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Integration of Photovoltaics in Modern Building Facade: A Comparison of Photovoltaic Integrated Façade

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Abstract: **The use of alternative energy in buildings is getting to a critical stage in the construction projects with the need of having sustainable building designs with energy efficiency and increasing the use of renewable energy sources in constructions i.e. wind energy, solar energy and heat pumps**

Photovoltaic systems have become an alternative in the energy efficiency of buildings, for this reason less energy consuming buldings using solar energy as an alternative in designs are increasing, and tends to provide solutions to energy problem and also lifecycle maintenance in building projects.

Photovoltaic systems integration in buildings have increase the performance through the utilization of some building components for energy generation i.e. use of standing solar panels , integration of PV cells in windows, roofs and facades of building .

For this reason, this paper will compare some modern building with photovoltaic integrated facades, explore the method of application of photovoltaic cells on façade, efficiency of the generation and a critic of the general use of photovoltaic integrated facades. Result of this work will encourage designers on specifications and integrations of such methods on their building projects.

Keywords: **Photovoltaics, Facades, Energy, Integration, modern Buildings.**

1. INTRODUCTION

Photovoltaic is a semiconductor which generates electricity directly from sunlight, since the discovery of photovoltaic effect in 1839. These systems are usually based on silicon and are used to convert solar radiation into electricity. Electrons which gain energy become free and they create electric circuit and then exposed voltage is converted to electrical current. Direct current (DC) is generate when the de vices are exposed to sunlight. The electricity generated is either converted using inverters to run AC appliances or used directly in DC appliances.PVs available are monocrystalline silicon, thin film silicon called amorphous silicon (A-Si) and polycrystalline silicon (Thomas et al., 2001).

According to the World Commission on Environment and Development, sustainable development is "*development that meets the needs of the present without compromising the ability of future generation to meet their own needs*" (WCED 1987)

The world is increasingly debating the climate change issues due to the emission of CO_2 gas which has a Negative environmental impact. . The existing buildings are responsible for use of large amount of energy for lighting, heating, cooling and use of various energy run equipment's mostly powered by fossil energy. As alternative, use of renewable, passive energy which is free and abundant can replace fossil fuel and as such brings about an eco-friendly environment. In addition, depending on the conventional energy i.e. hydro-electric, thermal energy sources is no longer enough considering the rapid increase in world population. It is estimated that global energy use will increase from 13.5 TW in 1990 to 20.3 TW in 2025 (Boyle G. 1996).

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In recent years, the European Union, the United States and other advanced countries have issued the design or construction cases of zero-energy building which have minimal energy consumption. Goals for the implementation of zero energy buildings are analyzed and proposed both local and international stages. For example, a new target has been set by the European Union to ensure the minimal consumption of energy by all buildings from 2020. They are termed as "zero-energy building". (Oracova 2014)

The cell is the smallest part of the photovoltaic. A single PV cell has a capacity to produce energy between 1 and 2 Watts. When 36 numbers of cells are combined together, a module/panel is created. An array can be created with the combination of several modules and panels. PV cell shape can be seen rectangular, circular and square. Each cell's dimension can be 10x10 cm (Sev, 2009)

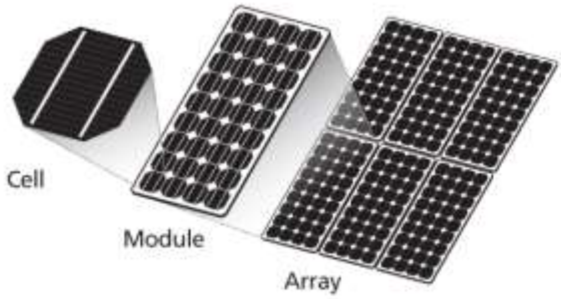

Fig 1.1: PV Cell, Module and Array (Samlex Solar, 2009)

2. ADVANTAGES AND DIADVANTAGES OF PHOTOVOLTAICS

ADVANTAGES:

- PV can be enlarged easily depending on the capacity needed by the users.
- 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.
- 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.).

DISADVANTAGES:

- Cost of first installation is expensive.
- When there is no sunlight, at night, there is no electricity generation. Therefore energy produced in the day time is needed to store and area the area for storage.
- 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).

3. PHOTOVOLTAICS ON BUILDING ENVELOPE

The integration of Photovoltaic technology in architectural building has brought a great change in sustainable building design. Buildings large surfaces gives opportunity to generate energy through the integration of the PV system. These systems can be integrated either in the façade, roof of the building or can be used as shading devices to control daylight. This building integrated systems provide savings in materials and electricity cost, reduce the use of fossil fuel and add architectural aesthetics to building.

However, façade integrated photovoltaics plays a great role as a city outline, due to the high visibility of the installation. The large building façade can be utilized by being covered with PVs to provide high output. The use of PV on the façade

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can give protection to the building from excessive solar radiation and also used as an alternative to convention material which only provide aesthetics and covering to the building.

