Evaluation of Integrated Photovoltaic Systems on Facades

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ABSTRACT

Nowadays energy usage in buildings became critical due to limited energy sources. Energy efficient building designers started to develop themselves in this manner. In addition to these, renovation of existing buildings started to be re-used in this manner also. Building techniques and construction materials should be selected accordingly. Constructions of photovoltaic (PV) systems are the part of the new design of architecture and they have affected the silhouette of the cities to use them on building facades. Today it is mostly used by the developed countries, but it is still an emerging technology. In this context many countries around the world are working to increase the use of renewable energy sources with the improving technology. In addition to this, architects who design energy consuming projects are responsible for the future of the world. For this reason less energy consuming projects with their design concepts by utilization of renewable energy sources are increasing day by day. Today using photovoltaic (PV) systems in architecture is an attractive solution to solve energy problem.

Technology use for PV is developing. PV as cladding wall material is different for each building enveloper systems. There are different construction systems and different PV panel systems like PV with aluminum frame, without frame, metal base or double base (glass to glass) and each system has their own construction strategy. These construction strategies and their construction details will be examined and evaluated in this research. The advantages and disadvantages of using PV on building facades, type of climate, orientation of PV panels on facades, integration of PV panels for different building envelope (on curtain wall, on double skin façade and on rainscreen cladding system), design feature and classification of PV’s will be part of this research. Moreover the factors which affected to the PV module efficiency (overheating, overshadowing, etc.) will be evaluated too. Result of this work will be useful for designers while using PV in their projects.

Keywords: Cladding Wall, Photovoltaic Panels, Building Envelope and Sustainable Construction.

ÖZ

Son günlerde sınırlı enerji kaynaklarından dolayı enerji kullanımı kritik bir hal almıştır. Enerji verimli binaların tasarımcıları bu konuda kendilerini geliştirmeye başlamışlardır. Buna ek olarak mevcut binaların yenilenmesine de bu bağlamda başlanılmıştır. Bina teknikleri ve yapı malzemeleri doğru seçilmelidir. Fotovoltaik sistemlerin yapımı, yeni mimari tasarımların bir parçasıdır ve bina cephelerindeki kullanımları şehirlerin siluetlerini etkilemektedir. Bugün fotovoltaik teknolojisi daha çok gelişmiş ülkelerde kullanılıyor olsa da halen gelişmekte olan bir teknolojidir. Ayrıca dünyadaki gelişmiş pek çok ülke bu gelişen teknoloji ile birlikte yenilenebilir enerji kaynaklarının kullanılmasını arttırmaya çalışmaktadırlar. Günümüzde enerji tüketen projelerin tasarımcıları olan mimarlar, dünyanın geleceğinden sorumludurlar. Bundan dolayı yenilenebilir enerji kaynaklarını kullanarak, az enerji tüketen tasarım kavramlı projeler gün geçtikçe artmaktadır. Bugün fotovoltaik sistemlerin mimaride kullanımı, enerji sorunu için etkileyici bir çözümdür.

Fotovoltaik teknolojisinin kullanımı gelişmektedir. Fotovoltaiklerin cephe kaplama malzemesi olarak kullanımı her bina kabuğu sistemi için farklılık göstermektedir. Farklı yapı tekniklerinin yanında, alüminyum çerçeveli paneller, çerçevesiz paneller, metal tabanlı veya çift katmanlı (cam – cam) paneller gibi farklı fotovoltaik panel sistemleri de mevcuttur. Bu çalışmada farklı yapı stratejileri ve yapı detayları incelenecek ve değerlendirilecektir. Fotovoltaik panellerin bina cephelerinde kullanımındaki avantaj ve dezavantajları, iklim çeşitleri, panellerin cephedeki yönlendirilmeleri, farklı bina kabuklarına entegrasyonu (perde duvar, çift kabuklu cephe ve kaplama duvar), tasarım özellikleri ve fotovoltaiklerin sınıflandırılması bu çalışmanın birer parçaları olacaktır. Ayrıca fotovoltaiklerin verimliliklerini etkileyen faktörler de (ısınma, gölgelenme vs.) tartışılacaktır. Bu çalışmanın sonuçları fotovoltaikleri projelerinde kullanacak olan tasarımcılara yardımcı olacaktır.

Anahtar Kelimeler: Duvar Kaplaması, Fotovoltaik Paneller, Bina Kabuğu ve Sürdürülebilir Yapı.

To My Beloved Family

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INTRODUCTION

1.1 Problem Statement and Methodology

Photovoltaic (PV) is still developing technology. The integration on facade or using it as a cladding wall material is different for each building envelope systems. There are different construction systems and different types of PV modules. The purpose of this research is help to understand PV systems, their construction technology on facades more specifically. Also this research examines the advantages and disadvantages of using PV on building facades, type of climate, orientation of PV modules on facades, integration of PV modules for different building envelope (on curtain wall, on double skin facade and on rainscreen cladding system), design feature and classification of PV's. Results of this work will be useful for designers while using PV in their projects.

The methodology of the research is theoretical investigations included case studies which selected randomly around the world. The thesis is focused on all the information about PV technology in order to describe their construction techniques, classifications, types, different aspects and structure.

The result of this research will be helpful who interested in photovoltaic technology more deeply.

1.2 Limitation of the Research

The limitation of this study is based on systematic evaluation of PV technologies and the installation details of facades according to different cell and module types, installations on different facades types, tilt and orientation, factors that affected to the module efficiency and economic factor. This research examines PV cell types, such as crystalline silicon and thin-film which are used in the market at the moment. This research suggests that future researchers can study deeply on future cell technologies such as organic and dye solar cells.

1.3 Literature Review

Negative developments in recent years such as; global warming, climate change, degreasing fossil energy sources and increasing awareness of environmental problems are caused increasing the interest of the renewable energy technologies (Ozbalta, 2009).

A researcher Altin (2006) mentioned that "Solar energy is the most important and easiest renewable energy source that can be used in buildings". In this context the photovoltaic (PV) applications have become popular in developed countries due to government supporting's and cost reduction of the technology. In many Europeans countries, first of all in Germany, also in USA, Japan and Chine designed buildings that can produce its own energy by using PV systems (Ozbalta, 2009).

1.3.1 Definition of Photovoltaic

Photovoltaic (PV) is a semiconductor material which generates electricity directly from sunlight. Photovoltaic transfers the photons of sunlight to the electron of the photovoltaic module elements. Electrons which gain energy become free and they create electric circuit and then exposed voltage is converted to electrical current

(Colak. *et al*., 2006). This voltage can be converted to electrical current with 5-30% yield depending on the photovoltaic material produced (Sev, 2009).

The smallest part of the PV is called cell. A cell of PV systems can produce energy between 1or 2 watts. Combination of 36 cells occur a PV module and the modules creates PV array (Figure 1).

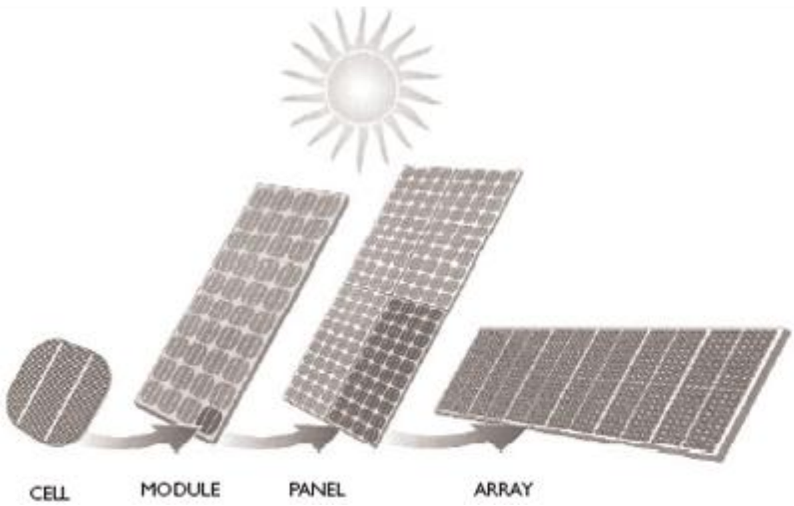


Figure 1: Shows the build up of a solar PV array from cell to module to panel to final array (Sustainable Energy Authority of Ireland).

PV cells might be design as a square, a rectangle and a circle. Generally its area is 100cm² and thickness is between 0, 2-0, 4 cm (Sev, 2009).

A PV module can be manufactured with aluminum frame, without any frame, with metal or plastic based or with double surface (glass-glass).

1.3.2 Historical Backgrounds of Photovoltaic

The term of photovoltaic consists of Greek word phos, which means light and the Italian physicist Alessandro Volta, who give the name to the unit of electrical voltage(Hegger, Fuchs, Stark and Zeumer, 2008, p 138).The photovoltaic effect firstly discovered by the physicist Alexandre Edmond Becquerel in 1839 (Ozbalta T.

G., 2009). But, until middle of the 20th century that workable photovoltaic systems were not developed (Hegger, Fuchs, Stark and Zeumer, 2008, p 138).

Firstly modern photovoltaic panels was started to be used on spacecraft and satellites by NASA as an expansive electricity producer in 1954 (Celebi, 2002). Depending on technological development PV was started to be used in places where there is no electricity and usually met the small demands of electricity after 1970s (Ozbalta, 2009). Also it was used for street illumination, watches, calculators etc. After 1981s PV panels started to be use on buildings as an integrate system. Firstly applied to roof section of the buildings and then after 1992s PV panels started to be integrated to the facades (Celebi, 2002).

However, the user area of photovoltaic was started increase day by day. The reasons for this are continuous increase in productivity of PV by developing technology, the cost reduction due to increasing demand, exhausting energy resources and environmental pollution.

1.3.3 Advantages and Disadvantages of Photovoltaic

Advantages

- PV panels produce energy by using clean and endless energy source of sunlight and PV does not leave any waste to the environment.
- PV can work many years without giving any problems after installation (Tonuk and Ozdogan, 2006).
- PV system does not have too many moving parts, because of that the system does not need continuous maintenance. Also because of the same

reason it is resistant to weather condition like humidity, wind, snow, lightning flash etc. (Tonuk and Ozdogan, 2006).

- Energy is produced, where there is a need for energy. Therefor there is no need for network cables and connection elements. Also there is no cost of energy transport.
- PV system is a module system and it can be enlarge easily according to increasing energy needs

Disadvantages

- Overheating reduces the production power of PV panels. According to some research studies determined that 1% yield reduces by every increase 10°C degrees. However, overheating can be reduced by ventilating back surface of the PV and choosing of the proper tilt (Celebi, 2002).
- Surface pollution could be a cause of the fewer yields. Some research studies show that yield of the PV decrease 3, 5% when the surface became dirty. For this reason surface of PV should be cleaned from time to time (Celebi, 2002).
- The cost of the first installation is expansive. Because of this reasonat first impression PV does not seem to be economic.
- Extensive installation space is needed for the large production of electricity.
- When there is no sunlight, for example at night, there is no electricity production. Therefore energy production is needed to store and area for storing.

1.4 Classification of Photovoltaic cells

PV cells are categorized according to their manufacturing methods (Figure 2):

1.4.1 Crystalline silicone cells

1.4.1.1 Monocrystalline silicon cell

1.4.1.2 Polycrystalline silicon cell

1.4.2 Thin-film solar cells

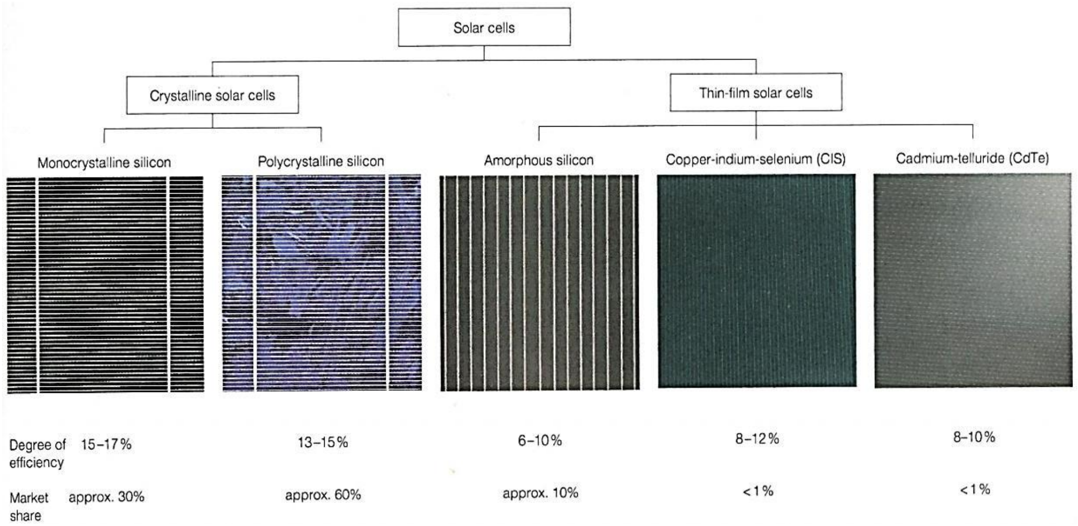


Figure 2: Classification of solar cells (Hegger, Fuchs, Stark and Zeumer, 2008)

1.4.1 Crystalline Silicon Cells

1.4.1.1 Monocrystaline silicon cells

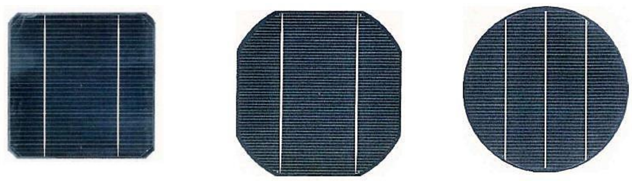


Figure 3: Square, semi-round and round monocrystalline silicon cells (Planning and installing, 2008).

Monocrystalline silicon cells are manufactured from silicone (Si). Silicon is a raw material of quartz and most abundant element after oxygen in the world. The most commonly manufacturing process of monocrystalline silicon cells which calls

Czochralski method. In this method a single crystal ingot of high purity is obtained by melted quartz crystal. The diameters of ingot are 12, 5 cm or 15 cm. This ingot is cut into thin circular wafers which are processed to make PV cells (Roberts and Guariento, 2009, p. 18). This manufacturing process is very energy consuming and expensive process.

Different cell forms are available such as square, semi-round or round (Figure 3) However, mostly square or semi-round cells are used. In order to mount the wafers in a module closer to each other, circular wafers are usually trimmed to form square. The reason of this cutting process is to get more efficient surface. The disadvantage of this process is the expensive material which was cut, cannot use anymore. Again, the cutting process is quite energy intensive (Messenger and Ventre, 2004, p 377).
The other methods of manufacturing monocrystalline silicon cells are edge-defined film-fed growth (EFG) and string ribbon process. These can be produced the right thickness and it can be avoided the slicing process and losses cells (Roberts and Guariento, 2009, p. 18).

The colors of monocrystalline silicon cells are depending on thin anti-reflection coating materials which increase the amount of light absorbed into the cell. Either silicon nitride or titanium oxide is used as anti-reflection materials which makes appearance dark blue or black. As a color alternative, cells can be covered with different thicknesses of anti-reflective material. However, the reflection losses increase from 3% to 30% (Roberts and Guariento, 2009, p. 18).

1.4.1.2 Polycrystalline silicon cells

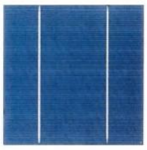


Figure 4: Polycrystalline silicon cell (Planning and installing, 2008).

Another way of manufacturing silicon PV cell is polycrystalline silicon. The silicon (Si) is melted and cast in a cuboid form and controlled the cooling rate. The result of the different cooling process many individual crystals are produced which is why the cells are called as polycrystalline silicon (Hegger, Fuchs, Stark and Zeumer, 2008, p 139).The cuboid form ingot firstly cut into the bars and then sliced into the thin wafers which are processed to make PV cells (Roberts and Guariento, 2009, p. 19). The square format is produced directly by this wafer, so there is no additional cutting process and no kerf loss (Messenger and Ventre, 2004, p 383).

Polycrystalline silicon cells manufacturing is more economic than monocrystalline silicon cells, but it is also less efficient (Roberts and Guariento, 2009, p. 19).
The colors of the polycrystalline silicon cells are usually medium or dark blue. The other color alternatives are available like monocrsytalline silicon cells by varying the thickness of the anti-reflection materials. While reducing the thickness of the anti-reflection materials, the efficient of the cell decrease by 15-30% (Roberts and Guariento, 2009, p. 28).

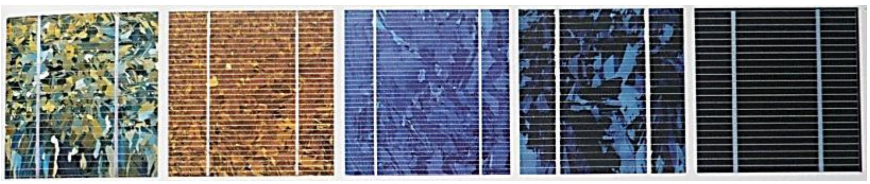


Figure 5: Colored solar cells through the use of different anti-reflective coatings (Lüling, 2009).

1.4.2 Thin-film solar cells

Semi-conductor materials such as amorphous silicon (a-Si), copper-indium-selenium (CIS) and cadmium-telluride (CdTe), are used to manufacture thin-film cells, which can be made by directly into modules. These semi-conductor materials are applied to a backing of glass, metal or plastic, so large amounts of materials and energy can be saved during production (Hegger, Fuchs, Stark and Zeumer, 2008, p 139).The thickness of the thin-film solar cell is approximately only 0.004 mm (Eisenschmidt, 2009). Also manufacturing temperature of thin-film cells is less than crystalline silicon cells. Because of these positive reasons the manufacturing of thin-film cell offers considerable cost and energy saving. However, thin-film cells are still less efficient than the others, although it is more flexible in practice.

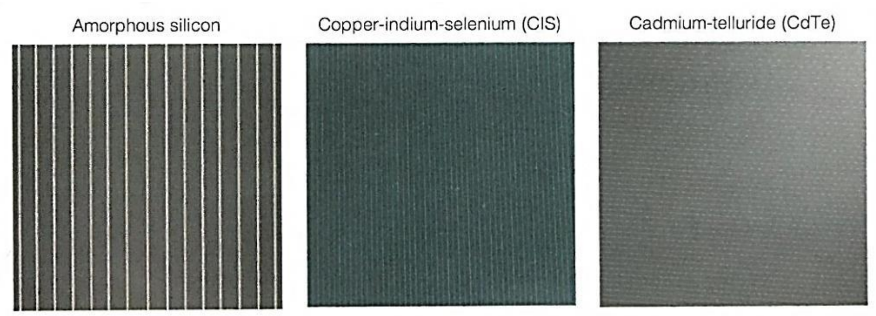


Figure 5: Available thin-film cells (Hegger, Fuchs, Stark and Zeumer, 2008).

1.5 Photovoltaic Modules

Photovoltaic modules are available as standard modules, special modules and custom-made modules. Standard modules are manufactured to achieve maximum energy yield at minimum module production cost. Cells are designed mostly square to fit within the module with minimum gaps to provide maximum output. They are mostly glass-film laminates with or without frames.

