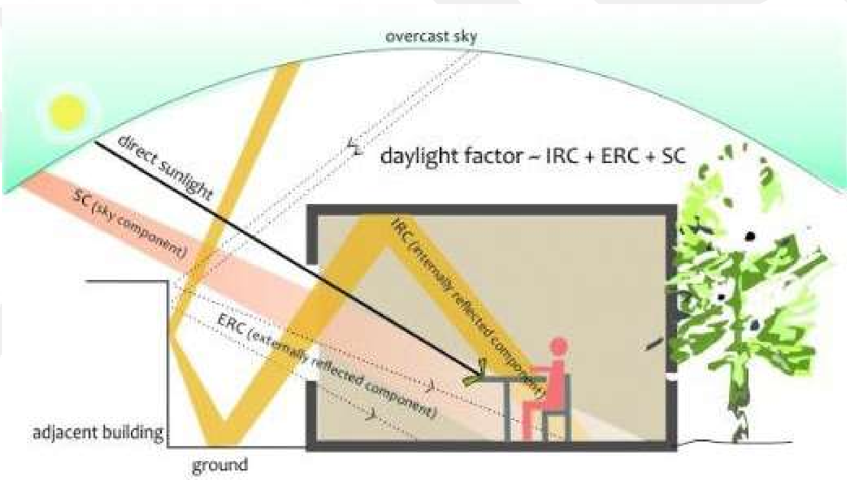



Figure 5. Components of Daylight Factor.
(Url 5)

Various standards have been determined to meet the required daylight levels in spaces. The most well-known of these was developed by the Illuminating Engineering Society (IES). It reveals which function should have daylight factor in which range. (Table 1.)

Table 1. Recommended Daylight factor by Illuminating Engineering Society. (IES, 1968).

| BUILDING TYPE | FUNCTIONS | DAYLIGHT FACTOR (%) |
|---|---|---|
| OFFICES | General Offices | 2 |
| | Typewriter, Calculator, Computer | 4 |
| BANKS | Bank, Accounting | 2 |
| AIRPORTS AND BUS TERMINALS | Bank, Customs, Passport | 2 |
| | Hall corridor | 1 |
| CONCERT HALLS | Foyer | 1 |
| | Corridor | 0,5 |
| | Stairs | 1 |
| LIBRARIES | Shelves | 1 |
| | Reading Areas | 1 |
| MUSEUM, ART GALLERIES | General | 1 |
| SCHOOLS | Meeting halls | 2 |
| | Classes | 2 |
| | Handicraft Workshops Laboratories | 4 |
| | Teacher Rooms | 3 |
| | | 1 |
| HOSPITALS | Acceptence – Wait | 2 |
| | Patient Rooms | 1 |
| | Pharmacies | 3 |
| DWELLING AND HOTELS | Living Areas | 1 |
| | Bedrooms | 0,5 |
| | Kitchens | 1 |

We can analyze what the determined values want to tell us as follows: It is insufficient and unsuitable for working when the DF falls below 2%. If it is between 2% and 5%, it is sufficient and suitable. The DF is high above 5%, the daylight level in the place will be self-sufficient, but in some cases, glare problems may occur. (Kaempf & Paule, 2016, p. 13). We can see the summary of the DF range in Table 2.

Table 2. Target Daylight Factors. (CIBSE, 1998).

| Daylight Factor | Quality of lighting within space |
|---|---|
| Less than 2% | • Room looks gloomy under daylight alone<br>• Full electric lighting will usually be required during daytime<br>• Electric lighting dominates daytime appearance, i.e, the space does not appear daylit |
| Between 2% and 5% | • Windows give a predominantly daylit appearance but some supplementary electric lighting will be needed<br>• Best balance between daylighting and overall energy use |
| More than 5% | • Room appears strongly daylit<br>• Daytime electric lighting is rarely needed<br>• Can be major thermal problems from large windows |

Some studies have shown positive effects of 4% daylight factors on performance and productivity. Considering this situation, it would be correct to use a 4% daylight factor in buildings such as educational buildings that include performance and productivity-based functions. Through the daylight factor, it is possible to make such generalizations. The evidence presented thus far supports the idea that, in some building codes, especially considering the daylight factor, it is said that the ratio of openings should not be less than 20% of the total floor area. If it is less than 20%, we may encounter with weak daylight zones and, therefore, excessive energy consumption in some parts of the space. For this reason, we should provide daylight at the most appropriate level without sacrificing energy efficiency and visual comfort. (National Association of Rooflight Manufacture, 2015).

Although the daylight factor is the most common metric used to evaluate daylight level, it has some handicaps. Overcast sky conditions, standardized by the International Commission on Illumination (CIE), do not contain sunlight. This means that it is insensitive to orientation, climate, cloudy or clear weather. In this case, it is possible to get the same results in terms of daylight factor value in two different buildings facing any facade in any city. For instance, when comparing two countries with different climates, such as Oslo and Barcelona, we can reach the same values. Therefore, in some cases, we may obtain inconsistent results with actual conditions, and these indicate the possible potential avoidances for using daylight factor metrics. This is not surprising given the daylight factor, which is insensitive to climate and orientation. (Mardaljevic et al., 2009). Factors affecting natural lighting and, of course, affecting the daylight factor will be discussed in *2.3. The Factors that Affect Natural Ligh* section.

In recent years, designers have turned to new metrics based on simulation and annual climate data, called dynamic daylight metrics. With such metrics, we can obtain values closer to actual conditions.

#### 2.1.2.2.The New Metric Based on Simulation and Annual Climate Data

Considering climatic conditions when deciding on the daylight-efficient design in the building will give the most realistic results. Besides the climatic assessment, the position of the building, variable sky conditions, and urban environment are also vital. Being conscious of such variables in the early design phase with climate-integrated simulations will help us control them. We need data from real-time monitored weather conditions in order to make climate-based assessments. Weather/sun conditions, cloud patterns, meteorological data that have been followed and collected in the field for years might be work with these metrics. We can list some of the metrics based on climate data as follows:

- Daylight Autonomy (DA)
- Continuous Daylight Autonomy (cDA)
- Maximum Daylight Autonomy
- Spatial Daylight Autonomy (sDA)
- Annual Sun Exposure (ASE)
- Useful Daylight Illuminance (UDI)
- Daylight Uniformity
- Daylight Saturation Percentage (DSP)

However, which one is the best choice for architects/designers? To answer this question, we should define some necessary terms.

*Daylight Autonomy (DA)* is defined as the percentage of annual working hours in which the lighting requirements for the building are met only by daylight. (Reinhart & Walkenhorst, 2001).

*Continuous Daylight Autonomy (cDA)* is the metric that natural light is important, even at a low level. If the illuminance in space is under the minimum level, partial credit is granted. We can explain as follow: if we want illuminance with 300 lux in space, but the measured level is 150 lux, the daylight autonomy gives 0 credits. In contrast, the constant continuous daylight autonomy gives 0.5 credit. (150/300=0.5). There is no exact accepted value. (Rogers, 2006).

*Maximum Daylight Autonomy* is the percentage of busy time that direct sunlight enters the space and increases daylight. This maximum level is determined by daylight autonomy. Maximum DA is worth ten times more than DA. For example, when the DA level is 200 lux, the maximum DA level will be 2000 lux. (Kaempf & Paule, 2016, p. 19).

*Useful Daylight Illuminance (UDI)* depend on climate-based condition. Location, building orientation, and climatic data take into account in this metric. There is some range in useful daylight illuminance to give full credit. Less than 100 lux daylight illuminance is insufficient; between 100-500 lux are sufficient, but it might be reinforced by artificial lighting according to needs; between 500-2000/2500 lux are autonomous, higher than 2000 or 2500 lux causes glare and thermal discomfort problem. (Nabil & Mardaljevic, 2005).

*Spatial Daylight Autonomy (sDA)*, according to The Illuminating Engineering Society (IES), spatial daylight autonomy (sDA) is related to adequate daylight level reach to space annually. It recommends an illumination level of 300 lux for 50% of the working hours (8 am to 6 pm in a local hour). According to IES LM-83-12, the recommended value for sDA is that the acceptable daylight sufficiency range is sDA300, 50% ≥ 55%, and preferred daylight sufficiency range is sDA300, 50% ≥ 75%. (*IES LM-83-12, Approved Method: IES Spatial Daylight Autonomy (SDA) and Annual Sunlight Exposure (ASE)*, 2012).

*Annual Sun Exposure (ASE)* is the task zone percentage that reaches excessive direct sunlight more than the optimum level per year. IES suggests the values, which are 100lux and 250 hours per year. Working hours (8 am to 6 pm in local time) are accepted similarly in sDA. Also, IES has not yet defined recommended values for the annual sunlight exposure (ASE). (*IES LM-83-12, Approved Method: IES Spatial Daylight Autonomy (SDA) and Annual Sunlight Exposure (ASE)*, 2012). In addition to this, some research suggests the following values: (Kaempf & Paule, 2016).

ASE ≥ 10%: unsatisfactory visual comfort

ASE < 7%: neutral, nominally acceptable spaces

ASE < 3%: clearly acceptable spaces

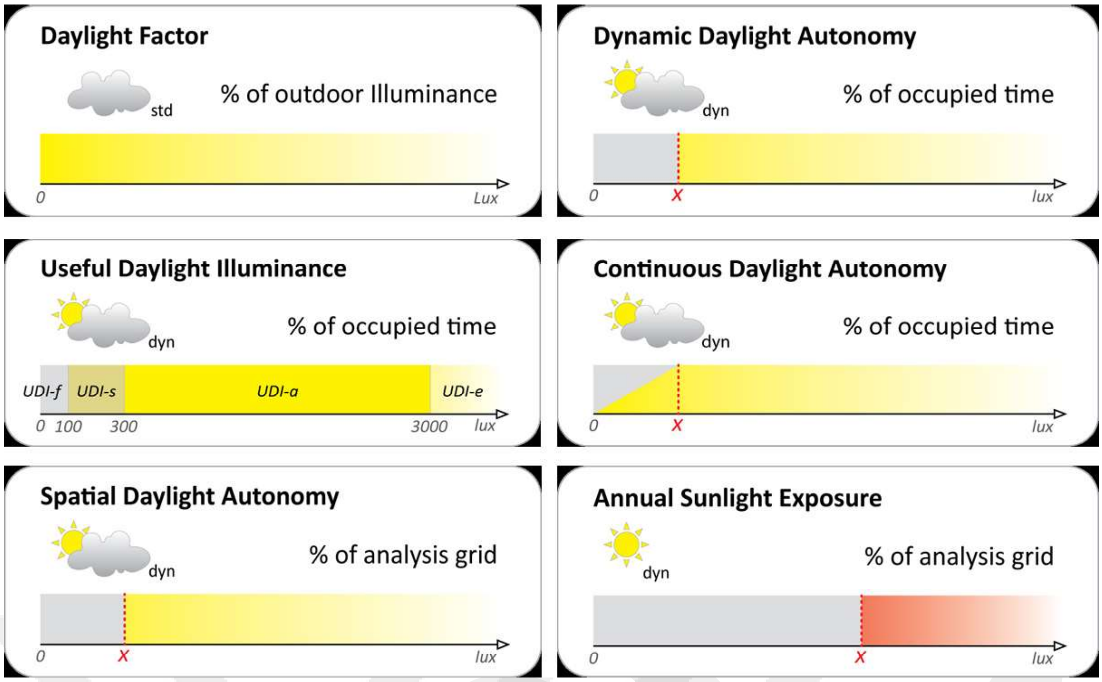



Figure 6. Illustration of Daylight Metrics.
(*IES LM-83-12, Approved Method: IES Spatial Daylight Autonomy (SDA) and Annual Sunlight Exposure (ASE)*, 2012)

According to Sterner, Spatial Daylight Autonomy (sDA) and Annual Sun Exposure (ASE) are the metrics that help architects to make good design decisions. The reason for using these two metrics together is balancing optimum daylight gain. There is no upper limitation on sDA. Therefore, this upper level should not be considered correct even though places with much direct sunlight look well. This is where the ASE becomes a part of necessity and tries to provide a balance between the potential issues. When we pay attention to the suggestion of some experts, it is crucial to maximizing sDA while keeping ASE under control. However, it can be hard to handle for designers or engineers because both metrics are affected by the same condition. We can balance these metrics using architectural design decisions such as shape and size of the building, orientation, shading devices systems, amount, and shape of glazing in different façades. With the help of all these design decisions, we can create places that are well lit, nonexposed to direct sunlight and use low energy. (Sterner, 2017).

In the light of all this information, daylight illumination is not limited to data such as building orientation, apertures design, climate. Beyond these kinds of data, it also contributes to the find for spatial meaning. Many cultures have tried to attribute meaning to light throughout history by adding their interpretations, so we encounter exciting designs. It would not be wrong to interpret daylighting as a combination of art and science in this respect. The following section claim that the semantic dimension of light.

## 2.2. THE SEMANTIC CHARACTERISTICS OF NATURAL LIGHT

The search for architectural meaning is a phenomenon that has been going on for years. This search for meaning has been tried to be answered by creating the intangible skin of the space with light. In other words, the story of the "space will be place" is made possible by the designed light.

With natural lighting, a multidimensional quality is provided in the space. With a properly designed light, the space creates the taste it deserves and its own spirit of space. The light types that we can examine as form-describing light, space-describing light, directional light, and meaning-producing light have important contributions to the formation of the atmosphere of the space.

*Form-describing Light*

While the light emphasizes the form, the shape of the building also affects the new forms of light. In this respect, there is an interdependent relationship between form and light. It allows us to perceive the permanent architectural composition in different ways.

While the light emphasizes the form, the shape of the building also affects the light conditions. In this respect, there is an interdependent relationship between form and light. It enables us to perceive the permanent and fixed architectural composition in different ways. (Tokyay, 2010).

Daylight entering from the oculus at the top of the Pantheon structure also circulates on the interior surfaces, the surfaces of the sculptures, and it creates a dynamic emphasis. Natural light is also used in Renaissance and Baroque churches to emphasize the architectural form, to show decorations and objects. (Ünver, 2000). Again, as we see in Mimar Sinan's mosques, the windows on the mihrab wall played a role in emphasizing the mihrab and the minbar. In addition, the light coming from the windows in the dome drum also emphasizes the dome and the central space phenomenon.

It is also possible to revitalize the surfaces or to put them into the background through natural light. One of the best examples of this has been given by Tadao Ando.

The sunlight entering through the cross-shaped slit on the wall of the Chuch of Light (see Figure 7) makes the whole place dim and emphasizes the cross form. It tries to reveal a religious meaning by highlighting symbolic religious figures with the help of natural light.

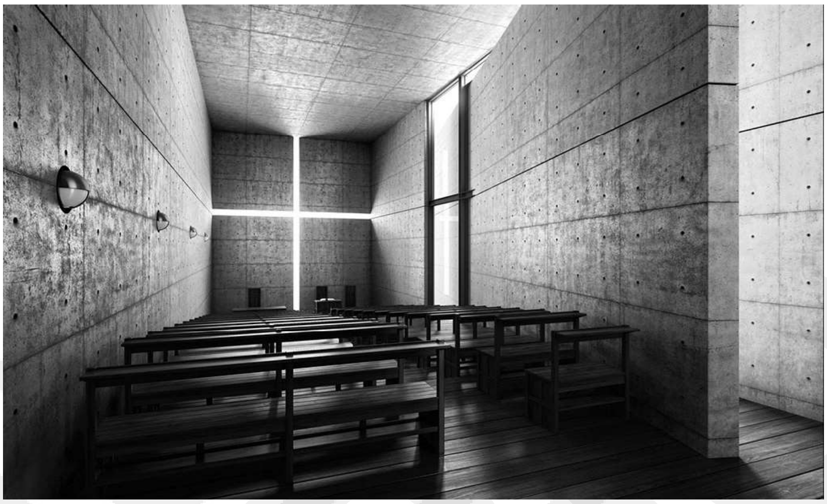


Figure 7. Church of Light by Tadao Ando.
(Url 6)

*Space-describing Light*

The apertures in the outer shell define the space. For example, the light from the rose windows in churches defines the nave, while the light from the high stained-glass windows defines the height of the church space and the aisle. (Tokyay, 2010). (see Figures 8 and 45).

Figure 8. Rose Window and Stained Glass Windows in Notre Dame de Paris Cathedral.
(Url 7)

*Directional Light*

This type of light might be used as a wayfinding sign. Giving direction with light; can be achieved by creating focal points and establishing a hierarchical order. Remarkably, the crucial parts of religious and monumental buildings can be emphasized with the help of natural light. To illustrate, in the Parthenon, which was built in the ancient period, the light filtering through the main door illuminated the statue of the goddess Athena. Similarly, in A. Aalto's Vuoksenniska Church in Helsinki, the light directed from the ceiling angled lights focuses on the three crosses in the altar area. (see Figure 9). This application provided by the light is so evident that the church is called "Church of The Three Crosses." As can be seen, giving direction with light is usually provided by daylight coming from a single point.

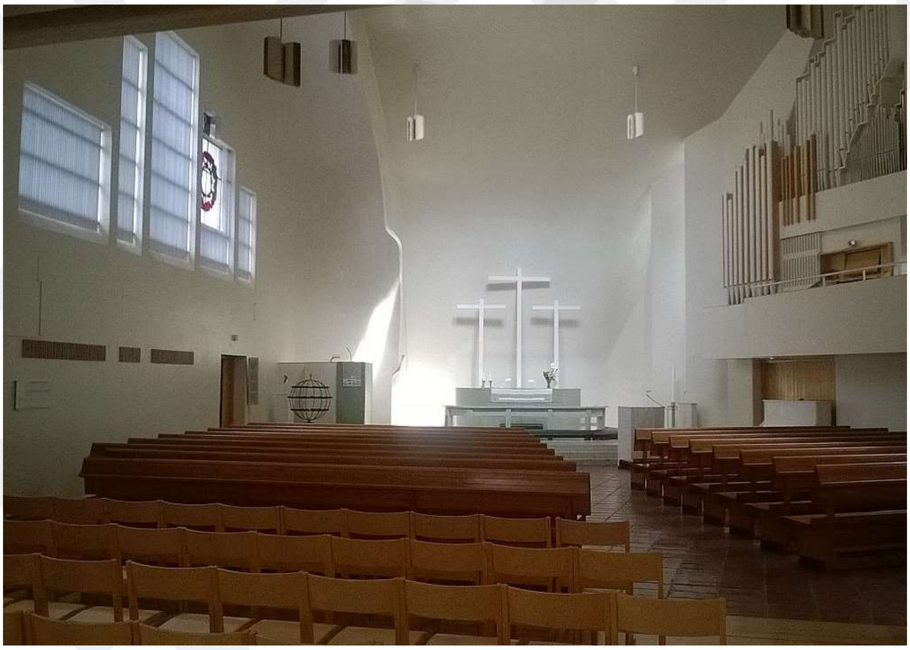


Figure 9. The Church of the Three Crosses by Alvar Aalto.
(Url 8)

*Meaning-producing Light*

It is inevitable for the meaning to exist together with the light in the architectural space. We can examine this meaning-making process under titles such as sacred light, symbolic/metaphorical light, and theatrical light. (Tokyay, 2010).

Sacred light often symbolizes divine powers in the space and tries to create a mystical atmosphere. It is possible to create a mysterious atmosphere with strategies such as the use of stained glass windows. Stained glass was used in the windows on the upper levels of the mosques. Thus, the daylight reaching the space is colored, and a mystical atmosphere is created. (Ünver, 2000). Another example is churches where stained glass is applied more than mosques. Stained glass was used in church windows both in the ancient and modern periods. Le Corbusier's Rochamp Chapel is an example. (see Figure 10)

Figure 10. Notre Dame du Ronchamp by Le Corbusier.
(Url 9)

In Selimiye Mosque, which is the masterwork of Mimar Sinan, we see applications that support the meaning of holy light. Through the windows placed rhythmically on the dome drum, the dome is almost floating in the air. (see Figure 11). An application of the concept of the heavenly dome, which strengthens the central planning, was realized in this way.

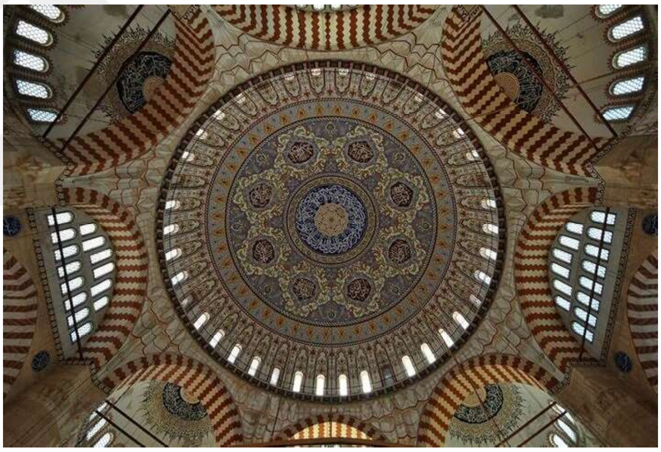


Figure 11. Dome of Selimiye Mosque by Architect Sinan.
(Url 10)

As a symbolic light, we can give the TBMM Mosque in Ankara, Behruz Çinici, as an example. (see Figure 12). It is a very innovative structure for mosque architecture to design a transparent mihrab by demolishing the classics and unusual design. The idea of lighting the mihrab, which was widely used in the period of Mimar Sinan, appears in a different way in Çinici's design. The daylight taken from the mihrab constructed with a glass façade has a symbolic and metaphorical meaning.

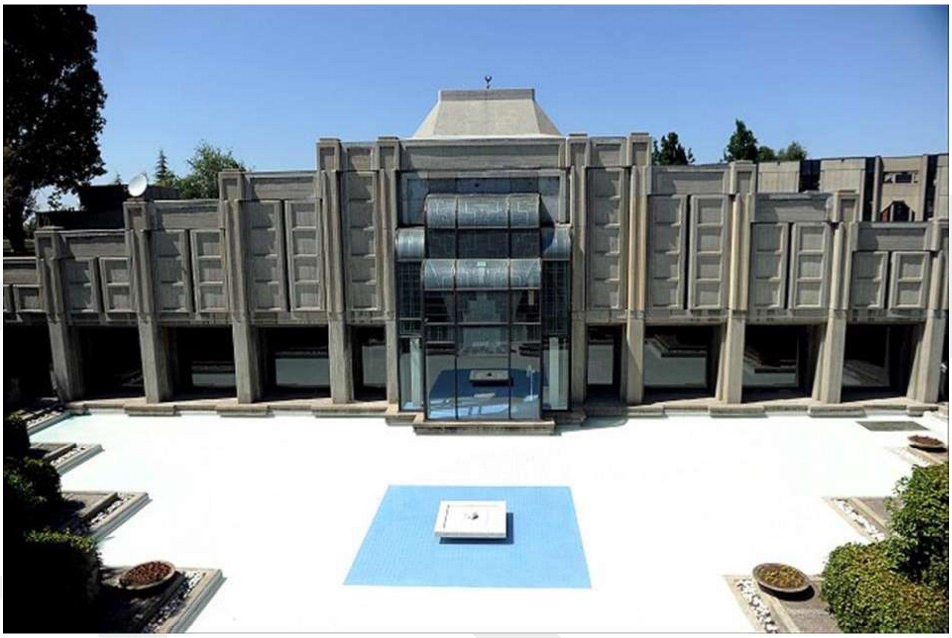


Figure 12. TBMM Mosque by Behruz Çinici.
(Url 11)

The penetration of daylight into the building in a geometrical order creates visually satisfying results. However, the stability of the space is lost, and dynamic space is created. We can see this effect in Maria Botta's "Church of San Juan Bautista." In this space, where the texture of the material is constructed with natural light, dynamic scenes are created according to the changing angle of the light during the day. It is an excellent example of understanding theatrical light. (see Figure13).

Figure 13. Church of San Juan Bautista by Mario Botta.
(Url 12)

As a result, as can be seen, the transformation of the spatial potential of light comes true with the meanings we assign to it. The character of a certain space is possible with properly designed lighting. Lighting has the potential to create a miserable atmosphere as a result of incorrect design. However, strategically designing natural lighting strengthens the relationship between occupants and building semantically. Light improves the structure in terms of aesthetics and quality. According to Theodorson, who supports this view, light is an abstract compositional element and at the same time creates rhythm, hierarchy, order, movement, and contrast. (Theodorson, 2006). These design principles he mentions are used in many types of buildings to create dramatic compositions. Designers often benefit from light's poetic and symbolic expression, especially in contemporary art museums, monumental and religious facilities.

