Strategy Towards Solar Architecture by Photovoltaic for Building Intergration

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ABSTRACT

In a time when climate change has got so much attention on account of fossil-driven fuel overuse, recognition and implementation of solar-driven energies play a crucial role in human being’s future career. The traditional system of heating, lighting, cooling uses huge amount of fossil energy and produces harmful pollution to the environment. Existing buildings and constructions have a great responsibility in using, undamaging and wasting. In recent decades, the focus has been on the replacement of fossil-driven source of energy with the solar-driven one, which is free, endless and free of harm to human life and also environment. Although the use of solar energy as photovoltaic and solar thermal collectors is increasing, but the demand, particularly in building area, is less and therefore it cannot easily replace the fossil source. One of reasons why the employment of solar facilities is not considerably welcomed is the lack of architectural consideration in implementing solar facilities rather than people’s unfamiliarity with the solar technology. There is a need of design and invention of new sophisticated models to create a harmony between integrating solar facilities and the structure of existing buildings. Hence, the aim of this study is to investigate the plausible ways of blending solar-oriented technologies into both existing buildings and the new constructed ones. The study has focused on the importance of architectural considerations as well as the energy production issues. The purpose is to recognize designing possibilities with respect to the implementation of solar-oriented energies into building construction while considering new and updated models and approaches. Since aesthetics issue is an outstanding point to the general public, the study has also highlighted the importance of external appearance and beauty of solar facilities’ integration in the buildings.

Consequently, photovoltaic systems and solar thermal collectors can be designed and implemented in such a way to fulfill the necessities of aesthetic concerns. The idea of a movement toward the phenomenon of passive houses in which the production and emission of energy reaches its lowest amount will lead to invention of buildings integrated with solar-driven facilities as a new source of energy which is free of pollution, has a very low cost and includes aesthetic criterion . Regardless of all benefits that solar system provides, its shortcomings regarding integration process of design, color, and framework of existing buildings might violate the ultimate architectural quality of the construction. Due to the technological advancements in the area of solar systems, market provides the costumers various sorts of solar facilities. The use of solar systems will not end in beneficial outcomes unless they are implemented in such a way to promote and fulfill the requirements of architectural concerns in one way or another. In this case, even if there be high qualified photovoltaic and solar thermal collector systems in the market, these systems will not be welcomed by customers or public if they do not consider the integration of aesthetic models. Whereas the technological developments have found their way and the new and updated facilities are introduced, the process of implementation and integration of these systems have not been deeply considered yet. The ideas of making buildings more energy efficient and using the highest amount of renewable energy are remarkable factors for wasting of energy would reach its lowest amount and the greenhouse effect would reduce. Based on these issues, the integration process of solar-driven energies into the buildings has become more crucial than before. The integration has not only led to have purer energy but also it has caused replacement of the systems in the previous traditional buildings. Regarding the above mentioned issues, both the economic and architectural considerations of integration would therefore be met. To put it briefly, this study is an attempt to investigate the plausible models of integration of photovoltaic and solar thermal collector systems while putting special emphasis on the aesthetic aspects of integration. Therefore, integration possibilities of both systems are compared and contrasted in order to find their potential benefits and losses.

Keywords: Solar Architecture, Building Integration, Aesthetic Aspect of Integration, Solar Thermal Collector, Photovoltaic

ÖZ

Aşırı fosil odaklı yakıt nedeniyle ikşim değişikliği oluşmuştur. Bu nedenle güneş odaklı enerjilerin zaman içinde tanınması ve uygulanması önem kazanmıştır. İnsanın gelecekteki yaşamı için güneş enerjisi önemli rol oynamaktadır. Yenilebilir enerjinin yanında fosil odaklı enerji üretimi ısıtma, aydınlatma ve soğutma için büyük miktarda kullanır ve çevreye zarar verir. Son yıllarda, ücretsiz, sınırsız ve zararsız olan güneş enerjinin, fosil odaklı enerji kaynaklarının değişmesine sebeb olmuştur. Güneş enerjisinin kullanımı fotovoltaik ve termal güneş kollektörleri olarak artmakta, özellikle yapı sektöründe fosil enerjinin yerini almaktadır. Yapılarda güneş enerjinin kullanımı önemli ölçüde memnuniyet sağlamamıştır, nedenlerinden biri yapılarda güneş enerjisi teknolojisinin insanların mimari algılamasını olumsuz etkilemesidir. Entegre güneş tesisleri ve mevcut binaların yapı arasında bir uyum yaratmak için, yeni gelişmiş modellerin tasarımına ve buluşuna ihtiyaç vardır. Bu nedenle, bu çalışmanın amacı mevcut binaların ve yeni yapılarda güneş odaklı teknolojilerin göze hitap edecek şekilde makul yollarını araştırmaktır. Tez çalışması; mimarlığın yanında enerji üretimin üzerinde de odaklanmıştır. Amacı yeni ve güncel modelleri ve yaklaşımları dikkate alarak, inşaat malzemeleri yanında güneş enerjilerin uygulanması ve tasarımının kabul görmesidir. Estetik sorunu çevredeki insanlar için önemli bir konu haline geldiği için, tez çalışması güneş enerji tesislerinin binalarda dış görünüşü ve estetik önemi vurgulamaktadır. Sonuç olarak, tasarlanan fotovoltaik sistemler ve güneş enerjisi kolektörleri estetik kaygıları önemsenmiş ve estetik değerlerinin dikkat alınması bu şekilde göstermiştir. Enerji üretim ve emisyonun en düşük miktarda ulaştığı pasif evlerin olgusu doğru bir yaklaşım olarak benimsenmiş, çevre kirliliği önleyen, ücretsiz yeni bir enerji kaynağı olarak güneş odaklı tesislerinin yapılardaki entegrasyonu analiz edilmiştir. Aynı zamanda düşük maliyeti ve estetik ölçütü de içerir. Güneş enerji tesislerinin avantajları yanında, mevcut binaların tasarım, renk ve çevre entegrasyonu sürecindeki eksiklikleri ve yapının mimari kalitesi olumsuz etkileyebilir. Güneş sistemleri alanında teknolojik gelişmeler nedeniyle, güneş enerji pazarı güneş tesislerinin müşterilerine çeşitli olanaklar sağlar. Onları bir şekilde estetik mimari kaygıların şartları teşvik etmek ve yerine getirmektir. İyi uygulanmadığı takdirde, güneş sistemlerinin kullanımında yararlı sonuçlar vermiyecektir ve estetik alandaki entegrasyonu dikkate almıyacaktır. Bu durumda, yüksek kaliteli fotovoltaik ve piyasada güneş enerjisi kolektörü sistemlerinin olması bile, bu sistemler müşteriler veya kamu tarafından memnuniyeti sağlamıyacaktır. Her ne kadar teknolojik gelişmeler tanınıp ve piyasade kendini kabul ettirdiyse de, uygulamada sistemlerin entegrasyonu sürecinde henüz kabul görmemiştir. Binalar daha enerji verimli hale gelmesi ve yenilenebilir enerjinin en yüksek miktarda kullanılması, enerji israfını önemli ölçüde azaltacak ve ve sera etkisini düşürecektir. Bu tesbitlerden yola çıkarak, binaların güneş enerji sistemlerinin entegrasyonu süreç içinde daha önemli hale gelmiştir. Entegrasyon sadece saf enerjiye sahip olma değil, aynı zamanda geleneksel yapılarda enerji sistemlerin değiştirilmesi neden olmuştur.

Anahtar Kelimeler: Güneş Mimarisi, Yapı Entegrasyonu, Estetik Uyumu, Fotovoltaik Sistemleri, Güneş Enerjisi Kolektörleri

To my family

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INTRODUCTION

It is estimated that all over the world, buildings have the potential to use around fifty percent of energy source at global levels. This energy is primarily originated from fossil fuel, which is the main root of gas emission and greenhouse gas. In this continuously developing world, energy will certainly play an outstanding role; consequently, attempts are made to replace the fossil driven source of energy with the endless solar-driven one. Moreover, energy can play a crucial role in improving economic level in the world. That is why some scholars believe that the present time is and would be the energy era. In this case, having access to the endless source of solar energy, and also implementing it would be of great advantage to those who have the knowledge, technology and also the ones who know how to install and integrate that energy. Unfortunately, in most building constructions, the most primary issues such as heat trapping, gas emission, suitable orientation and natural ventilation are simply neglected.

The major purpose of this study is to underline the employment of solar-driven source of energy and the consequent solar facilities leading to up-dated approaches for the sake of better recognition and implementation of this renewable energy. It is widely believed that the outstanding status of planning and design, which plays a crucial role in general content of solar structures and buildings by means of visualization and realization, should remarkably be taken into account. Saving time money in addition to saving energy are two beneficial outcomes of solar-oriented facilities installation during the reconstruction process and up-keeping the existing buildings. Giving an example will clarify this fact; if during the reparation process of a building its existing roof is going to be ameliorated, there might be at least two significant outcomes, that means money spent on roof tiling would be saved and also a pure source of energy production would be implemented. In this process, solar-oriented facilities would both easily and quickly be integrated into the planned extensions like conservatories (Hermannsdorfer and Rub, 2005, p.12).

Solar energy has several important benefits for human life among which are electricity and heating, which can be generated in a noiseless form without polluting the environment. However, implementation of solar systems is not merely solar facilities installation; furthermore, they are architectural models of high importance according to their design and application in construction of new buildings or renovation of existing ones. In most cases, in the process of integrating solar-rooted facilities, architectural planning have been overlooked at the expense of spending the lowest amount of money and time while gaining the highest amount of energy. However, it is more reasonable to consider both sides, which means having both an appropriate architectural design beside the economic benefit in producing cheap and clean energy deprived of noise and pollution. Kjellerup et al. (2010) declare that solar facilities have a capacity of fulfilling architectural requirements while being economic and produce free energy.

By the changes in global requirements, constraining the definition and the necessities of solar-oriented facilities has become a great concern particularly in their technological implementation, but the scope and definition should be broadened so to meet the needs of architectural design in construction and urbanization of modern buildings. Hence, the vital status of architectural planning and sketching in solar system implementation must be theoretically and operationally redefined. According to Hermannsdorfer and Rub (2005), solar system has the potential to promote architecture, giving it an outstanding position and making it easily differentiated. They can simultaneously represent both sides of the coin, in way that they adapt themselves to the needs and necessities of the modern world while keeping the traditional characteristics of old structures and buildings. Consequently a satisfactory atmosphere would be created in which the buildings preserve their identity and the owners consider their properties updated and modernized. Integration of architecture would be positively and warmly welcomed by both the owners and the construction buildings.

It appears that integration in existing buildings is more challenging than their integration in new buildings, since the implementation is to be designed in a way to accord the setting and context of the existing building; in other words, in their integration in existing buildings, the framework cannot be predetermined like the case of new buildings.

Why is it challenging? Since standard integrations are defined and designed in advance, the integration of solar–oriented facilities in existing buildings inevitably needs new and innovative approaches. Findings demonstrate that the existing buildings, constructions and landscapes typically require a slight amount of implementing technological elements such as systems of photovoltaic and solar thermal collector into the previously in-hand context and setting, whereas integrations in new buildings and monuments is an easy to tackle process if the theoretical and operational considerations be scientifically and properly determined beforehand.

1.1 Problems Statement

The recent environmentally sensitive attitudes in architecture are important responses, found in the interdisciplinary communication, to the critical statement of the man-made built environment, which has led to the crisis of contemporary architecture. The problems which are covered in this study are considering of integrated achieve technology for generating of electricity, thermal comfort and especially the increasing architecture quality in different structure.

1.2 Research Aims and Objectives

The current research focuses on environmental friendly solar energy. Setting producing electricity and warm water as the primer functions of solar panels aside, the PVs and collectors can be considered from aesthetic point of view in any architecture. This investigation strives to disclose the advancement of solar integrations to achieve more developed building. Under this scope, this research mainly via three great categories of structural system from three aspects of integration (form, function and structure) aimed to reveal differences of integration method in each structure and show the importance of Photovoltaic panels in the next generation of architecture beside structural system.

1.3 Research Questions

Research question so order to focus the study on the aesthetic or formal aspects of integration the question is:

How can Photovoltaic be integrated into structures while enhancing the architectural quality in different structure?

- How can we integrating photovoltaic in indifferent structure?

- To what extent can energy generation be compromised over architectural aesthetic aspects?

1.4 Scope of Research

With respect to architectural integration, this study initially aims to survey the implementation and integration of systems of photovoltaic and solar thermal collector into buildings either new building or already existing ones. In this study, the main emphasis is on the integration into the construction in situ, landscapes and spaces in urban area. Several examples of various parts of integration have been given so that it would be easy to make sense and clarify.

1.5 Methodology

The major purpose of this investigation is to find the plausible, convenient and conforming models of the architectural integration of the photovoltaic and solar thermal collector systems into already-existing or new constructions and buildings. The research also aims to improve the general architectural appearance of the buildings as well as introducing and implementing them as an essential element of every building. The study attempts to represent the fact that whether the solar facilities are capable enough to improve the quality of architecture; consequently, the answer was that they are highly beneficial to both the property owners and the system designers. Surely, the owners' viewpoints would be flourished to adapt themselves with the outcomes of the architectural integration. Ultimately, solar systems would be acceptable as an essential part of the building in the forthcoming days.

This qualitative study, in addition to scrutinizing literatures and theoretical documents as basic information, has chosen a case study to analyze the level of satisfaction and adaptation quality of architectural integration. To achieve the main aim, the author has conducted a direct observation while taking photographs from a chosen case study in Rome, Italy. Additionally, to understand the satisfaction level of users about the aesthetic adaptation of architectural integration of solar panels, some questioners were distributed among the staffs and parents of children.

1.6 Solar Energy

1.6.1 Solar Energy

As a source of thermal energy, solar energy is used as either for heating a place or generating electricity (Thomas et al., 2001, p.18). Passive solar heating "refers to architectural design techniques which enable the building structure to absorb as much solar energy as possible during daylight hours in the winter months" so that the energy can be released to replace the heat which is normally provided by traditional fuel fire or electric heating apparatuses (Thomas et al, 2001 p. 88). Active solar heating uses the sun’s energy, through the use of solar collectors for example, to heat water or other fluids and then circulating it through the building or using for hot water generation, while active solar electricity generation (the focus of this thesis) uses photovoltaic (PVs) or concentrated solar collectors to create usable power. Moreover, the energy used in today’s world comes primarily from fossil fuels, such as coal and oil, but since it is evident that those sources are diminishing and most probably going to be depleted in a relatively short period of time, their consumption has to be rationalized and using other sources of energy must be more widespread. Technological development in these alternative energies has been in progress rapidly since the oil shortage in the 70’s and more recently it has advanced by technological improvements in the science field. Sun is a fundamental source of life and the oldest form of energy that mankind has used since the beginning of history. In many places of the world, it can fulfill most of our necessities if we take advantage of its great quantity and learn a way to use this energy rationally. It is estimated that sun’s energy will last at least for the next 6000 million years (CENSOLAR, 2007, p. 77), so it can be considered as a renewable, free and clean source of energy. However, it must also be considered that the source varies by the length of the day, period of the year, latitude, geography, weather, etc. Solar radiation could be divided in two categories: ray lights that reach a surface on a direct way; and radiations which pass through clouds, as a diffuse form (Gauzin-Müller, 2001, p. 27). For architectural purposes, we can obtain three things from sun energy as:

- Natural light
- An electric source, converting the energy using photovoltaic cells
- Thermal energy

1.6.2 Photovoltaic

It has been a long time since the discovery of photovoltaic effect in 1839 till electricity was actually generated from photovoltaic (Energy Efficiency and Renewable Energy). These systems are usually based on silicon and are used to convert solar radiation into electricity. Direct current (DC) is generated when the devices are exposed to sunlight. The generated electricity is used either directly in DC appliances or is converted using inverters to run AC appliances. The DC current can also be stored in batteries to be used during the night when the PV systems do not produce electricity. PVs respond to both direct and diffused radiation, and the output rises with increasing sunshine which is called irradiance and decreases with the module's temperature escalation. Common available PVs are mono- crystalline silicon, polycrystalline silicon and thin film silicon called amorphous silicon (A-Si) (Thomas et al., 2001, p.18).

