OVERVIEW AND DISCUSSION ON RECENT APPLICATIONS OF BUILDING INTEGRATED DAYLIGHTING SYSTEMS AND PHOTOVOLTAICS

A Thesis Submitted to
the Graduate School of Engineering and Sciences of
İzmir Institute of Technology
in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCES

in Architecture

by

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July 2017
İZMİR

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ACKNOWLEDGMENTS

First of all, I am very much grateful to my supervisor and project coordinator Assoc. Dr. Z. Tuğçe Kazanasmaz for her patience, motivation, and efforts to expand the scope of this thesis and for her guidance throughout the whole research process. Further, I'm extremely grateful to Assoc. Dr. Tahsin Başaran for his contribution and support.

Moreover, I glad to Prof. Dr. Erol R. Sayın and Prof. Dr. Gülser Çelebi, I met at AHEP University, to share their academic studies with me. In addition, I would like to show gratitude to my previous companies. Firstly, I glad Karakutu Electroacoustic family. Especially, Prof. Dr. Feridun Öziş and Erdal KARA for their support. Moreover, I would like to thank Han Yapı Group's members and managers.

Last but foremost, I am extremely grateful to my big family; my mom, my dad, and my dear sister. They have always shown me their love and given me the motivation I needed. Further, a huge thank you is owed to my dear fiancée and my remarkable friends, who have always been with me during the good and bad times.

ABSTRACT

OVERVIEW AND DISCUSSION ON RECENT APPLICATIONS OF BUILDING INTEGRATED DAYLIGHTING SYSTEMS AND PHOTOVOLTAICS

Consumption of energy resources has been increased with industrial revolutions, and today it is continuing. As a matter of fact, one of the biggest results of this negative increase is global warming. In this respect, studies are being carried out for more sparing consumption of natural energy resources (water, mines, fossil fuels etc.). As well as work and applications for more common and correct use of renewable energy sources such as solar and wind energy. This study has emerged through the examination of the concept of "architecture integration". Today, the necessity and the positive increase in the use of renewable energy sources have led to the emergence of integrated energy systems with the building. Therefore, renewable energy resources are being used more actively with subsystems that provide integration between building and ecosystem. Renewable energy sources are energy resources that benefit from natural processes for energy and can renew themselves faster than resources are consumed. Solar energy, wind energy, geothermal energy are the main sources of renewable energy. In this study, daylighting systems and photovoltaic applications, which are subsystems of solar energy and building integration as a result of renewable energy sources, are examined. During the research, it was considered how the systems are integrated into the building, their levels, design and structural characteristics and how they are used and reviewed through tabularized forms. As a result, it has been determined that the shape and features of integration vary according to the building form, environmental factors, and requirements of construction.

ÖZET

BİNAYA BÜTÜNLEŞİK DOĞAL AYDINLATMA SİSTEMLERİ VE FOTOVOLTAİKLERİN SON UYGULAMALARINA İLİŞKİN GENEL BAKIŞ VE TARTIŞMA

Enerji kaynaklarının tüketimi endüstriyel devrimler ile artmış olup günümüzde de arış göstererek devam etmektedir. Nitekim bu olumsuz yöndeki artışın en büyük sonuçlarından biri de küresel ısınmadır. Bu nedenle tükenebilir doğal enerji kaynaklarının (su, madenler, fosil yakıtlar, vb.) daha idareli tüketimi için çalışmalar yapılmakta, bunun yanı sıra da güneş ve rüzgâr enerjisi gibi yenilenebilir enerji kaynaklarının daha yaygın ve doğru kullanılması için de çalışmalar ve uygulamalar yapılmaktadır. Bu çalışma "mimarlıkta bütünleşme" kavramının irdelenmesiyle ortaya çıkmıştır. Günümüzde yenilenebilir enerji kaynakları kullanımının zorunlu ve pozitif yöndeki artışı, bina ile entegre (bütünleşik) enerji sistemlerinin ortaya çıkmasına neden olmuştur. Dolayısıyla, yapı ve ekosistem arasında bütünleşmeyi sağlayan alt sistemler ile yenilenebilir enerji kaynakları daha aktif halde kullanılmaya başlanmıştır. Yenilenebilir enerji kaynakları, enerji için doğal süreçlerden yararlanılan ve kaynakların tüketildiğinden daha hızlı bir şekilde kendini yenileyebildiği enerji kaynaklarıdır. Güneş enerjisi, rüzgâr enerjisi, jeotermal enerjisi başlıca yenilenebilir enerji kaynaklarındandır. Bu çalışmada yenilenebilir enerji kaynaklarının en başında olan güneş enerjisi ve bina ile entegrasyosu sonucu oluşan alt sistemler olan doğal aydınlatma sistemleri ve fotovoltaiklerin günümüzdeki uygulamaları incelenmiştir. Araştırma sırasında sistemlerin bina ile bütünleşme şekil ve düzeyleri, tasarım ve yapısal özellikleri ve enerjisinin nasıl kullanıldığı incelenmiş ve tablolar oluşturularak gösterilmiştir. Sonuç olarak bütünleşme şekli ve özelliklerinin yapı formu, çevresel faktörler ve yapının gereksinimlerine göre farklılaştığı görülmüştür.

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CHAPTER 1

INTRODUCTION

Recent technological advancements led to new solar energy systems in building industry. Two basic ones have become prevalent nowadays; innovative daylighting systems and photovoltaics. Photovoltaics have been considered as the most reasonable and competitive renewable energy technologies in recent years (Jelle & Breivik, 2012a). They needed to be derived from two basic and global problems which are rapidly arisen after Industrial Revolution and now are called high energy demand and environmental pollution. Advanced daylighting systems named daylight redirecting systems are the other concerns in that sense, using solar energy to benefit from sunlight and daylight. They support the quantity of daylight inside the buildings, reducing the electricity usage for lighting and balancing cooling loads.

Energy demand increases day by day because of the mechanization, transportation, mining, etc., As the main resource of the energy was oil and the oil prices increased rapidly with the decision of reducing the production in 1973, the first global economic crisis after 1929 has happened eventually. Besides, the other reason for energy demand is due to the limited amount of fossil fuels. It is concerned that they can completely be consumed in the near future (Palm, 2017).

Energy production and industrialization produced huge amounts of wastes which polluted air, ground, and water, causing the environmental pollution. Global warming which is the name given to the increase in average temperatures measured on land, sea and air as a result of the greenhouse effect, is one of the most important consequences of the pollution (Schneider, 1989).

To overcome these problems, the attention was directed towards the renewable energy resources instead of oil and other resources which are limited and harmful to an environment like fossil fuels. As the sun is one of them, professionals and researchers developed technologies depending on its unlimited energy potential. Though the efficiency of such technologies has been an utmost concern, their integration for example, in building systems has become another inquiry for many scientists (Dubois &

Blomsterberg, 2011). When we examine the energy consumption structure of many industrialized countries, construction sector consumption has the largest share. For this reason, most of the precautions taken related to energy efficiency are on buildings. (Turhan, Gökçen, & Kazanasmaz, 2013).

1.1. Problem Identification

The production of recent daylighting systems and their application in buildings recently (Dávila, 2014; Thanachareonkit & Scartezzini, 2010) aim to achieve higher daylight performance which directly results in lower energy consumption and better visual comfort (IEA, 2000). Such widely known benefits of daylight's presence are better to work/or learning performance, motivation, and health (Kazanasmaz, Günaydın, & Binol, 2009; Leslie, 2003). There are many types of daylighting systems based on extensive ongoing researches. To overcome the complex geometry of these systems, such as light shelves, mirrored louvers and anidolic systems with light pipes, (IEA, 2000; Konis & Lee, 2015; S. K. Wittkopf, 2007; Stephen K. Wittkopf, Yuniarti, & Soon, 2006) innovative building integrated ones provide simple design solutions in terms of the method of application and maintenance. Some examples are parts of glazed area like laser cut panels, 3M films and acrylic lamellas between two sheets of glass etc. This feature makes them preferable also in existing buildings which are renovated and retrofitted. The application details and performance of daylight redirecting systems in test rooms and actual buildings have been evaluated in several studies and there are various products which are available in the market.

Introducing photovoltaics is significant in terms of its capability to produce electricity from solar energy. To increase its technical potential and efficiency, several researches have been conducted over years (Defaix, Van Sark, Worrell, & de Visser, 2012; Li, Lam, Chan, & Mak, 2009). Building integrated ones have become the recent applications in that sense. Instead of conventional photovoltaics which is stand-alone, building integrated ones are intended to decrease constructional costs, increase their operational performance, and support architectural appeals (Jelle, Breivik, & Røkenes, 2012).

It is known that buildings are responsible for 37% of energy consumptions approximately (Yılmaz, 2005). Hence, certain design principles are required to reduce the pollution to the minimum, realize the environmental conditions suitable for human health, choice of energy, elements and materials for the construction that maintain ecological balance (Uslusoy, 2012). These are the goals of the architect who has the responsibility to propose solutions about the living spaces which cause the energy demand and environmental pollution. In this context, it is revealed that the concepts of building systems and their integration are needed to be questioned once again with an architectural point of view and specifically the integration of a renewable energy technology—that is, building integrated daylight systems (BIDS) and photovoltaics (BIPV)—is necessarily required to be discussed regarding how it can be integrated with a building/ or building systems to increase its efficiency and work performance.

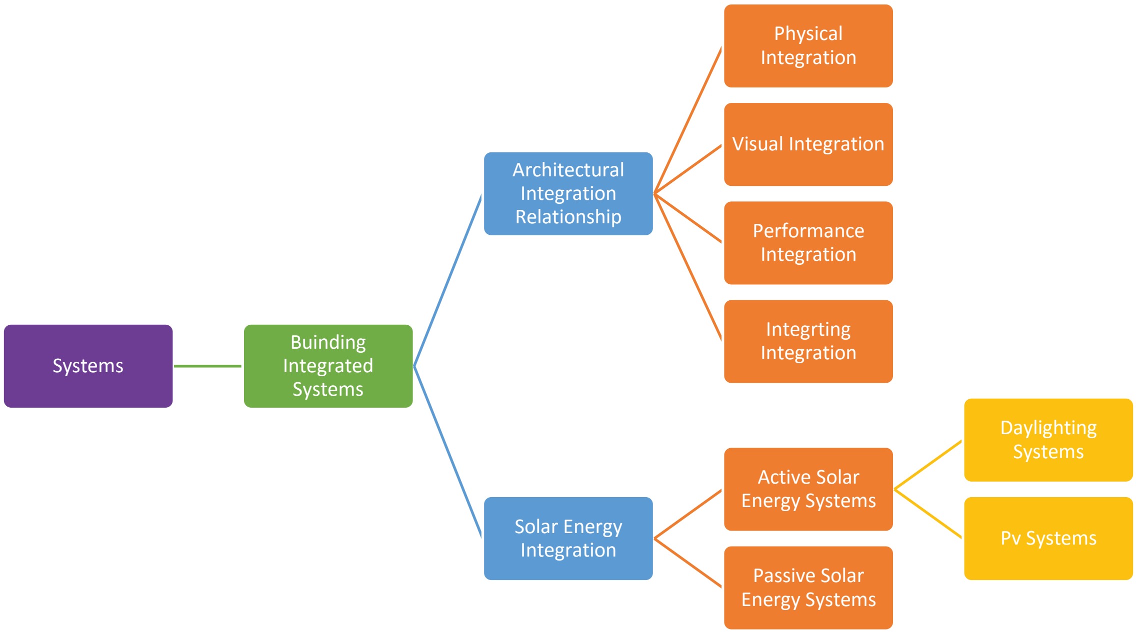
1.2. Aim

Incensement of energy demand and environmental pollution make the people think about researching for alternative energy sources, using the available energy sources effectively and efficiently.

The purpose of this study is to highlight the importance of advanced daylighting and photovoltaic systems in the context of integration of building systems and discuss how they are integrated in terms of adaptability and usability in visual, physical and energy efficiency aspects in architectural design. So, recent applications of building integrated daylighting (BIDS) and photovoltaic systems (BIPV) are overviewed comparatively and considered relatively.

1.3. Content and Methodology

Within the content of this study, building systems, integrated systems, solar energy integration with buildings, photovoltaic systems, daylighting systems, interpretation of photovoltaic system integration is investigated. Examples of recent applications of BIDS and BIPV are given as roof integrated systems, fenestration integrated systems, facade integrated systems, active system integrated PV and daylighting systems. Examples are chosen among the recent applications, in terms of the study of the point where technological development comes into this field. In this thesis, subjects are narrowed from general to special and this path is summarized in the following diagram.



The methodology contains a collection of data by a critical literature survey, examination of building integrated photovoltaic and daylighting systems examples, analysis of integration levels and forms and discussion of recent applications.

This study contains six Chapters. In Chapter 1, firstly, the problem is defined. After the definition of the problem, the aim and importance of the study, content, and methodology are explained.

In Chapter 2, building systems are explained with literature survey accordingly the subtitles of "system" notion, system types and the relationships of system notions with other disciplines. The meaning of the system, hierarchy of the system, features of the system is discussed.

In Chapter 3, integrated building systems are explained with literature survey accordingly the subtitles of "integrated" notion, architectural integration. Background and historical process of the architectural integration will be discussed. Besides the historical process, integration relationship with buildings is overviewed and analyzed in terms of their physical integration, visual integration and performance integration.

In Chapter 4, building envelope system which is one of the most common building systems which can be integrated with different functions are explained with the literature survey and existing samples accordingly the subtitles of building integrated photovoltaic systems (BIPVs) and building integrated daylighting systems (BIDSs). Roof, fenestration, facade and active system integrated PV systems are evaluated and application examples are given in this chapter.

In Chapter 5, the text includes discussions on adaptability of BIDS and BIPV in architectural design in terms visual impressions, potentials of visual comfort; their usability of in building performance in terms of visual, thermal integration and energy cost analyses.

In Chapter 6, which is the conclusion section, the results of the study are evaluated. Integration, system approach and innovations that come to an opinion after architectural considerations, the question of how the performances of building systems, which are gaining importance, can be addressed in the future.

CHAPTER 2

SYSTEM AND ARCHITECTURE

In this chapter, system notion, system types and the relationships of system notions with other disciplines is explained and discussed though literature survey.

2.1. System Notion

There is a lot of definition of "system" in literature. Generally, system is defined as "the whole" which is different from the sum of the parts that make up itself with features which are not in parts (Barlas). System was defined by Churchman as "a structure consisting of organized elements."(Churchman, 1979). Boulding definition of system was "Any situation without chaos." (Kenneth Ewart Boulding, 1985). Another definition of "system" was made by Langefors as *"A system is a set of entities with relations between them."* .(Langefors, 1995) According to Blanchard, "*A system is a bounded region of space-time, in which the component parts are associated in functional relationships.*" (Blanchard & Fabrycky, 1990).

Although, the philosophy of Aristotle is "the whole is greater than the sum of its parts" which is an initiative for system approach, in early centuries, "System approach" or "General Systems Theory" has begun to take shape in the early of the 19th century. George Wilhelm Hegel (1770-1831), a German philosopher, asserted basic concepts of system notion, but there was not enough interest at that time. A manifesto named "General Systems Theory" (GST) by Ludwig von Bertalanffy (1901-1972) has been one of the most important studies on this subject (Tosun, 2010).

Ludwig von Bertalanffy was an Austrian biologist known for interdisciplinary works that describe systems with interplay components, applicable to biology, cybernetics and other fields. Bertalanffy has expressed that "The whole is bigger than the sum of parts'. According to his work of "GST", the basic character of living things is organizations. Thus, the examination of individual parts or processes is unable to explain the life-event fully because this kind of research does not give any information about coordination between parts and processes (Kenneth E Boulding, 1956).

The parts of a whole, relationships between parts and relationships between system and environment must be understood to understand the organizational whole. It means that understanding the relationships between not only parts but also parts and environment, is getting important.

The necessary and sufficient conditions for a system to exist are as follows:

1. The formation of different components (from parts) represents the structure of this system.

2. The interaction between the components of the system interacts with each other in a certain order, which represents the function of this system.

3. A particular system can be thought of as a lower or upper system of another system in a hierarchical order (Evrendilek, 2004).

Besides the conditions, there are four important elements of system as:

1. The presence of multiple abstract or concrete components, which are parts of the system,

2. Relations between the components that save the system from a heap and connect it together,

3. All of these components,

4. Whole purpose (Erkut, 1989b).

Different types of systems may have different characteristics as well as some common features. Some of the common characters of the systems are:

- A system could be open or closed.
- The open system should be related to the external environment to live: it is necessary for the system to achieve a dynamic balance.
- Every system has at least a purpose. Every social system is established to achieve a certain purpose, and that is what gives the system its identity.
- The systems relate to the environment: within the architectural system (the whole), building systems are linked to the ecosystem, which provides integration as a design criterion.
- The system can learn deficiencies and defects in this respect thanks to feedback relation in the system.

- The system has no precise limits. However, in order to be able to talk about the existence of a system, it must have boundaries separating it from the outside. The organization must be distinguished from the outside.
- There are sub-systems of the system. Architectural systems consist of two sub-systems: building systems and ecosystems. These sub-systems that interact within themselves like structural system, external wall system, service system, etc.
- There is positive and negative ‘entropy’ in the system. There is a tendency to deteriorate activities, lose balance and eventually stop the system. Entropy refers to this tendency. Closed systems are under the influence of entropy. The increase in energy loss ultimately leads to the death of the system. Open systems have the ability to overcome (Tosun, 2010).

According to von Bertalanffy's GST, these are major aims of general system theory:

1. There is a general tendency to integrate to various science, natural and social.
2. Integration in that way seems to be focused on general theory of systems.
3. Theory in that way may be a significant means for aiming at exact theory in the non-physical fields of science.
4. Progressive unifying principles are running “vertically" through the universe of the special sciences. This theory brings us closer to the goal of the unity of science.
5. This can lead a much-needed integration in scientific education.

As a conclusion of system notion, system is a whole coming from parts, consists of relationships and interactions between the parts themselves and the environment and has a purpose.

Architecture occurs with systems like other sciences, arts, etc. For example, building envelope and roof are systems which provide energy transmission and conversion between internal and external environment, HVAC is a system which provides thermal comfort of building users and includes heating, ventilating and air conditioning systems.

Photovoltaic systems which are the main topic of this study are also one of the building system types with interaction to other building systems like roof system, building envelope system, etc.

2.2. System Types

The most known classifications of system types were made by Kenneth Boulding and Ludwig Bertalanffy. In this section, these two types of classification will be explained.

2.2.1. Kenneth Boulding's classification of the system

A classification of systems was made by Kenneth Boulding from simple to complex in nine articles:

1. Static structures: Atoms, molecules, crystals, biological structures perceived from electron microscopic to the macroscopic level. For instance, structural formulas of chemistry, anatomical description.

2. Clockworks: Simple dynamic system level with some specific motions. For instance, the solar system, the star systems, the operation of clocks, conventional physics such as laws of mechanics.

3. System with control mechanism: Cybernetics; feedback and information theory. These type of systems are able to adjust the balance automatically in terms of protection itself. For example, thermostats, machine guns.

4. Open systems: Self-protection and interaction with the environment. For instance: cells, organisms and flame.

5. Lower organisms: Plant-like organisms. Genetic- social level system influenced by the environment. For example, plants.

6. Animal systems: Increased mobility as it interacts with its environment, learning and beginnings of consciousness, feedbacks, autonomous behavior.

7. Man system is able to interact with the environment, mobility, self-awareness, as well as using the language and the symbols to communicate.

8. Sociocultural systems: Formed by groups of people like family, the army, the nation, the school, the group of friends. There are common goals, languages, values and belief systems and material and spiritual interests that keep all the people together and coalesce. These people approve that being in a certain place and order in certain hours or days, not only regarding interests but also emotionally. Because when a person is

alone, feels weak and wants to be with other people. Every human being is a part, element or sub-systems of his/her social system as if it were a system himself/herself.

9. Symbolic systems: Inevitable unknowns, events that are not fully explained. It is not possible to prove them like postulate and relativity in mathematics. However, their existences are accepted. For example, language, logic, mathematics, sciences, arts, etc. (Kenneth E Boulding, 1956; Tosun, 2010)

2.2.2. Ludwig von Bertalanffy's classification of the system

Another most known classification of systems was made by Ludwig von Bertalanffy:

1. Real system (Physical): The results are derived from the observations and are independent of the observer. They may be retrofit or natural, live or inanimate systems.

2. Conceptual System: Symbolic ideas like linguistics, mathematics, logic.

3. Abstract system: Really the same conceptual systems such as traffic model, a bridge.

4. Live and inanimate systems: Systems with biological characteristics are called living systems. The systems which do not consist of vitality in real meaning like birth and death, are inanimate systems. For example, structure and genetics, control and freedom.

5. Open and closed systems: Open systems are related to an environment which the system transfer material, energy or knowledge from it. Closed system is only open for knowledge (Erkut, 1989b).