In addition to all this concern for creating meaning, some factors directly affect natural light penetration into the building. In the next section, the factors affecting natural light will be examined in detail.

## 2.3. THE FACTORS THAT AFFECT NATURAL LIGHT

The interaction of human and natural light, which has played an influential role in shaping buildings for centuries, dates back to old times. People act with a life cycle compatible with natural light. While this cycle continued, they affected the existing conditions and were also affected by the current conditions.

Under favor of the knowledge accumulated over time, many technological developments have been experienced, and the inclusion or absence of daylight in architecture has become easily controllable. In addition, concepts such as the effective use of daylight, providing physiological and psychological comfort to users, and reducing energy consumption have emerged. Today, it is possible to solve such problems at an optimum level with technology. However, elements that are difficult to cope with, such as climate, urban design, and topography, still preserve their existence. We cannot ignore the impact of these elements on natural lighting. In summary, environmental factors, technological developments, social and cultural factors significantly affect natural light. In this section, the effect of these factors on natural light will be examined.

### 2.3.1. Environmental Factors

The structure is the whole of masses that come together by considering the conditions around the building. When we talk about the conditions around the building, environmental factors come to our minds directly. Environmental factors are very influential on natural lighting design in architecture. Environmental factors, including interdependent concepts such as climate, latitude, orientation, and the effect of the built environment, should be considered together with all aspects in natural lighting design. The elements handled holistically will add an invaluable quality to the building. Therefore, it is necessary to understand the effects of environmental factors in order to develop daylight saving methods and design criteria.

#### 2.3.1.1.Climate

Climate is one of the parameters that directly affect natural lighting. Buildings shaped based on the climate also affect the daylight spreading into space in terms of quality and quantity.

Understanding the relationship between the Sun and the shape of the Earth will help interpret the climate. Depending on the geoid shape of the Earth, the angle of incidence and energy of the Sun rays decrease from the Equator to the poles. (NASA, n.d.). Sun rays reaching the poles travel a long distance when we compare them to the Equator. The energy of the Sun rays' decreases because it travels both long distances and spreads over a wide area. *The Luminous Intensity* will be lower, as we mentioned before in 2.1.2. Daylight Metrics section. Sun rays coming to the Equator travel less distance, and they concentrate in a smaller area (see Figure 14). Therefore, sun rays have high energy and density. (Akkuş, 1998). In summary, over-illumination and under-illumination occur based on the shape of the Earth and the angle of incidence of the Sun's light. This situation directly affects the daylight design.

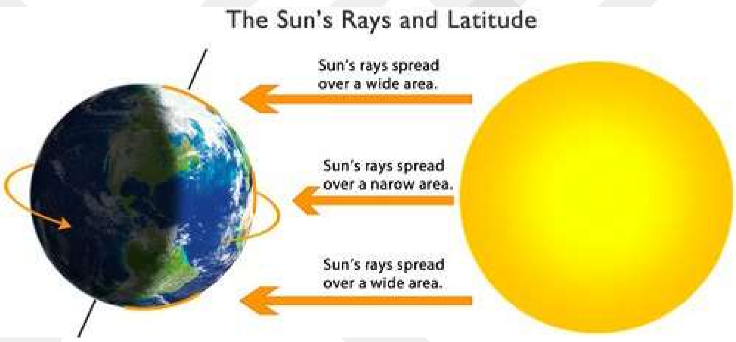



Figure 14. Sun Rays and Latitude Relations.
(Url 13)

Depending on the shape of the Earth and latitudes, some changes occur in conditions such as temperature, humidity, wind, and precipitation throughout the year. Climates emerge from observing all these meteorological conditions (temperature, humidity, wind, precipitation) for many years. The climate classification made by Köppen and Geiger divides the planet into five main climate zones and subgroups according to their annual precipitation and annual temperature patterns. These climatic zones are as follows: A (tropical), B (arid), C (temperate), D (continental), and E (polar). (see Figure 15). Each group and subgroup is symbolized by a letter. The first letters indicate the main climate, the second letters the precipitation regime of the region, the third letters the temperature character, and the fourth letters special conditions. (Arnfield, 2020; Kottek et al., 2006). In general, A (tropical) climate is hot and humid all year, B (arid) climate is dry and hot all year, C (temperate) climate is warm or mild in summer and cold or mild in winter, D (continental) climate is hot in summer and cold in winter, E (polar climate) climate can be defined as very cold all year. (see Figure 16.)

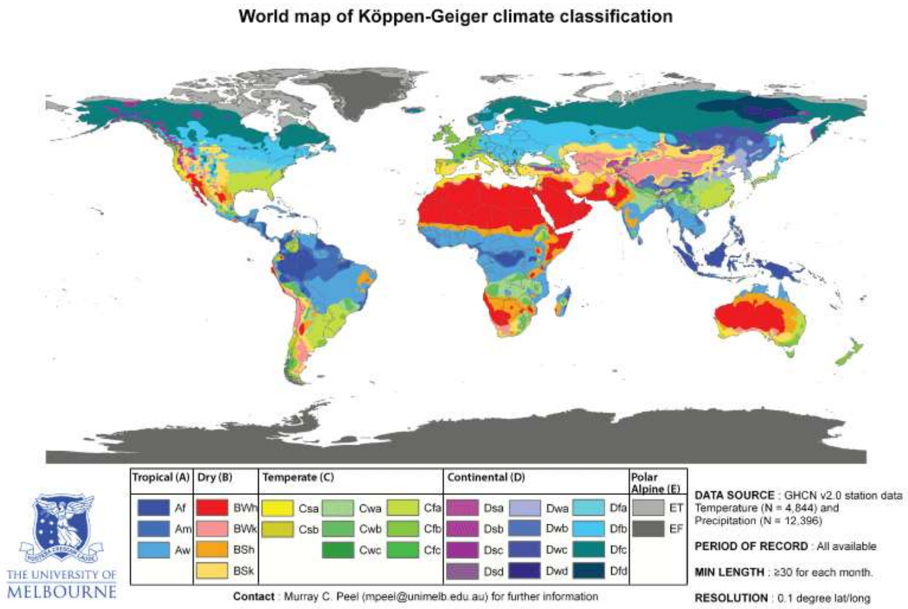



Figure 15. Köppen-Geiger Climate Classification.
(Peel et al., 2007).

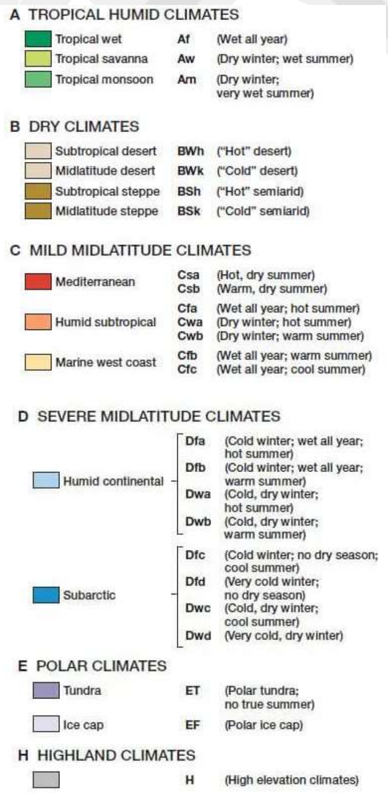



Figure 16. Climatic Types According to Köppen.
(Url 14)

It is possible to reach features such as benefiting/protecting from the Sun's rays and shading effect by reading the sun path diagrams. Diagrams showing the Sun's movements show us how the sun will affect the structure all year. Solar path diagrams are directly related to latitude. As it goes to higher latitudes (for example, around 60°), the need for solar heating and lighting gain increases and decreases as you get closer to the Equator. (see Figure 17). In this respect, sun path diagrams are an element that should be considered during the design phase. Inanlou ve Ataee, in their research, revealed that diagrams would be a guide for architects and designers on the decision-making processes such as calculating window sizes, determining the appropriate façade, and orientation of the building. (Inanlou & Ataee, 2017).

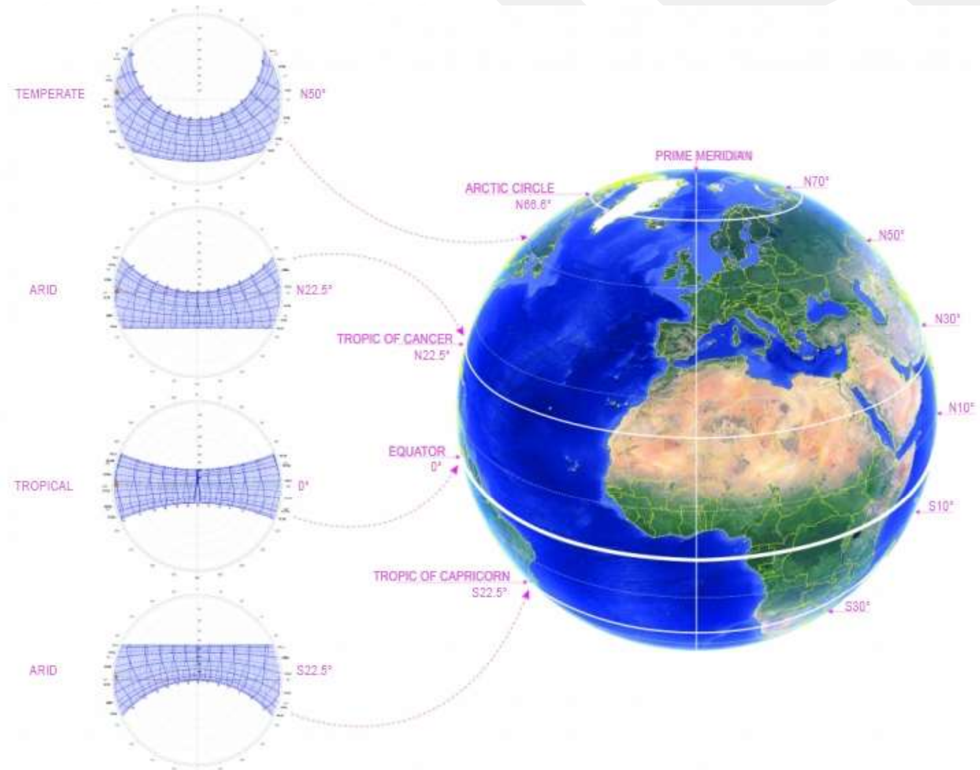



Figure 17. Sun’s Movement and Latitude Relation.
(Url 15)

Design strategy is significantly influenced by the local climatic conditions and sun path diagrams. Design decisions would vary according to the climate of the locality and sun path diagrams. Considering the characteristics of the climatic zones, the movements of the Sun, and the comfort requirements, we can sort out the design purpose and architectural proposals as in Table 3. While creating this table, Köppen's classification, which is the most widely used climate classification, was used.

Table 3. Summary Table for Relationship Between Climate and Architectural Design (prepared by author)

| CLIMATE TYPES | CLIMATE PROPERTIES | DESIGN PURPOSE / CRITERIA | ARCHITECTURAL PROPOSAL |
|---|---|---|---|
| TROPICAL (Around the Equator and expand to latitudes of 15° to 25° to the north and south) | Hot and Humid | - Maximum control of direct sunlight<br>- Reduce daylighting because of excessive heat gain | - Providing shading devices and overhangs (especially south façade)<br>- Protecting apertures and walls by trees (in East-West and South broad-leaved trees can be used)<br>-Orientation and shape of the building (east and west alignment for building plan)<br>-Arrangement of openings<br>- Arrangement of cores can be located on east and west sides to protect from low angles of the sun |
| DRY & ARID (Latitudes between 20° and 35° north and south of the Equator) | Dry and Hot | - Relief & protection from intense sunlight<br>- Reducing sunlight exposed surface<br>- Reflecting sunlight which reaches the surfaces | - Providing shading devices and overhangs<br>- Protecting surfaces by deciduous trees and plants (in East-West and South)<br>-Orientation and shape of the building<br>- Arrangement of cores can be located in east, west, and south to |

| | | | |
|---|---|---|---|
| | | | providing shading during summer<br>- Light-colored surfaces<br>- Windows should be located high on the floor |
| TEMPERATE (Mediterranean and Mild Zone) (Latitudes between 30° and 50° north and south of the Equator) | Warm in Summer and Mild in Winter or Mild in Summer and Cold in Winter | - Greater connection to inside and outside<br>- Reducing heat gains based on excessive sunlight in summer. | - Allowing daylight penetration Buffer Zones (transitional space) between exterior and interior can be used<br>- Increase Shading (East-West and South Surfaces protected by overhangs, shadings, and deciduous or evergreen trees<br>- Orientation and shape of the building<br>- Arrangement of cores can be located in the North. South side essential for solar heat gain during winter. |
| CONTINENTAL (Latitudes between 40° and 70° north and south of the Equator) | Warm or Cool in Summer and Cold in Winter | - Preventing effects of tremendous seasonal changing (especially sky conditions)<br>- Increasing heat gain based on sunlight in winter | -Orientation and shape of the building<br>- Optimizing the size of apertures (balancing between light and thermal in building envelope)<br>- No Shading Devices<br>- Arrangement of cores can be located in the center of the building to access sunlight and heat gain |

| | | | |
|---|---|---|---|
| | | | - Protecting East, West and South façades by deciduous trees and plants |
| POLAR & ALPINE (Latitudes above 70°) | Very Cold | - Reducing shading devices<br>- Maximum sunlight to maximize heat gains | - Glass surfaces but in a balanced thermal and lighting envelope<br>-Orientation and shape of the building<br>- The increasing area of South façade (exposed sun's path)<br>- Dark-colored surfaces |

As seen in the table, the control of daylight according to the climate is effective on the design. We encounter different applications in many different climate types. For example, in hot, dry climate regions, the urban texture is congested, the streets are narrow, and the buildings shade each other. Large squares are not created, and the created squares are also shaded. The purpose of these design decisions is to protect the building from intense daylight. Applications such as arcades, porticos, and iwans are widely seen, and traditional buildings in Mardin are the best examples of these practices. (see Figure 18). In cold climates, smaller windows are preferred to prevent heat loss (see Figure 19), while maximum use of the sunlight is required. Therefore, it is essential to maintain the optimum level of openings. Apertures can be constructed in larger sizes on south-facing slopes in the northern hemisphere as an architectural solution. Since it is crucial to protect from the cold in the winter and the heat in the summer in temperate climates, we observe more flexible solutions and balance between the heat and the light. In summer, buildings and streets need to be protected from the sun, while in winter, heat and light penetration into space is required with the help of surfaces. Arcades and porticos can be built like Bologna/Italy to protect from the sun in summer. (see Figure 20). In regions with a hot-humid (tropical) climate, the urban texture is generally more dispersed, and the buildings are designed so that they do not prevent each other's winds. In contrast, the surface areas of the building are reduced, and the areas in contact with sunlight are reduced in order to provide thermal comfort.

Figure 18. Mardin Houses.
(Url 16)

Figure 19. Iceland Vernacular Architecture with Small Window Size.
(Url 17)

Figure 20. Bologna Porticoes and The Iconic Arcades.
(Url 18)

As can be seen, regardless of the type of climate, the control of daylight; has always been perceived as a significant challenge due to the difficulty of establishing the balance between elements such as heat loss/gain and visual comfort. In addition to the design decisions applied for large-scale climate zones with similar characteristics mentioned in this section, design criteria are also applied for microclimates on a smaller scale. Urbanization, city design, and topography are some of them. In the next section, the effect of the city on daylight design will be examined.

#### 2.3.1.2. Landscape/Urban Design & Topography

Planning for daylight contains that impacts of neighboring are considered. Urban geometry and design, materials used on surfaces, vegetation, and topography, which we can describe neighboring effects, affect design decisions in terms of daylight.

Some arrangements are needed while creating the design, formation, and silhouette of the city. While preparing the master plans of the buildings and cities, it is taken into consideration that the buildings benefit from the sun or be protected according to their climate and location. However, with the rapid growth of cities in recent years, we have come across many structures that destroy each other in terms of access to daylight. Due to rapid/unplanned urbanization and economic reasons, some disruptions have occurred in the regulations regarding daylight. Megastructures and tall buildings have caused neighboring buildings to be in the shade and prevented them from reaching daylight. (see Figure 21). Undesirability, it has led to the formation of cold, dark, and gloomy urban streets. (Egan & Olgyay, 2002). We can see the most obvious example of daylight loss in New York City. (see Figure 22).

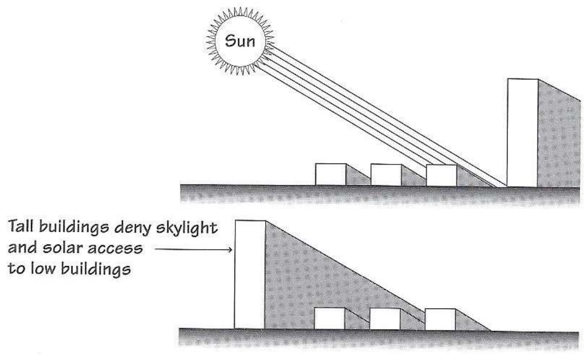



Figure 21. Obstruction of Daylight by Tall and Large Buildings.
(Egan & Olgyay, 2002, p. 101)

Figure 22. Look Building in New York.
(Url 19)

To avoid situations where buildings destroy each other and provide better natural light, stepped building form might be used to allow more daylight to surrounding buildings. In addition, the height of the building to the width of the street ratio is also effective in bringing the daylight into the interior. Increasing the height to width ratio reduces the sky visibility, increases the volumes remaining in the shadows, and therefore less sunlight reaches the space. On the contrary, decreasing the height to width ratio increases the sky view, and therefore, it allows more sunlight to reach the structure. (Bourbia & Awbi, 2004; Toudert & Mayer, 2007). Santamouris et al. define urban canyons as shallow street canyons if the height to width ratio is less than two and as a deep canyon if it is higher than two. (Santamouris et al., 1999). (see Figure 23). According to this definition, if we want to benefit more from daylight, we should prioritize shallow street canyon design and create spaces between buildings for landscaping, gardens, or parking.

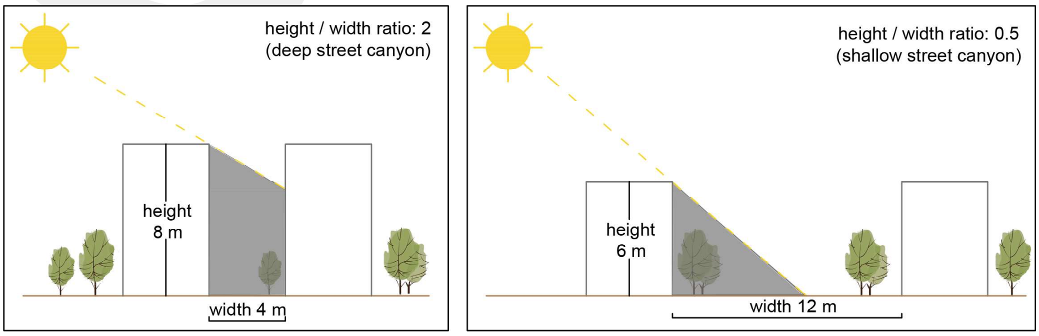



Figure 23. Height to Width Ratio for Urban Street Canyons. (prepared by author)

There are also regulations on building height and road widths in Turkey. Maximum building height and minimum road widths are determined in Article 29 of the “3030 Sayılı Kanun Kapsamı Dışında Kalan Belediyeler Tip İmar Yönetmeliği”. (Ünver, 2002). (see Table 4).

Table 4. The Relationship Between Building Height and Road Width According to the Regulation in Turkey (Ünver, 2002).

| Minimum Road Width (m) | Maximum Building Height (m) | Maximum Number of Floors |
|---|---|---|
| <7 | 6.5 | 2 |
| ≥ 7 | 9.5 | 3 |
| ≥ 9.5 | 12.5 | 4 |
| ≥ 12 | 15.5 | 5 |
| ≥ 14.5 | 18.5 | 6 |
| ≥ 17 | 21.5 | 7 |
| ≥ 19.5 | 24.5 | 8 |

In addition to the height to width ratio in the city, the materials used on urban-scale surfaces also have an effect on daylighting. The amount of sunlight reflected and absorbed by the surfaces is very important for the comfort of those living in the city. (Toudert & Mayer, 2007). The absorption and reflection capacity of light varies according to the characteristics of each material. It has been suggested that white and light-colored materials have higher reflectivity values than other materials. The materials that reflect the sun's rays the most are light-colored coatings, marble, stone floors, concrete, and asphalt, respectively. While the light-colored and smooth materials reflect the sun's rays the most, the dark-colored and rough-surfaced materials absorb the sun's rays the least. (Doulos et al., 2004). We have seen glass curtain walls a lot in recent years, which also cause daylight to spread uncontrollably. Therefore, the materials used in facades gain importance both in terms of the visual and thermal comfort of the city.

Obstacles in access to daylight are human-made, as well as elements of topography that cannot be handled by humans. Topography is difficult to handle but easy to manipulate with a few basic design criteria. Through the topography, it is possible to provide shade to a region or help the region benefit from sunlight. (Egan & Olgyay, 2002). (see Figure 24). Because of this, different strategies can be developed depending on the local climate and location. For example, in the northern hemisphere, north-facing slopes receive less sunlight than south-facing slopes. In this respect, in cold climates, it can be settled on the south side of the slope to benefit from passive heating and daylighting. In addition, the distances between the structures should be increased so that the shading does not reach extreme dimensions. On the contrary, the distances between buildings can be reduced on south-facing slopes. Thus, the potential for shading increases in hot climates. In the southern hemisphere, the opposite is true of these practices. (*Orientation | YourHome*, n.d.).

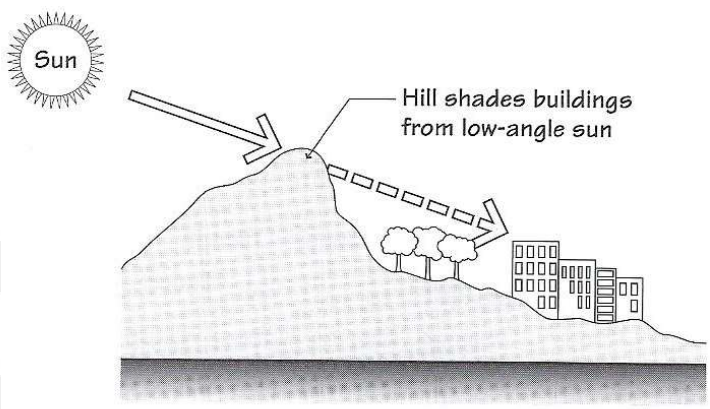



Figure 24. Obstruction Daylight by Tall and Large Buildings (Egan & Olgyay, 2002, p. 101)

It is also possible to control daylight with vegetation and external landscaping. Foliage and especially trees can be used to shade low buildings. In their simplest form, trees can be grouped as deciduous, evergreen, and conifer. Deciduous trees are more preferred as they adapt to seasonal flexibility in architectural design. From this point of view, deciduous trees, especially in the temperate zone of the northern hemisphere, are an effective way of blocking and filtering the sun in the summer season and allowing the sun to enter the winter season. (see Figures 25 and 26). In addition, using evergreen trees in summer in hot climates will be a suitable choice in terms of thermal comfort, as they absorb 75% of the solar radiation falling on the plants. (Lambers et al., 2008).

