ASSESSING FAÇADE-INTEGRATED PHOTOVOLTAICS: A METHODOLOGY FOR THEIR PRELIMINARY ASSESSMENT

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ABSTRACT: One strategy typically utilized to reduce the energy demand of buildings is the use of onsite renewables, typically photovoltaic systems. In this context, whereas the roof space allocated for photovoltaics is quickly reaching saturation, façade-integrated photovoltaics could be a good alternative. Unfortunately, however, compared to roof-installed photovoltaics, such systems require a higher design commitment, frequently accompanied with cost uncertainties, which are often cumbersome to assess in traditional building design. To address this the research being presented in this paper, describes a methodology which would enable building designers to preliminary assess their proposed design technical and economic potential in a quick and easy manner. The developed methodology was tested on one particular building, showing how the technical and economic performance varies depending of the inputs set by the building designer. Additionally, a section was also included to show the effect of façade orientation on the total monthly and annual energy yield, showing how façade-integrated photovoltaics which are not predominantly South facing should not be discarded *a priori* for not having an optimum orientation.
Keywords: *Façade-Integrated Photovoltaics; Energy Performance; Feasibility Analysis*

1 INTRODUCTION

In addressing the challenges posed in reducing the energy demand of buildings, two main strategies are typically utilised. A first strategy relies on reducing the energy demand of a building by improving its energy-efficiency [1-3]. A second strategy relies on utilising onsite renewable energy sources for energy generation [1, 4]. In this second strategy, although both wind and solar [4] have been considered as a potential renewable energy resource for use in the urban environment, solar driven renewable energy has been the technology which has been most successful in terms of market penetration [5, 6].

In most buildings, such a resource has so far most easily been exploited through roof-installed photovoltaics [7], as an add-on, away from the public eye. Space considerations, competing amenities and roof ownership issues can however limit the potential use of such a resource [8], especially in densely populated areas, where land uptake is at a premium. For this reason, building designers are now looking at building-integrated photovoltaics, more specifically, façade-integrated photovoltaics as an alternative for traditional façades [9, 10]. Such a design possibility is dictated not only from the fact that the façade is the centrepiece of a building, therefore an aspect which must be aesthetically prominent in nature, but also due to the fact that it is estimated that in urban areas, façades comprise 60-80% of a building surface [11].

Photovoltaic panels have, over time evolved greatly, in terms of their aesthetics, efficiency and customisation and a number of companies now provide innovative and customised products offering endless possibilities for building designers, to integrate such technologies in their building designs.

1.1 Façade-Integrated Photovoltaics

Façade-integrated photovoltaics have shown a high energy generation potential [12], however, compared to roof-installed photovoltaics, such systems require a higher design commitment, frequently accompanied with cost uncertainties, which are often cumbersome to assess in traditional building design.

Most of the research which has been carried out in this area currently presents only complex methods of analysing the problem, often leaving aside the cost issue [13], or if both aspects are considered, the results are then often very site specific [14]. This is of course a limitation for most professionals who often find the process of going into such detail a lengthy process.

In order to encourage the architectural integration of photovoltaics on façades, and ensure that such a way of designing buildings is seriously considered, there needs to be a simple, readily available methodology in place, to make sure that quick and easy decisions can be made by building professionals.

2 STUDY CARRIED OUT

2.1 Aim of Research

Based on the premise presented in the introduction, the primary aim of this study was to create a methodology which would enable building designers to preliminary assess their proposed design in a quick and easy manner, concurrently, investigating the technical and economic potential of façade-integrated photovoltaics. In the process, the impacts of various technical aspects, such as orientation and shading, were studied to determine optimal solutions. Cost uncertainties and economic aspects of façade-integrated photovoltaics were addressed through a purposely designed tool, assessing the system feasibility. With this tool the sensitivity of a particular project to varying fiscal incentives such as grants on capital investment and, or Feed-in-Tariffs (FIT) can be analysed.

The research which is hereby being presented utilises the particular case of façade-integrated photovoltaics on Maltese buildings as an example, however as discussed, the methodology is flexible and can be used anywhere, with the aim of encouraging designers and developers, to incorporate façade-integrated photovoltaics in their design.