2.3. The Relationships of System Notions with Other Disciplines

System approach is evaluated separately in different disciplines, and there is also an integration and interaction among the disciplines. As shown in Figure 2.1., systematics is related to, operational research, industrial engineering and cybernetics.

It is possible to see it as a sub-system in which different disciplines are at the same time forming the whole, interacting with each other as much as they are within the whole:

a. Systematics and management science: Management Science determines long, medium and short-term policies and decisions of system with scientific problem-solving techniques, considering the aims and resources of the organization.

b. Systematics and operational research: Operational research is an interdisciplinary scientific method to solve controllable problems of organizing systems in a way that best fits the integrated aims of the system.

c. Systematics and Cybernetics: Creator of the word "cybernetics" is Norbert Wiener. It means that control and communication theory about all animals and machines". Accordingly, Wiener, cybernetics represents the second industrial revolution. The aim of this new development is to ensure that the machinery taking the place of human muscles (1st industrial revolution) is controlled by machines (2nd industrial revolution). The primary field of cybernetics is the system concept.

d. Systematics and industrial engineering: Industrial engineering approaches to the systems from human-machine and other components in scientific method. For this reason, it is nearly related to system theory (Tosun, 2010).

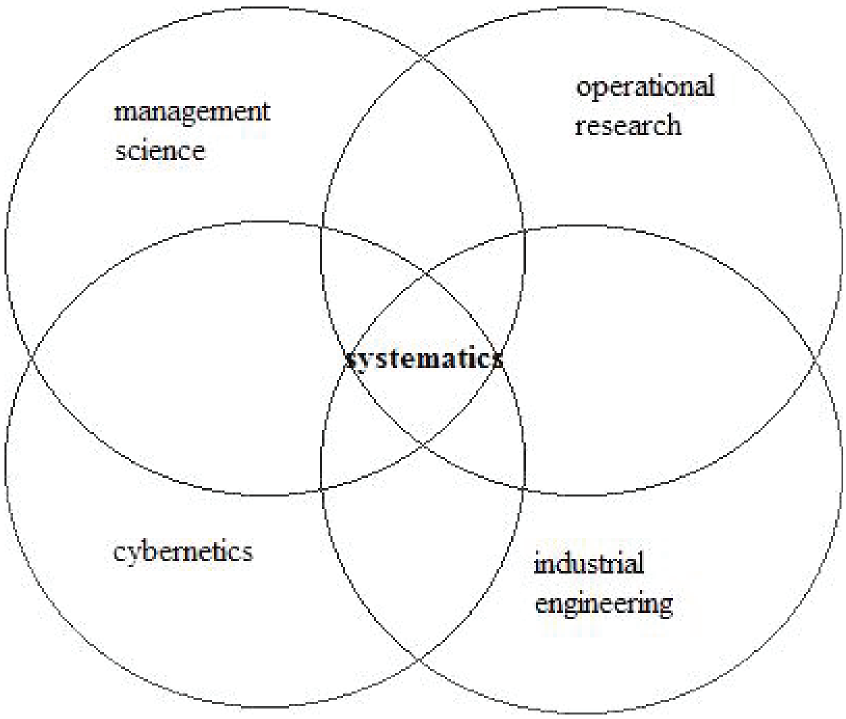


Figure 2.1. Relationship between systematics and other disciplines
(Erkut, 1989a)

It is obvious that system approach is related to other disciplines firstly, but also it is related to discipline of architecture. There are a lot of disciplines related to discipline of architecture like computer and information technology, environmental systems, mechanical and electrical installation technologies. This 'integration' takes a significant place in discipline of architecture.

2.4. Building Systems

Building is accepted as a system which is included different functional sub-systems, in architecture. The contribution of a great very of complex knowledge and components along with today's technology constitutes "the building system". Architects should take care about the coordination, organization and supervision of these components to achieve a building with successful performance (Çelebi, 1998).

There are a lot of studies which were realized about the analysis of the subsystems forming the building system. According to Markus, in the model developed by "Building Performance Research Unit (BPRU)", the system is defined under three main sub-systems as;

- Constructional System
- Contents System
- Services System (Markus, 1972)

Addition to BPRU's model, another study which was prepared by Broadbent, shows that there are four sub-systems as in the following:

- Structural System
- Space Separating System
- Services System
- Fitting Systems (Broadbent, 1973)

Accordingly, Bovill, analyzing the components required by function in details, as in the following:

- Structural System
- Acoustic System
- Vertical Transportation System

- Plumbing System
- Electrical System
- Lighting System
- HVAC System (Bovill, 1991)

Ehrenkrantz who classifies the choice of the building system contributing the maximum constructional performance in the educational centers, approaches the sub-systems, the relations between sub-systems and integration, makes a classification of basic systems as:

- Structure
- Partitions
- HVAC and Lighting Systems, in his project "School Construction Systems Development (SCSD) (Ehrenkrantz, 1989).

As a consequence, approaches of researchers to building system and sub-systems shows that the classification and definition of sub-systems related to their functions and tasks within the building. Basic sub-systems can be analyzed as follows,

- Structural System
- Building Envelope System
- Services Systems
- Space Separating Systems
- Circulation Systems
- Finishing Systems (Çelebi, 1994)

2.4.1. Building Sub-Systems

In this title, structural system, building envelope system, services systems, space separating systems, circulation systems and finishing systems are discussed as building sub-systems.

2.4.1.1. Structural System

There are loads which create internal stresses within the building as static loads and dynamic loads. Static loads are known as dead loads like self-weight, live loads like collected snow, collected rainwater, occupancy load, hydrostatic pressure and lateral soil pressure. Dynamic loads are known as earthquake loads, wind loads, and movements.

Structural system supports the building system to hold the dynamic and static loads, with the components: vertical and horizontal units (Figure 2.2). Vertical support components are known as load-bearing walls and columns. Horizontal spanning units are known as a beam, plate, truss, space frame, folded plate, shell, etc.

It is expected that structural system is the most long lasting, permanent system among the sub-systems because it affects building's and other sub-systems' security and health.

Structural system can be categorized as followings:

- Massive and Solid Systems, like load bearing system
- Frame Systems, like grid systems consisting columns and beams
- Composite Systems, including massive and skeletal system together.

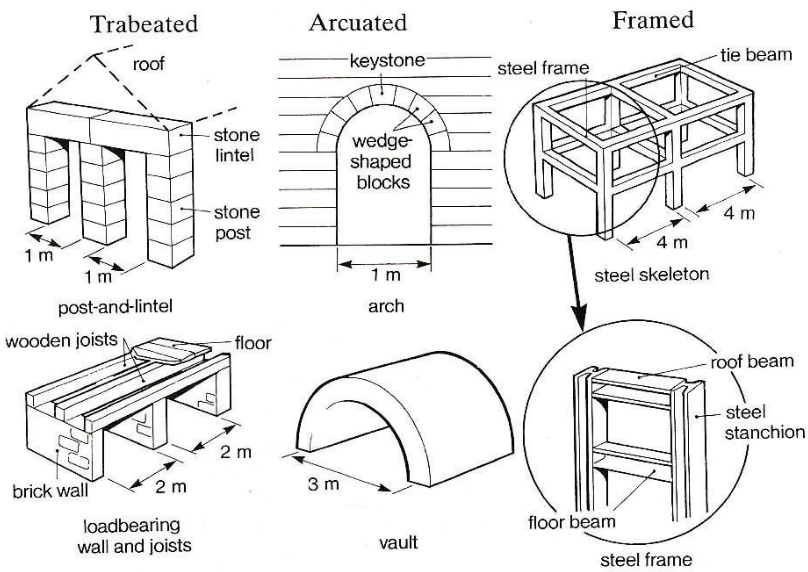


Figure 2.2. Structural system examples
(Cumming, 1991b).

2.4.1.2. Building Envelope System

Building envelope system divides the building interior environment from the exterior environment to provide users comfort requirements with providing a barrier and filter against environmental agents (Figure 2.3).

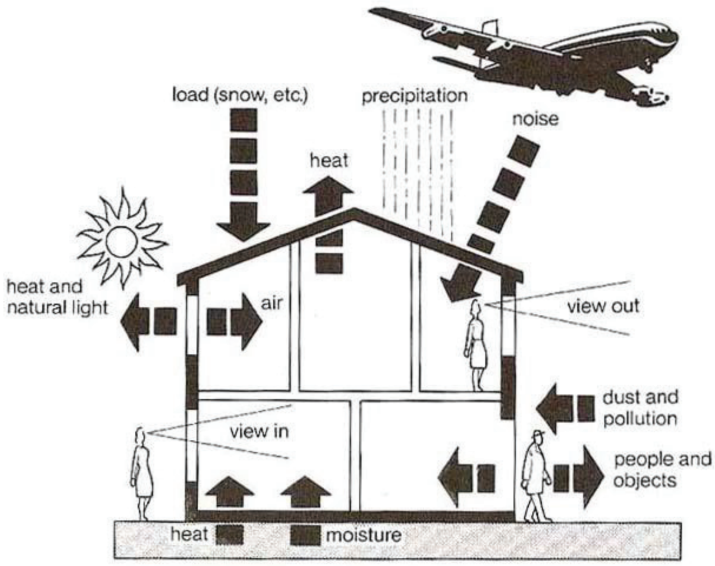


Figure 2.3. Building envelope system
(Cumming, 1991a)

There is two main sub-sub-system of building envelope system as non-load bearing systems and load bearing systems. Non-load bearing systems are independent of structural system and transfers self-weight load, earthquake load and wind load to structural systems. Load bearing walls are both building envelope system and building structural system. Providing strength and stability against the loads and separating interior building environment from external environment is duty of these types of walls.

Other building envelope systems' sub-sub-system is the roof system which is a slapped element of building separating external environment from internal environment. Providing user comfort requirements like thermal comfort, acoustical comfort, visual comfort and removing rain water as quick as possible be examples of duty of roof systems.

Besides these described utilities, the building envelope system has a wide and different utilization like minimizing the load on the ventilating, climatization, artificial heating and lighting, producing energy thanks to the contemporary construction and production technologies and new materials.

2.4.1.3. Services Systems

Services systems make buildings comfortable, functional, efficient and safe with different sub-sub-systems which can be categorized as

- Heating system
- Ventilation system
- Climatization system
- Lighting system
- Electrical, electronic and communication systems
- Plumbing systems,

Regarding their functions and task (Çelebi, 1998) (Fig. 2.4). They are generally used when building envelope systems are insufficient.

There are innovations in services systems with technological innovation. Advancing technology and innovations on services systems affect levels and types of subsystems' integration.

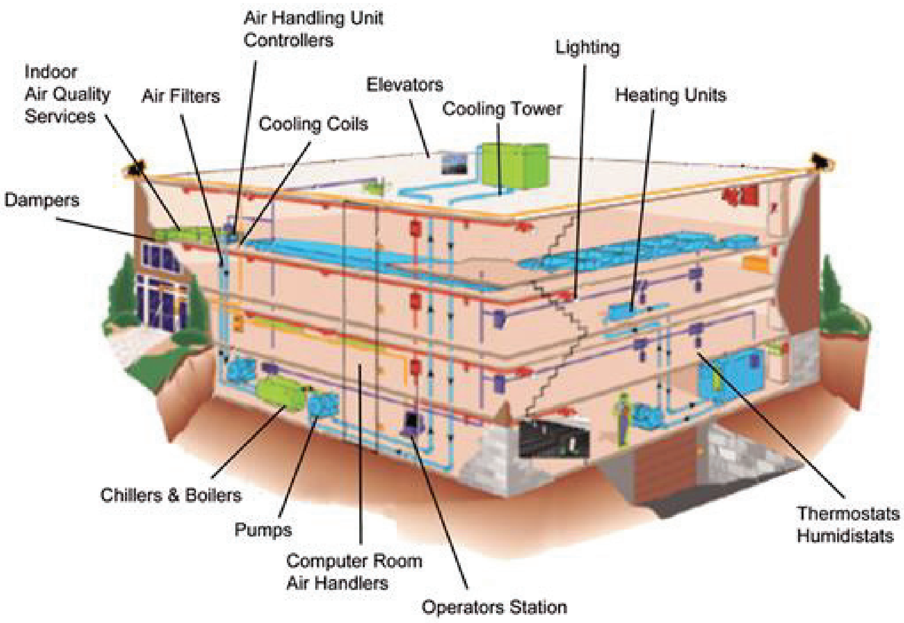


Figure 2.4. Building services system

(Technovator, 2017)

2.4.1.4. Space Separating Systems

Function of the space separating systems is to provide the physical space separation to specify quality of space like visual and/or acoustical comfort, insulation, form and dimensions of space. Considering or non-considering of flexibility is the main factor of specifying the sub-sub-systems of space separating systems. So, there are two main sub-sub-systems of space separating systems:

- Demountable systems
- Permanent systems (Çelebi, 1998)

Demountable components provide an opportunity to construct long- lasting buildings from the point of function thanks to its flexibility (Çelebi, 1998)

2.4.1.5. Circulation Systems

Function of the circulation systems is to provide access to different levels and spaces with vertical and horizontal elements (Fig. 2.5). Vertical elements provide transportation between the spaces on the different flats. They have divided two main groups as architectural elements like stairs and ramps, and mechanical systems like escalators and elevators. Horizontal elements provide to establish the relation between the exterior and interior spaces and transportation between the spaces on the same flat. Entrance hall, corridors, mobile bands or movable bands are examples of horizontal circulation systems.

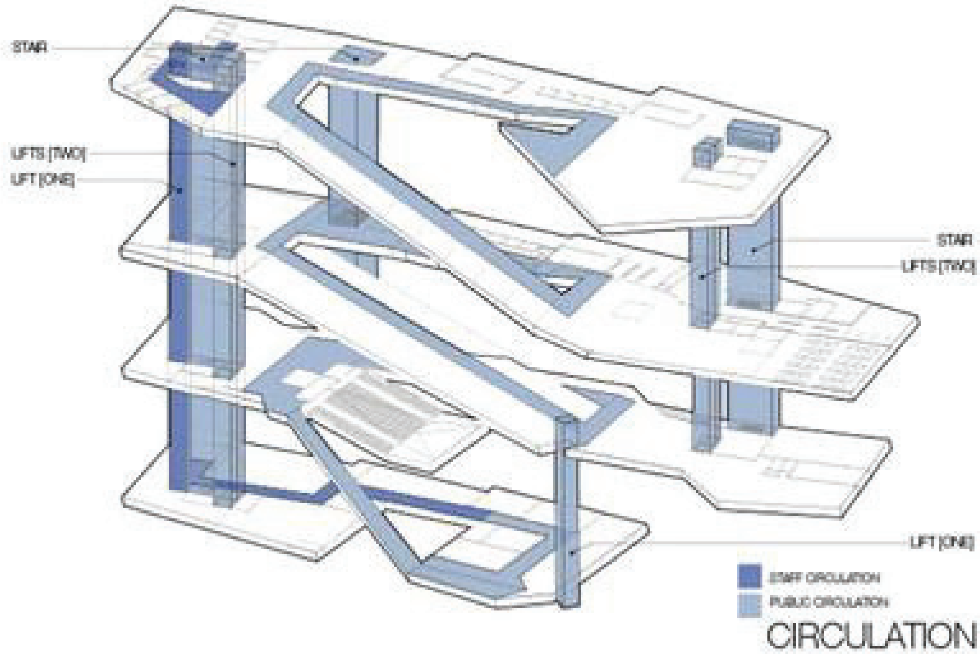


Figure 2.5. Building circulation systems in Helsinki Library
(Archinect, 2017)

2.4.1.6. Finishing Systems

The other system, except the basic subsystems mentioned above, is consisted of this particular system. The sub-sub-systems of finishing systems can be categorized as:

- Finishing systems (claddings/coatings, suspended flooring with service ducts below, suspended ceilings, carpentry, paints, etc.)
- Furnishing system
- Equipment's system stand by activities (TVs, PCs, mobile lighting fixtures, and etc.)

The most important characteristic of these systems is that their components can be changed and renewed easily (Çelebi, 1998).

CHAPTER 3

INTEGRATED SYSTEMS

In this chapter, integration notion, architectural integration with the historical process and integration relationship with building, solar energy integration with buildings as passive and active solar energy systems will be explained, discussed and exemplified with literature survey.

3.1. Integration Notion

The term of 'whole' is not a new notion, since Jan Christian Smuts, a South African Prime Minister and philosopher, coined the term 'holism', in 1926. He mentioned that everything in nature is not individual, is a part of nature, only patterns and arrangements that contribute to the whole. Buckminster Fuller, an American philosopher, engineer, and architect, said that: "*Synergy is the only word in our language that means behavior of whole systems, unpredicted by the separately observed behaviors of the system's parts or any subassembly of the system's parts.*", when he was studying on a space program in 1969 (Prowler, 2014). Synergy notion is thought with integration notion that defines as providing service from every part like other parts of whole.

According to Barton, 'integration' means that incorporation of diverse parts or groups into well-ordered whole. In other saying, the relation of parts with the whole is defined as 'integration' (Barton, Fryer, & Highfield, 1983).

3.2. Architectural Integration

As stated above, ‘integration’ is gathering different components and groups to create a well-designed whole. Even though all the subsystems are considered as a ‘whole’, they actually integrated to form a ‘greater whole’ (Angyal, 1969). In other words, all subsystems create wholeness of building system (Çelebi, 1998).

The term of integration is used in order to blend several sub-systems and form an altogether functional building, in architecture. Thus, it is aimed that building meets the expected performance criteria. These criteria are specified as:

- Maintaining the wholeness of building,
- Increasement of the level of comfort of users,
- Healthcare,
- Safety issues,
- Volumetric performance,
- Thermal performance,
- Indoor air quality,
- Acoustics performance,
- Visual performance,
- Functional performance and more (Çelebi, 1998)

Wholeness of building should be considered not only short term but also long term, according to these criteria. For this reason, the aim of integration is harmonizing building subsystems as function and providing an integration that answers the level criteria of the highest building performance (Rush, 1986).

Integrated building design consists of two components as integrated design approach and integrated teamwork. Integrated design approach is a perspective which deals with harmony, integration and participation of all subsystems like technique, plan, construction, building materials, systems (Smith, 2010). Integrated teamwork is an interdisciplinary collaboration like architecture, engineering, sociology, etc. (Tosun, 2010)

Different kind of knowledge should become together to design a building. Integrated building design contains various participants like users of building, experts of building technology, architects, designers, civil engineers, sanitary and mechanical engineering, electrical engineering and participants from other exporting areas. It is the key to successful integrated building design (Smith, 2010).

When a building is designed, it is considered that damages are rising in the future from a socioeconomic background as well as the physical pattern of the area or city that the building is in (Bourdeau, 1999). Sustainability in building is related to progress, using local resources judiciously and improvement of locals' life quality.

Integrated building design is important for existing buildings constructed with traditional methods as well as high-tech buildings. However, the implementation of criteria that provides efficiency and building integration is harder. If the building had been designed and environment responsive technologies had been tried to existing building, making the existing building 'green sustainable' would have been more expensive and there would have been a low architectural integration. Below graph shows that the earlier stage of design integration becomes a part of the process, the more successful the results will be (Figure 3.1). On the contrary, if a building is designed as usual and Green Technologies are applied later, the results will probably be poorly integrated into the overall building design objectives, and the greening strategies will be expensive to implement (Smith, 2010).

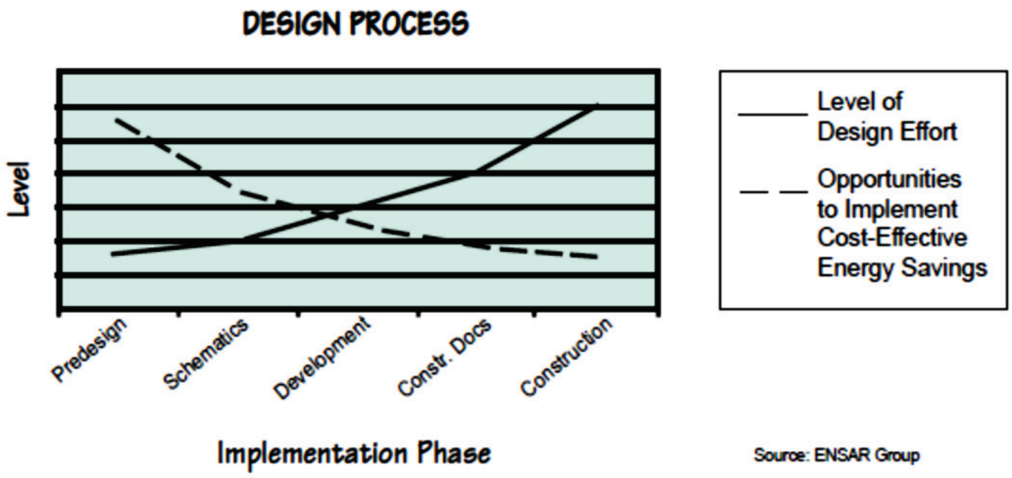


Figure 3.1. Relation between design process and integration
(Smith, 2010)

The process of integrated building design follows four steps as:

- Determining main problem,
- Determining solutions,
- Evaluation of performance of every singular strategy,
- Grouping strategies accordingly their performances (Tosun, 2010).