There are different classifications for Photovoltaic systems: autonomous or connected to a grid power line. The first one operates separately, usually on remote places or places with difficult access, such as islands, mountains, ships, etc. The second one works together with the electrical grid; that means buildings or equipment which are connected directly to the photovoltaic system, but they also can be alimented by electricity gained from the grid. Similarly, exceeding energy coming from the solar panels can be transferred and sold to the grid. Another classification could be defined by the system's specific use (Davidson, 2007, p.97). Among the major benefits of photovoltaic systems for electricity generation are:

- Low polluting energy

- Energy payback time (usually within 1-2 years, depending on the system)

- Low maintenance (absence of mechanical parts)

- Operation under direct solar radiation and even in cloudy conditions.

- Solar Panel Modules can be aggregated as needed

- 30 year life lasting system (depending on the company)

It is often believed that solar panel systems impact facades, style and landscaping; being an adaptation or improvisation to the original design. However, nowadays there are many solutions for satisfactorily adapting solar panels to facades and roofs, generating a growing acceptance within architects, their clients and society.

1.6.2.1 Photovoltaic Cells

Photovoltaic systems are sustainable, environmental friendly, quiet, light and they require minimal maintenance as they have no moving parts. In a PV system, cells combine to form modules, which give the system the flexibility to be expanded or reduced to suit any given application. The versatility of PV panels gives numerous possibilities for their integration into new and existing structures. Although cell types which are used more frequently are produced by the same base material silicon, different technologies offer cells with different technical and aesthetic characteristics.

1.6.2.2 Mono-Crystalline Cells

A singular unbroken crystal is the basis from which mono-crystalline cells are developed by the means of cutting them into wafers and that's why they are known as single mono crystal cells. The cells might be cut into other shapes or fully round, keeping approximately of the genuine circle in order to minimize waste, because each piece of cell is cut from a particular crystal, each one has a distinct color (Solar, 2011, p.112). Units of mono-crystalline silicon typically ranging from blue to black in Mono crystalline which are stable and long lasting color. An extensive range of colors are available but it should be noted that they are of minor efficiency. For instance according to Reijenga and Kaan (2011) Thomas et al (2001) magenta or gold leads to a loss of efficiency up to 20%. The sizes of the cells are around 10 x 10 cm2 and their thickness is estimated 350 micron with 14-17% efficiency. According to Fuentes (2007); Thomas et al (2001) in a modulate climate they typically produce, 900-1000 kWh per each kW installed (Fuentes, 2007; Thomas et al., 2001, p.8).

Figure 1.1: Mono-Crystalline Cells
Source:http://www.pvsolarchina.com//

1.6.2.3 Poly-Crystalline Cells

Polycrystalline cells and mono-crystalline cells are formed of similar materials but the only difference is that, they are melted and poured into a mold instead of being developed into a single crystal.

The result of these process is forming square shape blocks which are cut square like wafers which end up with fewer waste of material and space in comparison with wafers which are round single-crystal. Materials crystallize in an inadequate form and shape haphazard crystal forms as they cool off (Solar, 2011, p.18). According to Fuentes (2007), Thomas et al (2001) the performance rate which is estimated for equal dimension Polycrystalline cells is up to 12%. It is assumed to produce around 750-850 kWh per each kW installed in European weather (Fuentes, 2007; Thomas et al., 2001, p.22).

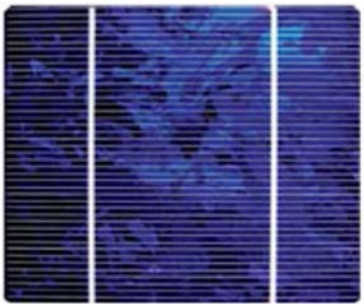


Figure 1.2: Poly-Crystalline Cells
Source: http://www.pvsolarchina.com/

1.6.2.4 Thin-Film Cells

The latest thin film technology also known as amorphous is either produced from silicon or even new base materials, like Cadmium-Telluride (CdTe), Gallium-Arsenide (GaAs) or Copper-Indium-Diselenide (CIS),(Solar, 2011, p.11). They are protected by encapsulation with front glass and back protection, resulting in PV modules. The estimated efficiency for thin-film cells is assumed to be up to 5-8% and produce around 600-800 kWh per each kW installed. They are also accessible in a variety of colors (Fuentes, 2007; Thomas et al., 2001, p.22).

Figure 1.3: Thin-Film Cells
Source:http://www.pvsolarchina.

Table 1: Efficiencies of Different Types of Cells

	Type	Appx. Cell Efficiency	Appx.modular Efficiency	Area Requirement
1	High performance hybrid silicon		17-18%	6-7m^2/kW_p
2	Mono-crystalline silicon	13-17%	12-15%	7-9m^2/kW_p
3	Polycrystalline silicon	12-15%	11-14%	7-10m^2/kW_p
4	Thin-film CIS		9-99%	9-11m^2/kW_p
5	Thin-film CdTe		6-8%	12-17m^2/kW_p
6	Thin-film amorphous silicon		5-7%	14-20m^2/kW_p

Source :(Roberts and Guariento 2012; Thomas et al., 2001)

1.6.2.5 The Photovoltaic Principle:

Crystalline silicon cells are made up of p- and n-type silicon's. These cells, which are of low voltage, join in series to form a module of higher, more useful voltage. Modules are constructed like a sandwich, having a backing sheet and a cover of low-iron glass for protecting the front surface of the material while keeping up high Tran's emissivity (Thomas et al., 2001, p.25). The backing sheet does not necessarily have to be opaque. It can be glass as in Doxford Solar Office. The PV cells are compressed between two layers of glass while having transparent spaces between them; thus light passes through the transparent areas (Fig 1.4). Crystalline silicon modules may have various sizes and shapes. Larger ones can have reductions in cost because of lower wiring costs and simple framing arrangements. Polycrystalline modules are normally blue although other colors are also applicable. The appearance of thin-film cells is identical, having a dark matt surface with colors ranging from grey, brown and black (Reijenga and Kaan, 2011; Thomas et al., 2001, p.44).

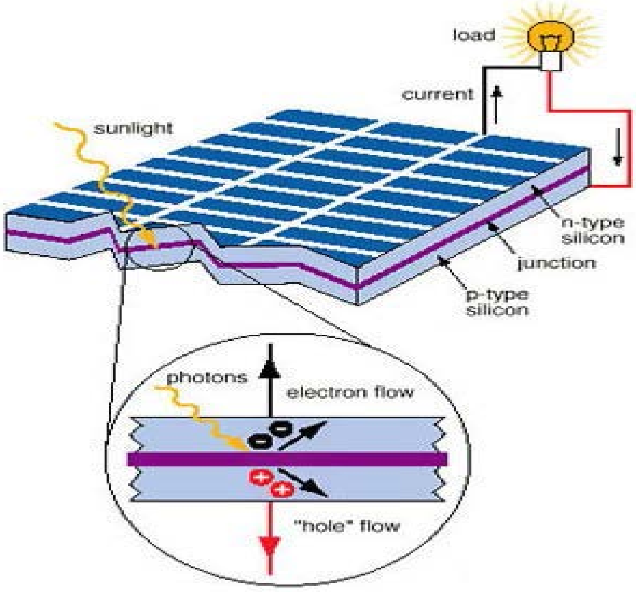


Figure 1.4: The Photovoltaic Principle,
(Source:http:// clengreenenergyzone.com/

1.6.2.6 PV Characteristics

With estimated output of minimum 80% and 5-year energy pay back rate for production, PVs are assumed to have longer lifetime of around 20 years. One of the significant benefits, which they have, is decreasing emissions, which in turn are very important from environmental perspective. In fact, the engineering processes for amorphous silicon and crystalline silicon raise no environmental concerns. There are many questions and concerns, which have been articulated about the possible environmental effect of using these new materials, primarily cadmium telluride. Though, according to Thomas et al (2001) the process of production is designed so that cadmium is not released and producers are developing constantly systems for recycling in order to avoid clearance problems. Totally, all PV technologies generate far less life-cycle air emissions per GWh than conventional fossil-fuel based electricity generation technologies and at least 89% of air emissions associated with electricity generation could be prevented if electricity from photovoltaic system displaces electricity from the grid (Fthenakis et al., 2008, p.22).

The output from the PV array will depend on (Thomas et al., 2001, p.99):

• The daily variation due to the rotation of the earth and the seasonal one due to the orientation of the earth's axis and the movement of the earth about the sun

• Location, (the solar radiation available at the site)

• Tilt.

• Azimuth, (orientation with respect to due south)

• Shadowing

• Temperature, (the drop in performance is more marked for crystalline silicon than amorphous silicon. Designs for building-integrated PVs need to consider this from the very beginning in order to allow air to flow over the backs of the modules to maintain high performance.)

1.6.2.7 Types of PV Modules

PV cells are put together to form modules. Modules are designed for outdoor situations, so they are able to be part of the building skin. However, different encapsulation technologies result in having a range of PV panels with different performances as a constructive element, such as a glass-plastic or glass-glass back sheet. Standard modules have an aluminum frame. For building integration, "laminates", which are modules without frames, are generally used (Fuentes, 2007, p.19).

1.7Architectural and Building Integration of Photovoltaic

1.7.1 Building Integration of Photovoltaic

The PV, when integrated in a building, become part of the general building design and often become general building elements (Hestnes, 1999, p.55). From economic point of view, it is essential that the systems be integrated into the building envelop so that no additional investments on the support structure be needed. These systems must replace the conventional building elements, in addition to their ability to produce energy, and serve dual function to decrease the whole cost. Hence, energy systems in a building must be designed, as an integral part of the whole, i.e. a ‘holistic’ approach to structure design should be implemented. These systems must be taken very early in the design phase and should not be treated as separate elements that are added after design or when the building is completed. Example of the largest solar thermal project integration is seen in the “Solar City” housing development, The “Sonnenschiff” solar city in Freiburg, Germany (Fig. 1.5). Integrating the systems into the roof was thought right from the conceptual design phase. These collectors cover the entire south facing part of the roof, replacing the traditional roofing materials, thereby reducing the total cost of the project. In addition to energy production for space and water heating, aesthetics of the structure is enhanced by the elegant curvature of the roofs. In summer, excess energy production is sold to neighboring buildings (Hestnes, 1999, p.45). The terms ‘component integrated’ and ‘building integrated photovoltaic’ (BIPV) refers to the concept of integrating photovoltaic elements into the building envelope, establishing a symbiotic relationship between the architectural design, functional properties and economic recovering energy conversion (Odersun, 2011, p.32). Accordingly, the photovoltaic modules take the place of conventional construction materials, and take possession of their function and performance. Even though this is not a novel idea, the idea is not widely harnessed due to the extensive planning and architectural challenges currently involved.

Figure 1.5: The Sonnenschiff Solar City in Freiburg, Germany
Source: http://inhabitat.com/sonnenschiff-solar-city-produces

Theoretically, building integrating photovoltaic can be used in whole parts of the construction envelope in building. Although roof surfaces are the preferred area for installing PV elements due to their advantageous irradiation principles, façades also offer huge potential. Façade surface area ratio to roof surface area increases along with the building height. Buildings integrating photovoltaic façades have special value in crowded and high density urban centers as the roof space is limited as a result of putting facilities and support structures on them. Moreover, according to Odersun (2011, p.21), integration into the facades has become even more significant.

In construction or architectural integration, along with generating energy, active solar elements have to play the same role of the traditional wall, windows or roof cladding elements they replace. Roberts and Guarantor (2012) in their handbook of BIPV, have declared that the requirements which must be addressed by building integrated active solar systems are color, image, size, weather-tightness, wind loading, durability and maintenance, safety during construction and in usage (fire, electrical, stability), and cost. Building integration concerns the physical integration of a PV into a building, with the emphasis of overall impression it gives to the building. For the architect, aesthetic aspect rather than the physical integration is the main reason for speaking about building integration. The optimal situation would be a physically and aesthetically well-integrated system. In fact, many examples of physical integration show absence of aesthetic integration. Visual analysis of solar systems in buildings shows that the look of a poorly designed building does not improve, simply by adding a well-designed system. Moreover, a well-designed building with a nicely integrated solar system will be accepted by people (Reijenga and Kaan, 2011, p.85).

1.7.2 Architectural and Building Integrations Difference

It is usually possible to do architectural integration, i.e. integrating systems architecturally in a good way so that the aesthetics of the building get enhanced. However, it may always not be that easy to do building integration.

PV or collector systems on the buildings are either architecturally integrated, building integrated, or both. However, these systems should not has to be building integrated to achieve architectural integration. It can be further said that building integration is architectural integration as well, but all architectural integration is not building integration. When the process of integration enhances architectural quality of the building, it is called architectural integration. In a building integrated PV roof, the roof may be especially manufactured with PV already fixed as its external part. In case of architecturally integrated PV roof, PV modules can be laid as normal roofing elements with normal construction techniques. In both cases, the integration may add on to the aesthetics of the roof and the whole building, hence called architectural integration. Integration also does not mean that PV and solar thermal collector systems be used in such a way that they are not recognizable. It would not necessarily be wonderful or important if the integrated PV and collector system be ‘hidden’ and not shown.

In practice, energy output of PV and solar thermal collector systems may have to be compromised over architectural integration; which means, in an approach to use these systems in such a way that the building’s architectural expression be enhanced, they may not located in the best position, direction and orientation. It is necessary to compromise, but the best thing would be not compromising. However, due to practical reasons, there are compromises. Architects must be more innovative and creative enough to tackle this issue (Hestnes, 2012, p.12).