2.2 Methodology

The methodology being presented here was split up into two main parts; a technical and an economic part, with the former feeding the latter.

For the purpose of testing out the methodology being proposed, and to show how the methodology can be applied in a design process, the parameters of a real life building in Malta (a free-standing building with a combination of glazed and cladded façades, facing various directions), were utilised.

The first part of the methodology aims at presenting the building designer with a series of step-by-step guidelines which can be used to technically assess the proposed project. Specifically, the guidelines are aimed at helping the designer analysing the energy generation potential of the project, based on site and project specific considerations such as latitude, orientation, shading from opposing buildings, usable frontage area (defined as the area which could potentially be covered by photovoltaics), tilt angle, rated maximum power and panel area of the proposed photovoltaic product.

The purpose of this part of the methodology is therefore to help the designer analyse the sensitivity of selected technical aspects on the energy performance of the proposed project, *e.g.* the sensitivity of energy generation potential to orientation for varying azimuth angles, as well as the effect of shading from opposing buildings. The latter was specifically modelled on the basis of an analysis carried out on different *façade height-to-(road) width ratios* of a typical urban/city scape and the resulting shading patterns, as shown in Figure 1. Table I shows the calculated *Shading Factors* (SF).

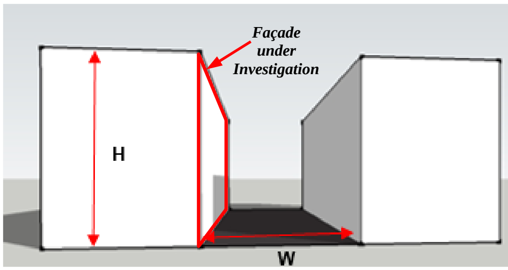

Figure 1: Calculation of *Shading Factors* using different façade height-to-(road) width ratios

Table I: *Shading Factors* for different façade height-to-(road) width ratios

Shading Factor (SF)	***Façade height-to-(road) width ratio***
1	1 >1:1 or for a property with an unobstructed frontage
0.8	>1:0.9 and <1:1
0.7	>1:0.7 and <1:0.9
0.55	>1:0.5 and <1:0.7
0.3	>1:0.3 and <1:0.5

An online tool, such as PVGIS [15], can then be used for simulation purposes to determine the potential annual energy generated.

The second part of the methodology makes use of a purposely designed tool, currently in the form of an excel sheet (but with the potential of becoming an interactive app), aimed at assessing the sensitivity of a proposed façade-integrated photovoltaic project to various fiscal parameters. The tool, feeds off the results produced in the technical part of the methodology to provide feasibility results in terms of the payback period of the project, the present worth (PW), specifically the Net Present Value (NPV) and the internal rate of return (IRR).

Project-dependent and independent variables can be introduced as input data for the model. These are financial elements which may or may not vary from one building to another. Project-independent variables include the inflation rate, the depreciated rate in energy generation, and the discount rate for future cash flow. Project-dependent variables include the usable frontage area and the grid electricity tariff.

The tool can consider both full-cost models, therefore excluding possible capital grants on the investment costs or FIT, and fiscally aided models, thus assessing the impact of fiscal incentives on the project's feasibility.

3 RESULTS

3.1 Initial Results: Creation of the Methodology

An initial result obtained through this research is as discussed the creation of a methodology which can be utilised for the preliminary technical analysis of façade-integrated photovoltaics. A high-level flowchart of the methodology being presented is shown in Figure 2.