Design process is created by election of strategies, starting to design and repeating the analyses based on these four steps (Tosun, 2010). The other work shows that design and analysis process for developing integrated building designs consists:

- Establishing a base case
- Identifying range of solutions
- Evaluating the performance of individual strategies
- Grouping strategies that are high performers
- Selecting strategies, refining the design and repeating the analysis (Wilson, 2001)

3.2.1. Integration Relationship with Buildings

Each system consists of components and relationships between components which reveal integration potential of intersystem and between system elements.

There are many studies about level and forms of building system integration. Accordingly Çakmak (2006), there are five relation levels as:

- Remote: Systems are physically separated and still coordinated.
- Touching: One of the systems remains on the other and it is in a position to touch with this system.
- Connected: Systems are permanently connected to each other in various forms.
- Meshed: Systems occupy the same space.
- Unified: The systems share the physical form of each other at the point of integration and they are no longer separate from each other.

According to Bachman (2004), there are three classifications about potentials of architectural systems as physical integration, visual integration and performance integration. In this study, selected examples of building integrated photovoltaic and daylighting systems will be examined according to Bachman's classification which is explained below in detail.

3.2.1.1. Physical Integration

Harmony between building components is a necessity. These components share a common space in building and interact in this space in different ways. In other words, physical integration contains interaction models of components and systems in common area. In standard practice, for instance, ceilings and floorings are generally divided into different zones: recessed lighting at the bottom and after that space for ducts, and then a zone for the depth of structure to support the floor above. These separated sections prevent 'interference' between systems by providing sufficient space for each individual remote system. Meshing the systems, by running the ducts between light fixtures, requires physical integration carefully (Bachman, 2004).

Connection between components of building systems, in general constitutes another aspect of physical integration where architectural details are generated. Structural, thermal and physical integration at joints between different materials must be considered carefully. Their integration is important as well as their separation in space (Bachman, 2004).

3.2.1.2. Visual Integration

Components of building systems come together to complete the appearance of the building. This is true of the overall visual idea of the building from individual elements to the systems and whole building. Colour, shape, size, and placement can be used to make an effect which is desired. So, it is obvious that visual properties of many components are significant for integration (Bachman, 2004).

Visual harmony between building elements and their agreement with the planned visual effect of design generally provide some opportunities to combine technical requirements with aesthetic targets. For example, lighting fixtures, HVAC system components like air-conditioning and plumbing fixtures are going to be a presence in the building in any case. Trying to cover or ignoring them is futile. In this situation, architects should be able to select, configure and deploy building elements in ways that satisfy visual and functional objectives (Bachman, 2004).

3.2.1.3. Performance Integration

Performance integration is related to share functions. For instance, load bearing wall can have assignments about both envelope and structure. In other words, more than one assignment can be provided with one building component. This approach can lead to save cost and reduce complexity if it is appropriate to the task at hand (Bachman, 2004).

3.2.1.4. Integrating Integration

Term of integrating integration means where three modes of integration: physical, visual and performance integration come together. For instance, the synthesis of major systems is characterized by unification and meshing among structure, envelope, services and interior systems and is incarnated by the reiterated use of a concrete vault in Louis Kahn's design at Kimbell Art Museum. The one element's assignments are structural support, envelope enclosure, forming interior space and lighting. So, the physical, visual and performance benefits are complete and convincing (Bachman, 2004).

3.3. Solar Energy Integration with Buildings

Basic reasons such as increasing energy demand with the development of technology, running out of fossil fuels in near future and fossil fuels used in energy production cause harm to environment and environmental pollution have caused the search for alternative sources in energy production. Solar energy is one of the most common alternative energy sources used in housing, industry, agriculture, producing electric energy, etc. Because solar energy is the most abundant, inexhaustible and clean one of all the alternative, renewable energy sources (Peng, Huang, & Wu, 2011). It can be used at buildings easily for different tasks in common ways. Solar energy technologies have a widespread usage in terms of method, material and technology. Such technologies are available for heating, cooling, ventilating and lighting purposes. Lighting energy can be produced as well as benefitting from daylight to illuminate interiors.

Potential of solar energy could be seen in Figure 3.2. In order to give a more concrete example of this potential, the Sun's 1-second irradiation on the Earth (when losses are ignored) corresponds to about 1700 times the annual energy production of Turkey (Kıyançiçek, 2013). According to Nowicki's (2015) work, the Earth receives approximately 170 MGw of power from the Sun, which is millions of times greater than global energy demand.

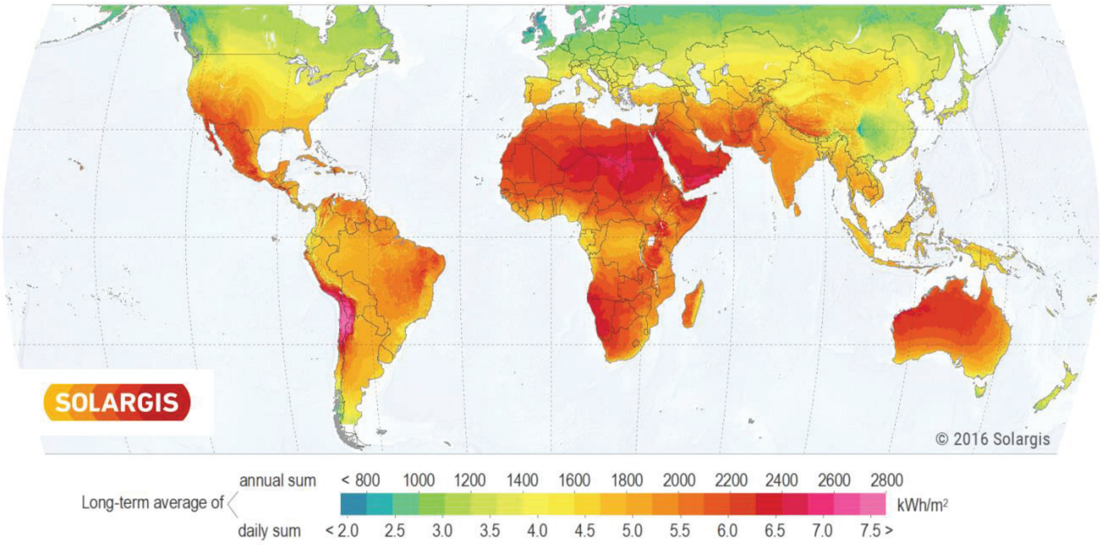


Figure 3.2. Global horizontal irradiation potential
(Solargis, 2017)

In order to decrease building energy consumption, different precautions or design criteria have been taken or different technologies have been improved by different disciplines like designers, architects, mechanical engineers and etc. In other words, a key to success in decreasing energy use that "designing new and innovative buildings requires a multidisciplinary design team" and that "it is necessary to consider the building as a system where the different technologies used are integral parts of the whole" (Hestnes, 1999)

The importance of using such a solar integrated design approach to coping with high energy demand and environmental pollution has been clearly demonstrated in The International Energy Agency' Solar Heating and Cooling Programme's Task 13: Advanced Solar Low Energy Buildings. According to one of the studies by IEA Task 13 (Fig. 3.3.), the footprint of a solar office building is smaller than typical reference office building that indicates better performance (Hestnes, 1999). As shown in Figure 3.3., solar integrated design approach provides decreasing of a footprint in different ways.

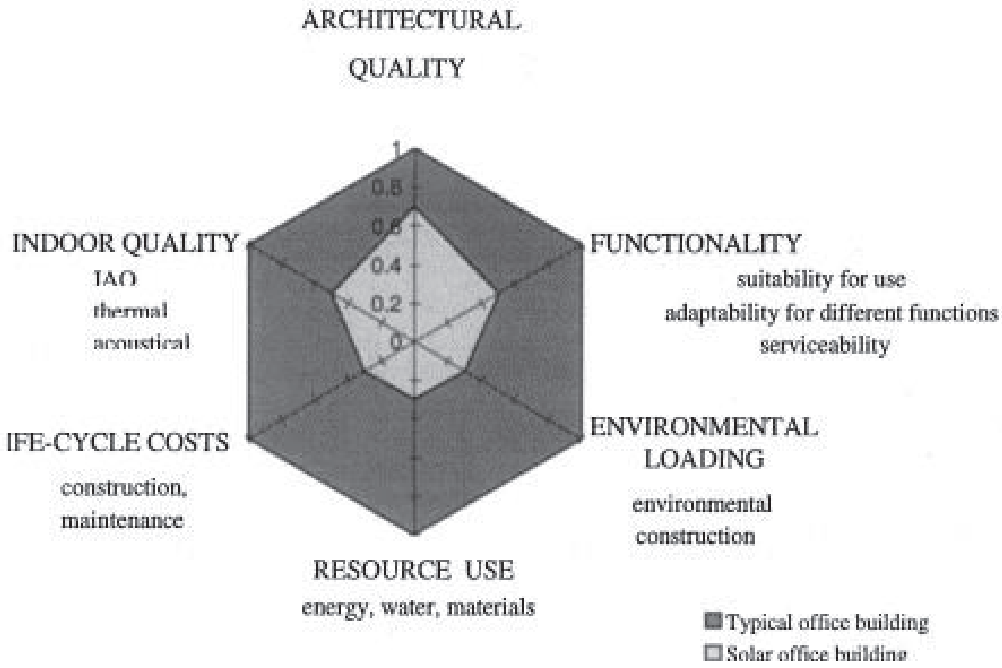


Figure 3.3. An example of a footprint of a solar office building and typical office building (Hestnes, 1999)

Solar energy which is the most used renewable energy in buildings systems can be used in different ways. Three main conventional solar energy systems which are integrated into building systems are, first passive systems using direct heat gain and thermal mass characteristics of building materials; second active systems capturing and storing solar gain to technical devices (solar cells) to produce energy for heating and electricity and third daylighting systems.

3.3.1. Passive Solar Energy Systems

Passive solar energy systems gain energy from the Sun. These systems have three stages as a collection, storage and distribution:

- Collection: Solar heat is collated with greenhouses, atriums, wide span double glazed windows accordingly buildings direction.
- Storage: A part of solar energy can be used instantly, remaining part of solar energy spread to floor and walls so-called as ‘thermal mass’, to use later. This thermal mass can be stone, brick or water.

- Distribution: Heat which is stored on floor and walls, spreads to the environment with the way of radiation and transport. Fans and Ventilators are also used for transportation.

3.3.1.1. Solar Windows

Direct solar gain is achieved by principally, the energy passing through the large openings during winter. The energy is stored at building systems such as the walls, on the roof or on the floor of the building or at all, at the size of the day allowed by architecture. After that, this energy is dissipated to building environment by convection if the need occurs (Figure 3.4). In the system, it is significant that orientation and dimension of the openings where the heat is collected and stored, and the wall and roof surfaces have enough solar energy input and the lowest heat loss (Demircan & Gültekin, 2017).

A well-designed window facing south with an appropriate size and location can act as a key role in satisfying the above process. Considering the right timing to get efficient sunlight and solar heat, and choosing the right type of glazing are necessary. (Anderson, 1981) Openings with heat input are shaded with shading elements (louvers, blinds, vertical or horizontal sun breakers, etc.) to minimize direct heat gain during summer or; are applied with movable insulations to avoid unwanted heat loss when sunlight is not active.

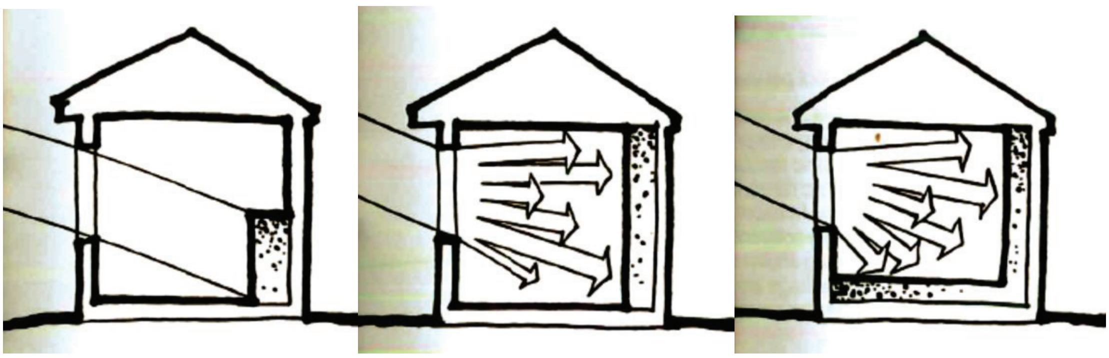


Figure 3.4. Solar heat gain from solar windows
(Anderson, 1981)

3.3.1.2. Solar Walls

Indirect solar gain systems function with the principle of transmitting heat from the wall through the glass surface and the thermal mass placed on behind of the glass surface by radiation or convection to interior space (Bekar, 2007). The heat stored in the thermal mass which continues to release to the heat in the evening hours. So the walls and the ceilings do not get cold, they remain warm. However, there are negative aspects of the system that the heat of the mass is late in the morning, and the inability to control the heat transferred to the interior (Alparslan, 2010). The most common systems are Trombe wall system, water wall system, roof pond system, sunspace system, water heater system and a solar chimney.

Trombe wall system consists of a glass surface and a thermal mass that stores energy places behind it. Thermal mass can generally be black concrete, mud, brick or stone. The way system works that solar radiation passes through the glass and is absorbed by the mass wall. Then, transfer conduits are opened to the upper and lower parts of the massive wall in order to convey the heated air to the interior and the cooled air to the space between glass and mass wall with convection. Trombe wall system is shown schematically in the Figure 3.5.

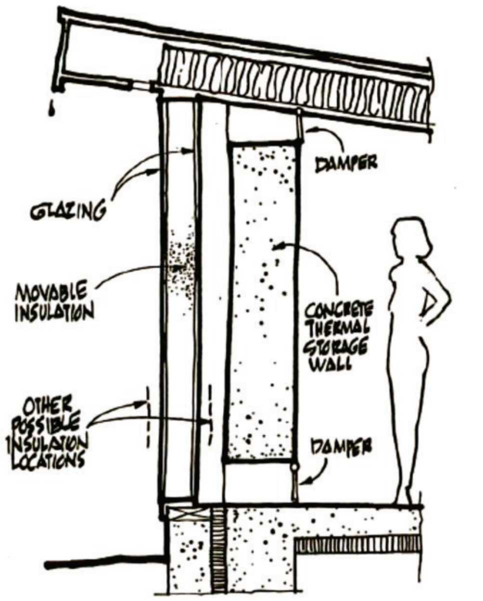


Figure 3.5. Trombe wall system principle
(Anderson, 1981)

Water wall system involves water/ or fluid in black containers. Waters acts like thermal mass (Figure 3.6). Solar radiation passes through the glass and is absorbed by the containers' black surface. It leads to heat the water. The heated drums transfer their energy into the interior with radiation and transport. To prevent heat loss, the wall-shaped insulated covers are closed in the night-time. The most important issue is evaporation, corrosion and leakage (Uslusoy, 2012).

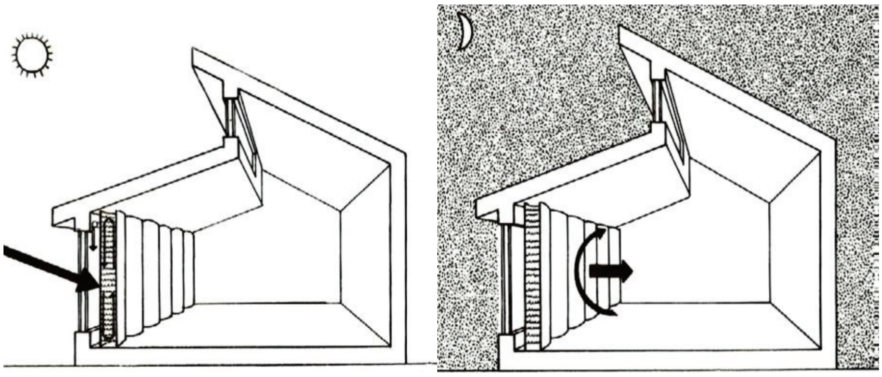


Figure 3.6. Water wall system principal, daytime and nighttime (Alparslan, 2010)

3.3.1.3. Solar Roofs

The principles of solar roofs are similar to solar walls. One type is *roof pond system* which is based on the principle that solar energy stored in a pool or plastic bags filled with water is transferred into the interior from ceiling. So, system requires a body of water to be located on the roof, protected and controlled by exterior movable insulation. The ceiling system corresponds to this type of solar systems. In winter, movable insulation is opened to provide heat gain during the daytime and is closed to prevent heat loss during the night-time (Figure 3.7). In summer, movable insulation is closed in order to prevent heat gain during the daytime and is opened in order to provide heat loss during the night-time (Uslusoy, 2012)(Figure 3.8).

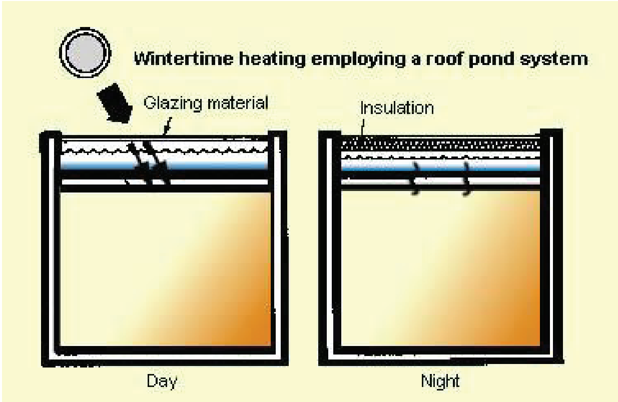


Figure 3.7. Roof pond system principal in winter
(Al-Jamal, Alameddine, Al-Shami, & Shaban, 1988)

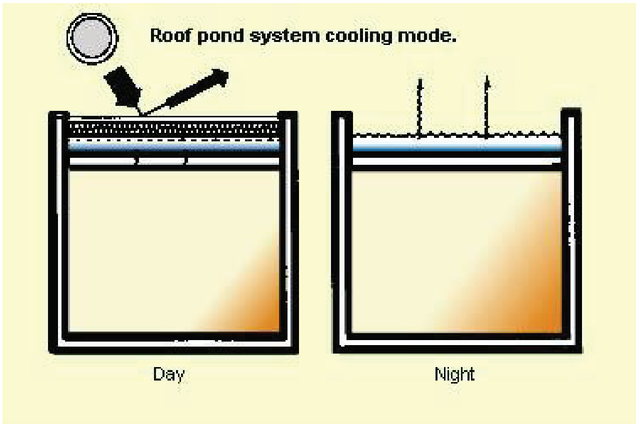


Figure 3.8. Roof pond system principal in summer
(Al-Jamal et al., 1988)

3.3.1.4. Solar Rooms

Solar rooms collect solar energy in a location separate is desired to be heated. Sunspaces are built on the southern side of building for direct solar radiation gain (Figure 3.9.). Basically, the solar radiation is stored in the sunspace- also known as a greenhouse- and converted into heat which is sent to other spaces of a building or to outside of the building. Sunspaces can be designed for only single level or multiple level heights and can serve more than one space (Danacı & Gültekin, 2009). They immediately can heat the house; however, precautions should be taken to lose heat during night time because of large glazings.

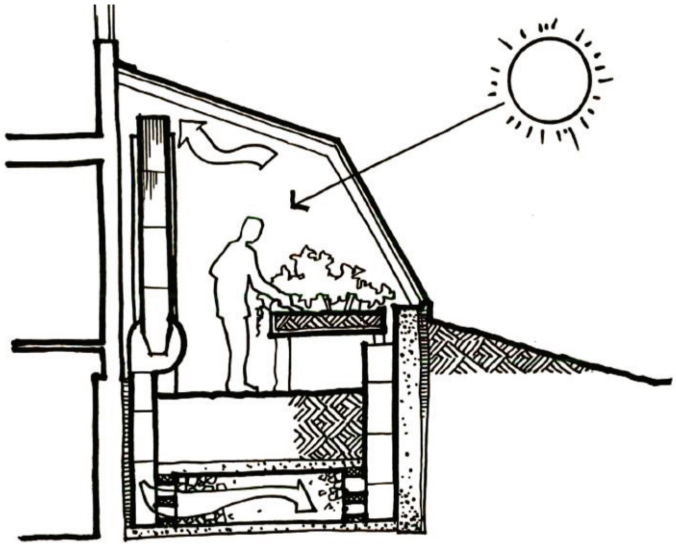


Figure 3.9. Solar room

(Anderson, 1981)

Water heater system which is known as thermosyphon system involves a separate space which is adjacent to the building to provide a direct connection between solar radiation and living space (Figure 3.10.). The cold air or liquid is warmed up through the solar radiation when it is at the lowest level of the collector space and moves up to the storage mass. There is a circulation of hot and cold air and liquid. The collecting space consists of dark wood or metal surface that are absorbed. So, heat is conveyed to thermal mass with this collecting area and heats the air or liquid (Özdemir, 2005).

