Architectural aspects for building integrated photovoltaics

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ABSTRACT

The present work is part of a student project performed at the School of Architecture at the University of Patras, Greece and summarizes and discusses principles and design concepts for building integrated photovoltaics. A review for the several types and properties of the photovoltaics with regard to integration aspects in the building envelope and their advantages and disadvantages are included. The work also includes aspects for the new aesthetic items that come from these new types of building components and suggestions for application requirements and future perspectives.

1. INTRODUCTION

The awareness on the significance of solar energy in building design and construction is gradually increasing. In new building designs or retrofitting the emphasis is placed on the effective use of passive and active solar energy systems to partially or entirely cover demands in natural lighting, space heating and cooling, air ventilating, domestic hot water and electricity. The emerging concerns for environmental protection and global energy saving have introduced new architectural design rules for buildings, aiming at reduced energy buildings with effective integration of several solar energy systems in combination with satisfactory aesthetics. Photovoltaics (PVs) that convert the absorbed solar energy into electricity constitute a new field for architects and engineers and require research on new forms of building façade, roof system installation, efficient operation and other practical aspects.

This paper includes main principles and design concepts for building integrated photovoltaics. The work is part of a student project performed at the School of Architecture at the University of Patras, Greece and includes a review for the several types and properties of the photovoltaics with regard to integration aspects in the building envelope and their advantages and disadvantages. Finally, aspects regarding the aesthetics, application requirements and future perspectives are included and discussed.

2. PV ASPECTS AND CONSIDERATIONS

The several types and forms of PVs constitute new and interesting material, which can be easily integrated to the buildings giving new shapes and a symbol of the ecological concept. It is a new material in the architect's hands ready to be shaped and to create an alternative building. It is also a material, which can be further developed with many advantages. The scientists are facing those new technology challenges effectively by giving encouraging results, since PVs are able to provide more and more ecological, aesthetic, socioeconomic and technical benefits. At global level, the electrical energy from the PVs stands for one crucial component of our energy future and aids to preservation of valuable natural resources. At local level, solar electricity can make a considerable contribution to immediate long-term sustainability, since it is able to be produced almost anywhere and on any scale.

Photovoltaic systems are both versatile in application and modular in structure and fit well into buildings and other structures, such as remote applications. Integrating photovoltaic elements has a double benefit. On the one hand, they can produce electricity and on the other they replace construction materials, such as building components. Thereby, the PV system may also be performing an additional function as part of the weatherproofing of the walls or roof. The products available are suitable for exposure to sun, rain, wind, and other climatic influences, while the operation of photovoltaic systems is considered technically reliable.

The expected lifetime of a PV module is over 20 years. The fact that it has no moving parts increases its lifetime and reliability and reduces maintenance requirements. On the other hand, the main source for the construction of PV cells and modules is the silicon, an element which is inexhaustible and free disposed, although the production cost of cells has not been reduced enough. Novel cell construction modes, as of thin-film, organic material or others, are new and promising techniques for new types of PVs, aiming to cost reduction and flexibility for a wider application of them in the future.

As far as the ecological aspect is concerned, is worthy of remark that photovoltaics are environmental friendly. They are undoubtedly beneficial for the direct conversion of solar energy into electricity and are considered environmentally efficient as the energy pay back time in most applications is calculated to be about four years. They generate energy virtually free of greenhouse emissions (CO_2, NOx and SOx), they are silent and they recover the energy used in production of the cells several times over.

Photovoltaics can already offer a number of economically viable and competitive applications within the built environment. Although the cost of the electricity generation from PVs has been significantly reduced in recent years, PVs are still considered as an economically expensive method of electricity production. However, by replacing conventional elements of the building envelope (roof tiles, metal roofs, façade elements, windows, shading devices, etc.) with PV modules, the total cost of a built construction is remarkably reduced. Furthermore, subsides to the cost of the PV system or/and the produced solar kWh in many countries make PV systems more attractive for application, mainly in grid connected systems.

Some other interest aspects are that PVs are also in position to meet cultural and social demands. They can be part of new, attractive and prestigious design approaches, they create new employment and emerging business opportunities while they contribute to raising social awareness about sustainability, energy saving and commitment to environmental protection. On the other hand, PVs use an inexhaustible and free supplied source, the solar energy, which means a more distributed and democratic disposal of energy.

3. PHOTOVOLTAICS AND BUILDINGS

PVs can be used as construction materials, which allow innovative architectural designs since there is a variety of colours, sizes and shapes of them. The various module types such as monocrystalline, polycrystalline and amorphous silicon, thin-film type, etc, have several interesting aesthetic considerations. The color of monocrystalline silicon cells varies from uniform black to a dark gray with a uniform surface structure. In contrast, the structure of polycrystalline cells may shows a wide variety of colored crystals. PVs may offer flexible and plastic forms.

