IMPACT ASSESSMENT FOR BUILDING INTEGRATED PHOTOVOLTAIC (BIPV)

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Several sustainable energy technologies (SET) exist at the moment as options for reducing carbon footprints in existing buildings. These include micro wind turbines, photovoltaic, combined heat and power (CHP), small hydro power generators, bio-tech units to name but a few. It is imperative that any process that imposes or reduces cost or value in the built environment, especially on refurbishment projects, requires a continuous assessment of the impact of its application. This becomes inevitably necessary in order to keep in check, factors which affect the health, safety and comfort of respective building occupants as well as the economic and architectural values of the applied buildings and the environment. This paper presents current ongoing research project on impact assessment of building integrated photovoltaics (BIPV) in commercial/office buildings. It discusses the methodological process for assessing impacts associated with the installation and use of BIPV technology in buildings. Preliminary results from this research include the identification of barriers' which influence post-occupancy performance of BIPV systems.

Keywords: building integrated photovoltaic, impact assessment, sustainable energy technology.

INTRODUCTION

Prior to this present study, there had been several attempts to develop some form of framework or method to measure or assess the impact of BIPV technology and systems on applied buildings (DTI 2000, EEP 2009). The summarized definition and principles of the process "environmental impact assessment" as provided in the literature particularly by the international association for impact assessment (IAIA, 1999) and the UK institute of environmental assessment could be considered as a yardstick which could be used to compare such studies. The first criteria for instance could be the degree of compliance of the structure, aims, objectives and research methodologies of such studies with the definition standards. A further criterion could be the degree of fulfilment of the stipulated principles for impact assessment.

Extensive literature review (Hagemann 2008, Shaari and Bowman 1998, Morgan and Richard 2002, Omer Wilson and Riffat, 2003) has shown that most of the previous studies focused their assessment on residential or non-commercial buildings with little or no consideration to commercial/office buildings. This is particularly in the refurbishments of old existing commercial/office buildings which according to Miller and Buys (2008), "makes up the bulk of commercial/office accommodation.

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Ikedi, C U, Okoroh, M I, Dean, A and Omer, S A (2010) Impact assessment for building integrated photovoltaic (BIPV). *In:* Egbu, C. (Ed) *Procs 26th Annual ARCOM Conference,* 6-8 September 2010, Leeds, UK, Association of Researchers in Construction Management, 1407-1415.

Shaari (1998) carried out a study of BIPV in buildings at two distinct locations: Rural England and Malaysia. The case studies involve application of building integrated photovoltaics where the photovoltaics (PV) modules are fitted as partial roofing material. Data from the monitored BIPV system in UK were analysed and compared with the predictions of Pvsyst 2.0 computer software. The computer model was then used to simulate BIPV applications for a standard school building in Malaysia. Based on the simulated system performances, it was shown that the application of BIPV technology in Malaysia seems to offer a much better impact on applied building whilst cost-effectiveness has been a major issue in its proliferated use.

CASE STUDY: BIPV SYSTEM AT THE ECO-ENERGY HOUSE

The first preliminary step in this study was to identify a specific BIPV case study and the main criteria used in the selection of a case study during the assessment process were that:

1. The applied building should be such that the PV modules are installed to replace or form part of the building envelope, in which case the PV is fully integrated and not adapted to the building. The essence of this condition is to give room for an economic impact assessment of the savings made from the replaced building materials as well as the architectural impact assessment of the PV modules on the aesthetics of the building envelope (the roof in this case study).
2. The BIPV system should be Grid connected, in which case the system can feed back or sell excess electrical energy generated to the utility or grid companies involved. This condition will form the main platform for the economic impact assessment in the selected case study.
3. Finally, the BIPV system should have undergone at least one year post installation monitoring, in which case the characteristic energy performance of the system at different seasons, all year round must have been monitored, measured and documented.