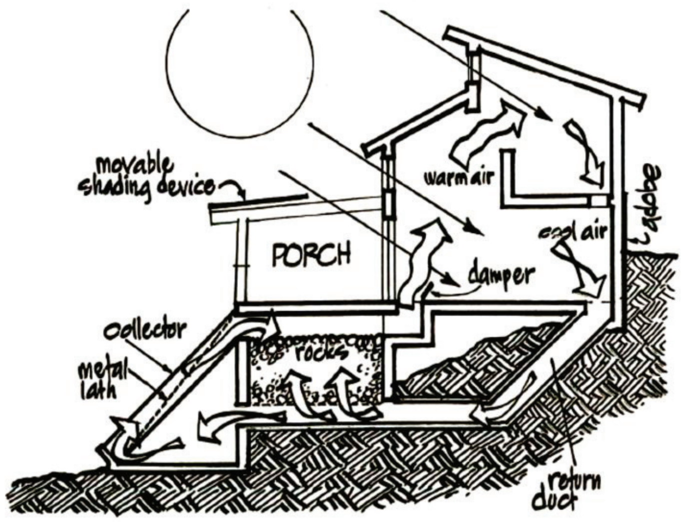


Figure 3.10. Thermosyphon system

(Anderson, 1981)

3.3.1.5. Solar Chimneys

Solar chimney is a natural passive solar system which utilizes solar energy to generate buoyancy effect that drives airflow through the air canal (Figure 3.11). Principle of solar chimney is converting thermal energy into kinetic energy of air movement (Kalkan & Dağtekin, 2015). Solar chimney is designed not to exceed the height of the roof on the southern facade of the building. The outer surface of chimney is covered with a transparent glass coating and the inner surface is covered with a dark metal material to absorb the solar radiation. The air in the chimney heats up by solar radiation and goes out from the chimney. When the wind speed is low, the revolving wind scoop placed in the upper part of the chimney accelerates the venting of the air. Air circulation and natural ventilation is provided with cool air entering from the bottom of chimney (Alparslan, 2010).

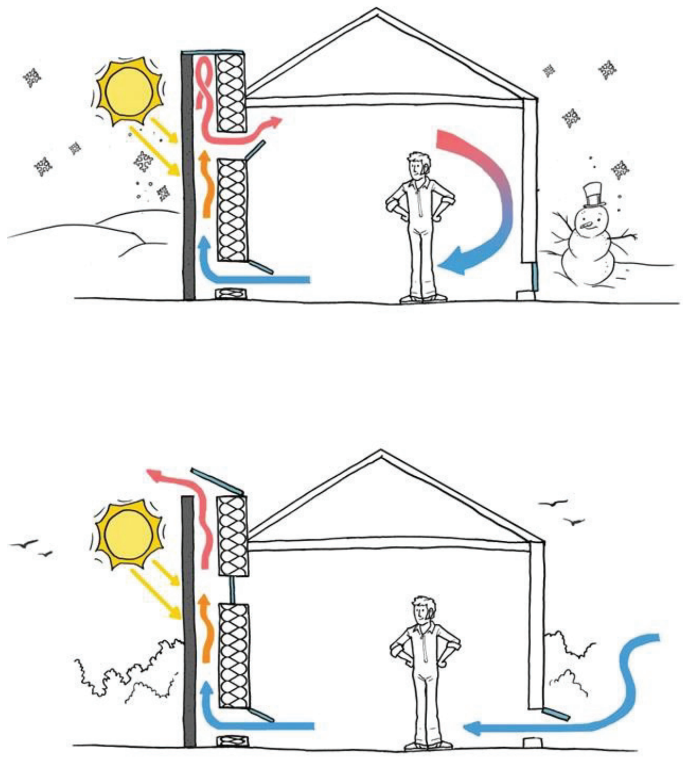


Figure 3.11. Solar chimney system principal for heating and cooling (Özdemir, 2005)

3.3.2. Active Solar Energy Systems

Active solar energy systems are defined as using of solar energy through technical equipment. In other words, they convert the solar energy through different technologies, to useful energy (electricity and heat energy) that can be used to support the building service systems.

Solar collectors and photovoltaic are two types of active solar energy systems used in buildings.

3.3.2.1. Solar Collectors

Solar collectors are devices that collect solar energy and transfer it as heat to a liquid in order to produce hot water from solar energy. Working principle of solar collectors is collecting and intensifying radiation emitted from the Sun (Uslusoy, 2012). The gained heat from collectors warms the water in the system and the hot water can be pumped to the hot water boilers or to the heat generators of the air conditioners (Danacı & Gültekin, 2009). The main problem of solar collectors is freezing during winter time. But it can be solved with insulated collectors, pipes and storage spaces. The efficiency of collectors is defined as the ratio of collecting energy to total energy coming to the collector surface (Özdoğan, 2005). To increase the efficiency of collectors, collectors must be settled with right angle accordingly to the Sun.

Types of solar collectors are flat plate solar collectors, evacuated tube solar collectors and batch solar collectors (Figure 3.12, 3.13 and 3.14).

The most commonly used collector in building is flat plate solar collectors. Components of flat plate collectors are enclosure which is a box or frame holding all components together; glazing which is a transparent cover over the enclosure to allow the sunlight to pass through to the absorber; glazing frame which holds enclosure and glazing together; insulation which is a material between absorber and the surfaces to prevent heat loss by conduction; absorber which absorb and transfer high levels of solar energy; flow tubes which are highly conductive metal tubes transferring heat from the absorber to the fluid (Florida, 2006).

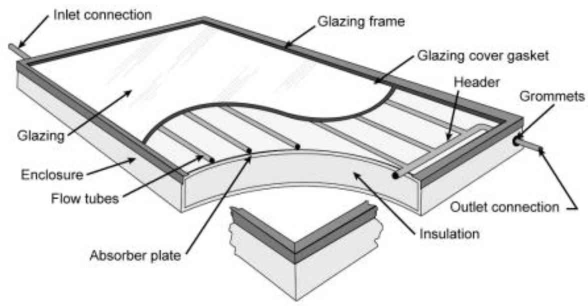


Figure 3.12. Flat plate solar collector
(Florida, 2006)

Of this type, there is a large heat loss are caused by convection from glass envelope. Whereas, there is a vacuum created between the transparent glass tube where outside of the evacuated tube collectors and the black painted tube inside in order to reduce convection losses. So, it can be said that evacuated tube solar collectors are more efficient than flat plate solar collectors (Alparslan, 2010). The tubes consist of highly tempered glass vacuum tubes for glazing and insulation, and absorber surface inside the vacuum tube for reducing heat losses (Florida, 2006).

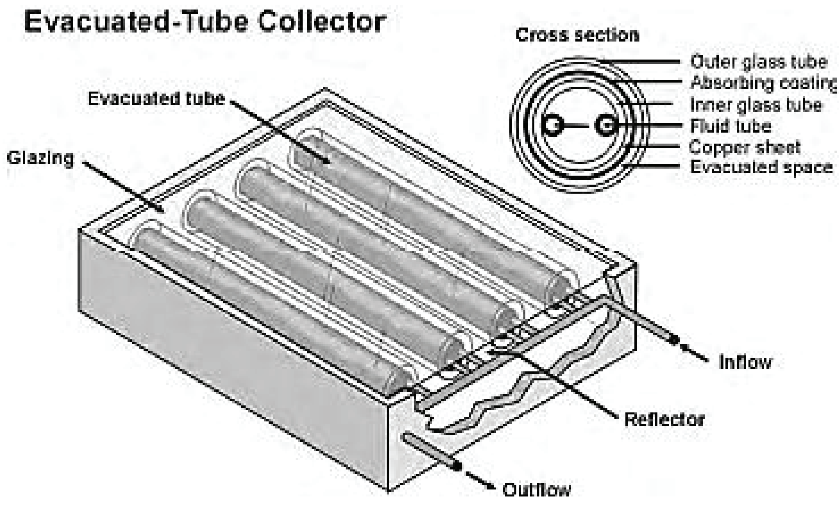


Figure 3.13. Evacuated tube solar collector
(Florida, 2006)

Batch solar collectors are a simple installation that consists of one or few black painted metal tanks that are placed inside an insulated box. Southern side of box is made of glass. The working principle is similar as flat plate collectors. The only difference between them is that the water is gathered in a bigger volume and the tank's glass surface instead of the absorber (Baker & Wykes, 1986).

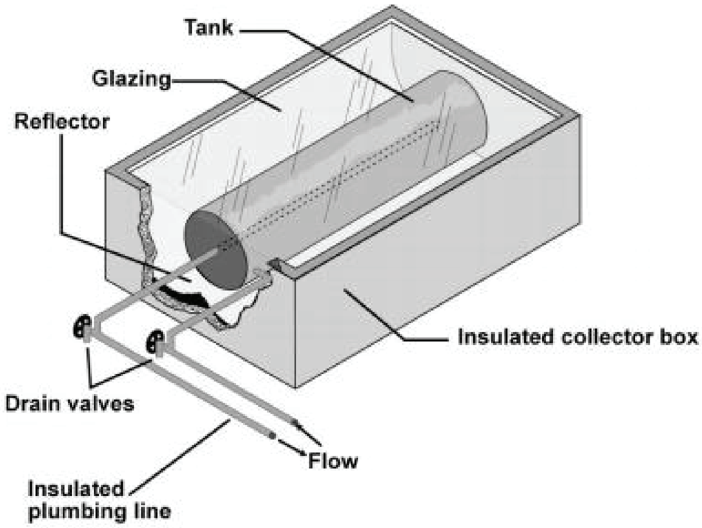


Figure 3.14. Batch solar collector
(Baker & Wykes, 1986)

3.3.2.2. Solar Cells (Photovoltaics) (PVs)

*Solar cells (photovoltaics) (PV*s) are technologies which generate electricity from solar energy. Such renewable energy advancement does not need any conventional fossil fuel sources (Stamatakis, Mandalaki, & Tsoutsos, 2016). The working principle of photovoltaics is that sunlight breaks the electrons on the plate and causes the electron flow to move. And this electron movement results in direct current energy (Danacı & Gültekin, 2009). Solar cells are commonly used nowadays thanks to improvement of solar energy industry. They are thought as one of the most important renewable energy technology. They can be used in buildings (Figure 3.15) and solar farms (Figure 3.16.).

Figure 3.15. Photovoltaic systems at building
(Inhabitat, 2017)

Figure 3.16. Solar farm in China
(Telegraph, 2017)

There are some advantages and disadvantages of photovoltaic systems (EPIA, 2015; Pagliaro, Ciriminna, & Palmisano, 2008):

Advantages:

- The energy source is endless and free.
- There are no moving parts that cause wearing or breaking down of PV system.
- Very low maintenance is required to keep the system running.
- System is modular and can be easily installed everywhere.

- Noise, harmful emissions and pollutant gases are not released during operation.

Disadvantages:

- The energy source is dispersed and not constant.
- No economic energy storage systems exist.
- Installation cost is high.
- Energy costs are higher than traditional fuels (especially fossil based fuels).

Although initial investment cost is high, ecological cost is a low and ecological gain is high in PVs systems. That is the reason why photovoltaic systems are so important for ecological design. As it is said before, there is a huge solar energy potential which has attracted the attention of the energy production sector over time, and photovoltaic research has gained momentum. After accelerating photovoltaic research, photovoltaic systems are became one of the most innovative and technological developments about solar energy usage. Usage of photovoltaic systems increases yearly thanks to technological development, as shown in Figure 3.17.

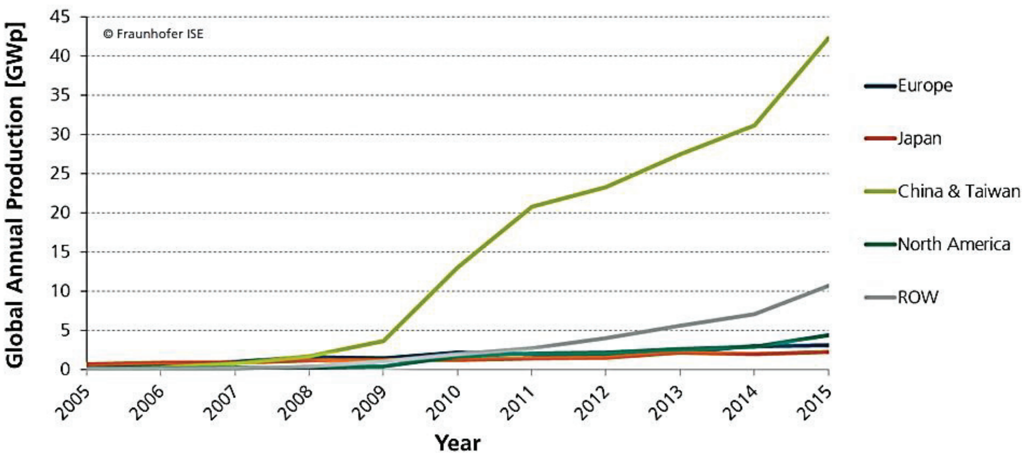


Figure 3.17. Global annual production accordingly regions
(Burger et al., 2014)

PV systems consist of PV panels, charge regulator, inverter and storage battery as shown in Figure 3.18.(Kıyançiçek, 2013).

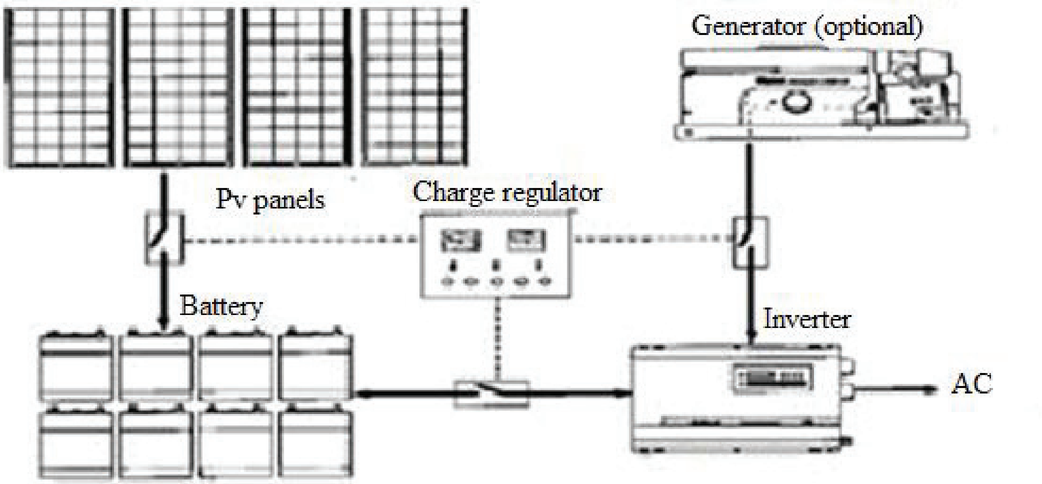


Figure 3.18. PV systems working principle
(Kıyançiçek, 2013)

Photovoltaic cells also known as solar cells are the primary building blocks of a PV module which are the building blocks of PV panels as illustrated in Figure 3.19.

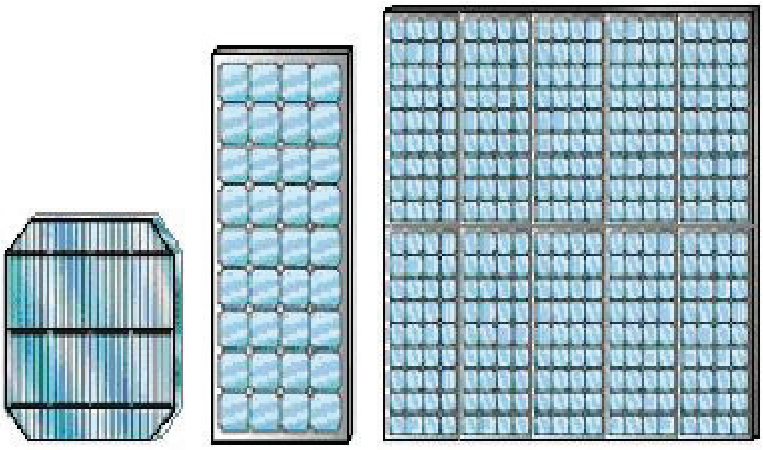


Figure 3.19. A photovoltaic cell, photovoltaic module and photovoltaic panel
(Kantaroğlu, 2010)

Working principle of PV cells is that when high-energy photons of sunlight hit a semiconductor material and are absorbed, the energy transferred to the electrons in semiconductor material. So, electrons are free to flow from negative phosphorus to the negative boron which is known as photoelectric effect. This process occurred in photovoltaic cells continues as the semiconductor material is hitting by sunlight (Jelle, Breivik, et al., 2012; Nowicki, 2015). A photovoltaic cell produces 0,5 Volts of voltage under laboratory conditions and this is not adequate for most of applications (Kalogirou, 2013; Kantaroğlu, 2010). Panels with maximum power generation of 17 Volt are produced at 12 Volt operating voltage with serial connection of 36 cells. The current generated by the panel is proportional to the panel and a 7 cm diameter circular PV cell can generate about 7 Amperes (Kantaroğlu, 2010).

The photovoltaic modules are designed for harsh outdoor environments. Modules are encapsulated for outdoor protection of photovoltaic cells and electrical connections (Kalogirou, 2013). The efficiency of solar cells depends on different design criteria and factors. To increase the efficiency of solar cells it is important that understanding the sun path accordingly location, which depends on geographical location and time of year. Azimuth angle (relationship to due south) and altitude angle (the sun elevation angle) are also considered by PV system designers (Nowicki, 2015). Besides them, solar cells are extremely sensitive to shading. Any object like a tree branch or birds that prevent the sun's light falling on the cell, is called shading and that decreases the efficiency of systems because, the solar cells are connected serially in the panel. If the power of one solar cell decreases, the other cells will have to descend to the power it decreases (Kantaroğlu, 2010).

The most common type of PV panel's material is crystalline silicon solar cells which have two types: monocrystalline silicon solar cells, polycrystalline silicon solar cells and the other type of solar cells is thin film solar cells, amorphous silicon solar cells and copper indium gallium selenite solar cells (Kıyançiçek, 2013). The reasons why crystalline silicon solar cells are so preferred are that silicon has superior technology and it is more economical than different materials.

Charge regulators who are also known as charge control device, are products that convert the voltage obtained from solar energy to the desired voltage value. Generally, the most important criterion for the selection of these products used in off- grid systems is the yield values (Kıyançiçek, 2013). The main function of the charge control device in PV systems is to prevent the panel from flowing out of the battery in the reverse direction when the panel voltage drops below the battery backlit at night and in closed weather (Kantaroğlu, 2010).

Inverter is a device that converts direct current (DC) to alternative current (AC). There are two types of inverter as On-grid and off-grid (Kıyançiçek, 2013).

Storage batteries are equipment that is attached to all other equipment and are used to store the energy produced in the systems that are independent of the electricity line and to use it later (Kantaroğlu, 2010).

As it mentioned, the photovoltaic systems consist of different parts with different aims. Photovoltaic systems can be on-grid (stand-alone) or off-grid (grid-connected) systems. On-grid systems is that the electricity generated from the photovoltaic panels is sold to the network with a separate tariff on a separate meter. Off-grid system is used for places where there is no electricity network. This system is called off-grid since they cannot give electricity to system even though they are installed in the place where the network is located and network-supported operations (Cezim, 2013).

3.3.3. Daylighting Systems

Daylight provides the condition for good vision with two properties: high illuminance, permits excellent color discrimination and color rendering. Besides the benefits of daylight, it can also produce uncomfortable solar glare and very high luminance reflections on displays, both of which interfere with good vision (Reinhart, 2014). Thus, daylighting design for buildings is getting more important to provide visual comfort. Besides the visual comfort, thermal comfort can be affected in a variety of ways with daylighting design. For example, surface of cold window can decrease thermal comfort during the winter, or surface of hot window can do the same discomfort during the summer. So, daylighting systems aim to overcome discomfort conditions with three major functions as:

- solar shading
- protection from glare
- redirection of daylight (Reinhart, 2014)

Light shelves, louvers and blind systems, sun directing glass, light tubes, anidolic systems and heliostats will be examined in this title.

