Review

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Guidelines for Integrating Solar Energy in Sicily's Buildings

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Abstract: Wise utilization of today's new solar energy technologies provides buildings with new aesthetic value which is no longer in conflict with efficiency in solar energy conversion. We outline the criteria for incorporating solar photovoltaic (PV) and solar thermal (ST) technologies in the building design in Sicily's built environment. Better education in solar energy and in solar architecture of architects and civil engineers, as well as better communication efforts of solar energy companies, will be instrumental to afford the long-awaited local and global boom in the adoption of building-integrated PVs.

Keywords: BIPV, BIST, photovoltaic, solar thermal, solar energy education, solar architecture

1 Background

Concluding a study summarizing the first achievements of building-integrated photovoltaics (BIPV), in 2010 we were writing that "the three forms of energy needed by a building – heat, cool and electricity – will be generated by solar energy and buildings will be converted from mere energy users to energy users *and* producers" [1].

Energy use in buildings represents about 40% of the total primary energy used in industrialized countries [2]. Hence, considering the huge built surface already available at no cost for the integration of the two main solar energy technologies, and their current low cost, both BIPV and building-integrated solar thermal (BIST) systems will likely play an important role to meet the energy demand of buildings for electricity, cooling and the provision of domestic hot water. The argument is not new. In 1999, a practitioner of the solar thermal industry ending a thorough account on BIST history and forthcoming perspectives in the US, wrote that "with more than 66 million residential buildings, nearly 5 million commercial buildings, and approximately 2.5 million farms and manufacturing facilities, the energy savings potential of large scale adoption of BIST systems in the US are enormous" [3].

What is new is that today lightweight, long life, elegant and low cost BIST and BIPV systems capable of minimizing load and aesthetic impact on existing roof and facade structures are now available on the marketplace at affordable cost.

For example, researchers at the Institute for Applied Sustainability to the Built Environment in Switzerland, and others in the Netherlands, after a survey of the current status of the BIPV market in Benelux and Switzerland recently reported that new buildings using BIPV products can be executed at "very similar costs compared to projects involving conventional building applied PV products" [4].

The problem of installation of solar thermal and PV systems once typically mounted on building roofs with no attempt to incorporate them into the building envelope creating aesthetic and space availability is now over.

Following two decades of intense researches originally carried out in Europe since the mid-1990s, a number of economically viable solar energy BIPV and BIST systems for full incorporation and integration into the traditional building envelope have been developed, affording additional advantages such as enhanced structural integrity, weather impact protection, fire and noise protection. In this context of rapid change, books [5] and guidelines [6, 7], on solar energy architectural integration have been published, including guidelines for BIPV in the Mediterranean regions [8].

The deployment of BIPV and BIST guidelines in Sicily, we argue in this study, is an urgent local need. Italy's largest and sunniest region today hosts a 1.4 GW PV power installed between 2009 and 2014. Whereas several large roof PV arrays were nicely integrated in order to access the highest Feed-In-Tariffs (FITs) granted to BIPV plants, most solar thermal plants installed in Sicily over

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domestic and commercial buildings are not integrated, resulting in aesthetically unpleasant architectures which contribute to consolidate the wrong, but still common, public perception of solar energy as an obsolete technology, certainly not adequate for a region hosting a huge historic and artistic heritage.

Referring to selected successful cases, we provide the long-awaited guidelines for the integration of the two main solar energy technologies in the built environment of the largest island of the Mediterranean Sea. Combining two main requirements, namely enhanced aesthetic compatibility *and* simplicity, the outcomes will be useful to policy makers, engineers, architects, public officials and renewable energy companies evaluating the integration of solar thermal and PV technologies in new and existing buildings in Sicily and in related Mediterranean areas.

2 Guidelines for integrating PV systems

In BIPV, as put by Heinstein, the PV modules are here both a functional unit of the finished building *and* also a construction element of the building skin [9]. Hence, newly developed BIPV solutions combine active properties such as PV energy generation with passive properties such as thermal and acoustic insulation, electromagnetic shielding, natural lighting, shading modulation, selective filtering of components of solar radiation, replacing conventional construction materials (Figure 1).

