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Retrofit and new PV integrated Buildings in Tuscany, Italy: case studies

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Abstract: When using the integrated approach, the solar systems become part of the general building design, In fact they are also often become regular building elements. This is due to the fact that integrating the solar systems in the building envelope often is a necessity if the systems are to be economically feasible. The solar elements cannot be separate elements that are added after the building, or at least the architectural design of it, is completed. They must rather replace other building elements, thereby serving dual functions and reducing total costs.

Case studies represents a coming of age of building-integrated photovoltaics.
The PV elements are specially designed for glass shading devices. The photovoltaics will serve as shading elements and use an area protected by the new system.
The overhanging shading roof provides adequate shade in the summer and allows for useful solar heat gain in the winter. These factors combined should help to keep the building's running costs to a minimum. In conclusion, the simulations and testing at the design stage show that the overall environmental strategy will reduce the building's running costs while optimizing visual and thermal comfort. The PV integration into architectural design offers more than cost benefits, it allows to create environmentally design and energy efficient buildings.
The systems will be realised with crystalline photovoltaic modules integrated with a semitransparent module and there is also an example with PV modules in thin films.
The PV integrated case studies described in this work are: Atrium of the Pediatric Meyer hospital in Florence, University Library and classrooms building and Physics laboratory building in Sesto Fiorentino, Virtual Competence Centre ITC in Lucca and University residential student building in Florence .

Keywords: Photovoltaic, integration, architecture

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1. Introduction

Combining technology and traditional architecture, PV modules or PV arrays can be mounted on buildings, and in retrofitting it can be made an integration part of the building envelope thus creating a natural onsite link between the supply and demand of electricity.

From an architectural, technical and financial point of view, PV retrofitted in buildings has today the following benefits:

- does not require any extra land area and can be utilized also in densely populated areas,
- does not require any additional infrastructure installations,
- can provide electricity during peak times and thus reduce the utilitie's peak delivery requirements,
- may reduce transmission and distribution losses,
- may cover all or a significant part of the electricity consumption of the corresponding building,
- may replace conventional building materials and thus serve a dual role which enhances pay back considerations,
- can provide an improved aesthetic appearance in an innovative way,
- can be integrated with the maintenance, control and operation of the other installations and systems in the building,
- can provide reduced planning costs. Once put in the building context, photovoltaics should not be viewed only from the energy production point of view. Because of the physical characteristics of the PV module itself, these components can be regarded as multifunctional building elements that provide both shelter and power.

Being a mixture of technology, architecture and social behavior, PV in buildings eludes unambiguous evaluation of its cost-effectiveness and market potential. To a large extent, the value of the concept remains to be assessed on a case by case basis given the economical, technological, architectural, social and institutional boundaries of the project under consideration.

1. Methodology

Abita Centre of Research of the University of Florence has projected and collaborate to the realisation of the following case studies projects. The Scientific innovation and relevance of the work consists in the experimentation and diffusion PV technology through public buildings, especially PV integrated systems into Architecture.

PV installation integrated in building roofs and facades allow the possibility of combining energy production with other functions of the building envelope, such as shading, weather shielding and heat production. Cost savings through these combined functions can be substantial, e.g. in expensive façade systems where cladding costs may equal the costs of the PV modules. Additionally, no high – value land is required and no separate support structure is necessary. Electricity is generated at the point of use. This avoids transmission and distribution losses and reduces the utility company's capital and maintenance costs. 'Multiple integration' is perhaps the appropriate expression. Building integration does not just mean the mounting of PV modules on roofs or facades. Real integration can involve much more, it includes all the steps incorporated in the process of new construction or in retrofitting building, starting from planning the production of the construction materials through to operation and recycling. Multiple integration does not produce multiple costs. However, if it is done in the right way, it results in multiple savings. Savings of landscape, cladding materials, engineering effort and so on have often been mentioned in the literature. The further steps of integration have not yet been studied in detail, but it is obvious that integration into the existing manufacturing process of cladding materials should lead to further cost reductions. Integration starts at the beginning of the planning process of a building construction or renovation and continues until the building is finished.