Figure 1: BIPV, Eco Energy House [EEH] (University of Nottingham, UK)

Based on the above stipulated criteria, the Eco Energy House (EEH) of the University of Nottingham in UK was identified and selected as the case study (figure 1). The Eco-Energy House has a total area of about 92m2 suitable for solar installations on the West, South and East faces of the roof. These all receive direct beam solar radiation, though some for only limited periods of the day. Half of this space has been reserved for four solar thermal collectors and the rest are available for PV integration, i.e., 16m2 on each face. The building, which provides office space for some staff of the University, is a four-bedroom detached house with solar thermal collectors to supply part of its hot water requirement, a solar-assisted ventilation stack, light pipes with stack ventilators, a ground source heat pump and a rainwater collection system. The

BIPV system is used to offset part of the building's electrical demand. The PV slates (which overlap in the same manner as conventional slates and work in conjunction with the roofing felt beneath to waterproof the building) were assembled on the inclined roof (tilt angle 52°, orientation south) in fourteen rows. The PV slates were located using hooks fixed to the roof battens and then nailed in place as shown in figure. 2. The PV array was electrically connected as two parallel sub-arrays of 66 serially connected 11.88 Wp modules, giving a nominal standard test condition (STC) open circuit voltage of 235.6 V, short circuit current of 8.9 A and peak power of 1568 Wp. A Sunny boy inverter with a standing wave ratio (SWR) 1100 was used to connect the system to the building main supply. See Figures 1, 2 and 3.

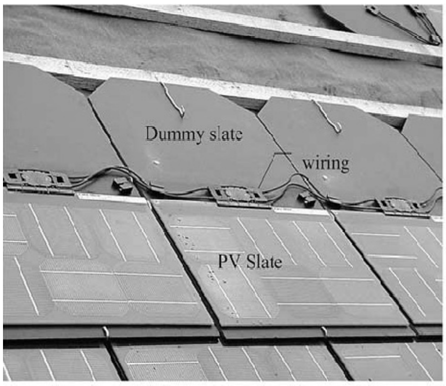


Figure 2: EEH PV slates integration *Figure 3: Roof View – EEH*

ASSESSMENT FRAMEWORK AND METHODOLOGY

In order to develop an assessment framework, critical areas of impact associated with BIPV systems were explored. The major problem here was how to gather and apply observable and measurable data associated with the system in such a way as to aid existing owners and potential investors decide whether the technology makes an economic sense or positive impact. To develop a good methodology therefore, the strategy used in the study was to first identify a specific BIPV case study, carry out technical and economic evaluations based on monitored performance of the system over a given time and then finally assess the projected benefits compared to the estimated costs and barriers associated with the BIPV system.

Selected principles of assessment adopted from the best practice guidelines for impact assessment developed by "The International Association for Impact Assessment (IAIA) and the UK Institute of Environmental Assessment" (IAIA 1999) were applied to the identified areas of impact and these together form the methodological framework for the assessments. To carry out the assessments, post-commission data of the BIPV system in the case study were retrieved from the system data bank which was collected with the aid of high performance data logger systems networked to different input and output terminals of the entire BIPV system.

The monitored parameters which include the PV array outputs, the inverter outputs, the grid power inputs, the building energy loads and the solar radiation measurements, were chosen between the 1st of January to the 31st of December 2003. This monitoring interval which appeared to be most comprehensive complies with the all year round criteria for selecting the case study and ensures measurements over different seasons. The BIPV monitoring device records the stipulated system parameters every minute and in order to apply the results sensibly, daily average values of the respective parameters and hence the monthly average values were deduced for easier analysis and presentation.

Finally, because some of the identified areas of impact are not quantifiable for use in parametric evaluations, the parametric aspect of the assessment process in the study was based on two aspects or areas of impact namely energy values or impact and economic impact. Based on these, the projected benefits were assessed and then compared to the estimated project costs and barriers associated with the BIPV system. The margin between the projected benefits and the estimated system cost with associated barriers give a measure of the net impact of the system on the applied building.

DISCUSSIONS AND BARRIER ASSESSMENTS

Having selected a case study, the next issue of importance, which needs to be considered in any installation decisions of existing BIPV system prior to their assessments are the barriers involved in the implementation and use of the system. These were identified and assessed under legislative, economics, technical and social barriers.