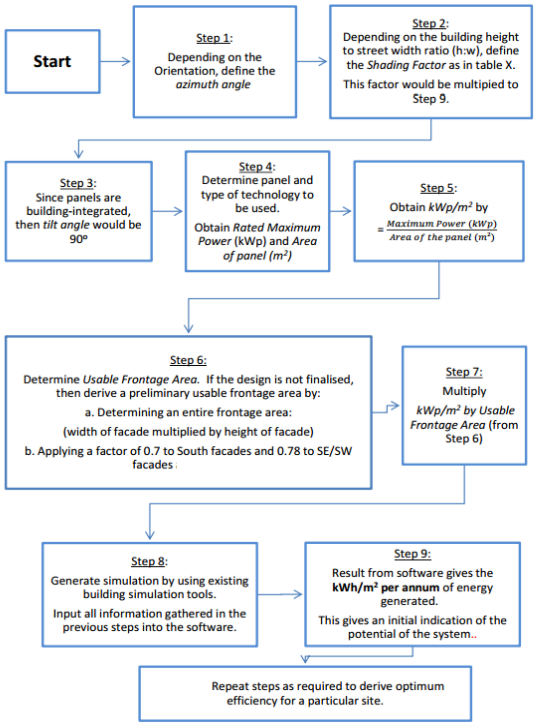

Figure 2: Proposed flowchart for the preliminary technical analysis of façade-integrated photovoltaics

The methodology provides a step-by-step approach on how to assess the preliminary technical parameters of façade-integrated photovoltaic technologies for any given project. This would allow the user to determine the optimal integration of façade-integrated photovoltaic for any building, with the aim of generating the highest possible energy generation levels. Also this way, designers can adopt a more design oriented approach, analysing what works best for their particular building, rather than applying general rules which do not necessarily apply for all case studies.

3.2 Specific Results from the Research - Energy

Figure 3 shows the building used to test the methodology - the newly built ICT Faculty at the University of Malta campus in Msida. It is a free-standing building with a combination of glazed and cladded façades, facing various directions

Figure 3: Educational/Office Building used to test the methodology (*Source*: Author)

The ICT Faculty was chosen as a case study in order to assess the potential of different types of photovoltaic systems, mainly crystalline photovoltaic panels and transparent photovoltaic glass. Different types of PV technologies were modelled and simulated in order to assess the feasibility of each different type of technology, with the usable frontage area necessarily varied to accommodate the different proposed designs. Each façade was modelled using its own azimuth angle, assuming a *Shading Factor* of 1. The existing façades are fully glazed, although with glazing units having different transparency levels. The lower and upper parts of the glazing for each floor are of a translucent nature, while the middle part is transparent to permit natural light ingress and outside views.

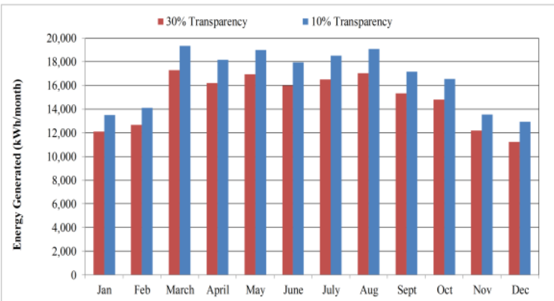

Figure 4: Total monthly energy generated (kWh/month) (*System 1:* Opaque crystalline and 30% transparent photovoltaic glass *vs. System 2:* Opaque crystalline and 10% transparent photovoltaic glass)

In the research being presented, the methodology was used to compare the energy performance of two types of façade-integrated photovoltaic projects. A first system, System 1 utilising 30% transparent photovoltaic glass, and a second system, System 2 utilising 10% transparent photovoltaic glass as a façade retrofit for the middle transparent part. The lower and upper glazed areas, requiring no transparency given their position were designed to be covered in both cases with opaque crystalline photovoltaic panels. The usable frontage area considered in both cases assumed an area of 1,170m^2 covered by opaque crystalline photovoltaic panels and an area of 642m^2 covered by transparent photovoltaic glass. Figure 4 shows the total monthly energy generated by the building for the two systems proposed.

3.2 Specific Results from the Research - Financial

Once the energy generation estimates are obtained for a proposed project, the tool designed to assess the financial performance of the proposed project, can then use this data to obtain a preliminary cost benefit analysis of the project.

