A Revolution for Architecture and Photovoltaic's Zero Energy Buildings: A New Opportunity and Challenge for Technology Based Design

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ABSTRACT

The recast of the European Directive 2010/31/EU establishes that starting from the end of 2020, all new buildings will have to be Nearly Zero Energy Buildings According to this directive, 'Nearly ZEB' means a building that has a very low energy yearly energy consumption, which can be achieved by both the highest energy efficiency and by energy from renewable sources, A relevant international effort on the subject of the Net Net ZEBs-Net ZEB meaning that the buildings are connected to an energy infrastructure-is ongoing in the International Energy Agency (IEA), joint Solar Heating and Cooling (SHC) Task 40 and Energy Conservation in Buildings and Community Systems.

Net Zero Energy Solar Buildings' both from the theoretical and practical points of view, this new 'energy paradigm'-or the Net ZEB) balance- might be a revolution for architecture and for Photovoltaic's (PV), too.The engineering only research taking into account mainly the energy aspects seems to be not sufficient to ensure the diffusion of ZEB models: in achieving the ZEB target, a major role will be played by architects and designers, who are amongst the main actors of this revolutionary change. More precisely, because the form of our buildings and cities might change radically because of this new energy requirement, the way architects will take up the challenge of designing ZEBs is crucial, as architects are highly responsible of the form of the city and of its symbolic meanings.In a near future, buildings will be designed to need very little energy (passive design strategies for energy efficiency) and to integrate active surfaces (i.e. PV modules) for generating energy.

In the future, design has to consider not only the space we use directly but also the space required to provide for electrical and thermal energies from renewable sources: the surface necessary for placing the energy generation devices. This area can be defined as the 'building's energy footprint' . Because the renewable energy generation systems, in contrast to conventional energy sources, are visible, for the first time in the tradition of architecture, energy can take a 'form' (i.e. shape, colors and features of a PV generator), and architects are responsible for designing this form(s). Photovoltaic's has many potentialities in a ZEB scenario, thanks to its features and enormous decrease in cost. Because of the high energy consumption of the European countries, PV can contribute significantly to the reduction of the primary, conventional energy supply, as well as to the reduction of the CO2 emissions PV seems to be technically the easiest way to obtain the zero energy balance, as the recent, sharp, drop in prices makes it competitive even with active solar thermal collectors and building materials in general.Photovoltaics is able to generate electric energy from the direct conversion of the sunlight; it can power any kind of energy request of the building (thermal and electrical), with the consequence that a ZEB could be theoretically entirely powered by Photovoltaic.

Keywords : *Zero Energy Buildings, COW emissions, Photovoltaics and future of PV generator.*

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1. INTRODUCTION

The consequent influence of the use of PVon the architectural image of the building, and on the way the city itself can look like, is very considerable, opening up a new wide perspective for the relationship between PV and architecture. For many reasons, which we will clarify later in the paper, if we look at the use of PV in ZEBs, the existing research on the use of PV in buildings could be not sufficient. Until now, in fact, much research has been carried out on how to use PV in buildings focusing on technical, aesthetical (and economical) aspects. Nevertheless, the relationship between PV and the energy balance of the building was not the main concern. The need to meet the ZEB balance opens new perspectives for the use of PV: PV might, in fact, be used into the building envelope ('Building-integrated PV (BIPV) or Building-added/attached PV (BAPV)), and also, it might be used close to the building ('on-site' or 'nearby' energy generation) accounting for the building energy balance. Furthermore, the boundary of the building's balance could be also extended to a cluster of buildings, with the consequence that the use of PV should be described and accounted not for a single building but for a cluster of buildings. In this condition, it seems unpostponable to open a design investigation on the use of PV in Net ZEBs, where ZEB balance is the main target of design. The main questions that the authors of this paper would like to bring forward are as follows: taking into account a hypothetical ZEB scenario, are there new research issues for PV? Are there new possible perspectives for investigating the relationship between PV and its use in our buildings, cities and landscapes? If there are some new issues and relationships to be taken into account, are there any consequences on the product market development for PV?