Legislative barriers

The sunrize project (2008), defined Legislative barriers "as the restraining problems in the preliminary/installation stages of BIPV implementation and usage in applied buildings as a result of the policies of different parties involved in the introduction of PV".

The PV system at the EEH was installed in March 2000 and began operation in June 2000. Before this time, some legislatures were developed which seem to constrain or restrict several degrees of freedom required for particular BIPV performance.

For instance, Conservation policies and other similar legislatures which restrict the introduction of structures or alterations on certain buildings are still in force even at this present era. According to Clark (2001); "conservation … seeks to question change and to reconcile modern needs with the significance of what we have inherited in order to safeguard the interests of future generations." BIPV is one of such modern needs within the context of this definition while "the questions to the changes" could be referred to the attached legislatures. Furthermore, in the same dispensation, BIPV is not allowed on listed buildings which are buildings officially designated as being of special architectural, historical or cultural significance. Therefore, a listed building may not be demolished, extended or altered without special permission from the local planning authority. This could imply that BIPV may not be used in parts of the existing buildings.

Economic barriers

These barriers cover market, commercial and financial barriers etc. and are related to the cost of BIPV and to the lack of knowledge concerning the added value of PV products within the building sector.

According to the Sunrise project (2008), "BIPV is still too expensive".Albrecht (2006) stated that "The current cost disadvantage of photovoltaics risks reducing its relevance in climate policy strategies."

A crucial argument however, is that PV modules are expensive when compared with more traditional building materials which BIPV can replace such as roofing tiles, laminated glass, parapet units and of course low cost traditional bricks, but what is neither sufficiently realized nor taken into account is the fact PV modules can generate electricity. This means that the total energy consumption of a building will be decreased and therefore the material itself (PV module) will ultimately pay back its initial investment cost.

Technical barriers

Hagemann (1996) in his analysis which centred on planning, design and installation stages of BIPV implementation concluded that whether the applied building is a residential or commercial/office building does not matter much, although the size of the project sites may vary in each case. Technical barriers are related to the structural problems engineers, architects and installers encounter when designing, engineering and installing PV systems into the building envelope as outlined below:

Shading

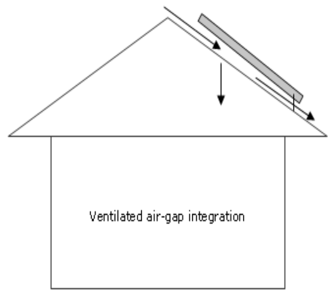
The first critical aspect of technical barriers from the planning and design stage of BIPV should be shading due to the building itself or buildings and trees close by and this usually implies substantial modifications in order to install the PV systems. The implication of this is that the resulting financial involvement for BIPV refurbishments sometimes could approximate to new built.

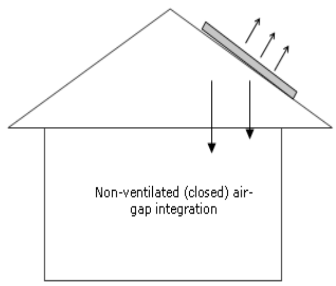
The measured energy production in the case study was lower at 636 kWh, which amounts to 12.2% of the building load and lower than the predicted PV contribution to the building load of 20%. One reason for this is due to partial shading of the PV array. The Eco \energy House (EEH) is surrounded by a number of trees that are in close proximity to the building. Omer (2003) carried out a simulation analysis with and without the trees which shows that trees reduce the annual energy production by about 20%.

Mode of installation

Studies carried out have identified three basic methods of BIPV roof installation and depending on the choice made in a given climatic location; there could be barriers in the system performance (Ordenes, Deivis, Priscila and Ricardo 2007, Albrecht 2006). Figures 4, 5 and 6 illustrate the three basic methods for BIPV roof installations and consequent impacts on system performance.

The pointing arrows represent the magnitude of heat which would be produced by each of the installation methods inside the applied building space.