However, the integration of PV into the architectural design offers more than cost benefits. It also allows designer to create environmentally design and energy efficient buildings without sacrificing comfort, aesthetics or economy.

2. Case studies Projects

The following case studies shows a wide variety of projects meeting the needs of a number of building sectors. This reflects the state of Tuscany region in Italy at the present. Same of the 5 case studies will be realized with the financial support of the Minister of the Environment and European Commission. Same project are refrofitted case studies such as: University Library and classrooms building (3), Physics laboratory building in Sesto Fiorentino (4), University residential student building in Florence (5) and the other are new case studies: Atrium of the Pediatric Meyer hospital in Florence (1) and Virtual Competence Centre ITC in Lucca (2).

New Projects:

1 Atrium of the Pediatric Meyer hospital

The Meyer's photovoltaic greenhouse is a structure with a southern exposition and unobstructed solar access to the main solar glazing of the greenhouse in order to maximize the collection of winter sunshine; it is not only a particular type of structure but also, and more importantly, a particular kind of space. The design objective not only considered energy and environmental aspects but also social impact: the primary objective is to create a pleasant and "socializing" space which can be used for semi-outdoor activities through most of the year without any extra energy space, a social space well integrated into the adjacent green park.

PV installation integrated into building greenhouse facades allows the possibility of combining energy production with other functions of the building envelope, such as shading, weather shielding and heat production. Cost savings through these combined functions can be substantial, e.g. in expensive facade systems where cladding costs may equal the costs of the PV modules. Additionally, no high-value land is required and no separate support structure is necessary. Electricity is generated at the point of use. This avoids transmission and distribution losses and reduces the utility company's capital and maintenance costs.

The Photovoltaic system is 30 kWp and realised with glass/glass PV modules.

Figure 1. (a,b,d) Few details of the photovoltaic integrated roof from inside. (c) Detailed face, external view.

Other innovative elements and materials in Meyer Children Hospital include:

* Green-roof: the green roof has a strong character in this project. The original idea, that the hospital is a place in which psychological aspects are very important for children and parents, suggested the

creation of terraces in green-roof, like gardens where it is possible to walk, look at the view of the hills and the green of the park.

* Buffer space on northern facade: it will be used as a hall during rainy winter days; the particular section and orientation of the buffer space will contribute to winter solar gains. It is partly openable to reduce overheating in summer.

* Optimum insulation inside walls: simulations have been done to find the optimum for cavity insulation.

* Light ducts: daylight inside the hospital will not only be a good solution for energy saving, but will impact on good spirits.

* Insulation material used on the first and second floors is recycled material

* Radiant panels: to achieve a better and uniform temperature in patient rooms

* Collector for heating system:

* BEMS: to control temperature and relative humidity in hospital,

* All greenhouses and windows are fitted with low emission glazing or double glazing. Glazing adopted for the Greenhouse has a very low U-value, 0.78 W/m2K . This type of glazing reduces transmission losses and the “greenhouse” effect.

2 Virtual Competence Centre ITC in Lucca

Client: Chamber of Commerce in Lucca

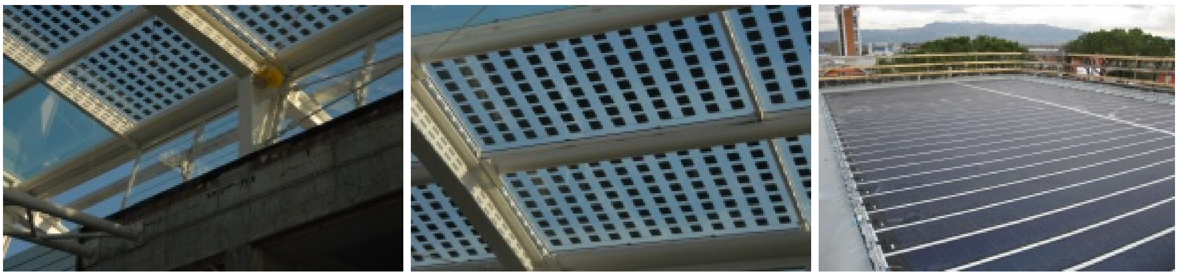
The photovoltaic integration facade is the more innovative element of the building .