3.3.3.1. Light Shelves

Light shelves are horizontal components located on inside or the outside surface of the windows to block sunlight ad guide the daylight to the ceiling. They could be an integrated element with a facade, or it could be an after-installed element. While protecting the area near the window from the intense sunlight to use the daylight more effectively in the interior, it provides a general illumination in the depths of the space with reflected light to the ceiling (Reinhart, 2014). As shown in Figure 3.20., when the space near the window protects the sunlight, the reflected light from the ceiling illuminates the depths of the room. Thus, light shelves reduce the daylight level at the rear of window and raise the daylight level in the depth of the room, so provide homogeneous light distribution (Uyan, 2011).

Figure 3.20. Light shelves
(Kılıç Demircan & Gültekin, 2017)

Designing light shelves must be considered at the beginning of design phase, because it affects the architectural and structural design of building to perform their aim effectively. Light shelves should be designed specifically for each window accordingly orientation, room configuration and latitude.

Types of light shelves are conventional light shelves, optically treated light shelves and sun tracking light shelves. Conventional light shelves are generally fixed, solid systems, but there can be incorporated slatted baffle systems with reduced upward reflection. Optically treated light shelves are result of two additions to the conventional light shelves which are curved and segmented to passively reflect sunlight or specific solar altitudes and incensement of efficiency thanks to commercially available, highly reflective, semi-specular optical films. Reflective plastic film surface over a tracking roller assembly within a fixed light shelf is used in tracking light shelves system (IEA, 2000; Reinhart, 2014)

3.3.3.2. Louvers and Blind Systems

Louvers and blinds are one of the classic daylighting systems which provide solar shading to protect against glare and to redirect daylight. Louvers and blind systems are based on the principal that obstruct, absorb, reflect and/or transmit solar radiation to a building's interior (IEA, 2000; Reinhart, 2014; Tsangrassoulis, 2008).

Position of the sun and their location (interior or exterior), slat angle, and slat surface reflectance characteristics affect their performance. Louvers and blind systems can be horizontal, vertical or sloping slats and there are various types of them, some of which make use of highly specialized shapes and surface finishes. They can be located on the exterior or interior of any window or skylight, or between two panes of glass. Generally, louvers are located on exterior of the facade; blinds are fitted inside or between glazing. In practice, horizontal louvers and blinds are generally selected for all orientation, and vertical blinds are generally chosen for east and west facing windows. Materials of louvers and blind systems change accordingly place of them: exterior or interior. High durability and low maintenance are properties of exterior louvers materials which are generally made of galvanized steel, anodized or painted aluminum or PVC. Small or medium sized PVC or painted aluminum is generally chosen for interior Venetian blinds (IEA, 2000; Reinhart, 2014; Tsangrassoulis, 2008)

Types of louvers and blind systems are fixed and operable louvers and blinds, translucent blinds and light-directing louvers. When fixed louvers and blind systems are generally used for solar shading, operable louvers and blind systems can be used for controlling thermal gains, protect against glare, and redirect daylight. Translucent blinds made of fabric, plastic or perforated plastic material, transmit a fraction of light when closed. Light directing or reflecting louvers have various types which are generally including an upper surface of highly specular material that sometimes has perforations and concave curvature (IEA, 2000; Reinhart, 2014)

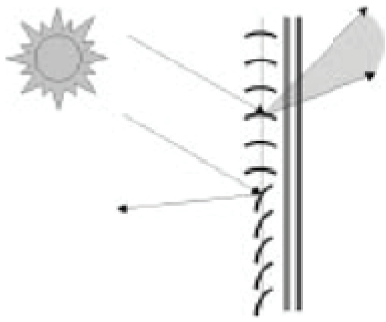


Figure 3.21. Louvers and blind system
(Johnsen & Watkins, 2010)

3.3.3.3. Sun Directing Glass

Direct sunlight from all angles of incidence is redirected to ceiling with concave acrylic elements stacked vertically double glazed unit (Figure 3.22.). Sun directing glass is based on the principal that deflecting light in the vertical and horizontal plane. In this way, light can reach the depth of room for all solar positions without the need for movable parts in the building facade. Shape of the acrylic elements causes vertical deflection as shown in Figure 3.23. and holographic optical elements or sinusoidal glazing surface causes horizontal deflection as shown in Figure 3.24. (IEA, 2000; Reinhart, 2014).

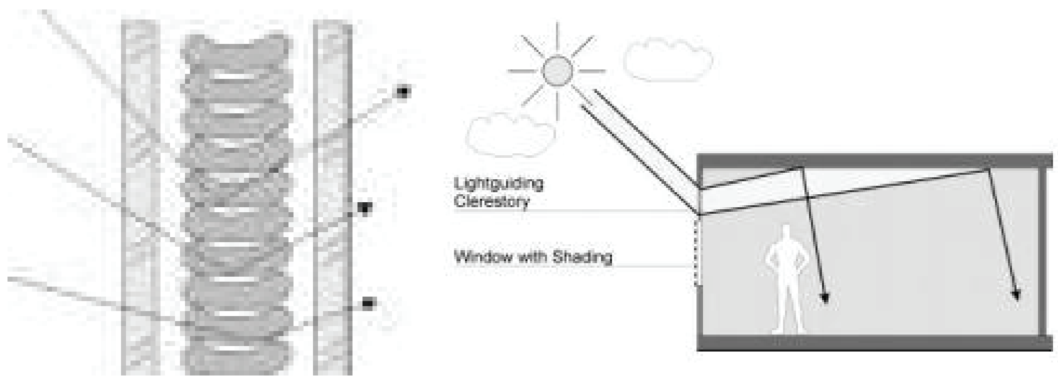


Figure 3.22. Sun directing glass
(IEA, 2000; Reinhart, 2014)

Sun directing glass is located in the window area above eye height to avoid glare and other visibility effects. In addition, they can be located in front of the facade or behind it in retrofit situations (IEA, 2000; Tsangrassoulis, 2008). South facade in moderate climate zones is the best orientation for this type of system. Using this system on west or east facades is not useful after afternoon. Benefits of sun directing glass are that there is no need for controlling thanks to any movable or adjustable parts, and there is no need for maintenance thanks to installation of sun directing profiles between two glass panes.

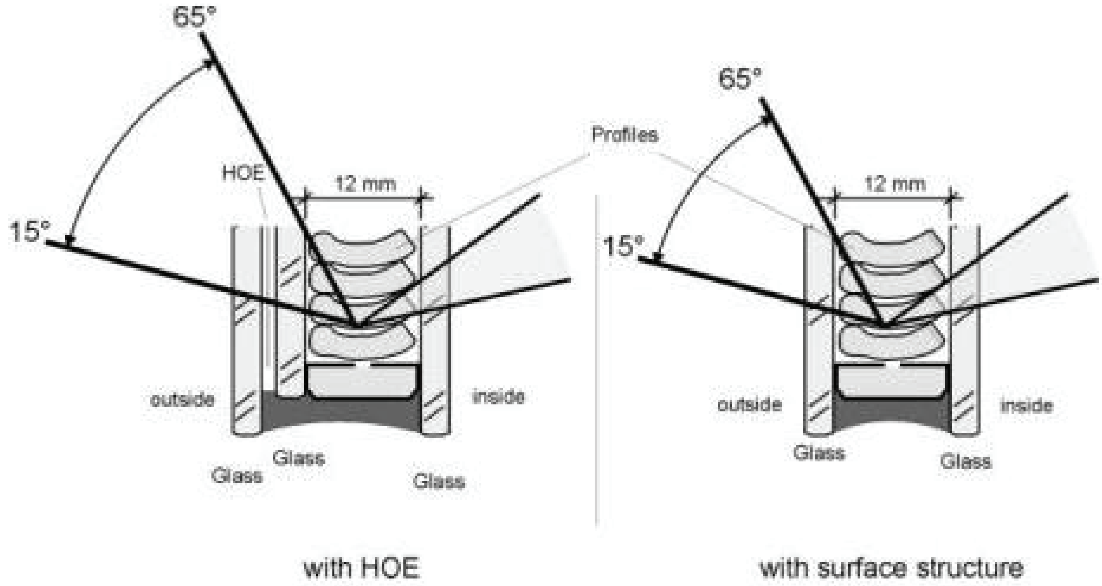


Figure 3.23. Vertical deflection of sun directing glass (HOE: Holographic optical elements) (IEA, 2000; Koster, 2004; Reinhart, 2014)

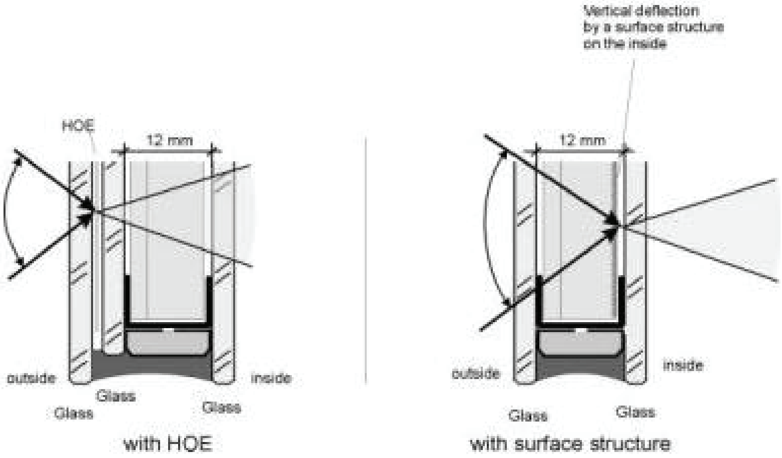


Figure 3.24. Sun directing glass

(IEA, 2000; Koster, 2004; Reinhart, 2014)

3.3.3.4. Light Tubes

Principal of the light tube, also known light pipes, is the element that the daylight taken from the small roof skylights is moved to the ceiling of the space with the reflective pipes (Figure 3.25.). The distribution of the light to space is provided by the internal emitter elements. The sunlight-sensitive lighting element, which is placed in the pipe or in the emitter element, can work in relation with the daylight. Light tubes are suitable for small spaces. If there is a grid layout, a smooth daylight distribution can be obtained in large spaces (Kılıç Demircan & Gültekin, 2017)

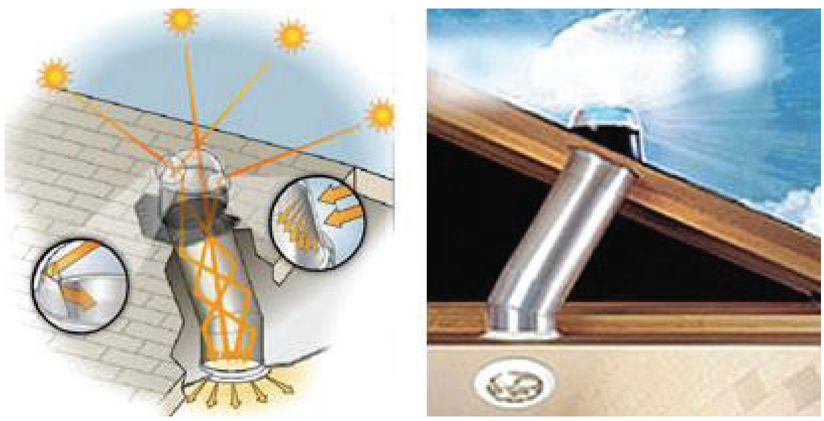


Figure 3.25. Example of light tube

(Kılıç Demircan & Gültekin, 2017)

3.3.3.5. Anidolic Systems

Anidolic systems use the optical properties of anidolic or compound parabolic concentrators to collect diffuse daylight from the sky and transmit light to the interior space. They are used in buildings in the regions under predominantly overcast sky conditions to provide adequate daylight (Reinhart, 2014). Types of anidolic systems are anidolic ceilings, anidolic zenithal openings and anidolic solar blinds.

Anidolic ceilings basically consist of a light tunnel and reflectors at the beginning and end of this light tunnel. The principal of anidolic ceiling is that the first reflector on the ceiling surface collects the diffuse light and transmits it to the light tunnel (Figure 3.26). And then, the inner surface of the light tunnel is highly reflective and the light transmitted through the tunnel with respect to the inner reflection principle. Finally, the parabolic reflector at the end of light tunnel uniformly distributes the diffuse light into space (IEA, 2000)

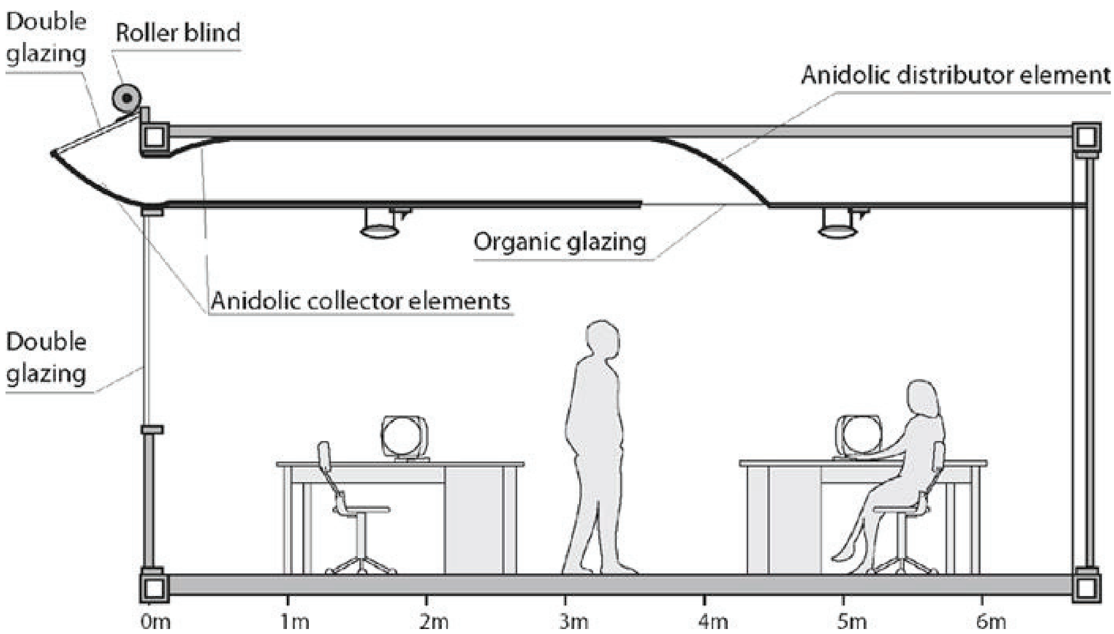


Figure 3.26. Anidolic ceilings scheme
(Ruck, 2000)

Anidolic zenithal openings are another type of anidolic daylighting systems which is best utilized to provide daylight to single storey buildings, the upper floor of multi-storey buildings or atrium spaces. Their working principal is based on non-imaging optics and they are similar to the design of any anidolic daylighting system. Anidolic zenithal openings are designed for roof applications to provide adequate illuminance levels by capturing diffused daylight from a northerly sky view (Figure 3.27). (IEA, 2000; Kleindienst & Andersen, 2006; S. K. Wittkopf, 2007)

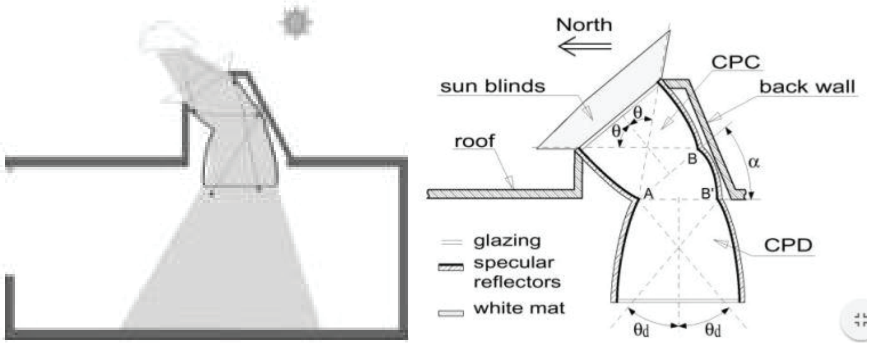


Figure 3.27. Anidolic zenith openings scheme and cross-section

(Reinhart, 2014)

Anidolic solar blinds include a grid of hollow reflective elements, each of which is composed of two three-dimensional compound parabolic concentrators. The blinds designed for the side lighting and provide angular- selective light transmission to control sunlight and glare. Studies of anidolic solar blinds are proceeding (IEA, 2000; Kleindienst & Andersen, 2006; S. K. Wittkopf, 2007)

3.3.3.6. Heliostats

Heliostats are systems that collect the light outside and transmit it to the building. Heliostat is an integrated system that follows the sun with an automatic tracking system in order to keep reflected light from a target and consists of one or more mirrors and a lens and collects the sun's rays. This system is not a stand-alone lighting system; it transmits the sunlight it collects to a light-carrying system, mostly light pipes. The sunlight, which is carried in the light pipes, then spreads into the building with a distributing outlet unit. An artificial light source (lamp) can also be added to this system so that it can be used at times when daylight is insufficient. The aim of the heliostats is to illuminate the spaces without windows with natural lighting facilities and daylight (IEA, 2000; Tsangrassoulis, 2008). A scheme of heliostat daylighting system is shown in Figure 3.28.

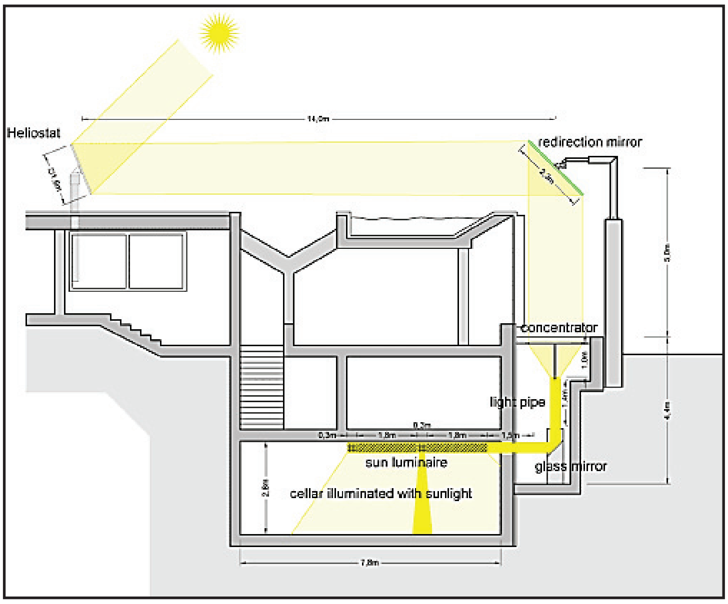


Figure 3.28. Scheme of heliostat daylighting system
(Kılıç Demircan & Gültekin, 2017)

3.3.4. Assessment of Solar Energy Systems

In this title, solar energy systems are assessed in one chart, and three group as;

A) Passive solar energy system
B) Active solar energy system
C) Daylighting system

While preparing this table, primarily the systems described by now are grouped under the three main headings above. Brief informations about the main function of each system are given. Depending on the function, the fields where the systems are integrated on the building are noted as wall, ceilling, floor, roof, fenestration or more than one. Finally, types of integration (physical, visual and performance integration) were chosen in line with the information obtained. In accordance with this analysis, it has been observed that each system is integrated in different forms according to the structure and system characteristics (Table 3.1).

System	Function	Intefration field					Integration type		
		Exterior Wall	Ceiling	Floor	Roof	Fenestration	Physical	Visual	Perfprmance
Direct gain	Storing energy passing through the openings	X		X	X		X		
Trombe wall	Heating space with convection	X					X		X
Water wall	Heating space with convection	X					X		X
Roof pond	Heat transfer between ceiling and interior				X		X		X
Sunspace	Collecting solar energy in a location to heat desired space	X					X	X	
Water heater	Conveying thermal mass			X			X		
Solar chimney	Converting thermal energy in kinetic energy of air movement	X			X		X		
Solar collector	Producing hot water from solar energy				X		X		
Solar cells	Producing electric energy from solar energy	X			X	X	X	X	X
Light shelves	Protecting sunlight and providing homogeneous light distribution		X			X	X	X	X
Sun directing glass	Sending daylight on to the ceiling or to location above eye height	X	X			X	X	X	
Louvres and blinds	Providing solar shading to protect against glare and redirecting daylight	X				X	X	X	
Light tubes	Taking daylight from the roof skylight and moving to the ceiling of the space with reflective pipes		X		X		X		
Anidolic	Collecting daylight from the sky with anidolic or parabolic compound and transmitting light to space	X	X		X		X	X	
Heliostats	Collecting daylight and transmitting it to interior space		X	X	X		X		

CHAPTER 4

INTEGRATION TO BUILDING ENVELOPE

Nowadays, buildings are being built with new building systems and construction techniques developed with the effect of new opportunities supported by new dimensions added to technology, industrialization and architecture. In particular, it appears that the integration principles of buildings are priorities and construction systems are beginning to be constructed in the light of 'systematic design' approaches, which consist of subsystems with different functions (Çelebi, 1998).