These questions should be approached both from the engineering and from the architectural point of view, trying to create a bridge over scientific knowledge and architecture's practice. The authors of this paper aim to give a contribution to the investigation of the architectural aspects by envisioning some possible new research issues that overlap the two disciplinary domains and opens towards an interdisciplinary approach.

2. A REVOLUTION FOR THE USE OF ARCHITECTURE AND PHOTOVOLTAIC'S ZERO ENERGY BUILDING A NEW OPPORTUNITY

What are the possible formal results for the use of PV in ZEBs? An analysis of the 30 case study buildings from 10 countries documented in the IEA SHC Task 40—ECBCS Annex 52—revealed that the buildings' solar PV systems were mostly delivering only a small fraction of the total energy need. In spite of this, in many cases, the solar PV modules were sticking out the building's footprint, in a way that the design challenges had not been adequately addressed. Nevertheless, conceiving a PV system in a Net ZEB so that its formal result is satisfying should be possible. In the following, we will show some possible formal results for PV in ZEBs. We will start from the single building scale and with the energy generation within the building's envelope, to enlarge the discussion to the energy generation within the building's footprint, up to the 'on-site' generation, in the case of a single building or of a cluster of buildings. The building can be seen as a fantastic integrator of technologies [1], which allows for the ZEB objective and for a good aesthetical performance, too. As a very early and pioneering example where the building is conceived as an integrator of technologies, we will give the House Chanelle, designed by the Norwegian architect Harald Røstvik [2], built in Stavanger (Norway), on the occasion of the Future Exhibition in 1988 (Figure 1).

Fig.1. Chanelle House, Stavanger, Norway, 1988. PV is used together other solar technologies, and its influence on the building's image is quite limited. Design

Here, the main design principle is to apply the most relevant technologies necessary for the service, in a way where the systems supplement each other, creating synergies.

The Chanelle house shows that in the case of use of different integrated technologies, the use of PV has a limited formal, aesthetical influence on the building (Figure 2).

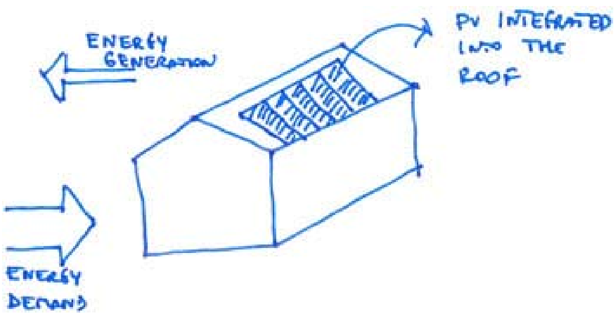

Fig. 2. Conceptual sketch for a minimal formal result for the relationship between PV and the building, when using several energy technologies.

But, as already said, PV has the potentialities to be the only energy carrier of a ZEB, and in this case, the aesthetics of the architectural design can be much more influenced by PV. More specifically, in this case, the PV area has to be calculated (kWp or m2) so to generate the required energy (kWh/year) according to the ZEB balance. As a consequence,because generally the available area for PV is limited and constrained by the building features, the yield of the PV system has to be maximized. Both these parameters greatly influence the architectural design. In fact, the yearly energy yield depends on both the placement, that is, the azimuth and tilt angles, of the modules and on the technical features of the PV modules. The optimal placement of the PV generator influences the shape of the building, and the technical features of the modules (e.g. colour, opaqueness and patterns of solar cells) limit the aesthetics of PV because they are chosen for maximum efficiency and minimum of costs. To suggest a possible formal 'minimalistic' result of the relationship between energy self-sufficiency and the architectural design, when using the only PV as an energy carrier, we will give as an example a minimal self-sufficient spatial unit named CAPA, designed by the Portuguese architects Cannatà & Fernandes [3], built in Matosinhos (Portugal) in 2003 (Figure 3).