Verticality of the façade reduces the efficiency because it is usually sub-optimal in orientation. However modules might be installed inclined in the vertical facades to improve the energy generation efficiency

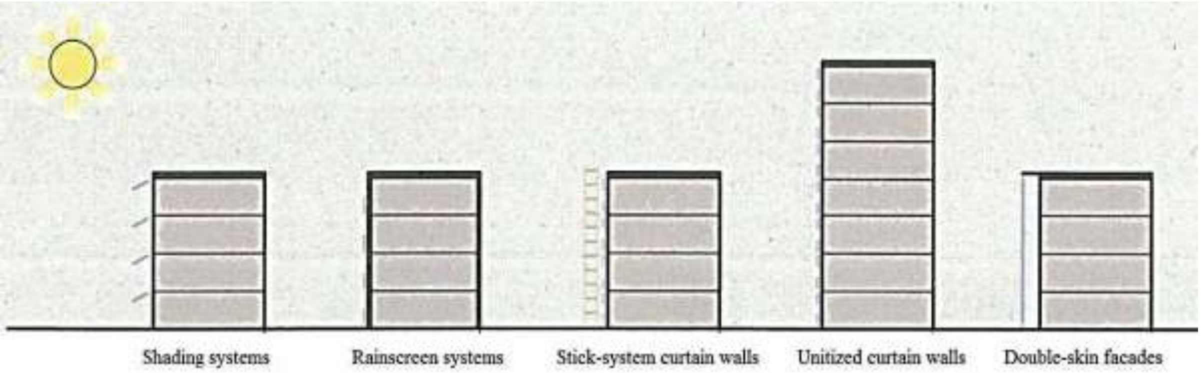

Fig. 1.2: The options of PV integration into the façade (Roberts and Guariento, 2009)

4. USE OF PHOTOVOLTAIC ON CURTAIN WALL SYSTEMS

Curtain wall systems are external vertical building walls composed of transparent, semitransparent or opaque, thin and light glazed components, dynamic loads are transferred to the structure of the building with the use of adjustable connection components and thus carried accordingly (Ilhan and Aygün, 2006). There are two types of curtain wall according to the system of installation and fabrication, the unitized system which is prefabricated and the stick system which is assembled on site.

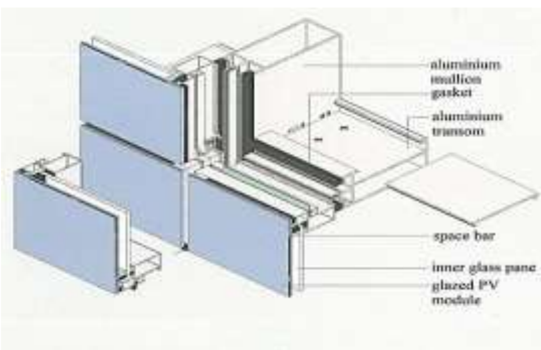

Fig 2. Exploded view of a stick PV curtain wall (Roberts and Guariento, 2009)

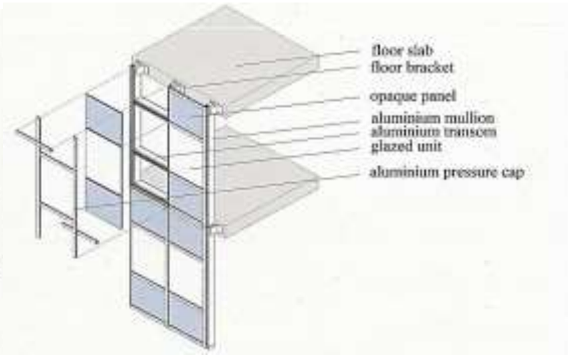

Fig 3. PV Stick system and erection process (Roberts and Guariento, 2009)

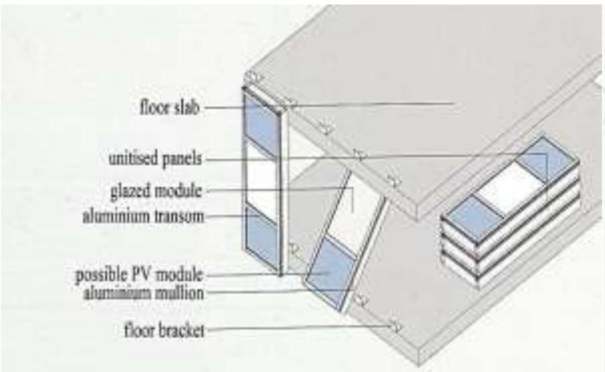

Fig .4: Unitized PV system and erection process (Roberts and Guariento, 2009)

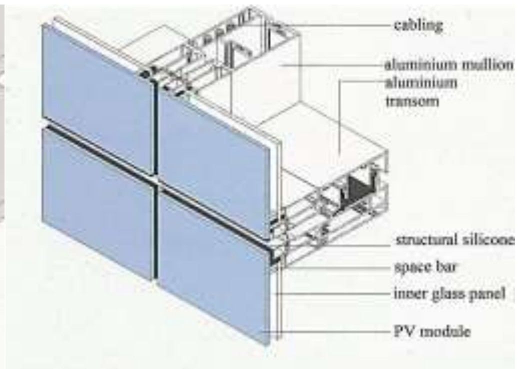

Fig.5: Exploded view of unitized PV system (Roberts and Guariento, 2009)

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5. USE OF PHOTOVOLTAIC ON DOUBLE-SKIN FACADES SYSTEM

Double-skin façade is a building 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, ventilation quality, energy efficiency and insulation of buildings and also it can reduce heating demand in winter and cooling demand in summer (Bjorn J. *et al.*, 2003). Double skin façade also serve as an acoustic barrier in the control of noise and also wind pressure.