The smart envelope is a unitised system modules, "dry" assembled and allows an easy installation on building site. This façade system has a simple geometric design made with two modules: transparent and opaque. The modules can be installed with different geometries and in their frames different types of materials with different colors can be placed

The modules consist of fixed and mobile parts, that can be operated trough automatic or manual controls. The mobile parts, placed in the aluminum frames, are:

- an aluminum shading device
- a transparent panel with stratified glass 4 + 4

Figure 2. (a,b,) Details of the photovoltaic atrium integrated roof from inside. (c) Detailed of the thin film integration on the roof



2.1. Technological features

A vertical mosquito net made with a metallic grid is placed in front of the indoor transparent module and prevents the entering of animals and insects in the office, and ensuring the night cooling.

The façade system is designed as a double skin façade system, where is possible to customize the indoor skin, the air gap and the outdoor panel.

The dynamic facade achieves good performance in the terms of:

- Thermal transmittance: the transparent indoor wall has a U value of 1,2 W/m2K and the opaque indoor wall has a U value of 0,3 W/m2K
- Acoustic insulation: 50dB
- Mechanical Resistance: the façade has a good fire resistance and mechanical properties and can be tested with accidental and dynamic loads
- Air and water permeability: the weather strip used in the frame avoids the formation of condensation and guaranteed a good air proof
- Maintainability: the modular elements enable to repair, with isolated action of maintainability, the facade system without changing the global performance of the façade

The facade system uses a technological solution with the recessed panels. This mechanism allowed to hide in the aluminum box the mobile elements: the glass panel and the shading device. The recessed panel can bear a weight of 180 Kg.

In the opaque outdoor module can be installed three PV panels that have a electrical energy production between 0,50 and 0,30 kWP. The energy production depends on orientation and localization of the façade system.

In winter the mobile glass panel is placed in front of the transparent module. So the smart facade will have the shape of a double skin facade with a buffer zone that increase its U value to 0.6 W/m2K. In this configuration the façade guarantees a good thermal insulation and doesn’t decrease the natural lighting into the work spaces.

In summer the panel with the shading device is placed in front of the transparent module, regulating direct solar radiation and decreasing heat load in the office. The mosquito net is down so is possible to obtain a natural ventilation in the indoor spaces all day long.

The san screen, made with mobile and metallic lamellae, allows to regulate the light and minimize the glare phenomena.

2.2. The simulations of the smart facade show that:

- In winter months for the smart facade, the primary energy supply for heating is lower than that required by a brick wall (Case 2, 50% of transparent module and 50 % of brick wall: 4500 kWh). The primary energy supply for the three cities chosen and the four cardinal direction is, in fact, of 4380 kWh.

But for the smart facade the energy primary need is bigger than that required by a glassed curtain wall and transparent double skin (Case 3: 3450 kWh and Case 6: 3750 kWh) because the solar heat gain decreases with decrease of transparent surface.

When the mobile glass panel is placed in front of the transparent module the heating needs decreases by the 5%.

In the future, aiming improve the summer energy performances, could be interesting to evaluat the input given by the use, in the mobile panel, of TIM or other change phases materials.

The smart facade should be oriented toward south in the purpose to improve the solar heat gains and decrease the energy consumption for heating .

- In summer months the smart facade guarantees good energy performance and in the configuration with the shading device placed in front of the transparent module the primary energy need is of 770,00 kWh (reduction by the 70% for the cooling), lower than that performed by a brick wall with central window (Case 1: 1100,00 kWh) and also lower than that of a glass curtain wall or of a double skin with fixed or mobile shading device (Case 4: 1500 kWh, Case 7: 895 kWh, Case 5: 1527 kWh and Case 8: 899,00 kWh).