Fig.3. CAPA,Matosinhos, Portugal, 2003. The PV generator is shaped as a sloped plane that characterizes the image of the building

CAPA is a parallelepiped with two glazed facades, based on a rectangle 30m deep and 9m long. The unit is equipped with a 2.2kWp PV plane, made of standard modules, which is placed on the top of the unit and supplies electric energy for lighting systems, informatics, phones and security. In the case of such a simple building (a one-storey small unit having only a demonstrative function, with no boundary constraints), the formal result of the ZEB balance can be quite expected: a large sloped PV plane (blue surface) added on the building volume, made of standard opaque PV modules (maximum power density and efficiency, minimum cost). This formal result can be defined as a minimal image of self-sufficiency, through PV, when optimizing the PV yield (Figure 4).

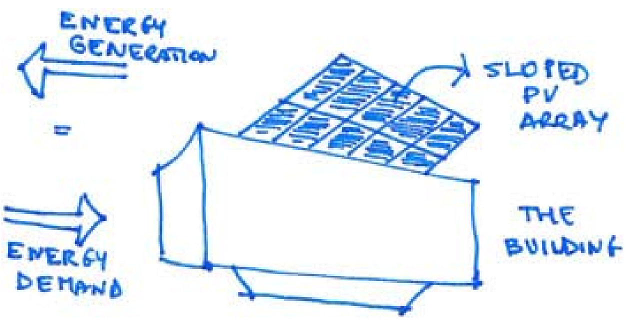

Fig.4. Conceptual sketch for a minimal formal result for the relationship between PV and the building in a one-storey building,when optimizing the PV yield.

To investigate further the possible formal relationships between the ZEB paradigmand the aesthetics of architecture, in contrast with the simple condition of CAPA, we consider now a 'normal' building: for such a building—for example, one of the multi-storey buildings, we are used to live in or to work in—characterized by a number of functions and by a certain energy consumption, the formal result is generally not that expected.

In this case, the only blue surface made of PV modules of CAPA, which looks like a 'hat' on top of the building, which is nevertheless included within the building's physical boundary, would be not enough. The building's physical boundary would be smaller than the PV area needed for powering the building energy consumption. If we consider the average solar yield of PV in Norway, and in Italy, and compare with possible average yearly energy consumptions of buildings, we can have an idea on how large the PV generator should be for meeting the ZEB balance (Table I).

$$\text{Formula : Required area } [m^2] = \text{energy consumption}(kWh/y)/\text{energy yield } (kWh/kW_p/y)/\text{efficiency}\,(kW_p/m^2)$$

The calculation of the building's yearly energy demand should include all consumption sectors, especially electricity consumption [4]. As a consequence, roughly, every time a building has more than two stories in Italy and more than one in Norway, PV should look like a blue 'hat', sticking out the building physical boundary (Figure 5). Because this kind of design outcome is not always appropriate (and feasible), it emerges the necessity to reduce as much as possible the building's energy demand, also through the improvement of the thermal performance of the PV modules. It emerges also that the ZEB target is feasible within the building's footprint, in reality, only for buildings having one or two floors. The range of formal solutions for PV in the case of a standard multi-storey building is theoretically very wide, being the form of the special PV 'hat' a good exercise for design: several studies show that the architect has more freedom than expected (tilt and azimuth angles variations) without penalizing the energy generation that much [5], and the domain of the architects creativity is very wide. Nevertheless, the constraints related to the cities' morphology, especially in dense areas, limit the range of the formal solutions to a couple of them. We will give two examples of such solutions: the Rainbow Headquarters, designed by the Italian architects Bianchi & Straffi and built in Loreto (Italy) in 2011 (Figure 6), and the SIEEB, designed by the Italian architect Mario Cucinella [6] and built in Beijing, China, in 2006 (Figure 7). Inthe Rainbow headquarters, the PV modules, having a total nominal power of about 360 kWp, can generate about 447MWh/year, which almost completely cover the energy needs for artificial lighting and power the HVAC system by using geotherma l heat pumps. Here, the conceptual PV 'hat' transforms into 'wings'. The PV modules are located on sheds (opaque on the South side and transparent for allowing the daylight on the North side), as well as on some canopies covering pedestrian walkways, and they are also placed on some support systems that create a sort of shed extension (wings) to the East. Despite the SIEEB is not a ZE one, PV is again arranged in 'wings' on sun-shading devices but in a different way with respect to the Rainbow building. The 'wings' are arranged on strips sticking out the building's profile, which modify the parallelepiped form of the building into a kind of semitransparent half-pyramid. The two examples we gave show that the formal repertoire for designing PV in Net ZEBs seems to be limited to a couple of solutions that benefit from the heritage of the outer-space architecture (Figure8), by conceiving PV generators as 'wings' that stick out the building to catch the sunshine [7]. Obviously, if we think that buildings are generally parts of clusters, organized in a certain urban morphology, then there is a strict limit on if and how much these wings can stick out the building. Definitely, in dense cities, with multi-storey buildings, such a wing solution would be not appropriate.