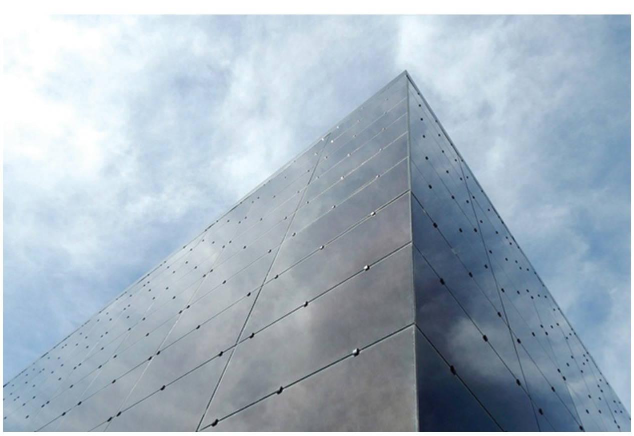

Figure 1: Photovoltaic glass was used on the facade of Onyx Solar's headquarters in Avila, Spain. Around 32% of the building's energy needs are met through the solar energy created. [Image: Courtesy Arcplan Consulting.]

It is perhaps therefore not surprising, considering the prolonged high cost of PV modules adding to the cost of the specific mounting systems for total integration, that in the very same 2013 study Heinstein and co-workers concluded that "none of the predictions that have been made about the emerging BIPV industry have really hit the target", with many BIPV producers having been forced to exit the market.

In a somehow less purist approach, still aimed to render an aesthetic value to constructions functionalized with PV modules, in 2007 Italy's government enacted a second FIT law which ascribed significantly higher tariffs to BIPV arrays connected to the grid.

In short, the government's body responsible to administer the FiT funds (GSE, Gestore Servizi Elettrici) quickly drafted 13 guidelines, 3 for partly and 10 for totally integrated PV arrays, on how to integrate the PV modules on the built environment which included even windows and billboards (Table 1) [10].

Table 1: Italy's typologies for partly and totally building-integrated PV [10].

Partial BIPV
1. PV modules on flat roof and terrace
2. PV modules coplanar on roof, facade and balcony
3. PV modules installed in urban fabric elements
Full BIPV
1. PV modules replacing building skin's materials
2. PV modules integrated in station-roofs, pergolas and outhouses
3. PV modules replacing transparent surface
4. PV modules integrated in noise barriers
5. PV modules integrated in lighting and advertising structures
6. PV modules integrated in sunshades
7. PV modules integrated in balustrades and parapets
8. PV modules integrated to windows
9. PV modules integrated to shutters
10. PV modules installed as cladding or roof

This prompted the deployment of a large number of partly or totally integrated PV systems throughout the whole country. In summer 2013, when the FiT programme was terminated with Italy hosting almost 18 GW of installed solar PV power, more than 60% of PV systems benefiting the FiT incentives were partly or totally architecturally integrated [11].

Having a rich history going back 7,000 years, Sicily hosts a large number of heritage buildings. In a recent elegant paper [12] on the architectural integration of active solar systems in Greece and Cyprus, Bougiatiotia and Michael emphasize that the historic character of a settlement does *not* exclude the application of new systems and new technologies; rather, as suggested by the 1987 Charter for the Conservation of Historic Towns and Urban Areas of the International Council on Monuments and Sites (ICOMOS, a non-governmental body established in 1965), active solar systems “should be in harmony with the surroundings” and “should not be discouraged since (they) can contribute to the enrichment of an area” [13]. In brief, they should be compatible with the character of the historic town or urban area.

The first set of aesthetic criteria for the application of active solar systems contributing to the enhancement of the architectural image of the buildings were published in 2004 by Kaan and Reijenga (Table 2) [6].

Table 2: Recommended criteria for good PV architecture (IEA-PVPS, 2004) [6].

Natural integration of the PV system
The PV system is architecturally pleasing, within the context of the building
Good composition of colours and materials
The PV system fits the gridula, is in harmony with the building and, together, forms a good composition
The PV system matches the context of the building (contextuality)
The system and its integration are well engineered
The application of PV has led to an innovative design

Figure 2: PV tiles over the roof of a church in Sicily’s Zafferia. The 5.5 kW PV array was realized in 2013, with the approval of the Superintendency of Arts. [Image courtesy of Wegalux.]