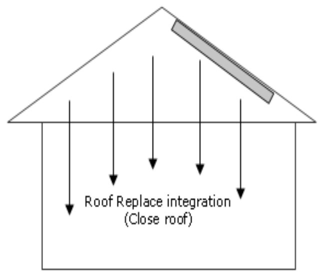


Figure 4: Ventilated air gap *Figure 5: Non ventilated air gap* *Figure 6: Roof replace*

Building overload

It may look simple installing BIPV modules on a roof of a building, but another subtle barrier is that most roofs especially in refurbishments have not been designed to support the additional weight. Consequently, some problems could therefore begin to appear due to wind load, water tightness, snow and ice.

Social barriers

The sunrise consortium (Sunrise Project 2008) described Social or Perception barriers as the lack of knowledge and the misleading statements in the media and communities that underestimate the added value of BIPV systems thus hindering their integration into the buildings. This description though appears a bit subjective could be validated. For instance, regarding the attitude of property owners and building experts in the building sector towards BIPV, a research conducted in the Brazil, Ordenes *et al.* 2007 on BIPV with 900 building professionals, shows that 88% need to be convinced first, while 49% are ready to consider them on demonstration. One can justify the description above by Sunrise based on the assumption that the pessimistic responses in the study could have developed through misleading information against the viability of PV or BIPV technology. On the aspect of lack of knowledge, the knowledge of planners, developers and architects about BIPV concepts and principles could be usually limited such that the advantages of BIPV could sometimes not be clear for architects and potential clients. For some architects BIPV may not to be attractive especially as it may affect the aesthetics of the building envelopes particularly in refurbishments.

Tables 1 and Figure 7 show the results of the parametric analysis carried out on selected parameters for the assessment of the energy impact of the BIPV.

Table 1, shows the average monthly power performance of the BIPV roof arrays with respect to average level of sunshine or insolation within the different months which is measured in watts. One interesting observation from the Table is the characteristic variations in the sunshine levels and the array outputs at different seasons of the year, which corresponds to summer and winter respectively. Higher levels of insolation and outputs are recorded within summer unlike winter.

Most importantly, Figure 7 illustrates and compares the final total energy contributed by the BIPV via the inverter to the applied building and compares it with the total energy demanded or consumed by the building occupants within various months of the year.

ENERGY IMPACT ASSESSMENT

Table 1: Average Monthly Assessment of the BIPV Array

Month	Sunshine (W)	Array Current (amps)	Array Voltage (volts)	Array Output (KW)	Array Efficiency
Jan	105.9824	0.631492	81.20802	0.100005	0.024324
Feb	104.1634	0.602597	54.50178	0.070934	0.015964
Mar	119.1883	1.175259	83.21064	0.104016	0.027922
Apr	147.4936	0.821709	86.69199	0.126459	0.025662
May	150.4783	0.838662	95.05764	0.129664	0.028211
Jun	168.1418	0.93513	100.1289	0.142265	0.028999
Jul	184.146	0.949237	115.0647	0.146243	0.033431
Aug	147.1153	0.801324	109.1522	0.112475	0.031526
Sep	132.3756	0.724248	80.87739	0.109794	0.023302
Oct	117.1066	0.685318	63.43814	0.109029	0.020238
Nov	45.68949	0.255524	46.16858	0.039323	0.01117
Dec	33.34786	0.156583	54.22564	0.023741	0.012484

From Figure 7, the total recorded average energy contributed by the BIPV system to the applied building within the period is 1.048645 KVA while the total energy demanded or used by the occupants was 12.66565 KVA.

The percentage energy impact or contribution made by the BIPV therefore is

[1.048645/12.66565 × 100] % = 8.26% of the total energy use.

This means that for every electrical load consumed or used by the building occupants, the BIPV system has the capacity or capability to cater for about 8.26% of the electrical power required.