Amorphous silicon is deposited on metal, glass or plastic substrates, meaning that different kinds of modules are available. Furthermore, they may offer different light transparency, depending on design demands. For semi-transparent modules the space between the single cells is enlarged to let light pass through. One may find also glass modules with predefined transparency with or without colors.

Building integrated photovoltaic systems (BIPV) apart from the fact that they produce electricity, they also form part of the building. There is a wide variety of PV modules and systems currently disposed on the market, suitable for BIPV systems. Most of these can be grouped into two main categories: façade systems and roofing systems. Façade systems include curtain wall products, and glazing, while, roofing systems include tiles. The fundamental first step in any BIPV application is to maximise energy efficiency within the building. Roof and wall systems can, for example, be designed to improve insulation and thus to reduce heating or cooling demand. Windows, skylights, and façades can be designed to increase the natural light in interior spaces. PV awnings can be designed to reduce unwanted glare and heat gain.

Photovoltaic systems have been installed on many types of buildings in a wide variety of ways. A wide range of building types, from residential buildings, schools, offices and hotels to industrial buildings, can use PVs. Office blocks have good PV potential because their electricity demand is significant all year round (including in the summer) and because this demand reaches its highest level between 9am and 5pm. The match between supply by PV and demand is therefore very good. Residential buildings on the other hand, even though they are occupied seven days a week, tend to use energy mainly at night. Nonetheless, individuals (and perhaps electricity suppliers) are likely to be interested in their PV potential. Commercial and industrial buildings with large available roof areas may offer a field of significant interest for the installation of PV systems.

4. PV GLOBAL MARKET

The market growth of solar thermal systems and photovoltaics in Europe depends on the policy of the governments towards the use of solar energy systems, on the sensitivity of the people concerning environment and on the improvement of the technology combined with price reduction of solar energy systems. According the White Paper, the installed capacity by photovoltaics must be 3 GW until 2010, from 0.03 GW in 1995. Setting up photovoltaic projects or photovoltaic policy means joining a market, which is doubling in size every three years. Thus, grid-connected photovoltaic systems are turning to be of great importance, especially in Europe. Building-integrated photovoltaic systems are expected to account for about 50% of the global photovoltaic market share by 2010, whereas in Europe the figures are even higher. According to the official statistics of EU, in 2004 the EU reached a figure of 410.4 MWp for a cumulated capacity of more than 1000 MWp (data from EC web-site, Table 1). Another lasting trend is the predominance of the grid-connected applications (solar roofs, facades and power plants) with a 98.1% market share in 2004.

The grid-connected segment now represents 91% of total installed European capacity. 2004 was a very good year for photovoltaic solar energy in Germany. According to the German Association of Solar Industrialists (BSI) approximately 363 MWp were installed during the year. This growth makes Germany the leading photovoltaic market in the world ahead of Japan (280 MWp installed in 2004) and USA (90 MWp). The other European markets have a completely different dimension. Netherlands and Spain are the countries with the larger European markets following Germany. This growth is essentially due to purchase conditions for electricity generation from photovoltaics. PV market is only little developed in the new member countries (+0.269 MWp in 2004), principally due to the absence of "solar roofs" type programmes. Poland was the main market (+0.127 MWp) in 2004. The Czech Republic has the largest total installed photovoltaic capacity of the 10 new member countries (0.363 MWp at the end of 2004).

Table 1: Cumulative PV installation in EU.

Country	Grid MWp	Off grid MWp	Total MWp
Germany	768.00	26.00	794.00
Netherlands	44.31	4.77	49.08
Spain	23.00	14.00	37.00
Italy	18.70	12.00	30.70
France	8.00	18.30	26.30
Luxemburg	26.00	0.00	26.00
Austria	16.49	2.69	19.18
United Kingdom	7.39	0.78	8.17
Greece	1.26	3.29	4.55
Sweden	0.19	3.67	3.86
Finland	0.19	3.51	3.70
Portugal	0.42	2.23	2.65
Denmark	2.03	0.25	2.28
Belgium	1.40	0.06	1.46
Czech Rep.	0.22	0.15	0.37
Poland	0.07	0.16	0.23
Cyprus	0.15	0.04	0.19
Hungary	0.05	0.08	0.13
Ireland	0.00	0.10	0.10
Slovenia	0.01	0.08	0.09
Slovak Rep.	0.00	0.06	0.06
Lithuania	0.00	0.02	0.02
Malta	0.01	0.00	0.01
Latvia	0.00	0.01	0.01
Estonia	0.00	0.01	0.01
Total E.U.	917.89	92.24	1010.13

5. THE CASE OF GREECE

Considering the target of EC for 12% from renewables in 2010, solar energy systems can play a significant role. Greece is one of the most successful countries worldwide in the use of solar thermal energy and the 2010 EU target on renewables could be achieved regarding solar energy, if solar collectors of about 11 million m² surface area and photovoltaics more than 15 MWp power are installed. In Greece, PV installation is still in primitive level. Even though its geographical position is rather advantageous, with plenty of sunlight days during the year compared to other European countries the Greece has in operation only 4 MW of photovoltaics during the year 2005.