Photovoltaic panels are integrated in the outer skin of the façade to obtain highest performance

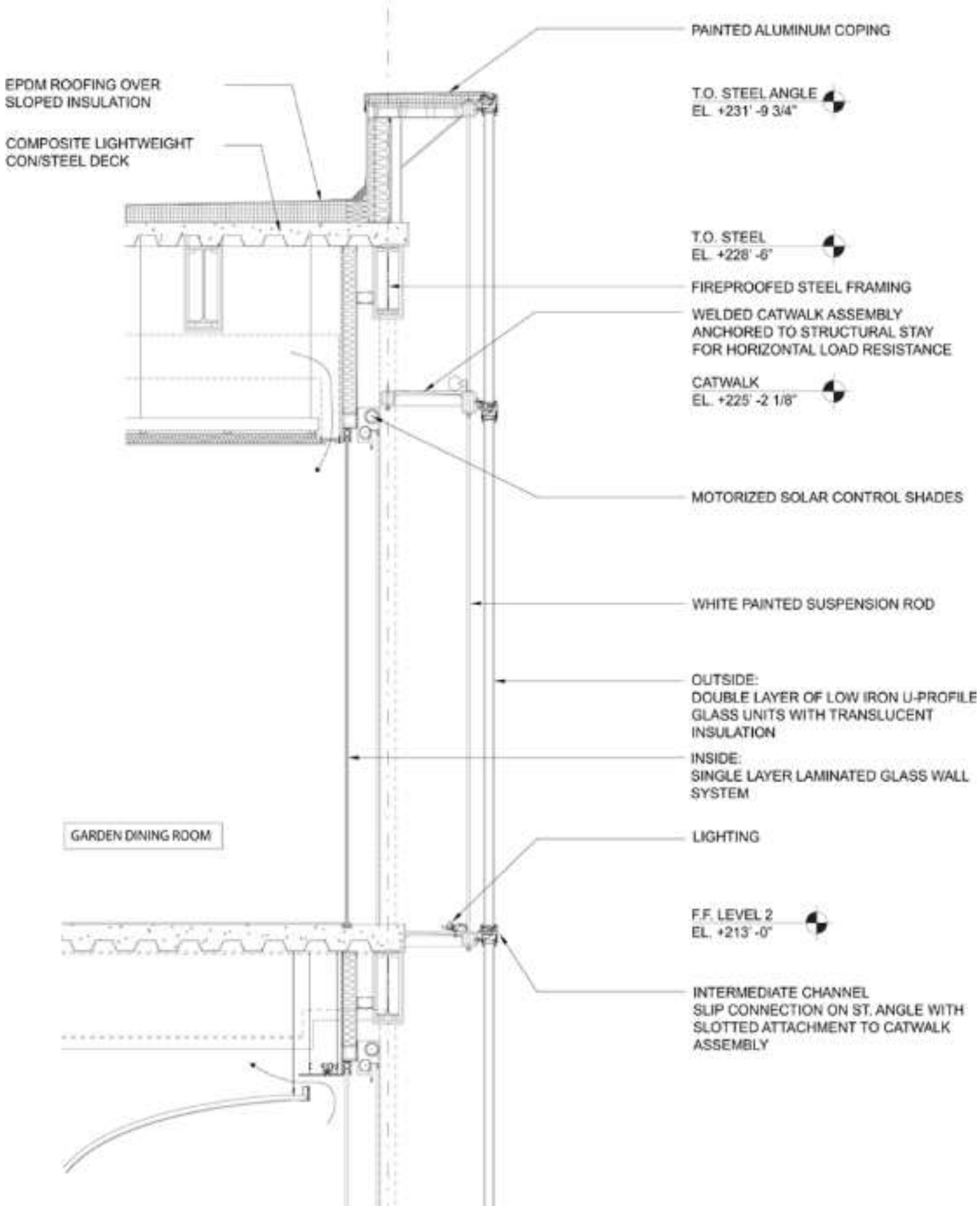

Fig 6: Section through PV integrated double skin façade (Roberts and Guariento, 2009)

6. USE OF PHOTOVOLTAIC ON RAIN SCREEN CLADDING

Rain screen façade systems consist of panels which are installed with a void from the building to allow for drainage and ventilation (Thomas, Fordham and Partners, 2001). The external glass is used for photovoltaic integration and also a barrier to rain penetration, the ventilated void allow for the running of mechanical, electrical services and also insulation.

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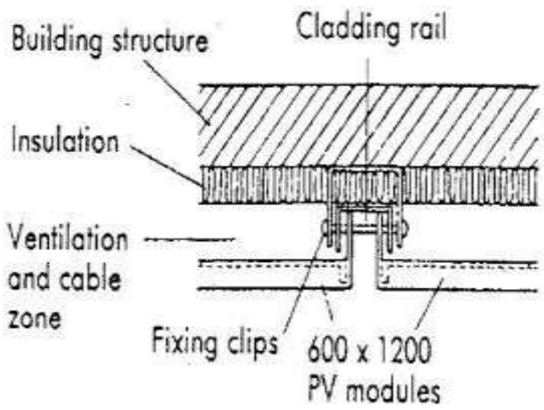

Fig 7: Detail of rain screen PV cladding system (Roberts and Guariento, 2009)

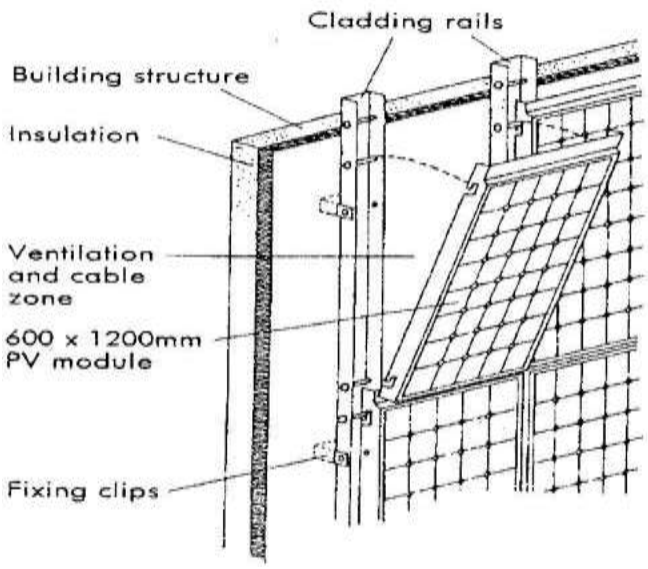

Fig 8: 3d view of a typical PV Rain screen system (Roberts and Guariento, 2009)

7. USE OF PHOTOVOLTAIC AS SHADING DEVICE

Photovoltaics can be used as a shading element to control natural daylight in a building. This is to reduce the amount of solar radiation into the building and at the same time produce electricity. PV can be integrated into the shading devices of the building of there is any. They can also be adjustable shading devices which can be arrange horizontally or inclined. PV modules can readily replace metal, timber or plastic louvres (Robert and Guariento, 2009). The photovoltaic shading system are of two category: movable and movable fixed systems. Movable system are more efficient than fixed system, but it is also more expensive because it is automated as such needs a lot of mechanical power.