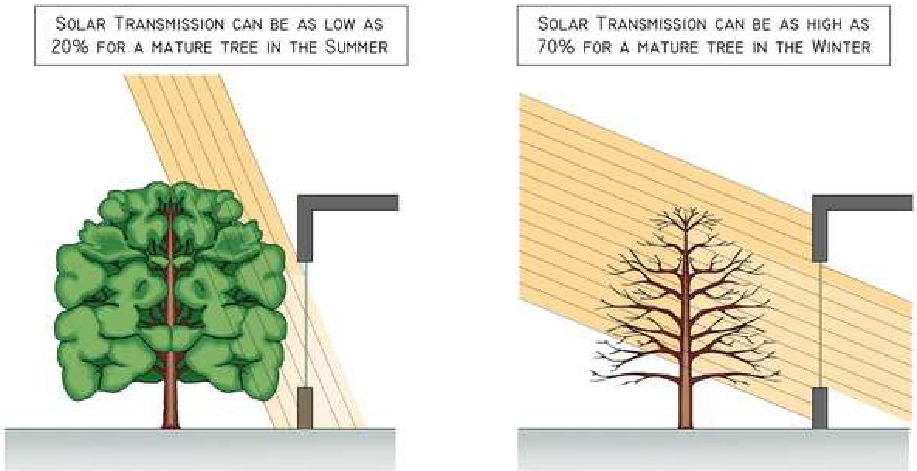



Figure 25. Vegetative Shading.
(Url 20)

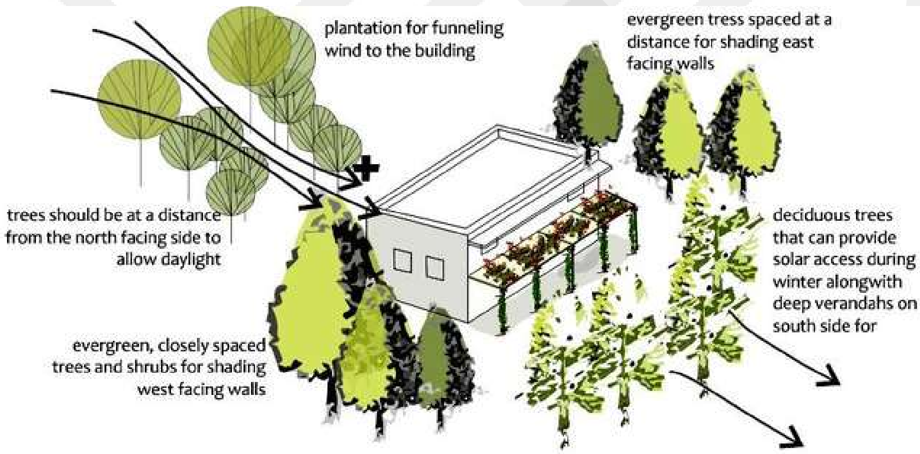



Figure 26. Vegetative Shading with Tree Species.
(Url 21)

### 2.3.1.3. Orientation

Orientation can be defined as the sitting of buildings to access solar gain and shading in proper climate and location. Building orientation and site planning are vital factors in determining the building's light-friendliness. The primary purposes of the orientation are passive heating/cooling and providing natural lighting. In this respect, depending on the climates and direction, orientation principles would be various, and each direction needs specific shading features. (Shue-Fan Yip, 1973).

The south direction is accepted as the best rotation in the northern hemisphere due to long hours of sunlight. However, quality problems and glare in space may occur due to direct sunlight. Sun path is higher in summer and lowers in winter. Therefore, south façades need to control the light. On the south façades, horizontal long-wide overhang and lateral shading are necessary. The shading elements should be designed to allow the sun to enter the interior for passive heat gain in winter and prevent excessive heat gain in summer. (*The Carbon Neutral Design Project | Society of Building Science Educators | American Institute of Architects - Carbon Neutral Design Strategies*, n.d.). Diagrams of the basic shading strategy for the south are shown in Figure 27.

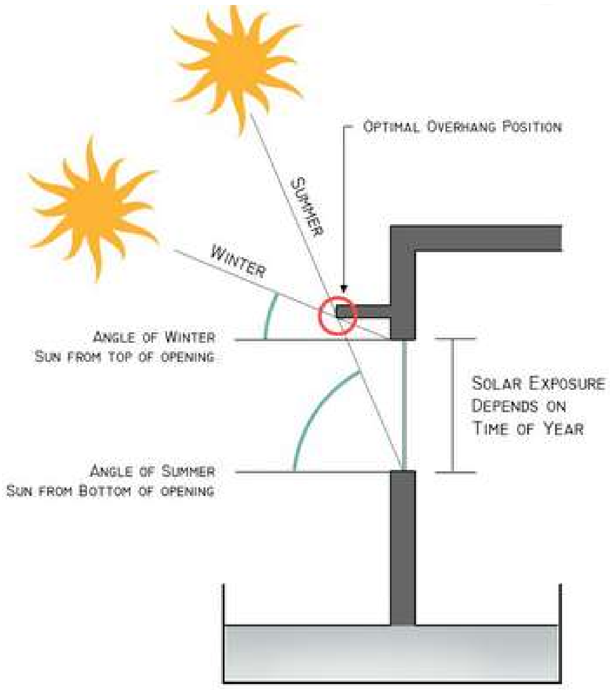



Figure 27. Basic Shading Strategy for a South Elevation.
(Url 22)

The second-best rotation is north. Since the angle of the sun is low, shading devices do not work correctly. (*The Carbon Neutral Design Project | Society of Building Science Educators | American Institute of Architects - Carbon Neutral Design Strategies*, n.d.). Only diffused light without the risk of glare is received from this direction. Thus, problems may arise in the quantity of lighting. On the contrary, uniform and soft daylight might be used effectively in architectural design. (see in Figure 28.)

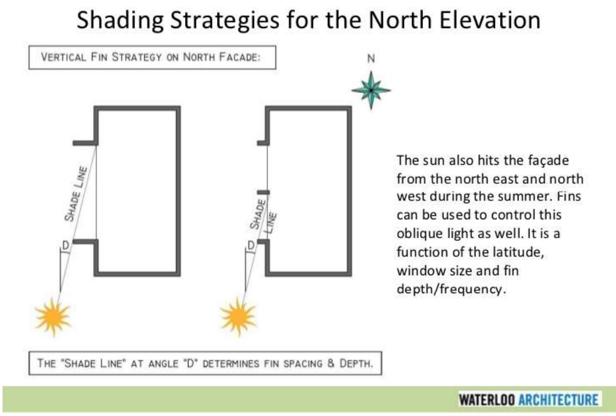



Figure 28. Shading Strategies for the North Elevation.
(Url 23)

The east and the west elevations are the worst rotation for orientation. The amount of light is variable due to sunlight for only half of the day. As depending on this, there is both quality and quantity problem of light. For instance, it is critical to solving the heat and glare problem in the late afternoon sun in the west direction. Also, reaching the maximum amount of sunlight in summer, not in winter, causes unsatisfied thermal and visual comfort. Both elevations are challenging to shade by using architectural elements. (*The Carbon Neutral Design Project | Society of Building Science Educators | American Institute of Architects - Carbon Neutral Design Strategies*, n.d.). Unfortunately, horizontal overhangs are useless to prevent light on the east and the west elevations because of lower angles of light. (see Figure 29). Shading devices such as verticle fins/egg-crates should be used on this side of the building. (see Figure 30).

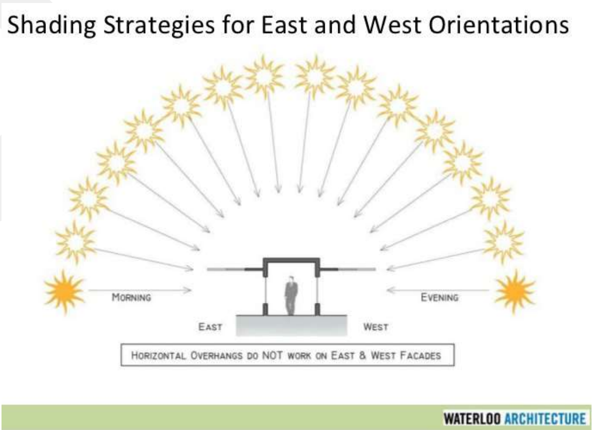



Figure 29. Shading Issues with East and West Facades.
(Url 24)

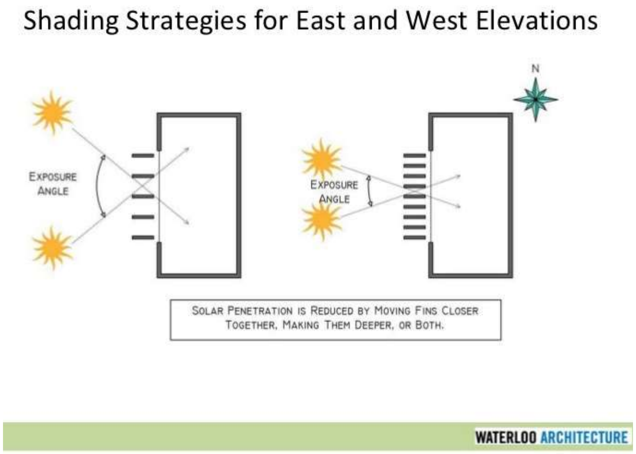



Figure 30. Shading Strategies for East and West Elevation.
(Url 25)

Generally, in the orientation, structures with a long axis extending in the east-west direction are preferred. This is because the sunlight in the north and south directions is easily controlled, and maximum light is provided. (Egan & Olgyay, 2002, p. 104).

### 2.3.2. Engineering and Scientific Development

Throughout history, engineering and scientific advancement have directly influenced how civilizations build their structures. Through technological developments, applications that can be described as architectural revolutions have emerged. The quality and quantity of daylight taken into the interior have also changed depending on these developments. Sometimes, with the product and strengthening of the structure, wide openings can be constructed, and adequate natural light can be taken inside. Sometimes, various difficulties were experienced in terms of design, and darker spaces were created. It would be correct to examine the technological innovations that contribute to the advancement of the search for architectural meaning over time, as the development in materials and structure in terms of factors affecting natural lighting.

#### 2.3.2.1.Development in Material Industry

The effect of materials on the spread of natural light into the interior is an undeniable fact. In parallel with developing materials such as adobe, wood, concrete, steel, natural stone, glass, plastic, and PVC, more adequate and controlled ingress of light was taken into the interior compared to the past.

It is challenging to establish various openings in floor, wall, and ceiling systems created with bricks, stones, blocks, dried mud, even non-reinforced concrete, so it is not easy to allow light to penetrate the interior. Since these materials have minimum tensile strength and moderate compressive strength (Macdonald, 2001), it is nearly impossible to create openings with building systems constructed with these materials.

*Concrete*, like stone and brick, has a minimum tensile strength and medium compressive strength. In this respect, there is not much difference between unreinforced concrete and masonry structure systems. However, concrete has many advantages compared to stone. For example, since it is in a semi-liquid form, it can be shaped as desired, allowing effective connections to be made during the casting process, thus increasing the strength of the structure. Again, a reinforcing bar made of steel can increase its strength to the semi-liquid concrete. Concrete, which is resistant to compressive stresses on its own, increases its resistance to both compressive and tensile stresses with the addition of steel reinforcement. On account of this application, its resistance against both tensile and compressive forces and bending effects is increased. Since reinforced concrete is a strong material, it is used in skeleton frame systems, long-span structures, and high-rise buildings that require slender sections and strength. (Macdonald, 2001). In addition to all these, with the technology developed in recent years, the concrete's massive and heavy appearance in the space has been alleviated by the fiber optics placed in it. (Tokyay, 2010). It has turned into a translucent material, just like natural stones such as onyx, so that progress has been made in the name of transparency, and it has become able to carry a little light into the interior. In addition, it did not compromise on strength conditions. Through this flexibility and technological advances in the construction process, the concrete and reinforced concrete have allowed natural light to enter the interiors.

*Natural stones* are one of the materials that allow light to circulate the interior place. Some natural stone types, such as onyx and alabaster, can transmit light in a translucent way. With the onyx panels used on the outer wall of the City Council building in Spain, designed by Madridejos and Sancho, controlled sunlight is taken into the interior. In addition, onyx creates a rich atmosphere in the interior with its textures and patterns. (see Figure 31). With the developing and changing design method, architects use not only translucent natural stone but also design opaque stones with different construction techniques to allow light into the interior. For example, natural stones placed in the steel mesh carcass without mortar carry the light into the interior by diffusing the spaces between them. Herzog's California Dominus Winery is an excellent example of this. (see Figure 32). By means of the detail applied on the wall, a dim interior was created, and proper air conditioning was also provided for the winery. (Tokyay, 2010).

Figure 31. Town Hall in Madrid by Madridejos and Sancho.
(Url 26)

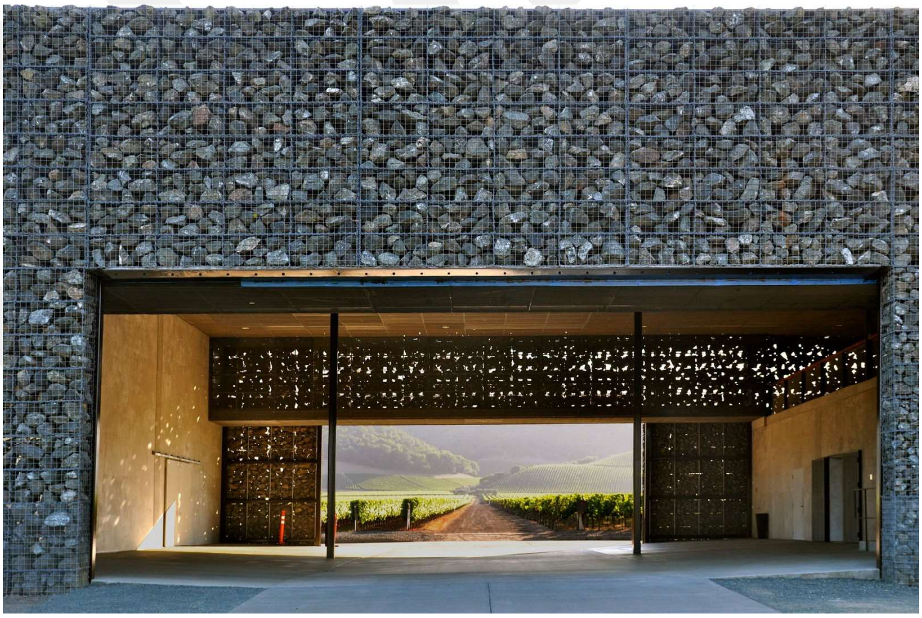


Figure 32. Herzog's California Dominus Winery.
(Url 27)

*Steel* is one of the materials that shape the 19th and 20th centuries. While it can pass through large openings with slender sections, it can also be used to construct tall structures with a skeleton system. Steel has put an end to the tradition of cumbersome masonry, thus increasing the possibility of opening spaces on the facades. (Tokyay, 2010). As a result, more daylight can be taken into the interior.

*Glass* is the material that can transmit natural light the best compared to other materials. The glass strengthens the visual relationship between indoor and outdoor. Its ability to pass and reflect daylight in different ways is a crucial tool in adding quality to architectural design. While transmitting the light to the interior, it also has the potential to change this light and has the effect of defining the atmosphere. For example, colored stained glass has been incredibly effective in creating the atmosphere of religious buildings such as churches.

We see that glass was first used in building windows during the Byzantine period. (Tokyay, 2010, p. 44). Later, it covered the windows of early churches. Afterward, it became more transparent, and the light transmittance increased. Parallel to light transmittance, it also made significant contributions to the emergence of the concept of visual permeability. Besides providing natural light, it also became a bridge between nature and interior space. As a result, eye-level windows that we see in Renaissance residential architecture have appeared. (see Figure 33). We see the same practice in mosques designed by Mimar Sinan. There are window systems designed stepped on the façade of Sinan Pasha Mosque in Beşiktaş. At the top level, there are rhythmic and arched windows placed on the drum of the dome. Then there are round designed windows, arched windows, and at the bottom, there are rectangular windows at eye level. (Erzen, 2008; Tokyay, 2010). (see Figures 34 and 35). Again, Sinan has various applications to control daylight. For instance, he applied different applications on the inside and outside-facing of the windows that he built on the ground level. We see on the outside latticework made of iron, a wooden frame, and a window shutter in the interior. With this design, both flexibilities in use are provided, and problems such as security are avoided.

Figure 33. Villa La Rotonda in Italy was designed by Andrea Palladio. (Url 28)

Figure 34. Sinan Pasha Mosque by Architect Sinan. (Url 29)

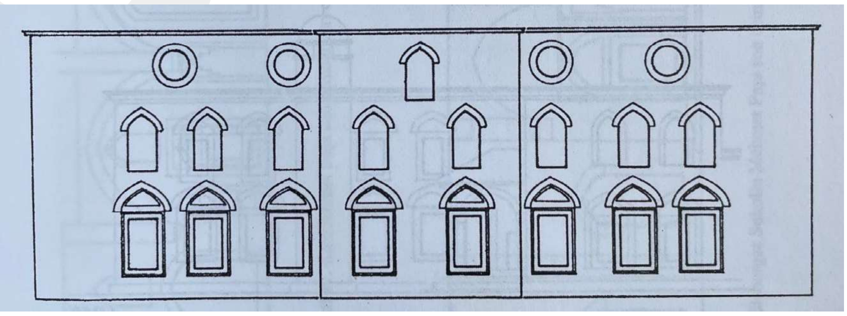


Figure 35. Sinan Pasha Mosque Façade. (Qiblah Direction) (Erzen, 2008, p. 91)

For example, at the end of the 18th century, glass production reached its most advanced stage in later periods. Parallel to this, the illuminance levels in the spaces have increased. The best example of this is the Crystal Palace, designed for the London Grand Fair in 1851. (see Figure36).

Figure 36. The Crystal Palace in London in 1851.
(Url 30)

When we classify contemporary glass products used in architecture and industrial design according to their forms, we can exemplify flat glass, curved glass, and glass brick blocks. According to application purposes, solar and climate-controlled products (reflective, low E coated glasses, insulating glass panels, spandrel glasses); can classify them as building safety and security-oriented glass products (fire-resistant glasses, tempered glasses, laminated glasses, smart glasses, etc.) and glass products for decoration (stained glass, mirror glass, textured glass, etc.). (Tokyay, 2010). All these glass types were born due to their needs over time.

In recent years, the importance of energy-efficient design and increased environmental awareness have impacted the glass industry, and glasses that adapt to climatic conditions have begun to be produced. In addition, it has been noticed that the light intensity varies during the day and according to the season. Various measures have been taken to prevent this and to provide the desired comfort. In this direction, smart glasses that control sunlight have appeared. Electrochromic, photochromic, and thermochromic glasses are some of them. Electrochromic glasses are the group that gives the best results for dynamic sunlight control. The desired level of darkness in the glasses is provided by electrical voltage. The electrical voltage changes the optical properties of the glass, making it reflective glass. Photochromic glasses turn light or dark under the influence of UV rays. On the other hand, thermochromic glasses change their color, and therefore, their light transmission changes according to heat and sun conditions. When glasses reach a specific temperature, they change their features from transparent to translucent. As can be seen, these smart glasses allow the passage of light according to the desired situation and environmental conditions and can control the light.

In addition to solutions that control sunlight, there are innovative and mechanical solutions for spaces that do not reach sunlight. We can count sunlight light pipe systems, which can be applied in different ways, among mechanical solutions. Sunlight pipe system delivers the rays it receives from the sky to places where natural light cannot reach. Light collectors, reflectors, lenses, and diffusers work together in this system. More homogeneous, diffused light is provided to the volumes that use more electrical energy, and the energy and cost of artificial lighting are reduced. More sustainable and environmentally friendly, these solar light tube systems can be implemented in various ways. For example, in industrial facilities, a suspended ceiling system can be applied as a tubular skylight (see Figure 37) and in multi-story buildings integrated with vertical axes (see Figures 38 and 39). Parallel to all these innovative solutions, the use of daylight in the interior has increased.

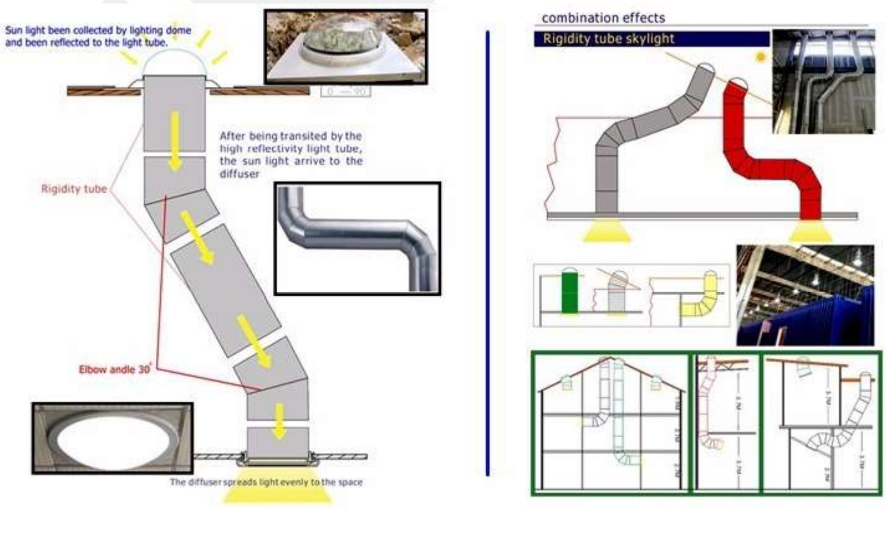



Figure 37. Tubular Skylight.
(Url 31)

Figure 38. Solar Light Pipe Application.
(Url 32)

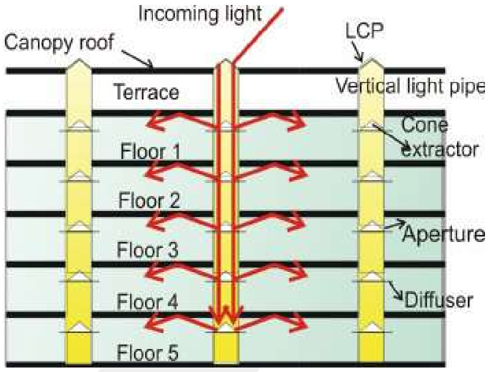



Figure 39. Vertical Light Pipe Application.
(Garcia-hansen & Edmonds, 2003)

In addition to all these, it is possible to use glass not only as a material covering apertures such as windows but also with glass bricks and systems in which glass and steel are designed together. Fuksas' Fiera di Milano is an excellent example of this application. (see Figure 40). As a result, it is possible to use glass as a window covering material and for insulation and decorative purposes.

Figure 40. The New Milan Trade Fair by Fuksas.
(Url 33)

With innovative approaches, it is possible to receive sunlight in a controlled manner with *plastic materials*. Alternatives have been created with materials such as *polycarbonate sheets* developed in recent years. This material warms up quickly and is easy to shape and color. Polycarbonate sheets are usually in the form of translucent plastic, but they might also be used by vitrification it with various processes. In this respect, it makes the design easier by providing flexibility in architecture. Polycarbonate materials are used in roof coverings, windows, facades, food establishments where glass is not used, but daylight is desired in factories. (see Figures 41 and 42). (Tokyay, 2010). With applications such as PVC (Polyvinyl chloride) stretch ceilings, the structures have become lighter, and more transparent spaces have emerged.

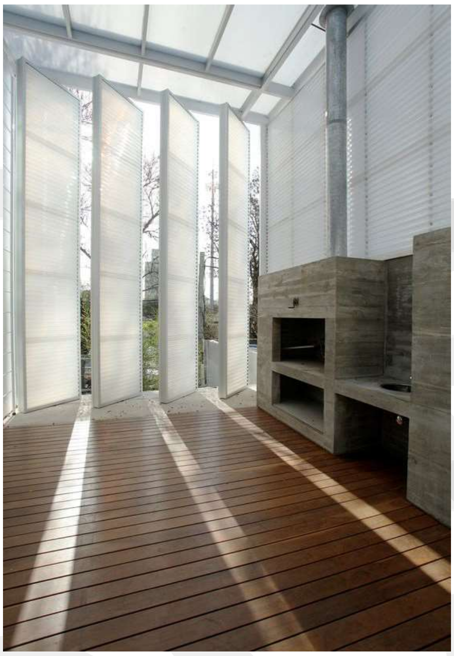


Figure 41. The Movable Panels are Composed by a Double Skin of Rough Polycarbonate.
(Url 34)

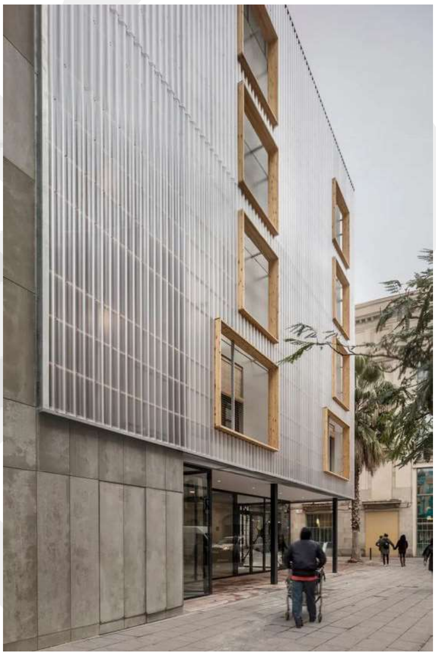


Figure 42. Façade Design with Polycarbonate Material.
(Url 35)

In summary, , the shaping of the spaces and the ability to use all these materials are related to the construction technique used. Construction techniques and developments in this field will be explained in detail in the next chapter, structural development.