The smart facade should be oriented toward south or north so to reduce the thermal loads and the solar heat gains and decrease the energy consumption for cooling.

- The best orientation during all year, in Florence and Palermo, is south, with a reduction of primary energy for heating and cooling by the 40%

The lighting simulations have been made with the software Relux, with wich has been possible to evaluate the average of natural lighting in the test room. The simulations have show that the smart façade, that has a transparent module of size 1,50 for 3,00, allows to achieve the following results:

- Good performances in summer months, with a illumination of 592 lux;

- Inadequate performances in winter months, when the glass panel is placed in front of the transparent module, with a illumination of 300 lux.

In order to reduce the energy consumptions for the lighting, the smart façade should be located in the spaces where is possible to have two window located in opposing wall. It’s also necessary to install a electronic light system that controls the artificial light and allows to switching on only the lights in areas that aren’t reached from the solar radiation.

Figure 3. (a) Smart Facade. Prototype (b) The dynamic envelope in east facade of the New Centre in virtual environments and ICT of Lucca Chamber of Commerce

Figure 4. (a,) Details of the photovoltaic integrated facade. (b) Photovoltaic atrium integrated roof from inside

Retrofitted photovoltaics:

3 Library and classrooms building . University of Florence

The system is composed by 160 PV glass/tedlar transparent modules with a power of 125 Wp/each, divided into five subsystem of 4000 Wp each.

Every subsystem has an inverter dedicated, completed with interconnection box

The photovoltaic system is composed by the following:

- Principle structure – 4 reticular beams of 22 m each positioned on the shortest side of the internal court.

- Secondary structure – 25 beams realised with 2 steel IPE supported by the principal beams

- Modules structure – modules are positioned for the longest side along beam direction, the photovoltaic modules, transparent glass/tedlar are supported by an aluminium tripod. Modules are then sustained and screw down to the aluminium easels realised with three L steel profiles.

- Footbridges – to guarantee maintenance operations and security grill footbridges have been realised (made of Alugril or Orsogril) these are positioned behind the PV modules on the principal and secondary beams. In the executive project we put many handrails, but during a function check we decided to keep the handrails off to improve photovoltaic efficiency in wintertime.

Figure 5. (a,) Details of the photovoltaic integrated structure of shading devices. (b) Photovoltaic shading devices

Photovoltaic modules are 35° tilted and south oriented. The electricity produced in DC current by PV modules will be fed, after conversion into alternate 400 V and 50Hz, into the building grid connected to the Medium Voltage Distribution National Grid. The energy produced will be measured trough a proper meter, installed by the grid manager and accounted under the directive n° 224/00 by the National Energy Authority. System production

On the base of sun values on floor and on the modules plane tilted 35°, and assuming an average energy 75%efficiency of the system in the different situations, system electricity production, agreed as electrical energy given to the ENEL grid is: about. 32.996 kWh/year.

Figure 6. (a,) View from the roof (b) Detail of the structure

The system has a completely automatic operation and it doesn't require any help for the regular functioning. During the first hours of the day, when it is reached a reasonable quantity of radiance on the plane modules, the PV system automatically begins to pursue the point of maximum power to maximize power from the PV field.

3.1. Control System and Monitoring

For operation control of the system and its diagnostic a monitoring system will be realised, able to be connected to a PC from which it will be possible to have indication of:

- operation of inverters with indication on possible system malfunction;

- Energy input and output indications: voltage, DC and alternate current provided

- historical file of the electric performances in the last months.

The software developed on purpose for these applications has an easy to understand graphic interface. The elaboration of the data of the historical file is realised with the development of graphs and charts, and it will allow to have a report every six months. Through the constant internet connection data will be visible to the PV Enlargement group of research. The inverters must be predisposed for the assemblage of the data acquisition system. The acquisition system essentially constituted of sensors and converters, and by a Data acquisition system.