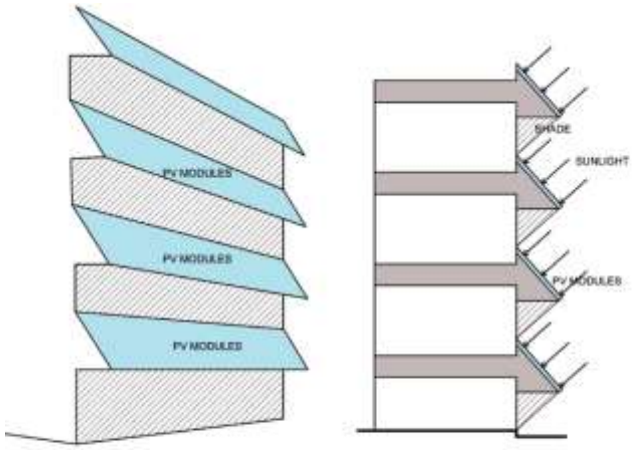

Fig 9: Saw-Tooth PV Facade Consisting of Overhanging PV Shade Screens Source: Drawing based on (Wolter, 2003)

8. CASE STUDIES

This paper will compare three different buildings with photovoltaic integrated facades.

- The Cité du Design (International Design Center) France
- Genyo Building, Granada Spain
- Xicui entertainment complex in Beijing
- Solar-Fabrik building, Freiburg, Germany

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CASE STUDY 1:

The building-The International Design Center in St. Etienne, France is great achievement in both building design and renewable energy. The building was constructed in a historic site of the former National Arms Manufacture which is more than 185,000-square foot. More attracting is its successful integration of a solar power facade on the Center's most notable building, the 'Platine. The building Comprised of 14,000 triangles made from a variety of materials, the facade is strategically designed to control temperature, light and air flow throughout the building. Many of these triangles are actually photovoltaic solar panels integrated in the curtain wall system that generates electricity to the building. In a fitting and clever way, passive and active solar design where illustrated a unique way.

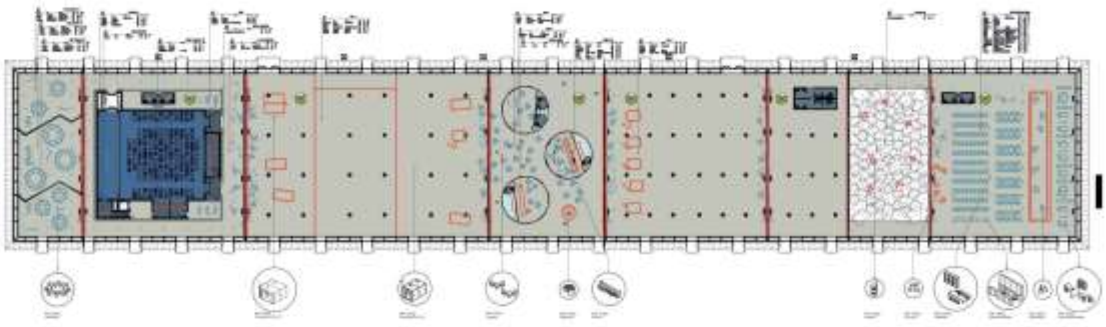

Fig 10: Ground Floor plan (Karen Cilento 2009)

Fig 11.:Daytime pespective view of building (Karen Cilento 2009)

Fig 12:Daytime pespective view of building (Karen Cilento 2009)

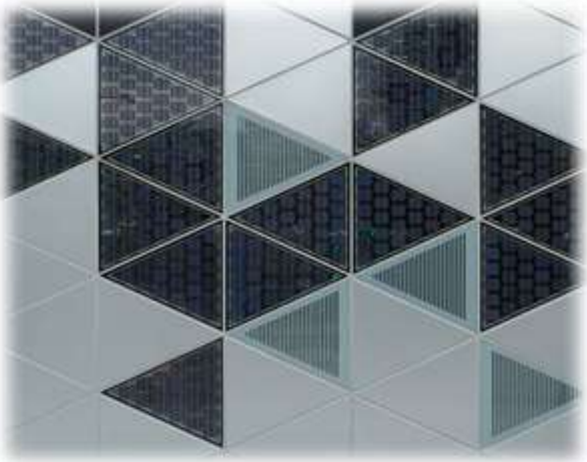

Fig 13: south elevation view of building (Karen Cilento 2009)

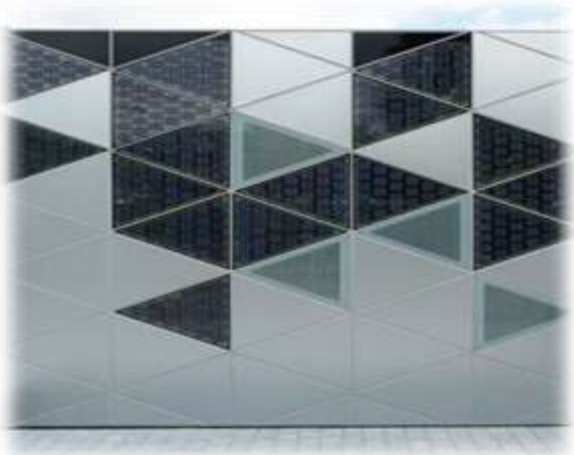

Fig 14:south elevation view of building (Karen Cilento2009)

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CASE STUDY 2:

The building-The building façade is a combination of three different types of glasses: conventional serigraphic glass, 2.5 x 1 meters photovoltaic glass designed for this project and a white glass. Thus, the PV is integrated in an aesthetic pattern, replacing conventional materials such as cladding, ceramic, glass or stones with a great final result.