#### 2.3.2.2. Structural Development

As Louis Kahn said, when you decide on a structure, you also decide on the light, which clearly expresses the effect of the structure on natural lighting. It would not be wrong to say that structural systems control where and how light travels to space with Kahn's contribution.

Structural elements and systems are affected by the nature of the material from which they are made and how they are put together. In order to better understand this, in this section, structural systems and elements that directly affect natural lighting will be examined. Masonry structure systems, reinforced concrete structural systems, steel and timber frame structural systems, and related techniques (such as vault, arch, dome, buttress, etc.) are the main systems to be examined.

Masonry structure is a type of load-bearing wall structure. This means all of the building's loads pass through walls to the ground. Due to this reason, without walls, this type of building cannot be constructed. In addition, due to the large stresses within the brick or stone walls, the high load-bearing structure is limited, and the type of wall has a small window to wall ratio. It is not very easy for daylight to reach the spaces built with the masonry structure for all these reasons. In the early time of architectural history, when stone and masonry load-bearing wall constructions were prevalent, it is difficult to mention the presence of light where the structure is. (Charleson, 2014).

With the discovery of concrete in the Roman Period, which we can also call the *Concrete Revolution*, and its high resistance to compressive stresses, it became possible to build stronger structures. Architectural elements such as arches, domes, and vaults were developed. Although these building elements look different from each other, they come together to form the other. Moreover, they designed oculus-type spaces in the middle of the dome, as we saw in the Pantheon. (see Figure 43). In this way, they were able to get natural light into the interior and reduced the dome's weight. The walls that are supposed to support the dome are thicker since the flying buttress system has not been invented yet, so it is challenging to construct a space. In the Romanesque Period, the walls were thickly built to carry the load of the vault, which was used as a roof covering element. However, with the development of the cross vault after the cradle vault, the thickness of the walls decreased. The cross vault is formed by the cross-joining of two barrel vaults on a rectangular area, and the load distribution is transferred to the floor through the columns at the four corners. (see Figure 44). In this way, it is possible to construct the area under the arches as a space or a window.

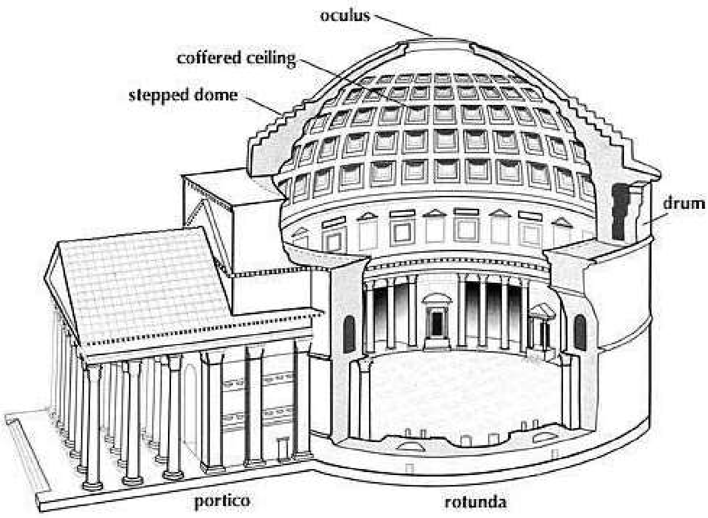



Figure 43. The illustration of Oculus.
(Url 36)

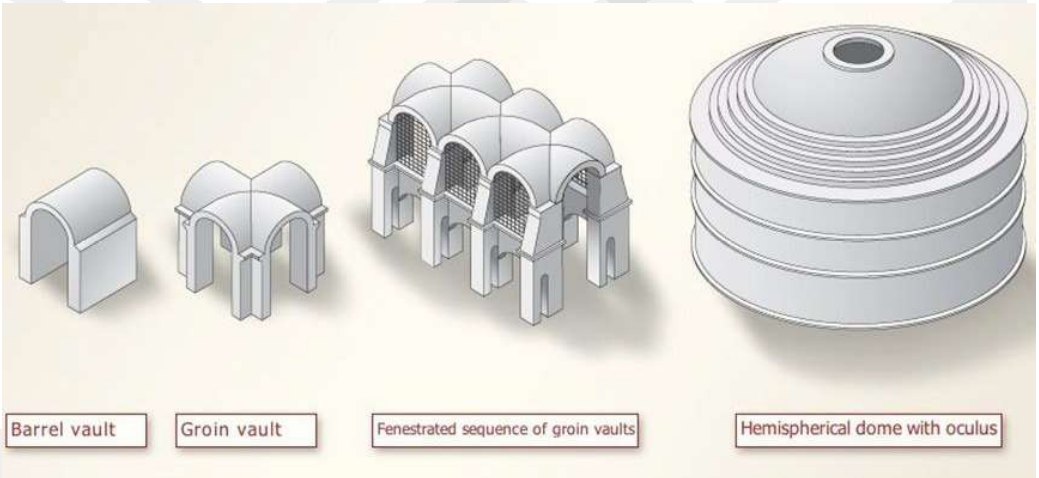



Figure 44. The Roman Architectural Revolution.
(Url 37)

Significant developments have been experienced in the absorption of daylight into the interior with Gothic architecture. By favour of the revolution in structure and building techniques, the Gothic period became one of the milestones of the concept of transparency in architecture. The load-bearing systems constructed with pointed arch, dome, buttress, flying buttress, and rib vault helped the structure be lighter and thus more flexible. These structural elements (pointed arch, rib vault, dome) created a high interior space; loads are concentrated at specific points. Through the flying buttresses applied at these points, support was provided in the opposite direction; as a result, the walls were saved from collapsing. (Charleson, 2014). Thus, with the help of rib vaults and flying buttresses, loads were transferred to the ground, the walls were thinned, and the structure was raised. However, more windows were made, and more daylight entered the interior. These narrow and long windows illuminated the interiors of tall churches. These significant innovations that emerged in the Gothic Period were an essential indicator of the transition from masonry to skeleton systems. Figure 45 is an explanatory illustration of the structural element in the Gothic period.

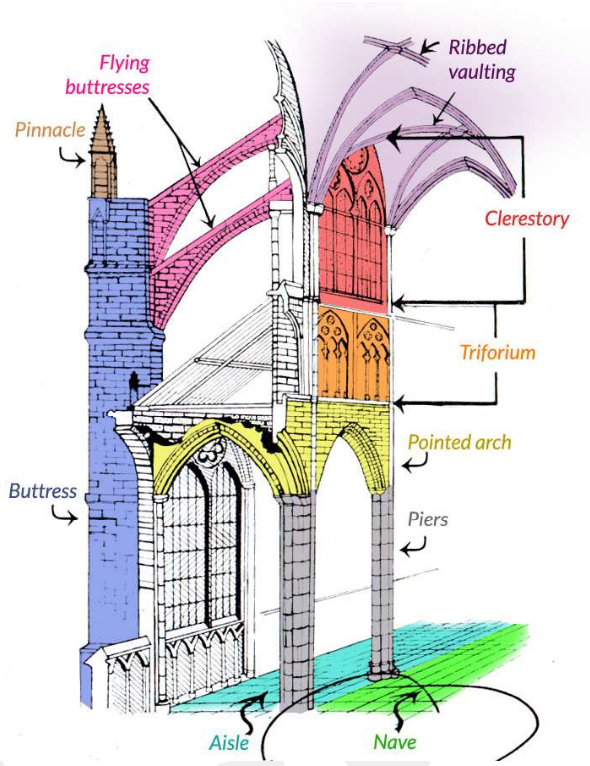



Figure 45. Structural Elements in Gothic Period.
(Url 38)

Natural light has been tried to be used with various uses of the dome. For instance, in the Renaissance period, the central space was attempted to be illuminated with the cupola located at the top of the dome. Again, Mimar Sinan tried to increase the effect of light in terms of quality and quantity by trying various innovations in dome design. Architect Sinan also used drums used to reduce the impact of tensile stresses on the base of large domes. However, he emptied this area by opening arched window spaces where tensile stresses would occur and tried to prevent this problem. For example, he designed the windows with niche applications made to the dome in Selimiye Mosque. The excess load on the pulley was reduced through this application, and a healing technique was used in terms of natural lighting. These niche areas above the windows cause the light to reflect more vertically, thus reducing the dark places of the dome. With the daylight, the dome appears lighter, higher, and wider. (Güngör, n.d.). In Figure 46, Güngör illustrates this point clearly.

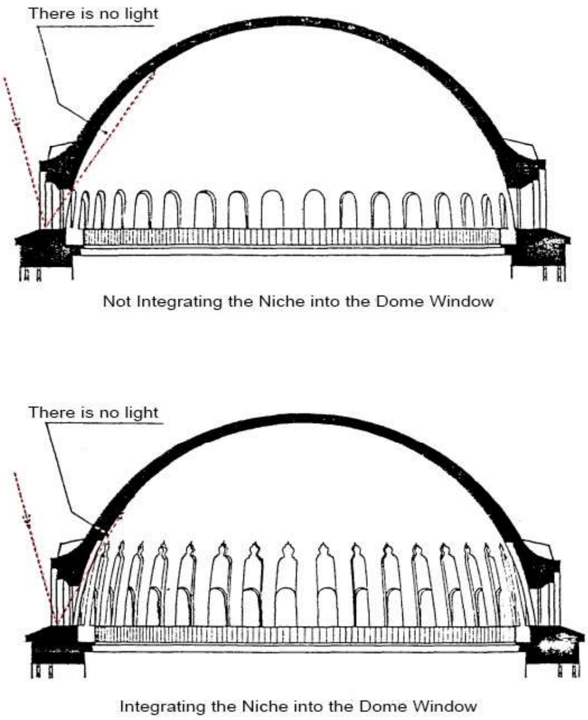



Figure 46. Dome of Selimiye Mosque.
(Güngör, n.d., p. 145)

With the development of reinforced concrete systems compared to masonry systems, resistance to both tensile and compressive forces has increased. In this way, lighter structure systems have emerged. Shells that can be designed easier and more flexibly for the designer have emerged. By creating three-dimensional plastic forms, slits are opened on it as desired, and the sunlight is redirected. Le Corbusier's Notre Dame du Ronchamp (see Figure 10), Tadao Ando's Chuch of Light (see Figure 7), and Zaha Hadid’s Phaeno Science Centre (see Figure 47) can be an example of these buildings where the traditional window concept has been destroyed.

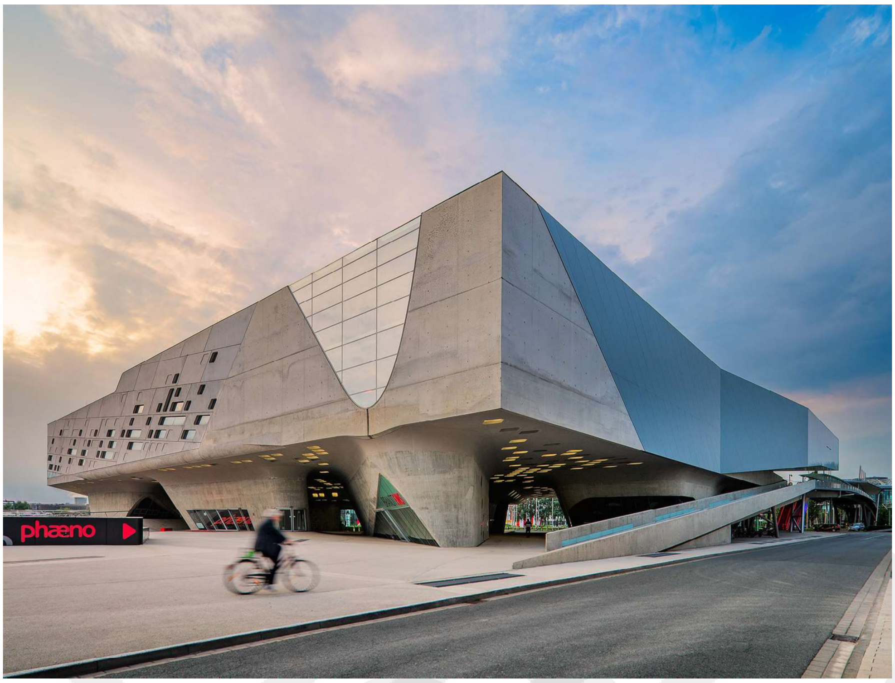



Figure 47. Phaeno Science Centre by Zaha Hadid.
(Url 39)

In addition to the reinforced concrete system, wooden systems also help to lighten the structure by forming frames. It has been used a lot in the past to provide transparency in civil and religious facilities. In addition to the transparency that it provides, it is frequently used in places where reinforced concrete structures are not suitable, depending on the climate. It pioneered the formation of reinforced concrete and steel carcass systems centuries ago in the process of ensuring transparency.

Some structural elements are more convenient than others in terms of transmitting light to the interior. For example, steel-framed constructions can be easily used in buildings that require a high amount of sunlight and transparency. On the other hand, it is possible to manipulate, filter, and modify the daylight with the flexible design of the steel frames. Depending on the way the elements come together, the intensity and amount of daylight change. For example, in Santiago Calatrava's L'Umbracle structure, many and spaced elements act like filters. (Charleson, 2014). (see Figure 48). Reducing the structural elements' dimensions is also a solution for easy penetration of light into the interior. Steel has equal and high strength against tensile and compressive stresses. It resists bending moment, axial stress, and axial compression. Although its density is high, the ratio of strength to weight is also high. (Macdonald, 2001). Thus, light appearance structure and thin section might be produced, and the dimensions of the elements are reduced. (Macdonald, 2001).

Figure 48. L'Umbracle by Santiago Calatrava's.
(Url 40)

As a general observation, we can summarize the influence of the structural development on the daylight in the historical process as in Figure 49. Building envelopes have evolved towards lighter structures from solid masses owing to the developing technology. More transparent facades and shells have begun to be designed compared to the past. Brighter and more spacious environments have replaced dark interiors.

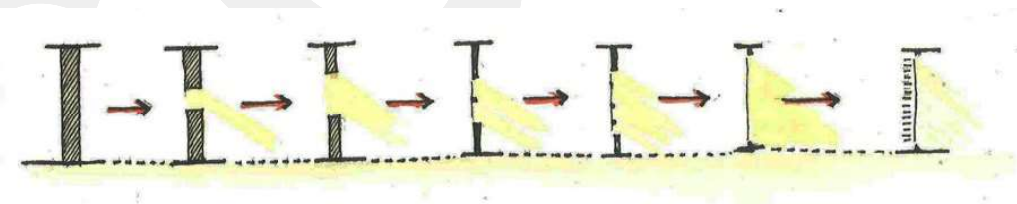


Figure 49. The Evolution of the Use of Light in Architecture.
(Url 41)

In the light of all this information, we see that the use of natural light in the historical process is directly proportional to the structure's efficiency. As the efficiency of the structure increases, more flexible workspaces are offered to the designers. The illustration shown in Figure 50 has grouped the structural systems according to their efficiency level. As can be seen, while non-form active elements at the top of the table are low in terms of structural efficiency, efficiency increases towards the bottom of the table. (Macdonald, 2001). Taking into account such tables, we can select the optimum specification structural systems required for daylighting.

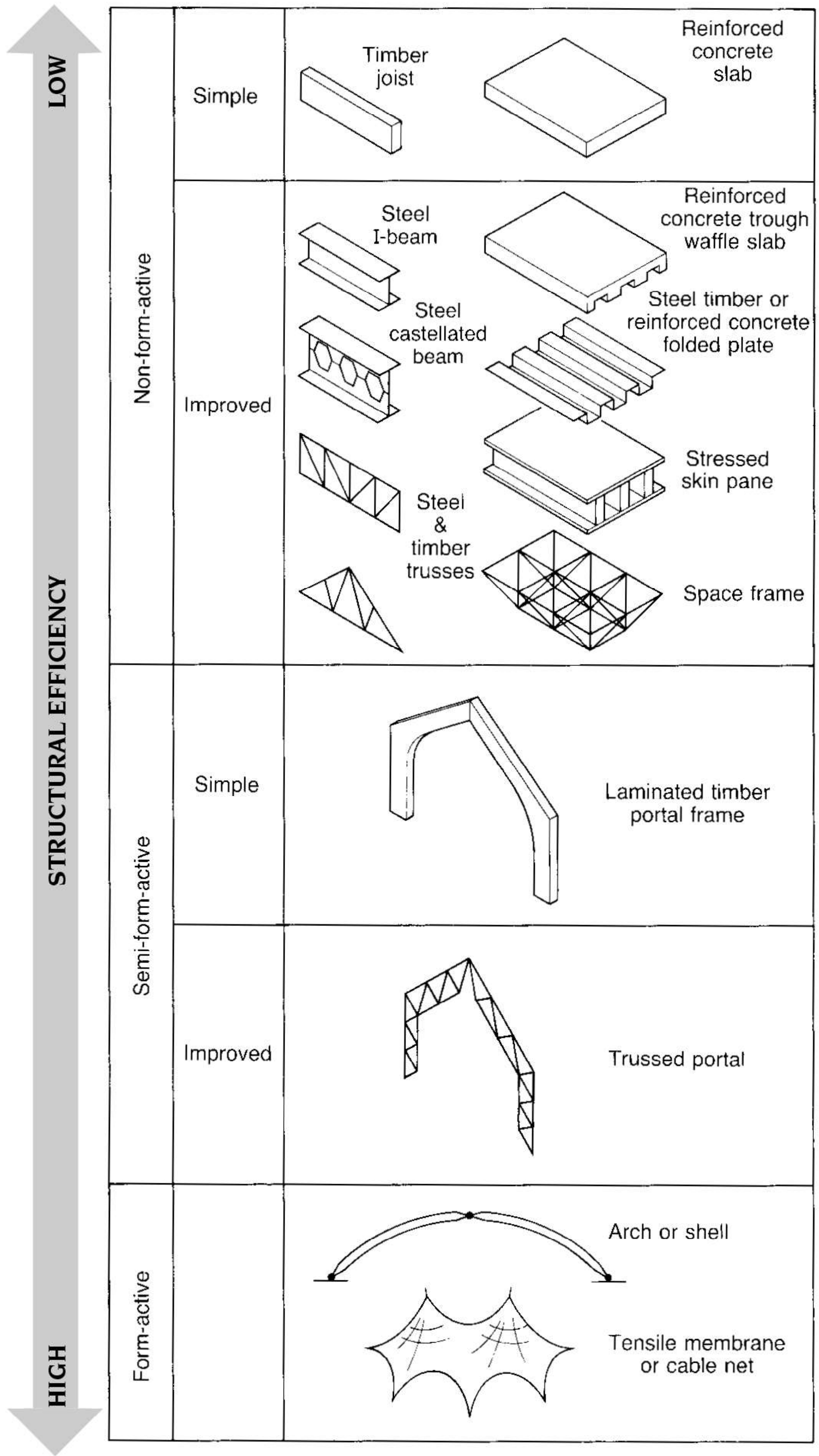



Figure 50. Structural Systems According to their Efficiency Level.
(Macdonald, 2001, p. 46)

### 2.3.3. Social and Cultural Factors

Social and cultural factors are critical elements that impact the thoughts, feelings, and behaviors in society. Social and cultural factors, including values and norms, religion and belief system, lifestyle, education, power, and economy, are influential in shaping the spaces we live. Therefore, social and cultural factors play a significant role in architecture. In this respect, architectural structures can be used as a tool to read the culture and beliefs of the period in which they were built. Architecture also used light as a tool, particularly natural light.

Natural light increased its influence in architecture until artificial lighting developed. Throughout history, many civilizations and cultures have directly affected the use of light in different ways. For example, the only opening in the prehistoric Çatal Huyuk settlement structures consists of a gap in the roof. Since the structural systems were not yet mature in the prehistoric period and provided needs such as defense, the openings in the buildings could not be constructed on a large scale. This reveals that the primitive period buildings did not benefit much from natural lighting.

In later civilizations, we encounter many times that the light-shadow dialectic symbolizes God. Ra, known as the Sun God in Ancient Egypt, and Osiris, known as the God of the underworld, can be given as the first examples of this symbolism. They made the first examples of clerestory applications to create emotion in the temples they built for their gods.

The metaphor of light attributed to God in the ancient Roman civilization exists with the oculus at the top of the Pantheon. (Fitoz & Berkin, 2007). In the Byzantine period, when the monotheistic belief systems were passed to polytheistic religions, it reinforced the meaning attributed to light. Natural light has become a part of the religious world. This is supported by Paolo Urbano, who specializes in the lighting of holy places, stating that light is the main supporting element for worship. (Kart, 2006). The embodiment of heaven on earth is depicted with light. The sunlight filtering in from the dome of Hagia Sophia is a unique example of this.

With the beginning of scholastic philosophy in the Medieval Ages, works that require creativity, such as science, sculpture, and literature, which developed considerably in Ancient Greece and Ancient Rome, were prevented. (Tokyay, 2010). When religion and scholastic thought prevailed, the dialectic of light and shadow is frequently encountered in this period. Despite the declines in fields such as science and literature, there were revolutionary structural developments in Gothic architecture.

The main reason for this situation is also due to religious reasons. According to Durakan, due to the image of God's greatness prevailing in Christianity, it is aimed to feel the respect for God in the church interiors, and more dim and overwhelming spaces have been constructed. (Durukan, 2017). (see Figure 51). In this respect, light has been described as a concept coming from God, and to support this, light has been penetrated from the upper levels to the space. Ünver also stated that the windows in churches usually construct at a very high level from the floor. (Ünver, 2000). The stained glass used in these windows also helped the light change color as it filtered into the interior and supported the formation of the atmosphere. (Fitoz & Berkin, 2014). As can be seen, natural light in churches has created a spiritual sense rather than providing functional needs.

Figure 51. Milan Cathedral (Duomo di Milano).
(Url 42)

When we examine Islamic culture, we encounter a different approach from churches. The depiction of a sacred image is not supported in the religion of Islam. In particular, the creation of images of God's and prophets' images is prohibited. Therefore, the sanctity of the space has been tried to be expressed in different ways, and more emphasis has been given to the use of abstract symbols. An impressive atmosphere is designed with the help of natural light.

The number of windows in mosques is higher than in churches, and light is received from different elevations and directions. (Durukan, 2017; Ünver, 2000). Light has spread to the interior from both the ground, middle, and upper levels. Therefore, the natural light in mosques has a different effect on the space than in churches. Functional needs such as reading the Qur'an were provided through the light received from the windows built on the ground level. Light is taken from the scale of the person praying to the interior. The light from the upper elevations (for example, from the dome drum) also created the concept of the heavenly lighted dome, thus reinforcing the existence of God. Through the light taken from different elevations, besides creating bright and spacious interiors, the idea of God being everywhere in the religion of Islam is supported. (Durukan, 2017). (see Figure 52). Under favour of the variety of openings, unlike churches, the connection with the outside world is not broken in mosques. As can be understood, all these differences in architectural approaches are shaped by social and cultural norms.

Figure 52. Interior of The Süleymaniye Mosque.
(Url 43)

Different religions and cultures affect the openings on the façade as well as the building orientations. As Barut points out, the Synagogues face the city of Jerusalem, and the Mosques face the city of Mecca. Churches are also built to be located on the East-West axis. (Barut, 2016).

The different geographies in which people live affect the culture and architectural formation. For example, illumination has become a problem in Northern countries, where sunlight sometimes exists all day and sometimes inexistence all day. Scandinavian put the light at the center of their daily activities and adopted a lifestyle accordingly. Therefore, daylight was among the main requirements for space in

Scandinavian culture. They tried to create a cozy environment with light. In the formation of architectural masses, the element that allows the light into the interior space is used rather than the shading devices. Thus, a relaxing habitat was created using natural light. Finnish architect Aalto has also made designs in such a way that the light is most appropriate for the interior. He tried to eliminate the physiological and psychological needs with daylight and developed the atmosphere based on sunlight. This creating warm atmosphere role, culturally attributed to the light, is often seen in Scandinavian countries. Among the reasons for this are social and cultural factors, as well as the impact of *environmental factors* (in title 2.3.1) described in the previous section is undeniable. As a result, there is an interdependent interaction between the cultures and lifestyles and the geography which is lived.

When we consider the Japanese architecture located in another geography, we encounter concepts such as integration with nature, simplicity, and transparency. Therefore, calmer interiors have been designed, and an unpretentious atmosphere with soft and diffused light has been created. The light can penetrate as diffuse into the interior with the shoji panels. (see Figure 53). In Japanese architecture, solid and void are considered equally valuable, so daylight is diffused into the interior spaces, while shadows are created simultaneously. In this way, the movement of daylight in the space is provided. (Tokyay, 2010).