Table I. Surface requirements for PV modules to cover yearly energy consumption. Module efficiency: 12.5%. Evaluation PV Gis, JRC.

	Italy (Bari)	Norway (Oslo)
PV Yield (kWh/kW$_p$/year)	1350	750
Total yearly energy consumption (kWh/m^2/year)	PV area for each 10 m^2 of floor space	
30	1.8	3.2
60	3.6	6.4
90	5.3	9.6
100	60	107

Note: Typical consumption for household electricity (illumination, appliances etc. is in the order of 30 kWh/m^2/year).

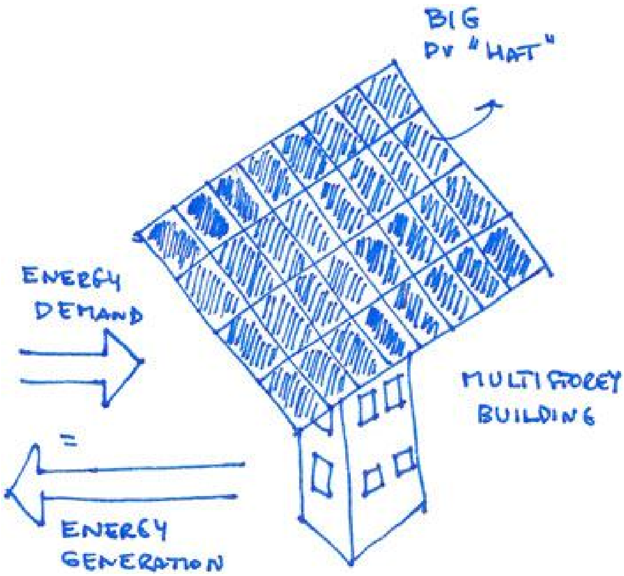

Fig4. Conceptual sketch for a minimal formal result for the relationship between PV and a multi-storey building, PV looks like a big 'hat' sticking out the building.

Fig.5. Rainbow Headquarters, Loreto, Italy, 2011, PV modules are arranged as wings hanging over from the building's boundary

Fig. 6. SIEEB building, Beijing, China, 2006. PV modules are arranged as wings that perform as sun-shading devices and give form to a kind of semitransparent half-pyramid.

As examples of a possible formal solution for the use of PV in a ZE cluster of buildings, located in a dense city, we will give two projects: 'The Roof', designed in 2010 by the Italian architects a [8], for an area in the city centre ofMilan (Tortona), Italy, and the project for Plaza del General Vara del Rey in Madrid, Spain, designed by the Spanish architects ELII Oficina de Arquitectura (Uriel Fogu, Eva Gil Lopesino, Carlos Palacios) in 2009.