With the integration of the new Ventilated Photovoltaic Façade, the building will generate most the energy needed for its operation while avoiding the emission 21 tons of CO_2 a year, leading to a the reduction in electricity bills.

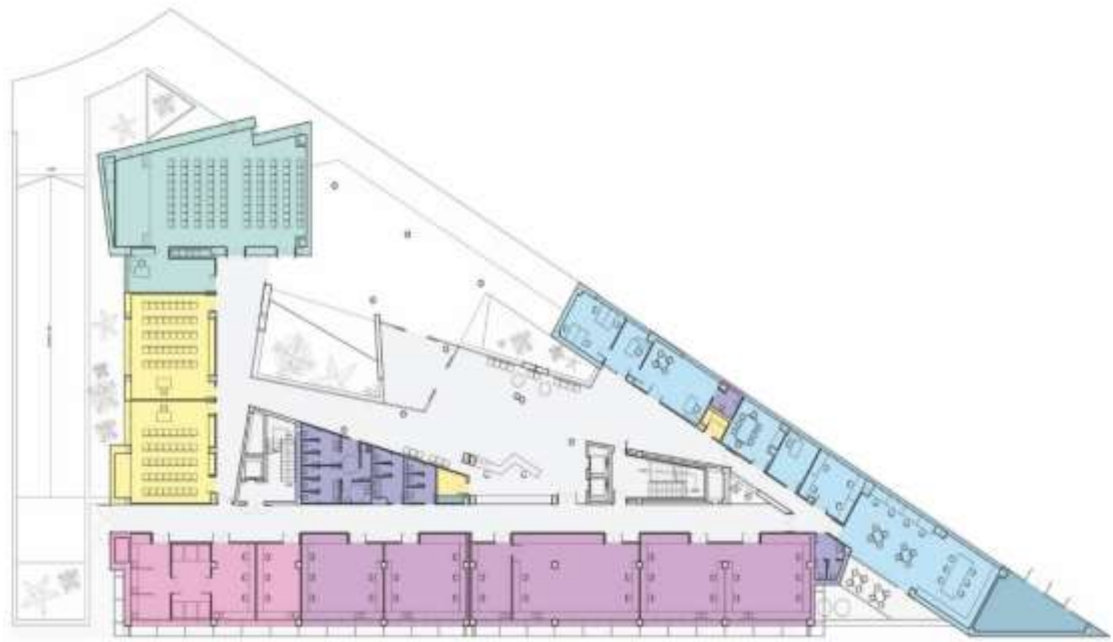
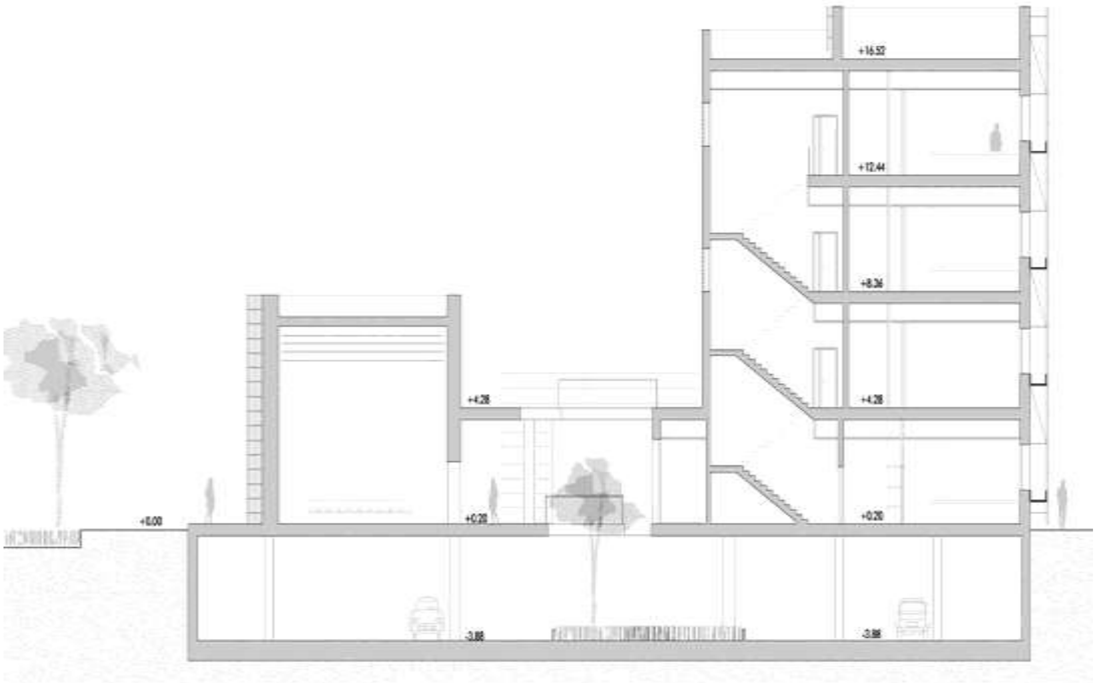


Fig 15:Ground floor plan
(http://www.archdaily.com/328262/genyo-laboratories-planho)



16 :Section through the building
(http://www.archdaily.com/328262/genyo-laboratories-planho)