1.7.3 Between Integration into Existing and New Buildings Challenges

Current or historic buildings, like new buildings, offer a broad range of possibilities for PV system integration. However, installations on existing buildings unavoidably tend to be more fragmented than on new buildings, since they have to comply with an existing situation. As standardized products are often not applicable, the situation calls for innovative approaches with custom made products (Hermannsdorfer and Rub, 2005, p.44). It is always not an easy task to make integration in an existing building due to various practicalities. Integration task will have to be planned according to the situation observed in location, which varies from building to building. In case of historically essential buildings, sometimes the PV and thermal collector systems might have to be integrated somewhere else other than the building itself, if there are regulations not to make interventions. In particular cases, little intervention is allowed like in the church in Carlow, Germany (Fig. 1.6). The church was equipped with PV in the course of roof repairs. The polycrystalline module was produced to match the existing roof tiles in shape and color; one photovoltaic module replaced six roof tiles. The PVs were integrated into only a small part of the roof, replacing the usual roofing material. Thus the historical appearance of the church was preserved as stipulated by the monument protection authority (Hermannsdorfer and Rub, 2005 p.77).

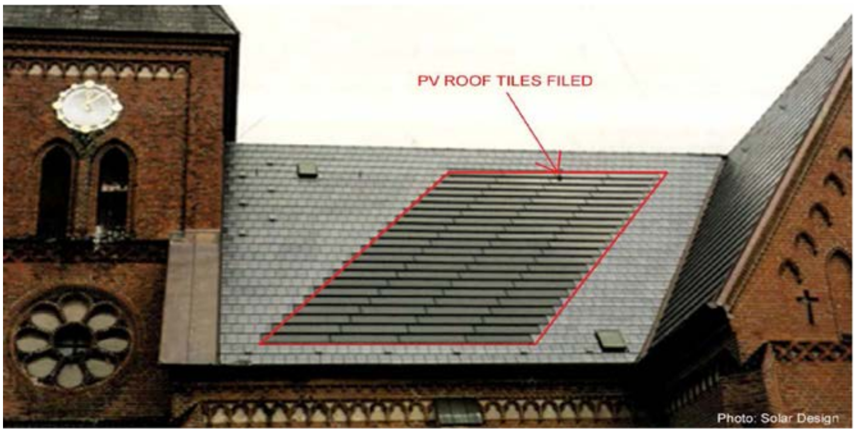


Figure 1.6: Architectural Integration of PV on the Roof of a Church, Carlow, Germany. The Formal Characteristics of the PV System have an Impact on the Integration Quality (Source: Solar Design)

In case of new buildings, integration of photovoltaic or solar thermal collector systems is conceived from very early stage of the design. As such, these systems would be an integral part of the design concept; forms may be derived accordingly and material use was determined as well. Solar cells are interesting as a material when integrated in the architectural concept. The possibilities of working with photovoltaic or solar thermal collector as a part of the concept can vary. This depends much on when these systems are introduced in the project (Lundgren and Torstensson, 2004, p.77). In this way, integration in new buildings looks comparatively easier than the existing ones as these solar systems will be used accordingly after appropriate design have been developed.

1.7.4 Integration of Photovoltaic Systems in Buildings

For architects, the application of PV system in buildings must be part of a holistic approach. A high-quality one of these solar systems can provide a substantial part of the building's energy needs if the building has been designed in the appropriate way. By holistic approach, integrating these systems does not only mean replacing a conventional building material, but also aesthetically integrating it into the design which is called architectural integration. The integration also takes over other functions of the building's skin. Mounted on a sloped roof for instance, profile systems mean that PV can be part of the watertight skin. A distinction can be made between literal integration of these systems in the building skin as cladding elements and integration of them into the roof or as building components like awnings, shading devices etc. (Reijenga and Kaan, 2011, p.20). The goal of architectural and building integration of these systems into constructions is to decrease the requirement for land and costs, in addition to aesthetics that is produced by the process. This could be the cost of support construction and also building components, such as tiles and cladding elements. It is evident that PV systems integrated into buildings give them a more elegant look, besides it is more effective to integrate these systems when constructing the building, rather than mounting it afterwards.

Usually there are three locations for integrating these systems into buildings; which are the roofs, facades and building components such as balcony railings, sunshades and sunscreens (Reijenga and Kaan, 2011, p. 77).

1.7.5 Appropriate Integrating Type

Pleasing PV systems in buildings in sense of architecture, a decent composition of material and color which finely adapts to modularity in whole, grid's visual aspect which generates a satisfying composition and is in line with the building's harmonization, would result in good integration and render high architectural quality (Roberts and Guariento 2012, p.108). Further, these systems which are suitable in buildings, their integration is well designed, and their use has generated an innovative concept, often make the architectural integration rich and successful.

1.7.6 Integration Method

Both photovoltaic and solar thermal collector systems can be incorporated into buildings by superimposition, i.e. the attachment place of system over the existing building integration or envelope, where the system forms a part of the building envelope (Fuentes, 2007, p.18).

1.7.7 Integrated of Photovoltaic

Photovoltaic and solar thermal collector systems are used both as a component of architecture along with a means of energy generation. This method is most likely appropriate for new buildings. Photovoltaic and solar thermal collector materials replaced traditional constructive elements. When the traditional elements' cost is higher than the one of the substituted elements, savings would be possible. It offers a pleasant and clean appearance (Fuentes, 2007, p.14). The most common integration types and techniques would be discussed in the following two chapters in chapter 6 and 7.

1.8 Integration of Photovoltaic

With the discovery of photovoltaic, it is comprehend that buildings' skin have the energy production capacity as well. Photovoltaic modules, in most cases, still are considered to be technical devices that need to be adjusted to the building skin, despite the fact that a variety of products that convert them into building components have been developed lately. However, in case solar modules become part of the building skin, they would gain multiple functions and require aesthetical integration into the overall design concept (Farkas, Façade Integration Typologies of Photovoltaic).

Architectural potential of integration into both roofs and facades has always been an interesting subject to be explored; even roofs which are pitched or inclined and are as visible as facades can provide architects with both challenges and opportunities for integration. All parts of an external wall or roof which properly faces the sun, e.g. claddings, windows, skylights, railings and external shading devices, can potentially be employed as PV integration. Employing dummy 1 unit is one of the possible solutions in surfaces which are not exposed to the sun or even in those which are not suitable for integration.

The advantages of integrating PVs into the building are listed below according to what Reijenga & Kaan (2011) and Voss et al. have proposed:

- Particularly in areas with high density, additional space is not needed.

- The cost of PV roof or wall, which can be used as building material, is effective comparing to the traditional ones.

- On site electricity production which is cost effective and avoids distribution losses.

- Guaranteeing the security of supply if PV is connected to network and avoiding storage expenses.

- From architectural point of view, they are more beautiful and appealing in the market.

1.8.1 Facade Integration of PV

External walls of buildings being covered with insulation and protective cladding is a normal building practice. This cladding can be wood, metal sheets, panels, glass or PV modules. For luxury office buildings, where the cladding is often costly, integrating PV modules as cladding on opaque parts of the building would not be more expensive than other commonly used materials such as natural stones, granite or aluminum cladding. In the Solar XXI building (SHC, 2012) in Portugal, vertical bands of photovoltaic panels are integrated into the south facade, with an alternative rhythm with the glazing (Fig.1.7). This confirms that an elevation based on modularity concept and recurrence PV can equally be integrated into the glazing of the façade. Structural glazing or structural facades are constructed using highly developed profile systems which can be filled with all types of sheeting, such as glass or frameless PV modules (Reijenga and Kaan, 2011p.44). Transparent and semi-transparent modules of PV have been developed and used in curtain walls for controlling daylight in addition to producing energy. The arrangement of solar cells on the glass cladding, with gaps in between functions, both in shading as well as contributing to the passage of controlled light into the interior space can be seen in the Tobias Grau Production Building in Germany (Fig. 1.8). Beside generating electricity and shading the building's southern front, solar cells also insulate the building quite successfully. Semi-transparent glazing prevents direct sunlight from entering the building, which reduces cooling loads (SHC, 2012 p.14).

Figure 1.7: PV Integrated into the Opaque Parts of the Façade of Solar XXI Building. (Source: www.enginsolar.com)

Figure 1.8: PV Integrated into the Opaque Parts of the Façade of Solar in Germany. (Source www.enginsolar.com)

A vast space is provided by facades for the purpose of integrating PV panels. Besides producing electricity there are some advantages which are mentioned for integrated

PVs such as being attractive and also protective against bad weather conditions. PV modules can be integrated in day lighting, windows and even shading schemes in order to produce multiple and various advantages. The typical building integrating photovoltaic facade is vertical and faces southward. Although comparing to panels which are sloped toward the sun, vertically leaning PV panels produce much decreased power output the typical BIPV facade is usually vertical and faces southward. The reduction is greatest when the electricity is most valuable and the sun is high in the sky especially in summer. As it is shown in figure 1.9 facades can be inclined by employing a saw tooth design in order to solve this problem. According to Wolter (2003) where there are no windows Saw-tooth PV façade entail overhanging PV shade screens on the façade which decreases direct sunlight during summer time but on the other hand allows solar heating in the winter.

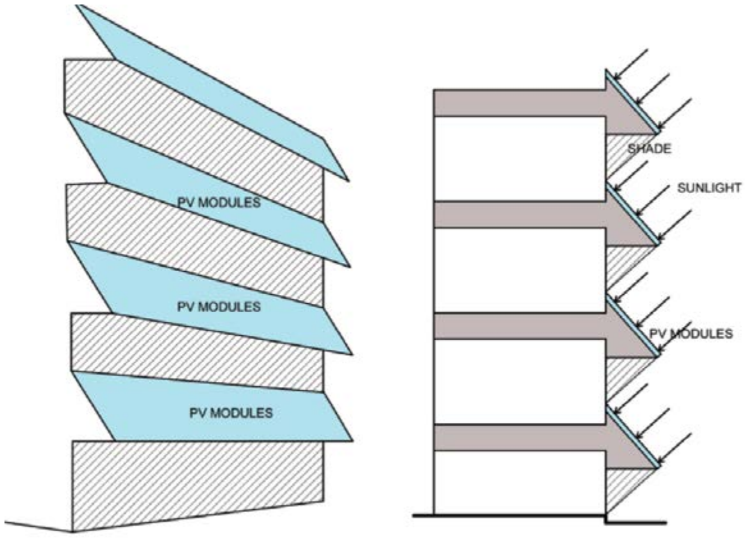


Figure 1.9: Saw-Tooth PV Facade Consisting of Overhanging PV Shade Screens
Source: Drawing based on (Wolter, 2003)

1.8.1.1 Vertical Integration of PV

Although a transparent PV facade is possible to be planned in the same way as a standard glazed façade, opaque PV units can be employed as covering units in opaque areas of the facade. In comparison with normal solutions, the possibility of producing architecturally attractive, eco-friendly façades, which consequently provides buildings with well-designed look and high-tech, should be taken into account.

1.8.1.2. PV on Inclined Walls

It is quite interesting to incline the façade where PV is integrated basically for two reasons; first because it would then be easy to optimized the PV modules' position for the maximum energy yield and secondly because this would further add to the elegance of the façade. The west side of the Vocational College in Tirol, Austria is treated in similar fashion (M9 Architects, 2009). The PV integrated façade is curved and inclined which is one of the main features of the architectural expression of the building (fig 1.10).

Figure 1.10: Inclined PV Integrated Glazed Façade of Vocational College in Tirol, Austria. Source: http://www.m9-architekten.at/

During summer time, according to Solar-Fabrik, PV units are placed in front of the south-facing wall positioned such at an angle to make shadow on the glass building during the summer when the sun is at its highest position. However in winter, the low sun effortlessly enter into the building and aids in passive heating in winter.

Figure 1.11: Inclined PV Integrated Façade of Solar-Fabrik Building, Freiburg, Germany
Source http://www.solar-fabrik.de/

1.8.2 Roof Integration of PV

A PV system can be integrated into the roof in several ways. One choice is for the integrated system to be part of the external skin and therefore part of an impermeable layer in the construction. The other type is that the PV is glued onto insulation material. This type of warm roof construction system is very well suited to renovating large flat roofs. Using PV modules as roof covering reduces the amount of building materials needed, which is very favorable for a sustainable building and can help to reduce costs. There are also many products for small-scale use to suit the scale of the roof covering, for e g., PV shingles and tiles. The small scale of these products makes them very convenient for use in existing buildings. Transparent PV modules used as roofing materials serve as water and sun barriers and also transmit daylight. In glass-covered areas, such as sunrooms and atriums, sun protection on the roof is necessary in order to avoid overheating in summer. The PV cells absorb 70-80% of the sun radiation. The space between the cells transmits enough diffused daylight to achieve a pleasant lighting level in the area as through the double glazed roof (fig 1.12) (Reijenga and Kaan, 2011, p.45).

Figure 1.12: PV Integrated Double Glazed Roof of
Café Ambiente, Berlin Germany
Source http://www.pvdatabase.org/

PV cells convert sunlight into electricity (typical efficiencies of 6-18%) with the remainder of the solar energy being converted into heat. At the project ‘Haus der Zukunft’ in Linz (Austria), this residential heat is also used to warm the home. An air cavity has been created underneath the PV modules, through which warm air heated by the PVs above, is exhausted. The hybrid collector provides warm air to the heating system in the home, which in this case, makes it a cost- effective use of the collector.

PVs laid horizontally on the flat roofs are normally not visible from the ground and hence the significance of aesthetic part of integration can be less. However, from efficiency viewpoint, mono and poly-crystalline PV systems produce the most energy when their angle is optimized to that of the sun. Therefore, usually it may not be a good idea to lay these cells horizontally on the flat roofs both from aesthetic point of integration and energy yield. Unlike to this, thin films work equally well even when laid horizontally on flat surfaces proving to be the best options for integrating into flat roofs. However, installing the PV systems in an angled position on the flat roof may not play a positive role in adding to the aesthetics of the building and hence may not be termed as architectural integration.

Photovoltaic facilities on inclined or pitched roofs when facing in the right direction is suitable for good energy yield. Architectural aesthetics should be taken into consideration while integrating as these are visible parts of the building unlike the flat roofs. PVs can be integrated as a combined roof elements or they can be added to the roof structural system and has been termed as ‘retrofits’ (Solstice energy, 2012). In retrofits, PV modules are laid onto the existing roof above the roofing material. The modules are held on to the rails, which are clamped by roof hooks from under the tiles. In this case the PV module is not a multifunctional element and usually the aesthetics is lost if the color of the roofing material is different from that of the PV (fig 1.13 left).

Figure 1.13 (left) PV Modules Added on to the Roof as Pure Technical Element, (right) Semi Integrated PV Modules on the Roof
Source: http://www.solarplaza.com/, http://www.energyenv.co.uk/

It is important to note that what keeps the units much more closer to the roof- than retro-fitting to give a more integrated appearance is line semi-integrated mounting.

Employing this technique help users avoid wasting tiles or slate in the condition when new build or re-roof is necessary, it also causes a minimum roof weight. As it is stated by Solstice energy (2012) no problems or damages will occur under the units, it means that all fixing and re-roofing procedures can be easily done around the PV array without destroying it. Although, this approach cannot be considered as an architectural integration when the general appearance is not enriched by integrating PV units .This technique might be called building integration and its facade may look better than the retrofit one.