In the Italian project, the density of the built area, as well as the various shapes of the buildings, is serious obstacles to the use of PV; therefore, the design of PV results in a semitransparent roof, which protects a cluster of buildings, providing it with energy (Figure 8) and supporting a swing figure 9. Here, the result of the use of PV is a hybrid space defined by the roof, used for both the habitat (buildings) and the energy generation [9] Nevertheless, at the urban scale, one might also conceive an energy generation space, which is a hybrid space (people enjoinment and energy generation) but designed so to be separate from the buildings.

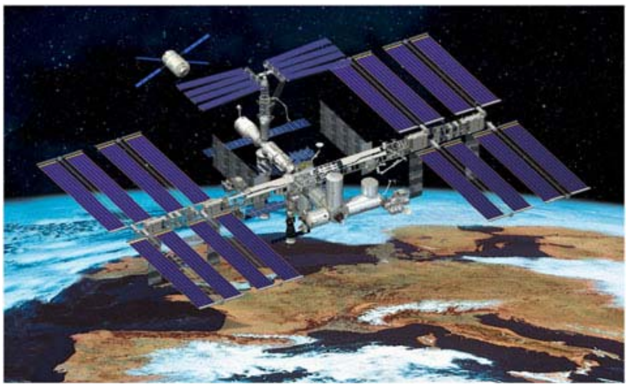

Fig.7. Outer-space architecture shows the attitude to extend large solar surfaces (wings) out the craft, to catch the solar radiation.

Fig. 8. The Roof project, Milan, Italy, 2010. PV modules are arranged in a semitransparent roof that covers a cluster of buildings.

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Fig. 9. Plaza del General Vara del Rey project, Madrid (Spain), 2009. PV is shaped as a pergola made of technological trees that characterize the square. Design: ELII Oficina de Arquitectura. Picture by courtesy of the architects

3. CONCLUSION

From a design point of view, the main challenge in a near future will be approaching the issue of the use of PV in Net ZEBs from a systemic perspective. This means to look at the building not as to a single building but as a part of a larger system of buildings (cluster), being also this system of buildings part of an even larger system (i.e. the city or the landscape). We know from Biology that it is not possible to investigate a living unit without taking into account the environment whit that this unit interacts . In a similar way, it seems that it is not possible to achieve the Net ZE balance of a building without taking into account the complex systems the building is part of and the other single units the building interacts with. For instance, a true NZEB could also account for the carbon balance of the original site. Questions such as has vegetation that ties carbon been removed and will the building create shade to other buildings thus cool them and increase their heat and daylight need are issues that should be addressed in future research. As a first result of this work, we believe that at least, the existing categorizations for the use of PV in buildings have to be rethought taking into account the ZEB definitions and the enlargement of perspective required for considering the 'on-site' and 'nearby' energy generation mentioned in the EU EPBD. We think that, to describe the way PV is used in a ZEB, some information on the building boundary conditions taking into account the energy balance should be given to compare different ways of using PV in Net ZEBs, for example: the building typology (office, educational, housing, etc.); the climate (cooling dominated, heating dominated, heating and cooling dominated); the number of occupants (people/m2). The PV system should be described in terms of energy generated versus power installed (kWh/m2/year vs kWp/m2), in relation to the energy balance boundaries (which consumptions are accounted) and percentage of the building's energy balance powered by PV. We showed some possible formal results both for the use of PV on building's footprint and on building's site. The building's footprint energy generation does not require new categories for describing PV. The only addition would be the typology of the 'wings': PV elements sticking out the building. In terms of generation 'at-site', then the detached PV systems should be described for the form they take in relation to the building and to the landscape they belong to. We showed that when dealing with dense city, it is necessary to think in terms of cluster of buildings for achieving a ZE balance. The formal result of the use of PV for clusters of buildings can be the design of hybrid public spaces where the people's enjoinment is mixed with the energy generation. We also showed that the 'at-site' energy generation should be approached from the Landscape Ecology perspective. The formal results of the use of PV 'at-site' can be appreciable at the landscape scale. This demonstrates the possibility to think of 'Landscape Integrated Photovoltaics (LIPV)' as the next domain for the PV investigation from the design point of view (site-integrated PV).

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