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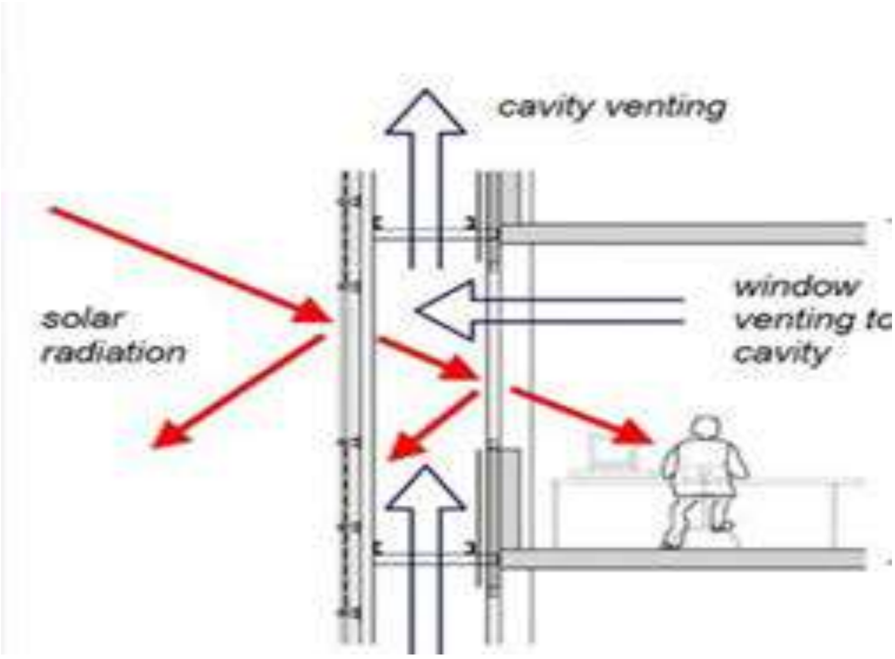

Fig 17:Detail through the façade
(http://www.archdaily.com/328262/genyo-laboratories-planho)

Fig 18 :Perspective vew
(http://www.archdaily.com/328262/genyo-laboratories-planho)

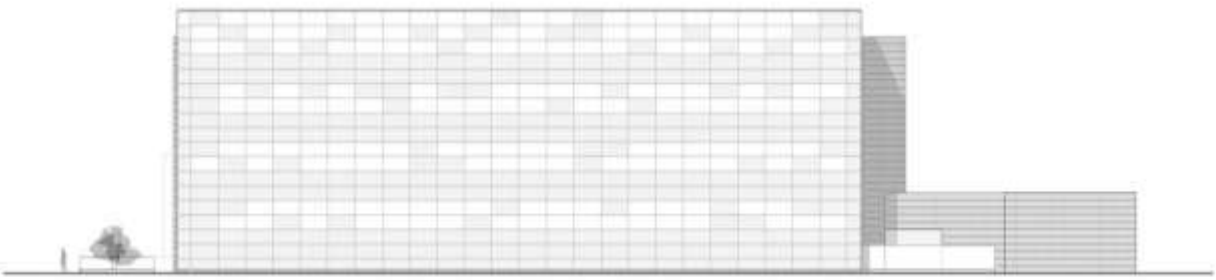

Fig 19 :South Elevation
(http://www.archdaily.com/328262/genyo-laboratories-planho)

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Fig 20:Perspective view
(http://www.archdaily.com/328262/genyo-laboratories-planho)

CASE STUDY 3:

The 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 32 to the inside and increase the comfort. The PVs ventilated by using the rain screen. The façade has special modular unit design with a convenient size for ease installation and shipping to the construction site.

Fig 21: Closer Perspective view
(http://www.greenpix.org/download.php)

Fig 22 :Perspective View
(http://www.greenpix.org/download.php)

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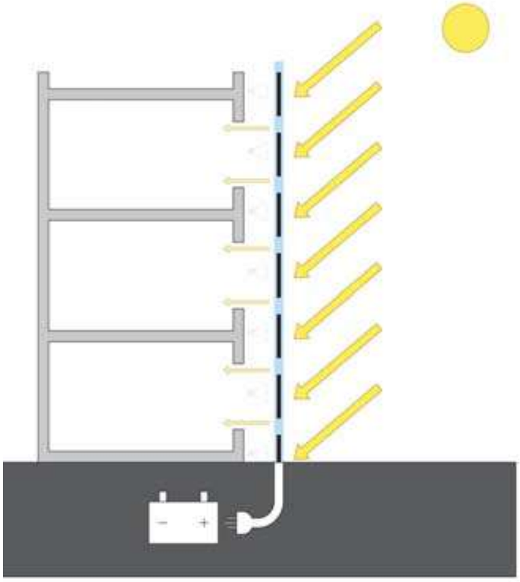

Fig 23: solar analysis at the daytime
(http://www.greenpix.org/download.php)

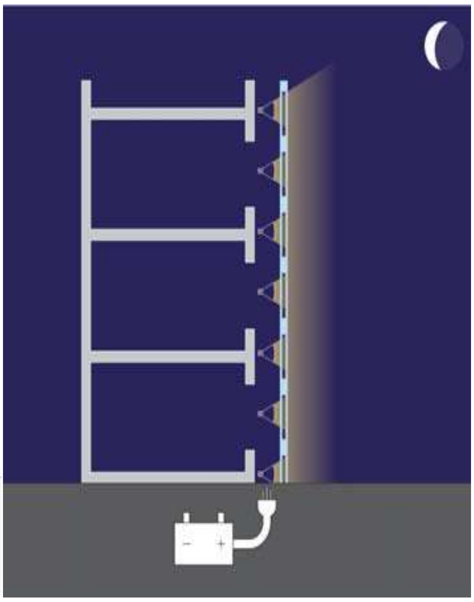

fig 24: façade light in the Night
(http://www.greenpix.org/download.php)