Figure 53. Shoji panels are used in Japanese Architecture.
(Url 44)

As can be seen, daylight, used in different ways in many cultures and religions, continued to be used as an architectural tool in the modern and later periods. The events in the social memory of the period played a role in determining the architectural style, and the light helped this. For example, Libeskind designed the Jewish Museum using forms and daylight in an allegorical way to make people feel the pain of the Holocaust. (see Figure 54). In this museum in Berlin, spaces and circulation elements designed integrated with natural light adopted a symbolic expression.

Figure 54. Jewish Museum in Berlin.
(Url 45)

In conclusion; Elements such as religion, belief systems, lifestyle, geography, philosophy, and values come together and shape society's social and cultural structure. In this section, the use of light in the interior of social and cultural factors has been tried to be explained with examples. As can be analyzed, environmental factors and engineering and scientific factors generally affect light in a functional dimension. In contrast, social and cultural factors are more effective in the symbolic use of light. Social and cultural factors affect us to construct the space through an allegoric expression. This evokes the direct relationship of light with meaning. The finding of meaning in space has been discussed in the previous section, which is "*2.2. The Semantic Characteristics of Natural Light*".

After examining the factors affecting the use of light in the interior, it is necessary to explore the ways of accepting daylight into the space. Because where and how natural light comes from is also very effective in forming the atmosphere in space.

## 2.4. TYPOLOGIC APPROACH TO DAYLIGHTING

In general, the methods of providing daylight into the space have an extended historical background, which is constructed with openings. These apertures, which are determined according to certain factors, appear with various typological approaches. For example, Egan mentions three primary forms for bringing daylight indoors. These are *top lighting, side lighting,* and *atriums*.

*Top lighting*

Light coming from above are types of openings that are widely used in architecture as skylight and clerestories. Top lighting was used in important buildings in architectural history, such as the Pantheon. Top lighting causes fewer glare problems than side lighting. In addition, overhead lighting provides more light than side lighting. (Egan & Olgyay, 2002).

Horizontally designed skylights perform best in cloudy sky conditions. (Egan & Olgyay, 2002). Because when the sun's rays come at a right angle, heat and light gain are high. This is a disturbing situation in terms of thermal and visual comfort.

With the vertically designed top lighting such as clerestories, daylight can be controlled independently from the orientation of the building. For example, east-facing windows for morning light and south-facing windows in the northern hemisphere for more light can be designed. (Egan & Olgyay, 2002).

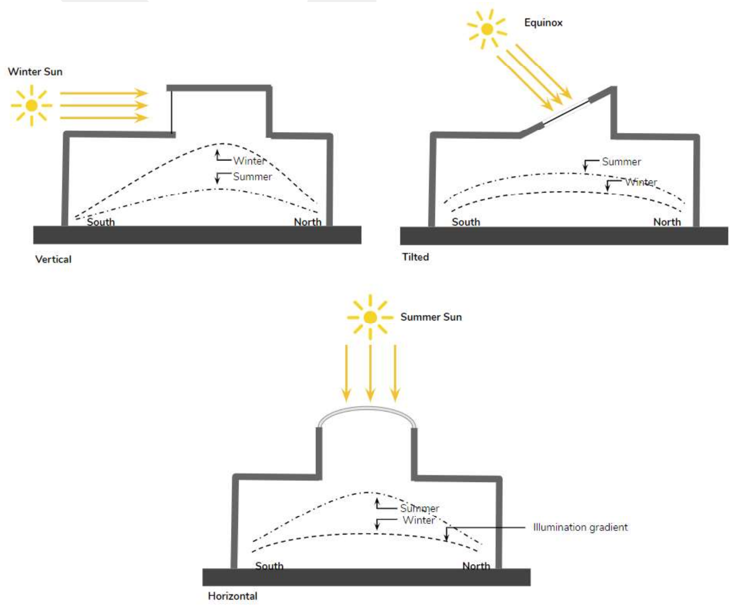



Figure 55. Types of Top Lighting.
(Url 46)

*Side lighting*

We can define *side lighting* in the simplest way as the openings created on the outer vertical sidewalls of the building. The location of the gaps in the walls directly affects the distribution of light. (Egan & Olgyay, 2002). The location of the opening spaces, which we can divide as the *upper section, middle section*, and *lower sections*, contains different features. (see Figure 56).

The windows in the *upper section* are located above eye level and provide the best light distribution on cloudy days. When properly designed, it accepts multiple levels of sunlight without glare. When it is designed without shading devices, the risk of glare is high. Although the *middle section* is the most preferred type, they are not used on sunny days due to the field of view. Since there can be a risk of glare problems, balancing it with various elements is necessary. The windows in the *lower section* are very effective homogeneously light distribution, and the risk of glare is at the lowest level. In practice, all these varieties are combined, and the best result is tried to be achieved. (Egan & Olgyay, 2002).

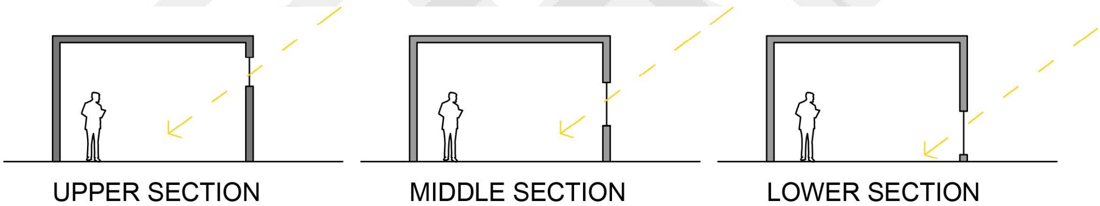



Figure 56. Side lighting Sections. (prepared by author)

*Atrium*

It is difficult for light to reach the floor in large and narrow spaces. For such places, *atrium* application can be applied. Atrium is formed by combining top lighting and side lighting, creating a central space. It is an essential strategy in illuminating shared central areas. When designed effectively, atriums will balance thermal comfort and lighting needs. (Egan & Olgyay, 2002). They can be configured in various ways and strategies to supply the lighting needs and provide thermal comfort. For example, it might be used integrated with mirrors, reflective devices, clerestory openings, and stepped construction to achieve maximum illumination. (see Figures 57, 58, and 59).

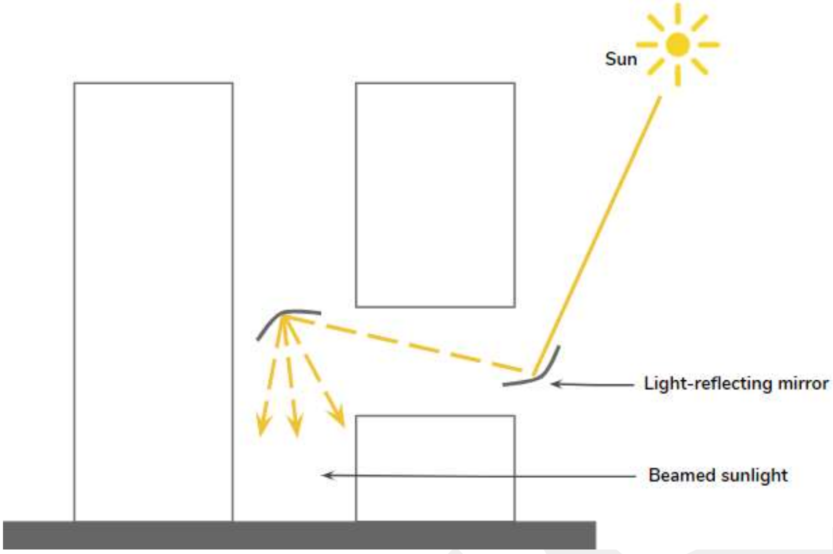



Figure 57. Atrium Design with Reflective Devices and Mirrors.
(Url 47)

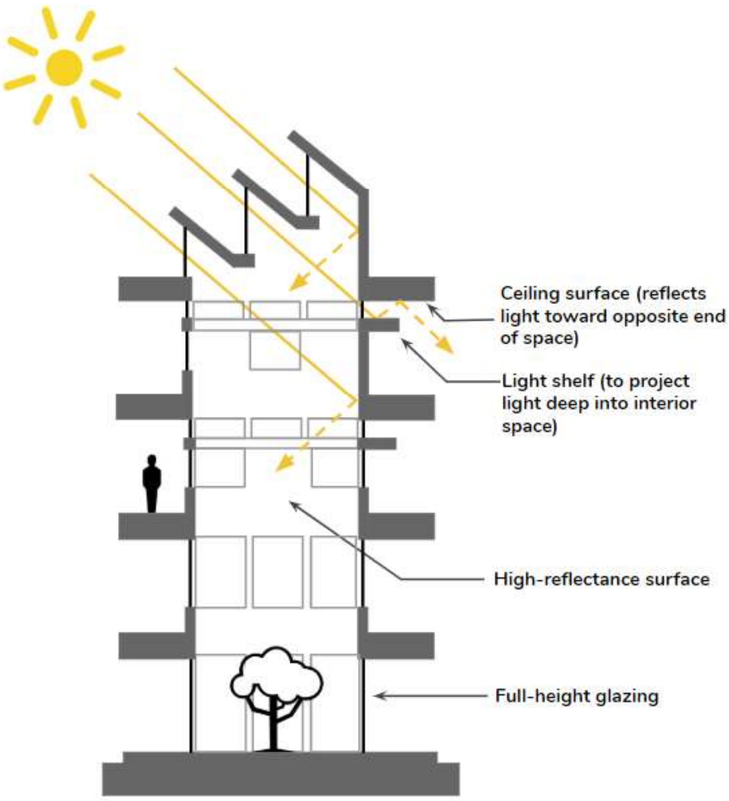



Figure 58. Atrium Design with Clerestory Openings and Reflectance Surface.
(Url 48)

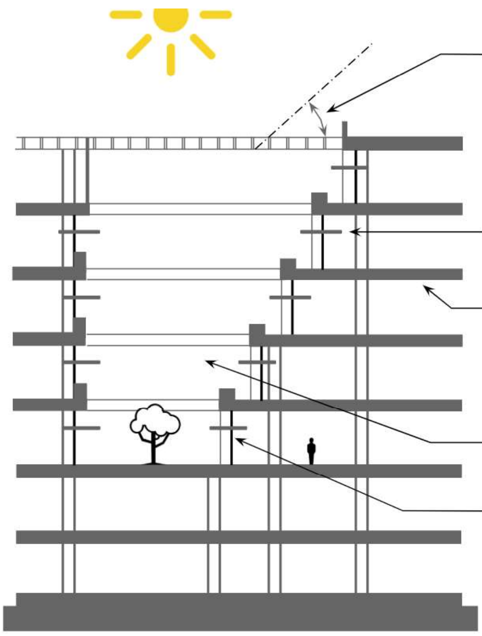
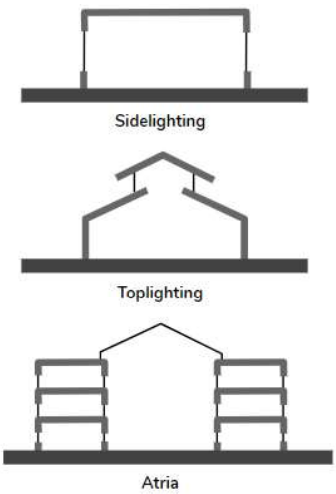



Figure 59. Atrium Design with Stepped Structure.
(Url 49)

When we examine all these aperture systems in terms of views of nature, glare potential, depth of light penetration, and height limitations, we reach a short conclusion as in Figure 60.




| Views of nature and people | Glare potential | Depth of light penetration | Height limitations |
|---|---|---|---|
| Yes | High | Limited by ceiling height | None |
| No (limited) | Low | Excellent (uniform distribution) | Yes (single story only) |
| Yes | Low | Excellent (Limited by aspect ratio of atria) | None |

Figure 60. Chart Created by Egan and Olgyay to Compare the Forms of Admitting Natural Light to the Space.
(Egan & Olgyay, 2002, p. 107)

# CHAPTER III

## THE HISTORICAL ANALYSIS AND ASSESSMENT ON THE FACTORS THAT AFFECT THRESHOLDS

From primitive times to the present, light and architecture have continued on their way by completing each other. The way of using natural light has transparently explained the information about civilizations throughout the process. In Chapter II, analysis was conducted to collect this information. When we come to Chapter III, the data collected in the previous chapter will be evaluated according to the determined criteria and thresholds. At this point, it is necessary to explain why we examine the thresholds while making evaluations in the historical process. There are various definitions of *threshold* in the literature. For example, Benjamin and Tiedermann state that a threshold refers to a zone, not a boundary. (Benjamin & Tiedemann, 1999). Also, the Longman Dictionary defines the concept of threshold as "the level at which something starts to happen or have an effect" and "the beginning of a new and significant event or development". (*Longman Dictionary of Contemporary English | LDOCE*, n.d.). In this respect, it would not be wrong to explain the critical events, innovations, and developments that have affected natural lighting design throughout history with the concept of the threshold.

In the literature review, it was seen that not only environmental, technological and cultural factors but also the lighting typology should be examined depending on all these. Therefore, information about the natural lighting typology used in the evaluated period was also tried to be given.

It is thought that reading this whole development according to the criteria (environmental factors, engineering and scientific developments, social and cultural factors) and thresholds determined in Chapter II is beneficial for understanding and interpreting modern ages.

## 3.1. THE REACHING DAYLIGHT INTO SPACE IN THE HISTORICAL PERSPECTIVE

In this section, natural light reading according to environmental factors, engineering and scientific factors, social and cultural factors, and natural lighting typology in the historical process will be presented together with summary tables.

### 3.1.1. Prehistoric Times (12.0000 BC to 3500 BC)

Humankind has produced various solutions for the need for shelter since its existence. It is accepted that the first people used the dark interiors of the caves for various rituals, while they spent most of their time in the cave entrance areas where natural light could penetrate. As Baker and Steemers mentioned, the light was often associated with the need for security at that time. (Baker & Steemers, 2002).

After people left the caves and settled down, they began to follow the cycles of nature and began to shape their lives with light. They had described the sun as a divine power. For instance, the Stonehenge megaliths pointed out light as the source of life, and people here followed the solstice, equinox, eclipse, and celestial events.

In the settlements of Çatal Huyuk and Mesopotamian architecture, a single opening was usually constructed, and the space was entered from here. Therefore, the light would also penetrate the area through a single gap. Figures 61 and 62 are good illustrations of using space and the typical house layout in Çatal Huyuk. Many openings could not be built, both for protection reasons and the lack of technological developments. Çatal Huyuk houses were entered through the upper hole, and the Ziggurat temples in Mesopotamia were entered through a single door. The light reaching the interior from the entrance on a specific date symbolized the beginning of agriculture for them. (Kostof, 1995).

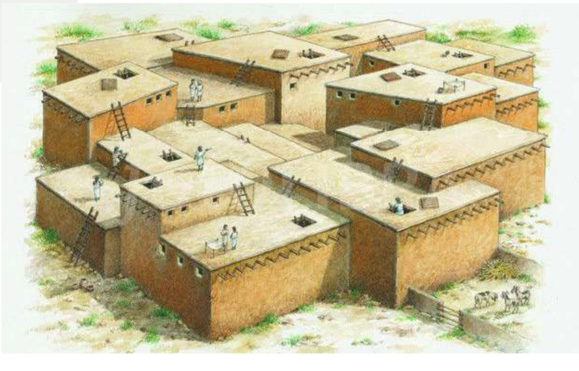


Figure 61. Illustration of Çatal Huyuk.
(Url 50)

Figure 62. A Reconstruction Showing the Use of Space and the Layout of a Typical House. Illustration by Kathryn Killackey.
(Url 51)

The habitats were different in each of the ancient historical periods. It is seen that social factors are also considered while arranging suitable places according to natural conditions and environmental factors. In Table 5, the factors affecting natural light reaching the interior space are classified, and the prominent characteristics of the period are given together.

Table 5. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Prehistoric Times. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -There is no conscious approach in the field of climate, orientation, and topography. However, they have to construct their shelter according to environmental conditions. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -They could not construct with many openings because of limited technology.<br>-They entered the Çatal Höyük houses through the upper hole for protection. Small openings under the eaves illuminated the interior.<br>-Top lighting was used. |
| **SOCIAL & CULTURAL FACTORS** | -Meaning of light links with safety, warmth, and community. They used top lighting for safety reasons.<br>-They shaped their lives according to sunlight and attributed divine powers to sunlight. |

### 3.1.2. Ancient Egypt (3050 BC to 30 BC)

Egypt is a region with abundant sunlight and a warm climate. For this reason, openings were minimized against overheating and glare. Limits in structural developments also affect this. Aperture sizes are limited by the spanning ability of stone, with most of them being square-headed and covered with massive lintels.

Different strategies used in the Great Temple of Ammon, such as clerestories and roof slits, provided light deep into the interior. (Moore, 1985). The Great Temple of Amun, with its hypo-style hall, consists of densely organized columns. (see Figure 63). These columns provided ornament light illumination.

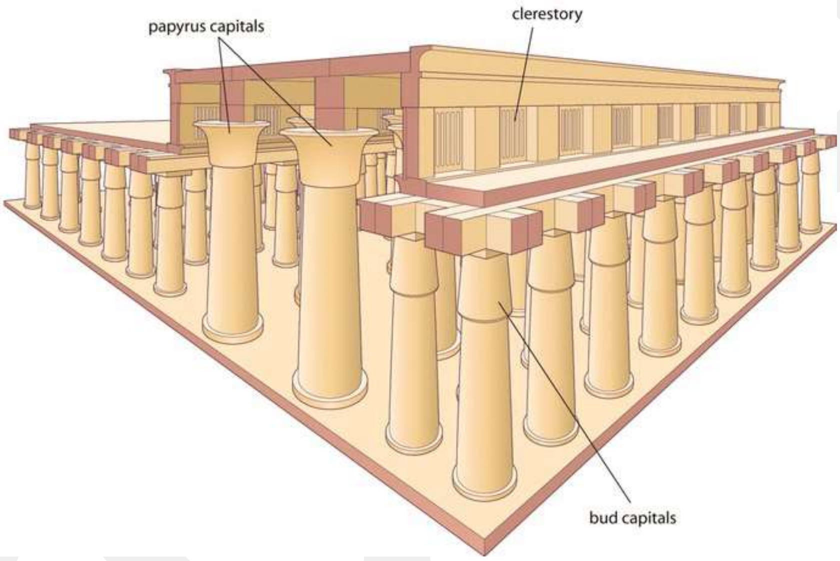



Figure 63. The illustration of the Great Temple of Ammon.
(Url 52)

The importance of the light emitted by the sun, which was attributed to the divine in ancient Egypt, is indisputable. In the pyramids and some temples, depending on the sun's position at specific times of the year, the sun's rays are penetrated indoors. It has a sacred ritual character, which is remarkable in terms of the relationship between natural light and architecture. Table 6 indicates the factors and practices that affect daylight during the Ancient Egyptian period.

Table 6. Summary Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Ancient Egypt. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -The dimensions of the wall and roof openings are minimized, as it receives much natural light and has a warm climate.<br>-Bringing direct sunlight can create some problems such as glare in this region. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -The spanning ability of the materials such as stone, mudbrick, and clay limited the aperture sizes.<br>-Clerestories and courtyards that allowed for deep plans also enhanced the daylight to the interior.<br>-Thick walls served to soften and diffuse the sunlight through multiple reflections.<br>-Different opening types were used, such as roof slits, clerestories, small windows, and entrance doors.<br>-Thick walls and several columns used in the building provide diffusion of daylighting.<br>-Side lighting in the upper section and top lighting was used. |
| **SOCIAL & CULTURAL FACTORS** | -They used light to create feelings. Clerestory was added to their buildings to create ornamented lighting.<br>-Also, Ra is the ancient Egyptian deity of the sun. He was the god of the sun, order, kings, and the sky. |

### 3.1.3. Ancient Greece (700 BC to 146 BC)

The Parthenon is the most appropriate example to understand the Greek treatment of light and architecture. Parthenon is a post-beam structure constructed by masonry technique. (see Figure 64). The temple is oriented to the east to point out the importance of daylight. The light in the Parthenon only came in through the main door but completely illuminated the gilded statue of the goddess Athena. The spanning limitation resulted in small apertures, and therefore the illumination was characterized by the light beam. (Chepchumba, 2013).

Figure 64. The Acropolis of Athens: The Parthenon.
(Url 53)

The ancient Greeks recognized the significance of light and created the solar zones of their cities to provide solar access to all houses for lighting and heating. The city of Olynthusis was a city that considering solar zoning. Streets in Olynthus were built orthogonally and designed to run in the east-west direction, allowing houses to be built with dominantly southern exposure. (Bronin, 2009). (see Figure65). Building heights were limited to let all dwellings have enough natural light and avoid shading. In addition, courtyards and porticos could reach the daylight. (see Figure 66). The walls around the courtyard provided shade according to the sun's angles during the day or allowed sunlight to enter the interior.


Figure 65. The City Plan of Olynthus.
(Url 54)

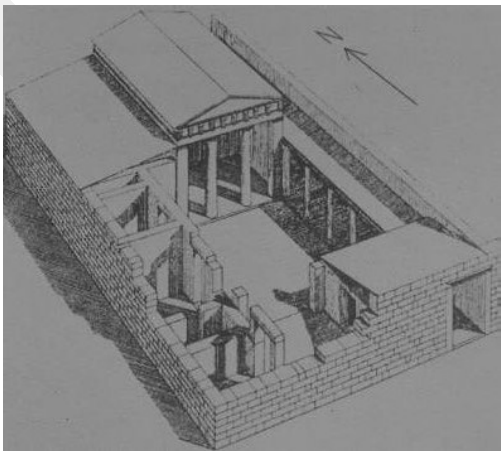


Figure 66. The illustration of Greek House.
(Url 55)

In Table 7, the factors affecting natural light reaching the interior space are classified, and the prominent characteristics of the period are given together.

Table 7. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of Ancient Greece. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -The city of Greek was constructed orthogonally, with all dwellings facing south. Greek houses were positions in the towns with a north-south orientation because these are attached buildings with a long axis extending in the west and east. Thus, taking advantages of passive solar heating and lighting are provided.<br>-Building heights were limited to give all residents enough natural light and avoid excessive shading.<br>-Solar access to all houses for lighting and heating is important.<br>-With the portico and courtyard, they could reach daylight. Surrounding walls in the courtyard allowed the sunlight and created a shadow according to time.<br>-In the City of Olympia, the buildings especially temples, generally were oriented to the long axis extending in the west and east. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -They had small windows and minimal opening.<br>-Clerestories and skylight applications were used to reach daylight.<br>-In general, top lighting and side lighting in the upper section were used. Atrium lighting can be mentioned as courtyards are used in some houses. |
| **SOCIAL & CULTURAL FACTORS** | -The light had more of a spiritual meaning for early Greeks.<br>-Evidence suggests that the layout and orientation of Greek temples were aligned to the position of the stars and planets in the Universe.<br>-The outer perspective was more significant than the inner view. Buildings did not have many apertures to let light through.<br>-The most famous monument of Ancient Greece is the Parthenon. Light at the Parthenon only penetrated the interior through the main door and skylight to illuminate the statue of their gods. |

### 3.1.4. Ancient Rome (200 BC to 476 AD)

The Pantheon is an excellent example from the old world, showing how the Romans consciously designed the space and using light to enhance the space. As the sunlight moves through the area, it illuminates the figures and statues under the Pantheon's oculus. (see Figure 67). Dramatic sunlight is provided by oculus. The oculus represents the connection between heaven and earth. (Moore, 1985).

They could create an arch, vault, dome, and stone wall structures through advancements in technology. Thus, it was possible to capture more light.