As it is demonstrated in figure 1.14 right, despite the integrated PV in the same method, it has not been successful in properly enhancing the quality of the building from architectural perspective. On houses which are being re-roofed or buildings which are new, roof integration technique can be tried in a way that the general appearance is boosted. It is mentioned that the integrated PV system typically acts as a multifunctional unit. As it can be seen in figure 1.14 left as in the vacation house Bartholomäuspark in Germany, the entire roof might have the PV units placed in clean line and finish substituting the traditional materials for roofing. This building is small with a particular roof design which is inclined (alignment east/west), in accordance with which the roof of the building is entirely designed with an integrated photovoltaic system. The units are designed with double with double glass (PV Database) and installed with a drainage canal over the roofing battens. As it is clearly shown in fig 1.14 right the buildings are covered with PV integrated roofs in the Schlierberg Solar Settlement in Freiburg.

Figure 1.14: (left) Integrated PV on the Pitched Roof of Vacation House Bartholomäuspark in Germany (Right) Integrated PV Roofs in Schlierberg Solar Settlement in Freiburg Source: http://www.pvdatabase.org/, http://www.rolfdisch.de/

Laying or integrating larger standard units of PV on the roof has been usual for the purpose of producing energy. Nevertheless, at the time of practicing integration on traditional tiled roofs, it should always be taken into account that it may not always be probable to use large units and the other important thing in that case is that the character of the roof possibly will ruin. In order to solve the problem a type of photovoltaic roof tile is produced which looks like the standard tiles.

It is very interesting to know that they can be manufactured very similar to the normal tiles from the color and dimension perspectives. Lists of advantages, which are assumed for PV tiles or shingles over panels, are as follows:

1. They look like normal roofing tiles
2. They are accessible and available in various colors
3. They are more attractive from aesthetical point of view
4. They have characteristics of a noble architectural integration.

As it is illustrated by (fig 1.15) below (Horizon Renewables, 2010, p.25) PV tiles can act just like traditional tiles as they protect the building from the elements and also integrate with a great range of roofs. They are joint to normal timber roofing lathe, which is in turn tied to the rafters.

Figure 1.15: Integrated PV Roof Tiles on the Roof in Berlin Germany
Source: nait5.wordpress.com

PVs can equally be integrated as multifunctional elements in transparent roof structures or atriums that allow controlled light into the interior. As semitransparent roof units, they can protect the building from heat, sunlight, glare and the weather. On way of integration would be to place small sized PV cells on the atrium glass creating transparent gaps between them to allow controlled daylight into the interior of the building. Well-designed PV integrated atriums may also be a strong feature of the building when viewed from the interior.

Although glazing systems, are mostly appropriate for systems which are called small capacity PV, they have this potential to be develop great visibility and visually attractive. Semitransparent PV glazing can be considered as proper alternatives since atrium, skylight and greenhouse glass are often colored in order to reduce glare. The glazing panels are formed of PV substantial tied to the glass. It is assumed that many of off-the-shelf PV units are appropriate for this purpose. According to Wolter (2003) as the PV units do not need extra air circulation, open-air PV atriums are particularly cost-effective (fig 1.16).

Figure 1.16: (left) Atrium with PV Modules, Ludesch/Voralberg., Austria; (right) PV on Coloured Skylights at Bejar Market, Salamanca, Spain Source: http://www.solarfassade.info/

Saw-tooth roofs can be implemented as (semi-)transparent or opaque. Glass saw-tooth roofs make optimum use of daylight, protect against direct sunlight, and thus minimize a building’s cooling loads. The world’s largest Integration of thin-film PV systems on the saw-toothed glass roof of Paul Lobe Haus, Berlin optimizes interior light conditions in addition to producing clean energy (fig 1.17) (CBD Energy).

Figure 1.17: (left) Integrated PV on the Saw-Toothed Glass Roof of Paul Lobe Haus, Berlin (right) Saw-Tooth Roof with PV Integration, DIY Store, Hamburg Source: http://www.cbdenergy.com.au/, http://www.solarfassade.info/

In buildings which are considered to be energy efficient, the role of absorber is played by south facing glazing and therefore the building can be designed in a way to distribute all the solar heat energy from the south façade (fig 1.18). However, some problems such as overheating and becoming uncomfortable may occur in the summer. High rate of solar heat captivation may result in increasing the request for using air conditioning which consequently rises energy requirement in building. External sunshades can be used as good solutions in order to control transition of the heat into the interior part of the building. They are available in different forms but typically take the form of a fixed glass louver system and may be installed on the façade of building vertically or even horizontally. Solar PV cells can equally be integrated into the glass louvers as multifunctional elements both in order to generate electricity as well as providing shading to the building. These shades can both be fixed or movable. Besides, opaque PV modules can equally be used in similar way as a conventional.

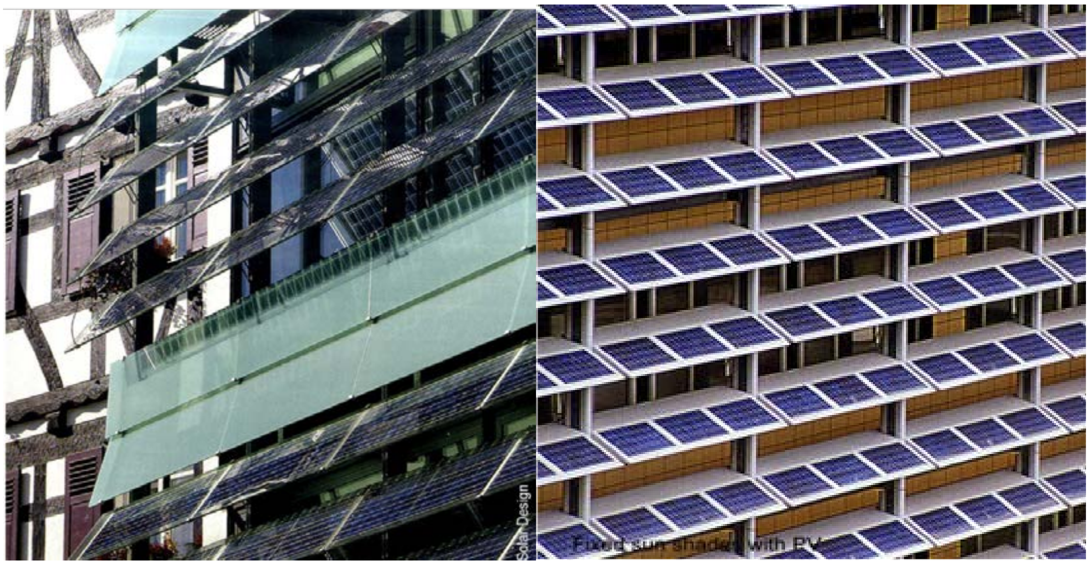


Figure 1.18: PV Integrated into the Glass Louvered Sun-Shades in the Editing Office, Albstadt-Ebingen, Germany. Source: Solar Design

1.9 Architectural Integration Ability of Photovoltaic

To achieve quality in the architectural integration of photovoltaic and solar systems, certain requirements need to be fulfilled. The global integration quality depends not merely on module shape, size and color but also on all formal characteristics such as (Probst and Roecker, 2011, p.18):

1. Field size and position of PV or collector systems

2. Materials and surface texture

3. Color of the cells for PV systems and absorbers for solar collectors

4. Shape and size of the modules

5. Type of jointing

6. Multifunctional elements

For successful integration, the above mentioned characteristics must all be coherent with the overall building design logic. These characteristics with the relevant examples in using PV and collectors are described below.

1.9.1 Field Size and Position

It is essential that PV and collector systems' position and size be coherent with the overall architectural composition of the whole building and not just with the façade or part of the building where they are installed (Fig 1.19). However, this may always not be easy to achieve, so to achieve it, certain parameters have to be followed. The parameters that influence the location, shape and size of the PV and collector systems are (Probst, 2009; Probst and Roecker, 2011, p.58):

- Position and dimension of the available exposed surface of the roof or façade

- Orientation of the available surface

- Desired energy requirements

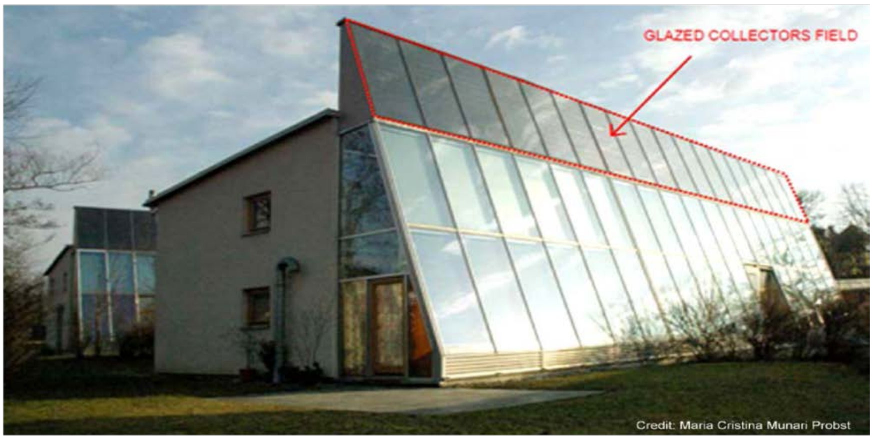


Figure 1.19: Architectural Integration Systems as Inclination
Source: energy gain façade.com

The surface or part of the building that is available for integration directly influences the energy production of the solar systems. In case of new constructions, available exposed surface can be created according to the energy requirement aimed for. However, for retrofit projects, energy production has to be adjusted according to the available exposed surfaces. In addition, the choice of solar technology also influences energy production and exposed surface requirements. In case of PV systems, crystalline cells produce much more electricity than amorphous solar cells. Accordingly, to yield same amount of power, amorphous solar cells have to be installed on a larger surface than crystalline cells. Same applies to solar collectors. Evacuated tube collectors are more efficient than flat plate collectors, so the choice of a specific solar thermal technology affects the exposed surface requirements. An effective approach toward positioning and dimensioning the issue is to use PV and thermal collectors as multifunctional elements serving both as energy generators and roof/façade elements. With this approach, the architect has to make the design in such a way to use fewer elements possible, for each fulfills several functions. Usage of PV or solar collectors all over the surface may often be unnecessary and difficult due to practicalities. So, the use of dummy elements will help to decouple the geometric dimensioning of the system and bring uniformity in its appearance.

However, the downside of this technique is that in most occasions, such applications require the development of a tailored product being specialized for just one project, and would therefore be very expensive (Probst, 2009; Probst and Roecker, 2011, p.12).

Positioning of both PV and solar thermal collector systems is defined by the energy and architectural needs. It is only some proper locations in the building which is determined by solar exposure, suitable area, energy production goals, and etc. that is equipped with PV and solar thermal collector systems. In case of specific architectural needs, remaining spaces can be covered or clad with dummy elements (Probst and Roecker, 2011, p.47). Positioning STC field on the roof provides a little more flexibility than on the facades. It is normally the modules produced for the roof that are also used in the facades which of course are not ideal for façade application. This is mainly because solar collectors are less available commercially for facade application. Thus, there is even less possibility of dummy elements being available so that solar collectors could be used in areas where ‘real’ collectors have not been integrated. In case of integrating PVs, more positioning options are available. There are separate modules available for roof and facade integration including the dummy elements.

Solar thermal collector systems are comparatively more efficient hence need less space for integration compared to PV systems, since the building does not need that thermal energy as it requires electricity. This can be further explained, as the covered area that the PV requires to produce a specific amount of electricity being used to heat water is more than that of a solar thermal collector system for heating the same quantity of water. Although electricity cannot be compared to a low grade energy like heat, in case of producing heat energy, a solar thermal collector system needs comparatively less area than that of a PV system if we happen to use the electricity to heat water

1.9.2 Materials and Surface Texture

The characteristics of the material and their surface texture used in PV and solar thermal collector systems must be in harmony with the same characteristics of other elements of the building envelope

In the case of PVs, both opaque and semitransparent modules can be used in the building fabric as desired. Semi-transparency characteristic of PV cells and modules is an important design feature, offering new application possibilities and providing a good potential for architectural integration. Glass, as a shiny material that is commonly used as a module cover, strongly contrasts with the matt and respectively uneven finish of traditional building materials such as brick, render or roof tiles, and the reflections on its surface make the modules highly visible at a distance and occasionally cause undesirable glare. To overcome this problem, matt surfaces have been created using sandblasting, producing all kinds of regular and irregular patterns. Various types of structured glass can also be used as a glass cover to create a matt finish (Hermannsdorfer and Rub, 2005, p.28).

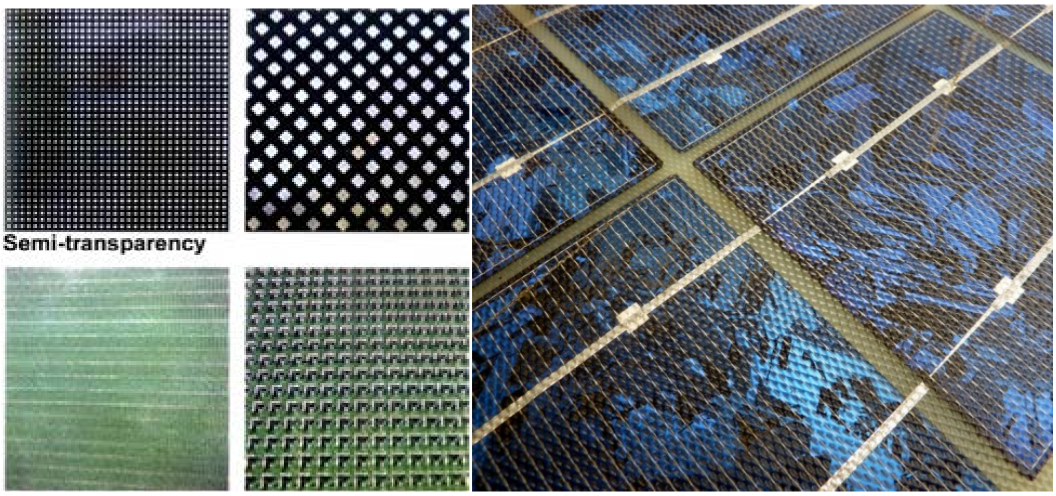


Figure 1.20: Illustrations of Some Possible Variations in the Surface Texture of PV
Source: http://www.pvdatabase.org,

In the case of glazed thermal collectors, it is again the glass that is visible. Glass is normally extra white to optimize solar energy transmission. Its surface can be lightly textured to become slightly diffusing, or it can be perfectly smooth and transparent with anti-reflection coating, which is sometimes available to increase the energy transmission. The absorber is usually black metal sheet mainly made of copper, aluminum or steel and can be in one piece or made of a row of metal strips. The geometry and surface texture of absorbers can be quite diverse depending on the manufacturer, but usually no flexibility is offered within one specific product. For unglazed collectors, the absorber metal sheet is the only visible layer. The glass tubes, the absorber metal strip inside and in most cases the back module sheets are also visible in the case of evacuated tubes (Probst, 2009; Probst and Roecker, 2011, p.88).