Because building envelope system is exposed to direct sunlightht, building envelope system is one of the most suitable systems to apply photovoltaic and daylighting systems. Application of photovoltaic systems without attention can create unsuited effect visually. It is possible that photovoltaic systems can be considered as an architectural element as a part of the construction in order to the integration of photovoltaic systems into the building envelope require both sufficient efficiency and unintended consequences for building aesthetics (Uslusoy, 2012).

In this context, building envelope system is one of the most common building systems which can be integrated with different functions. In this title, building integrated photovoltaics (BIPVs) and building integrated daylighting systems (BIDSs) will be examined.

4.1. Building Integrated Photovoltaics (BIPVs)

Basically, PV systems are used for converting solar energy into electric energy. Building integrated photovoltaic (BIPV) cells are performed on roofs, facades and solar shading systems with replacing conventional materials. BIPV serves simultaneously as both a climate screen and a power generating system because BIPV systems replace the outer building envelope system. There is a saving in materials and labor, in addition to reducing the electricity costs (Jelle & Breivik, 2012b). Building integrated photovoltaic (BIPV) systems, where solar cells are integrated within the climate envelopes of buildings and utilizing solar radiation to fabicate electricity may represent a powerful and versatile tool for reaching these goals with respect to aesthetical, economical and technical solutions (Jelle & Breivik, 2012a). In other words, BIPV systems are able to replace elements such as roofs, facades, glazing or even SDs and they contribute positive effect on reducing energy requirements, combining aesthetic and environmental factors as well (Stamatakis et al., 2016).

There is also another term as building attached photovoltaic (BAPVs) products which are defined as add-ons to the buildings, hence not directly related to the building structures' functional aspects (Peng et al., 2011). BAPVs and BIPVs should not be confused with each other due to BAPV systems are different from BIPV systems.

There is a wide range of building integrated photovoltaic products which can be categorized in different ways. According to manufacturers' description, the main categorization of BIPV products are BIPV foil products, BIPV module products, BIPV tile products, and solar cell glazing products (Jelle, Breivik, et al., 2012). These products are used in different building systems.

In this title, building integrated photovoltaics will be explained and exemplified as roof integrated PVs, fenestration integrated PVs, facade integrated PVs and active system integrated PVs.

4.1.1. Roof Integrated PVs

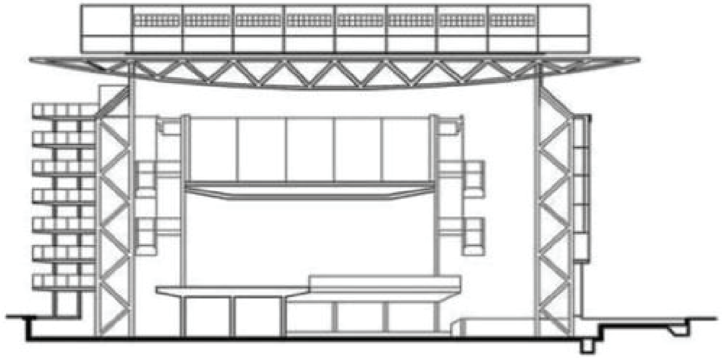
Generally, south sloped roofs are best suited for PV installation because of the favorable angle with the sun. To provide favorable angle with the sun and increase efficiency of PV modules, modules might have to be inclined. Roof integrated PVs should perform as a roof and produce electricity efficiently. So, integrated systems consist of the properties of the one roofing element or several. Lack of air flow under the PV module can be a challenge in order to decrease the temperature (Jelle, Breivik, et al., 2012) BIPV foil products, BIPV tile products, BIPV module products and solar cell glazing products can be used for roof integrated PVs (Jelle & Breivik, 2012b).

The technical potential for photovoltaics on buildings in the European Union, Crotia, Norway and Turkey is investigated by Defaix's and co-workers' study. After calculation of BIPV area potential, a compression was done between their study and another study by Nowak. As shown is Figure 4.1., there is a huge potential of roof about BIPVs on residential buildings (Defaix et al., 2012).

British Pavilion by Nicholas Grimshaw and Partners is examined as an example of roof integrated PVs. The building was designed for Expo 92 in Seville and created a modern Crystal Palace by designer to mark British participation in the event (Bachman, 2004). Details of building are given in Table 4.1.

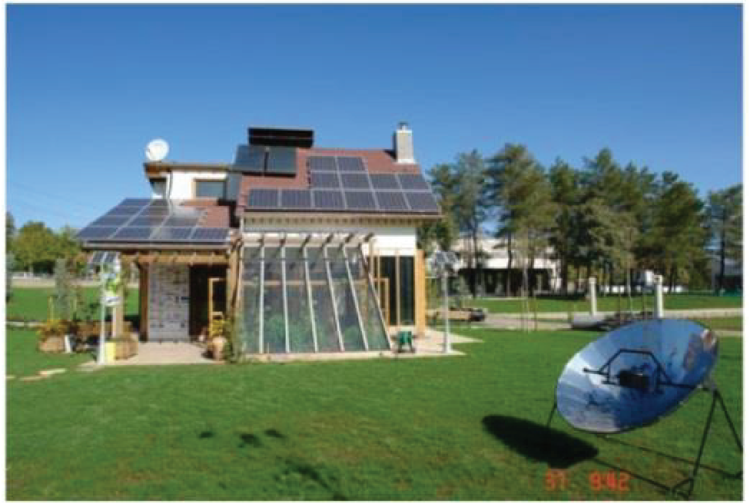
Diyarbakır Sun House Education and Practice Park by Çelik Erengezgin is examined as an another example of roof integrated PVs. The project was realized with the support of Diyarbakır Municipality and Dicle University within the scope of EU Project.The building was designed for This building has been built to attract attention and pioneer in the use of renewable energy. In addition, active and passive integrated energy systems other than PV panels are also used in the building. Details of building are given in Table 4.2. (Aykal, Gümüş, & Özbudak Akça, 2009).

British Pavillion, Expo 92.

  ect er	UK. Department of Trade and Industry Sevillle, Andalucia, Spain Nicholas Grimshaw and Partners Ove Arup & Partners (structure and mechanical)	
al Integration	It was provided by prefabrication which ensured accurate field fit of all elements and necessitated a small construction team. The arrayed photovoltaic panels and building systems share a common area and interact with each other in different ways.	
Integration	Photovoltaic arrays were located on building a roof and completed the visual integrity of building.	
mance tion	Because of photovoltaic arrays were used as a roof covering material this was sloped to remove rainwater and provide to shade. So, there is also performance integration.	
ting tion	Physical, visual and functional integration principles are seen as integrated, so there is an integrating integration in British Pavillion.	

Diyarbakır Sun House Education and Practice Park, 2008

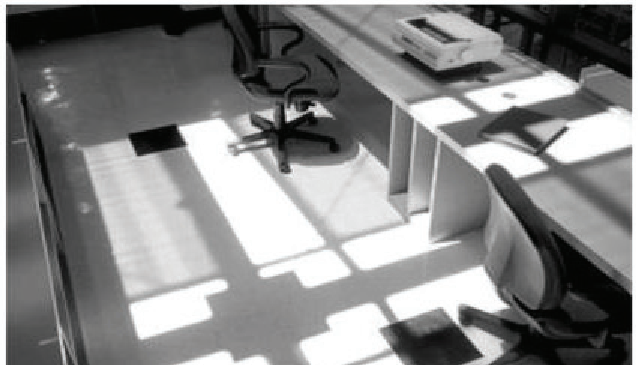
	NA
	Diyarbakır, Turkey
ect	Çelik Erengezgin
eer	NA
al Integration	Because of photovoltaic panels are used only for one purpose, no physical integration observed in the building.
Integration	The photovoltaic panels are positioned completely in conformity with the roof slope, so there is a visual integration.
mance tion	24 photovoltaic panels were used in the building. Thanks to the panels used, all the electricity requirements of the building are provided. It is planned to distribute excess energy generated in the future to the network, so there is also performande integration
ting tion	Physical, visual and functional integration principles are seen as integrated, so there is an integrating integration in Diyarbakır Sun House Education and Practice Park.



4.1.2. Fenestration Integrated PVs

Fenestration integrated photovoltaics may provide regarding daylight, solar heat gain, solar shading, miscellaneous architectural expressions, and eventually converting solar energy to electric energy (Jelle & Breivik, 2012b)They can act as shading devices and also semi-transparent elements of fenestration. Moreover, "One might also envision incorporating solar cells or photovoltaics with electrochromic materials in completely new fenestration products, where the photovoltaic and electrochromic material or materials cover the whole glazing area." (Jelle, Hynd, et al., 2012).

Photovoltaic Manufacturing Facility by Kiss + Cathcart Architects, Fox & Fowle Architects and PV system designers is examined as an example for fenestration integrated PVs. The building was completed in 1993 to manufacture a new generation of production lines tailored to thin-film PV technology. The building also consists of its design several applications of thin-film solar modules that are prototypes of BIPV products (Eiffert & Kiss, 2000)Details of building are given in Table 4.3.

  ect eer	BP Solar Fairfield, California, USA Kiss + Cathcart Architects, Fox & Fowle Architects and PV system designers Ove Arup & Partners	
al Integration	There is a physical integration between glazing and photovoltaics because they share common space.	
Integration	Thin-film photovoltaics were located on fenestration of building and completed the visual integrity of building.	
mance tion	There is also integration as performance integration. Because thin film photovoltaics were used as a glazing and shading material.	
ting tion	Physical, visual and functional integration principles are seen as integrated, so there is an integrating integration in Photovoltaic Manufacturing Facility.	

4.1.3. Facade Integrated PVs

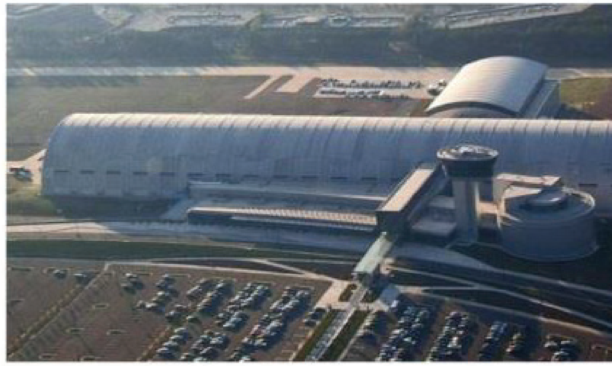
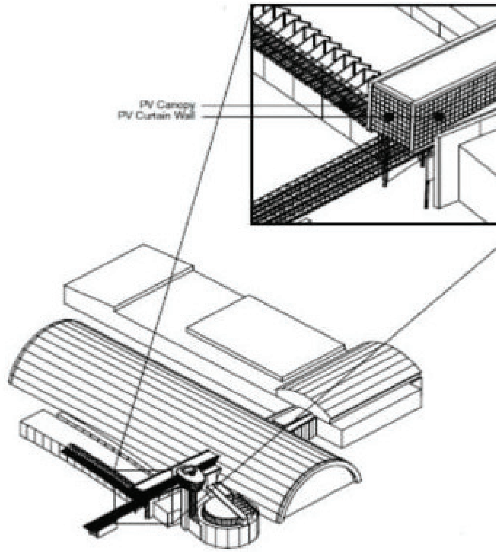
Facade Integrated PVs displace traditional construction materials to fulfill the function and also produce electric energy. Photovoltaic systems where they can be applied on facade as:

- shading device,
- rain screen,
- curtain wall,
- double skin facade,
- atrium and leaves (Roberts & Guariento, 2009).

As it shown before, one of the most efficient places to apply photovoltaic systems is building facade. But there are some points to take care. The geographic position has an important role when planning the use of photovoltaics on facade. Efficiency is higher at northern and southern latitudes accordingly the position. So it must be considered in designing stage by designers (Jelle, Breivik, et al., 2012).

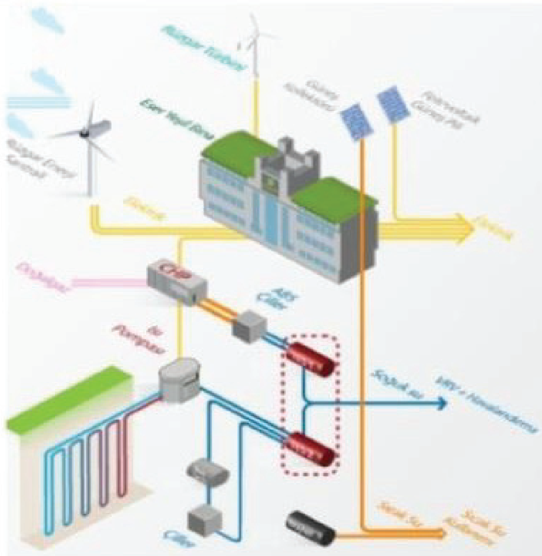
National Air and Space Museum by a work team of architects and designers is examined as an example for facade integrated PVs. The building was completed in 2003 to expand the facility. The building includes BIPV products on the south wall and skylight of the entry 'fuselage', the roof of the space shuttle hangar and restoration hangar, the facade of the observation tower and awning canopies (Roberts & Guariento, 2009). Details of the building are given in Table 4.4.

Eser Holding Central Building by a work team of Eser Holding is examined as another example for facade integrated PVs. This building was built as a green building and received a leed platinum certificate. The building includes BIPV products on the roof, south wall and used as a sunshade on the facede. Therefore, both energy is being produced and shading is being done in the building (Öncül & Aş; Özdoğan & Hıraoğlu, 2011). Details of the building are given in Table 4.5.

ect er	Smithsonian Institution Dulles Center, Washington DC, USA HOK, Building Architects: Kiss+Catchcart Architects, PV System Designers: Satish Shah, Speigel, Zamel, & Shah Inc. N/A	
al Integration	It can be said that there is a physical integration between facade and photovoltaics because the PVs are being used on the exterior of the building and are forming the facade of the building. The south and west facing facades of the entry hall are glazed with polycrystalline glass laminates.	
Integration	PV arrays on entryway catch attention of visitors by visually, because there is a visual integration between PV arrays and entry facade. PV arrays complete the visuality of building.	
mance tion	There is also integration as performance integration because PV arrays were used as a facade element. In other words, the PV array acts as a facade material.	
ting tion	Physical, visual and functional integration principles are seen as integrated, so there is an integrating integration in National Air and Space Museum.	

Eser Holding Central Building

	Eser Holding
	Çankaya, Ankara
ect	Eser Holding
eer	Form Temiz Energy
al Integration	While some of the PV panels form part of the building facade, the other part is also used as a sunshade, so thre is a physical integration.
Integration	All the systems used are completely overlapped with the building and appear as part of the building. As a result, there is visual integration.
mance tion	Thanks to PV panels, both energy production and shading are provided, so there is a performance integration.
ting tion	Physical, visual and functional integration principles are seen as integrated, so there is an integrating integration in Eser Holding Central Building



4.2. Building Integrated Daylighting Systems (BIDSs)

There is a balance between electric light contribution and daylight contribution to illuminate interior spaces (Figure 4.1.). Correct management of this balance helps to reduce lighting energy consumption. So, there is an opportunity to reduce both lighting electricity consumption and peak demand for electricity by using daylighting systems (Design, 2017).

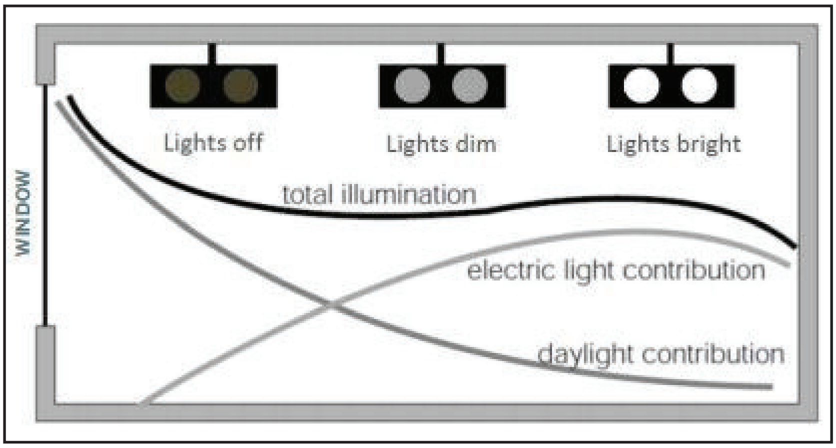


Figure 4.1. Balance between electric light contribution and daylight contribution

There are some daylighting system's design criteria which have significant roles:

- building geometry,
- location, orientation, area and transmissivity of openings,
- different static or dynamic opening controls which can be located either inside or outside of the opening
- interior design elements like ceiling, wall and partitions,
- the electric lighting system (Design, 2017)

Building integrated daylighting systems (BIDSs) are performed on roofs and fenestrations and active systems with taking on a task of conventional materials and systems. BIDSs serve simultaneously as both a visual comfort system that cause cost and material saving and replacing traditional building materials. Besides these benefits, correct design of daylighting system makes people wellbeing psychologically.

In this title, building integrated daylighting systems are explained and exemplified as roof integrated DSs, fenestration integrated DSs and active system integrated DSs.

4.2.1. Roof Integrated BIDSs

Roof integrated daylighting systems provide the condition of visual performance with redirection of daylight when sunlight is not enough. Roof integrated BIDSs take sunlight from sky and transmit it to the interior to provide its aim.

Static prismatic systems and micro sun shielding louvers are some of the examples of roof integrated daylighting systems which are innovative and preferred mostly. The stationary prismatic systems consist of prismatic plates which are cut to suit and installed in insulated window panels, roof lights and canopy glazing (Figure 4.2.). These systems are mainly applied as solar protection. They be able to however also be used for light control and both functions can be combined with ease (Siteco, 2017c). Micro-sun shielding louvers include plastic louvers featuring specular ultra-pure aluminum, with outstanding reflective properties. They have been for roof glazing and their application is optimal in lightly inclined roof constructions to create a pleasant room atmosphere (Figure 4.3.) (Siteco, 2017b).

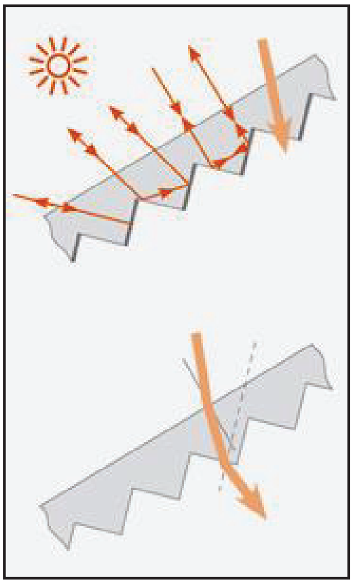


Figure 4.2. Static prismatic systems
(Siteco, 2017b)

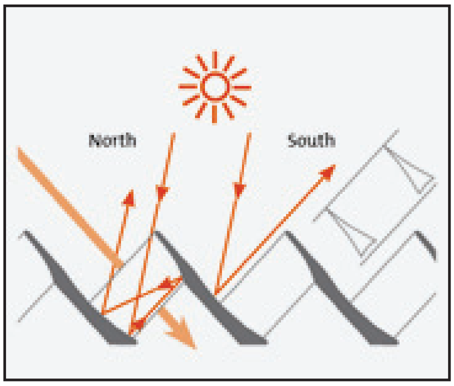
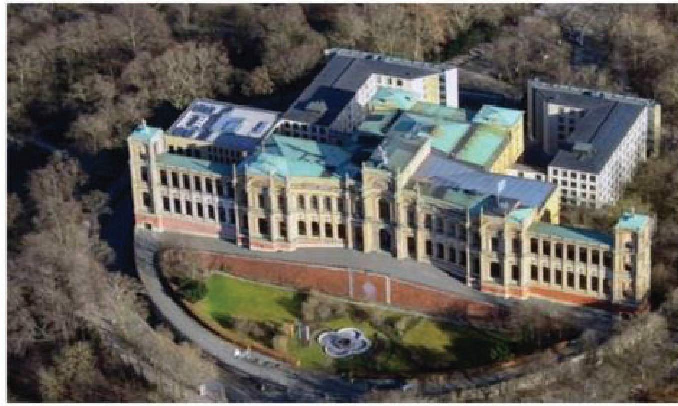
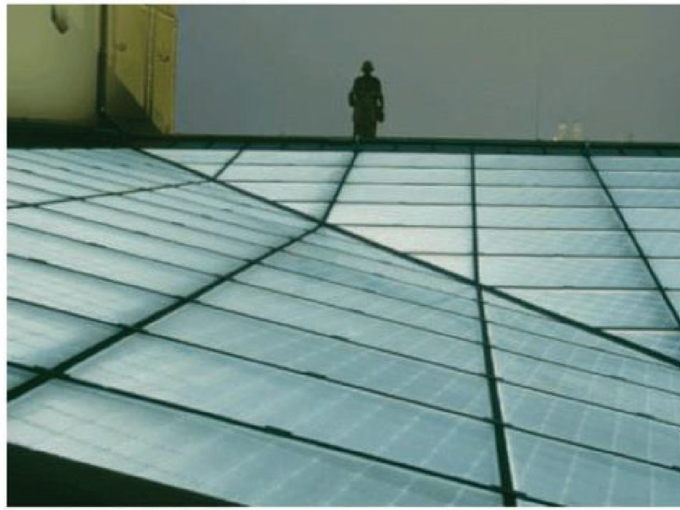


Figure 4.3. Micro-sun shielding louvers
(Siteco, 2017b)

Bavarian Parliament by Volker Staab Architekten is examined as an example for roof integrated DSs. The building was completed in 1993 and 470 square meter large surface is equipped with stationary prismatic plates (Siteco, 2017a). Details of building are given in Table 4.6.