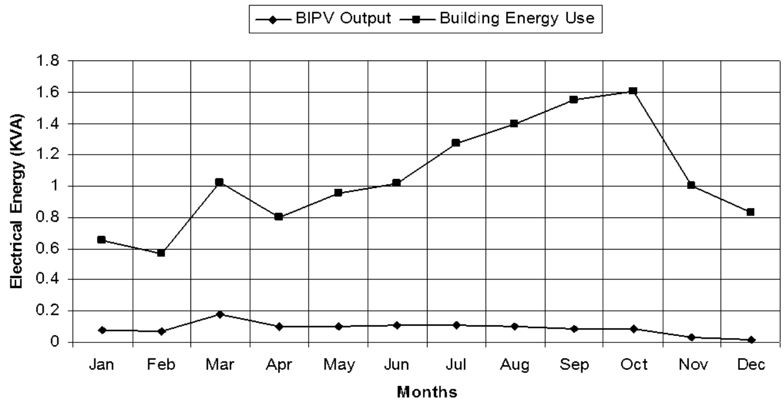


Figure 7: Graphical illustration of the BIPV impact on building energy demand

ECONOMIC IMPACT ASSESSMENT

Table 3-4 and Figure 8 show the results of the parametric analysis carried out on selected parameters for the assessment of the economic impact of the BIPV.

In general, two parameters are used to assess the economic impact of a BIPV system. The first is the "Energy Cost Produced," which takes into account the cost of initial capital, interest rate of any possible loan, maintenance and reparation costs and costs of replacing parts of the system like the inverters.

Table 3: Deduced values of excess energy exported by BIPV

Month	Initial meter readings (Kwh)	Final meter readings (Kwh)	BIPV excess Export (Kwh)
Jan	433.36	438.88	5.52
Feb	447.76	472.82	25.06
Mar	473.30	490.78	17.48
Apr	491.06	509.61	18.55
May	509.71	524.76	15.05
Jun	0.84	1.06	0.22
Jul	532.24	536.54	4.3
Aug	547.33	555.24	7.91
Sept	16.79	25.67	8.88
Oct	25.67	31.07	5.4
Nov	31.60	33.78	2.18
Dec	33.97	35.13	1.16

The second is the “Value of Excess Electricity Exported” by the BIPV system into the grid network of the building. The exported electricity can pay or make returns to the BIPV owners in either of two ways: Reducing the overall cost of electricity imported from the grid company or generating direct cash as the selling price to the grid company. This present assessment is based on the second approach. Table 3 show the deduced values of the excess electricity exported by the BIPV while table 4 show the import from the grid.

Figure 8 on the other hand gives a clear picture of the economic impact of the revenue generated by the excess electricity from the BIPV compared to the economic impact of the grid supply.

Table 4: Deduced values of energy imported from grid

Month	Initial meter readings (Kwh)	Final meter readings (Kwh)	Grid Import (Kwh)
Jan	3281.03	3369.34	88.31
Feb	3429.15	3611.53	182.38
Mar	3628.39	4173.58	545.19
Apr	4196.85	4643.52	446.67
May	4656.83	5161.05	504.22
Jun	525.94	536.54	10.06
Jul	5716.52	5748.09	31.57
Aug	5983.12	6021.04	37.92
Sept	1350.00	2130.09	780.09
Oct	2153.53	3046.72	893.19
Nov	3062.42	3613.05	550.63
Dec	3738.10	4169.70	431.60

The approximate unit cost of electricity in UK is about 12 pence per KWh (EEP, 2009) and from Table 3, the average total excess energy exported by the BIPV system into the grid network within the one year monitoring period is about 111.71 KW.

The economic value of the total annual excess electricity within the period therefore is about £13.5

The total capital installation cost of the PV systems at the Eco Energy House was £17,550 (incl. VAT at 17.5%),

The life expectancy of the BIPV system is typically about 25 years. This implies an annual capital cost of about £438.75.

The percentage economic impact of the BIPV system based on the value of excess electricity exported into the building therefore becomes

$[13.5/438.75 \times 100]\% = 3.08\%$ with respect to the life expectancy period.