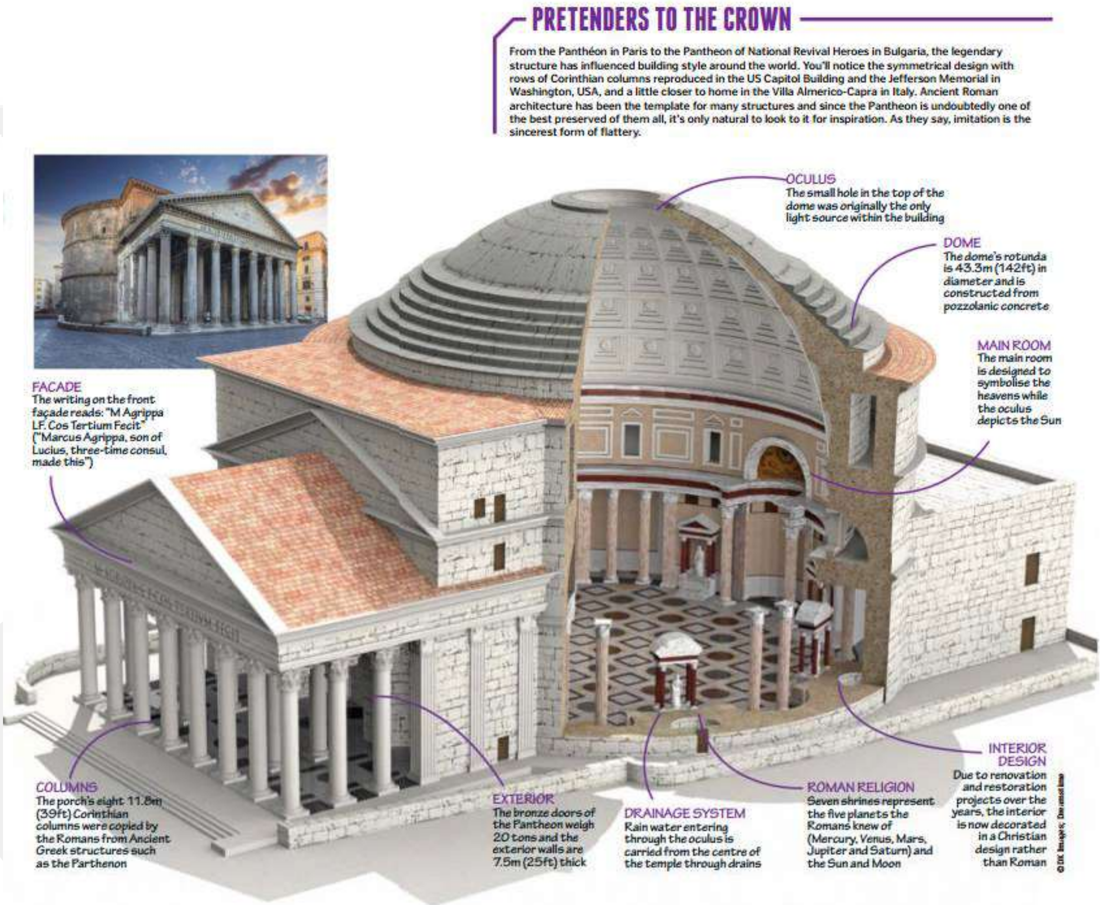



Figure 67. The Illustration of Pantheon.
(Url 56)

Engineering and scientific factors were the main factors affecting the interior of light in Ancient Rome. In this period, Table 8 shows us the factors and practices that affect daylight during Ancient Rome.

Table 8. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Ancient Rome. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -Religious factors and scientific developments were more important than environmental factors. But the first application of glazing allowed light in a while keeping out cold winds and rain.<br>-The rectilinear building plan with the east and west axis provided light gain from the South façade during winter. However, this application cannot be mentioned for the positioning of the Pantheon. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -The Romans, who made significant progress in architecture, achieved brighter spaces by using domes, arches, and vaults. Their technological advancements created the possibility of greater openings that could capture more light.<br>-Skylights and clerestories were also used in this period and admit more light into deep interiors.<br>-Slit in the Pantheon's dome with large spanning provides light to the interior.<br>-In addition, we can see the first application of glazing.<br>- Generally, the top lighting strategy was used. |
| **SOCIAL & CULTURAL FACTORS** | -Through the oculus, dramatic sunlight was provided to the interior. The oculus represents the connection between heaven and earth. |

### 3.1.5. Early Christianity (Before 325 to 800)

The basilica-type building was used for religious functions by making additions. (see Figure 68). Instead of the vault, they used timber trusses during this period. Thus, the opportunity is provided for the clerestory window. (Chepchumba, 2013). They did not illuminate the interior appropriately because these clerestory windows were not constructed on a large scale. The influencing factors and the characteristics of the period are presented in Table 9.

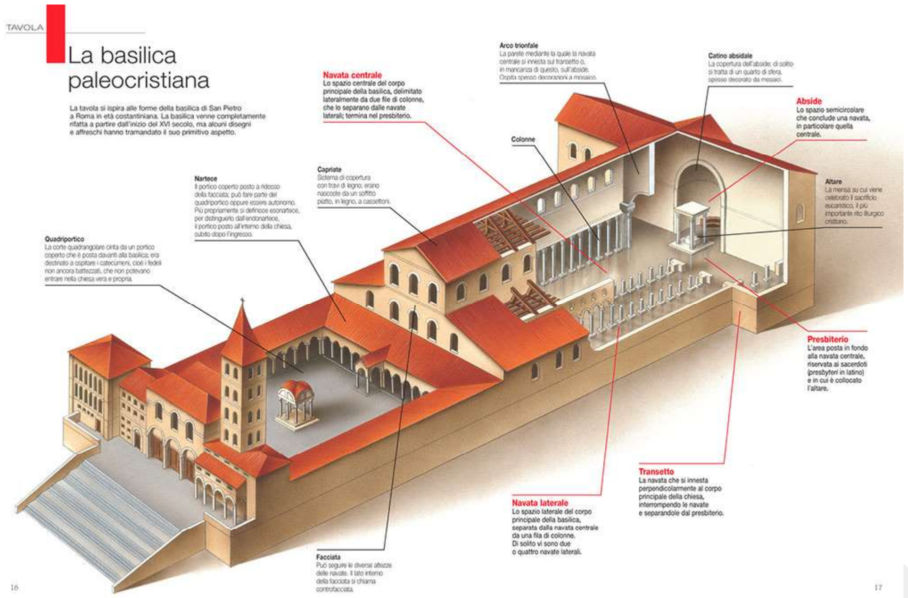



Figure 68. The Axonometric illustration of Early Christianity Church.
(Url 57)

Table 9. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Early Christianity. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -The building was elongated along the East and West provided greater exposure to the South which was important during winter.<br>Religious factors and scientific developments were more important than environmental factors. |
| **ENGINEERING & SCIENTIFIC FACTORS** | - Instead of Roman vaulting techniques, they used timber trusses. This causes the sloped roof to allow clerestory windows, but clerestories became smaller and reduced interior illumination.<br>-Both top and side lighting strategies were used. |
| **SOCIAL & CULTURAL FACTORS** | -The Basilica type of building was adopted with little change for religious functions.<br>-Clerestories became smaller and reduced interior illumination. The mystical atmosphere was created in sacred space with this application.<br>-The apse where the altar was located was surrounded by high-level windows to attract attention. |

### 3.1.6. Byzantine (330 to 1453)

Byzantine architecture and culture were influenced by Christianity. With this effect, a new architectural style was created. Churches have used the natural light in space to highlight the concept of heaven. The architecture of the Byzantine period is, most significantly, distinct through the use of the dome supported at four corners that covered a rectangular floor plan. (Chepchumba, 2013). This structure resulted in a central dome, surrounded by secondary spaces covered by half domes called pendentives. (Moore, 1985).

In particular, Christian churches in Eastern Byzantine culture used gilded structures and mosaic applications to improve the relationship between architecture and light. These applications contributed to the atmosphere of the space by reflecting and refracting the light. The best example of using mosaics is Hagia Sophia, which was dedicated to the Roman Emperor Justinian. (see Figure 69). In addition to this sparkling interior, the dome of Hagia Sophia with windows created dynamic lighting in the interior.

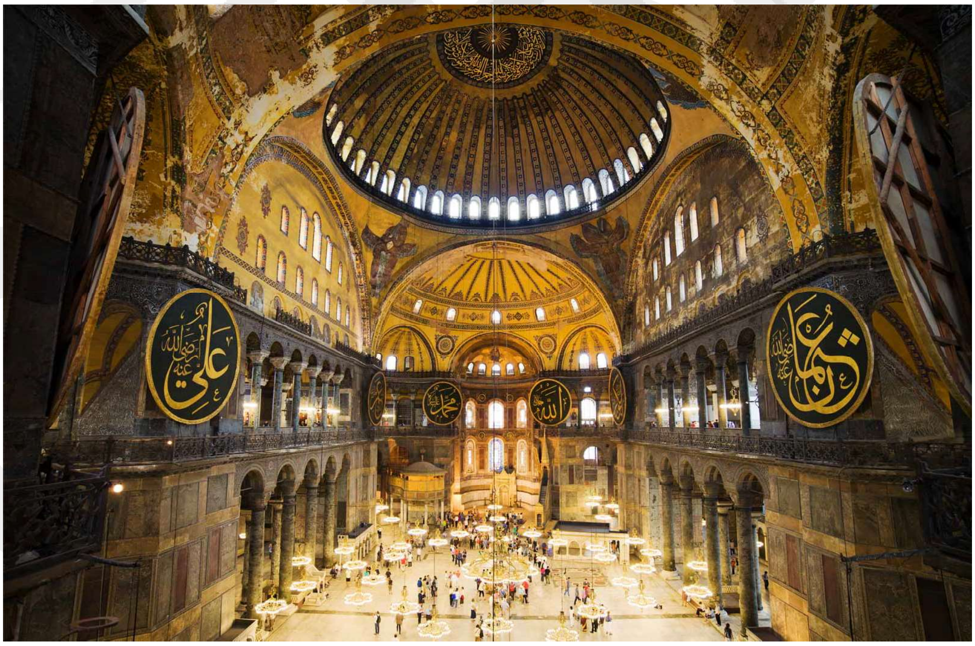


Figure 69. Interior view of Hagia Sophia.
(Url 58)

As seen in this period, the phenomenon of religion, which can be evaluated under social and cultural factors, played a role in forming light in space. Table 10 indicates the factors and practices that affect daylight during the Byzantine period.

Table 10. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Byzantine. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -Environmental factors remain in the background. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -Dome with supported at four corners in order to cover a rectangular floor plan is used This type of dome is called pendentive. This structure resulted in a central dome, surrounded by secondary spaces covered by half domes.<br>-The light penetrated through grouped small windows in the base of the dome. This created an illusion. The dome appears to float above the structure.<br>-Openings are semicircular headed with either horse-shoe or arched openings seen.<br>-Both side lighting in the upper section and top lighting strategy was used. |
| **SOCIAL & CULTURAL FACTORS** | -The Christian churches of the period focused on developing the close relationship between architecture and light through the use of mosaic applications and gilded structures to create splendid interior lighting effects. They emphasized the concept of heaven with the use of light in the interior. |

### 3.1.7. Romanesque (800 to 1200)

In this period, Roman vaults and arches were used instead of the wooden beams used in the Early Christian period. Thick walls made of stone were also used in Romanesque architecture. The reasons for this were to protect them from fire, make them last forever, and carry heavy roofs covered with vaults. The spaces were dark and shadowy due to the vaults, heavy masonry walls, and the materials they used in the interior.

One of the primary means of construction in the Romanesque period was the circular arch. The use of such construction methods allowed for windows to be punctured more quickly, but they remained relatively small due to thick bearing walls. Windows remained relatively small with clear glazing in Italy, while slightly larger in France than in northern Europe. (Chepchumba, 2013). Rose windows application began to appear during this period. (see Figure 70). Also, combined with the eastern light coming from the windows behind the altar, light in Romanesque architecture created a lighting strategy used in Christian buildings. In Table 11, we can see the factors affecting natural light reaching the interior space are classified, and the prominent characteristics of the Romanesque period are given together.

Figure 70. The Church of San Zeno, Verona, Italy – Rose Windows.
(Url 59)

Table 11. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Romanesque.

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -In the Romanesque period, the use of light changes depending on scientific and engineering approaches. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -Return to the masonry vaults and arches of Roman instead of using timber trusses of Early Christianity is the character of this period.<br>-One of the primary methods of construction in the Romanesque period was the circular arch.<br>-The use of such construction methods allowed for windows to be punctured more easily, but they remained relatively small due to thick bearing walls.<br>-Still, the early Romanesque churches and cathedrals developed the use of clerestories, lanterns, and domes to allow natural light penetration.<br>-Combined with the eastern light coming from the windows behind the altar, the Romanesque use of light in architecture created a lighting strategy very much used to this day in Christian buildings.<br>-During this period, rose windows began to appear slowly.<br>-Both top and side lighting in the upper section (rose windows) strategy were used. |
| **SOCIAL & CULTURAL FACTORS** | - It is thought to have some approaches as the Early Christianity. |

### 3.1.8. Gothic (1100 to 1550)

The Gothic period is a more defined and mature continuation of the previous, Romanesque architecture, with the elevated stone masonry structures reaching the highest level of sophistication and engineering. Development of the pointed arch, flying buttresses, cross vault gave architects the possibility of intersecting roof vaults of different heights. (see Figure 71). External walls became thinner and lighter for the first time, losing their primary role of carrying the roof load. (Tokyay, 2010). This meant larger openings covered in stained glass, supported by parallel buttresses that transferred the roof load from the bearing walls.

The gothic architecture defined natural light as a divine resource. Therefore, Gothic architecture is the architecture of increased openings and transparency in buildings and larger areas of fenestration glazed in colored glass. The monumental cathedrals and churches of Europe, many of which stood the test of time, are filled with colorful light provided through rose windows and big, stained glass windows. In addition, for religious reasons, the long axis of the churches extended in the east-west direction. (see Figure 72). This made providing maximum daylighting easier. (Chepchumba, 2013; Tokyay, 2010).

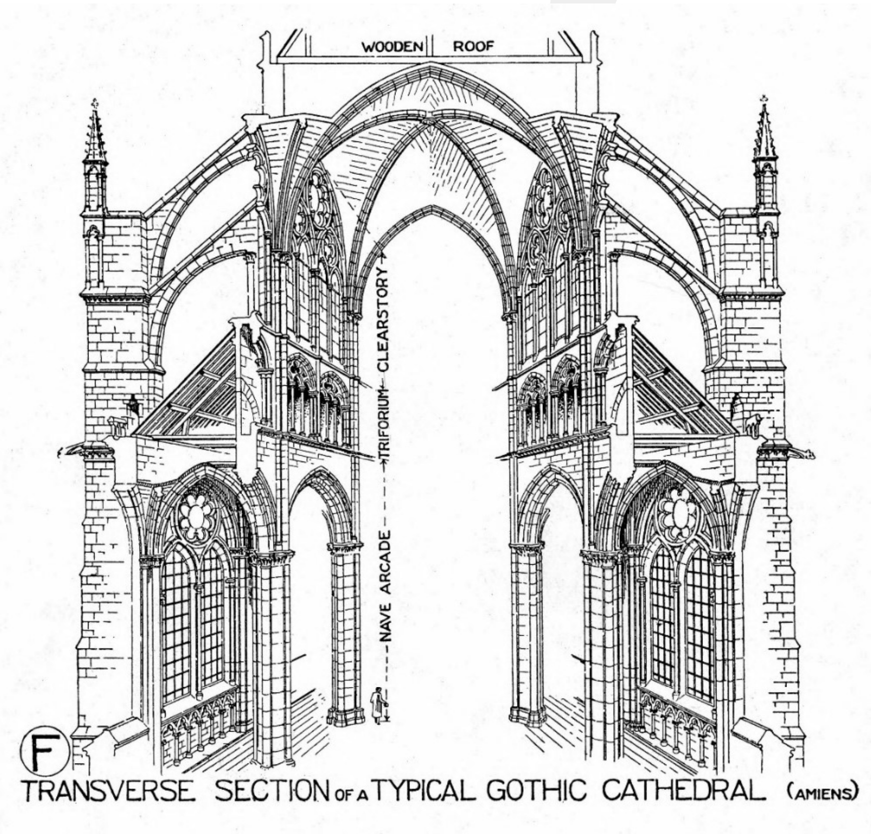



Figure 71. Transverse Section of a Typical Gothic Cathedral.
(Url 60)

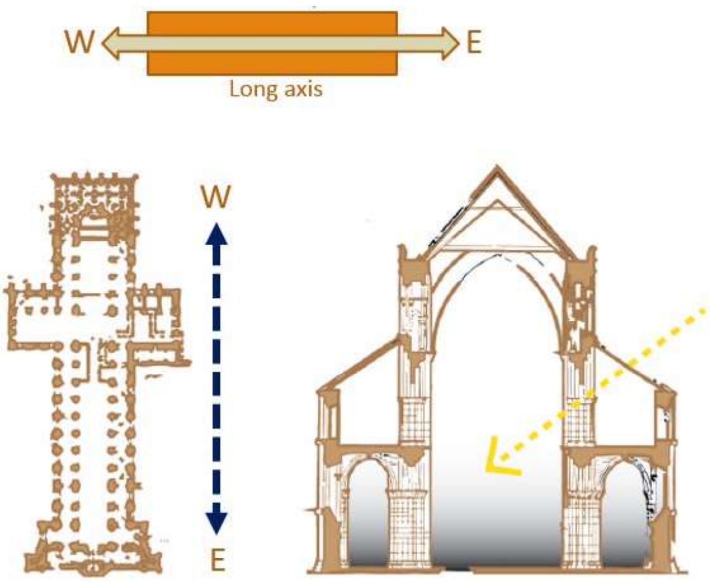



Figure 72. The section of St. Peterborough, England.
(Chepchumba, 2013)

Figure 73. The photo of St. Peterborough, England.
(Url 61)

In Gothic Architecture, like the ancient Roman period, the main factors affecting the internal structure of light were engineering and scientific factors. Table 12 shows us the factors and practices affecting daylight during the period.

Table 12. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Gothic. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -We can see the southern-facing opening for maximum daylighting. |
| **ENGINEERING & SCIENTIFIC FACTORS** | - The structural revolution occurred in the Gothic period. Flying buttresses, pointed arch, and ribbed vault began to be used. Thus, these types of methods provided long-span construction and allowed large window openings.<br>-They control light by playing with the transparency of glasses such as stained glass windows.<br>-Both top and side lighting strategies were used. |
| **SOCIAL & CULTURAL FACTORS** | -The Gothic period was a milestone in the relationship between natural light and architectural space.<br>-The light was defined as a divine source. The light and shadows create dramatic and mystic effects. |

### 3.1.9. Renaissance (1400 to 1600)

Renaissance architecture tended towards more realistic sculpture and painting and preferred to let natural light into the spaces without being manipulated. It is complicated to say that the relationship of architecture with light is as intense as in Gothic architecture. Despite all this, natural light was tried to be incorporated into the design by Renaissance architects and used light to enhance interior spaces. One of the best examples of natural light used is Michelangelo Buonarroti's dome for St. Peter's Basilica in Rome. (see Figure 74). High openings and the application of a dome allowed natural light to fill the church's high ceilings. (Tischhauser et al., 2006). In Table 13, the factors affecting natural light reaching the interior space are classified, and the particular characteristics of the period are given.


Figure 74. The St. Peter's Rome Interiors.
(Url 62)

Table 13. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Renaissance.

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -Proportions and opening size had designed to provide a balance for brightness without heat gain.<br>-They manipulated the daylight with the rhythmic relation of tall walls. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -The light was designed more uniform way and consistently for clear vision.<br>-Significant functions were placed where there were more openings while services spaces were placed within the thicker walls.<br>-Both top and side lighting strategies were used. |
| **SOCIAL & CULTURAL FACTORS** | - More realistic way of thinking and rational ideas had emerged. The light began to lose its divine meaning.<br>-No concentrated light and no fascination are aimed. |

### 3.1.10. Baroque (1600 to 1750)

According to Brogan, Baroque architecture in the brightest examples of the symbolic use of light as a means of expression was given in the 16th and 17th centuries. The baroque architecture contains psychological features. There is a vitality created by light and shadow on forms. The symbolism of light and darkness and their use are ideal tools for the expression of religious mysteries. They are used to inspire worship. Baroque architecture and art are defined by their appeal to movement, emotion, rationality, and spirituality. (Brogan, 1997). All this was represented with light by the architects.

During Baroque architecture, we see that the symbolic meaning of light comes into prominence compared to the functional approach. Also, it is possible to mention that the effect of social and cultural factors is more prominent than other factors. Table 14 demonstrates to us the factors and practices that affect daylight.

Figure 75. St. Carlo Alle Quattro Fontane.
(Url 63)

Table 14. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Baroque. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -Environmental factors remain in the background. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -Also, they used white and gold colors in interior space.<br>-Both top and side lighting were used. |
| **SOCIAL & CULTURAL FACTORS** | -The mystical and dramatic aspect of light reappeared with Baroque architecture.<br>-While the upper sections were illuminated with the windows used at the top, dark and dim spaces were created in the lower sections. Thus, the play of the light and openings created heavenly domes with a spiritual meaning.<br>-User comfort had remained in the background because of the importance of spiritual values.<br>Illumination of sculptures, paintings, and ornaments considered sacred has gained importance. |

### 3.1.11. Daylighting During the Industrial Revolution (1760 to 1840)

When it comes to the industrial revolution, there have been significant innovations in architecture with natural light. First of all, with the industrial revolution, the developing technology and material of the building envelope reached a different level compared to previous periods. In addition, natural light is an indispensable and accessible resource for efficient production spaces demanded by capitalism in this period. Therefore, since the 18th century, places where natural light is an essential input are no longer churches or residences, but factories gain importance. The world fairs (Expos) that came to the fore with the industrial revolution -especially the Crystal Palace example- are important. (see Figure 76). Crystal Palace, built in London in 1851, has become a vital precursor of the relationship between modern architecture, technology, and light.  As technology progressed, the facades got thinner; light is taken indoors to the deepest possible points. (Phillips, 2004).

Figure 76. Crystal Palace.
(Url 64)

The symbolic values of light have begun to be represented less, and natural light has been used more to make the space visible and create a comfortable environment, together with functional and rational approaches. With the industrial revolution, plenty of sunlight penetrated the areas from the wide glass curtains that formed the building envelope, and engineering and scientific developments became the determining factor in terms of natural light. In Table 15, the factors affecting natural light reaching the interior space are classified, and the prominent characteristics of the period are given together.

Table 15. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Daylight During the Industrial Revolution. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -Due to the large openings on the façade, the risk of excessive heat gain in summer and excessive heat loss in winter has increased.<br>Glare problems occurred and the thermal comfort of the users was damaged. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -With the fabrication of high-strength steel elements and the development of the structural framework, buildings stood only through columns.<br>-More light was brought into the interior by providing large spanning and the production of large glazing.<br>-Both top and side lighting in the upper, middle, and lower sections or fully glazed façade were applied. |
| **SOCIAL & CULTURAL FACTORS** | -Through the development of technology, natural light was seen as an indispensable and inexpensive source for production spaces.<br>Because of this, in this period, natural light loses its importance in residences and churches; instead, it increases its importance in factories. |

### 3.1.12. The Modern Movement (the 1900s)

We see that there are significant transformations in the field of lighting in modern architecture. Several ideological activities that started to be effective in this period, the participation of artificial lighting in architecture and technological developments, can be listed as the main elements that created this transformation process. The most remarkable feature of this period was losing the mystical, metaphorical, and poetic power of light. The functional purpose of natural light has come to the fore.

With the industrialization era, the development of new building materials (such as glass, steel) and social changes have changed the design approach of modern era architects. The growth of the glass in the steel frame allowed more light to enter the space. The relationship between natural light and technology, which started with the construction of the Crystal Palace and continued with the construction of the Bauhaus building (see Figure 77) in 1926, is one of the distinctive characteristics of this period. (Moore, 1985).


Figure 77. Bauhaus Building by Walter Gropius.
(Url 65)

As can be seen, the facades became thinner, and the light spread to the deepest possible points as technology progressed. This design approach, which has developed with technology development, has brought some negativities for the space. For example, problems such as glare, excessive heat gain, and loss have occurred.

In addition to this functional point of view, which is based on the excess of light, there are also architects who have succeeded in using it aesthetically. For example, in the place of worship in Le Corbusier's Ronchamp, he used light not only to add a historical atmosphere like the stained glass of Gothic cathedrals but also to create a special environment for individual places of worship. (see Figure 78). The light has reached the interior in its filtered form. The value of light has increased due to the architectural shell shaping and its meaningful effect on the space. Through these techniques, he created symbolic and poetic enlightenment in the interior.

Besides Le Corbusier, important names in the architecture of the 20th century are, among many, Frank L. Wright, Alvar Aalto, and Richard Meier. Mainly, architects had the freedom to use materials and colors that better reflected and refracted light, thus creating intricating juxtaposed surfaces.

In this period, the factors affecting natural light reaching the interior space are classified, and the particular characteristics are given in Table 16.