Standard PV modules in sizes from about 0.5 to 1.5 m² (Hegger, Fuchs, Stark and Zeumer, 2008, p. 140). They are consist of 36 to 216 cells and typical cell sizes are length 100-150 mm. Module has a power output of 100 W_p to 300 W_p (crystalline cell). Strings of 36 to 72 cells are connected in series. Larger modules parallel connections of 2 or 3 of these strings (Robert and Guariento, 2009).

Special modules are produced for special purposes and special materials or a special frame may be used if necessary. These modules mostly are used for small scale application such as solar tiles, solar vehicles etc. and these are not used for building integrations (Planning and installing, 2008).

Custom-made modules are produced specially for a specific location such as facades, a glazed roof or a shading device. Module structure, size, shape, color and etc. determine according to location (Planning and installing, 2008).

1.6 Production of Photovoltaic Modules

Crystalline solar cells serially connected to each other. After connection, they are encapsulated (or laminated) to increase efficiency and durability, to protect them from outsides influences, and to protect their surroundings from the electric current produced by the solar cells; these are called solar modules (Erban, 2009, p. 63).

Different encapsulating methods are available; such as EVA encapsulation, PVB encapsulation, Teflon encapsulation and resin encapsulation. Most common encapsulating for crystalline cells is polymerizing foils such as EVA. The cells are sealed together between films of EVA in a vacuum chamber under high pressure and up to 150 °C. The EVA melts during this process and surrounds the solar cells on all sides (Robert and Guariento, 2009). As the EVA has not UV-resistant, the cells are still need the protection. Therefore after this process, the cells are generally placed between a low-iron glass behind which allows up to 92 per cent of the light (Planning and installing, 2008) and thin opaque plastic foil in front such as Tedlar (Figure 6).

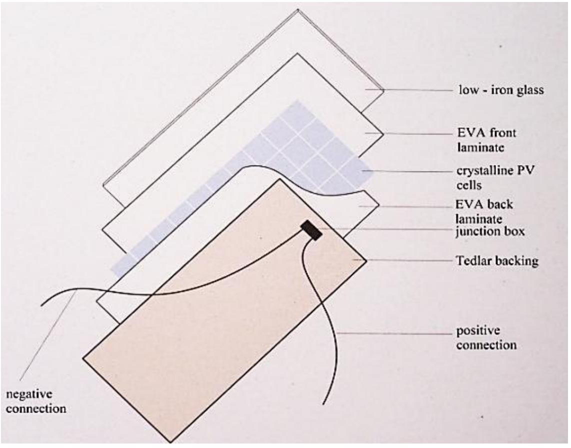


Figure 6: Typical crystalline silicon PV module, with Tedlar backing (Robert and Guariento, 2009).

Also PV module can consist of a sheet of glass behind and front. This type of module is called glass-glass laminates and they are usually frameless modules (Figure 7). For this type of module encapsulation is usually done, either a polymerizing foil like EVA or a thermoplastic foil like PVB.

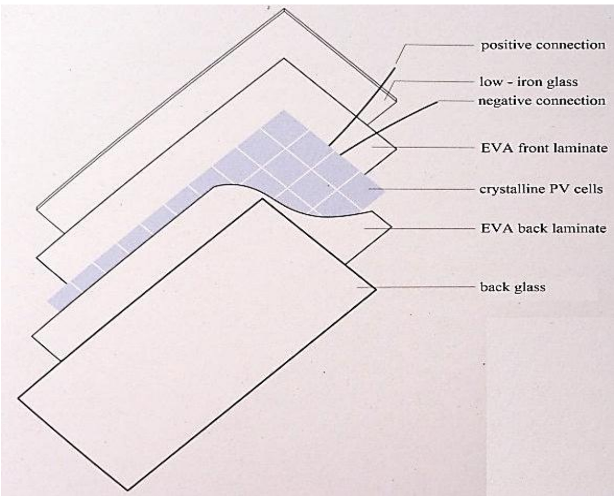


Figure 7: Typical glass-glass semi-transparent crystalline silicon PV module (Robert and Guariento, 2009).

Some modules are encapsulated between plastic foils both behind and front. In such cases, both EVA and OVB foils are used for cell encapsulation. These kinds of modules are very light and mostly used in flexible construction or when the weight restrictions are a priority (Erban, 2009, p.67).

Another encapsulation method is Teflon which is solar cells enclosed in a special fluoropolymer (Teflon) (Figure 8). In contrast to EVA, Teflon is UV resistant, so encapsulated cells require no further covering on the front. Teflon also highly transparent repels dirt and has a lower reflectivity than glass (Planning and installing, 2008). The Teflon layer on the solar cells only 0.5 mm thick and thus it conducts heat better than a thicker front glass would. Therefore the back surface of the module can be cooled where the poor ventilation exists. This kind of encapsulation mostly used for small-scale installations (Robert and Guariento, 2009, p. 23).

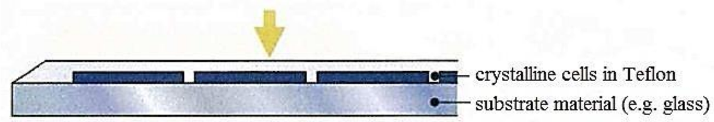


Figure 8: Teflon module (Planning and installing, 2008).

Resin encapsulation usually use to fabricate large custom-made modules for integrating within buildings (Figure 9). This also can be used to form glass-free modules which cells are encapsulated between two Makrolon sheets. Also resin is used for sound-absorbing glazing. Thus, resin module has sound attenuating properties from the outset (Planning and installing, 2008).

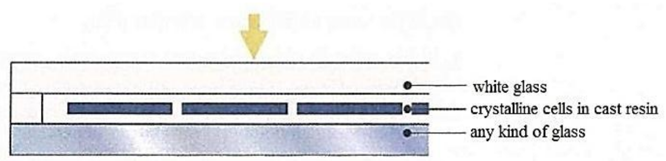


Figure 9: Resin (glass-glass) module (Planning and installing, 2008).

Thin-film solar cells serially connected to each other during the fabrication which is produced raw module that still requires encapsulation. Encapsulation of EVA is the same as for crystalline modules. The front can be covered by a sheet of glass and the back face can be finished with Tedlar, a metal film or any kind of glass sheet (Robert and Guariento, 2009, p. 25).

Raw thin-film module already has a superstrate glass sheet that is coated with the semiconductor material (Figure 10). It is not possible to use tempered glass for these superstrate sheet as the high temperature used for the semiconductor coating would destroy the glass strengthening. If the finished thin-film modules is to fulfill demands for toughness (e.g. in a facade), the raw module must be laminated with a sheet of toughened safety glass sheet (Robert and Guariento, 2009, p. 25).

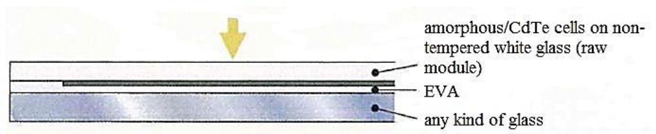


Figure 10: Glass-glass thin-film module (amorphous/CdTe cells in EVA) (Planning and installing, 2008).

Amorphous silicon and CdTe are fabricated onto superstrates. So any kind of glass or Tedlar film can be used for the back. CIS and amorphous silicon coated onto substrate need a front glass and low-iron white glass is used for high transparency (Robert and Guariento, 2009, p. 25).

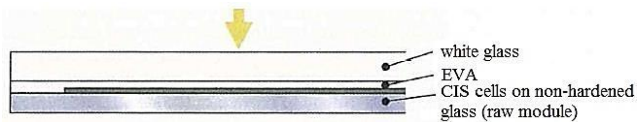


Figure 11: Glass-glass thin-film module (CIS cells in EVA) (Planning and installing, 2008).

Dimension of CIS and CdTe modules are usually available in set dimensions of 0.6 x 1.2 meters, with or without frames. Larger dimension of 2.2 x 2.6 meters are available for a-Si modules. Smaller dimension of CIS and a-Si modules are available for small-scale applications (Eisenschmidt, 2009).

1.7 Frame Types for Photovoltaic Modules

1.7.1 Framed Modules

Mostly PV modules are usually framed by aluminum frame to support mounting (Figure 8). On the other hand sometime stainless steel or plastic frames are used too. The module frame can have holes drilled in it for easy mounting and electrical terminals for grounding cables. The electrical terminals are enclosed in a junction box which is fixed on to the back of the modules (Hankins, 2010).

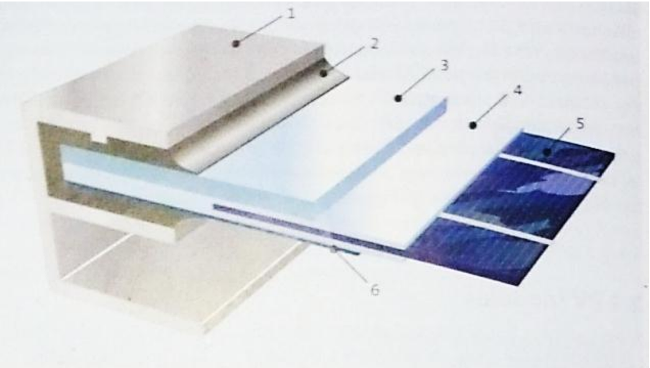


Figure 12: 1. Aluminum frame, 2. Seal, 3. Glass, 4. EVA, 5. Solar cell, 6. Tedlar sheet (Antony, Dürschner and Remmers, 2007).

1.7.2 Frameless Modules

Frameless PV modules mostly preferred for aesthetical reasons. Glass-glass PV modules are mostly frameless; however, other types of PV modules may be frameless too. There are different types of fixing system for these type modules.

1.8 Application of Transparency to Photovoltaic Modules

Modules can be opaque or semi-transparent. Semi-transparent modules can be used where light is required to pass inside of the building. There are three methods for producing semi-transparent PV modules:

- On glass-glass modules crystalline opaque cells are arranged with 1 to about 30 mm gap between cells so that light can pass between the cells (Robert and Guariento, 2009, p. 27).

Figure 13: Monocrystalline PV in a semitransparent module (glass on the back) (Robert and Guariento, 2009)

- Tiny perforation can be produce on crystalline cells by using a mechanical method to make them 10 percent transparent so the cells become themselves semi-transparent (Erban, 2009, p.69).

Figure 14: Transparent module with transparent cells (Lüling, 2009).

- Thin-film modules are already 20 percent transparent. The modules transparency might be increase maximum 50 percent (Eisenschmidt, 2009). Thin-film modules are drawn fine horizontal and vertical lines by laser to provide more transparency. The degree of light transmittance is approx. 20%

(Hegger, Fuchs, Stark and Zeumer, 2008, p. 140). Alternatively the cell spacing can be increased for strip (Robert and Guariento, 2009).

Figure 15: Transparent CIS thin-film modules (Lüling, 2009).

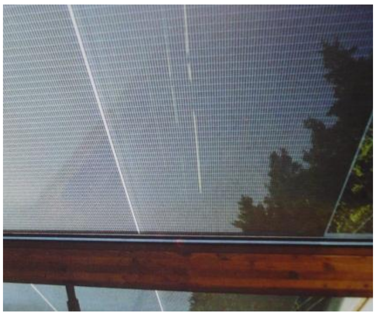


Figure 16: Transparent a-Si modules (Lüling, 2009).

1.9 Glass Types for Photovoltaic Modules

The front covering of the modules must be of highly transparent material to get maximum sunlight. So glass is the most suitable material for the front covering of PV modules. Low-iron that is ultra-white safety glasses by application of an anti-reflective coating is generally used. The transmission efficiency of low-iron glass is more than normal iron glass; it is about 92% (Roberts and Guariento, 2009, p.22).

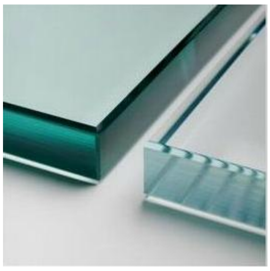


Figure 17: Standard glass (left) has a greenish tint. Low-iron glass (right) has ultra-white tint which is usually used in PV technology (Weller, Hemmerle, Jakubetz, Unnewehr, 2010).

On the other hand PV modules provide additional constructional features due to front glass types; such as weatherproofing, solar protection, heat insulation, soundproofing, and safety functions (Planning and installing, 2008). These features make PV multifunctional. Possible glass types include toughened (tempered) glass, laminated glass, insulating glass, body-tinted glass, screen printed glass, colored coated glass, solar protection glass.

1.9.1 Toughened (Tempered) Glass

Toughened (tempered) glass is a type of safety glass that has increased strength and in the events of breaking it will usually shatter in small, square, blunt pieces to minimize the risk of injury (Moezzi, 2009).

1.9.2 Laminated Glass

Laminated glass is a type of safety glass that is consist of two sheet of glass bonded together with PVB film (Planning and installing, 2008). When glass is breaking, the interlayer holds all the glass in place providing optimum safety (Muhammad, 2010). Laminated glass on buildings is typically used in curtain walls and windows when it's necessary. Also laminated glass provides higher sound insulation rating by PVB interlayer, and blocks 99% of transmitted UV light (Moezzi, 2009).

1.9.3 Insulating Glass

Insulating glass consists of two or more panes, which the air space between them encloses hermetically-sealed. The insulating glass ensures the heat insulation of the building (Moezzi, 2009).

1.9.4 Body-Tinted Glass

Body-tinted glass or heat-absorbing glass made by adding a number of tints to normal clear glass green, blue, grey, or bronze in color. As the tinted glass is hot, normally heat-strengthened glass is used to produce tinted glass (Muhammad, 2010). This type of glass is much less preferred used with crystalline cells because of it negative influence on the conversion efficiency. However, this type of glass might be used with very dark colored thin-film cells. Because the color of dark surface cannot be changed. For this reason body-tinted glass might be used to improve visual aesthetic of thin-film modules. However, this product is only used by special order (Weller, Hemmerle, Jakubetz, and Unnewehr, 2010).

1.9.5 Screen-Printed Glass

Screen-printed glass is tempered glass which is covered with mineral pigments. This type of glass is used for glazing and cladding facades. This type of glass can be produced with one or colors and with different figures or latters (Glass on web, 2007).

1.9.6 Colored Coated Glass

Colored coated glass is manufactured by coating with ceramic colors onto the glass surface with anti-reflective coating for PV modules (Planning and installing, 2008). Heat-strengthened glass should be used because of the changing thermal stress of colored glass (Muhammad, 2010).

1.9.7 Solar Protection Glass

Glass is coated with selectively reflecting metal oxide layers on the back side that reflect long-wave solar radiation. In contrast, visible light penetrates almost unhindered through the glass so that the interior of the building remains both bright and cool in summer (Planning and installing, 2008).

1.10 Usage PV in Different Climates

Today PV panels are installed on buildings in different countries, although the climate hot or cold. The important is that the sunlight angle comes perpendicular to the surface of the panel, rather than cold climate. Cold, clear days increase power production, while hot, overcast days reduce array output. However, the sunlight angles comes more inclined to the world surface where the cold climate or winter time exist. So PV modules which positioned incline will more efficient in colder countries (Celebi, 2002).

On the other hand duration of the insolation is longer where the hot climate exists. So the output of PV module can be higher during the long daytime. The disadvantage of using PV in hot climate is the high temperatures affect which reduces output of the PV. The cell temperature (not ambient temperature) of PV modules standardly should not more than 25 °C for efficiently performance. Generally, cell temperature up to 60 °C, a module loses 0.5 per cent efficiency per degree centigrade (Hankins, 2010). Thus, PV should be ventilated leaving a space between structures. This space should not be less than 15cm, especially where hot climate exist. The figure 18 below shows the effect of heat gain to the PV module efficiency.

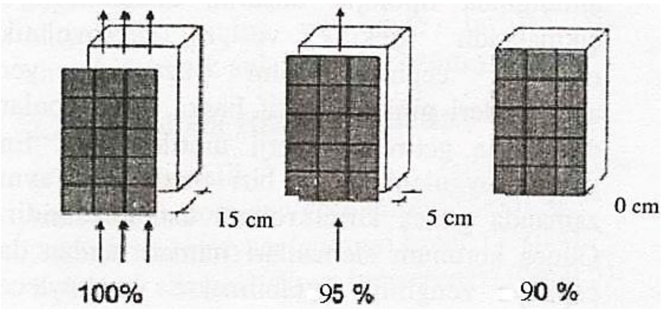


Figure 18: Change in energy production of PV module due to ventilation (Ozdogan, 2005).

It is also necessary to avoid unwanted heat gain from PV modules inside of the building which affects comfort of occupants. For this reason ventilation cavity should be allowed and if very hot climate exist this cavity might be ventilated also with funs which might powered by PV modules.

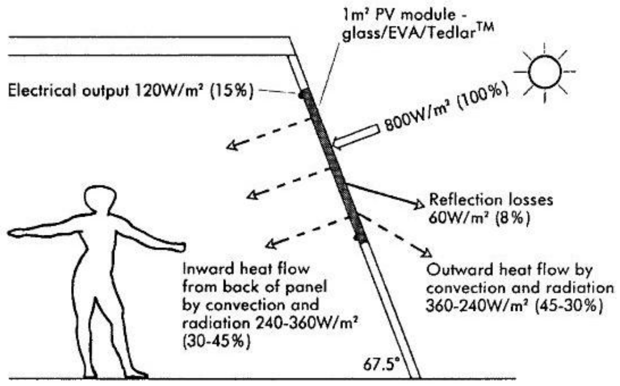


Figure 19: An approximate energy balance of monocrystalline silicon PV module which was integrated into the facade (Thomas and Fordham, 2001).

1.11 Tilt and Orientation

The most important part of the design process is the tilt and orientation of the façade. The PV panels should be set for maximum irradiation which depends on the true orientation and the angle of the collection surface (Prasad and Snow, 2005, p. 32). Façade integration might be convenient in some countries, at a northern (above 50°N) or a southern (above 50°S) latitude. Sloped façades or even horizontal facades might be more suitable in countries between these latitudes (Reijenga, 2003).

In the northern hemisphere, the south aspect is the most appropriate direction to obtain the maximum yield and the tilt from the horizontal equal to the latitude of the site minus 20° (Thomas and Fordham, 2001). “This angle comes from the fact that peak insolation takes place in summer, when the sun is higher than the latitude of the site” (Roberts and Guariento, 2009, p.33).

However, different orientation gives different energy output. Table 1 shows the output of different 50m² PV arrays in London. The directly south orientation gives highest output on vertical wall for both monocrystalline and thin-film PV array. Comparison of orientations according to power yield of PV arrays in London, between south and 15° west of south shows that, there is not so much difference of PV array's power yield. On the other hand according to the table, PV arrays give minimum output when they oriented to 45° east of south. It shows that the orientation of PV arrays directly effect to the energy output. However, roof integration of PV is more efficient comparison with facades integration. According to table 1 roof integration with angle 30° is most efficient position in London. So roof integration of PV is mostly preferred than facades around the world.

Position	TFS			Monocrystalline silicon		
	45° east of south	south	15° west of south	45° east of south	south	15° west of south
1. Vertical wall	2.00	2.15	2.13	3.50	3.75	3.72
2. Roof 30°	2.96	3.09	3.08	5.18	5.41	5.38
3. Roof 45°	2.86	3.03	3.01	5.00	5.30	5.26

Table 1: Comparison of PV array output (MWh/y) according to different orientations on vertical façade in London (Thomas and Fordham, 2001).

