32st European Photovoltaic Solar Energy Conference and Exhibition
Munich, Germany, 20-24 June 2016

A MULTI CRITERIA OPTIMIZATION TOOL FOR BIPV OVERHANGS

Marco Lovati*, Jennifer Adami, Giuseppe De Michele, Laura Maturi, David Moser.
Institute for Renewable Energy, EURAC Research, Via G. Di Vittorio 16, 39100 Bolzano (BZ), Italy
*Phone: +39 0471 055667; Fax: +39 0471 055699; *E-mail: marco.lovati@eurac.edu
Keywords: energy, photovoltaic, buildings, efficiency, optimization, BIPV.

Summary: BiPVs are characterized by a inherent complexity as they sum the requirements of building industry and PV industry [1]. The complexity of the system generates risks and diffidence among stakeholders. The whole idea of BiPV is based on the concept of multifunctionality. To obtain it performance driven design should be used. Is there a method to tune the parameters of a BiPV architectural system, given its constraints? In this paper a new method is shown for the optimization of fixed BiPV overhangs taking into account electricity production and impact on the solar gain. The overhangs are described parametrically by the angle they form with the building façade. The first step is to reduce the total number of possibilities, using the net present value (NPV) of the system as a criterion [2], [3]. After the simulation of annual electricity yields, the thermal impact is accessed using EnergyPlus [4]. An optimization algorithm is used to find the best set of parameters.

Purpose of the work and approach: The method works on overhangs shading windows of 3 residential high rise buildings within a district. The aim is to optimize the design based on the annual electricity production and the energy savings generated by improved annual solar heat gain. The optimization is carried out through a genetic optimization algorithm [5], each combination of 3 tilt angles (one angle for each façade: west, south, east), is considered as an individual. The performance of every combination, both in electricity production and energy demand, is accessed through the simulation software EnergyPlus and Radiance [6]. Thanks to the selection of the best performing individuals generation by generation, the optimum combinations are found.

Scientific innovation and relevance: The method is innovative as there is no need from the designer to give the specific position of a building element as an input. It is instead based on architectural systems. Examples of architectural systems are the ventilated façade, the Trombe wall or complex fenestration systems. In this paper the architectural system explored is the BiPV overhang. Every architectural system can be parametrically designed, therefore optimized, and can be simplified with a model focused on the most compelling physical phenomena. In this example the parameter is the angle between the façade and the overhang where the main physical aspect is the solar heat gain. The method fits a widespread approach architects have toward environmental design as they prefer conceptual statements (e.g. "*F.L. Wright used white surfaces in the atrium to reflect light, The offices facing the atrium have all-glass walls."*[7]). The parametric optimization do not influence the decision of the strategy but gives as a result a set of optimal configuration that fulfill the strategy.

The (preliminary) results and conclusions: The described method has been applied on a residential district chosen as demo case, where we found a set of angles, with a specific annual cumulative production, and a specific difference in the seasonal thermal balance. In the paper we will present various strategies based on yield maximization, best NPV over a fixed timeframe, best configuration towards nZEB, etc. For certain configurations, as an example, the cooling load is reduced while the heating load is increased. Considering a higher coefficient of performances in winter, the primary energy demand over the year is improved.

Explanatory part

- Purpose of the work and approach

Figure 1: Schematic representation of a window with a overhang. In this paper the overhang used are active BiPV components

This paper shows a method to find an optimal way of using a particular BiPV system, specifically BiPV overhangs for windows are addressed. These consist in an opaque PV module hanging over a window [Figure 1], the idea is to block the solar gain mainly in summer when the sun angle is high while allowing most of it in winter. In this example, overhangs are optimized for three high rise residential buildings in a contemporary urban environment.
The method is based on the definition of the system using parametric design. In this case we used only one parameter: the angle between the overhang and the normal to the façade (0° = perpendicular to the façade, 90° = parallel to the facade). The method is used to find the best set of angles to obtain specific performance indicators. One set of angles is composed by 3 angles: west, south and east. The performance indicators are the electricity production and the annual energy demand for heating and cooling. The method uses multi-target genetic optimization algorithms, the best solution is found by combining electricity production and thermal energy demand for each combination of angles. Considering each combination of angles as an individual, the best performing will be conserved or recombined in the following generation. The output of the simulation is a group of solutions occupying the Pareto front of the two objectives optimization and is left to the designer to choose which one to develop in the following stage of the design. The choice comes from the will of privileging electricity production or energy savings, but the multi-functionality is kept in both cases. For each individual the electricity production is evaluated simulating the annual cumulative irradiation using the backward ray-tracing capability of the RADIANCE software. The number of modules is reduced based on economic suitability. Especially in the lower floors of the building, in shadowed conditions, a module would have a low yield and the window underneath would not benefit from a overhang. Because of this the least irradiated modules were discarded following the procedure described in [2], [3]. The procedure is based on two formulas [Equation 1 and 2:]

$$\mathrm{E}(n_{modules}) = \mathrm{A} \cdot \eta \cdot PR \cdot \sum_{n=1}^{n_{modules}} H_n \ \mathbf{and} \ NPV = \sum_{t=1}^{life} \frac{\mathrm{E}(n_{modules}) \cdot Cp(t) \cdot P_E(t) - \mathrm{m}(n_{modules})}{(1+r)^t} - I_0.$$