Commissioned by the International Energy Agency within its Photovoltaic Power Systems (PVPS) programme, the said work used a Delphi analysis of a group of experts to formulate a number of criteria whereby integration of PV in buildings could be architecturally classified and evaluated.

One of the first new PV products developed to provide heritage buildings or buildings in conservation areas with PV electricity was solar slates and solar tiles. Unlike traditional solar panels, these systems blend in with standard roof slates to create a solar roof such as that in Figure 2.

Yet, in the same study [9], Heinstein and co-workers were rightly emphasizing that solar tiles, being comprised of hundreds of tile-shaped solar cells, each applied on a traditional tile with its own cabling and the same large number of electrical plug-in connections, and each susceptible to water and moisture, are technically deficient and entirely uneconomical due to the variety of existing different tiles and the associated geometric variations that make these BIPV products linked to a specific tile producer, and to just one type of tile from its assortment.

More compact intermediate solutions like roof-shingle units compatible with different types of tiles, they concluded, would be “far more promising and cost effective”.

One successful example of such solar shingles is the *Elettrotegola* system installed on several Italy’s roofs by substituting any kind of European tile (Marseillaise, Portuguese, Roman, pantiles and others) with a flat, thin solar module comprised of blue polycrystalline silicon solar cell laminated onto a polymer further attached to insulating polyurethane. The resulting architectural outcome in an old building based in the city centre of Catania, Sicily’s second largest city, is shown in Figure 3.

Figure 3: The PV roof of Hotel Rigel, in Catania, is comprised of polymer-supported PV modules covering 55 square metre, with an overall 6 kW power. [Image courtesy of Brianza Plastica.]

The integration of the PV technology in Sicily's buildings, we argue herein, will conform to GSE guidelines published in 2007 [10], using mounting systems for total integration. Modules, however, will be preferentially coloured in black and strictly antireflective, which is far more elegant when compared to conventional blue of conventional poly-Si modules (Figure 4).

Whenever possible, solar companies will install modules with no frame, as displayed in Figure 5 in the case of the 800-year-old Castello di Sant'Alessio built 400 m above the sea level off Sicily's eastern coast, wherein twenty black modules, each with a 300 W nominal power, cover a 33 square metre surface affording an overall nominal power of 6 kW, capable to generate each year almost 9,000 kWh.

We remind here that, like in other southern areas of the Mediterranean basin, PV modules with southerly orientation will be exposed to excellent solar irradiation. To maximize the yearly energy output, the tilt angle of the modules should be equal to the latitude angle of that specific area. Sicily is comprised between 36.3° and 38.1° N.

Hence, South-oriented modules tilted between 36° and 38° from the horizontal will provide the maximum output. Yet, deviations from the optimum tilt, usually with smaller angles down to totally horizontal position in order to be integrated to the inclined or flat roof, reduce the incident solar radiation only to a limited extent, especially during the summer hottest hours when electricity demand (and economic value) is remarkably high due to air conditioning. This can be shown using BIPV producibility analysis based on the Photovoltaic Geographical Information System (PVGIS) estimations, which allows the adoption of PV models for all the main PV technologies commercially available [14].

For example, deviations from the southern orientation have an effect on both parameters, but in no case do

Figure 4: The BIPV roof of this home, located in Sicily's Casteldaccia, comprises of black solar modules replacing the corresponding tiles. [Image courtesy of the home's owner.]

Figure 5: Installed in 2009, the BIPV array of the Sant'Alessio Castle comprises 20 black frameless modules, covering 33 square metres. [Image courtesy, SunPower Corporation.]

they exceed 252 kWh, for the yearly electricity production, and 390 kWh/m^2, for the yearly sum of global irradiation, which is less than 20% of the average of the respective quantities.

Main orientations, up to a ±90° deviation from the South (Figure 6), as well as the different slopes from the optimum down to flat position (Figure 7) largely exceed the threshold values and are, therefore, acceptable for the application of solar collectors, as well as PV systems.