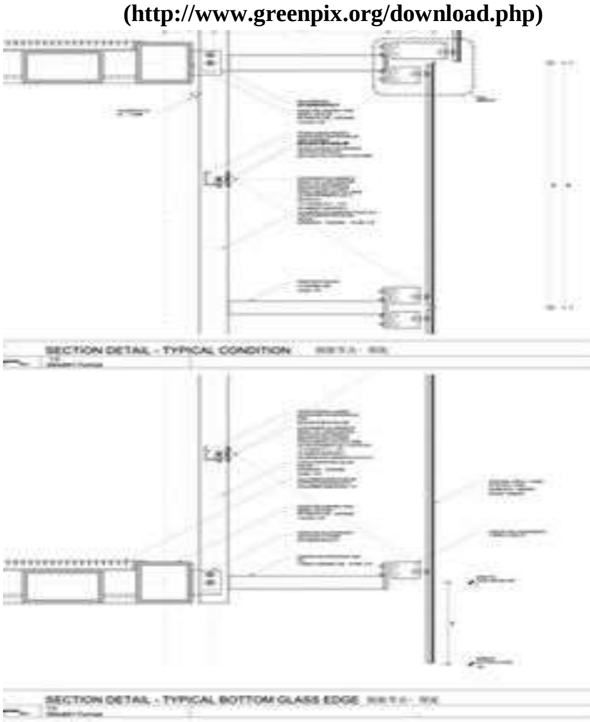

Fig 25: Detailed section
(http://www.greenpix.org/download.php)

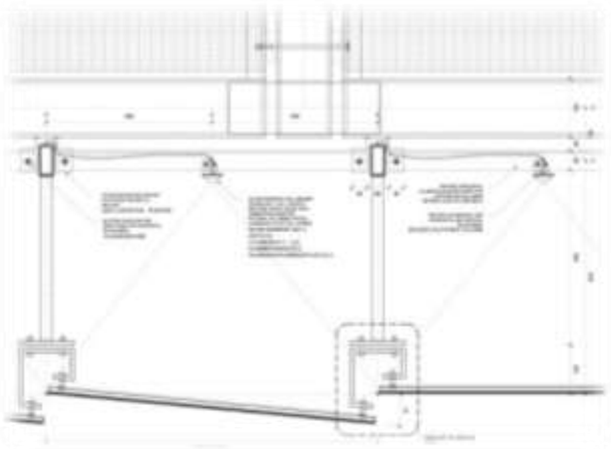

Fig.26: Detailed Plan
(http://www.greenpix.org/download.php)

CASE STUDY 4:

The building- In the Solar-Fabrik building, Freiburg, Germany, PV modules cover the entire glazed facade. This zero-emissions factory is integrated with around 575 m² of solar power modules that generates one-fifth of its electricity need. PV modules are also fixed in front of the south-facing wall positioned such at an angle to shade the glass building when the summer sun is at its highest. However In winter, the low-lying sun can easily penetrate into the building and helps in passive heating (SolarFabrik).Daxford Solar Office the 15metre tall PV façade is designed to slope back at an angle of 60° mainly for two reasons. First is to maximize the solar radiation exposure whilst the second is to ensure that there is no disturbing glare reflected from the wall. Since daylight enters from the south side between the PV bands, on normal days no artificial lighting is need (Phillips, 2000)

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Fig 27: Inclined PV Integrated Façade of Solar-Fabrik Building, Freiburg, Germany (http://www.solar-fabrik.de/)

Fig 28: Interior perspective of the inclined façade (http://www.solar-fabrik.de/)

Fig 29: exterior perspective of the inclined façade (http://www.solar-fabrik.de)

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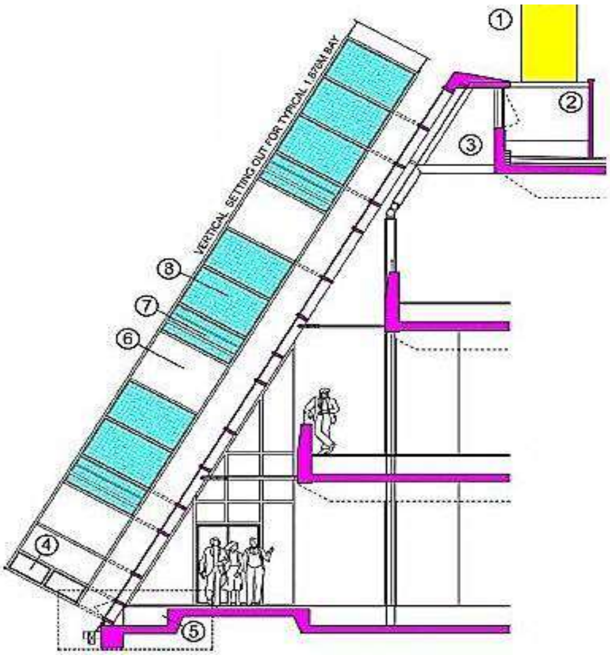

Fig 30: Section through the façade
(http://www.solar-fabrik.de)