One of the features that should be taken into account is visible surface texture, which can improve the general appearance of the building and is not necessarily related to increasing heat and energy production. Many research projects have focused on producing more efficient PV cells with new surface textures which are different and have a number of advantages such as:

- They can transform more of the sunlight into energy,
- They can achieve higher power density
- They can offer a new class of performance.

These variations in the surface texture and finishes will definitely be an added advantage to the integration of PV on to the visible parts of the building. Normally PV modules come in glossy and shiny finishes and are both opaque and semi-transparent. Reflections on this surface may make the modules highly visible at a distance and occasionally cause undesirable glare. To avoid this, matt finished surface would be desirable. PV modules with matt finish surface would be more suitable to integrate into buildings where exposure of traditional building materials like brick, render of roof tiles and so on. Usually structured glass is used as glass cover to give a matt finish (Hermannsdorfer and Rub, 2005, p.22). The PV cell texture depends on different technology. Mono- crystalline have a more solid finish while poly-crystalline cells have marble-like texture (Farkas, Formal characteristics of Photovoltaics and their architectural expression). The absorbers of the STC also have variations in terms of surface texture and finish. These are available from corrugated, embossed, perforated, regular and irregular in terms of surface geometry. Evacuated tube collectors have exposed glass tubes. The surface is matt, glossy or structured finishes (Probst and Roecker, 2011, p.45). The glazing above the absorbers in case of glazed STC systems may shine when sunlight falls on the surface and glare could be a problem. Also, the variations in the surface texture and finish inside the glass covering may not be visible from the outside. However, they can be well integrated to complement with the glass surface of the façade or even roof. In case of unglazed, the absorber surface texture and finish is clearly visible and hence can be an option concerning possible patterns on the envelop they are laid to. With the above mentioned characteristics, PV modules have the flexibility to be integrated both into opaque and transparent facades and roofs. When mounted on a glass-glass module, the PV cells can be freely spaced achieving various designs and pattern and can be best suited in atrium, glazed facades, canopy, and verandah applications. Flat plate solar thermal collectors with their opaque nature can only be integrated into the opaque parts of façade and roof (Probst and Roecker, 2011, p.78).

1.9.3 Colours of Crystalline Silicon Cells

The colours of the crystalline and amorphous silicon cells are normally blue. By modifying the anti-reflection layer it is possible to create other colours. Thin film solar cells consisting of amorphous silicon or CIS are black in colour while CdTe-cells have a greenish look. The range of colours gives the possibility to produce any kind of pattern that is desired in a building fabric (Hermannsdorfer and Rub, 2005, p.55).

The absorbers used in solar thermal collectors are usually black or dark blue to assist their heat collection function. The absorber colour results most of the time from selective coatings used to optimize absorption and to reduce emission losses. The colour of these coatings can change according to the angle of vision, so that a black absorber may look violet or blue or red depending on the incidence angle of the sun on the surface. Dark brown and dark green shades have also appeared in the market but very little (Probst and Roecker, 2011, p.18).

Within the chosen technology, the different products available in the market should be explored to find the colour and surface texture most suitable for the given application. PV products provide more freedom compared to the collectors in this regards. However, it would be a clever approach to define the materials of the other envelope elements to be compatible with the materials, textures and colours of the chosen collectors which is possible in new construction.

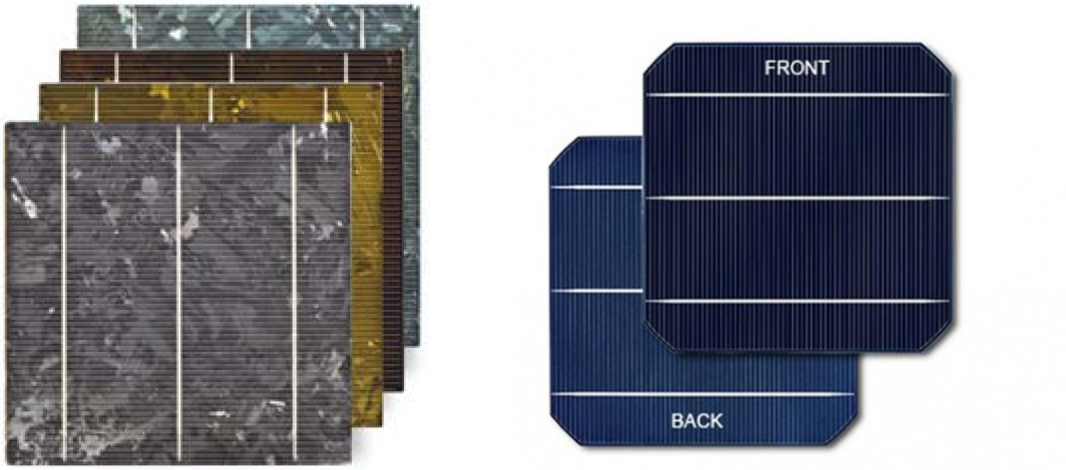


Figure 1.21: Range of Colours in PV Cells
Source: Klaudia Farkas; Maria Cristina Munari Probst

Comparing to absorbers of the solar thermal collectors PV cells have wider range of colors, this is a great advantage from the architectural and aesthetic view, especially in façade or parts of the buildings which are visible. Colored PV cells open up a new field of design possibilities in architecture. These colored cells offer a wide range of new design applications adding aesthetic value to the building especially in the facade. PV modules are available in a wide range of colours. Crystalline modules are crystal-blue to black in order to maximize sunlight absorption. Other colours can be achieved by modifying the thickness of the anti-reflection coating on the surface of the solar cell. Lighter the shade, the less efficient the solar cell. Thin-film modules are reddish-brown or black (Solar Fassade, 2011, p.8).

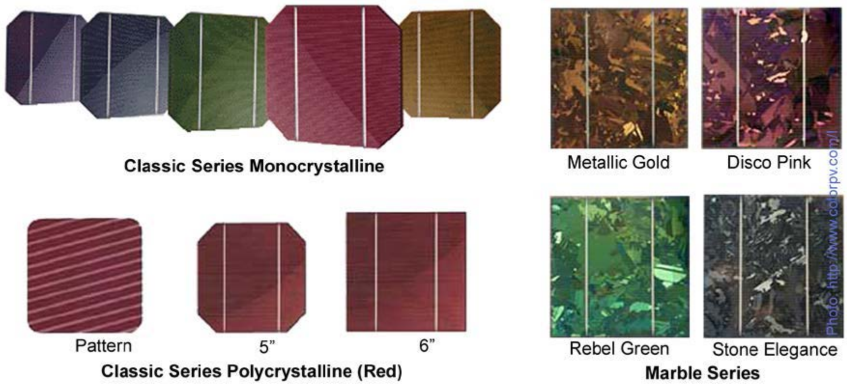


Figure 1.22: Range of Colours in PV Cells
Source: http://www.colorpv.com/

The blue coloured mono and poly-crystalline are the most efficient of the PVs. Even the coloured PVs seen these days are approaching closer to the blueones in terms of efficiency. Solandum Solar Energy Systems & Colour PV (Solandum) have produced PVs in 15 different colours of which green, purple, red, gold and grey are few to mention. High quality coloured mono- and polycrystalline PV cells are available in the market. The cells are colorized with a patented method which guarantees a high cell performance of upto 16.6%. The colour cells are designed in two basic series called Classic Series and the Marble Series (Fig 1.22). The Classic Series are characterized by the even colour appearance. The Marble Series is characterized by its lively colours shades. For these colours only polycrystalline cells are being used. As with all the coloured cells due to the patented colouring process high cell efficiency comparable with conventional blue cells is achieved. Integration of these colored PV modules can be seen in (Fig 1.23).

Figure 1.23: PV Modules Based on Metallic Gold Cells are Integrated in the Balcony, Rails and Facade, Tirol, Austria

The "home+" building project submitted by Stuttgart University of Applied Sciences (HFT) has also made use of coloured PV modules. The building envelope is characterised by the beautiful shimmering integrated multi- crystalline photovoltaic (PV) system with bronze and gold coloured silicon solar cells as a distinguishing feature (Fig 1.24) (Konstanz, 2010).

Figure 1.24: Multi-Crystalline PV System with Bronze and Gold Coloured Silicon Solar Cells Used in the "Home+" Building Project Submitted by Stuttgart University of Applied Sciences. Source: Credit: http://www.sunways.eu/

According to Tripanagnostopoulos et al. (2000) using integrated collector system should be well matched with the architectural design, it is better to employ solar collectors that have colored absorbers, because they are more fixable than those with black collector for different positions when aesthetic compatibility of solar collectors is needed.

Glasses of various colours combined with several diffusing finishing (acid etching, structured glass etc) are produced that are able to hide the absorber. Such glazing will allow the use of the same product both on façade areas equipped with solar absorbers (as collector external glass) and in front of the non-exposed areas (as façade cladding), opening the way to a broad variety of active façade designs. The active elements can then be positioned on the exposed areas, and their quantity determined only by thermal needs. However, in reality only very few manufacturers have been able to offer the flexibility to choose between different absorber colours. The ranges have mainly been limited to black, blue and bronze (Probst and Roecker, 2011, p. 45).

1.9.4 Shape and Size of the Systems

The shapes of the module of the PV and collector systems have to be compatible with the building composition grid and with the various dimensions of the other façade elements (Probst and Roecker, 2011). It is actually the choice of the technology that affects the basic form of the module. For PV systems, mono and polycrystalline modules come in standard sizes and can be bulky while thin films can have varied shape and sizes. The development of cut-to-size module prototypes had the aim of providing modules whose size can be adapted directly on site as in the Surplus-house of team Germany for the Solar Decathlon 2009. Even though most of the products in the market come in standard module size, there is maximum freedom in the use of PVs on roofs and façade elements. There will be variations in the basic form of collector module shape and size as according to the exposed available surface and type of collectors chosen.

PV systems available in the market are manufactured usually in larger and bulky sizes compared to a PV system. So in general even smaller buildings will have to use PV systems of larger sizes. Smaller custom sized PV can be manufactured, however the sizes will still be larger than PVs as the former has number of other parts like the hydraulic system which involves liquid transportation. Integrating large sized collectors into smaller buildings architecturally, will certainly require extra effort for architects. The smaller the unit, the easier it is to integrate. So, the freedom offered by available STC products in terms of shape and size is not that convenience (Probst and Roecker, 2011). The PV systems definitely do have an advantage over PV in shape and size as they can be produced in very small sizes and in any shapes which become easier to integrate (Hestnes, 2012). Mono and Poly-Crystalline cells are available in sizes as small as 10 to 12 cm and module size as small as 0.1m 2. As these crystalline cells are produced by cutting silicon ingots, they have limitations in shape and size of cells. However, thin film has no limitations due to different technology (Farkas, Formal characteristics of Photovoltaic and their architectural expression). PV, usually glazed flat plate collectors are much larger with their dimensions ranging from 1.5 to 3m 2. PV are equally large with tube lengths from 1 to 2m and diameters from 6 to 10 cm (Probst and Roecker, 2011, p.25).

The characteristics of the cells, the framing and the added elements together with the conceptual grid of the facade define the shape and size of the module. The classic roof integration/addition of systems as in can be considered a failure in terms of integration as the collectors are used only in their primary function of heat generation. Due to less ‘inerrability’ compared in terms of a PV system, are added to the roof as independent roof elements and do not go in co-relation with the tiles used. The same problem will not be faced while integrating PV on the roof which can be seen in the integration of PV roof tiles in a building. The black PV tiles perfectly match with the normal tile used for roofing in both shape and size (REM, 2012).

In case of PV systems, The Techtile Therma, produced by company called REM can be a new and innovative way of integrating into tiled roofs. It is equipped with a solar collector consisting of a series of 6 glass tubes with dia. 47mm, length 1,500 mm, double cavity borosilicate, welded at the ends, creating a vacuum inside with this, the integration looks clean and each tile appear to be separate unit even though six such tiles integrate one vacuum tube collector. However, this method is certainly not that easy in terms of installation compared to that of a PV system and hence have not produced examples of their integration. We can find few more examples of this kind of products but they have not usually been commercially used (REM, 2012, p.25).

1.9.5 Type of Jointing

Jointing types must be carefully considered while choosing the product as different jointing types differently underline the modular grid of the system in relation to the building (Probst and Roecker, 2011, p.33). In the surplus-home by TU Darmstadt for the Solar Decathlon 2009, the PV facade cladding was done in the traditional shingles principle. It is also the jointing that makes the PV module much similar to the roofing shingles (fig 1.25). The appearance of the jointing in the collectors used in the multifamily dwelling in Gleisdorf is made to look similar in size and proportion to that of the glass facade which has added to the value of the integrated appearance

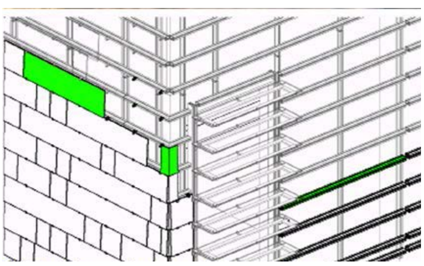



Figure 1.25 (left): Integration of PV Shingles on the Façade of Surplus-home of Team Germany, (Right): Jointing of PV Shingles used, Jointing in the Multifamily Dwelling

Visible jointing of modules between different PV modules has an important influence on the integration quality. The jointing is usually observable hence must be similar to the jointing other cladding materials on the same surface for uniformity. PV systems with their slim thickness can be clad on both opaque and transparent facades similar to the installation of conventional cladding with normal jointing. It is comparatively easier to achieve similar modular jointing grid to achieve that of other cladding used on the façade in case of PV modules. It is equally possible to achieve sized fitting with the modular rhythm of the standard cladding or to attain the same type of jointing in systems for it is easier with PV systems. However, to achieve jointing appearance similar to that of other claddings, used on the same façade or sloped roof, custom design modules have to be used in most cases.

1.9.6 Multifunctional Elements

The best part of integration is the possibility of using PV and collector systems as multifunctional elements, thereby replacing the conventional building elements. Multi-functionality of the systems makes it easier to deal with the formal aspects of the integration. It provides the decisive advantage for the designer to architecturally compose with fewer elements, as each fulfills several functions. In the surplus-house (Fig 1.25, left), PV shingles are used as multifunctional cladding elements and same is with the case of STC system that is used on the façade of the multifamily housing in Austria (Fig 1.25, right).

According to Voss et al. (2012) there are some functions which are defined for the external surface of the building other than keeping water away which are controlling heat loss such as controlling the entry of light, offering a sound barrier, providing ease in technical maintenance to be architecturally and aesthetically satisfactory.