On the other hand the integration PV into the building façade may have to consider non optimal orientation. Design tools such as global insolation charts can be used for the area of construction site to find out the true direction for the maximum output (Roberts and Guariento, 2009, p.34).

1.12 Use of PV in Building Envelope

The most important advantage of the PV technology is that the readily integration with the architectural buildings. Buildings give high opportunities with their large surface areas to provide energy by integration PV systems. These systems can be integrated either into roof or façade of the building. Also they might be used as a shading glazing element to control natural daylight. This is the passive way to reduce solar gain and produce electricity at the same time. Moreover PV might be integrated atriums, balconies and skylights. PV module might be designed opaque, semi-transparent, it might be double or single glazed and it might be design with or without frame. Also the base of module might be metal, plastic or glaze.

However, façade installation plays important role as city silhouette, due to high visibility of the installation. The large surface area can be covered by PVs to provide high output. Nevertheless the main problem is that the verticality of façade which is the usually sub-optimal in orientation and reduces the efficiency. Also there are advantages to be gained by using PV on facades, modules can protect to the building from excessive solar radiation and PV modules can be an alternative to expensive cladding for prestigious buildings. However, PV might be installed on an incline façade or modules might be installed inclined on the vertical facades to improve module output.

On the other hand the mounting is difficult into the facade than roof, because of the wiring and junction boxes, which have to be hidden (Prasad, Snow, 2005, p.33). The other things that have to be considered for a building-integrated PV system is the color, image, size, weather-tightness, wind loading, lifetime, maintenance, provision of ventilation to the back of the modules and avoiding shading (CIBSE TM 25, 2000, pp.7). Facades can be affected by external shadows very easily, so site evaluation and shade modeling have to be done successful.

However, as the research will be mentioned only the façade integration systems, the investigation of the different integration systems on façade are in order shown below:

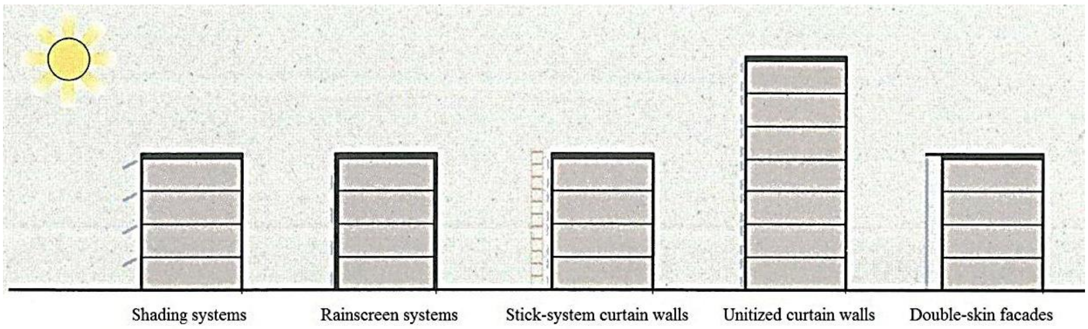


Figure 20: The options of PV integration into the facades (Roberts and Guariento, 2009, p. 45).

1.12.1 Use of Photovoltaic on Curtain Wall Systems

Curtain wall systems are the exterior wall which does not carry the floor or roof loads of the building. The dynamic loads are transferred to the structure of the building with the use of adjustable connection components and thus carried accordingly (Ilhan and Aygun, 2006). A curtain wall is designed to resist air and water infiltration, seismic forces, wind forces acting and its own dead load forces on the building (Roberts and Guariento, 2009, p. 48).

Curtain walls are typically designed with metal- framed glazing which provides architecturally aesthetic of the buildings. The curtain wall facades can be transparent, semi-transparent or opaque glazed with the benefits, such as day lighting (Ilhan and Aygun, 2006). PV modules can cover the entire façade surface. There are two types of curtain wall systems according to the system of fabrication and installation: stick system which is erected on site and unitized system which is prefabricated in factory.

1.12.1.1 Use of Photovoltaic on Stick System Curtain Wall

In the stick system, the curtain wall frame (mullions) and glass or opaque panels are installed floor to floor and connected together piece by piece. The horizontal transoms are fixed in between the mullions (Figure 7). The stick system curtain walls are mostly used for low-rise buildings. The scaffolding is used to the outside of the building. For this reason they are not recommended for high-rise buildings. The stick wall system is the less expansive per square meter and less complex replacement than the other curtain wall systems (Roberts and Guariento, 2009, p. 49).

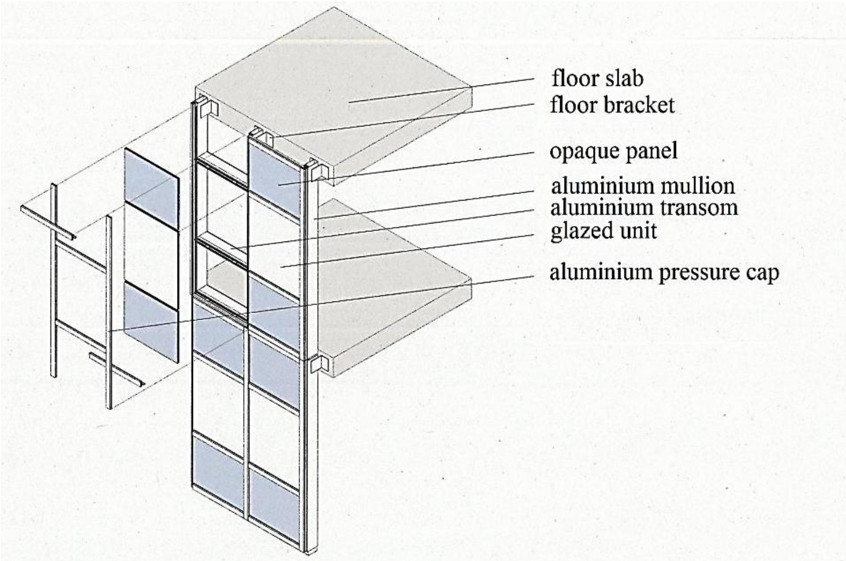


Figure 21: A stick-system curtain wall and erection process. (Roberts and Guariento, 2009).

PV installation on the curtain wall is the same as installation of glass panels. PV modules can be integrated in the vision area or in the spandrel area of the façade. The PV module which will be integrated into the vision area of the façade would be laminated onto a carrier glass and also it would be a double-glazed unit that is included low emissivity, solar control or high-performance coatings. On the other hand an opaque or semi-transparent solar laminate would be used to integrate PV modules into the spandrel area of curtain wall. The modules could be integrated into single or double-glazed units. Also face of an insulated sandwich panel can be used as an area to be integrated PV modules into the spandrel area of the curtain wall. The main issue is the wiring installation which is needed careful consideration relating the space requirements, access weathering performance etc. (Roberts and Guariento, 2009, p. 92).

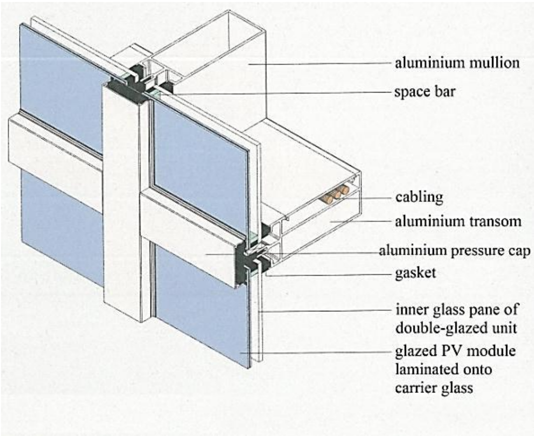


Figure 22: Detail of PV module and connections in a stick system curtain wall. The PV modules are laminated onto a carrier glass (Robert and Guariento, 2009).

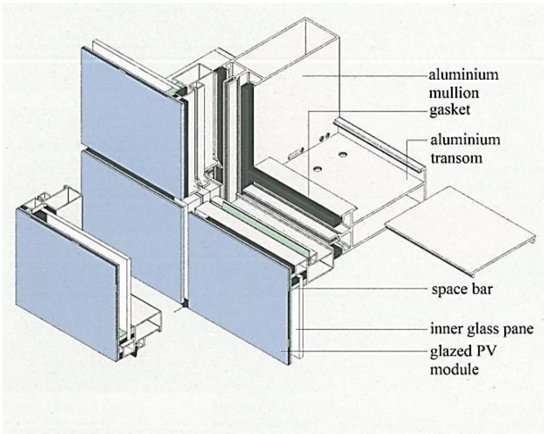


Figure 23: Exploded view of a stick curtain wall with PV module fixed with structural silicone (Robert and Guariento, 2009).

1.12.1.2 Use of Photovoltaic on Unitized System Curtain Wall

Unitized curtain walling reduces the construction time because it is prefabricated directly in the factory which it contains external weathering elements, insulation, vapor barrier, structural framing, fire protection, vision panels and internal finish (Roberts and Guariento, 2009, p. 100).The unitized system consists of storey high units of steel or aluminum framework (Vigener, PE. and Brown, 2009). It can be carried out from the floor slab inside the building so there is no needed external scaffolding (Roberts and Guariento, 2009, p. 100).

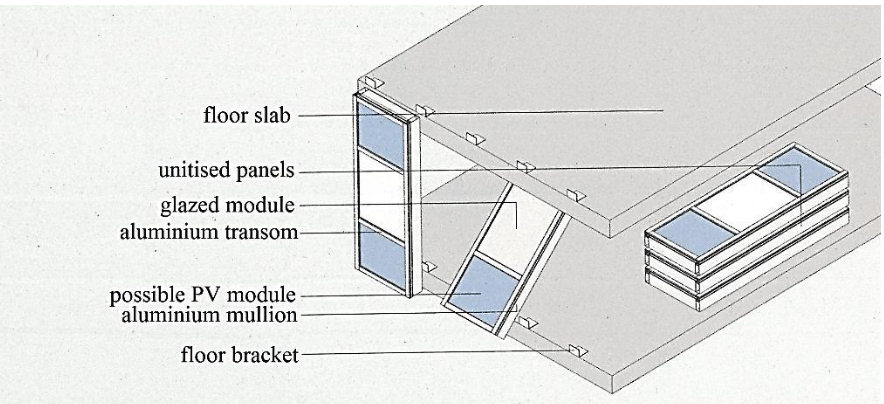


Figure 24: Unitized curtain-wall storage and the erection from inside (Roberts and Guariento, 2009).

PV modules can be integrated in the vision area or in the spandrel area or the façade as stick wall system and it might be single or double glazing and clear or opaque units. Also PV can be integrated into the prefabricated panels in factory. All the electrical wiring can be hided in the aluminum frames in the factory under the high control. As the stick system curtain wall, double glazed unit included low emissivity, solar control or high-performance coatings can be used when the PV will be integrated into vision area. Structural silicon should be used between joints and used as spacer because as with laminated safety glass, silicone and the outer weathering seals cannot touch to each other (Roberts and Guariento, 2009, p.103).

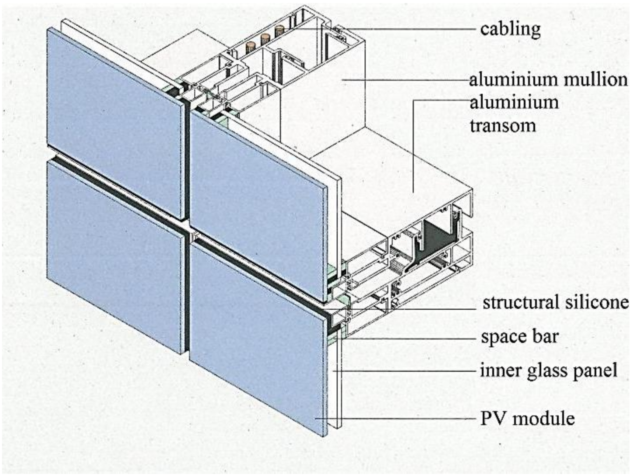


Figure 25: Detail of a unitized curtain wall system with PV modules in double-glazed panels. Cables are installed on the mullion (Roberts and Guariento, 2009, p.103).

1.12.2 Use of Photovoltaic on Double-skin Facades System

Double-skin façade is an envelope system which consists of two transparent surface separated by a ventilated cavity that can be natural, fan supported or mechanical (Saelens, 2002, Alibaba and Ozdeniz, 2011). The extra skin can improve energy efficiency, ventilation quality and insulation of buildings and also it can reduce cooling demand in summer and heating demand in winter (Bjorn J. *et al.*, 2003). Double skin façade reduce the negative effects of the external environmental such as wind pressure effect, heat, coldness, light, noise and etc.

PV panels should be integrated into the external façade to obtain the highest performance. Double skin unitized module installed into the façade generally, but it can be installed as a stick or unitized system. Therefor the integration of PV on a double skin façade is the same as stick and unitized system. External skin might be covered with single or double glazed PV modules. When the PV module will be integrated curtain wall, the double glazed unit could be used which equipped with low emissivity, solar control or high-performance coatings. Besides if PV modules will be installed into the spandrel area, an opaque or semitransparent solar laminate could be used. PV modules also can obstruct the solar gain to entre in the building and protect the internal environment. While PV modules are protecting building from the solar gain, they heat up and the efficiency of modules increase. Because of that reason the air within the cavity of double skin façade can be used as cooling devise for modules (Roberts and Guariento, 2009, p.122).

1.12.3 Use of Photovoltaic on Rainscreen Cladding System

Rainscreen façade systems consist of panels which are installed with an interspace from the building to allow for drainage and ventilation (Thomas, Fordham and Partners, 2001).The external layer of the wall provides major barrier to rain penetration and the ventilation cavity allows for evaporation of moisture vapour and drainage. Insulation can be installed within the cavity.

There are two types of the rainscreen systems: drained and back-ventilated rainscreen and the pressure-equalized rainscreen. Both systems consist of lightweight metal panel, often coated aluminum. The other coating materials are also available such as, stone, terracotta and concrete (Roberts and Guariento, 2009, p.122).

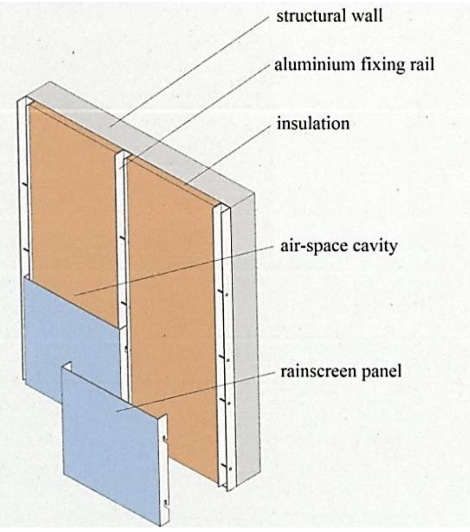
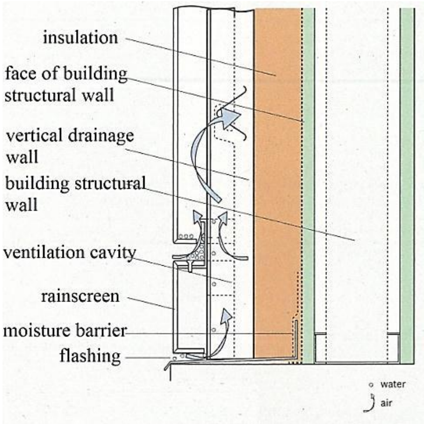


Figure 26: Detail of rainscreen cladding system (Robert and Guariento, 2009).



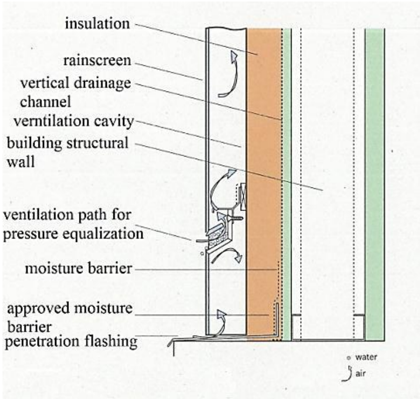


Figure 27: Vertical section through a typical horizontal joint detail in a drained and back-ventilated metal rainscreen (Robert and Guariento, 2009).

Figure 28: Vertical section through a typical horizontal joint detail in pressure-equalised rainscreen.
(Robert and Guariento, 2009).

The rainscreen systems are very suitable for PV integration. The ventilation cavity gives possibility to reduce PV temperature and increases enhancing performance. Also it provides space for cable routes (Thomas, Fordham and Partners, 2001).

The lightweight metal panels of the rainscreen can be adapted as a form of frame and the PV modules can be fixed into it. The modules can be framed with aluminum extrusions/stainless steel by edges and fixed to the cladding rails or proprietary brackets (Roberts and Guariento, 2009, p.122).

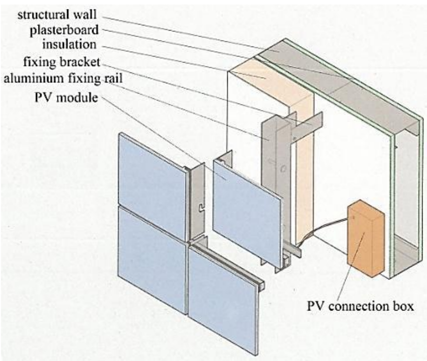


Figure 29: Detail of a rainscreen panel integrated with PV module showing electrical connections (Robert and Guariento, 2009).

1.12.4 Use of Photovoltaic as Shading Systems

PV also can be used as a shading glazing element to control natural daylight. This is the passive way to reduce solar gain and produce electricity at the same time. PV can be integrated into the façade after construction but, it is needed independent carrier construction systems or they can be integrated into the shading devices of the buildings. Also they might be adjustable shading devices which are known as louvres and can be arrange horizontally or inclined. PV modules can readily replace metal, timber or plastic louvres (Robert and Guariento, 2009). PV shading system divided into fixed and movable shading systems. Movable system provides more efficiency than fixed system, but it is also more expensive because of the mechanical systems.

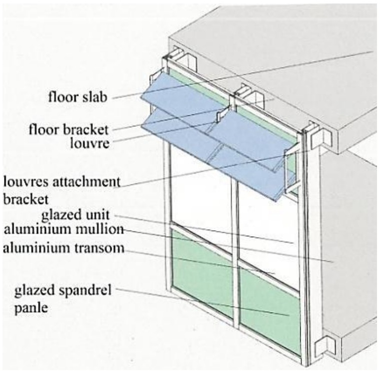


Figure 30: General features of a curtain wall with louvres (Robert and Guariento, 2009).

1.13 Examples of Buildings with PV Integration on Facades

In this section the buildings examples are categorized according to position of PV integration.

1.13.1 PV on Vertical Surface

Following four different buildings will be presented. All buildings have integrated PV on their vertical facades.

Figure 31: Vertical position of PV module (Thomas, Fordham and Partners, 2001).

Figure 32: Xicui Entertainment Complex; an example lighting pattern at night of the LED array (http://www.greenpix.org/download.php).