Equation 1 and 2

In these two formulas, $\mathbf{E(n_{modules})}$ is the energy output [kWh] for one year, $\mathbf{n_{modules}}$ is the number of installed modules, **A** is the area of a PV module, **η** is the module efficiency, **PR** is the performance ratio of the system, and $\mathbf{H_n}$ is the cumulative insolation of the $\mathbf{n}^{th}$ module [kWh/m2 yr]. **Cp(t)** is a coefficient of performance taking into account degradation, $\mathbf{P_E(t)}$ is the price of electricity in the given year, $\mathbf{m(n_{modules})}$ is the yearly maintenance costs associated to the number of modules. The number of modules chosen is always among the most irradiated as the modules list is sorted by irradiation from the most to the least. Once the NPV is calculated for every number of modules, the number which maximizes the economic gain in a target time-frame is chosen. An example is given in Figure 2 where the selection was based on different payback time, other option are possible.

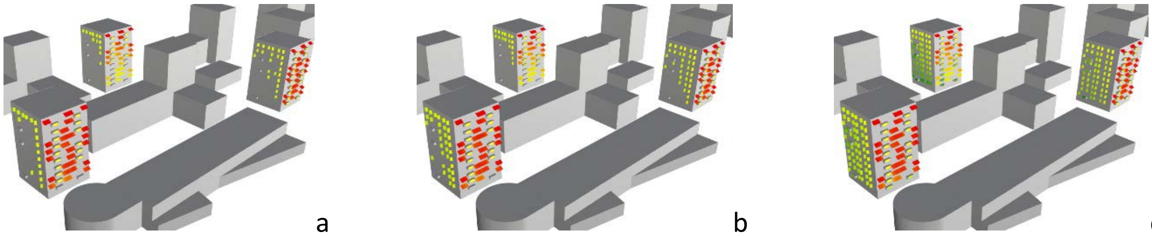

Figure 2: Three different configuration of the BiPV system: a) corresponds to a system with a short payback time (fewer modules), b) corresponds to a system with a medium payback time, c) corresponds to a system with a long payback time but more electricity production. These three examples are based on the same set of angles.

Once the number of PV modules is chosen, the impact on the energy balance of the building can be evaluated through an EnergyPlus simulation where the building energy consumption is modelled. The construction materials and components employed in each thermal zone envelope have their own thermal properties and characteristics (i.e. thickness, conductivity, density, specific heat, roughness, thermal absorptance). In this example one thermal zone corresponds to one floor of one building, the model is simplified through the assumption that the thermal zones cannot exchange heat among each other, therefore they are separated by adiabatic boundaries.

-Scientific innovation and relevance

The main innovation of the method consist in the input, which is parametric and based on a finished architectural system, which allows to perform optimization. This approach is especially relevant for BiPV because they are always part of an architectural system. Architectural systems are meant in this paper as specific structures within the building with a particular function (e.g. complex fenestration systems, ventilated facades, overhang, Trombe walls and so on) and they are associated with a specific model and physics (natural ventilation in a ventilated façade, solar heat gain in overhangs, etc). The designer will chose to apply a chosen BiPV architectural system over a specific surface. From this conceptual operation the simulation engine produces a model to study the system specific behavior and optimize its parameters. Tools and methods for the weather data analysis and environmental performance assessment already exist [8], [9]. Parametric optimization of architectural systems can be included in the architectural workflow. Designers begin a plan with conceptual statements or strategies such as “south glazing and high thermal inertia”, or “sun shading in summer and penetration in winter”[7]. In many countries, especially in Europe, Asia and the Middle East, designers look at historical buildings as examples of clever and sound environmental design [10], and these buildings are analyzed in a conceptual way. On the other hand, once the conceptual strategy has been chosen there is no way of proving it if not through series of trial and error. As an example, if the planner decides to use a Trombe wall on the southern façade, the output could be highly performing as well as poorly based on the dimension of the vents or other parameters. The method described in this paper is thus innovative because it does not interfere with the culture and the choices of the designer, leaving the freedom to the designer to select which environmental strategy to use. The method is relevant as BiPV are complex architectural systems and, once a specific system is chosen, they need a fine tuning of its parameters to be a desirable option and optimize all the concurrent effects such as energy yield, cost analysis, impact on the energy demand of the building and on the internal comfort.