Bavarian Parliament

[illegible]	Universitatsbauamt Munich	  
	Munich, Germany	
...tect	Staab Architekten GmbH	
...eer	N/A	
...cal Integration	Static prismatic panels and roof share a common space, so there is a physical integration between them.	
...l Integration	Panels on the roof complete the visuality of roof with harmony. So it is possible to mention about visual integration.	
...rmance ...ation	Static prismatic panels are not only used for daylight system element but also a roof covering element. So there is performance integration.	
...ating ...ation	Physical, visual and functional integration principles are seen as integrated, so there is an integrating integration in Bavarian Parliament.	

4.2.2. Fenestration Integrated BIDSs

Fenestration integrated BIDSs provide redirecting daylight into space in order to optimize its luminous properties. Bringing natural light into space provides benefits as well as reducing the need for artificial lighting
(Leso, 2017).

Light diffracting films, clear light guiding films and reflective solar cell films are one of the most common used and preferred fenestration integrated daylighting systems. Light diffracting films consist of a diffraction pattern applied with a photographic process onto a gel. Light is redirected into space with great specificity by pattern. These systems are more effective in direct sunlight than diffuse light (D-lite, 2017c). Clear light guiding films can be applied on existing glazing to direct light deeper into the space or toward the ceiling (D-lite, 2017a)Reflective solar cell films provide reflecting light beside producing energy (D-lite, 2017b)

Geyssel Office building by Prof. Erich Schneider-Wessling is examined as an example for fenestration integrated BIDSs. The building was completed in 1993 and besides the aesthetic and functional aspects, innovation and environmental conservation were the top priorities (Geyssel, 2017). Details of building are given in Table 4.7.

Geyssel Office Building

	Geyssel Company	
	Cologne, Germany	
ct	Prof. Erich Schneider-Wessling	
er	N/A	
l Integration	Sun-directing glasses take place upper windows of the building. and the ground floor is equipped with a holographic lighting system. Daylighting system is integrated with the fenestration system physically, because they share a common space.	
Integration	Building integrated daylighting systems complete the visuality of building. So there is visual integration.	
nance tion	Sun is directing glasses both receive and direct daylight. Receiving daylight is a function of fenestration system, so there is performance integration.	
ting tion	Physical, visual and functional integration principles are seen as integrated, so there is an integrating integration in Geyssel Office Building.	

CHAPTER 5

INTERPRETATION OF DAYLIGHTING AND PV SYSTEMS INTEGRATION

This chapter includes discussions on adaptability of BIDS and BIPV in architectural design in terms visual impressions, potentials of visual comfort; their usability of in building performance in terms of visual, thermal integration and energy cost analyses. Such interpretations are based on recent research mentioned in literature. (Pvresources, 2017).

5.1. Adaptability of BIDSs and BIPV in Architectural Design

Technological advancements allow the use of BIDSs and BIPVs in building construction sector rapidly and widely. Increasing their efficiency, making them work with other building systems in harmony and easiness of their installation may result in their wider use and higher performance. It is necessary to adapt these systems as functional parts of the building.

Significant detailing in installation integrates these systems in construction. One detail is derived from the necessity of decreasing the temperature of BIPV in a roof system. An air gap under the solar cells leads to air flow for this purpose (Kalnæs & Jelle, 2015). Another detail is based on the fact that the inclination of BIPV is accordance with the roof slope angle, although "Geographical position and orientation towards the sun and area coverage" are other considerations in their integration. Adaptation, here, in general terms corresponds to mostly physical integration to the building systems.

5.1.1. Visual Impressions of Roof and Facade Integrated DSs and PVs

Several factors affecting aesthetical quality of these systems integration in buildings, are position and size of the module considering the location at which it can be installed; module's surface colour and texture (whether it is compatible with the other materials on the building surface); module's shape and form and its joints (how it is fixed to the building's conventional systems) (Probst & Roecker, 2012). The key point in visual impressions of such integrated systems is based on satisfying a clear look/or appearance as much like a standard part of the building as possible. For example, a BIPV roof can be made very much like a standard tiled roof when silicon tiles are installed. In some situations, dummy modules can be applied to provide a full visual integration on roofs and facades (Kalnæs & Jelle, 2015). The appearance of PVs which are characterized by its obviousness of size, material, color, texture, form and joints has the primary role in the systems' visual impression. They represent the quality of their integration (Probst & Roecker, 2012; Xu & Wittkopf, 2015).

To present a case, overlapping roofing shingle PV modules made of glass fibre-reinforced composite materials are introduced because of its significant cell incapsulation, its light-weights and elimination of additional material, i.e. base or covering. Curved and complex geometries are possible in that sense. Its visual adaptation is very well completed applying special details in a building in Mons, Belgium (Fig. 5.1.). Such modules have become preferable due to aesthetics.

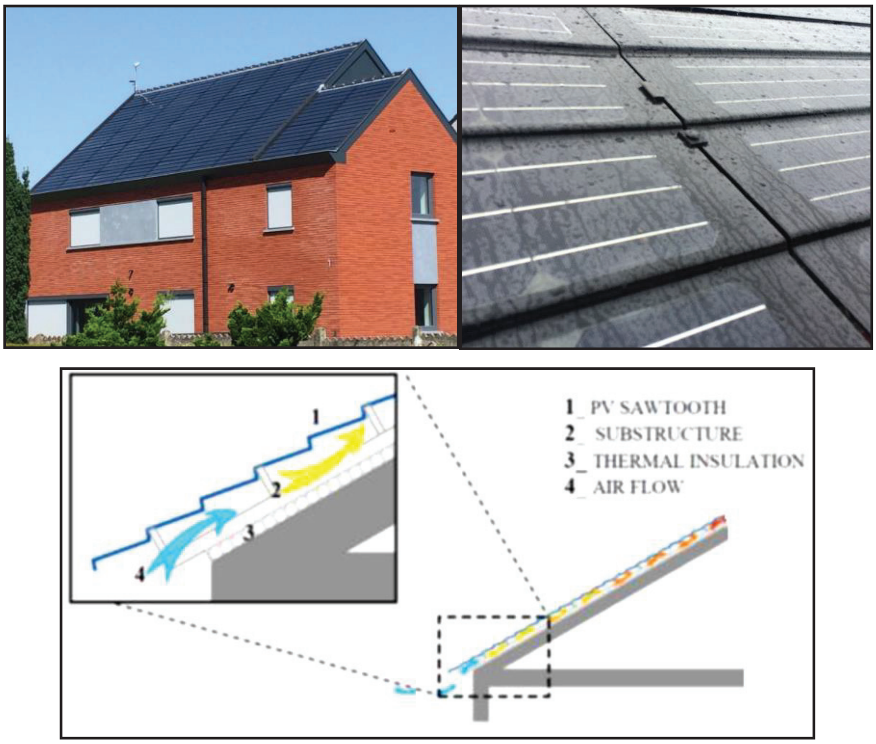


Figure 5.1. The roof structure indicating the way of the air flow behind the PV panels(Agathokleous, Kalogirou, & Karellas, 2017).

Visual impressions of installing solar cells on cultural aspects of historic buildings is another concern under this topic. The existing historic building facades can be renovated while solar installations are allowed and desired under certain standards and rules.The aesthetics have taken the priority at this time. So, research is based on this argument (Xu & Wittkopf, 2014). The aesthetic judgments are found to be very subjective and linguistically determined. Evaluation words are such “pleasantness”, “uniqueness”, “specialness” obviousness” etc. Xu and Wittkopf (2014) proposed a new method called “saliency map” to quantify such linguistic explanations into significant and objective judgments.

“The saliency map is a neurobiological and psychological tool to predict human visual attention. For every point in a certain human visual field, the probability of human paying attention to this particular spot can be calculated. These probabilities (on a scale from 0-1) can be presented on a saliency map” (Xu & Wittkopf, 2015)

Although the physical integration of BIDS is as successful as the BIPVs physical impression, position of the sun, redirection effect and type of materials in BIDS make them differ from clear glazing in the fenestration unit. A skylight in Figure 5.2. which is composed of lasercut acrylic panels fixed in the skylight frame looks like a conventional clear glazed pyramid-shaped skylight from underneath point of view and from the general view of the building. The existence of panels cannot be distinguished unless the light redirection from the surface is visible. That type of redirection in this system is called angular selective transmittance which controls the irradiance during the day and prevents also overheating and sun patches (IEA).

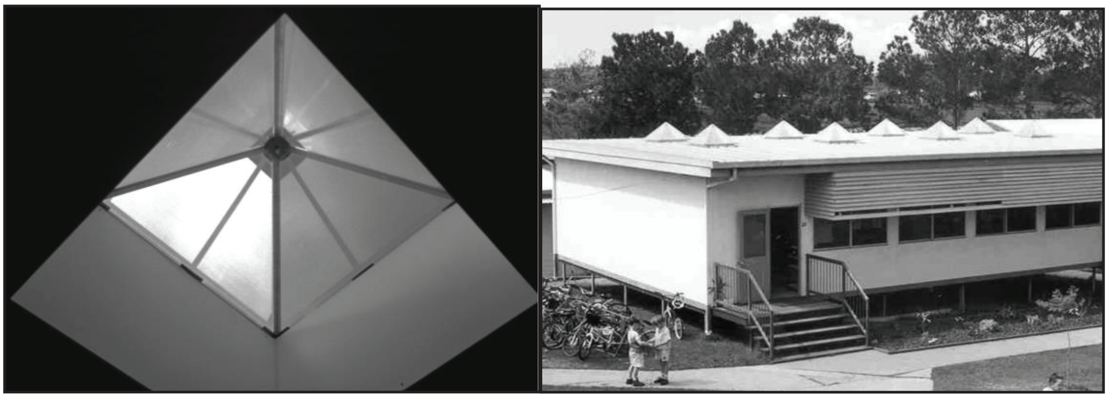


Figure 5.2. Views of skylight with lasercut panels
(Ruck, 2000).

Visual impression of sun directing glasses (microstructured prisms) which are located in window frame is defined as a “technical barrier” by an IEA research. Its “milky” appearance makes his daylight redirecting component different than a transparent clear glass. It does not affect the view since its location is always in the upper region of the window area above the eye level to avoid any glaring problem. However, when the redirection is active in a sunny time the very bright appearance takes all attention in a general view from the interior room (Ruck, 2000) (Fig.5.3.). A similar application is combined with a light shelf in a fenestration (Greenup and Edmonds, 2017) (Fig.5.4.) Panel is visually adapted in the exterior wall system; however, transparency is not as much equal as the clear glass in the fenestration.

Figure 5.3. Sun directing glasses
(Ruck, 2000)

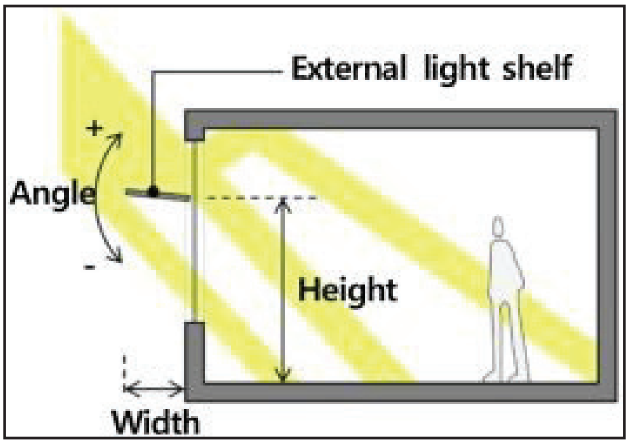


Figure 5.4. Combination of sun directing glass and a light shelf
(Freewan, Shao, & Riffat, 2008)

Laser cut panels and prismatic panels which are called complex fenestration systems have become subjects of matter in daylight performance studies. Their system performance was experimentally tested in several ways while modeling them as scale models or in computer-based simulations (Thanachareonkit & Scartezzini, 2010). The below case in Figure 5.5. shows us their attachment condition in a fenestration in such a study. Their appearance is not as successful as the micro-prismatic light guiding systems because of the size of light guiding surfaces in the system inherently.

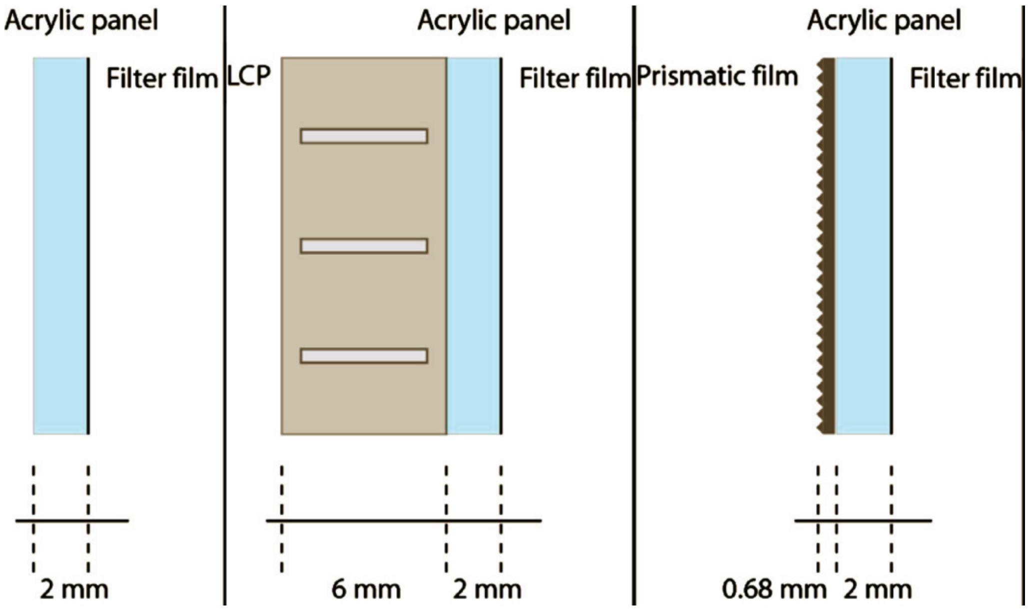


Figure 5.5. Attachment types of CFS and their appearance on the fenestration (Thanachareonkit & Scartezzini, 2010)

5.1.2. Potentials of Visual Comfort

Semi-transparent BIPVs achieves visible light transmittance on building facades; so they both have a strong influence on colors rendered inside the rooms and on the visual appearance of facade surface. This feature is subjected to research by Lynn, Mohanty, Wittkopf (2012) who state that the color rendering index is a significant criterion for semi-transparent BIPVs on facades in assessments of visual comfort and aesthetics. Six PV modules varying according to their cell size, material type and gap in addition to diversity of spectral/optical characterizations are tested whether they significantly change the visual comfort (Figure 5.6.). Their color rendering index for transmitting the daylight is the criterion. Regarding the findings "the modules in neutral a-Si-color showed excellent color rendering index above 90 and good color neutrality at all angles of incidence; the modules in red and blue colors showed CRI below 90 for all angles of incidence" (Lynn, Mohanty, & Wittkopf, 2012).

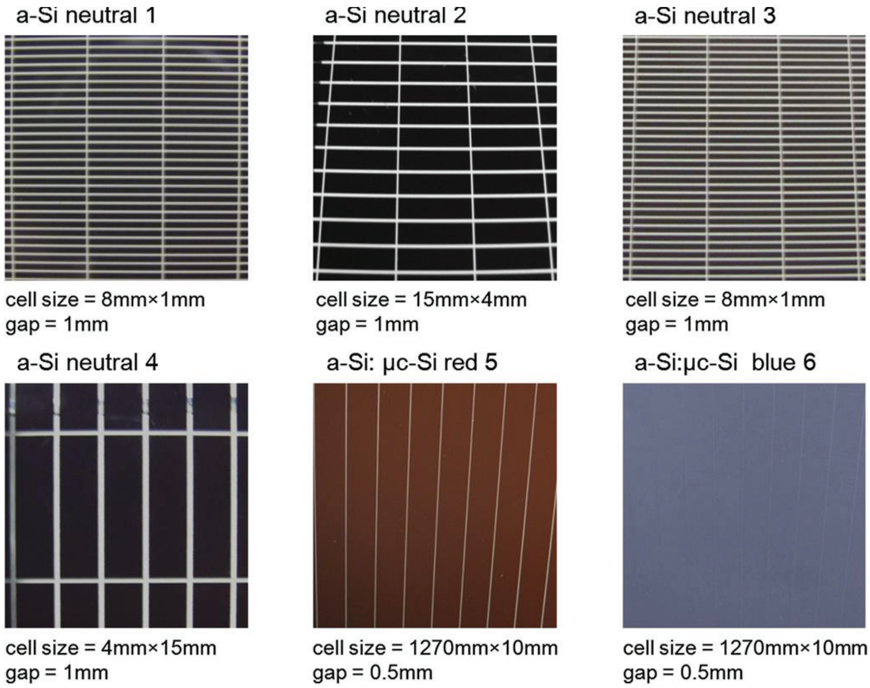


Figure 5.6. PV modules in various types
(Lynn et al., 2012)

Jelle, Breivik, Røkenes (2012) mention the potentials of semitransparent PV modules adapted in the fenestration/skylight system to propose different visual effects in the building as shown in Figure 5.7. Shading patterns vary during the daytime.

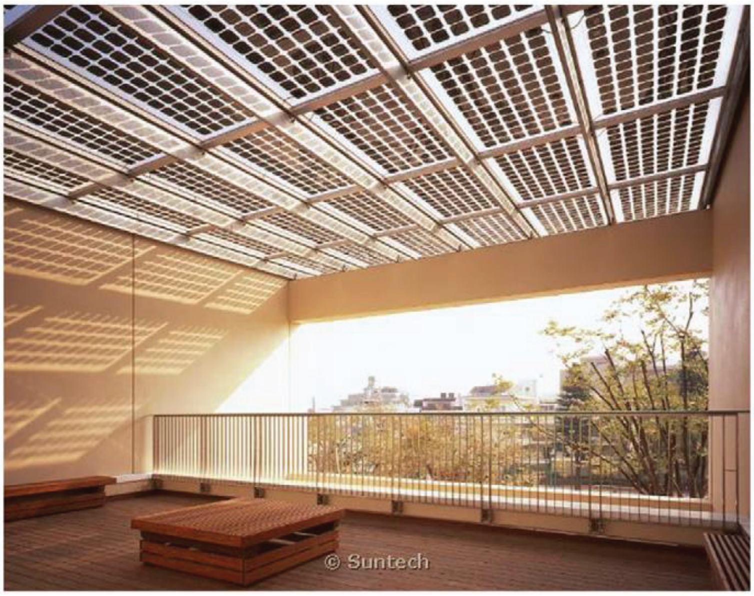


Figure 5.7. BIPV modules in the ceiling system
(Jelle, Hynd, et al., 2012)

classification	system type	system integration	Visual adaptability	Usability in performance
BIPV	Shingle PV module	Roof	• Ease of overlapping and shaping like a shingle due to significant cell incapsulation, its light-weightness and elimination of additional material	
BIPV	Semi-transparent PV modules	Fenestration	• NA	• Measuring the solar heat gain coefficient(SHGC) to test their sc • Higher sun altitudes above 45 degrees, SHGC was observed to b • Connecting an electric load reduces the SHGC.
BIDS	Electrochromic glazing	Fenestration	• Distinguishable when the system is active • Changing the color of glass	• Darkening the window surface to reduce glare • Capability of energy savings in heating-cooling and lighting bec dynamic window technology.
BIPV	Semi-transparent PV modules	Fenestration	• Apparently seen on the surface • Percentage of the area of PV modules between glass panes changes the visible transmittance	• Analyzing the heat transfer processes through the PV modules, • Reducing daylight utilization • Solar heat gain is the dominating parameter which affects the to through the PV module, and the southwest is the most effective
BIPV	PV module	Roof	• Attached to the roof tiles • Not well integrated visually • Color difference between the modules and roof tiles is very clear	• Comparing the efficiencies of two technologies, CIS and C-Si. • CIS demonstration performed better than C-Si one, 23% more t • Results are based on tilt angle, configuration, and operating con
BIDS	Sun directing glass (microstructured prisms)	Fenestration	• Distinguishable from a clear glass due to its milky appearance;	• Improving the daylight illuminance at the rear of the room, abov increasing the uniformity • Best performance in sunnier performance. • Reducing the occurrence of glare; diminishing the sun patches • Users getting more satisfied with their physical/visual environm • Benefits of aesthetics for interior designers
BIDS	Laser cut panels	Roof/ Skylight	• visually adapted well in the skylight; • not distinguishable unless the sunlight is redirected from these panels. • looking like a regular skylight with clear glass in the	• Redirecting light at low sun altitudes into the interior unlike a co skylight • Redirecting light at high sun altitudes outside the inner space, (t outside) unlike a conventional skylight

			Aesthetically appealing	
BIDS	Microprismatic film	Fenestration	• Visually adapted well in the fenestration • Milky appearance	• Redirecting the sunlight to the interior • Improving the spatial daylight autonomy above 75% even at its
BIPV	Semi-transparent PV modules	Roof/ Skylight	• Covering the two third of the total cell area • Not evaluated for visual impressions	• Analyses in terms of energy and cost • Providing daylight and producing energy • Reducing the cooling requirements and adapting well with dayl systems
BIPV	Transparent thin-film PV modules	Fenestration	• Testing color rendering index; • Affecting visual comfort inside due to diversity of their spectral characterization	NA
BIPV	PV modules	Fenestration/Shading Devices	• Visually adapted well on shading devices • Canopy type and brise-soleils type of shading devices with PVs were found to be more appealing and successful in terms of aesthetics, among architects.	• Supporting the whole energy balance with brise-soleils type of • Contributing the power energy generation with 14% (with brise • Canopy type of shadings did also supported heating and cooling consumptions with 14 % separately.
BIDS	Laser cut panels, prismatic panels	Fenestration	• Changing the luminance distribution on the fenestration surface • Visually distinguishable by the naked eye.	• Performance testing in virtual and scale model • Well performed to increase daylight illuminance • Calculating errors in terms of various glazing transmittance, s sky options
BIPV	PV, solar cells	Facade	• Proposing a new method to quantify verbal expressions of visual impressions of PV. • Emphasizing the aesthetic judgments on historic buildings	NA

5.2. Usability of BIDSs and BIPVs in Building Performance

BIDSs were preferred to increase the daylight performance of buildings and to decrease the lighting electricity usage. Regarding this concern, Kazanasmaz et.al (2016) optimized the fenestration area and micro-prismatic film area to increase the daylight performance. Microprismatic film as the BIDS in the window redirected light to the deep inside the room and improved the spatial daylight autonomy above 75% even at its optimized area. Similar types of microstructured prisms are subjected to other studies and it was concluded that they perform well to retrofit the daylight quality inside the rooms. They performed well in a sunnier climate, reduced glare and diminished sun patches, improved the daylight illuminance above 500 lux and the uniformity (Freewan et al., 2008; IEA, 2000). Laser cut panels were found to be successful when they are applied in skylights depending on the sun altitude angles. The skylight with these panels look like conventional types but modifying the passage of irradiance on the transparent surface and changing the daylight condition inside the room (Ruck, 2000).