Discussion of building

Xicui Entertainment Complex was built in 2005 to house movie theatre and high-quality restaurant in the western part of Beijing, close to some of the 2008 Olympic Games sport facilities. In 2006 the old east façade which was done metal cladding, was replaced with a 60 x 33 m curtain wall. This wall is called GreenPix- Zero Energy Media Wall with an organic solution made of translucent PV modules and light emitting diodes (LED). About 2300 LEDs was fitted behind the translucent glazed module which powered by polycrystalline PV cells and it is the largest LED wall in the world at this time. During the day time, energy produced by PV modules is not used and exported to the national grid. During the night, the media wall takes the energy back to put through the LED in the form of bursting light. There are three different modules designed, low, medium and high according to the density and number of PV cells. The PV cells integrated on open-joint laminated glass with dimension 890 x 890 mm. the half of the glass have a 5° tilt outward to left or right to increase the power output. The openings on the backing wall admit of the daylight to the inside and increase the comfort. The PVs ventilated by using the rainscreen. The façade has special modular unit design with a convenient size for ease installation and shipping to the construction site. The mullions are connected to the horizontal steel trusses and vertical steel columns. The catwalks at each level are supported by trusses to provide easy access for maintenance and cleaning. All PV modules and LED fixture are supported by steel structure (Robert and Guariento, 2009).

Figure 33: The cladding structure detail of Media Wall (Robert and Guariento, 2009) and (http://www.greenpix.org/download.php).

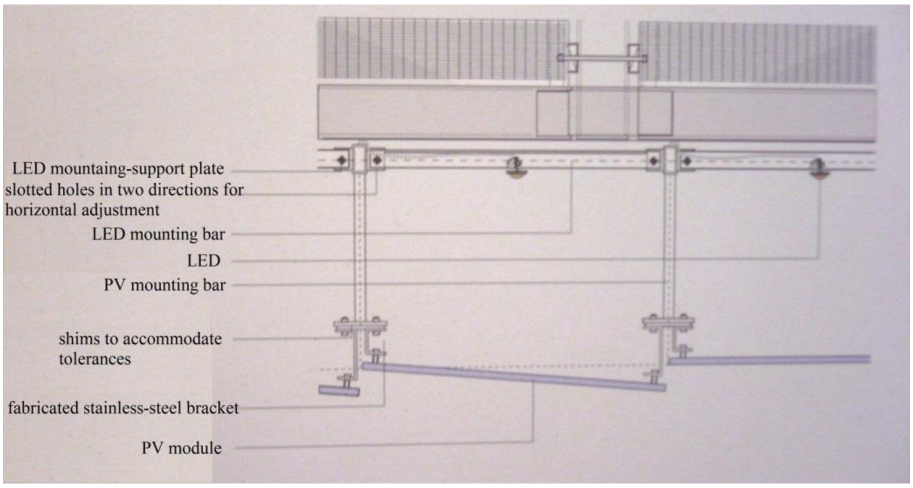


Figure 34: Plan detail for mounting LEDs and PV modules on the Xicui Entertainment Complex façade (Robert and Guariento, 2009).

Figure 35: Pompeu Fabra Library, Spain, Mataro. View the south of the PV on double-skin façade (Robert and Guariento, 2009).

Figure 36: Interior view of the Pompeu Fabra Library (Robert and Guariento, 2009).

Discussion of building

Pompeu Fabra Library one of the first cases of completely integrated photovoltaic systems into the building, was built in 1996 in Spain, Mataro. Different PV systems were used into the building such as semi-transparent polycrystalline silicon integrated into south side double-skin façade, monocrystalline silicon and amorphous silicon was installed on the roof skylight. The total area of the façade is 255 m² covered PV module and each module is 1, 2 x 2, 15 m cell with laminated between two glass panes. The horizontally spaced of 14 mm square cells allow daylight penetrate the building and thus reduce the use of artificial light. In summer double-skin façade with 150mm cavity allows mechanical/ natural ventilation and PV module are ventilated by incoming natural air. In winter, the air heated by the PV modules and it is mechanically moved to a heat-recovery system to send it inside the building. The overall PV/thermal system performance had an efficiency of 62% and the power output is 20,000 kWh/y (Robert and Guariento, 2009).

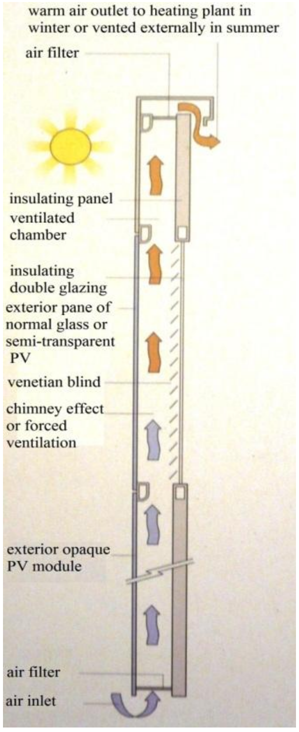


Figure 37: Ventilation scheme of the double-skin façade (Robert and Guariento, 2009).

Figure 38: The Co-operative Insurance Tower before and after PV integration http://www.monoroof.co.uk/single-ply-roofing-projects/roofing-projects-index.htm http://www.consumerenergyreport.com/2009/05/12/ten-of-the-greenest-skyscrapers-in-the-world/

Discussion of building

The Co-operative Insurance Tower was built in 1962 as a 28-storey office tower in central Manchester, UK. The building consists of three distinct parts: a podium at the base, office accommodation with glazed aluminum curtain walling and windowless concrete service tower on south-west side. The concrete service tower was covered with 14 million mosaic tesserae or tiles each 20 x 20mm. In 2003, the tower was needed to repair due to falling tiles. For this reason PV technology was chose to repairing by authorities. The polycrystalline silicon modules were chosen which were particular designed with dimension 1200 mm wide, 530 mm high with a frame thickness of 35 mm. For the integration, a cassette form was designed which consist of seven modules. Each cassette corresponded to the floor to floor with height of 3, 71 m. The wide south façade and narrow east and west facades were incompletely covered by 1200 mm cassette system PV modules. The less prominent parts were covered by blue powder-coated steel panels. A pressure- equalized type of rainscreen used for cladding concrete façade (Robert S., Guariento N.,2009).

Figure 39: The façade cladding of The Co-operative Insurance Tower (Robert and Guariento, 2009).

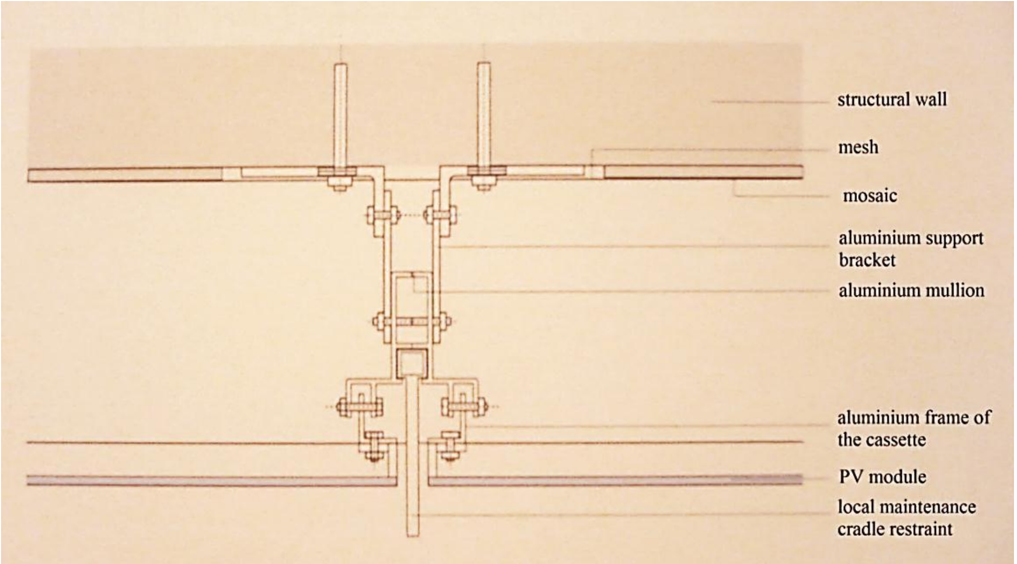
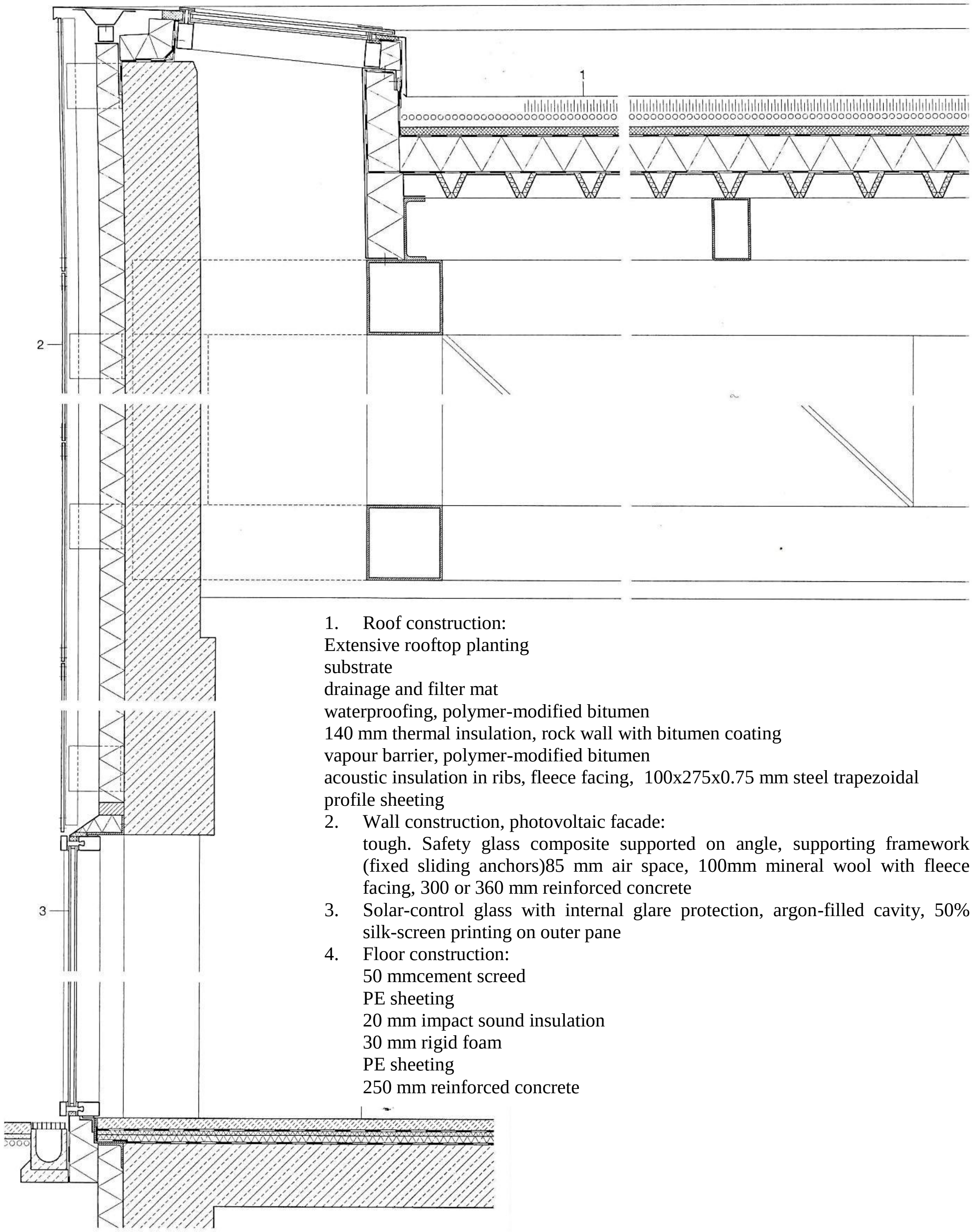


Figure 40: Cross-section of the bracket fixing system for attaching cassettes of PV modules to the wall of The Co-operative Insurance Tower (Robert and Guariento, 2009).

Figure 41: General view of the Sport Hall in Tübingen, Germany (Hegger, Fuchs, Stark and Zeumer, 2008).

Discussion of building

The multi-functional facility was built in Tübingen, Germany, 2004. The external concept of the building was designed with considering the necessities as well as internal volume in the concept. All four facades have additional functions, complete solar façade, outdoor climbing wall and half-pipe. While the green color is dominate on the building facades, shimmering green solar modules with white borders were installed on the entire surface of the south-west elevation to generate electricity as well as provide aesthetical aspect. The active solar areas are 525 m² and the electricity yield of PV façade min. 24 000 kWh annum. Also the system is grid-connected; the surplus of the electricity is exported to the national grid (Hegger, Fuchs, Stark and Zeumer, 2008).



1. Roof construction:
Extensive rooftop planting
substrate
drainage and filter mat
waterproofing, polymer-modified bitumen
140 mm thermal insulation, rock wall with bitumen coating
vapour barrier, polymer-modified bitumen
acoustic insulation in ribs, fleece facing, 100x275x0.75 mm steel trapezoidal profile sheeting
2. Wall construction, photovoltaic facade:
tough. Safety glass composite supported on angle, supporting framework (fixed sliding anchors)85 mm air space, 100mm mineral wool with fleece facing, 300 or 360 mm reinforced concrete
3. Solar-control glass with internal glare protection, argon-filled cavity, 50% silk-screen printing on outer pane
4. Floor construction:
50 mmcement screed
PE sheeting
20 mm impact sound insulation
30 mm rigid foam
PE sheeting
250 mm reinforced concrete

Figure 42: Vertical Section of the Sport Hall in Tübingen, Germany (Hegger, Fuchs, Stark and Zeumer, 2008).

1.13.2 PV Between Windows on Vertical Surface

Following three different buildings will be presented. All buildings have integrated PV on vertical facades with windows.

Figure 43: Vertical wall position of PV modules between windows (Thomas, Fordham and Partners, 2001).

Figure 44: Showing William Farrell Building, Canada, Vancouver.
http://www.perkinswill.com/work/telus-william-farrell-building.html

Discussion of building

This building is the eight-storey commercial building and it was built in 1940 to serve the city's telephone system and housed communications equipment as well as offices for technical and administrative staff. In 1999, the building was renovated and minimized environmental impact of the building. The new natural ventilation cavity was organized by removing the original brick veneer. The optimum temperature within the cavity controls by electronic temperature sensors. The air space is ventilated with funs which are powered by PV modules. In addition, the air flow behind the façade cools the PV array and enhances its performance. Two subarrays of custom-designed semi-transparent, polycrystalline silicon photovoltaic modules were installed into the northwest and southwest walls of the office tower’s new glazed curtain wall façade to powered ventilation funs during the summer. Only the specific part of the façade was covered with PV modules to meet the energy needs of the ventilation funs. The PV system power is 2.2 kWp. The PV modules were mounted as pre-manufactured sealed glazing units in the factory and the mullions were pre-drilled to accommodate the electrical wiring. The curtain wall mullions are used as wire raceways (Prasad and Mark, 2005).

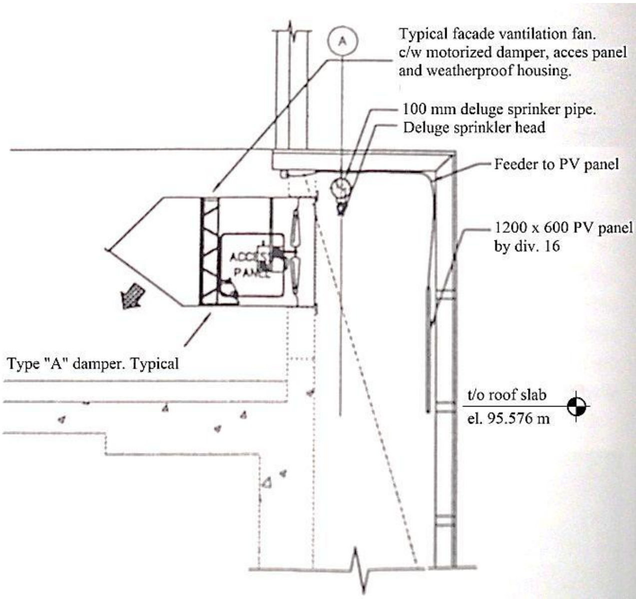


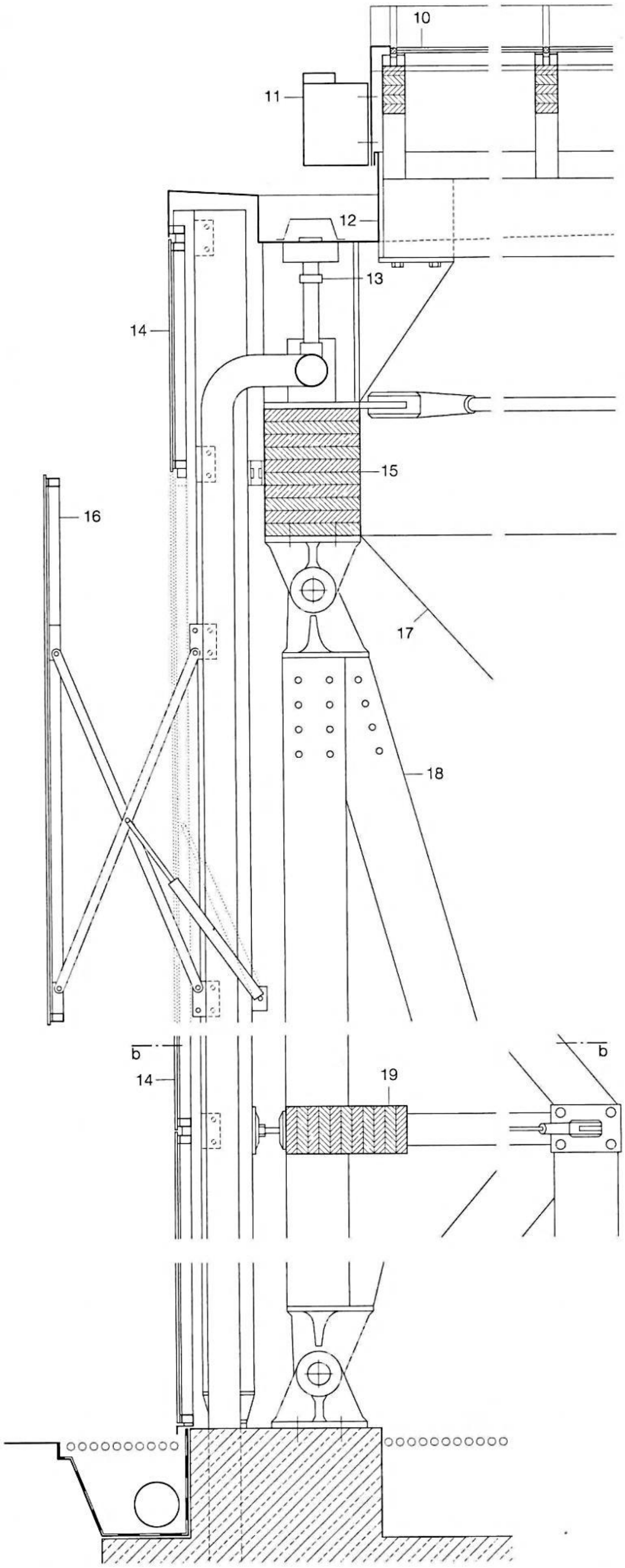
Figure 45: Architectural detail of fun / PV module layout of William Farrell Building, Canada, Vancouver (Prasad and Mark , 2005).