A very crucial feature in integrating PV systems is the fact that they can be employed not only as energy producers but also as an alternative for the traditional building units on the external surface of the building to improve the general appearance of the building. It also should be mentioned that PV systems benefit from more than one function and are more diverse, but then again on the other hand systems are restricted. Both systems can be employed as substitutions for usual building materials for they have functions, which are listed by Fuentes (2007) as follows:

- External skin for insulation,
- Waterproofing, fire protection,
- wind protection,
- Acoustic control and shading

Because of some characteristics such as being larger, and having inflexible shapes and thickness, PV systems are not that easy to integrate as sun shading and covering on facades of buildings. Though controlling daylight is possible by employing semi-transparent PV systems.

The use of PV cells on the south-facing glass façade of the 1960s administrative building in Stadtwerke Aachen in Germany was which one of the first multipurpose applications of PV modules (Fig 1.26). The fact was conceived during a renovation in 1991. Light-diffusing modules developed especially for this south-east front, direct daylight into the staircase behind. The chessboard type combination of glass elements and the modules with dark-blue crystalline silicon cells between the compound glazing’s offered surprising patterns both outside as well as inside. The PV modules act as a semitransparent façade providing sun protection, as a wall element including thermal insulation, in addition to producing power. Its cabling is completely integrated into the metal frames of the façade (Hermannsdorfer and Rub, 2005; Lundgren and Torstensson, 2004, p.22).

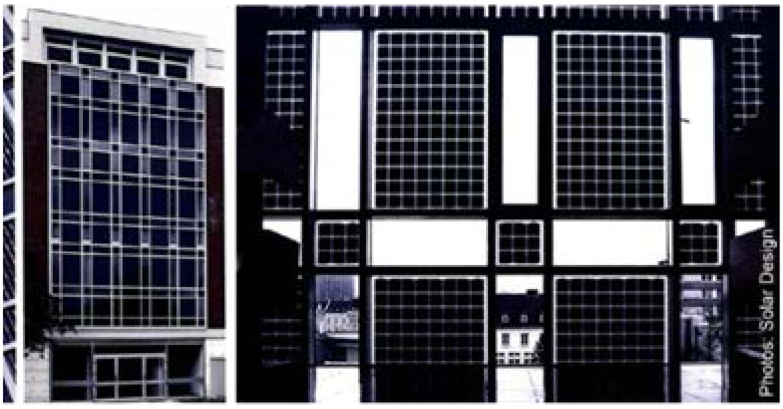


Figure 1.26: One of the First Applications of the Multifunctional Use of PV Systems in the Administrative Building on the Stadtwerke, Aachen, Germany,

1.9.7 Flexibility in Integration

From architectural integration point of view, it is assumed that PV systems have more flexibility than solar thermal collector systems as they are more available in small size and also can be produced in various forms and shapes. A level of relative transparency is probable through employing glass-glass units. It should be state that thin film units can be made of plastic sheets or flexible metal which presents a new freedom level. In comparison, it can be recognized that solar thermal collector systems with their fixed forms and larger size are not that much flexible which is principally because of the necessity of a non-flexible hydraulic circuit attached to the solar absorber in order to gather the heat. According to Probst and Roecker (2011) as the lack of restrictions in unit shapes , forms and size needs reviewing the pattern of hydraulic system each time, it is not that much practical.

For architectural integration, the shape and size of the solar module should be compatible with the building composition grid and with the various dimensions of the other envelop elements. It is difficult to achieve this kind of results with the integration of solar thermal collector systems while with the PV system it is fairly easy mainly because of their flexibility. This difference in flexibilities implies very different constraints when choosing the shape and placement of these solar elements especially for façade integration (Probst and Roecker, 2011, p.18).

1.10 Quality of Architectural Integration

Integration of photovoltaic is influenced and guided in a certain criterion to achieve quality in the process. There are number of architectural issues that need to be taken into consideration while integrating these systems into buildings. These issues play very important roles in achieving quality architectural integration. In order to achieve quality in architectural integration, fundamental aspects of building such as its functional, constructive and formal aspects, need to be fulfilled (Probst and Roecker, 2011, p.12).

Quality architectural integration of PVs and solar collectors can hence be achieved by their controlled and coherent integration simultaneously under functional, constructive and formal (aesthetic) features (Probst and Roecker, 2011, p.15) among the functional, constructive and formal issues.

1.10.1 Functional Aspect

A very important feature of architectural integration is multi-functionality. PVs and solar thermal collectors must be integrated into buildings in such a way that they perform as multifunctional elements, i.e. in addition to collecting solar energy, they must replace conventional buildings envelop materials. Solar element must be able to perform as a typical building envelop with all the necessary functions that a traditional building element fulfills. Some are listed as follows (Probst and Roecker, 2011, p.25):

1. The interior must be protected from various external intrusions such as rain, wind, noise and other impacts;

2. Enough insulation must be ensured both for cold winters and hot summers;

3. The integrated solar element should be able to regulate the visual relations inside-outside and vice-versa, the supply of fresh air, daylight and passive solar gains;

4. They should be able to maintain user's comfort even when a reduction in the use of non-renewable energy for heating, cooling and lighting is made;

The opaque parts of the envelope in a building such as walls and roofs, protect the interior from intrusions, rain, wind, noise, heat, cold and other impacts (Huan, 2011; Probst and Roecker, 2011, p.78). These opaque parts are structural/non-structural multilayer systems which may also include insulation. Insulations are usually used in buildings' outer layer in very cold or very hot places to minimize loss or gain in temperature in the interior of the building. Transparent or translucent parts like windows, atrium, and glass cladding allow daylight, natural ventilation and passive solar gains into the building. They also visually link the interior with the exterior along with ensuring the whole set of protection functions similar to that of the opaque parts. These transparent parts may also be composed of mobile components and systems such as shading devices, for regulating views, day lighting, passive solar gains and even natural ventilation (Probst and Roecker, 2011 p.77).

As stated by Probst and Roecker (2011), integrating PVs and collectors into the building envelop requires to understand where opaque parts, transparent parts and fixed mobile elements are located plus having knowledge about their compatibility in terms of material and function; e.g. standard opaque PV modules and thermal collectors are most likely get integrated into the roof or even on the opaque parts of facades while thin film PVs get integrated into the atrium or windows. Normally, solar thermal collectors have less compatibility with the transparent parts of the building, mainly due to the fact that their absorbers are opaque. In case of PV systems, they can be well integrated into these transparent parts by the functionality of laminate PVs in glass modules (Fig 1.27, left). Probst (2009) has declared that multilayer composition of flat plate collectors is suitable for the integration into the multilayer composition of the opaque envelop parts such as walls and roofs. The insulation behind the absorber plate and the insulation of the building envelop can potentially become one single element or they can complement each other; the absorber for unglazed collectors and the glazing for glazed ones can, under a purely functional point of view, take the place of façade cladding layer. This is a very interesting aspect of integration in reducing the use of materials and bringing down the cost. Evacuated tubes have been used as balcony railings (Fig 1.27, right). Similarly, PV modules (Fuentes, 2007, p.21)

Figure 1.27 (left) Integration of PV as Shading and Daylight Control; (right) Evacuated Tube Collector Used as Balcony Railing
Source: http://www/esru.strath.ac.uk/, http://csc.esbensen.dk/

1.10.2 Formal Characteristic

This section, being the key part of the thesis, would be explored in detail. Aesthetics is what people see and admire. So if PV integration is popular today and also it be in the upcoming days, the popularity would depend on one important reason; the ability to enhance the architectural expression of the buildings. To achieve this, a coherent and controlled formal composition of the different architectural elements necessary to satisfy the constructive and functional requirements is crucial for designing the parts that are visible such as facade and sloped roof. However, this aspect is rather subjective and the opinion of people regarding it varies. This has been shown in the survey taken by Probst (2009) in which architects, engineers and façade manufacturers all had various opinions about the integration of solar collectors into different buildings. The architects had a consistent agreement on the value of the integration quality of objects, being good or bad, with only minor differences in the intensity. Engineers and façade manufactures are generally demanding less on the subject of integration quality. These appreciation differences highlight the fact that judging architectural quality rely on architects' professional competences, and shows the importance of using architects' skills in dealing with formal issues. When we have to compare the 'integrality' of, it is observed that there is more flexibility in integrating PV systems as multifunctional elements in opaque and transparent parts of a building, enhancing its overall expression. This is basically due to the fact that PV systems are available in varied shapes and sizes from a small cell to a large module which makes it appropriate to be used in buildings of any scale. The range of colors they are available in is another advantage of using PV systems as architectural elements to enhance architectural expression. Unlike the first generation PVs, availability of thin film and amorphous systems nowadays has eased the task for the architects as these systems can be used in any external part of the building irrespective of the direction and angle of the sun. As a result, these thin film systems can be used in place of any traditional cladding elements.

Figure 1.28: Integration of PV, Considering the Formal Aspect. (Left) Solar Ark Japan, (Right) BMW Welt Building in Germany, Architect: Zaha Hadid

PV also offers wide range of flexibility in integration considering the formal aspect of architecture. In Monte Rosa Hut (Farkas, Facade Integration Typologies of Photovoltaic), Solar Ark Japan, form of the building has been such as to optimize the sun's angle on the PV façade (Fig 1.28, left). While in case of Solar Ark, Japan, PV modules have been laminated onto the transparent curved glass roof for reducing direct solar heat, maintaining the architect's formal concept of the design (Fig 1.28, right).

1.10.3 Constructive Aspect of Architectural Integration

PV and solar thermal collector systems (Fuentes, 2007, p.25) can be incorporated into buildings either by superimposition where the system is attached over the existing building envelop or by integration where the system forms a part of building envelop. In either case, if they enhance the appearance of the building, they are collectively called architectural integration. While integrating PVs and solar thermal collectors into the façade and roof, it is important to consider the construction characteristics of the specific technology to be integrated together with the specificities of the constructive system hosting them. This is to ensure that the new multifunctional façade elements meet all the safety façade constructive requirements such as (Probst and Roecker, 2011, p.25):

1. The load of the PV and collector systems must be correctly transferred to the load-bearing structure through appropriate fixing; making sure that the fixing avoids thermal bridges;

2. These solar technologies must be able to withstand fire and harshness of the weather;

3. They should resist wind load and other impacts, and should be safe in case of damages;

4. The resulting problems due to the rise of temperature behind the systems must be rectified;

5. Fixing and jointing details should make the PV and collector system's material expansions compatible with those of the other envelop materials.

6. Vapor transferred through the wall should avoid condensation layers, and allow the wall to dry correctly.

It is very crucial to remember that while integrating flat plate collectors or covering PV systems without an air gap, usually the direction of vapor transfer is from the higher temperature, which is inside, to the lower temperature, which is outside. Thus, in order to avoid condensation layers, vapor obstacles are positioned in the inner part of the wall which is warm. For this purpose, a lot of attention should be paid in order to protect wood and insulation materials if they are employed. According to Probst and Roecker (2011), a substantial modification in transferring vapor might happen as a result of rising solar collectors directly to the wall in the absence of an air gap; for example, vapor pours out when the covered PV systems are cold and is the other way round when they are warm. To explain the construction aspect of integration, solar module temperature could be one factor. The output in case of PVs starts degrading as the module temperature starts rising. In the BP solar building at NTNU, Trondheim, 80cm cavity has been created between the glass façade and the adjacent building's wall which assists venting the cells, thereby increasing the efficiency (Fig 1.29) (Aschehoug et al., 2003 p.78). Similarly, in Albstadt-Ebingen editing office in Germany, the solar slats used also as shading are hung 50cm in front of the existing facade (Fig 1.29) (Hermannsdorfer and Rub, 2005, p.45).

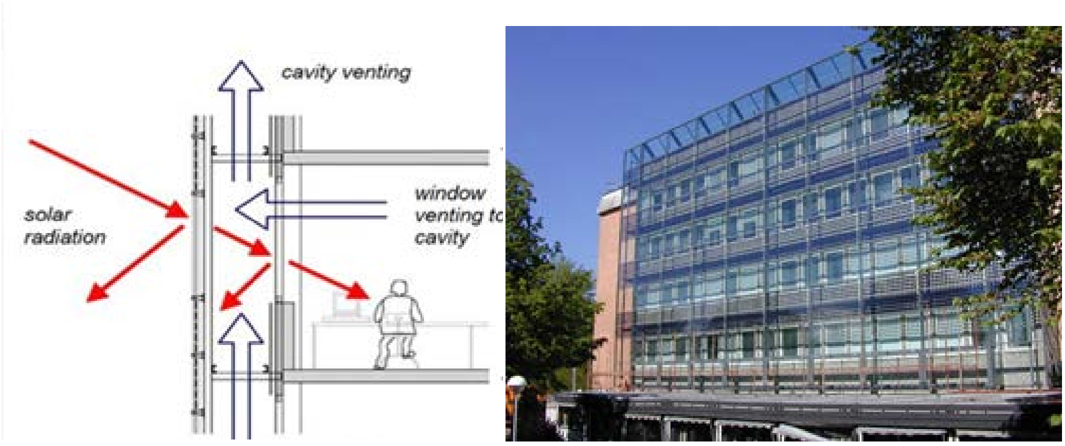


Figure 1.29: Venting Cavity Behind the PV Modules. Source: http://www.sintef.no/

Chapter 2

ANALYSIS OF CASE STUDIES

2.1 Reinforced Concrete Structure

Most of the buildings that aimed to be a formal monumental are built by reinforced concrete. thus this category of the research contains some formal buildings that is integrated by PVs.

2.1.1 Mono-Crystalline Cells

Figure 2.1: EWE Arena, Oldenburg, Germany. Source http://www.iea-shc.org/

EWE Arena Oldenburg is a sports- and multiuse hall. The exterior walls are totally glazed. To avoid the building from overheating in summer the exterior walls are shaded by Reinforce Concrete overhangs as well as by a huge movable PV-Shading system that circulates 200° around the structure exterior according to the position of the sun. The 6,5m high and 36m long PV-Sunscreen covers a 60° segment of the circular structure.

Figure 2.2: Kyusyu National Museum, Dazaifu, Fukuoka, Japan
Source: www.solar.integrateing.com

Kyusyu national museum is one of the national museums in Japan and is located in Dazaifu, Fukuoka.. The dimension of the structure is around 160m * 80m and the height is 36m, and the scale is bigger than a football stadium. The building was designed for optimizing the use of natural blessings, the PV system was installed as one of the environmentally friendly facilities, and structure system is Reinforce Concrete.

Figure 2.3: Solar Ark Building Ohmori, Japan
Source: www.solar.integrateing.com

The Solar Ark is the Solar Lab, a museum of solar energy and one of the more unusual museums in the world. Solar ark is an ark-shaped solar photovoltaic power generation facility that offers activities to cultivate a better appreciation of solar power generation. This structure 315-meter-wide, 37-meter-tall in total, the construction area for the Solar Ark is 3294.48 m^2 reinforced concrete was used for the base of the construction.

2.1.2 Poly-Crystalline Cells

Figure 2.4: The Optic Centre, St Asaph, United Kingdom
Source: www.solar.integrateing.com

The Optic Centre was built by the Welsh Development Agency to provide research and development. It has the largest PV array in Europe and was the first application of this type of cells in the UK. PV formed part of the project from the initial design stage - the whole of the south facade is covered in PV modules at 70 degrees to the horizontal. The facade merges into the roof and makes a large colonnade that gives access to the workshops and laboratories beneath. The PV system inspires the whole shape of the building and the structure is reinforced concrete.

