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City Hall, London, from Tower Bridge (left)
Fitting a flat roof system (top right; photo courtesy of Sundog Energy Ltd)
Performance display (bottom right)

Back cover photograph:
Rain screen cladding on CIS Tower, Manchester
(photo courtesy of Solarcentury)

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Executive summary

The performance of solar photovoltaic (PV) systems on buildings has recently become a subject of much scrutiny. The reason for this is plain: driven by concern over the expected effects of climate change, security of energy supplies and finite fossil fuel reserves, governments across the globe have introduced financial incentives to install solar-generating systems, thus attracting many different types of investor, from individuals to social housing providers and large supermarkets. In the UK, investors are paid according to the amount of electricity generated and, because such schemes are government-backed, the financial risks are very low. Furthermore, the incentives tend to be guaranteed for periods of 20 years or more. All in all, this is an investor's dream – as long as the technology lives up to expectations.

Understanding and avoiding the causes of potential underperformance in generating electricity has therefore become very important: performance figures are now scrutinised by investors and multinational companies, and are no longer the preserve of the cottage industry enthusiasts who pioneered the use of the technology on buildings.

With no moving parts, no fuel delivery system required (the 'fuel' is sunshine!) and relatively simple integration into buildings, PV systems have been shown to be inherently reliable.

So, how could a PV system underperform? Over a period of a few years, the amount of solar energy arriving at any particular location is surprisingly predictable, so the possible causes of PV underperformance break down into a few simple 'man-made' categories:

- poor system design
- poor siting
- poor-quality components
- poor installation practices.

Under each of these general headings, there are usually several factors that can trip up the unwary designer, installer or project manager.

BRE has had the benefit of in-depth experience on this subject via its consultancy activities and certification services, eg managing a five-year government PV Field Trial, managing the technical and contractual compliance for a variety of grant schemes, setting up the Microgeneration Certification Scheme (MCS) and performing technical inspections.

This report aims to explain clearly all of the likely causes of underperformance of PV systems at a level of detail that will be useful to architects, building engineers, system designers and installation engineers. Best practice, methods of countering the loss mechanisms and performance data from real systems are also presented, arming the reader with the understanding required to attain the best possible performance from their solar PV installation.

Although the focus of this report is non-domestic installations, much of the information is applicable to all building-mounted systems, and it draws on experience from within the domestic sector, where relevant. In fact, a central aim of this report is to present key lessons drawn from real projects and system monitoring experience.

The two key metrics commonly used to characterise PV performance are explained:

- Annual yield is the annual energy output as a function of rated system size – kilowatt hours of electrical energy per kilowatt-peak system size (kWh/kWp). The average UK benchmark figure for annual yield has historically been taken to be 850 kWh/kWp.
- Performance ratio is the ratio of actual energy produced compared with the output of an ideal system of the same design and in the same location. It therefore gives a measure of the energy losses in the whole PV system, a typical figure being 0.75.

The report then explores in detail the performance factors that are influenced by the building on which a system is mounted, the system design and the subsequent operation of the PV generator. These factors are summarised in section 6. Within certain limits, the performance of PV systems turns out to be relatively insensitive to array orientation: somewhere between south-west and south-east at a tilt of 35° is ideal in the centre of the UK, but the charts presented show that other orientations are perfectly possible with only a minor reduction in energy production. However, performance is shown to be highly sensitive to any shading of the array by obstacles such as trees, vents and other buildings.

Other factors explored are:

- solar panel (module) quality and performance over time
- module ventilation
- variations in output power of modules within an array
- inverter selection
- quality of installation and commissioning
- variations in grid voltage
- availability of status information for the user.

By following the advice given in this report it should be perfectly possible to obtain performance ratio figures of 0.8 and above, and to maximise the annual yield and reliability of the system.

A collection of interesting case studies, which includes performance figures derived from monitored data, and the lessons learned from these projects, is presented in section 7, with the main conclusions drawn from field trials and other experience collated in section 8.

A chapter on system costs, feed-in tariffs and carbon savings is also included (section 9). It is interesting that, whilst feed-in tariffs have recently been the main driver for the rapid expansion of the PV market, these incentives exist mainly because of the global imperative to reduce carbon emissions. So, in reality, estimates of the carbon savings are just as important as financial benefits, if not more so. The financial payback, energy payback and carbon savings information offered here can only be a 'best guess' at the current situation because of:

- rapid fluctuations in module prices
- the potential for further changes of government policies on incentives
- the continual upward trend of grid electricity prices
- gradual and continuous reductions in the energy intensity of manufacturing processes and embodied energy of PV products
- ongoing efforts to decarbonise grid electricity.

Nevertheless, a key finding is that a well-designed and installed crystalline silicon-based system in the UK will, over its lifetime, pay back at least five times the energy consumed in its manufacture, installation, maintenance and decommissioning. Furthermore, this figure is rapidly improving as more manufacturers become members of end-of-life recycling schemes, and manufacturing techniques evolve to use less photo-active material within solar cells, resulting in shorter energy payback times.

The appendices provide some more detailed information on the performance of various PV materials, mounting methods and examples, and testing and certification standards. The reference section includes further information on related topics, such as technical installation standards, best practice guides and sources of data used within the report.

This report has been funded by BRE Trust

Performance of photovoltaic systems on non-domestic buildings

This report provides information on the design and operational factors affecting the performance of photovoltaic (PV) systems on non-domestic buildings. It is aimed at decision makers, developers, architects and engineers involved during the conceptual stages of PV projects on buildings, and will inform system design decisions at the earliest stages. The report uses monitoring data from real buildings and recent research. It focuses on commercial systems but also draws on experience in the domestic sector. Appendices contain background information on PV for those in the building industry with limited knowledge of the technology and its use in building systems. The report does not aim to be a design tool but provides key information for use in developing a PV building project in order to help maximise energy generation performance. It reviews the background to PV systems, performance measurement, their use in buildings (including building integration methods, performance design choices and operational issues affecting performance) as well as system costs and carbon savings.

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