Figure 46: Air cavity of the structure of William Farrell Building, Canada, Vancouver http://www.perkinswill.com/work/telus-william-farrell-building.html

Figure 47: Front and back view of the façade of The Mont-Cenis Training Academy, Germany (Hegger, Fuchs, Stark and Zeumer, 2008).

Discussion of building

The Mont-Cenis Training Academy was built in Herne, Germany,1999. The academy was covered by glass structure with a footprint of 16 000 m² and microclimatic envelope was developed for passive solar energy gains. Photovoltaic glass modules covered about half of the roof and façade surfaces with the area 8400m². Individual photovoltaic modules were installed in curtain areas of the single glazing façade. In addition the PV glass modules provided sun shading and control the amount of incoming daylight. In order to realise a clouds effect, the module were installed in different densities. Also co-generating plant was included to produce energy, which uses the methane escaping from the former mine shafts. Total installation of PV for power generation is 1MW peak into the roof and façade, with 1200 kWh battery storage to cover peak loads, methane-fired 2, 9 MW co-generation plant (1150 kW elec. 4 + 1740 kW therm.) (Hegger, Fuchs, Stark and Zeumer, 2008).



10. Roof glazing, laminated safety glass:
    6 mm extra-clear heat-strengthened glass
    2 mm photovoltaic cells in casting resin
    8 mm heat- strengthened glass
11. Inverter
12. Galvanised steel gutter
13. Rainwater quick-drain system
14. Façade, single glazing:
structural sealant glazing on
    160 x 60 mm glulam façade posts
individualphotocoltaic modules in
certain areas
15. Glulam edge beam, 300 x 400 mm
16. Opening lights
17. Timber roof girder
18. Timber girder to resist wind forces
19. Glulam façade rail

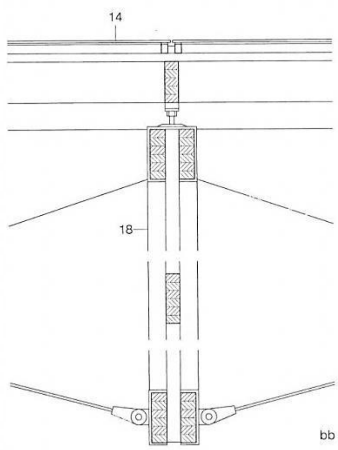


Figure 48: Vertical and horizontal sections of The Mont-Cenis Training Academy, Germany (Hegger, Fuchs, Stark and Zeumer, 2008).

Figure 49: Facade details of The Mont-Cenis Training Academy, Germany (Hegger, Fuchs, Stark and Zeumer, 2008).

1.13.3 Inclined PV Between Windows on Vertical Surface

In this section Mountain Refuge in Austria and Northumberland Building in UK will be presented which were PVs integrated inclined on vertical façade.

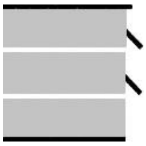
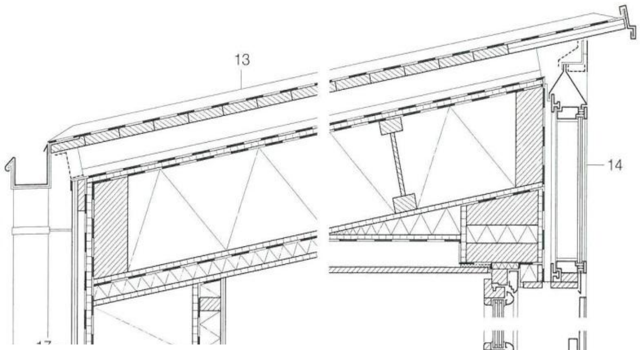


Figure 50: Inclined PV between windows on vertical façade (Thomas, Fordham and Partners, 2001).

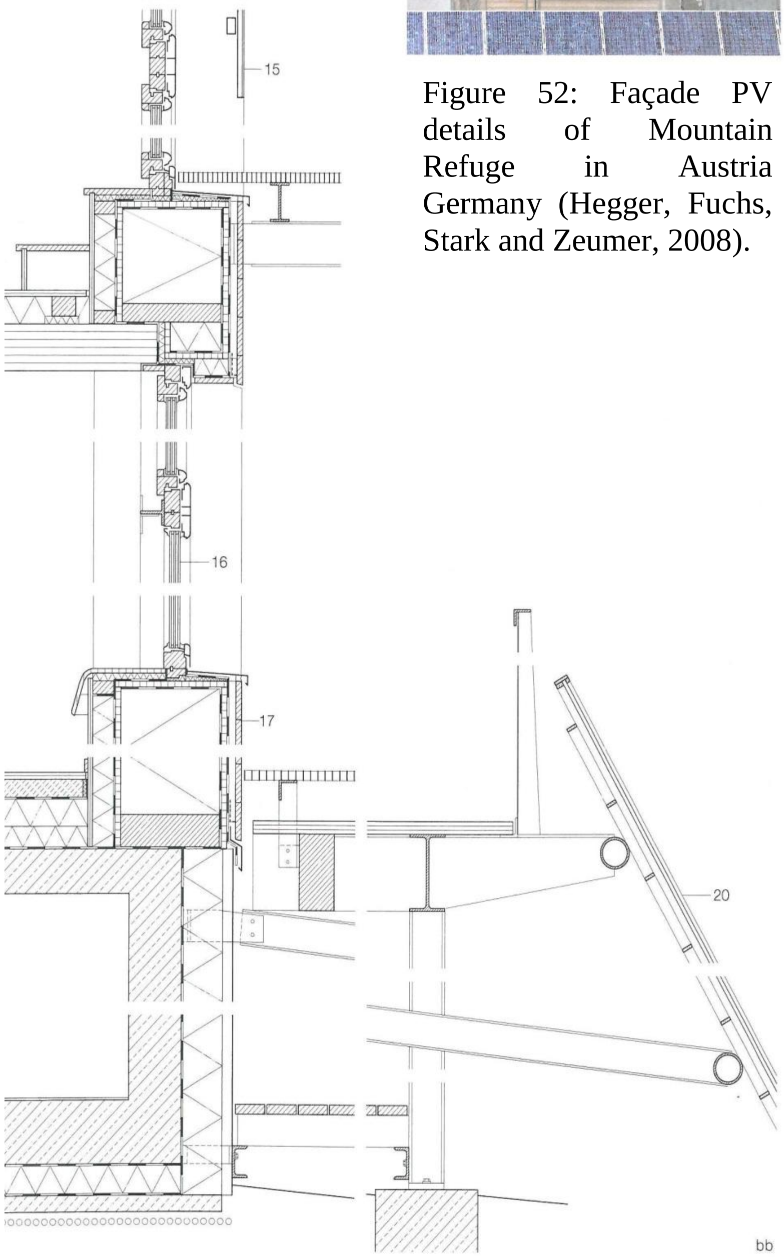
Figure 51: General view of Mountain Refuge in Austria (Hegger, Fuchs, Stark and Zeumer, 2008).

Discussion of building

In 2005 a self-sufficient mountain refuge was built in passive-house quality in the Austrian Hochschwab region in the Alps at an attitude of 2154 m. The design of the building was completed by considering extreme climatic condition. Photovoltaic module and solar collector for water heating were installed on the south elevation of the facade to utilize passive and active source of solar energy at the same time. Solar collectors integrated into the façade cover an area of 64 m^2 which provides all the hot water requirements. Photovoltaic modules can meet about 65% of electricity needs, which cover an area of 70 m^2 (Hegger M., Fuchs M., Stark T., Zeumer M., 2008).



13. Roof construction, U = 0.10 W/m²K:
Stainless steel standing seam roof covering
Separating layer, diffusion-permeable
30 mm untreated timber decking
100 mm ventilation cavity/battens, airtight membrane
16 mm wood-fibre board, diffusion-permeable, hydrophobic coating
airtight membrane
300 mm rock wool thermal insulation between timber members
18 mm OBS
vapour barrier, airtight PE sheeting
60 mm rock wool thermal insulation between battens
Fleece mat to retain fill
15 mm 3-ply core plywood, oiled/waxed spruce
14. Solar thermal collector
15. Translucent photovoltaic panel
16. Triple glazing: 52 mm, low E coating, argon filling, Ug=0.6 W/m²K, in wood/aluminum frame, Uw=0.8 W/m²K
17. Façade construction U =0.10 W/m²K:
19 mm larch decking
30 mm ventilation cavity/battens
airtight membrane
16 mm wood-fibre board, diffusion-permeable, hydrophobic coating
airtight membrane
rock wood thermal insulation 346/240 mm (lounge/standard) between timber studs
18 mm OSB
vapour barrier, airtight PE sheeting
80 mm thermal insulation/battens
15 mm3-ply core plywood, oiled/waxed spruce
18. Floorboards, oiled/waxed spruce
19. Ready-to-lay wood-block flooring, oiled/waxed ash
20. Photovoltaic panel on galvanized steel framework



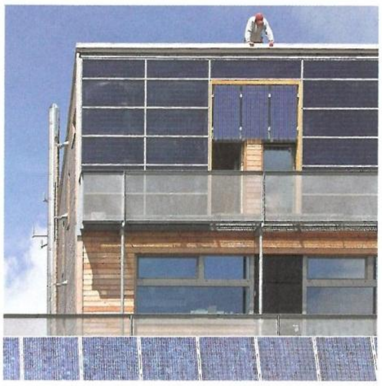


Figure 52: Façade PV details of Mountain Refuge in Austria Germany (Hegger, Fuchs, Stark and Zeumer, 2008).

Figure 53: Vertical section of Mountain Refuge in Austria Germany (Hegger, Fuchs, Stark and Zeumer, 2008)

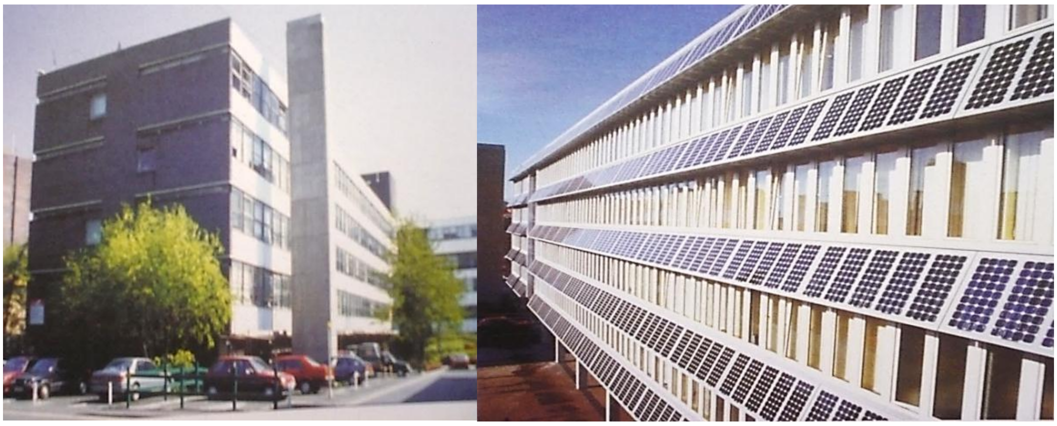


Figure 54: Northumberland Building, UK, Newcatle (Robert and Guariento, 2009).

Discussion of building

This is a Northumberland University building in UK, Newcastle which was built in 1960. It is four storeys building and with main elevations facing approximately north and south. The building had a concrete framed building with precast concrete cladding units before renovation in 1994. The entire cladding and window frames had to be removed. Photovoltaic modules with 3mm aluminum coated framework were installed to the south side of façade with 25° vertical inclination to provide better solar collection, particularly the low winter sun. Inclined design provided space between PV module a structure to ventilate back surface of PV and it was given the possibility for the installation of wiring trunking, junction boxes and monitoring equipment. Also this design gave chance to reduce summertime solar gain in the building. Monocrystalline silicon PV modules were used with the dimensions of 1180 x 520 mm and a nominal rating of 85 Wp. Five of these modules were assembled into a cladding unit and each cladding unit conveniently aligned with four windows unit. There were installed 465 PV modules which provide around 30% or the average electrical building load (Robert and Guariento, 2009).

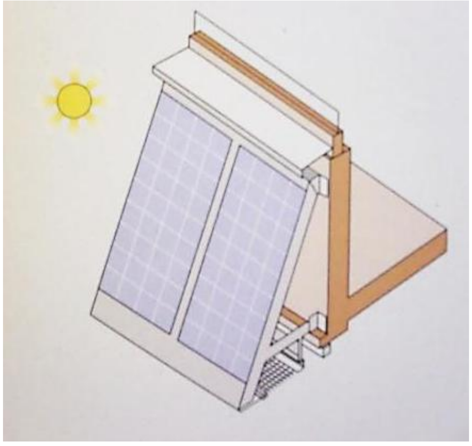


Figure 55: Schematic of 2 PV modules in the incline facade (Robert and Guariento, 2009).

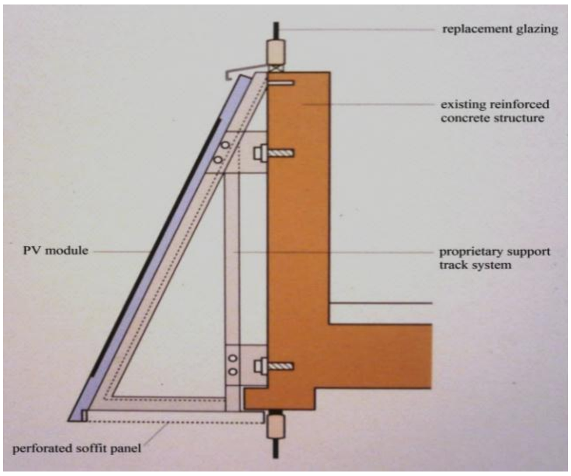


Figure 56: Vertical section through support inclined façade system (Robert and Guariento, 2009).

1.13.4 PV Between Windows on Inclined Surface

Integration of PV on inclined facades improves the output then the vertical facades.

Solar Office, Doxford International Business Park will be presented in this section.

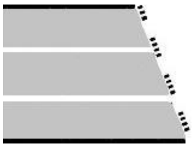


Figure 57: Inclined façade with inclined integrated PV (Thomas R., Fordham M. and Partners, 2001).

Figure 58: Solar Office, Doxford International Business Park, UK, Sunderland (Prasad D., Mark S, 2005).

Discussion of building

The office building was built in 1998, located near Sunderland in the northeast of England. The building has a vast solar façade which is the largest constructed in Europe to date. Monocrystalline silicon cells were integrated into the inclined façade with area 600 square meters of 100 x 100 mm opaque solar cells. 73 kWp arrays provides 55,100 kWh of electrical power per annum, which represents between one third and one quarter of the electricity expected to be used by the building over one year. The surplus of the electricity is exported to the national grid. The curtain wall façade sloped at 60° to the ground without compromising internal planning and it was faced south to provide maximum output of PV. There are a balance between maximization of PV power and maximization of daylight. Band of clear glazing have been introduced into the façade to ensure good internal light level. Also semi-transparent PV modules were chose where the cells that make up the module are themselves banded and graded to allow diminishing intensities of daylight to enter the interior. Nine different module designs were used, in terms of size, shape and cell destiny. The mechanical ventilation has been installed at the bottom and top of the façade to help encourage airflow and to keep the PV arrays cool (Prasad and Mark, 2005).

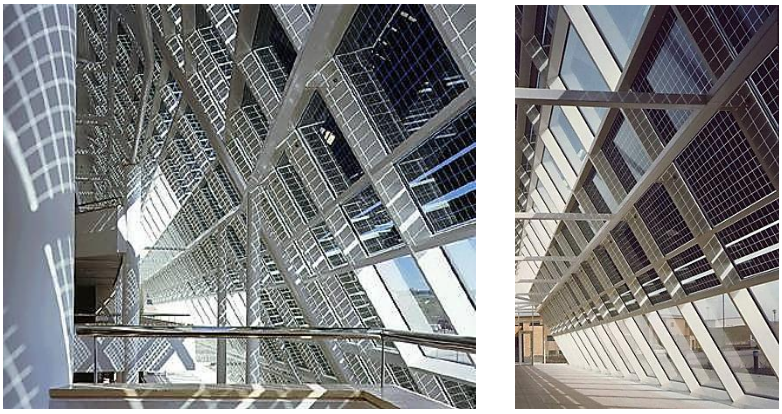
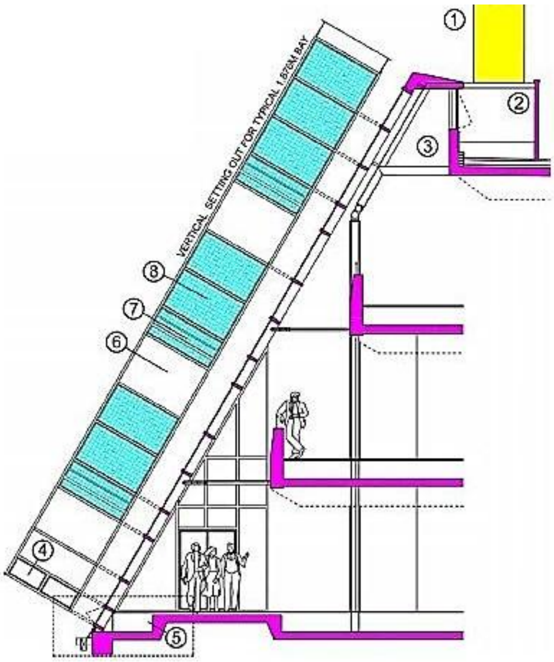


Figure 59: Top and bottom of the façade show that glass-glass modules how effect the interior spaces when the sun is out (Prasad and Mark, 2005).



1. Wind baffle
2. Wind trough
3. Top vent
4. Bottom vent
5. Service trough
6. Vision panels
7. Banded PV modules
8. Opaque PV panels

Figure 60: Detailed section through solar façade and single bay in elevation (Prasad and Mark, 2005).

1.13.5 Fixed Shading System

Integration of PV as a fixed shading system on vertical facades will be shown in this section. Energy Research Foundation (ECN) - Building 31 in Netherlands will be present below as an example.

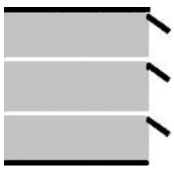


Figure 61: Fixed shading system on vertical facades (Thomas, Fordham and Partners, 2001).