As discussed earlier the methodology can cater for any type of financial scenario, including full cost models where the revenue stream is derived from the saved electricity costs (1), or fiscally aided models where FIT are utilised as financing mechanisms for grid fed electricity (2). Likewise, any capital grant (G) on the investment costs can be included or excluded.

$$NPV = -(1-G)I - \sum_{n=1}^{N} \frac{C\&M}{(1+r)^n} + \sum_{n=1}^{N} \frac{E \times c}{(1+r)^n} \quad (1)$$

$$NPV = -(1-G)I - \sum_{n=1}^{N} \frac{C\&M}{(1+r)^n} + \sum_{n=1}^{N} \frac{E \times FIT}{(1+r)^n} \quad (2)$$

Table II: Financial Parameters

Parameter	*Units*	*Rationale*
I	€	Installation costs *incl.* the cost of PV panels, mounting systems and installation
G	%	Percentage of capital investment financed as grant
C&M	€	Annual cost for cleaning & maintenance
c	€/kWh	Electricity cost
r	%	Discounted rate
FIT	€/kWh	Feed-in-Tariff rate
E	kWh	Energy generated
N	-	Number of years

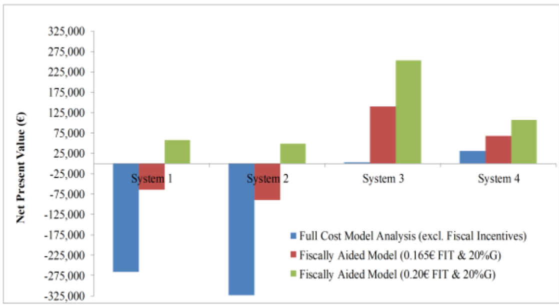

Figure 5: Net Present Value (€) for the different systems modelled for the Educational/Office building tested

Figure 5 shows the results for the financial return (in this case the Net Present Value) obtained for the two technical systems analysed for the educational/office building used to test the methodology. Three different fiscal scenarios were taken into consideration, namely:

- *Full Cost Model (excl. Fiscal Incentives)*;
- *Fiscally Aided Model (0.165€ FIT & 20%G)*; and
- *Fiscally Aided Model (0.20€ FIT & 20%G)*.

In all cases the discount rate for future cash in today's value flows was assumed as 2.2%, whilst a 30-year period was considered as the expected lifetime of the project. System 1 and System 2 describe, as per previous technical description, two different systems incorporating opaque crystalline photovoltaic panels and different types of transparent photovoltaic glass. System 3 and System 4 are two additional modelled systems. The former considers only the installation of opaque crystalline photovoltaic panels with a usable frontage area of 1,170m^2, without any transparent photovoltaic glass. The latter similarly considers only the installation of opaque crystalline photovoltaic panels without any transparent photovoltaic glass, but assumes a smaller usable frontage area of 341m^2.

3.3 Additional Results - Orienting Façades

In a study conducted by Pantic *et al.* [16], field and theoretical measurements were carried out using PVGIS for a vertically mounted PV panel and for three façade orientations: South, East and West, that is, 0°, -90° and 90° respectively. Results from this study showed that out of the three possibilities the South façade was the best in terms of energy generation. Results showed also that the energy generated by a façade facing either East or West was approximately half of that generated by the panels installed on a South facing façade. Pantic *et al.* did not however consider the intermediate angles between South and West and South and East. For buildings constrained by orientation and siting limitations, such azimuth angles are an important consideration for the integration of photovoltaics, as the overall applicable azimuths for which photovoltaic façades may be considered, increases from the dogmatic true South orientation.

For this reason, aside from the main research, a study was also carried to determine the effect of orientation on the performance of photovoltaic façades. Simulations on intermediate angles other than 0°, -90° and 90° were carried out using a photovoltaic clad façade sited on a four storey office block having a frontage of 6.4m (Simulated location Malta: Latitude ~ 35°). A *Shading Factor* of 1 and a usable frontage of 0.7 were assumed. Crystalline photovoltaic cells having a rated maximum power of 0.165kWp/m^2 were assumed for the simulations. The heat map shown in Figure 6 shows the total monthly energy generated for different orientations. Values are normalised on a per m^2 basis.