Figure 2.5: BMW Welt Building in München, Germany . (Source: www.enginsolar.com

On the huge roof of the BMW building in Germany (about 16.000m²) Sun Strom installed a rooftop integrated photovoltaic with 3660 modules and a nominal power of 824 kWp. Alone the external appearance is exclusive. One extraordinary function of the photovoltaic is that it works like the “fifth façade” of the structure. its exposed position next to the Olympia Tower and to the BMW Group-Building, the BMW building is always visible from top. Therefore, the architectural design of the rooftop was planned with great care in this building. The structure of building constructed from rain forced concrete.

2.1.3 Thin-Film Cells

Figure 2.6: Cultural Centre in Milbertshofen, Germany
Source: www.enginsolar.com

Colored panels, the façade of the culture center consists of translucent PV modules that create pleasant shading while still maintaining an unobstructed view. The warm façade was created with vertical glazing. The photovoltaic thin-film modules generate around 3000 kilowatt hours of energy a year and the building structure in this building is reinforced concrete.

2.2 Steel Structure

2.2.1 Mono-Crystalline Cells

The second categories of the cases are the steel structured buildings. The cases of this classification, in addition to having the same steel structure, possessing the modular columns and beams. This property resulted in an extra rhythmic structural element for the solar panels could be seen in the façade and the modular form of the PVs.

Figure 2.7: BP Solar Skin, NTNU, in Trondheim Norway
Source: www.enginsolar.com

The existing office building at NTNU a prototype solar façade, combining a double façade with a building-integrated photovoltaic, has been constructed on an existing university building in Norway. It produces both electricity and heat, and is appropriate for existing and new buildings. The prototype has been monitored for a year with reasonable results. The PV system generated 7200 kWh this year. The heating request for the building behind the new façade was reduced with 7-8%. The offices on the top floor of the building experienced summer periods of overheating. Revising the control strategy for double façade cavity venting will reduce this issue. In addition, this building with steel structure supported double-glazing.

Figure 2.8: Energy Base, Vienna, Austria, Source: http://www.m9-architekten.at/

The energy idea is based on the activation of steel core by the means of the heath pump (underground-water temperature is used for heating and cooling). The south façade is composed of 400m² photovoltaic that additionally provide for cooling and heating energy as well as to own electricity production. The ventilation includes 500 plants in “green-buffer-zones” that provide appropriate humidity in the winter months (WWF, 2007).

Figure 2.9: Zero-Energy Building of Acciona Solar, Sarriguren, Spain
Source: www.enginsolar.com

The office building certified as "zero-emissions", which means that all its energy supplies are met without any greenhouse emissions. The energy consumption decrease of the building compared to a conventional building of similar use (office) is 52%. The PV is integrated in 2 different areas of the building: - Façade. 153 PV of 175 Wp each (total, 26.8 kWp) joint with glass element in a curtain wall, operating as a greenhouse in this building. Either the air enters through the lower part, from the outside or from conducts coming from the structure geothermal air conditioning; after being heated in the greenhouse, the air can be expelled to the outdoor through automatic lock gates, or it can be recovered for the air conditioning. - Roof. 119 PV modules of 180 Wp each (total, 21.5 kWp), integrated horizontally.

2.2.2 Poly-Crystalline Cells

Figure 2.10: Children Museum in Rome Italy

Children museum rhythm of the photovoltaic in the roof and facade is irregular with special low-reflecting glass panels, which were made to organize the roof construction. The resulting beams of daylight illuminate the building with the beauty of the original cast iron structures. The museum's program did not originally call for photovoltaic integrations, but once the designers presented the idea, it fitted its environmental and educational aim, which was giving technology a central role in the design. The photovoltaic installation contains three industrial, plus skylights and shading devices to convert the integral part of the pavilion. An 8.2-kilowatt photovoltaic replaces sections of the old roof with skylights, while 7-kilowatt photovoltaic canopy systems work with alternating fixed and flexible canopies to cover the south façade with shade, so to have controlled levels of daylight in the exhibit region. Furthermore, added, specially designed structural posts in this building reinforce the new canopies. The vertical telescope-shaped components are placed near the current cast iron columns, and on the original roof structure they echo the "spider web" light.

Figure 2.11: Centrosolar Office Building in Paderborn, Germany
Source: www.enginsolar.com

The Centrosolar Office Building in Paderborn, Germany also as a Biohaus (ecological house) expression clearly: modern ecological architecture in combination with solar power generation and an aesthetically pleasing look is possible. The three-story construction with high insulation and ecological building technology a passive house includes 11 different solar systems that are installed on, in and on top of the construction in. the entire range of the application options of PV is represented on and in the construction: from semi-transparent entrance roofing, bi-facial balcony enclosures, ventilated facades with Poly-Crystalline Cells, and various cell types integrated into the glass curtain wall to solar roof felt suspended above or integrated straight into the roofing to the tracking installation crowning the building.

2.2.3 Thin-Film Cells


Figure 2.12: Tourist Information Centre, Hameln, Germany

The building is the mutual home of different municipal institutions The 3-story building provides office spaces in the upper floors. The building design focused in particular on an innovative energy concept, meeting the “Passive House” energy standard. Among the features employed within the construction are also a fixed PV-shading of the south facing façade and overhead PV-Shading of the glazed atrium roof. Totally in all the construction serves as a regional showcase for sustainable construction design and strengthens Hamelin’s efforts to be the „Solar City “of Northern Germany.

2.3 Timber and Masonry Structure

The third groups of the structural classification are containing two themes. The first one is rooted in natural material for construction like timber. This type of structure, in addition to reducing the negative effect of construction, have more natural feature thus the integration of the pvs also can have two different aspect, producing healthier energy, and preventing the damage of simple utilization of solar panels.

Masonry buildings are built mostly based on the load bearer walls, thus the structure of the panels most be leaded directly to the walls to be conveyed to the foundation.

2.3.1 Mono-Crystalline Cells

Figure 2.13: Passive House, Emmendingen, Germany.
Source: www.enginsolar.com

The roof of a newly built three family Passive House in Germany had designed to accommodate an integrated photovoltaic. The building includes photovoltaic in a very efficient building energy concept and fulfills the German Passive House standard this building with masonry material constructed and integrated PV in roof for construction limitation.

Figure 2.14: Prefabricated PV-Roofs' in Nieuwland District, Amersfoort, Netherlands

The roof elements of the nineteen luxury private semi-detached dwellings with solar system in the Nieuwland district contain prefabricated photovoltaic. The sunroofs are in three variations. Five roofs have 27 solar systems each; seven have 30 photovoltaic systems and another seven have 33 panels. The generated electricity is transferred onto the grid. The yearly solar electricity output from the 19 semi-detached houses with photovoltaic is expected to be 48000 kWh. The sunroofs contain of a wooden basis with special aluminum. In one of the residences, the entire construction of the roof is manufactured beforehand. However, the profiles and the cells seemed to get damage during transport and the joining of the construction was actually more difficult than usual.

Figure 2.15: Balanced Energy Houses Nieuwland, Amersfoort, Netherlands
Source: www.enginsolar.com

A double residence has been built in the new housing district Nieuwland in the city of Amersfoort, where the yearly energy consumption is fully protected by an integrated solar energy. One of the semi-detached building was for some years used as an Information for sustainable energy, the other house was (and now both houses are) used as (test) houses for normal habitation. The construction are low-energy ('energy-performance of 0.56), while the energy roofs are producing sufficient energy on a yearly average to fulfill the energy request of the houses. This building is one of the first modern 'zero-energy' houses with PV.

Figure 2.16: Akademie Mont-Cenis, Herne, Germany
Source: http://www.m9-architekten.at/

The Mont-Cenis-Academy is a public institution. The construction consists of a Timber frame construction covered by glass that is inserted into an aluminums frame. The glass envelope has an area of 20.000 m² and causes to a climatic transfer so that inside always occur a Mediterranean climate. Into the half of the glass area are integrated photovoltaic in such a way that the room is exposed and shadowed optimally.

2.3.2 Poly-Crystalline Cells

Figure 2.17 Social Housing Moyrand Street (22 kWp), Grenoble, France
Source: www.enginsolar.com

Social Housing, in a sustainable development and energy loan decrease aim, has decided to install a PV on one of his social housing building. Here the PV-modules are integrated in sunscreens and in water protection and sun shading in this building. The semi-transparent PV is integrated in sunscreens and in water protection and sun shading. This building has too many limitation for installing PV because the structure with masonry materials therefore the designer designs PVs as sunscreens.

2.4 Discussion of Analysis

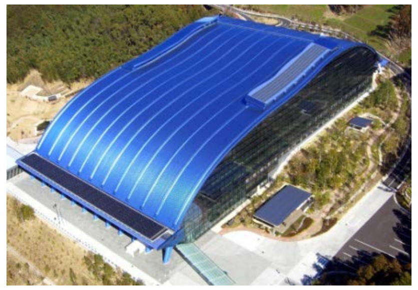
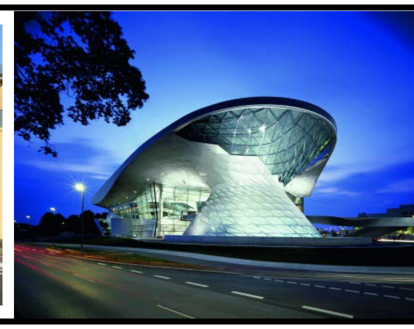
After mentioning the case studies information and the basement of their structural system, to achieve our aim we need to classify them to be able to compare in a clearer method. Generally, from structural point of view, the cases can be categorized in three main types: reinforced concrete, steel, and masonry and timber structures. From the type of the PV panels, the cases are chooses from the three different types of solar panels.

In regard to more influential aspect for integration of construction, all the cases are tabulated in three different tables below based on structural system. To understand the commonalities and differences of same PV models, the cases are subcategorized in regard to the solar panels. Finally, for each case a succinct information is mentioned in details on integration methods. As an instance, the cladding strategy, using harmonic color and texture, utilizing suitable dimension of solar panels and joint, can be mentioned as architectural integration from formal point of view of a reinforced concrete building.

Each table belonged to one structural character, classifies the cases based on three types of PVs, Mono-crystalline Cells, Poly-Crystalline Cells and Thin-film Cells. The three next tables summarize the strategies for integration of solar panels in formal, functional, and constructive aspects.

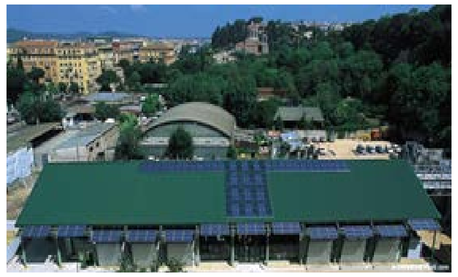
2.4.1 Integration Methods of Reinforced Concrete Structure

Summary of Utilized Integration Method Reinforced Concrete Structure (Source: Drawn by the Author)

Reinforced Concrete Structure		Mono-Crystalline Cells			Poly-Crystalline Cells		Thin-Film Cells
		Ewe Arena	**Kyusyu National Museum**	**Solar ark**	**The Optic Centre**	**BMW Welt München**	**Kulturhaus Milbertshofen**
							
Quality of Architectural Integration	Formal Aspect	+ Harmony with curved surface + Harmonic colours + suitable dimension of solar panels with curved facade	+ Harmony with curved surface + Harmonic colours + suitable dimension of solar panels with curved facade	+ Harmony with curved surface + Harmonic color + suitable dimension of solar panels with curved façade + Create smooth glass surface	+ Harmony with curved surface + Harmonic color + suitable dimension of solar panels with curved façade + Create smooth glass surface	+ Harmony with curved surface + Harmonic color + Good view on façade + Create smooth glass surface	+ Harmonic color + Geometric shape in harmony with architectural form
	Functional Aspect	+ Cladding element + Reduction of material for façade + Wind Protection	+ Cladding element	+ Cladding element + Reduction of material for façade + Thermal insolation	+ Cladding element + Reduction of material for façade + Building skin + Thermal insolation	+ Cladding element + Reduction of material for façade + Building skin	+ Cladding element + Reduction of material for façade
	Construction Aspect	+ No Extra element + Fastened to the surface as skin	- Extra element on roof + Fastened to the surface as skin	+ No Extra element + Fastened to the surface as cladding	+ No Extra element + Fastened to the surface as cladding	+ No Extra element + Fastened to the surface as cladding	+ No Extra element + Fastened to the surface as cladding

2.4.2 Integration Methods of Steel Structure

Summary of Utilized Integration Method Steel Structure (Source: Drawn by the Author)

		Mono-Crystalline Cells			**Poly-Crystalline Cells**		**Thin-Film Cells**
		BP Solar Skin, NTNU	**Energybase Building**	**Acciona Solar Building**	**Children Museum**	**Centrosolar Office**	**Tourist Information**
Steel Structure							
Quality of Architectural Integration	**Formal Aspect**	+ Harmonic colours + Modular frame in façade + Rhythmic net frame on facade	+ Harmonic colours + Rhythmic modular frame in façade + Horizontal linear structure	+ Harmonic colours + Modular frame in façade + Rhythmic net frame on façade	+ Harmonic colours + Invisible panels on roof	+ Harmonic colours + Rhythmic modular frame in facade	+ Harmonic colours
	Functional Aspect	+ Double skin facade + Natural ventilation + Passive solar gain + Laminated glass as shading + Thermal and noise insolation	+ Natural ventilation + Passive solar gain + Shading element + Thermal and noise insolation	+ Shading element + Passive solar gain + Optimization by louvers	+ Shading element + Passive solar gain + Laminated glass as shading	+ Natural ventilation + Passive solar gain + Laminated glass as shading + Heat and noise insolation	+ Shading element + Passive solar gain + Optimization by louvers
	Construction Aspect	+ Avoid Condensation + Extra construction frame + Modular structure in harmony with modular columns	+ Extra construction frame + Modular structure in harmony with modular columns	+ Avoid Condensation + Modular structure in harmony with modular columns	+ Moveable sun shade	+ Avoid Condensation + Extra construction frame + Modular structure in harmony with modular columns	+ Moveable sun shade

2.4.3 Integration Methods of Steel Structure

Summary of Utilized Integration Method Masonry and Timber Structure (Source: Drawn by the Author)

Masonry and Timber Structure		Mono-Crystalline Cells				Poly-Crystalline Cells	
		Passive House	**Nieuwland District**	**Balanced Houses Nieuwland**	**Akademie Mont-Cenis, Herne**	**Kuppenheim,**	**Social Housing Moyrand**
							
Quality of Architecture Integration	Formal Aspect	+ Contrast color with façade + Extra element + Making monolithic roof cover	+ Contrast color with façade + Extra element + Making monolithic roof cover	+ Contrast color with façade + Extra element + Making monolithic roof cover	+ Contrast color with facade + Making a pattern on roof cover	+ Contrast color with façade + Extra element	+ Contrast color with façade + Extra element
	Functional Aspect	+ Roof cladding	+ Roof cladding	+ Roof cladding	+ Shading element + Link between interior and exterior	+ Shading element	+ Shading element
	Construction Aspect	+ In order to lead the loads to foundation, the panels are in the roof	+ In order to lead the loads to foundation, the panels are in the roof	+ In order to lead the loads to foundation, the panels are in the roof	+ The panels are jointed to the structural timber	+ The light panels are jointed to the load bearer wall	+ The light panels are jointed to the load bearer wall

2.4.4 Discussion

Each implemented strategy has some positive and negative effects. For example, these buildings have curved surface, and consequently the integrated systems must have rectangular shapes, which on one hand make the integration aesthetic, and on the other hand reduces the efficiencies as a result of unpleasant angles toward the sun. These case studies are all constructed by reinforced concrete and are integrated by means of Mono- Crystalline cells.