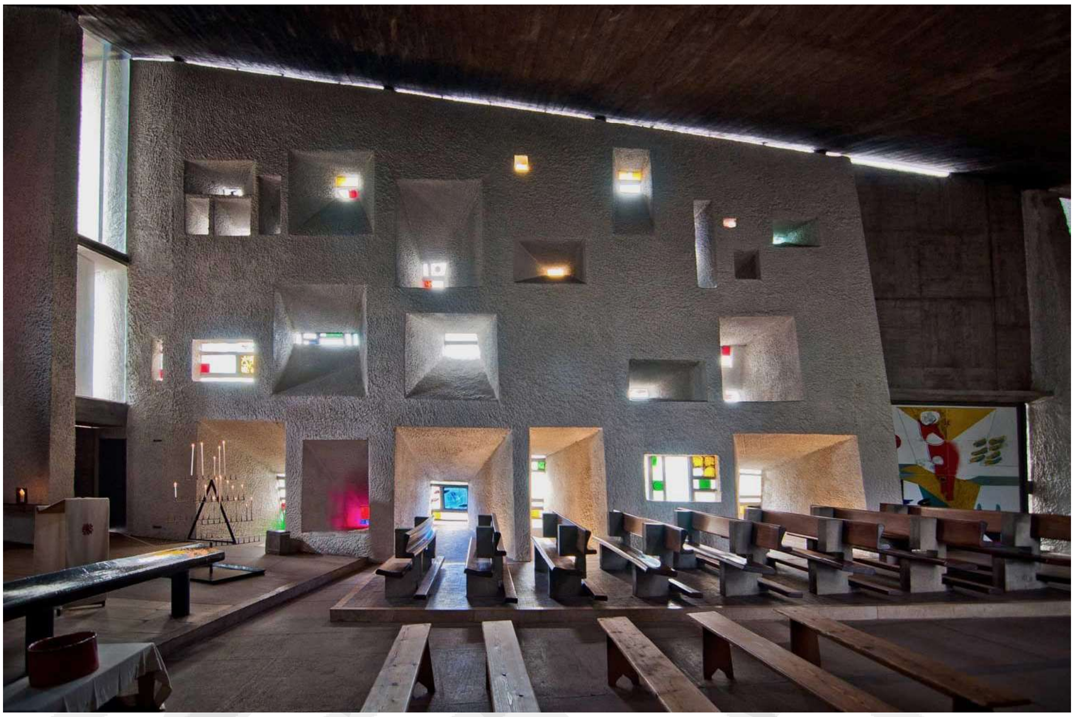


Figure 78. Notre Dame du Haut in Ronchamp.
(Url 66)

Table 16. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Modern Movement. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -Natural light was used for making space visible and creating a comfortable environment with functional approaches.<br>- The large window has often been used on the facades to benefit from daylight, even if orientation and positioning are not considered.<br>-In northern climates, the building had been positioned in the north and south axis in order that it can receive light from all directions. However, using large openings causes heat loss in winter. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -With the industrial revolution, new construction methods suitable for wide openings and new materials such as glass and steel ensured that as much light as possible was taken into the interiors.<br>-Fully glazed surfaces have been used on facades and the roof.<br>-The increasing of openings caused some problems such as glare, excessive heat gain, and loss.<br>-Both top and side lighting in the upper, middle, and lower sections or fully glazed façade were applied.<br>-Electricity and energy consumption in buildings began to increase.<br>-After a while, they had encountered the energy crisis. In this period also there are some conflicts about daylighting. Should the light reach the space or not? |
| **SOCIAL & CULTURAL FACTORS** | -Bright and balanced light was used instead of dynamic and symbolic light.<br>-Side and top lighting and atrium application provided a direct relationship with the sky and the outdoors.<br>-Some architects have also composed light as a guiding element.<br>-Light loses its semantic quality and sacred character compared to other periods, and its functional quality becomes prominent. However, light and shadow reflections created diversity in perspective. |

At that time, it was believed that energy was abundant and unlimited. Any precautions have not been taken to prevent overuse. With the energy crisis in the 1970s, the increasing power and costs were realized. (Chepchumba, 2013). With this movement, environmental concerns began to emerge gradually. This situation directly affected the architecture. It necessitated the revision of design methods and strategies. Thus, energy-efficient design has come to prominence.

# CHAPTER IV

# EVALUATION OF USING NATURAL LIGHTING IN CONTEMPORARY APPROACH

This section aims to clarify the uses of daylight indoors in a contemporary approach, how light is used in today's spaces and what significant developments and factors will be evaluated. It will be tried to reveal what kind of changes will be effective in the coming years.

It is difficult to classify the architecture of modernism and after modernism according to a particular group. In this respect, it is not easy to mention the unity of style. Even Jencks states that modern architecture died after the 1970s and says: “Modern Architecture died in 1972 at St. Loui, Missouri, when the infamous Pruitt-Igoe scheme, or rather, several slab blocks, was given the final blow by dynamite.” (Jencks, 1977). On the other hand, there are some critics who think that modern architecture still continues.

As can be seen, it is clear that after the 1970s, architecture tended towards a new understanding. We can say that the modern movement continues but is divided into phases within itself. Today, buildings have begun to be evaluated and designed through concepts such as energy efficiency, sustainability, parametric design, computer-based design. Therefore, the contemporary approach is separated by "Natural Lighting within the Context of Energy Efficiency” and " Natural Lighting within the Context of Computer-based Approach" in this section.

## 4.1. NATURAL LIGHTING WITHIN THE CONTEXT OF ENERGY EFFICIENCY (AFTER THE 1970S)

There’s no surprise in saying that the overall energy use on the planet is increasing at an alarming rate, and developed countries are experiencing increased energy consumption. It is also expected to increase in the upcoming years. We should be aware of the change that the building sector is capable of making in lowering the increasing use of energy. For instance, the energy used for lighting is among the components that significantly affect the energy consumption of a building.

The awareness of architects about the environment has also increased the importance of the use of daylight. The artificially lit spaces of the 20th century were gradually illuminated by daylight. (Chepchumba, 2013). Today, increasing energy needs and energy costs with the developing technology reveal the dependence on energy around the world. In addition, with the increase in $CO_2$ emissions, which have adverse effects on nature, countries are developing various policies to reduce energy consumption and minimize the damage to nature.

In addition to this environmental awareness-based approach, energy-efficient architecture also considers the social factors included in the sustainable design approach. These factors, including concepts such as equity, involvement, livability, values, culture, history, and universal design, have also directly affected the use of daylight. In energy-efficient architecture, it is aimed to reach qualified daylight for everyone. Briefly, in this architecture, daylight should allow everyone to use it without any obstacle. Nevertheless, it should not cause excessive gain while providing light. At this point, the evaluation of the design in terms of user comfort emerges. Hence, some precautions have been tried to be taken. As a result, we see that energy-efficient architecture adapts to the social and cultural structure of the environment and tries to produce optimum answers to problems.

With today's developing materials and technologies, the understanding of sustainable design gains a new perspective with changing living conditions. Some solutions are used today, which are considered together with environmental, engineering, and scientific developments. The systems, which we can call advanced daylight systems, are applied in order to increase the efficiency and quality of daylight in the interior space. These systems, which enable efficient use of daylight, contribute to energy efficiency. Some of these, which are generally applied to windows, provide more illumination of the interior volume, while others prevent excessive brightness. (Yüceer, 2015). It is possible to sort the systems used as follows: light shelves, louvers and blinds, prismatic panel systems, light guiding shades, sun-directing glass, spectrally selective glass, light pipes, roof light pipes, mirror shaft, heliostat.

*Light Shelf*

Shade elements applied horizontally on the south facades are called light shelves. Light shelves are applied horizontally to the upper part of the window, approximately 1/3 of its vertical dimension, in a way that does not cut the eye level. These shadow elements applied to the south facades provide shade to the lower part of the window. At the same time, it increases the daylight quality in the environment by reflecting the daylight from the part of the window above eye level to the ceiling of the interior space. (Soler & Oteiza, 1997). Light shelves can also be designed as inclined or mobile depending on the angle of incidence of the sun. (see Figure 79a).

*Louvers and Blinds*

Louvers are the most common systems used in daylight and shade control. It can be used in all climatic zones. Also, it is applied to the inner and outer surfaces of the windows. The size and angle of the louver parts play an essential role in adjusting the light indoors. Shutter spacing, size, and angle should be adjusted according to the angles of the sun. (see Figure 79b).

*Prismatic Panel Systems*

Prismatic panels are widely used as fixed and mobile tools in the skylight and direct sunlight. (Yüceer, 2015). Prismatic surfaces refract direct sunlight. Thus, they create a constant level of illumination by letting diffuse light in the interior volume. It can also provide shading. Prismatic glasses refract and reflect light during hot periods when the sun rises, depending on the angle of incidence of the sun. It is a suitable solution for hot climates.

*Light Guiding Shades*

They are systems used to cut direct radiation that increases glare and temperature in the interior space. In this respect, it is suitable for hot climates. It is applied to the upper part of the windows or as a building overhang. It diffuses the light from the sky and the sun by reflecting it on the ceiling of the interior volume. Thus, heat gain and glare in the interior are prevented. (Ruck et al., 2000). (see Figure 79d).

*Sun-directing Glass*

In this system, acrylic elements are placed between two glass surfaces. The horizontally ordered elements between the glass surfaces direct the daylight to the ceiling depending on the angle of incidence of the sun, and the system prevents glare. However, this system can interrupt the view outdoors. In addition, this system can be applied to the south, east and west facades of buildings in temperate climates. (Yüceer, 2015). (see Figure 79e).

*Spectrally Selective Glass*

These glasses reflect the light coming from the sky at certain angles and change its direction. Rays from other directions enter directly into the interior volume. (Yüceer, 2015). These systems provide daylight to the interior without blocking the view through the window.

*Light Pipes*

They take the light from the outside and bring it indoors. It is used to illuminate large volumes and closed-faced buildings with daylight. (Ruck et al., 2000). Sunlight received from the outside through the light tube is transmitted to the suspended ceiling. Thus, with the provided daylight, energy savings are provided.

*Roof Light Pipes*

The skylight from the small roof lights can be carried into the volume by reflective pipes in the light tubes. Sloping roof tubes towards the south increases the light efficiency. (Yüceer, 2015). The efficiency of the light can be improved through reflective elements or mirrors placed in the tube. Light tubes placed on the south façade work very efficiently in climates with a long period of sunshine. (see Figure 79f).

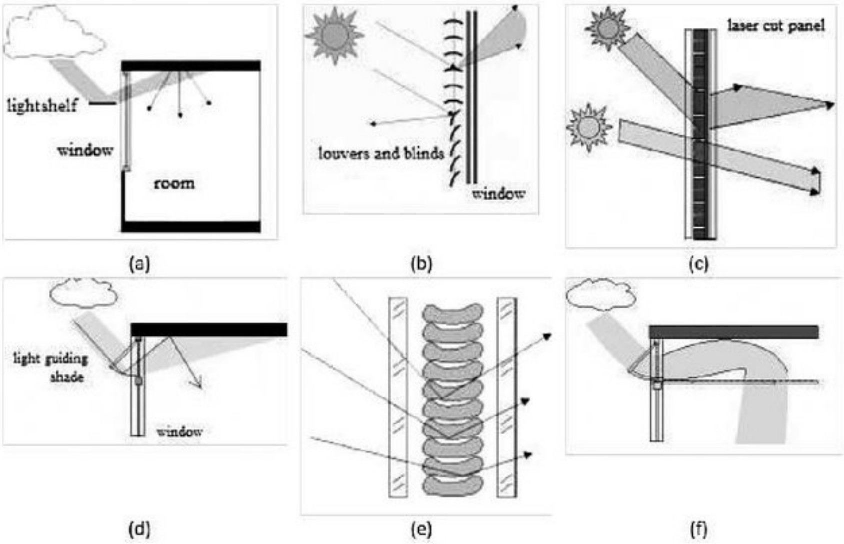



Figure 79. Daylighting Systems.
(a) Light shelf system (b) Louvers and Blind System (c) Laser cut panels (d) Light Guiding Shade (e) Light Guiding Glass (f) Light Pipe
(Url 67)

*Mirror Shaft*

This type of application provides a naturally lit basement. (see Figure 80). Link to the outside world, extra living spaces, and fresh air has been provided by using a mirror shaft.

Figure 80. Section and Example of the Mirror Shaft.
(Url 68)

*Heliostat*

A heliostat is a rotating device to reflect sunlight towards a predetermined target. It often works with a plane mirror, providing daylight to light-deprived spaces. (Kennedy & Terwilliger, 2005). (see Figures 81 and 82).


Figure 81. Jean Nouvel's Heliostat in Australia.
(Url 69)


Figure 82. The Working System of Heliostat Application.
(Url 70)

As can be seen, daylight can be controlled with different systems. There are several advantages that result from the use of advanced daylight systems. It is possible to sort them as follows:

- Daylighting systems allow sufficient daylight to penetrate the city layout consisting of crowded and adjacent buildings.
- It provides sufficient daylight to areas with low sun exposure.
- It controls the light and heat in places exposed to direct sunlight. Also, these systems prevent the glare problem.

- It provides flexibility and originality in design.
- Through advanced techniques, daylight can be manipulated and directed according to needs.
- Daylight is provided to places that cannot be illuminated inside the building, thus reducing the energy consumption required for artificial lighting. It allows us to obtain a sufficient illuminance level.
- It provides a variety of functions by changing the quality and quantity of incoming light.

In addition to all these systems, governments have put forward regulations and standards to determine building energy performance. Because, it is known that the energy consumed in buildings is a large part of the energy consumed worldwide. Thus, certification systems are developed to determine energy performance. For example, EN 15193 Energy Performance in Buildings – Lighting Energy Requirements standard has been published. This standard includes items such as the amount of benefiting from daylight, lighting systems used, devices, control systems. (*EN 15193-1:2017 - Energy Performance of Buildings - Energy Requirements for Lighting - Part 1: Specifications, Module M9*, 2017). Various simulations were used in lighting design to ensure these standards. It is possible to pre-evaluate the lighting designs created with lighting simulation programs such as Daysim, Energy Plus, Dialux, ReluxEnergy in terms of energy consumption. As a result of detailed analysis and calculation, annual/monthly/daily lighting energy requirements, energy costs, and the amount of $CO_2$ emissions can be calculated. (Şener Yılmaz & Köknel Yener, 2013). Environmental factors in sustainable architecture are also important in terms of the effective use of daylight in the architectural design process. (Williams, 2007). Environmental factors such as the sun's path, weather, climate, landscape, topography affect the use of daylight. Such inputs can integrate with simulation programs with technology and allow us to reach the most accurate result.

With technological development, architects carried a continuous path of daylight integration in architecture. As can be seen, many daylighting strategies have been developed and continue to grow in order to make maximum use of the environment. In this respect, it would not be wrong to say that environmental factors affect the use of daylight indoors in the first place. In table 17, we can see that the factors and practices that affect daylight during energy-efficient architecture.

Table 17. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Energy Efficient Architecture. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | -Light is again a major focus in architecture in terms of reducing energy consumption, demanding greener and environmentally friendly architecture.<br>Human comfort and energy minimizing-based design<br>-They realized the relationship between the historic principles of daylighting design and energy efficiency. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -In addition, some techniques are used, such as skylights, roof monitors, clerestories, atrium.<br>-Light pipe, mirror shaft, heliostat, light shelves, louvers and blind system, laser cut panels, light guiding shade, and light guiding glass are used to provide efficient daylight.<br>-Computer technologies are available to allow optimizing the indoor climate and daylighting. |
| **SOCIAL & CULTURAL FACTORS** | -In this period function of natural light is more important than meaning.<br>-User comfort-based design is preferred. |

## 4.2. NATURAL LIGHTING WITHIN THE CONTEXT OF COMPUTER-BASED APPROACH

The understanding of contemporary architecture with computer-aided design has to consider more criteria than in the past. Criteria such as sustainability, low use of natural resources, energy efficiency, ecological balance are most regarded. Unfortunately, the designer cannot be a master of all the subjects. It is possible to overcome this problem with a computer-based design. Calculations can be made using suitable simulation software and complex algorithms. (Acosta et al., 2018). Thus, a fast and convenient solution is provided for the designer.

With modernism, architects gave up working on complex forms until the early 1990s. With digital design and product development since the 2000s, it has become possible to work with more complex shapes and parameters. This has affected the use of daylight indoors. Architects such as Rem Koolhaas, Zaha Hadid, and Patrick Schumacher have made great use of the possibilities offered by the computer. Concepts such as suitability, design process optimization, and modularity can be counted among the opportunities brought by computer-aided design.

While designing by considering natural lighting, environmental factors (such as topography, climate, orientation) can be used as input through computer-aided design. In this way, both user comfort is prioritized, and structures that consume less energy can be built. Thus, environmental factors are more consciously integrated into the design. When modernism was effective, environmental factors remained in the background. Later, it was integrated into technology with computer-based design. Thus, it is possible to say that engineering and scientific factors are influential together with environmental factors in this age. For example, the Abu Dhabi Louvre Museum dome, made by Jean Nouvel, filters daylight into the interior. Thus, both a visual feast was created, and the problem of overheating and glare caused by perpendicular sun rays was prevented. All factors affecting the spread of daylight indoors are considered together. (see Figure 83). (Kasinalis et al., 2014)

Figure 83. The Abu Dhabi Louvre Museum by Jean Nouvel.
(Url 71)

As mentioned, evaluations related to lighting designs are made with the use of simulation programs today. In this way, it is possible to carry out the necessary evaluation in a more practical way. In order to obtain the annual natural lighting performance value of a place, it is required to determine the daylight brightness that occurs throughout the year in the place. For this purpose, natural lighting simulations are made, and data on the illumination level in the space can be determined. Areas, where natural lighting is sufficient during working hours or building usage hours, can be determined, and the problematic regions can be revealed. Obtaining the percentage of the comfortable area through simulations is essential in terms of expressing the evaluation numerically. Thus, it is possible to determine the visual performance of the lighting on an annual basis. (Şener Yılmaz & Köknel Yener, 2013).

As can be seen, there has been a transition from the architecture based on visuality to the architecture based on performance in recent years. The influence of engineering and scientific factors on daylight design has gradually increased. It would be correct to talk about kinetic façades, which is an innovative approach here.

With the developing computer technology, conventional buildings have been replaced by innovative, energy-efficient, kinetic structures that use the latest technology as materials and construction systems. (Karakurt Tosun, 2013). Buildings are expected to have harmonious facades that respond to changing environmental conditions and can continuously change themselves. The adaptation of the façade should not only depend on environmental conditions (climate, topography, landscape, orientation) but also on the user. The interior comfort conditions of the building (illumination level, temperature) and the user-related conditions (relationship between object and view) largely depend on natural lighting. In order to provide such conditions, it is possible to carry out activities such as shading with kinetic facades, solar radiation gain, thermal insulation, ventilation, and benefiting from the sun. (Güney Tok, 2019). In this context, we can define the purpose of the movement on the kinetic facades as keeping the indoor conditions at an optimum level according to the outdoor conditions. (Sarıcıoğlu & Ayçam, 2018). Moreover, advanced shading systems and dynamic facades change their geometry according to the climate and the angle of daylight and aim to provide the optimum balance between light, air, and solar energy. (Elzeyadi, 2017).

The One Ocean Pavilion in Figure 84 is an excellent example of a kinetic façade application. The kinetic façade is made up of 180 undulating lamellas, which were created from fiber-reinforced plastic. A central computer instructs the panels to move in sync, helping control heat and light conditions inside the building. Day by day, experience shows how the movable lamellas of the kinetic façade can get the light into the foyer in the best way possible. The lamellas of the kinetic façade control the solar energy input, and the solar panels on the roof generate energy. The movements of these facades are regulated according to the climatic characteristics of the building. Thus, it reduces energy consumption and increases efficiency. (Güney Tok, 2019).


Figure 84. One Ocean Pavilion by SOMA in South Korea.
(Güney Tok, 2019, p. 57)

Another example is the Al Bahar Towers in Dubai. The design of the façade is adjusted according to the angle of incidence of the sun's rays. In this way, both facade shapes are created, and sun rays' direct penetration into the interior is prevented. (see Figure 85).

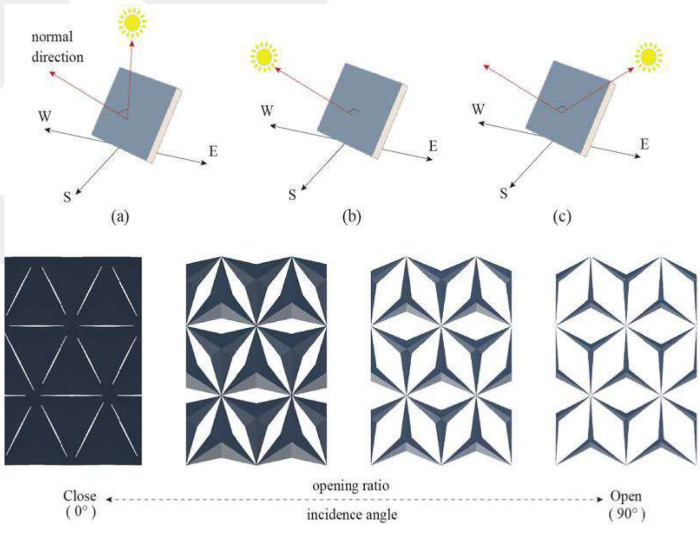



Figure 85. The variation of complex kinetic facades is based on the incidence angle.
(Kim & Yan, 2015).

In summary, daylight has gained various flexibility with computer-based design. We can list them as follows:

- Daylight can be used more efficiently and in a controlled manner with kinetic and smart facade designs.
- Daylight can be utilized as much as possible in all seasons with the facade panels designed, considering parameters such as climate and orientation. As a result, the metrics determined to meet the required daylight levels in the spaces will be positively affected. For instance, the daylight factor will be sufficient level, and metrics based on simulations and annual climate data (daylight autonomy, special daylight autonomy, annual sun exposure, useful daylight illuminance) will also maintain their optimum values. In addition, the energy consumed for artificial lighting is also minimized.
- The inclusion of the computer-based process in the design will also strengthen the light-space relationship. With the opportunities provided by technology, different daylight levels can be provided in different places. This has a positive effect on the quality of the space.
- Some studies show that adapted facades improve indoor environmental conditions and can save 15-18% energy compared to non-adaptive building façade. (Kasinalis et al., 2014).

Besides providing flexibility, the adaptable façade design also has a positive effect on user comfort. However, it is not easy to provide user comfort by considering daylight. Because indoor and outdoor are different areas that affect each other, it is difficult to balance thermal and visual comfort due to the contradiction between them. (Hosseini et al., 2019). However, it is possible to provide optimal solutions with an interdisciplinary study and the use of technology. This solution is provided with adapted building shells, as we mentioned before. With an adapted building façade, indoor environmental quality and thus user comfort can be improved. In recent years, with the inclusion of the user in the design, interior spaces with a high level of well-being have emerged. A study by Bakker et al. also supports this. Their study has argued that the ability to personal control over automated façade systems is an essential requirement. Participants have appreciated the fact that they had daylight control. They have overcome the glare problems caused by direct sunlight in accordance with the request. Automatic façade systems with user control also prevent distracting factors in the exterior. (Bakker et al., 2014). When we look at the study results, it is predicted that human-technology interaction will come to the fore in the coming period. In this respect, it is an inevitable fact that human experience will be an important parameter in the development of high-performance dynamic facades.

While advanced façade techniques maximize occupant's comfort and energy savings, they have adapted to the environmental data. In this respect, in order to achieve high-performance building design and provide human comfort, it will appear as a concept that we will encounter a lot in the future. (Bakker et al., 2014).

As can be seen, it is indisputable that engineering, scientific factors, and user needs depending on environmental factors will significantly affect the use of light in architecture in the coming years. Factors such as the development of composite materials, nanotechnology, and developments in the field of computers will significantly affect the use of daylight in architecture in the future. In table 18, we can see that the factors and practices that affect daylight during today's approach.