	90	60	45	30	15	0	-15	-30	-45	-60	-90
Jan	6.5	11.1	13.4	15.5	17.2	17.9	17.2	15.6	13.5	11.2	6.6
Feb	7.7	11.4	13.0	14.5	15.9	16.4	15.9	14.5	13.1	11.4	7.7
Mar	12.1	15.2	16.3	17.0	17.7	18.0	17.7	17.1	16.3	15.3	12.2
Apr	12.8	14.2	14.2	13.7	13.0	12.6	13.0	13.8	14.3	14.3	12.9
May	14.8	14.6	13.5	11.8	9.9	9.0	9.9	11.8	13.5	14.7	14.9
Jun	14.8	13.7	12.0	9.7	7.4	6.4	7.4	9.7	12.1	13.7	14.9
Jul	14.9	14.3	12.8	10.6	8.4	7.3	8.4	10.7	12.9	14.4	15.1
Aug	14.2	15.0	14.5	13.2	11.7	10.9	11.7	13.3	14.6	15.1	14.4
Sep	11.1	13.6	14.3	14.6	14.8	14.9	14.8	14.6	14.3	13.6	11.1
Oct	9.5	13.2	14.8	16.1	17.3	17.9	17.3	16.1	14.8	13.2	9.5
Nov	6.8	11.1	13.2	15.2	16.7	17.3	16.7	15.2	13.2	11.1	6.8
Dec	5.9	10.4	12.7	14.8	16.4	16.9	16.4	14.8	12.7	10.4	5.9

Figure 6: Heat map showing energy generation per month (kWh/m^2) for varying azimuth angles (°)

As can be seen from the heat map, monthly energy generation is very susceptible to the azimuth angle. Counter intuitively to what one would expect, whereas for roof mounted systems the South orientation is practically always favoured, in the case of façades, results show that the monthly energy generated varies significantly. The reason behind these results can be attributed to the losses due to angular reflectance, where some of the energy falling on the photovoltaic façade is reflected (rather than absorbed) by the photovoltaic surface, proportionally to the angle of incidence. For predominately South facing façades (considered in this instance as being all angles between ±30°), during the summer months, the naturally occurring high angle of incidence between the solar radiation and the façade leads to high angular reflectance losses and hence in a decrease in the monthly energy generated. On the contrary during the autumn and winter months, the typical low angle of incidence leads to low angular reflectance losses and hence to an increase in the monthly energy generated, notwithstanding the lower magnitude of the solar radiation. For East and West facing façades the inverse is true. During summer the low angle of incidence typical of the daily early or the late afternoon hours, results in a significant energy yield.

On an annual basis (per m^2) as can be seen in Figure 7 the best results are obtained where a compromise is reached between the reduction in angular radiation losses and the actual irradiation falling on the façade, resulting in the fact that façades which are not predominantly South facing (considered in this instance as being all angles between ±30° and ±45°) should not be discarded *a priori* for not having an optimum orientation.

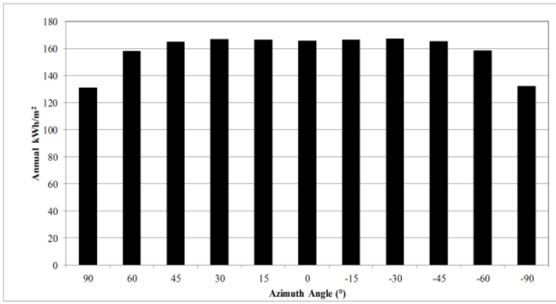

Figure 7: Annual energy yield (kWh/m^2) for varying azimuth angles (°)

4 CONCLUSIONS

The research presented in this paper, presents the work done in the creation of a specific methodology for the preliminary assessment of façade-integrated photovoltaics. The methodology looks at both the technical and financial aspect of a proposed project and enables a building designer to quickly assess the feasibility of a proposed photovoltaic project based on a number of project related variables such as latitude, orientation, shading from opposing buildings, usable frontage area, rated maximum power for the technical part, and typical financial parameters for the cost benefit analysis part. The resulting methodology was then applied to a specific project relating to the possible retrofitting of a glazed building, with different photovoltaic systems, including a combination of opaque photovoltaic panels and transparent photovoltaic glass.

Additionally, a section was also included to show the effect of façade orientation on the total monthly and annual energy yield. Results showed that contrary to roof installed photovoltaics, façade-integrated photovoltaics may be favourably affected from not having a perfect south facing orientation, and that façades which are not predominantly South facing (considered in this instance as being all angles between ±30° and ±45°) should not be discarded *a priori* for not having an optimum orientation.

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