Preliminary results and conclusions

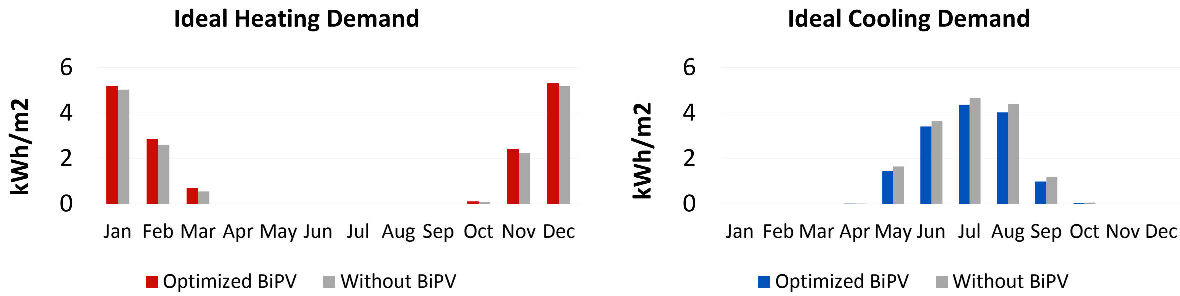

Figure 3: Ideal monthly heating and cooling demand. The presence of overhangs shows proportionally more effective in decreasing the cooling load than increasing the heating.

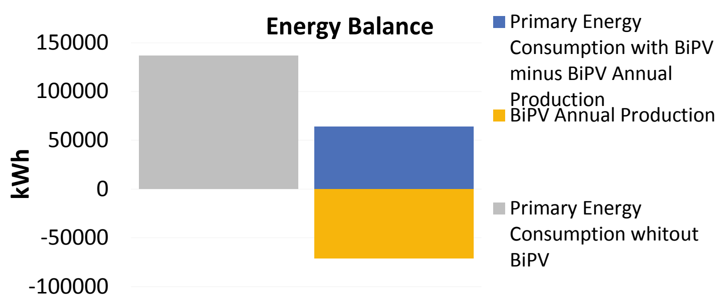

Figure 4: Energy balance of the district. The primary energy is only slightly reduced The production from PV considerably improves the energy balance

In this example the effect of the overhangs is beneficial for the cooling load but has a negative impact on the heating load [Figure 3]. Nevertheless, due to the higher COP for heating, the impact of the overhangs on the primary energy demand is positive. Furthermore, if the production from the PV is considered in the energy balance, the performance energy improvement is as shown in [Figure 4].

[1] R. J. Yang, “Overcoming technical barriers and risks in the application of building integrated photovoltaics (BIPV): hardware and software strategies,” *Autom. Constr.*, vol. 51, pp. 92–102, 2015.
[2] M. Lovati, P. Ingenhoven, G. De Michele, L. Baglivo, L. Maturi, and D. Moser, “Energy, daylight and thermal analysis of a geodesic dome with photovoltaic envelope.”
[3] K. Fath, J. Stengel, W. Sprenger, H. R. Wilson, F. Schultmann, and T. E. Kuhn, “A method for predicting the economic potential of (building-integrated) photovoltaics in urban areas based on hourly Radiance simulations,” *Sol. Energy*, vol. 116, pp. 357–370, Jun. 2015.
[4] D. B. Crawley, L. K. Lawrie, F. C. Winkelmann, W. F. Buhl, Y. J. Huang, C. O. Pedersen, R. K. Strand, R. J. Liesen, D. E. Fisher, M. J. Witte, and others, “EnergyPlus: creating a new-generation building energy simulation program,” *Energy Build.*, vol. 33, no. 4, pp. 319–331, 2001.
[5] L. Sean, *Essentials of Metaheuristics*. Lulu, 2013.
[6] Grynberg Anat, “Validation of RADIANCE.” Lawrence Berkeley Laboratory, Applied Sciences Division, Lighting Systems Research Group, 1989.
[7] N. Lechner, *Heating, cooling, lighting: Sustainable design methods for architects*. John wiley & sons, 2014.
[8] M. S. Roudsari, M. Pak, A. Smith, and G. Gill, “Ladybug: a parametric environmental plugin for grasshopper to help designers create an environmentally-conscious design,” in *Proceedings of the 13th International IBPSA Conference Held in Lyon, France Aug*, 2013.
[9] J. A. Jakubiec and C. F. Reinhart, “DIVA 2.0: Integrating daylight and thermal simulations using Rhinoceros 3D, Daysim and EnergyPlus,” in *Building Simulation-12th Conference of International Building Performance Simulation Association*, 2011.
[10] H. Fathy, “Natural energy and vernacular architecture,” *Princ. Ex. Referances Hot Clim. Univercity Chic. Press Ed Chic.*, 1986.