3 Building integration of solar thermal systems

The integration of solar thermal technology is a now a well-developed field of practical action, and no longer the domain of developmental research [7]. Recognizing that the architectural quality of most existing BIST systems was poor, the first guidelines were published by Probst and Roecker in 2007 [15].

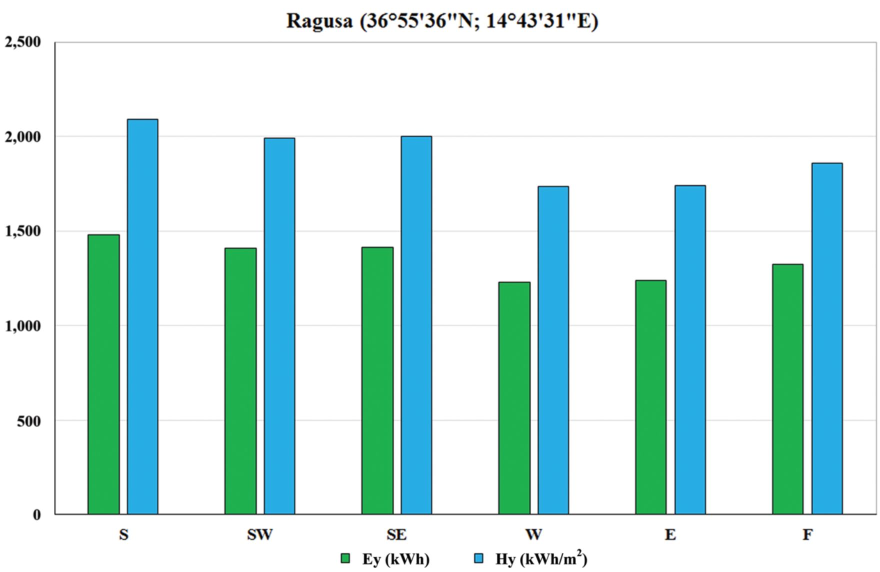

Figure 6: Total yearly electricity production (Ey) and sum of global irradiation (Hy) per square metre for different BIPV orientations for Ragusa (RAG). S = south, SW = south-west (45°), SE = south-east (–45°), W = west (90°), E = east (–90°), all adopting optimum slope. F = flat (horizontal modules). Installed power = 1 kWp, estimated system losses = 14% (PVGIS online software: http://re.jrc.ec.europa.eu/pvgis/).

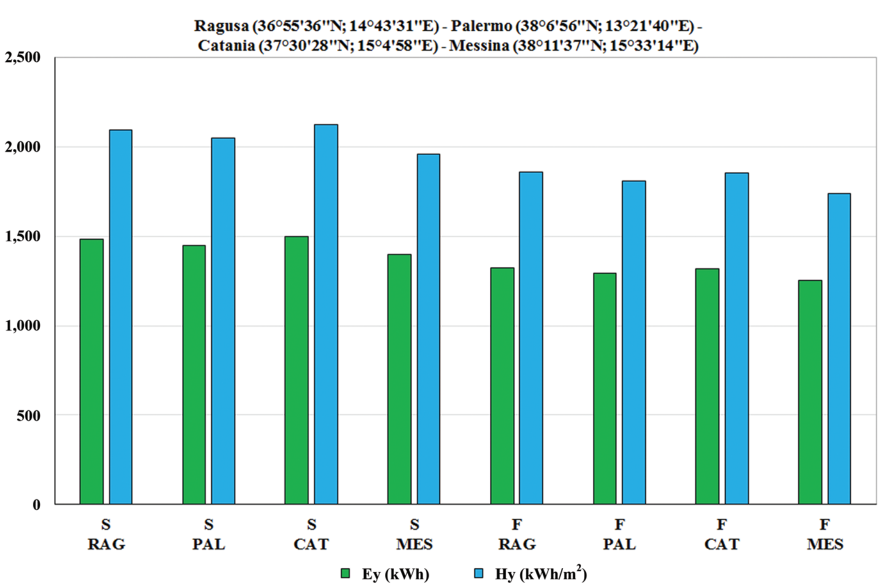

Figure 7: Total yearly electricity production (Ey) and sum of global irradiation (Hy) per square metre for Ragusa (RAG), Palermo, (PAL), Catania (CAT) and Messina (MES). S = south, adopting optimum slope. F = flat (horizontal modules). Installed power = 1 kWp, estimated system losses = 14% (PVGIS online software: http://re.jrc.ec.europa.eu/pvgis/).