In other words, the value of the excess electricity exported into the building grid by the BIPV system has the capability to provide financial savings of up to 3.08% of the original investment cost every year.

CONCLUSIONS

Key areas of impact identified in this study where BIPV systems could make some influence are economic, energy, environmental, architectural and social values.

In conclusion therefore, taking into consideration the impact of the barriers as identified and analysed in the study which in no doubt impedes the implementation and hence the post commission performance of BIPV systems, one can conclude that BIPV technology has a relatively positive impact on applied buildings.

It would be important to always put into account, the life expectancy period, the payback period and the prevailing barriers before making decisions on the viability of the technology as a sustainable energy option in today's built environment and the building sectors.

Compared to other sustainable energy technologies existing at the moment as options for reducing carbon footprints in the built environment like micro wind turbines, combined heat and power (CHP), small hydro power generators, bio-tech units etc. BIPV is aesthetically appealing and forms part of the applied building envelopes while most other options could deform the building aesthetics and require large spaces for both installation and operation especially, the wind turbine. Nevertheless, there is a need to reduce prevailing impact of identified barriers in order to achieve better performance and impact on applied buildings.

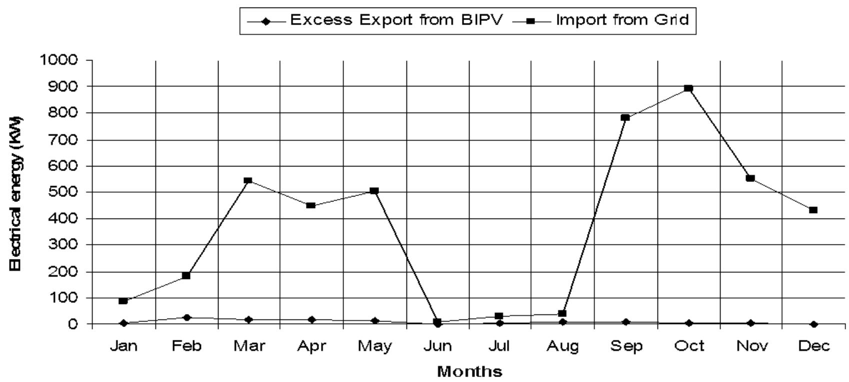


Figure 8: Illustration of the ratio of excess energy exported by BIPV to the grid import

REFERENCES

Albretch, J (2006) The future role of Photovoltaics: A learning curve versus portfolio perspective. *Energy policy* **35**, 2015-2040.

Clark, C M (2001) Informed conservation: Understanding historic buildings and their landscapes for conservation. *English heritage*.

Department for trade and industry (2000) Energy technology support unit (ETSU).

Europe's energy portal (2009) *Gas and electricity domestic prices*.

Hagemann, A (2008) *Building integrated photovoltaics: a new design opportunity for architects*.

Hagemann, I (1996) PV in buildings: the influence on the design and planning processes of a building. *Renewable energy* **8**(1-4), 467-470.

International association for impact assessment and Institute of environmental assessment, UK (1999) Principles of environmental Impact assessment: Best Practice.

Miller, Evonne, and Laurie B (2008) *Retrofitting commercial office buildings for sustainability: tenants' perspectives*.

Morgan, Richard K (2002) *Environmental impact assessment: a methodological perspective*. Kluwer academic publishers.

Omer, S A, Wilson, A and Riffat S B (2003) Monitoring results of two examples of building integrated PV (BIPV) systems in the UK. *Renewable Energy* **28**(9), 1387-1399.

Ordenes M, Deivis L M, Priscila B, Ricardo R (2007) The impact of building-integrated photovoltaics on the energy demands of multi-family dwellings in Brazil. *Energy and Buildings* **39**, 629-642.

Shaari, S and Bowman N (1998) Photovoltaics in Buildings: Case study for rural England and Malaysia. *Renewable energy*.

Sunrise Project (2008) Barriers for the introduction of Photovoltaics in the building sector: European Photovoltaic industry association; European construction industry federation; European association of electrical contractors; International union of Architects.