Figure 62: General view and detail of PV shading system of Energy Research Foundation (ECN) - Building 31 in Netherlands.
http://www.iea-pvps.org/cases/nld_02.htm

Discussion of building

The Netherlands Energy Research Foundation (ECN), is the leading institute for energy research in the Netherlands. Building 31 is the General Laboratory of the Netherlands Energy Research Foundation ECN, was built in 1963 and the total area of building is 3530 m². Building was renovated in 1997 because of the several technical and thermal problems. PV system was installed on roof (72 kWp) and façade (42 kWp) to provide 30% of electricity demand. To reduce overheating and improve the indoor thermal comfort of the building, PV shading device system was decided to install on façade. The system was constructed as a separate façade, about 80 cm from the building, but connected to the main structure of the building, due to maintenance, accessibility and windows cleaning. As there are no high solar gain differences between fixed and movable system, the designers decided to install fixed system. After some calculation and computer simulations, four PV modules fixed as a lamella per floor with an inclination of 37° which is the optimal position for the Netherland. The lamellas are made by folded aluminum with dimension 840 mm wide, 3000 m long and it was covered three standard polycrystalline PV modules. However, the one lamella can be moved by occupants of the room at eye level in a horizontal position, in order to have a good outside of view. After 20 minutes or so, the lamella will automatically take the position of 37° again (Prasad and Mark, 2005).

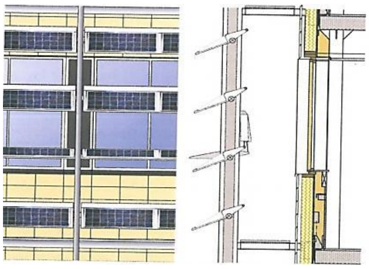


Figure 63: Detail and section of PV shading system on façade of Energy Research Foundation (ECN) - Building 31 in Netherlands (Prasad and Mark, 2005).

1.13.6 Movable Shading System

Integration of PV as a movable shading system on vertical facades will be shown in this section. Würth Solar CIS Factory in Schwabisch Hall, Germany and Extension to the Goethe School in Essen, Germany will be present below as an example.

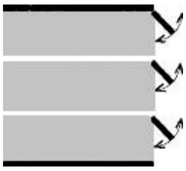


Figure 64: Movable shading system on vertical façade (Thomas, Fordham and Partners, 2001).

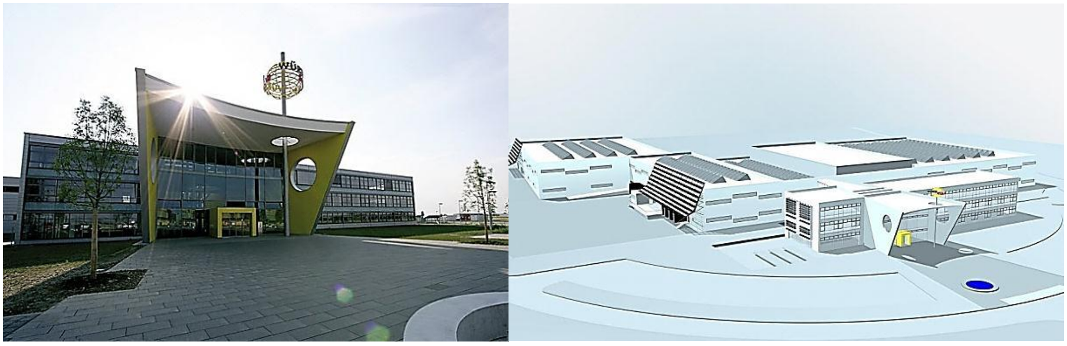


Figure 65: Würth Solar CIS Factory in Schwabisch Hall, Germany
http://www.fkn-gruppe.de/projekte/solarfabrik-cisfab_schwaebisch-hall-hessental__16.htm#

Discussion of building

Würth Solar CIS Factory is the first large scale factory in the world which is produce CIS thin-film solar modules, opened in 2006. The movable shading PV system was installed on some of the facades of the factory. Rotatable individual elements which have been made of thin-film PV modules were attached via lateral clasps to a steel substructure on the exterior layers of double skin façade, below the window level of each floor. The system can move according to position of the sun to provide maximum solar efficiency and protect façade from the sun. The solar modules have 20 percent transparency to supply visual contact between inside and outside (Lüling, 2009).

Figure 66: Opened and closed view of PV modules of Würth Solar CIS Factory's façade in Schwabisch Hall, Germany (Lüling, 2009).

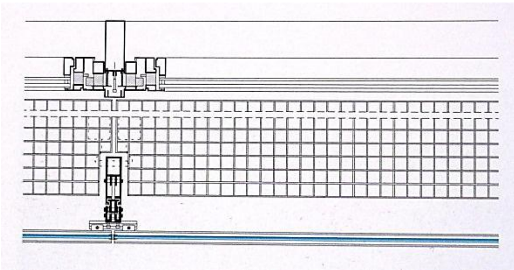


Figure 67: Plan section of the Würth Solar CIS Factory's façade in Schwabisch Hall, Germany (Lüling, 2009).

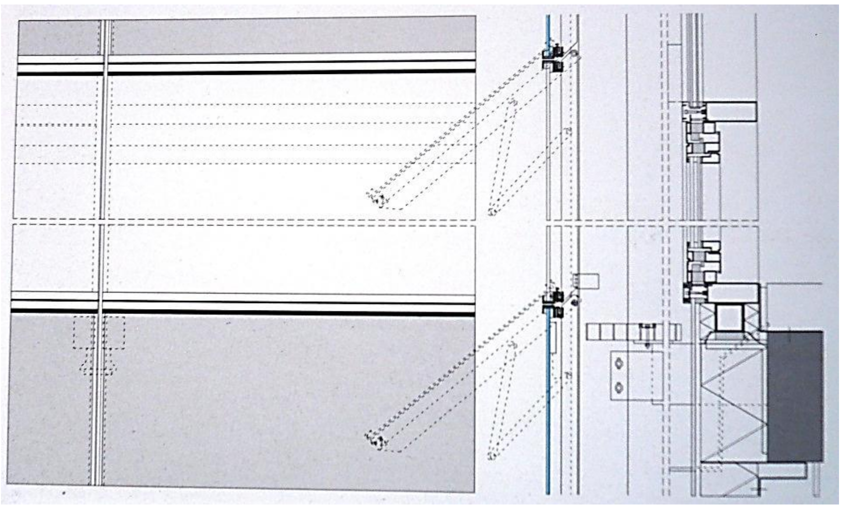


Figure 68: Wall section and detail of the Würth Solar CIS Factory in Schwabisch Hall, Germany (Lüling, 2009).

Figure 69: Extension of the Goethe School in Essen, Germany (Lüling, 2009).

Discussion of building

An extension science building was built in 2005 for Goethe School in Essen, Germany. The building has 12 classrooms for students. Movable shading system has been mounted as a self-supporting system at a small distance from the building façade.Polycrystalline silicon cells laminated between two glasses. These glass lamellas fixed between aluminum structures and wiring systems installed in this structure. The lamellas are point-fixed to a movable structure, are driven by a hydraulic system to track the movement of the sun (Lüling, 2009).

Figure 70: View from inside of extension of Goethe School http://www.ahnepohl-metallbau.de/

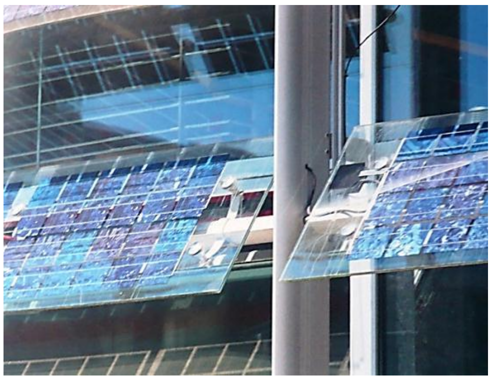


Figure 71: Detail of movable shading system of Goethe School (Lüling, 2009).

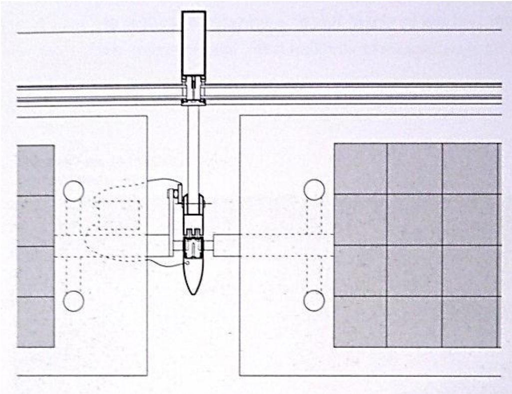


Figure 72: Plan section of the extension of Goethe School in Essen, Germany (Lüling, 2009).

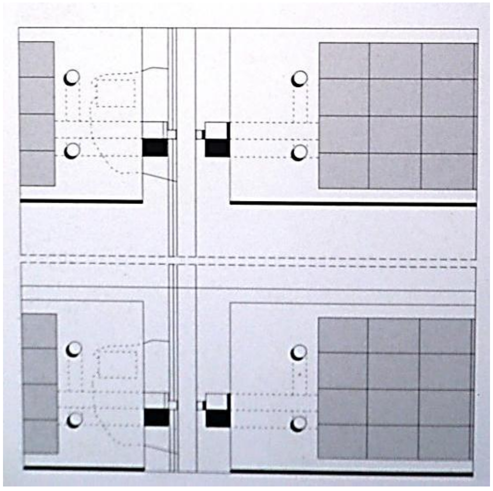


Figure 73: Wall section of the extension of Goethe School (Lüling, 2009).

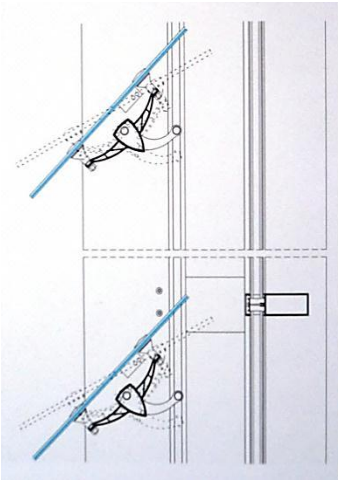


Figure 74: Detail of the movable shading system of the extension of Goethe School (Lüling, 2009).

1.14 Photovoltaic Systems

There are two types of photovoltaic systems for building integration; stand-alone (off-grid) photovoltaic system and grid-connected photovoltaic system. These systems will be evaluated in this section.

1.14.1 Stand-alone Photovoltaic System

This system mostly preferred in remote areas from national grid or it is also preferred in some countries where there is no necessary legal arrangements to connect PV arrays to the national grid.

Stand-alone PV systems consist of a solar generator which means PV modules, charge controller, an inverter, batteries, and cables. Photovoltaic cells generate DC (direct current) electricity. For this reason an inverter is need to generate DC electricity to the AC (alternative current) electricity at the level of the grid voltage which is standardly used in all of the world (Sick, 1996). PV arrays are connected to the batteries for storage the energy generated. Energy stored in the batteries during the day is used when energy generation are not enough or during the night time.

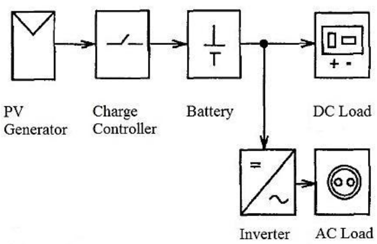


Figure 75: A scheme of stand-alone PV system (Sick, 1996).

1.14.2 Grid-connected Photovoltaic System

Grid-connected PV system is the most preferred system on domestic and industrial areas especially in developed countries. PV arrays are connected to the national grid and surplus energy generated sell to the grid. When energy production are not enough, it is bought from the national grid (e.g. during the night) (Markvart and Castaner, 2003). This system consist of a solar generator which means PV modules, an inverter, batteries, protection elements and cables (Eicker, 2003). There are no need batteries for energy storage in this type of PV system.

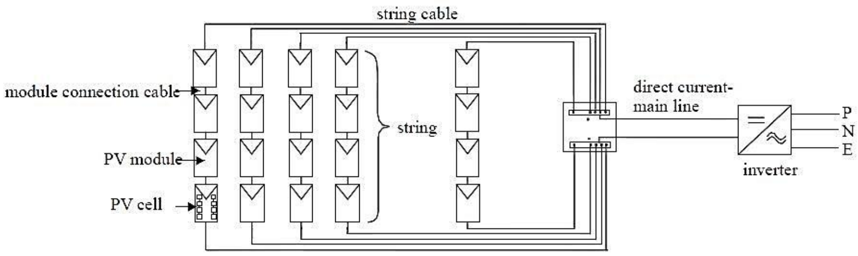


Figure 76: A scheme of grid- connected PV system (Eicker, 2003).

Chapter 2

ANALISES OF PHOTOVOLTAICS

2.1 Critical Evaluation of Photovoltaic Cells

In this chapter photovoltaic (PV) cells will be evaluated according to data collected in chapter one. Crystalline cells and thin-film cells were analyzed according to architectural view, indoor environment, energy producing and cost. Also this chapter included indoor environmental view of PV and their additional functions are discussed. Other aspects were examined by comparison them.

2.1.1 Crystalline Silicon Cells

2.1.1.1 Monocrystalline Silicon Cell

2.1.1.1.1 Architectural View

Nowadays PVs become popular with their aesthetical appearance on building facades apart from energy generation. Crystalline silicon cells are mostly used to produce PV modules. The first examples of PV modules which were mounted into the building facades are crystalline silicon modules.

Different shapes, dimensions and color options are available for monocrystalline silicon cells which allow different façade design (Table 1). These different cells are firstly developed for maximum efficiency and then for aesthetical view in architecture. Monocrystalline silicon cell has homogenous and clear appearance. Dark blue and black are standard colors for monocrystalline silicon cell. On the other hand different color options are available on the market such as; yellow, violet, turquoise, dark and light grey to meet different architectural demand. The shapes of monocrystalline silicon cells are square, semi-round and round. Today square type of cell is not preferred. Because when the square cells are fixed up on the module, there are too many empty spaces leaved between cells and it degreases the efficiency of PV module.

Also apart from standard crystalline modules production, custom-made module can be produced to meet the needs of design. Glass-glass crystalline modules allow controlling daylight by their transparency. Also these type of modules while prevent other to seeing interior from outside, insiders can see the outside by arrangement of semi-transparency of the cells.

2.1.1.1.2 Energy Producing of Monocrystalline Silicon Cell

Efficiency of PV cells changes according to cell manufacturing material. Monocrystalline silicon cell is the first type of PV cells and it is most efficient cell on the market. Generally PV cell types determine the module efficiency. So monocrystalline modules are most efficient modules, their degree of efficiency is between 15-17 % on practice.

2.1.1.2 Polycrystalline Silicon Cell

2.1.1.2.1 Architectural View

Today most popular PV cell on the market is the polycrystalline silicon cells. The appearance of this cell is different than monocrystalline silicon cell. For this reason it is very easy to distinguish between monocrystalline and polycrystalline silicon cells. Due to manufacturing process polycrystalline cells lose their characteristic crystal structure and do not appear homogenous like monocrystalline cells. It has mostly particles appearance.

Polycrystalline silicon cells are manufactured only square form due to way of production (which is shown in chapter one in Figure 3 and 4). Different color availability of these cells make possible to design different facades.

Same PV modules types can be manufactured by using monocrystalline and polycrystalline silicon cells. Costume-made, glass-glass modules can be produced by using polycrystalline silicon cells too.

2.1.1.1.2 Energy Producing of Polycrystalline Silicon Cell

Polycrystalline silicon cell was developed as an alternative to monocrystalline silicon cell. This cell is the second efficient cell on the market. The degree of efficiency of polycrystalline modules are between 13 -15 % on practice.

2.1.2 Thin-film Solar Cells

2.1.2.1 Architectural View

Thin-film solar cells are the other class of solar cells to produce PV modules. They have homogenous and smooth one-piece appearance with limited color availability. So they might be distinguished according to their colors. Each three type of thin-film cells has only own color; amorphous silicon is black-brown, CIS is black-grey and CdTe is black-green. However, colored glasses are used for the back-side of the modules to create different aesthetical view (Figure 75). Moreover CIS thin-film modules can be designed with silkscreen printed surface and it might be written anything on the module surface such as company name etc.

Figure 77: Façade and interior of Schott Office Building in Spain. http://www.pvdatabase.org/projects_view_details.php?ID=302

Thin-film solar cells cover whole of their carrier material while producing thin-film PV modules. So there is not any empty spaces on PV module like crystalline PV modules, they are full-surfaced.

Thin-film solar cells are very thinly than crystalline silicon cells. This positive difference makes thin-film solar cells more flexible. The suitable lightweight modules give more design freedom to the designers.

2.1.2.2 Energy Producing of Thin-film Solar Cells

Thin-film solar cells have been developed as an alternative of crystalline silicon cells. Different cell materials are used to produce thin-film modules and every type of thin-film modules has different efficiency. Amorphous silicon thin-film module is the most developed type of thin-film modules. However, it is not most efficient thin-film modules. The degree of efficiency of this type modules are between 6-10%. Thin-film CdTe modules have efficiency between 8-10%. CIS thin-film modules are most efficient with degree between 8-12 % and, today developers are trying to develop CIS thin-film modules. This type might be most popular thin-film modules in the future.

Table 2: Comparison of the PV cells

Type of PV	Degree of module efficiency	Market share	Area requirement	Energy payback period	Cell color availability	Cell diameters	Cell thickness
Mono crystalline silicon cell	15 – 17 %	approx. 30%	7 – 9 m²/kWp	approx. 5 years	Blue Black Violet Turquoise Dark and light grey Yellow	100 mm 125mm 150 mm	between 0,2 - 0,4 mm
Poly crystalline silicon cell	13 – 15 %	approx. 60%	7 – 10 m²/kWp	approx. 3 years	Blue Violet Brown Green Gold Silver	100 mm 125 mm 150 mm	
Thin film amorphous silicon cell	6 – 10 %	approx. 10%	14 – 20 m²/kWp	approx. 2 to 4 years	Black - brown	Variable	approx. 0,004 mm
Thin film CIS	8 – 12 %	< 1%	9 – 11 m²/kWp	approx. 1 to 2 years	Black - grey	Variable	
Thin film CdTe	8 – 10 %	< 1%	12 – 17 m²/kWp	approx. 1 to 3 years	Black - green	Variable	

2.1.3 Cost of Photovoltaics

The cost of PV installations may change according to PV system types (off-grid or grid connected), module type and other system components (inverters, cabling etc.) and the method of building integration. The PV modules are a significant amount of system cost. The PV modules are separated according to their cell types, size (number of cells), module types (laminates, glass-glass, framed, frameless) and efficiency. The amount of the cells and electrical yield of them hardly effected to the module cost. However, all of these variations determine the cost of PV module, consequently PV system cost.

The retail cost of PV modules changes every year. According to a market research which done in November, 2011 the lowest cost of monocrystalline silicon module is $ 1.28 per watt (€ 0.91 per watt), given by an Asian retailer. The lowest cost of polycrystalline silicon module is $ 1.31 per watt (€ 0.93 per watt), given by a US retailer. The lowest cost of thin-film module is $ 1.25 per watt (€ 0.89 per watt), given by a Germany based retailer (Solarbuzz, 2011).

Germany is the leader country on world market by producing and integrating PV modules. However, the costs of PV applications depend on size of the PV systems. According to national survey report of PV application in Germany which was submitted to the international energy agency (IEA) in 2010, the turnkey prices of typical PV applications are between 3200 €/kWp if the system size between 1-2 kWp and 2300 €/kWp if the system size more than 100 kWp.