Table 3: Integration BIST guidelines [15].

1	*The use of solar energy system as a construction element (façade cladding, roof covering, etc.) greatly eases the integration design work: The building design logic is easier to follow when the architect has to balance fewer elements fulfilling more functions.*
2	*The position and the dimension of the collector field should be defined considering the building as a whole (not just within a façade or the roof): Energy production goals, formal integration needs and solar thermal technology choice are all parameters to play/work with in defining a suitable system dimension and position.*
3	*The colours and materials of the system should be chosen together with the colours and materials characterizing the building and the context: The initial choice of technology is fundamental, as it imposes the material of the external-visible-system layer (glass, metal, plastic, etc.). Within the chosen technology, the material treatments (surface colour and texture) offered by the various available products can then be considered.*
4	*Module size and shape should be chosen considering the building and the façades/roof composition grids (or vice versa): Proposed jointing types should also be carefully considered while choosing the product, as different jointing types differently underline the modular grid of the system in relation to the building.*

The integration criteria and design guidelines (Table 3) resulted from a survey on architectural quality, addressed to more than 170 European architects and other building professionals.

Lamenting that integration requirements were difficult to achieve with the collectors then available on the market, they described a range of design possibilities for the collectors (size, shape, colour, etc.) capable to ensure both energy efficiency and architectural integrability that were subsequently further advanced in a seminal textbook [7].

Today, as mentioned above, a number of new BIST products are commercially available that were developed taking into account said integration guidelines. For example, the natural circulation solar water heating system shown in Figure 8 elegantly integrates with the roof's tiles with its coloured boiler only 26 cm thick, whereas the use of the evacuated tube technology maximizes the production of hot water during winter and autumn seasons, when the need for sanitary hot water is highest.

Full integration of the solar collectors is even easier when the forced circulation solar thermal technology using either flat plate or evacuated tube collectors is adopted, such as in the case of the hotel in Palermo's downtown displayed in Figure 9 [16].

Realizing a thorough BIST system requires that architects and civil engineers be fully aware of today's solar thermal technologies and available products. For instance, *Solarair* is a solar thermal air collector specifically designed for building heating. No other fluid is involved in the heat transfer process, so the collector does not suffer from losses due to thermal exchange, typical of most existing heating systems [17].

What is unique to this collector and relevant to this study is that every single collector is specifically designed for the use and arrangement it is meant for.

No shape standardization is undertaken, so as to obtain the best aesthetic and energy results by designing

Figure 8: This new-generation solar thermal system (*Plano*) uses a 180 L boiler of limited height (26 cm) whose colour further minimizes the visual impact on roofs comprised of tiles. [Image courtesy of CST Solar.]

Figure 9: The BIST forced circulation system on the roof of Hotel Porta Felice in Palermo. [Photo courtesy of the authors.]

the panel according to its final positioning and canalization length (Figure 10) [18]. Rather than a liquid, the collector uses air as thermovector fluid, heating and pumping air inside the building thereby warming and dehumidifying its entire mass.

In addition, the collector does not recycle the air inside the house, but swaps it with fresh air from outside, granting excellent air exchange and lowering internal moisture levels.

Savings in heating expense in Sicily can go beyond 70%, with significant health benefits due to the oxygen-rich, fresh air continuously made available during the sunny hours of the day.

4 Meeting educational needs

Solar architecture is a young profession, lacking professionals with adequate education. In 2014, Cappel and co-workers in Germany and in Austria, namely from two of the world's leading countries in solar energy, published the outcome of a survey among 40 planners, construction companies, collector manufacturers and customers, mostly aiming to identify the barriers related to solar thermal façades [19].

Surprisingly, they found that after solar thermal technology cost, a "huge lack of knowledge" was the second most important problem identified.

The same team emphasized that the "good news is that all the technology is available and that the companies are able to construct solar façades". Similar considerations hold true for PV energy, a field in which lack of global educational was first identified by Broman three decades ago, and still found persisting in a recent broad account on the global status of renewable energy education [20].