The same year, the installed thermal collectors were 3.5 millions m² and for many years, the number of solar thermal collectors was the highest within Europe. The current annual solar thermal market in Greece is about 200.000 m^2 per year including single family or multiflat houses, hotels, small commercial and industrial consumers and athletic centres.

Regarding PV installations in Greece, most of them are at the islands, in off-grid and remote applications and in the telecommunication sector. The single family market for PV systems has not been developed in Greece, because the incentive was not sufficient to generate any interest especially for grid-connected PV systems. Now, a new law is estimated that will push more PVs to be installed in buildings and other grid-connected applications.

The production of energy in Greece was and is still based on traditional fuels: lignite, oil and electricity generation by hydro. The share of renewable energies (including firewood) is estimated to be 10% of the total production. The application of solar systems for satisfying needs in heating and cooling is a strategic option of great importance for Greek energy system and for electricity system in particular. It is also an important choice for the national economy in total, since a very dynamic and competitive industry concerning the manufacturing of solar systems has already been developed.

Regarding photovoltaics, it is estimated that the use of the hybrid Photovoltaic/Thermal (PV/T) solar systems that convert solar energy to electricity and heat simultaneously, it will contribute to a wider PV installation. The use of PV/T hybrid systems creates a synergy that works in favour of the PV systems and a potential market window could open for the reintroduction of the PV technology, through a modified product. It is considered that the PV/T hybrid solar system is an opportunity to develop a series of new solutions for the electric and thermal energy needs of the consumers and enterprises. It is obvious that an increase of funding support by the State is necessary, as PV cost is high and also the promotion of installation on public buildings could encourage the wider application of photovoltaics.

6. APPLICATION ASPECTS

PV integration in buildings is interesting from the architectural side of view and considering as examples the Cycladic houses and the block of flats (multiflat) buildings, some suggestions are done. In these cases the PV modules can be installed at several inclinations, to adapt the architectural demands, although in some cases they are not the optimum. Regarding Greek conditions, it would be better if the building design is based on inclined surfaces, so as PV panels could be perfectly integrated. In the following these examples are briefly presented.

6.1 Block of flats

As far as block of flats buildings are concerned in Greece, they have usually both horizontal and vertical elements. Thus, the integration potential of photovoltaic elements inclined roof is reduced, as the surfaces are limited and the vertical façade surface is not effective. In cases where the block of flats has a roof, panel integration is rather easy. Roof's tiles may be replaced by photovoltaics panels. In order to have a better aesthetic result, those panels may be of color similar to the one of the rest of the building's tiles. Like this, perfect incorporation to the building can be achieved. Otherwise, red photovoltaics panels may be placed, in order to prevent a noticeable chromatic variation on the roof. The above mentioned solutions may are less economical, but they certainly offer a better aesthetic result (Fig. 1).

One characteristic of the block of flats in Greece is that they have big balconies. Those balconies apart from the contact with the exte-

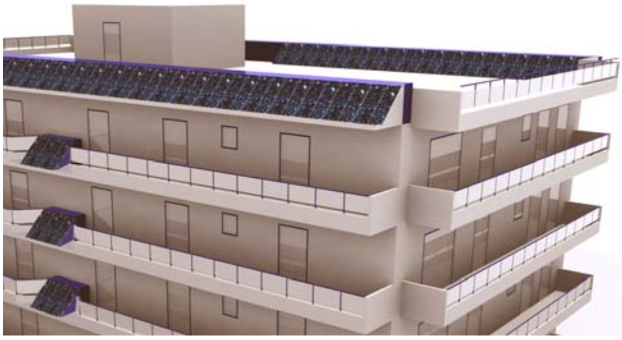
Figure 1: PVs on a block of flats bulding.

rior/outdoor environment they also offer shading. Photovoltaics may be integrated to those elements, in horizontal position (but with reduced efficiency) because of the lack of the proposed inclination, or to be installed inclined producing more shading to the apartment of the lower floor (Fig. 1).

Another solution would be the integration of photovoltaic panels at the interior of the balcony, in a way that they function as bulkheads between two neighbor apartments. The space below can be used as storage area. As a result, the empty spaces between the two balconies would be covered, providing an inclined element suitable for PV integration.