Will be measured:

1) Radiance on the modules plan., 2) Global radiation, 3) Photovoltaic module Temperature

4) String DC current, 5) String DC tension, 6) Ambient Temperature,

7) String Power and energy, 8) Inverter output power and energy, 9) Global output Power and energy

4 Physics laboratory building in Sesto Fiorentino University of Florence

The Pv integrated system is a 50 kWp divided in two systems, one in the façade and the second in the roof as shading devices.

Figure 7. (a,) View of the shading devices integrated in the façade (b) Detail of the structure

The 3 subsystems are realised by 60, 54 e 74 photovoltaic modules divided in variable strings from 9 to 12 modules.

The total panel numbers is

1 Subsystem: 54 modules 290Wp - 15,66 kWp

2 Subsystem: 60 modules 290Wp - 17,40 kWp

3 Subsystem: 74 moduli da 225Wp - 16,65 kWp

Total peack power: 49,71 kWp, for a total production: 51.766 kWh

The PV modules area

The photovoltaic modules used are of the type with high peak power composed of 60 multicrystalline solar cells 156x156 mm.

The integration of the photovoltaic shading devices in the facade can improve the thermal comfort conditions in summer, the facade shielding from solar radiation and reducing glare in interior hallways of the building.

5 University residential student building in Florence. University of Florence

The system is integrated into the roof of the building of the university residences in Mezzetta Street in Florence.

The plant type is grid-connected and the connection mode is "in-phase low voltage." The power plant is equal to 19.92 kWp, and the estimated production of 21 320 kWh of energy per year (minimum value to ensure), derives from 94 amorphous silicon modules occupying an area of approximately 220 m2 and 34 silicon modules monocrystalline occupying an area of 44 m2 approx., power, respectively: - 12.784 kWp - 7.14 kWp.

Figure 8. (a,, b) View of roof with the two PV systems, thin film and monocristalline modules

3. Results and Conclusions

The Tuscany photovoltaic integrated projects constitute an excellent example of PV application and moreover for PV integration in retrofitting cases.

Same are retrofitting projects, for the urgent need to cover the energy supply of those buildings and put accurate attention to bioclimatic and solar active technologies, exploiting the favourable moment of Government incentives.

The main idea is to stimulate the Public Administration to be an example of an environmental political action. The action comes as a consequence of previous partners experiences in their own countries, and a consequence of the evaluations about PV researches carried out in schools and public buildings

Public actions result therefore necessary to stimulate such systems adoption, to encourage the firms to find new process and technical solutions, knowing that interesting borders amelioration exist, whether to costs level or to devices efficiency increase. A great activity of new products development - more suitable for the architectural applications - is to remark as effect of the support's mechanisms until now adopted by several countries.

In Italy the PV market is not yet adequately benefited, it is constituted above all by applications not covered by other systems. For the big fittings demand is obviously institutional piloted therefore by political will and by opinions movements, rather than by real demands and needs to satisfy.

The most recent typology of Photovoltaic technology applications is the one using buildings integrated systems: PV systems can be used as integrative source, a contribution - according to the dimension of the plant – to the building global electric budget. These applications introduce different advantages:

- energy produced near user has a greater value than energy furnished by the traditional electric power station;
- electric energy production during insulation times allows to reduce the demand to the net during the day, just when there is the greatest request. Hypothesising a high development of building integration of PV systems, it is possible to foresee a levelling of the daily peak request, usually corresponding to the more expensive kWh electrical cost. It is a more and more interesting alternative, particularly for the increasing use of the conditioning systems in the residential, commercial and public buildings;
- the PV installation cost could also be an avoided cost decreasing the global building cost, because the PV modules can be constructive elements replacing tiles or façades glasses;
- the adoption of these systems allows the diffusion, directly among the consumers, of a great “energetic conscience”, with positive increase of the use of electric energy produced and exchanged with the net.

It is necessary to highlight the PV systems esthetical value: the silicon cell has a pleasant aspect and a particular effect, making it an interesting material for the contemporary architecture. It is possible to use different colour cells, adapting them to the several contexts.

Conflict of Interest

The author Lucia Ceccherini Nelli declare “no conflict of interest".

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