For example, in Sicily very few architects and engineers are aware that PV membranes exist and even installed in their own cities such as the BIPV system on the roof of a Palermo's theatre portrayed in Figure 11.

Five years later, new flexible PV technology has brought the nominal efficiency of related membranes and modules from about 6% to 11%, making their

Figure 10: Wall-mounted Solarair collector. Each collector is specifically designed to meet the shape and configuration of the building's surface to be integrated. [Photo courtesy of Solarkup.com.]

Figure 11: The flexible 20 kW PV array on the roof of the Teatro Crystal, in Palermo, uses a polyolefin membrane supporting the amorphous silicon modules. [Photo courtesy of Medielettra.]

installation even more convenient, while retaining all the other advantages of covering the roof with an impermeable, insulating polyolefin membrane such as those integrated with flexible PV modules [21].

Clearly, new and better education in solar energy and solar architecture for construction professionals and building companies needs to be organized, deployed and made easily accessible in both economically developed and developing countries, preferably by independent research and educational bodies.

For example, very different estimates still exist for the price of solar PV modules: $0.62/W at the end of 2014 [22], or $0.45/W [23]. What is then the price a construction company's purchasing manager should consider convenient: $3.52/W as in the case of >100 kW installed solar systems in early 2014 [24]?

By the same token, it is often claimed that solar PV energy is intrinsically limited to face mankind energy needs due to the huge amount of land it would take to meet the global electricity demand. Yet, is this true? A recent study identifies and clarifies this and related aspects [25].

In brief, governments across the world need to take the initiative and organize new educational activities in the crucially important field of solar energy.

Similarly, solar energy companies which today offer a broad selection of economically viable and new BIPV and BIST solutions need to intensify, broaden and improve their communication and marketing efforts [26], to reach out to both construction professionals *and* new customers.

5 Outlook and conclusions

In the distributed generation scenario invoked by Scheer [27] and the other pioneers in renewable energy, the architectural, structural and aesthetic integration of PV and solar thermal collectors into the facades and roofs of buildings allows to transform the built environment comprised of homes, schools, offices, hospitals, hotels, recreational and commercial buildings, stations and airports into a set of scattered energy generators providing valued energy exactly in the form required by people living and working in said buildings (electricity or low-temperature heat).

This transition is now taking place in numerous countries beyond the EU including China, the US, Japan, Chile, Brazil and several African countries as well. The policy outcomes of the UN Conference on climate change (COP21, December 2015) and the continuous lower cost of solar modules and solar collectors will only reinforce this trend.

This study outlines the criteria for incorporating solar PV and solar thermal technologies in Sicily's buildings. Adding to the guidelines published in 2007 by Italy's government body for BIPV [10], and by Swiss researchers for BIST [14], we specify selected further requirements for the aesthetic integration of solar PV and ST collectors, providing examples of successful integration in buildings erected in protected areas.

Accelerated innovation is taking place in both solar photothermal and PV domains. New solar collectors, new solar systems and new PV modules (from solar PV glass through flexible panels) simplify and enable economically viable architectural solutions technically simply not feasible until a few years ago.

Eventually, architects and engineers using these guidelines will be able to provide their customers with elegant, efficient, convenient and reliable solar energy solutions. By doing so, they will contribute to renew and enhance the perception of solar energy technologies as a perfectly suited means to add beauty and value to all sorts of buildings, including heritage constructions, to the benefit of workers and of the whole community.

The education of architects and civil engineers, though, must be broadened to encompass solar energy technology and solar architecture for an intelligent and diversified application of each solar technology based, as suggested by Heinstein, on its physical eligibility [9]. The urgency of this need has been lately identified in several studies [17, 18, 28]. How this could be effectively accomplished is the subject of another study [29].

Finally, in Sicily like in several other world's regions, massive adoption of solar energy technologies to provide buildings with clean, low-cost energy requires solar energy companies to undertake new communication and marketing efforts to reach out to both construction professionals and potential customers, namely all of us who live and work in buildings which remain far from a full and wise utilization of the significant amount of solar energy reaching each building every day.

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Bionotes

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