BIPVs systems were developed for sustainable building field. Systems make smart building structure for everywhere. The power of systems, smart homes, roofing was developed by technological systems. BIPVs have great advantages for buildings. This system can adapt for roof and facade the most. Companies add this system to buildings and roofs then catch energy with solar systems which integrate into solar systems. The best result is efficiency for buildings and helps to gain from energy without spending. Then spread the energy to increase heat in building's part. Integrated into the buildings is tight but solar systems are added. As solar cell efficiency, open circuit voltage, short circuit current, maximum effect and fill factor on buildings. BIPV s distribute the energy as increasing heat or electric energy inside of buildings.

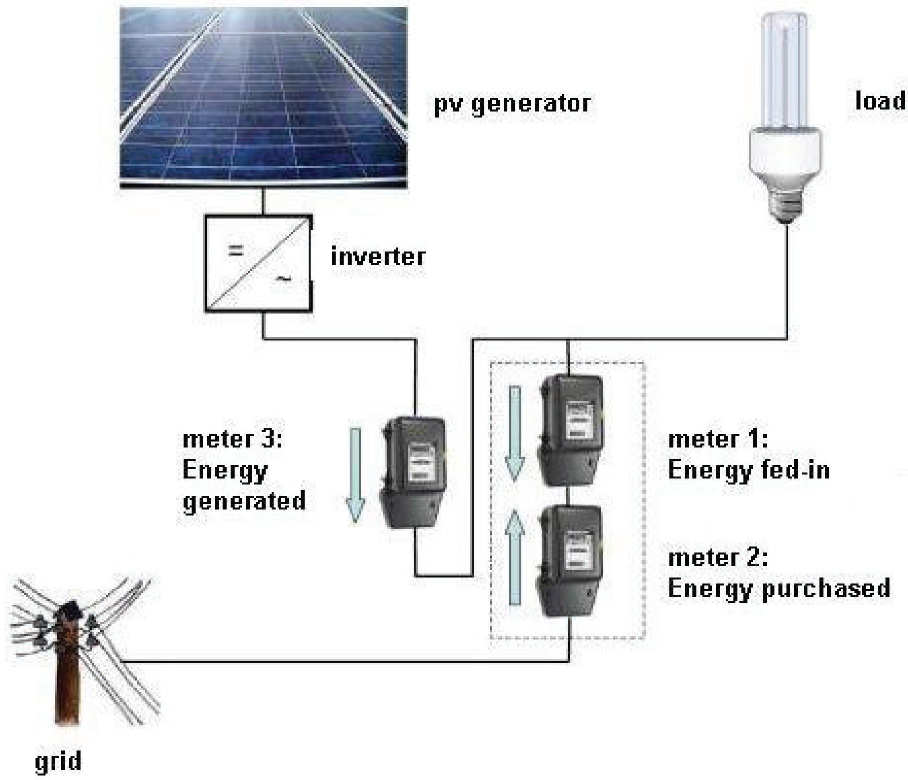


Figure 5.8. Diagram of a grid-connected PV system
(Solar, 2009)

Recent studies test the BIPVs' usability in building performance in terms of their energy generation or some other aspects. Stamatakis, Mandalaki, Tsoutsos, (2016) analyzed PV modules integrated on thirteen types of shading devices generated from variations of louvers, canopy, and brise-soleils. Their contribution to heating, cooling and lighting loads provide clues for their energy producing performance, while visual comfort aspects are additionally evaluated according to users' satisfactions about view, glare, and aesthetics. Qualitative assessments based on users such preferences depict that "horizontal louvers" inclining inwards/and outwards which are generally used in offices are found to be least preferred; while "brise soleil" full facade is evaluated as the best solution.

Jelle, Breivik, Røkenes (2012) review available BIPV products, their physical and performance-based characteristics referring to some related standards. (Li et al., 2009) analyzed the electricity generation regarding cooling and lighting energy loads and economical aspect of such a system integration. Therefore semi-transparent BIPV panels generate electricity, decrease heat gain on solar energy, and facilitate daylight regulations that save on lighting energy consumption and nominal cooling requirements.

Integrated building construction may offset construction costs. These results can help architects and building professionals to anticipate the possible benefits of using these building plans and contribute to the creation of a renewable and sustainable energy policy goal to provide a healthy environment. (Li et al., 2009)

In buildings, BIPV s perform to increase the heat inside changing the air and heat, protecting the balance inside the spaces. This is called as renewable energy for urban environment. Climatic conditions can adjust with BIPV s system. Basically, integration element maintains the solar energy as a generator and keeps it inside the wall.Operation mode has many reported on temperature. BIPV s systems have many reports on improvement of thermal integration.

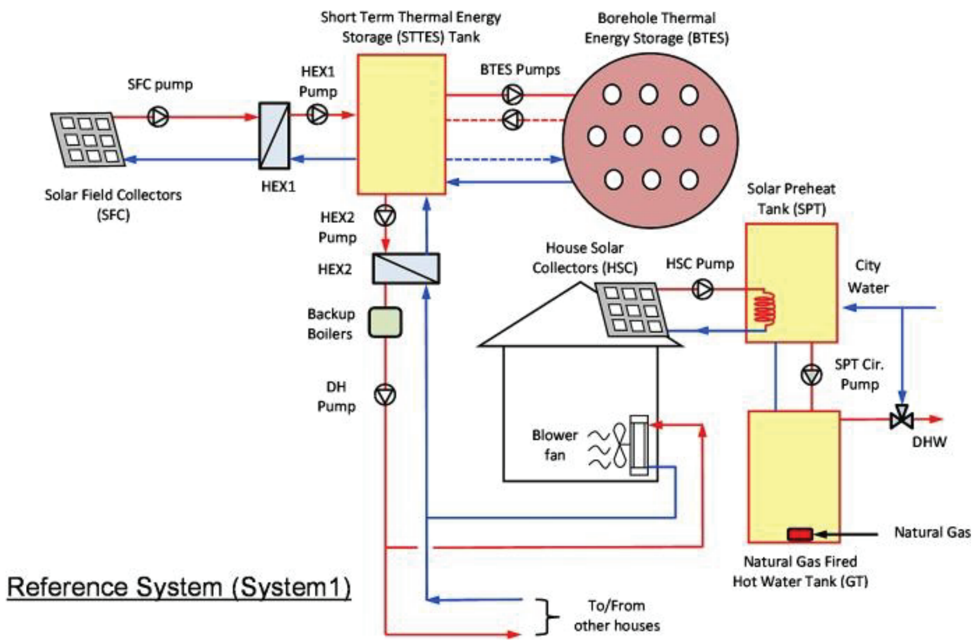


Figure 5.9. Thermal Integration

(Yang, Entchev, Rosato, & Sibilio, 2017)

Integration in recent Materials with Solar Heat Gain has been improved for increasing thermal integration. This system is reduced at the same time by limiting the energy demand of the building and the temperature increase (photovoltaic) in the buildings. HVAC supplies air with solar collectors and build thermal balance in rooms. Solar collectors catch energy in daylight. When it comes to nighttime, PCM or systems deliver energy to the whole building. Panels keep warm same period. BIPV and PCM, are both tend to keep warm outside the wall to prevent loss, and they keep warm inside and turnover the air inside the building.

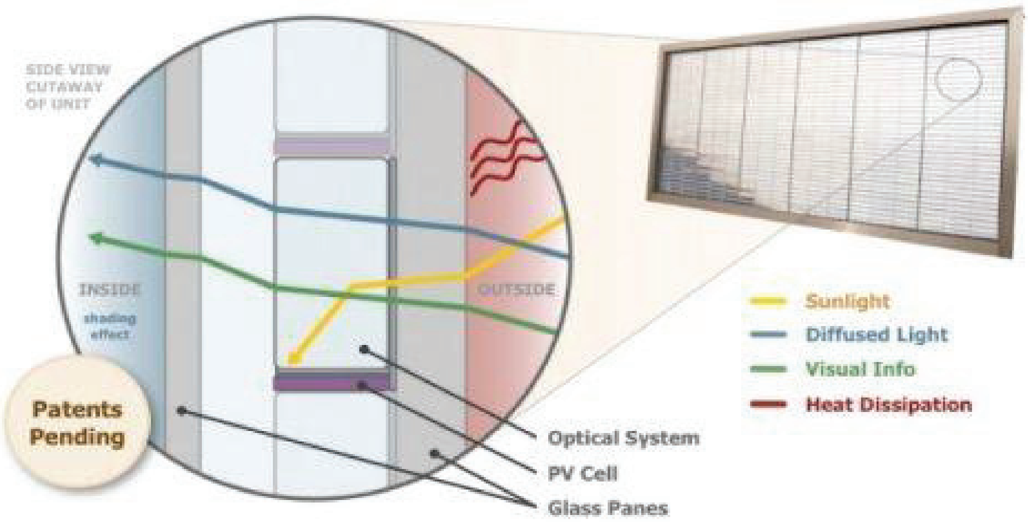


Figure 5.10. Materials for window

BIPV system and materials for roofs provide savings in both material and electric costs. Foil products are flexible and light so that, it helps weight constraints between building and roof. It also provides high efficiency at high temperatures. Tile products used to keep the temperature inside are the part of roofs. Arranged modules cater to thermal adjustments. Curved tiles types cannot effective much more, but this is also the part of the thermal integration. Figure 5.10. shows us the part of window's systems according to thermal integration materials. Modules and cells are used as a skin. They call it making skin solution. This material keeps warmth and helps to disperse into the building.

5.2.1. Energy and Cost Analysis

BIPVS systems envelop buildings as a skin, eliminating air conditions and helping to air activity and warming inside the buildings. Energy safety is increasing in buildings with solar systems. Actually, systems help to build to decrease demand of electric. As a result, system supports reducing in electricity costs. For example, %42,9 rate is founded as the energy saving rate (Breivik,2012). Actually, it supports the idea on our thoughts.
%38,2 rate is cost decreasing for spending about energy. The system gives the opportunity to reduce demand for energy. Solar collector cost is lower than energy using without solar collectors in National Renewable Energy Laboratory (NREL). The

advances in these PV technologies and their increasing efficiencies can naturally be exploited in the coming BIPV products to be made (Breivik,2012).

Jelle, Breivik, Røkenes (2012) review available BIPV products, their physical and performance-based characteristics referring to some related standards. According to this study, data were obtained related to the amount of energy consumed by the material used. When different renewable energy systems are considered, energy repayment time is essential. It describes the time it takes for the solar module to generate as much energy as it uses to create itself. In order to determine the energy payback period, the envisaged energy of the system must be estimated. Embodied energy in the materials required to make a manufacturing a 2.1 kWp BIPV system is indicated in Figure 5.11. (Jelle, Breivik, et al., 2012).

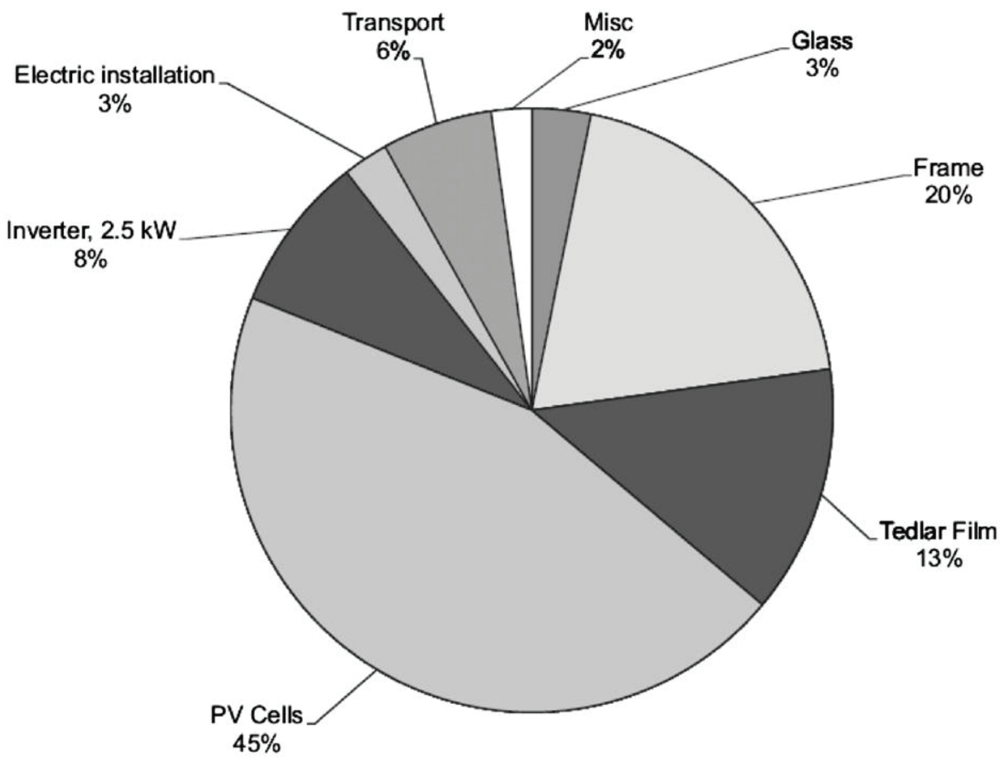


Figure 5.11. Concretized energy of a 2.1 kWp BIPV grid-tied system (Jelle, Breivik, et al., 2012)

Li, Lam, Cheung (2009) analyzed the electricity generation regarding cooling and lighting energy loads and economical aspect of such a system integration. Therefore semi-transparent BIPV panels generate electricity, decrease heat gain on solar energy, and facilitate daylight regulations that save on lighting energy consumption and nominal cooling requirements. Integrated building construction may offset construction costs. These results can assist architects and building professionals to anticipate the possible benefits of using these building plans and contribute to the creation of a renewable and sustainable energy policy goal to provide a healthy environment (Li et al., 2009).

Soğukpınar, Bozkurt (2015) analyzed the economic direction of PV usage for residencel. The study was carried out in Adıyaman, which is one of the Turkey's high potential solar energy sources. As a research result, it is seen that the average daily sunshine duration in July is 12.25h with the highest, and the lowest level of 4.01h in December (EIE, 2015). A fully equipped home consumption was analyzed by taking into account the regional situation. The result of this analysis is shown in Figure 5.12. (Soğukpınar & Bozkurt, 2015).

Electrical appliances	Power (Watt)	Used Days	Used Hours	Annual Consumption (kWh)
Refrigerator (400 liters, A+ energy class)	42	365	24	368
Air conditioning (A+ energy class) cooling mode	2200	70	8	1232
Vacuum cleaner	1000	104	0.5	52
LCD TV	100	365	5	182.5
Laptop	75	240	4	72
Washing machine AAA (cotton 60 °C)	2000	208	0.75	312
Iron	1000	104	2	208
Hairdryer	400	365	0,3	43.8
Bulb (CFC - 5 pieces)	50	365	5	91
Electric furnace	2500	52	1.5	195
Toaster	1000	52	1.2	62.4
Mixer	100	52	0.16	1
Cooker Hood	150	365	0.66	36.1
Dish-washing machine	1200	260	1	315
Phone charger	4	300	2	2.4
Other uses	1300	365	1	474
	TOTAL			3647
	DAILY TOTAL			10

Figure 5.12. The average consumption table of a house (Soğukpınar & Bozkurt, 2015)

Daily consumption of a house is about 10 kWh according to the table. However, for other uses an additional 1.3 kWh consumption was considered and added to the table. Given the seasonal changes in daily length, a total of more than 50% is added to the total consumption. Thus, daily consumption was thought to be 15 kWh. Then the prices of the units required for the system were determined and calculated as shown in the table on the Figure 5.13. The price quoted was valid for Turkish conditions and prices may vary in other countries. The system was required a total of 15,600 TL installations (Soğukpınar & Bozkurt, 2015).

Item list	Amount	Unit price ₺	Total price ₺
250 W solar panels	12	600	7200
Full sine inverter 4000 W	1	2000	2000
150 A gel batteries	8	750	6000
Charging control unit	1	400	400
TOTAL			15,600

Figure 5.13. System component price list
(Soğukpınar & Bozkurt, 2015)

CHAPTER 6

CONCLUSION

Energy production and industrialization caused to wastes which polluted air, ground and water. That was the other problem, environmental pollution, which threatens the nature and life. Global warming which is the name given to the increase in average temperatures measured on land, sea and air as a result of the greenhouse effect, is one of the most important consequences of pollution.

To overcome these problems, the attention was directed towards the renewable energy resources instead of oil and other resources which are limited and harmful to an environment like fossil fuels. As the sun is one of them, professionals and researchers developed technologies depending on its unlimited energy potential.

Integrated building design consists of two components as integrated design approach and integrated teamwork. Integrated design approach is a perspective which deals with harmony, integration and participation of all subsystems like technique, plan, construction, building materials, systems. In view of these concerns, this thesis reviewed and demonstrated knowledge about the integration of solar energy technologies through examining their technical issues and recent studies about them.

BIPVs systems are developed to design energu eficient buildings. The power of systems, smart homes, roofing are consequences of such technological systems. BIPVs have great advantages for buildings, producing energy to use in buildings. As a result of the overview of their applications, it is concluded that they are adaptable for roof and facade systems mostly. Companies use these systems on roofs to catch solar energy and integrate into solar systems. The best result can be obtained analysing their efficiency for buildings which are not intended to consume energy, but spreading it to increase heat inside the building. Their integration into the buildings is observed to be tight in terms of usability, when examining the recent products and cases in this study, as their solar cell efficiency, open circuit voltage, short circuit current, maximum effect and fill factor on buildings have become the evaluation parameters. BIPVs ability to generate and distribute the energy inside of buildings can better perform when they are successfully adapted in building systems. Thus, their efficiency has become improved.

BIDS also support daylight utilization inside the buildings, reducing electricity usage for ligthing and providing shading to balance coolling loads. Energy saving can be satisfied with such solar systems, both paasive and active ones. As the technology develops day by day, their efficiency and integration in building systems continue with an accelerating growth. Their improvement seems to be promising in building sector when we consider their recent architectural and engineering applications, products and operational performance.

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