6.2 Traditional settlements

The PV panel integration to the traditional settlements of Greece must respect the architectural character and particularity of each zone. We may use as an example the villages at the area of Epirus (North-West of Greece), where a main characteristic of local architecture is the traditional gray-black stone at the houses' roofs called "schistoplaka" and those stones might be replaced by photovoltaics tiles of the same dark color. In addition, the residential areas of Cycladic islands offer a promising field for PV integration, since they are characterized by a high level of sunlight, therefore they are able for giving a great efficiency. Photovoltaic panels may be easily incorporated to the Cycladic landscape by integrating blue PV modules of polycrystalline silicon type, which are perfectly matched with the scene.

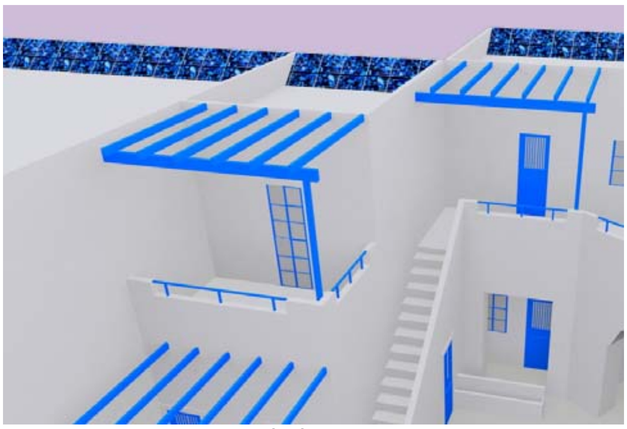
Figure 2: PVs on the roof of a Cycladic house.

Firstly, PV panels may be placed at the roof of the houses (Fig. 2). Cycladic houses have horizontal roofs, which are surrounded by a wall of about 30-50 centimeters. PV panels could be placed there inclined, in order to be not visible from the road. At the same time, because of their blue color, photovoltaic panels are unified with the other blue elements of the houses.

Another case could be the PV integration to the doors and the windows of the houses. In this case, PV efficiency is reduced because it is placed vertically, while the benefit is rather aesthetic. Blue PV panels replace harmonically the old wooden frames and at the same time material saving is achieved (Fig. 3). Regarding the efficient operation of photovoltaics it is rather augmented to those settlements, because of the reflected sun-light from the opposite wall, which is normally white and diffused contributing to an increase of the electrical output of photovoltaics.

Finally, series of photovoltaic panels could be integrated to the pergola, which can be found in every Cycladic house (Fig. 4). Always in blue color, they can be placed in lines over the pergola, leaving spaces for the ventilation of the area below. The horizontal PV arrangement may cause a reduction of their electrical output in winter, however they are effective during summer due to the high altitude of the sun.

In all above case-studies, the photovoltaics are effectively combined with other solar energy devices, such as solar thermal collectors, either side-by-side (separated units) installation or as hybrid photovoltaic/thermal solar systems, where photovoltaics and thermal collectors are combined in one unit providing simultaneously electricity and heat.

7. CONCLUSIONS

Photovoltaics are considered to be a new and potential material. They offer a variety of benefits, and they can be found in different types,

Figure 3: PVs on doors and windows of a Cycladic house.

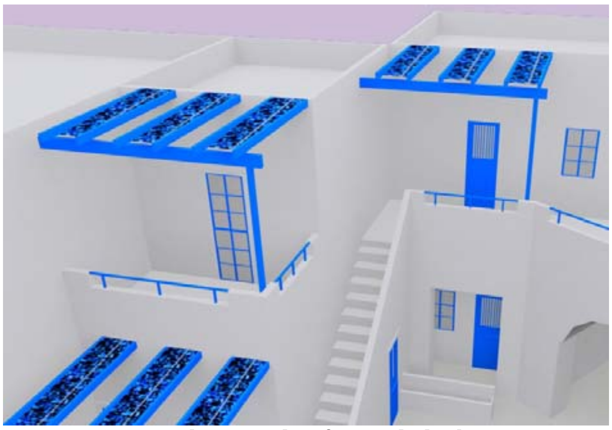

Figure 4: PVs on the pergola of a Cycladic house.

forms and colors. This environmental friendly source of energy can be widely used in traditional and modern buildings in Greece. The advantages of PVs allow the combination of this new material with the traditional architecture of each place, like Epirus and Cyclades. Apart from energy supply, their use may offer space economy for their installation and aesthetic results. Encouraging scientific attempts on this field, as well as political initiatives are considered essential in order to achieve further development of the photovoltaic systems.

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