9. COMPARISON OF THE PHOTOVOLTAICS INTEGRATED FAÇADE IN THE CASE STUDIES

Table 1.0: Comparison of PV integrated facades

WALL SYSTEMS	POSITION OF PV	TYPE OF PV CELL	CHARACTERISTICS AND COMMENTS	CASE STUDIES
Curtain wall system	PV on vertical surface	Polycrystalline Cell	Opaque or semi-transparent PVs are mostly used. But nowadays other PV systems, such as thin film PV are been used. No optimal PV power output	The Cité du Design (International Design Center) in St. Etienne, France
Double Skin Facade	PV on vertical surface	Thin film silicon cells	Double-skin facades systems are very convenience for PVs. Ventilation gap gives chance to ventilate Inner surface of PV. Also mechanical services are installed on this gap. Suitable for hot climate regions	- Genyo Building, Granada Spain
Inclined curtain wall	Inclined on vertical surface	Polycrystalline Cell	Output of PV is higher. Construction detail and complexity increased. It is aesthetically pleasing	Solar-Fabrik building, Freiburg, Germany
Rain screen system	PV on vertical surface	Polycrystalline Cell	This system is very convenience for PVs. Ventilation gap are not wide as double skin façade.	-Xicui entertainment complex in Beijing

10. FINDINGS AND DISCUSSON

From the first case study, the PVs are integrated vertically a Curtain wall system to generate energy, control light, temperature and air flow through the building. In this system, the wiring is installed on the mullions carefully. Due to an unventilated façade (absence of cavity between curtain wall and building) as such there is possibility of overheating in the PV modules, thereby reducing their output. And moreover curtain wall systems are hard to maintain.

From the second case study, the PVS were integrated vertically on a double skin façade system which apart from the energy Generation will insulate the building and also reduce cooling demand in summer and heating demand in winter with the extra skin. The ventilated cavity provides airflow to the PV modules thereby preventing overheating of the modules .This cavity provide ease of maintenance of the façade. Building mechanical and electrical services can be placed in d cavity.

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From the third case study, the PVs were integrated vertically on a rain screen façade system, which they generates energy to the building.in this building, the PVs are dedicated to power the façade alone, which at night features the world largest color LED display and at the day time serves as a daylight breaker and also reduce cooling demand in summer and heating demand in winter with the extra skin.

From the fourth case study, the PVS were integrated vertically inclined on a Curtain wall system .The façade was inclined at 60 degrees to get the maximum output of the electricity and also to prevent glare in the building .in this system, there is possibility of overheating because there is no cavity to ventilate the PV modules. Also the shading louvres improves efficiency and architectural aesthetics.

From all the case studies, the PVs serves as an alternative to the conventional building material on facades and also as an energy generator to the building. There are factors that affects the energy efficiency of all photovoltaic modules in different systems. This efficiency depends on the type of cell, tilt and orientation, overheating, over shadowing and annual average daily insulation.

There are different modules of cells in PV as such due to manufacturing methods and structure, every PV cell has its own degree of electrical efficiency the efficiency depends on the chosen cell types .Crystalline modules are more energy efficient than thin-film modules. For you to achieve the same energy efficiency, the integration requirement of thin-film modules will be more than crystalline silicon.

The angles and orientation of PV affects the efficiency, as such the integration of PV on facades must be done with true orientation to get the maximum solar irradiation. Also, PV modules are integrated inclined on facades to increase the modules output.

PV module output reduces as temperature on them gets above 25 degrees Celsius, given that, not all sunlight on modules are converted to electrical energy, the ineffective sunlight tends to heat up the modules and lower the output of electricity. Overheating results to the ventilation of PV modules, giving slight gap between the building and PV modules allowing for air flow within. Thin-film modules are better than crystalline silicon modules in terms of overheating.

Shadowing affects the PV modules output, they shouldn't be placed under or near any shadow of either trees, lamp or any building, slight shadow can affect the amount energy generation.in the integration of the PV, distance between buildings are calculated to get the accurate and possible positon of PV to be integrated.

PV modules are oriented based on the location of the building on the hemisphere .Sunlight being the fuel to the PV modules, output and generation will be more at long sunny days. As such, to make use of the sunlight more effectively the façade integrated with PV is placed more towards were the sunlight duration is more i.e. in the northern hemisphere south areas will be more effective.

11. CONCLUSION

With these discussions, it is clear that the integration of photovoltaics in building façade is a very good and efficient alternative to the conventional building material used in façade designs .Not only as building material, the integration of PV have changed the building position from energy consuming to the energy efficient. This integration also protect building occupants from outer weather influence, noise and daylight control.

PV integration in façade may not seem to be highly efficient due to verticality and orientation, but it is more effective in the case of PV inclined façade where the façade is tilted to a certain angle as such there is maximum output gotten from the PV panels. This vast façade gives space for large installations and generation of power to the building but still roof integration gives more popularity than façade integration due to efficiency factor.

There are similarities between the installation on façade and the conventional cladding materials used, this makes the technic of PV integration on facades not complicated. The installation of the PV module on the façade can be done using the standard glazing system like the structural sealant glazing or using the standard curtain wall system.

Furthermore, from the different integration systems of the case studies. Double skin system and the Rain screen façade systems are the most suitable system for PV integration due to its ventilated cavity, the cavity shouldn't be less than 150mm for sufficient circulation of air. The lower the cavity spacing the lower the efficiency of the PV panels especially in the hot climate regions where there are high temperature differences. Because every increase in 5 degrees of cell temperature will cause 2.5% decrease in module output, as such affecting the efficiency of the modules. The outer skin having the PVs also serving as shader from the building from solar radiation and weather protector while providing architectural aesthetics to the building.

The use of PV on façades as an alternative to normal non glass cladding material e.g. aluminum panel, stone is more cost effective economically. In the installation of PV system, the highest cost of the integration is the PV modules, this modules replace the conventional cladding materials which when installed don't produce any energy and don't have any payback time rather they require money for regular maintenance. Moreover, PV systems gives a pay back to their initial cost of installation after some years .They have a high guarantee value that they work for years without any need for maintenance.

Furthermore, the integration of PV in building façade gives a wide range of opportunity in terms of the sustainable energy generation, alternative to conventional building materials and also gives a life cycle effectiveness to building efficiency and maintenance.

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