The average of standard PV installation costs in Europe are about 3500 to 4000 €/kWp including system technology (Stark, 2009). If looking at the a case study in chapter one according to PV application cost; the solar office, Dexford international business park in UK has 600 m² inclined façade area with over 400.000 PV cells which produce 55.100 kWh of electricity per annum. This building was built in 1998 and cost of PV content including the monitoring system was about £ 450.000 (Prasad and Mark, 2005). In any case were paid a cost for a façade construction and the designers chose the PV application. If the cost of possible facade construction of that building will calculated and deducted from the PV façade cost, remainder cost will be the extra which was paid for PV facade and this extra cost was paid by energy producing of PV facades. So it is considered to PV façade might economic.

2.1.4 Environmental Control

Photovoltaic becomes component of building envelope with their additional functions including weather and noise protection, heat insulation, sun and daylight control.

All PV modules consist of multi-layers included laminated assembly and glass components. These components and wind-tight outer skin protect building envelope from external weather factors and heat protection can be contributed by insulated glass which is used for module manufacturing.

PV modules have good sound absorbing properties due to laminated assembly. The multi-layers body of PV can supply noise protection up to 25dB (Schuetze, Hullmann and Bendel, 2009).

The light control can be provided with arrangement of transparency of the modules. Glass-glass modules can be used to allow daylight into the building. The distance between PV cells determines how many light will be enter to the inside of the building. So daylight can be controlled by organization of the cells on PV modules. Also semi-transparent PV modules can be used. Furthermore PV might be used as shading devices to control daylight while producing electricity.

2.1.5 Comparison of Photovoltaic Modules on Other Aspects

As mentioned before crystalline PV modules are the most efficient, especially mono crystalline module. However, there are some reasons to prefer thin-film modules in spite of this difference in the market. The first reason is the lowest manufacturing cost. The pay-back period of the thin-film modules will be shorter than crystalline modules due to lowest cost. Another reason is that the overheating is less affective to the thin-film modules than crystalline modules. Especially CdTe thin-film module is least heated modules.

PV modules not only convert sunlight into the electricity, they also convert reflected light into the electricity. It means that the energy production can continue on cloudy weather too. Efficiency depends on amount of the reflected light. On the other hand thin-film modules are most efficient on cloudy weather. Apart from these reasons tiny structure provide flexibility in practice.

The low efficiency makes thin-film less preferable in spite of all these positive factors. In this context thin-film technology is still tried to develop by researchers and engineers. The percentages of use of thin-film modules will increase in coming years depend on the positive developments on this technology.

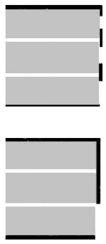
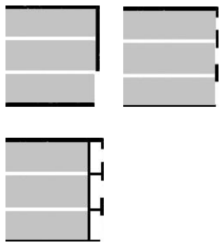
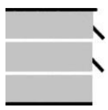
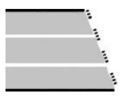
2.2 Critical Evaluation of Photovoltaic in Different Aspects

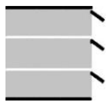
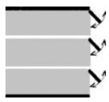
In this chapter photovoltaics were examined according to different aspects. Position of PV, use of PV on different façade systems, their installation details and fixing systems, their frame types were analyzed. Also the factors which affect to PV module efficiency were discussed. PV systems were compered and their features were examined. Finally, PV technology were discussed about its past, now and future.

2.2.1 Position of Photovoltaic on Building Façade

As shown in table 3 PV modules which are manufactured with various technologies, can easily adapted with different facades systems and offer a flexible design. However, the disadvantage of using PV on facades is less output compared with using it on roofs. For this reason PVs can be installed on facades in different ways to improve efficiency. PV modules should take sun rays perpendicular in order to improve output. So PV modules can be put incline position on vertical facades or they can be integrated on inclined facades. PV modules can be integrated between windows with inclined design which provides space between PV modules and structure to ventilate modules. Also wiring and other equipment can be installed on this space (Figure 52). However, complexity and detail of construction increased on this design option. On inclined façade option, before construction optimal angle of facade should be calculated to provide maximum yield from PV modules. This option is mostly optimal for glazing structure. Opaque or semi-transparent PV can be integrated on inclined façade to control daylight inside the building (Figure 56). On the other hand building floor area is not being efficient on this option.

Table 3: Comparison of the different facade integration of PV

POSITION OF PV	WALL SYSTEMS	CHARACTERISTICS AND COMMENTS	CASE STUDIES
PV on vertical surface 	Curtain wall systems	Opaque or semi-transparent and standard, economical PV are mostly preferred. But nowadays other PV systems, such as thin film PV are started use.	Pompeu Fabra Library in Spain. Sport Hall in Germany. William Farrell Building in Canada. The Mont – Cenis Training Academy in Germany.
PV on vertical surface 	Rainscreen cladding systems Double-skin facades	Rainscreen cladding and double-skin facades systems are very convenience for PVs. Ventilation gap gives opportunities to ventilate back surface of PV. Also cables and wirings are installed on this gap.	Xicui Entertainment Complex in China. Co – operative Insurance Tower in UK.
Inclined PV between windows on vertical surface 	Glazing or Rainscreen systems	Output of PV is higher. Construction detail and complexity increased. Provide shading on windows.	Mountain Refuge in Austria. Northumberland Building in UK.
PV between windows on inclined surface 	Glazing	Output of PV is higher than vertical surface systems. Provides good architectural appearance.	Solar Office, Doxford. International Business Park in UK.

Fixed shading systems 	Glazing	Provides architectural aesthetics. Efficiency of PV improved. Less daylight entrance to inside of building. Suitable for office or commercial buildings.	Energy Research Foundation (ECN) – Building 31 in Netherlands.
Movable shading systems 	Glazing	Provides architectural aesthetics. Efficiency of PV is more than fixed systems. Entrance of daylight is more than fixed systems. Most expensive than fixed systems because of mechanical systems.	Würth Solar CIS Factory in Germany. Extension of the Goethe School in Germany.

2.2.2 Use of Photovoltaic on Curtain Wall Systems

Curtain wall systems generally are used in prestigious buildings and other expensive cladding materials such as stone panels or stainless steel can be replaced with PV modules. Also PVs display building more prestigious, provides good aesthetical appearance and contribute to the economy while producing electricity. Numerous design options are available and there are possibilities to create combinations of opaque or semi-transparent PV panels with different module design (Figure 56). Design strategies depend on architects and amount of the light which is needed inside of the building. In curtain wall system wiring can be installed on aluminum transoms or millions carefully (Figure 76).

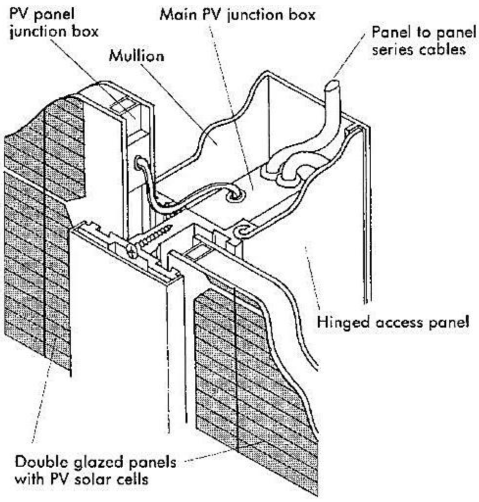


Figure 78 : Curtain wall detail (Thomas, Fordham and Partners, 2001).

2.2.3 Use of Photovoltaic on Rainscreen Systems

In applications leaving spaces between building and PV modules provide drainage and ventilation. Also the electrical wirings installed on this space. Rainscreen cladding system can give possibilities to easy installation of electrical wirings with its ventilation cavity. Moreover this cavity provides ventilation of back surface of PV modules (Figure 77).

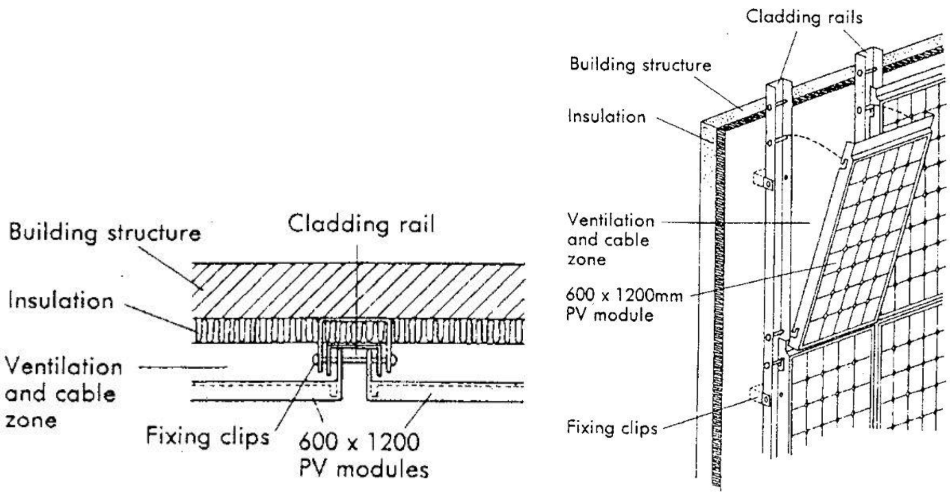


Figure 79 : Rainscreen wall details (Thomas, Fordham and Partners, 2001).

2.2.4 Use of Photovoltaic on Double Skin Facade System

The installation principles are the same as curtain wall systems. However, the ventilated cavity acts positively to the PV systems as rainscreen cladding wall system. The cavity between two transparent surfaces is bigger than rainscreen systems and it provides easy maintenance and good ventilation for PV panels. For this reason double-skin façade system is very suitable for PV installation especially where hot climate exists.

2.2.5 Photovoltaic as Shading Systems

Use PV as a shading system (shading louvres) on facades also improves efficiency and provides architectural aesthetics at the same time. Mostly glass – glass PV modules are used in this system. The modules can be without frame or framed. Aluminum or plastic frames are mostly used in terms of lightness and aesthetic. Also an economic point of view there is not so much differences between PV shading systems and other shading systems with elements such as metal or glass (Planning and Installing, 2008). For this reason PV shading systems can be attractive than before. On the other hand the PV shading systems cannot provide good shading compared with standard louvres. The tilt and space between PV shading systems are set according to sun as well as set to do not make shadow to each other. For this reason the space between PV modules is bigger than standard louvres so the result of this light transmittance will much more than standard louvres. Also fixed systems which are set according to summer sun with high angle will not be efficient for the winter period.

2.2.6 Photovoltaic Module Frames

PV modules might be with or without frames. Both framed and frameless modules are used on building facades and also they are used as a shading system. Mostly aluminum frames are used for framing. The advantage of the frame is the easiness of mounting. PV module can be mounted to the building with help of frame. So the frames can be used as support and fixing point. Also frames provide additional protection of PV modules. On the other hand framed modules are very recognizable and this sometimes impairs the aesthetic. For this reason thinner frame in the same colors (dark blue, black etc.) as the cells are used to improve visually. However, frameless modules are preferred for aesthetical value. Simple and elegant appearance can be achieved. Also the disadvantage of the aluminum frame that the reflection of sunlight, can be avoided. Rain can be clean the module effectively and snow can be slip from the module surface easily. Frameless modules are mounted into the special profile system.

2.2.7 Installation Details of Photovoltaics on Building Facades

Architectural design and façade design of any building determines how much the building is aesthetic. So buildings and their facades effect to the city silhouette and beauty of it. However, there are different module fixing and details which are effected to the façade appearances also city silhouette. These different fixing or installation details give possibilities to design various facades. The details of installations change according to module types. Framed and frameless modules are installed by using different techniques. Usually PV modules are installed to the facade with help of their frames. If PV modules are frameless, firstly auxiliary carrier profiles are mounted to the façade and then PV modules installed to them. Glass-glass PV modules might be framed or frameless too. If they are frameless fixing systems resemble the other glazing systems. Glazing beads, pressure plates fixing systems are used for framed modules. Structural sealant glazing, two-sided linear fixing and point fixings systems are used for frameless modules. The table below shows which type of modules fix by using which type of fixing system. Shading PV systems installed into the facade with same techniques as facade PV module installations. Usually frameless PV modules are used for PV shading system and, point or linear support fixing generally used for façade installation.

Table 4: Module types and their installation systems

Type of installation systems	Framed module	Frameless module	Laminate module	Glass-glass module
Glazing beads	x			x
Pressure plates	x			x
Structural sealant glazing		x	x	x
Two-sided linear support fixing		x	x	x
Point fixings		x	x	x

2.2.7.1 Glazing Beads

Glazing beads is the most common form of windows construction. PV modules can be fixed to the façade with windows too. Glass-glass PV modules can designed with windows and can be used on unopened part of windows. The important thing is timbers must be first drilled for the cabling. This system is suitable for small applications. Because only some part of glass facade are covering with PV modules (Appendix B, figure 81).

2.2.7.2 Pressure Plate Glazing

Framed glass-glass modules can be installed on curtain walls with pressure plate glazing wall framing system. In this systems glass-glass PV panels are installed from the exterior of the buildings as a standard glass sheets with supporting frames. Sealing of all joints in the framing ensure water tightness. The important thing when using PV element that supporting structure must be narrow and flat. Cells must be not covered or shaded by frames. For this reason distance between cells and structure must be taken into the account before the design and installation. Also horizontal support structure must be not impeding snow from sliding off on slopping facades. The other important thing is that any electrical contact with metal façade must be avoided. The cabling must be installed on shortest path away from the glass rebates (Appendix B, figure 82).

2.2.7.3 Structural Sealant Glazing

This façade glazing as an alternative to pressure plate glazing is usually used on unitized system curtain wall. In structural sealant glazing system glass elements adhered directly to the carrier steel or aluminum frames with silicone. These carrier frames behind the glass sheets or PV panels, create facades as frameless and without any support. It brings a simplicity and aesthetic to the facade. Also shadow of carrier frames is eliminated. For this reason structural sealant glazing is very suitable of PV module installation. Frameless glass-glass or laminates PV modules can be installed with structural silicon glazing (Appendix B, figure 83).

2.2.7.4 Two-Sided Linear-Support Fixing

Frameless laminates or glass-glass PV modules can be installed with this fixing system on the upper and lower edges with glazing bars. PV panels screwed to the façade supporting structure. This fixing system is used on rainscreen cladding facades. Also it is suitable for PV modules due to rear ventilation (Appendix B, figure 84).

2.2.7.5 Point Fixings

Point fixing is the most common fixing system for glazing facades. Glass-glass PV modules can create glazing facades with energy producing by using point fixing systems. There are different types of point fixing systems. Point fixing bolted glazing is the most popular type of point fixing. The PV glass panel is perforated and assembled by using special bolts and brackets. Stainless steel spider fittings mostly used on bolted glazing (Appendix B, figure 85). This is an expensive solution of point fixing systems. Also it might create shadow on PV modules by their fixing members. For this reason other point fixing is developed by companies as an alternative. Frameless glass-glass PV modules can fixed by using undercut anchor on the module back. The supporting glass is drilled (10 or 12mm, not all) before tempering which is using on module back. Anchors, metal dowels and plastic are put on drilled shape (Appendix B, figure 85). Star-shaped solution might be used as a support structure for hanging. The PV modules supported without penetrating to the structure and all fixing elements are hidden to the back of PV modules. So, smooth façade surface can be created by using this fixing method (Appendix B, figure 86). Another alternative of point fixing is clamp fixing system. The advantages of clamp fixing is the prevent PV module from damage of drilling. This system does not require penetration in the glass. Frameless PV modules (opaque or glass-glass) are fixed to the façade with helping clamps to the rail system supported structure. The elimination of glass penetration make this fixing system economic than others and it provides smooth and aesthetic façade without any frame (Appendix B, figure 87, 89).

2.2.8 The Factors Affected the Efficiency of Photovoltaic Modules

Electrical efficiency of PV modules relates how many sun’s energy is transformed into the electricity. There are some principles which affect to the modules output: the types of cells, overshadowing, overheating, tilt and orientation and annual average daily insolation.

- The types of cells: The module efficiency mostly depends on the selection of cell types. Every PV cell has own degree of electrical efficiency due to their manufacturing methods and structure (see section 1.3). Crystalline silicon modules are more efficient than thin-film modules. It means that the integration area requirement of thin-film modules will be more than crystalline silicon modules to achieve the same energy output.
- Overshadowing: Shadowing is one of the important factor that influences the module output. PV module should not be under any shadow. Even partial shading from trees or lamp post can affect significantly to the amount of electricity generation. Also the shadowing effects of neighborhood buildings are important. Building facades are affected more sensitively from shadows than other parts of the buildings such as roof. For this reason the distance between buildings should be calculated and possible shadowing effects of other buildings should be taken into the account.
- Overheating: PV modules convert some percentages of the sunlight to the electricity, not all of them. So the large majority of the energy converts into the heat and when the cells temperature get up to 25 °C, the output of electricity will be lower. Overheating is the common problem of most PV modules. On the other hand thin-film modules less heated in comparison to crystalline silicon modules. The result is every type of modules should be

ventilated. At least very slightly space between structure and PV module should be left for air flow. In this context the rain screen cladding and double-skin facades are very suitable for PV modules where very hot climate is exist.

- Tilt and orientation: As mentioned in chapter 1, tilt and orientation of the façade is one of the important part of design process. PV modules should be integrated on facades with true orientation to get maximum solar irradiation. However, the angel of the modules may not set for maximum solar irradiation due to verticality of facades. So as the alternative PV modules are integrated incline on facades (see section 1.9.3) or on inclined facades (see section 1.9.4) and PV shading devices (see section 1.9.5) are designed to increase module output of facades.
- Average daily insolation: As sunlight is the only energy source for PV modules, output power will be more at long sunny days. So in northern hemisphere south areas will be more suitable for installation of PV modules.

2.2.9 Comparison between Stand-alone and Grid-connected Photovoltaic Systems

Today grid-connected PV system is mostly preferred due to the economic reason. In developed countries the network load can be reduced by using grid-connection PV system. PV systems can be generated electricity more than used during the day. It is possible to obtain a gain by selling this surplus electricity to the national grid. At the same time there is no need to store extra energy and batteries for storing. The batteries bring extra cost and extra area for installation is needed. The warm weather can affect to the performance of the batteries, so they should be installed on cool place such as in basement. However, the long cables between PV modules and batteries cause of the energy losses. For this reason using stand-alone PV system on high-storage buildings cannot be suitable. On the other hand using stand-alone PV systems in remote areas from national grid might be more economical to bring electricity from national grid.

2.2.10 Comparison of Photovoltaic Technology in 2000 and Now

Developed countries have been started take precaution about environmental problems at the end of 90s. The interest in renewable energy sources have increased through fossil fuels which are exhausting and damaging to the environment. Especially since the beginning of 2000s photovoltaics is started to use on building envelop effectively. Firstly PVs were mounted on existing buildings and this was caused poor aesthetical appearances on city silhouette due to lack of technical experience. Today PVs are considered with building as new construction materials in design process. Therefore PVs are become whole with design and created distinctive architecture. Photovoltaic modules use as a cladding material on facades that is most visible part of the buildings, add aesthetic to the modern architectural designs. In first applications stand-alone PV system was preferred. However, nowadays grid-connected PV systems are used intensively in countries where the legal regulations were made. Façade integration of PV is mostly preferred on commercial and high-rise buildings. Using PV as a cladding material on building facades to appear building more prestigious and the companies exhibit environmentally sensitive manner. In addition, the various support and incentives are provided by the government for the companies who interested in photovoltaic technology.