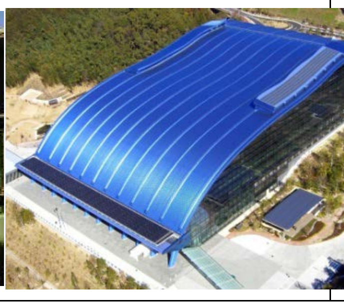
	Reinforced Concrete Structure		
	Ewe Arena	Kyusyu Museum	Solar Ark
Mono-Crystalline Cells			

Figure 2.18: Comparison of Case Studies about Reinforced Concrete Structure Drawn by Author

Concerning formal aspect of integration, different strategies have been used. Modular façade of PVs is revealed to have positive effects in integration, but then again these modular cladding panels make the curved surface a polygonal unsmooth surface. Color, being one of the important factors in architecture, can be observed in all the cases. On one hand, a harmony can be detected between the color of panels with the surface, and on the other hand necessarily use of dark blue less efficient panels. Since the integration of first and last cases has happened in the façade of the buildings, dimensions of each panel are then important regarding the formal aspect.

Functional aspect of integrations also contains some reciprocal strategies and their effects. These positive effects are mostly rooted in the skin-like materials.

Moreover, usage of cladding, which works as an insulation to protect the walls from wind, can be mentioned as the positive effects in the functional point of view. However, this cladding element causes not to have a good view and enough appropriate openings, separating inside and outside, and also limiting the façade design; all of which can be negative effects of this type of integration. For instance, limitation concerning the combination of raw reinforced concrete and solar panels can be mentioned as the most important negative aspect in design limitation. Condensation is another significant factor relating to the functional aspects. The building's walls via the usage of skin-like panels would have more possibility for condensation, and this issue should be taken into account in design process.

The last factor of integration taken into consideration is its constructive aspect. All the panels must be attached firmly to the structure of the building. These types of buildings which are erected by reinforced concrete, can have the most possibility for attachment, and accordingly their panels can be fastened to the walls easily. This criterion prevents requiring an extra element as supporting PVs which leads to have a more qualified aesthetic factor. Consequently, the PVs are fastened with a simple joint to the reinforced curved surface as a cladding element.

Reinforced Concrete Structure			
Poly-Crystalline Cells	Optic Center	BMW Welt München	Kulturhaus Milbertshofen
			

Figure 2.19: Comparison of Case Studies about Reinforced Concrete Structure Drawn by Author

These cases are created by reinforced concrete and the first buildings utilized by Poly-Crystalline Cells and the last one are integrated by Thin-Film Cells type of PVs. These buildings are integrated by means of skin-like panels. Regarding the formal aspect of integration, harmonic color is an advantage of this cladding strategy. Nonetheless, the modular PVs are appropriate and well jointed to the flat plate in the first and third case, they are not suitable for the BMW building since it has an organic, free curved form and the modular panels cannot get fit appropriately.

From the functional viewpoint of integration, the panels protecting the walls, make a separation between inside and outside of the building and a disturbance for external visual connection in the first two cases. Preventing to have the appropriate opening also causes a negative effect on supplying natural ventilation and an increase in condensation problems for all the mentioned buildings. Another functional aspect of these formal buildings is related to the panels’ angle. The panels being not in the best situation with sun rays, is due to their being fastened to the facade walls following the formal aspect of architecture. The first case, having a flat inclined surface, has a better angular shape; but the second and third buildings are departed from perpendicular appropriate angle for solar facilities.

Regarding the constructive aspect of integration, the panels have no joint limitation in attaching to the PVs, protecting the building easily. This factor plays a crucial role especially for inclined walls. Consequently, the vast opportunity for attaching causes to have a better joint regarding the formal aspects, especially for the smooth surfaces.

For instance, in the above mentioned buildings with reinforced concrete, formal aspect is more prominent in comparison to the functional and constructive aspects, because it increases the creativity in facade and roof in terms of aesthetic view, for having a reinforced concrete has less limitation while joining, especially in contrary to masonry and timber structures.

The below cases are created by steel structure while the first buildings had utilized Mono-Crystalline cells.

	Steel Structure		
Mono-Crystalline Cells	BP Solar Skin, NTNU	Energy Base Building	Acciona Solar
			

Figure 2.20: Comparison of Case Studies about Steel Structure
Drawn by Author

Regarding the formal aspect, the majority of buildings with rectangular shape among these three cases have harmony with the glass used in their façade; for instance, there is much flexibility in integrating small sized PV cells with rhythmic net frame on their facade. This issue can improve the aesthetic view and improve the harmony in the shape of the building. An important point regarding the formal aspect is that all integrations in three PV cases are embedded in resin layer. In the laminated glass module, the cells look like small square dots at regular intervals, creating a smooth pattern in façade. Moreover, PV's horizontal modules which are following the grid of facade and jointing it are similar to the normal glass on the façade.

Regarding the functional aspect, in the major cases, PVs act as a double skin façade which leads to having too many positive points in building integrations. Firstly, it helps to improve natural ventilation and try to decrease condensation in building. Secondly, it acts as a shading device for avoiding overheating during over-heated periods. Thirdly, it increases passive solar gain and acts as thermal insulation and noise insulation. In addition, in steel constructions, the role of multi functionality is prominent in comparison to the other aspects of construction.

Regarding the constructive aspect, it can be mentioned that all the joints are similar to the normal glass on the façade and the disadvantage of these cases is that photovoltaic acts as an extra element in façade and it therefore causes the purity of architecture to be lost in these case studies.

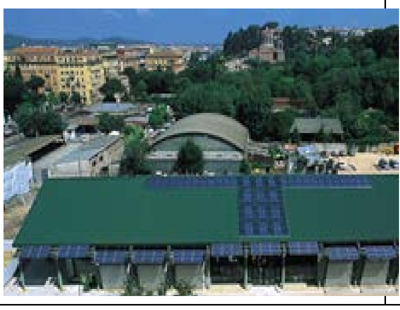
	Steel Structure		
Poly-Crystalline Cells	Children Museum	Centrosolar Office	Tourist Information
			

Figure 2.21: Comparison of Case Studies about Steel Structure
Drawn by Author

The above buildings, with a same structure in terms of shape, have different characteristics. Children Museum has PV integrated on façade and roof, but the others just have façade solar facilities. Paderborn building has fixed panels in contrast to the Tourist Information building that has movable louver shape integration.

Regarding the formal aspect, Children Museum has two textures as a result of using panels on its roof. These panels have reduced the formal aesthetic of roof plan since they are not only in visionary behind the taller buildings but are also watchable from inside of the building. The same problem can be seen also in Paderborn building: different texture, pattern and color not only have reduced the aesthetic aspect of the building, but also have reduced the transparency and purity of the building’s formal composition on the façade. The last building had utilized a shade in both elevations of the building; in one façade, a movable shade has been placed, and in another façade the PV acts as a shade. These shading devices provide a harmonic, rhythmic, and recognizable different texture for the whole building.

Regarding the functional aspect, Paderborn building, by means of fixed PVs and transparent glass, has got use of the different advantages of double skin façade such as natural ventilation, passive solar gain, and noise and thermal insulation. In contrast, the other buildings have utilized movable PVs that can articulate the favorite perpendicular angles. Thus, the most efficiency was gained by the PVs with movable shade-like panels. Consequently, the first and last cases are profiting from movable PVs, and the other one profits from the double skin façade.

Regarding the construction aspect, PVs attached to the pillars resulted in having an extra construction element to be a supportive net of the PVs. Not only the pillars have a same rhythmic span, but also the PV panels and the supportive structure accordingly have a net-shaped cell. Consequently, modularity can be a structural feature in the façade of the buildings.

	Masonry Structure		
Poly-Crystalline Cells	Passive House Emmendingen	Nieuwland District	Balanced Houses Nieuwland
			

Figure 2.22: Comparison Case Studies about Masonry Structure
Drawn by Author

few advantages has some limitation for integration as well. These buildings have load bearer walls that make an opportunity for attaching the PVs. But having a non-flat wall makes some problems for jointing the facility to the walls. To solve this problem, there is a must to have a plaster cladding element before attaching the facility to the walls. From another viewpoint, the load of the panels that are commonly used in a vast scale leads to the walls beneath. There should be a brief awareness about the loads imposed to the walls; thus this feature has a negative criterion for vast scale integration, but an advantage for few panels. Consequently, in this type of building, to solve the construction problems, in vast scale, a masonry structure has been utilized on roof (to spread the loads to different walls), and in small scale it was utilized on façade (since the imposed load is not significant). It may be significant to mention that the Mono Crystalline cells are used in vast scale, thus these buildings have the same integration method as a result of having the same structural system.

Regarding the formal aspect, the PVs that were mostly used on the roof, have a contrast pattern with the walls' material, not only with the color but also with the glazing, roughness, and reflection aspects. Another positive point related to the forms is that the messy unorganized roofs can hide behind the monolithic pattern of the PV cells.

This type of integration from the functional viewpoint has the best efficiency. The following buildings by means of pitched roof have desirable angles toward the sun rays which result in having the best efficiency. The PVs also act as a cladding element on the roof that improves the insulation against rains, noises, and overheating load especially in summer time.

	Masonry Structure		
	Akademie Mont-Cenis, Herne	Kuppenheim	Social Housing Moyrand
Thin-Film Cells			

Figure 2.23: Comparison of Case studies about Masonry Structure
Drawn by Author

on walls were utilized. The small scale integration of cells on façade, in addition to reducing the imposed load, has made a slender, delicate façade element as well.

Concerning the formal aspect, this type of integration takes place on walls. This factor, in regard to the construction issue, results in small scale utilization. Thus these panels are small extra elements over the walls. The scale of the integration results in not to change the purity of form, and neither the feature and composition of the building.

This type of integration from functional viewpoint has the best efficiency for its being movable. The PVs also act as a shading element on top of the opening, and prevent penetration of unfavorable sun rays inside the building, in addition to providing free healthy energy for the building.

Chapter 3

CONCLUSION AND FURTHER STUDY

The first table belongs to reinforced concrete buildings and shows the integration method of solar panels. Since most of the projects with special forms are being built by reinforced concrete structure, thus the formal aspect of this particular form plays a very important role, both in a small magnitude or even a national monumental structure. Consequently, the integration must not have a negative effect on the formal aspect of the architecture. In these buildings, solar panels are fastened to the wall of the buildings as cladding elements to prevent having extra supporting structures. From functional point of view, since there is no possibility for natural ventilation between the panels and the walls, encountering a condensation is more probable. Nonetheless, to prevent this negative effect, the insulation always needs a narrow scrutiny. Modular structure of panels on one hand can help the construction process, but on the other hand it may cause negative straight line in façade of the buildings. Although modular structure of panels is used as a cladding element, there is no relation between the concrete structure and the panel structure.

Altogether, since reinforced concrete is a flexible load-bearer material for the structure, most of the buildings with special forms are built by this material. Thus, not surprisingly, the first criterion of integration focuses on the formal aspect of architectural integration.

The second table contains some cases using the steel structure. All the attachments must be connected to the structural elements so to lead the loads to the foundation appropriately. To integrate the PVs into this type of building, the panels should be attached to the pillars and slabs. As the pillars in steel structure are mostly modular with a significant span, there is no opportunity to fasten the panels to any place. Thus, an important limitation of this type of construction system relates to its attachment. Consequently, we need an extra net-shaped structural element to support the panels and lead the loads to the pillars. This supporting element of the panels can be right on the façade of the building or with a distance. Consequently, to prevent condensation and have better functional aspects, there is a gap between the added structure and the façade of the buildings. The modular extra elements make double skin façade and have different functional advantages such as natural ventilation, passive solar gain, natural light possibilities and etcetera in addition to preventing condensations. The rhythmic steel structure makes a modular façade by means of the rhythmic panels.

Finally, in this type of building, the functional aspect of integration can be mentioned as the first factor having more qualified architecture.

The third table displays masonry and timber structured buildings. Masonry building loads lead to the foundation by means of the walls. These load-bearer walls make an opportunity to fasten the panels to the walls in any place. In contrast, since these walls are mostly not smooth enough for hanging the panels, a plaster, as the base of the solar facility, is required before the integration of PVs. Consequently, although this structural element has the advantage of load-bearer walls, it possesses the negative effect of plaster requirement. Moreover, most of the buildings with masonry structure were integrated by means of two strategies: having it in roof or as a light element on smoothed walls. Finally, structural aspect of integration in this category is a crucial factor.

After analyzing tables in different structure and with different architectural quality tastes, it is worth mentioning that there are different limitations for each kind of integration strategies. This study was an attempt to evaluate the inter-related models and requirements to achieve the significant concept of quality in integration. For this purpose, an investigation of the plausible ways in integrating the photovoltaic systems and focusing on the quality of architectural integration was thoroughly considered based on formal, functional and constrictive aspects in various structure systems of construction.

As a result, a simple comparison between the structural differences shows that the integration aspect of reinforced concrete relates to the formal aspect, while steel structure focuses on functional criteria, and the masonry integration mostly is affected by the construction issues. These results show the limitation of each type of structure and are required to be concerned. As an example, a formal building constructed by reinforced concrete, with an unfavorable angle of form, cannot be easily integrated without having the negative effect on the form of the building. In a steel structure building with wide span pillars, an extra supportive element is necessary. And lastly, in a masonry building, the vast scale of integration without suitable supportive elements on the wall is impossible, and the integration can be summarized in roof or light PV panels on the wall.

In conclusion, in the installation process, integration of photovoltaic into the external part of the building is reasonable, since the integration plays the role of a multifunctional element which covers the function of energy production in addition to increasing the aesthetic of the building. In order to achieve a fruitful goal, there must be some determined criteria and benchmark based on which the quality and homogeneity in integration process be gained. However, there are too many limitations for building integration in different structures for approaching higher quality of architectural integration which can be enhanced by means of equipping solar facilities. To cut it short, designers have to pay more attention to the feature of buildings during the design process and also while implementing panels with reference to the color, size, shape, position, surface texture and the combination of materials and modules.

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