Table 18. The Table Related to Factors Affecting the Natural Light and the Characteristic Features of the Computer-Based Approach. (prepared by author).

| | |
|---|---|
| **ENVIRONMENTAL FACTORS** | - The light and azimuth (the angle of the sun), topography, wind direction, and even material properties can be considered as parameters.<br>-The shape of the structure can be designed to reach the most efficient sunlight, or it can be shaped according to environmental factors. |
| **ENGINEERING & SCIENTIFIC FACTORS** | -In this period, energy consumption, efficiency, and environmentally friendly architecture are important.<br>-The development of composite materials, nanotechnology, and computer-based design is the most effective approach in this period.<br>-Form and function affect each other. |
| **SOCIAL & CULTURAL FACTORS** | -In recent years, dynamic and symbolic light are preferred more frequently than in the previous period.<br>-User comfort-based design is preferred. |

# CHAPTER V

# RESULTS AND DISCUSSION

In the research conducted from the prehistoric period to the present, it is seen that natural light is affected by some developments. Tables have demonstrated these examined periods for understanding easily and quickly. Table 19 demonstrates the thresholds analysis. Table 20 indicates the typological approach to daylighting in the historical process. Comparative analysis of factors affecting natural light in the historical process is shown in Table 21. Lastly, the typology of natural lighting combined with factors affecting natural light, where we can see all these analyzes together, are set out in Table 22. When the examined periods are reflected in the table, we can present the results as follows:

The entrance door is the only opening in prehistoric times. For example, in the Neolithic city of Çatal Huyuk, houses were entered through a hole in the roof. The light could only reach the space through the entrance door, which can be classified as top lighting. In this period, as we can see in Table 21, the use of natural lighting was mainly shaped by environmental factors. Since the building technology has not yet developed, external factors such as rain and wind have shaped the architectural structure.

In Ancient Egypt and Ancient Greece, apertures were in the form of unglazed holes in the walls. The earliest form of skylight and clerestory window applications has begun to appear. Therefore, as shown in Table 20, it is possible to mention that the top lighting strategy is used. As in the prehistoric period, environmental factors played a more influential role in natural lighting in Ancient Egypt and Ancient Greece.

Many developments in the field of architecture were experienced in the Ancient Roman period. The first architectural application of glass was seen in the Roman period. Glass with low optical quality was used by Roman architects in the homes of their wealthy clients. Thus, brighter interiors were created. (Demirbilek et al., 2009). They developed many architectural elements by discovering concrete (such as arch, dome, vault). Therefore, they were able to provide the long-spanning, and they were made aperture like oculus in the middle of the domes. With the spread of Christianity as well as scientific developments, social and cultural factors have begun to show their effect on natural lighting design. They are associated with the light coming from the oculus-type opening, which we can define as top lighting, with God. As shown in Table 21, while the engineering and scientific factors have primarily affected the use of natural lighting in this period, social and cultural factors have also affected.

With the development of timber trusses, high-level windows were used in Early Christianity. Top and side lighting was used. From the first period of Christianity, the metaphor of god in space began to be strengthened with light. Thus, social and cultural factors have dominated the use of light in architecture.

In the Byzantine period, stained glass windows application was used. As we can see in the Hagia Sophia, both top and side lighting are used. The concept of a heavenly dome was supported by the glasses used in the drum of Hagia Sophia's dome. As in the Early Christian period, social and cultural factors have affected the penetration of natural light.

Generally, arch, vault, dome was used instead of timber trusses in Romanesque architecture. The openings are mostly designed as top lighting like rose window. Therefore, encountering dim and dark places was possible. Also, eastern light was invited from behind the altar, and natural light was used to create a focal point in these spaces. With these approaches, it would not be wrong to talk about the impact of cultural and social factors, including concepts such as religion. Briefly, social and cultural factors, engineering and scientific factors had an impact on natural light rather than environmental factors.

The Romanesque style, known by its thick wall and massive quality, has changed over time. (Demirbilek et al., 2009). As indicated in Table 19, in the Gothic period, with the development of structure (flying buttresses, ribbed vault, pointed arch), they created easily long-spanning and high-level openings. Through these construction techniques, they were able to build more apertures on the walls. (Charleson, 2014). Hence they used both top and side lighting techniques. They had supplied the light in diffuse ways with stained glasses. Thus, it became easier to control the light, and they were able to add symbolic value to the space. Through the structural revolution in the Gothic period, engineering and scientific factors came to the fore in terms of the effect on the use of light. Due to religion and the values of the era, social and cultural factors were a secondary influence. As seen in the tables (Tables 19, 20, and 21), Renaissance and Baroque architecture also showed the same characteristics as Gothic architecture.

The technological innovations with the industrial revolution are accepted as a milestone that started a rapid development in the field of architecture. The reflection of the construction and production technologies developed with the industrial revolution on the architectural sector has brought about the transformation of natural light in architecture. The use of new building materials (glass, iron, steel, reinforced concrete) produced with the development of industry and social changes also affected the architectural shell formation. By means of steel frame and reinforced concrete structure, top lighting such as skylights and side lighting strategies were designed with larger openings. As a result of all these, we can mention that engineering and scientific factors again take place on the top.

Table 19 demonstrates to us that the invention of electricity led to competition between natural and artificial light. They had shifted the use of natural light to artificial light. However, with the energy crisis in 1970, an environmentally friendly design approach became more of an issue.

The industrial revolution and its reflection on social life led to the development of a simple and unconventional formal language in architecture. As a result, modern architecture emerged. Advancing technology allowed fully glazed façades and large-scale atriums. Large amount of fenestrations and fully glazed façades were used since they provided more light and better views; however, they also caused difficulties with glare and overheating. (Mansfield, 2017). This both increased the energy consumption of the building and affected user comfort. As can be seen, modern architecture has put environmental factors into the background and used the opportunities provided by technological developments. Engineering and scientific developments have shaped architecture.

Environmental factors are taken into account in energy-efficient architecture. Technology has allowed many different daylighting strategies. (Skylight, sawtooth, clerestory, roof monitor). Top, side lighting, and atrium application are used. In addition, as a result of the façades becoming transparent, daylight penetration into the interior has increased. Excessive daylight has caused heat gain. The energy spent to cool the building has increased. The opposite circumstance is also possible. Due to large openings, heat loss may occur in cold climates and the energy used to heat the space increases. Additionally, the loss of the semantic value of light has reduced the effect of social and cultural factors on the use of light. We see this clearly in Table 21.

It has become easier to use daylight in architecture with computer-aided design, which has become increasingly widespread in recent years. Many variations related to fenestration are provided in the design. Optimal solutions have started to be provided between light and human well-being with interdisciplinary work. (Hosseini et al., 2019). As shown in Table 21, although recent engineering and scientific developments have affected the use of light indoors, environmental and social factors have also been taken into account through the interdisciplinary design.

To sum up, Table 22 was used to evaluate all of these developments in one place and make them easy to understand. It has been observed that the diversity of openness has increased due to the development of technology and structural capacity, and factors such as religion and social values have affected the use of light in space in previous times, especially in the medieval era. In recent years, with the integrated work of energy-efficient design and digital architecture, environmental factors have also been involved and have given direction to natural lighting design.

Table 19. The Thresholds Analysis prepared by the author

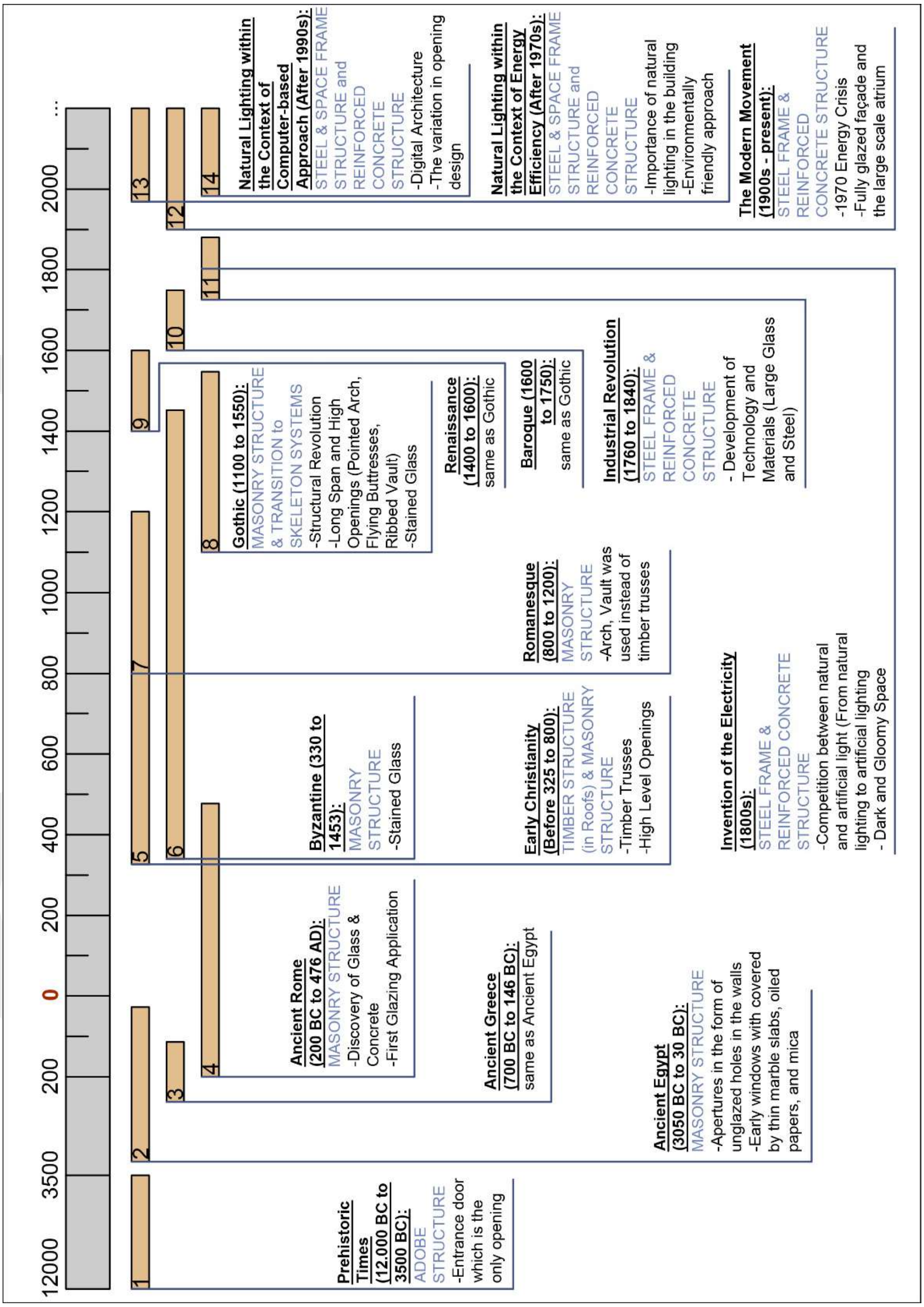


Table 20. Typologic Approach to Daylighting in the Historical Process prepared by the author

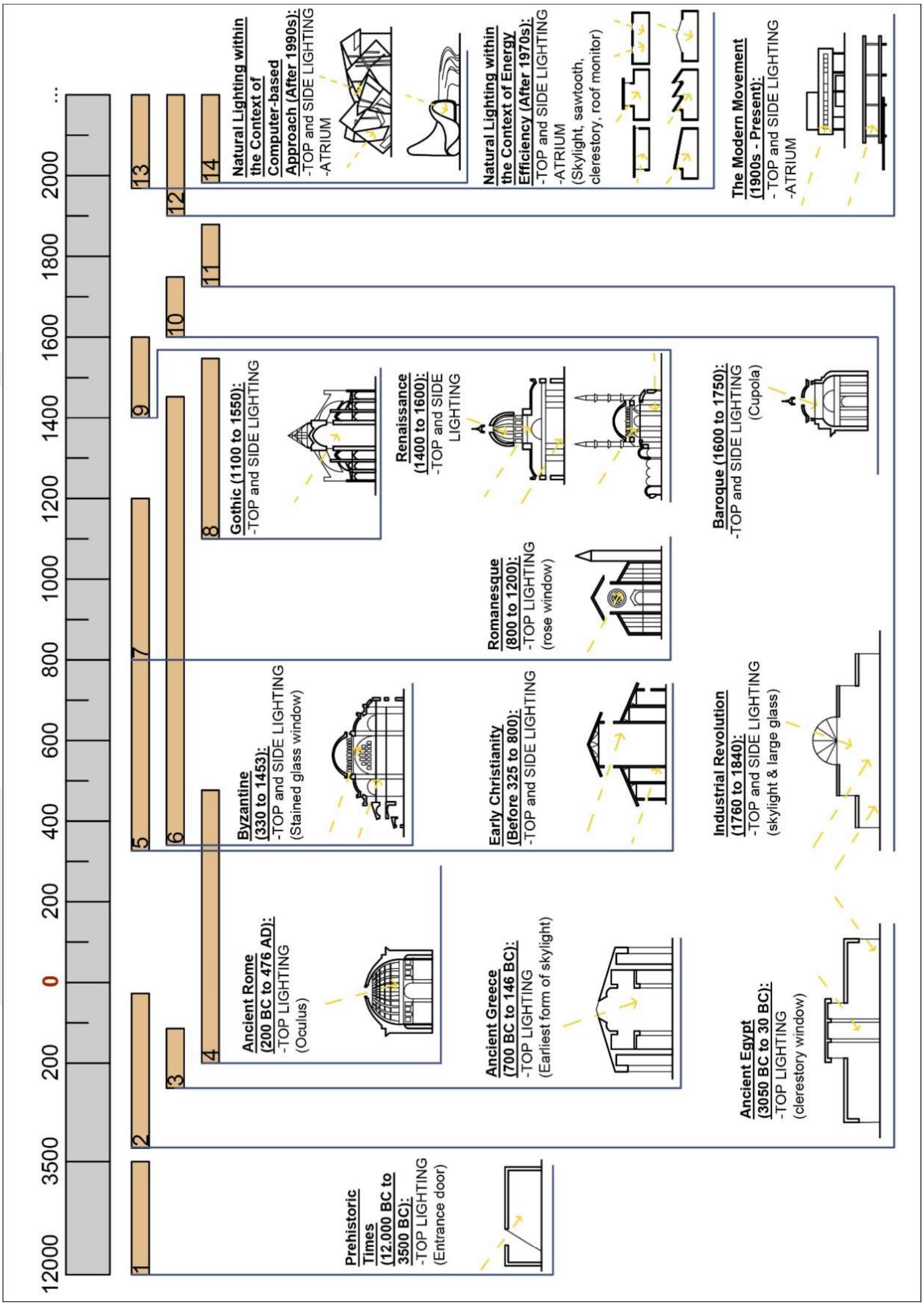


Table 21. Comparative Table of Factors Affecting Natural Light in the Historical Process prepared by author

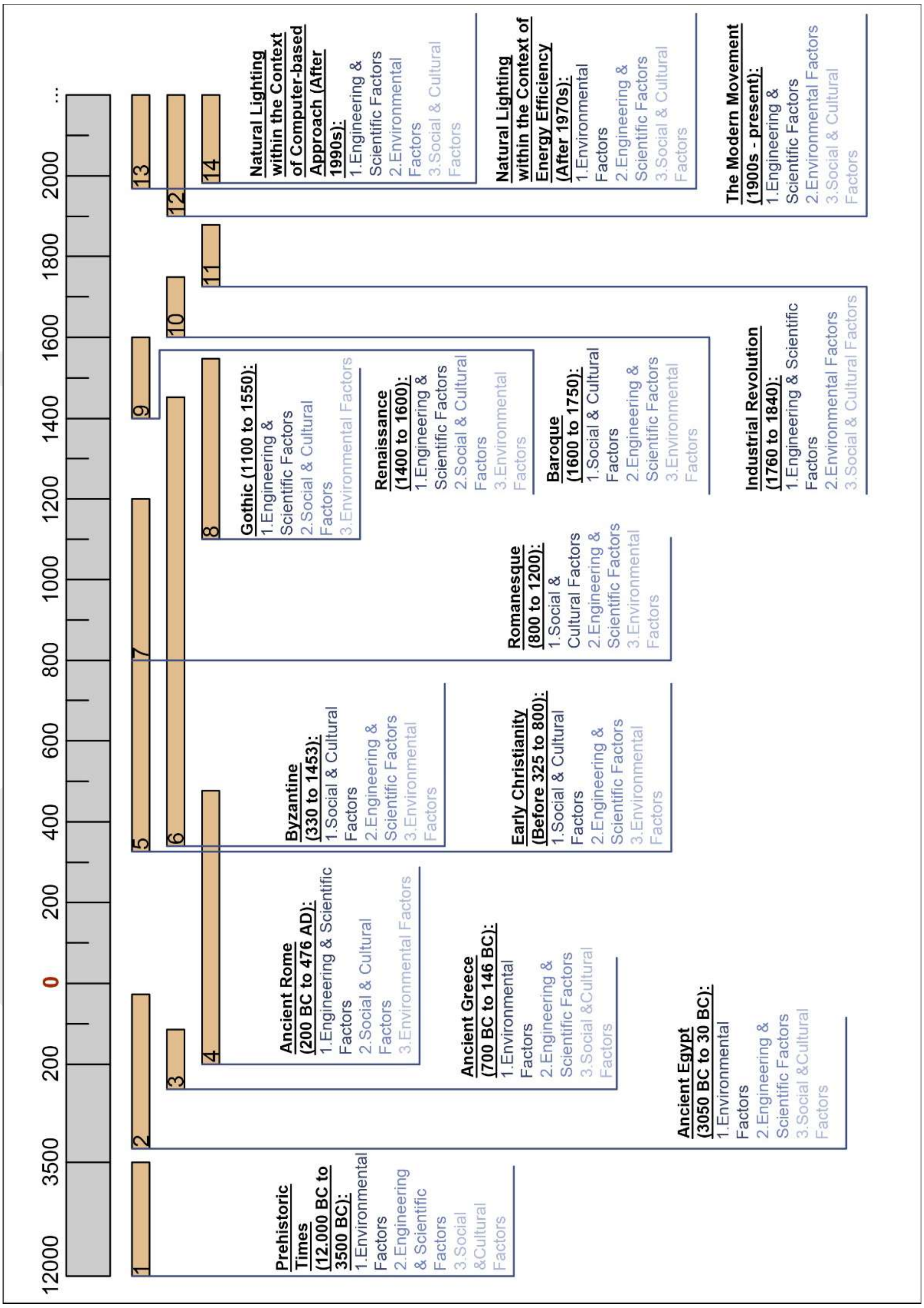


Table 22. Merged Table of Natural Lighting Typology with Factors Affecting Natural Light prepared by the author

| | FACTORS AFFECTING DAYLIGHT | | | TYPOLOGICAL APPROACH | | |
|---|---|---|---|---|---|---|
| | ENVIRONMENTAL FACTOS | ENGINEERING & SCIENTIFIC FACTORS | SOCIAL & CULTURAL FACTORS | TOP LIGHTING | SIDE LIGHTING | ATRIUM |
| Prehistoric Times (12.0000 BC to 3500 BC) | 1 | 3 | 2 | X | | |
| Ancient Egypt (3050 BC to 30 BC) | 1 | 3 | 2 | X | | |
| Ancient Greece (700 BC to 146 BC) | 1 | 3 | 2 | X | | |
| Ancient Rome (200 BC to 476 AD) | 3 | 1 | 2 | X | | |
| Early Christianity (Before 325 to 800) | 3 | 2 | 1 | X | X | |
| Byzantine (330 to 1453) | 3 | 2 | 1 | X | X | |
| Romanesque (800 to 1200) | 3 | 2 | 1 | X | | |
| Gothic (1100 to 1550) | 3 | 1 | 2 | X | X | |
| Renaissance (1400 to 1600) | 3 | 1 | 2 | X | X | |
| Baroque (1600 to 1750) | 3 | 2 | 1 | X | X | |
| Daylighting During the Industrial Revolution (1760 to 1840) | 2 | 1 | 3 | X | X | |
| The Modern Movement (1900s to Present) | 2 | 1 | 3 | X | X | X |
| Natural Lighting within the Context of Energy Efficiency (After 1975 to Present) | 1 | 2 | 3 | X | X | X |
| Natural Lighting within the Context of Computer-based Approach (1990 to Present) | 2 | 1 | 3 | X | X | X |
| 1: Primary Effects | | 2: Secondary Effects | | | 3: Tertiary Effects | |

# CHAPTER VI

# CONCLUSION

Light from nature; is significant for architecture, interior architecture, and the human body. It has directly affected energy efficiency, sustainability, and responding to psychological and physiological needs. In many cultures, divine power has been attributed to light. As can be seen, it is possible to talk about the effect of natural light in many areas. In this respect, natural light is a complement to the architectural design process.

Although the practice of natural lighting is multi-disciplinary, it transforms our buildings into perfect spaces when designed effectively. There are some questions that should ask at the beginning of natural light design, which is one of the complex parameters in architecture. What is the amount of light required by the action? What is needed in space? How should daylight be distributed to interior volumes? Is it possible to give the place identity with daylight? In order to answer questions like these, it is necessary to understand the structures that have been built before. Because as designers, we cannot design the future without knowing what has been done in the past.

At this point, it is necessary to remember briefly the questions from which the study set out and the answers given.

- Which developments and events throughout the history of humanity have caused or prevented the penetration of daylight into space? (Thresholds)

In order to answer this question, significant developments in the history of natural lighting have been examined, and the thresholds are presented to the audience in Table 19 with summary keywords. In general, although the use of natural light in spaces has drawn an increasing curve, it has been observed that it has declined at some points. With the development of technology, the amount of light taken into the interior has increased due to the advanced construction techniques. However, with the development of technology, the tendency towards artificial lighting has grown, thus the use of natural light has decreased. Although efforts have been made to increase the integration of natural lighting into buildings with the development of environmental awareness in recent years, it has not reached the desired point.

- How did people admit daylight to indoors throughout history? (Typological Approach)

Although there are various classifications in the literature on openings in space (Ching, 2007), Egan's classification about admitting natural light into space was found to be more appropriate in this study. (Egan & Olgyay, 2002). In Table 20, typologies used in the historical process are visualized and revealed. It has been observed that the diversity of openings has increased in parallel with the development of technology and structural capacity.

- What kind of parameters has an effective role in the use of natural light in buildings? (Factors that Affect Natural Light)

These parameters, which are classified as environmental factors, engineering and scientific factors, social and cultural factors in this thesis, have been in conflict with each other over time. And it continues to be in conflict. Considered from a general point of view, a parameter that significantly affects social and cultural factors such as religion has dominated the use of natural light indoors for ages. It has been an essential factor that creates the character of the space, especially in the natural lighting design of monumental buildings. With technology, social and cultural factors lost their priority in architectural design. With the developments in the structure and structural materials, factors called engineering and scientific factors have taken a step forward. We see that environmental factors are also considered important in natural lighting design with environmental awareness in recent years. However, due to the widespread use of artificial lighting, it has not gained the desired importance. In Table 21, these factors are given in the order of historical continuity.

In order to see all these developments in one place and be easy to interpret, evaluation as in Table 22 was made. It is aimed to examine the use of natural light and to guide new designs with this table, which ensures the emergence of the factors and typologies affecting natural lighting.

- What kind of changes in the future are expected regarding natural lighting in the interior?

Conditions such as global warming and climate change increase the importance of energy-efficient buildings day by day. The design of dynamic and variable facades in architecture, the emergence of smart and efficient daylight systems, and nanotechnological materials are the results of the energy-efficient and computer-based design approach. The unstoppable progress of technology, being compatible with environmental variables, will significantly affect the natural lighting design in the future. These approaches that we have mentioned have also been influential on the architecture of the last period. Furthermore, some studies have revealed that the user will also guide the interactively adapted facade design. (Bakker et al., 2014). hus, it is estimated that the comfort perception of the occupants will come to the fore and will significantly affect the design.

The study tried to bring multiple perspectives to the use of natural light over time and in the future. The results obtained from this study have been attempted to make a summary contribution to the current literature.

As a result, it may be difficult to cope with daylight. Still, its presence is essential in terms of strengthening the relationship between humans and the built environment, making sense of space, human health, and biological rhythm. Well-designed natural lighting can improve occupants' well-being, comfort level, and sensory reactions. It also makes our cities and environment more livable. In this respect, it has emerged that we need to examine many criteria in the design phase, as presented in the thesis.

Designs made by paying attention to environmental, engineering, and scientific factors, social and cultural factors are more distinguished and worth examining. Moreover, examining these factors in the thesis together with the natural lighting typology in the historical process has helped understand today's conditions. When any of these factors are entirely put into the background, spaces lacking quality and quantity emerge. Therefore, it is crucial to guide the design and the process by evaluating the factors together at the optimum level. Although natural light seems to affect the design first in the design process, the structure also affects the natural light after the building is built. For this reason, there is a mutual relationship and a network of inputs. How all these inputs will come together is hidden in the designer's knowledge. In this respect, this study has been designed as a guide to give direction to the designer who is interested in natural lighting. When designers use natural light as a design tool, considering all factors, the resulting works will be more qualified, sustainable, and of high quality. In addition, as Meiss stated, the fact that the least taught phenomenon in the design of a building is natural light (Meiss, 1990) causes severe deterioration in the quality of the spaces. In this respect, it would be appropriate to suggest that the thesis improve awareness of natural lighting design.

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