2.2.11 Looking to the Future

Photovoltaic technology has become one of today's most interesting technologies and it is bound to be one of the popular solutions of the future. Especially in recent years photovoltaics have been engaging by architects and they have been started to use as a building material on building envelope. In later years, photovoltaics which produce electricity from endless solar energy will be an indispensable building material with developing new generation photovoltaic cells.

In the future it will be possible to encounter frequently with photovoltaic modules on building envelopes all over the world, especially in countries which have high solar radiation.

The governments supports are significantly increase the use of photovoltaics in developed countries. Also over the next decade is expected to drop cost by 50-60%. In 2020 it is projected to be 60% of the market share will be crystalline cells and 40% of the market share will be thin-film solar cells. The efficiency of thin-film solar cells might be more efficient in the future. Despite this crystalline cells will be most efficient cell the near future. For this reason the large majority of the market will be crystalline cells. However, new generation of solar cells is expected to enter to the market in 2015 at a much smaller percentage. Although the cost of these cells is very low comparison with crystalline and thin-film solar cells, they have very low efficiency. In this context studies are still in progress (Cubukcu, 2011). These positive developments will be made photovoltaic more attractive in the future.

Chapter 3

CONCLUSION

Interest of sustainable and green architecture has increased day by day. In this context, photovoltaic technology have been started to keep important role in architecture. Building integration of PV changes building position from energy consuming to the energy efficient. Building facades should protect occupants from outer weather influences while providing architectural aesthetic. PV systems can be integrated into the building facades as multi-purposes. Also PV integration into the facades combines passive and active architecture. At first glance PV integration into the facades may not be seemed efficient due to verticality and orientation. On the other hand PV modules might replace with other cladding materials and protect building from weather influences, noise and control daylight, like convention cladding materials while producing electricity at the same time. Different glass types give PV modules this multi-functionality. Also thermal insulation and security requirements can provide as well. Furthermore the large surface of the facade gives possibilities for large scale installations. On the other hand today, roof integration still is most popular than façade due to efficiency factor.

The technic of PV integration into the facades is not complicated. There are similarity between PV modules installation and other cladding materials installation. PV modules can be installed into the facade by using standard curtain wall cladding systems or standard glazing systems like point fixing or structural sealant glazing etc.

Rainscreen facade system is the most suitable for the PV modules due to ventilation cavity between structure and PV modules. This cavity should not be less than 15 cm for sufficient ventilation. If the cavity will less than 15 cm, efficiency will decrease up to 10%. Especially ventilation of PV modules should be taken into the account in hot climate countries. Because every 5 °C increases of cell temperature will cause a 2.5 per cent decrease module output.

Framed PV modules are installed by using their frames as a support material. Frames provide convenience in practices but somehow may not be aesthetically good. Framed PV modules might be laminates or glass-glass modules. Laminates are opaque modules and they are used where daylight is not needed. If standard crystalline PV modules installed into the facade, aesthetical dark blue appearance is acquired. Thin-film modules have darker appearance like dark metal cladding materials. Also frame of the modules can be same color with PV modules to minimize the perceiving of frames. However colored PV modules sometimes are preferred due to aesthetical reason, although their efficiency is lower and cost higher than standard modules.

Frameless PV modules both glass-glass and laminates are preferred at least as framed PV modules. Frameless modules need a support structure for hanging them. Glass-glass PV modules are installed like glazing and same installation techniques are used. Construction companies are trying to develop new fixing techniques. For example clamp fixing system developed an alternative to other glazing systems. It is architecturally aesthetic and economic at the same time. Also shadowing by frames is problem avoided. A common important things that to be considered for all type of the installation systems, electrical cables and wirings do not contact with supporting elements of facades like stainless steel or aluminum, all the electrical systems should be isolated.

Use of PV as a shading system is a good invention finding by architects and designer. Especially this is a good solution for glazed office buildings or university buildings which effected from high amount of daylight. PV modules can be used as shadow component and produce electricity at the same time. The construction of PV as a shading system is not complicated too. Usually point fixing is used to mounting of glass-glass PV modules to the support structure. Furthermore the PV modules can be set to the sunlight easily and getting more output than sloped facade.

The modules which are produced from crystalline silicon cells still most preferred on the market, especially polycrystalline silicon and it will continue to be most popular for a while. Many companies try to develop thin-film modules day by day, but they still less efficient although less expensive. In the coming years thin-film modules and other types of PV modules will be developed, and cost of technology will be decreased. Thus PV technology will be more preferred as a clean, green and sustainable energy sources with their multi-functional characteristics for buildings.

In economic terms PV applications can be most cost effective than other non-glass cladding materials, such as stone or metal panels. The highest cost of the PV system is the glass base materials namely PV modules. When price comparison will be done between PV system and other cladding materials to be considered that which type of PV module will be replace which cladding material. Furthermore it should be note that PV systems pay back the cost after 3 or 5 years by producing electricity and they can work more than 25 years without giving any problem. Since PV systems are not complicated systems, they have not need regular maintenance. So PV integration to the building might be cost effective where used high quality non-glass and glazing material for façade cladding. Considerable green value of the PV should take into the account too.

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APPENDICES

Appendix A

1. Manufacturing detail of crystalline modules

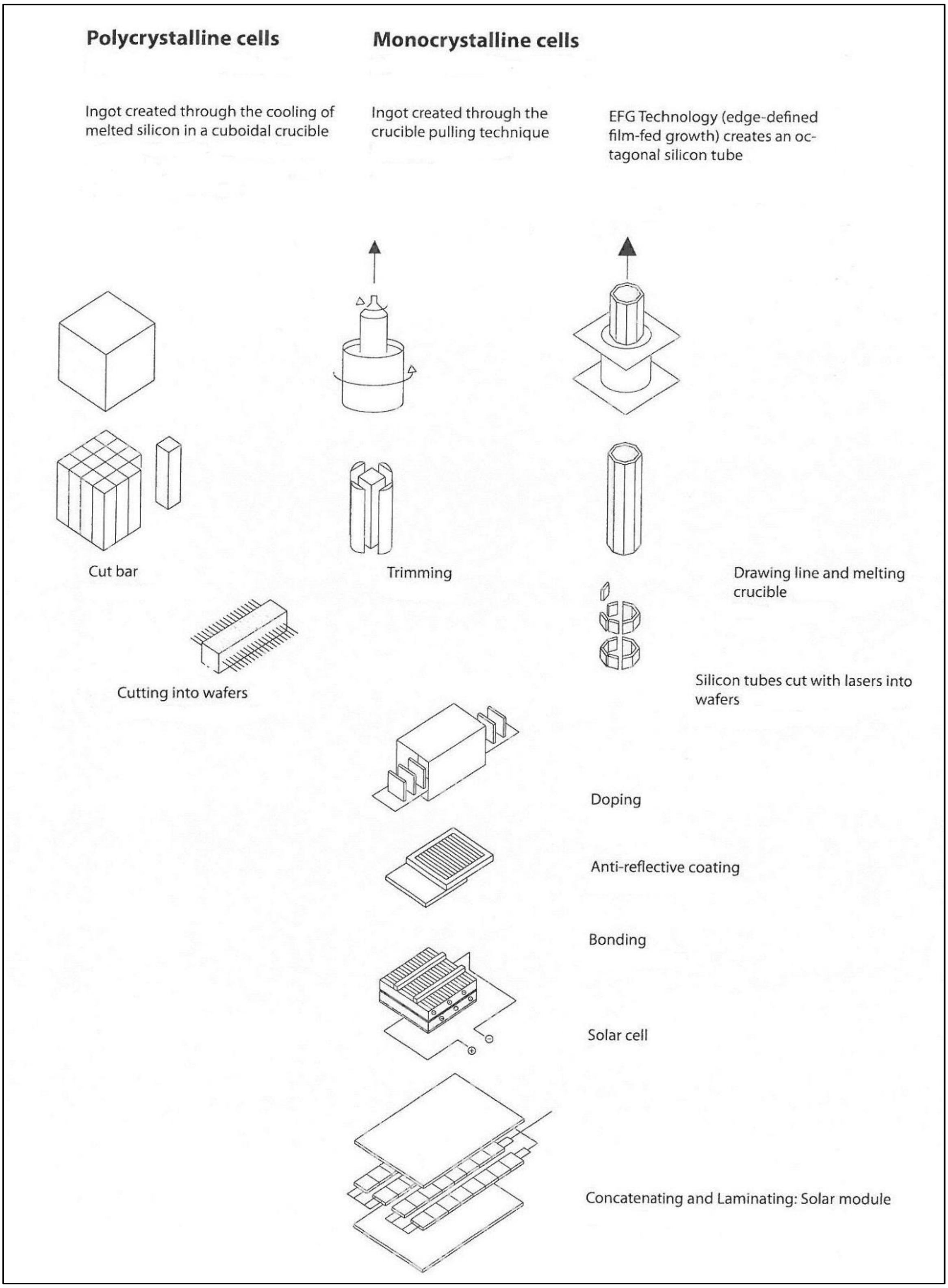

Figure 80: Scheme of manufacturing detail of crystalline modules (Lüling, 2009).

2. Manufacturing detail of thin-film modules

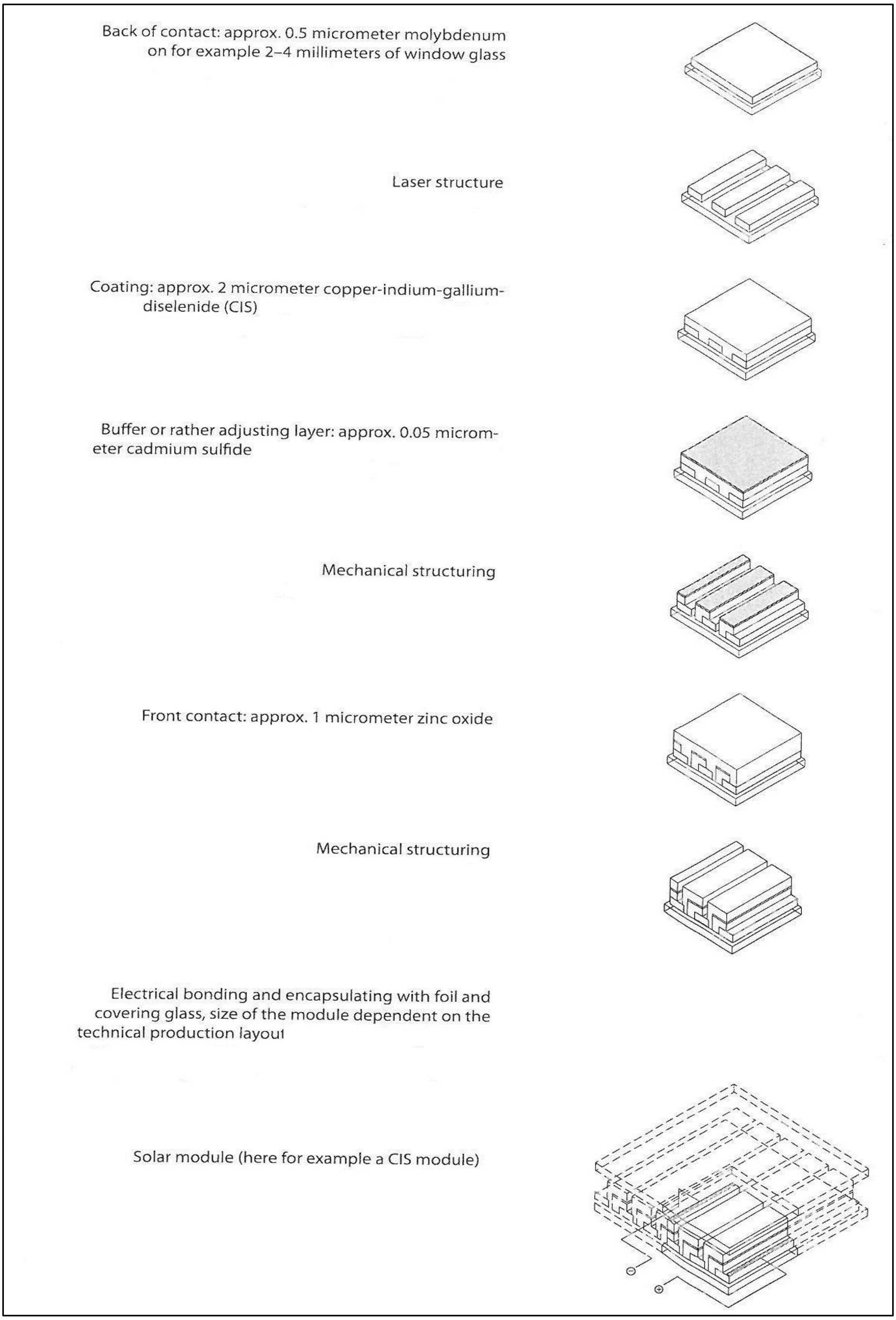

Figure 81: Scheme of manufacturing detail of thin-film modules (Lüling, 2009).

Appendix B

1. Installation Details of Photovoltaic on Building Facades

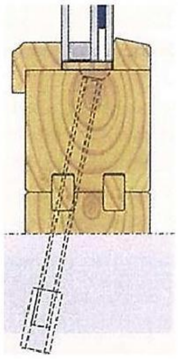

Figure 82: Section glazing beads and cable ducting on timber frame (Planning and installing, 2008).

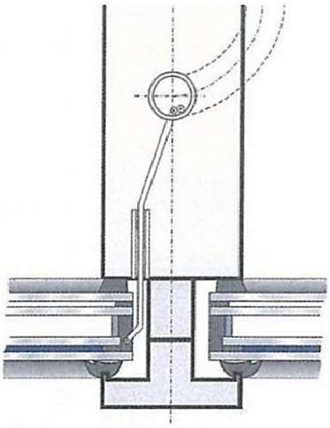

Figure 83: Detail of PV module fixing by using pressure plate fixing on mullion-transom stick system and cabling in the profiles (Planning and installing, 2008).

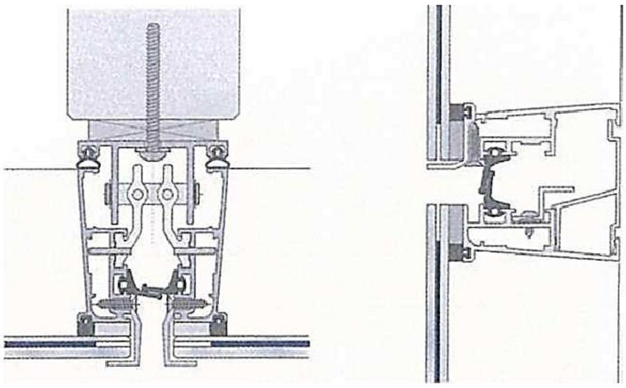

Figure 84: Detail of glass-glass PV module fixing with structural sealant glazing (Planning and installing, 2008).

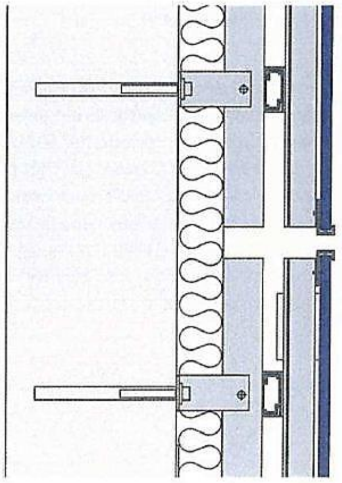

Figure 85: Façade section of two-sided linear-supported fixing (Planning and installing, 2008).

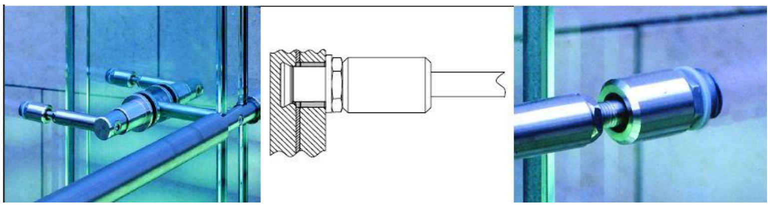

Figure 86: Detail of bolted glazing (point fixing) (Fischer Company, 2006).

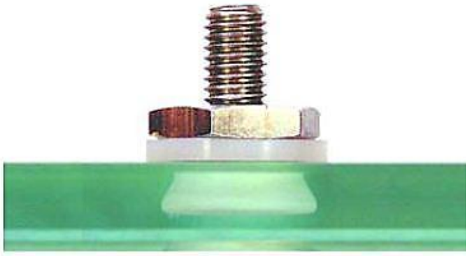

Figure 87: Detail of anchor in glass which is used for PV mounting with point fixing on the module back (Fischer Company, 2006).

Figure 88: Detail of PV installation with point fixing and star-shaped as a support structure (Fischer Company, 2006)

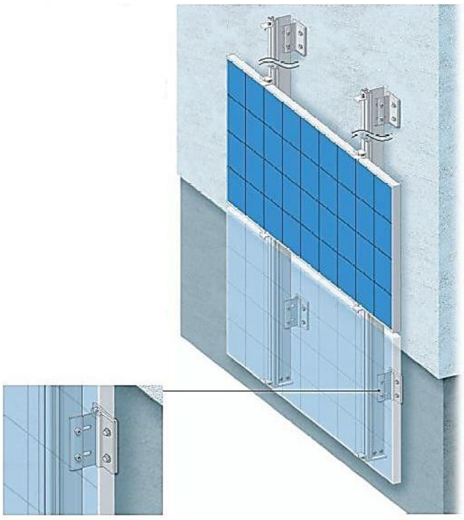

Figure 89: Detail of clamp point fixing on façade (Schüco company, 2011).

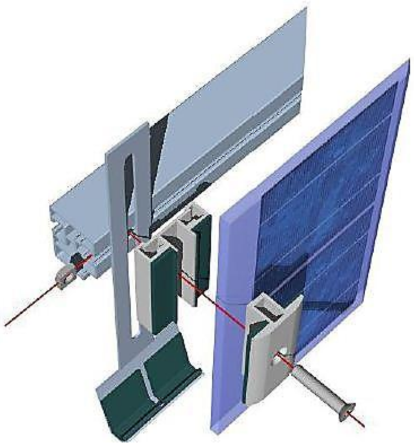

Figure 90: Detail of clamp point fixing on façade (Becker, Grottke, Helm, Schuster, 2005).

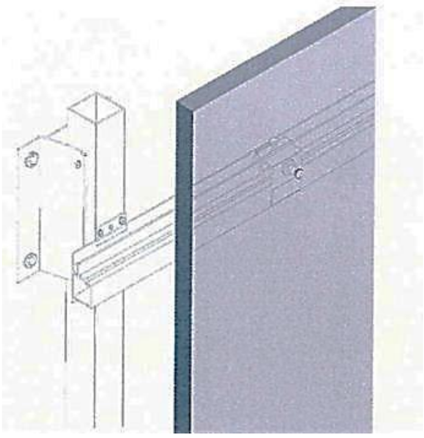

Figure 91: Substructure with hanger solution of PV module point fixing (Planning and installing, 2008).