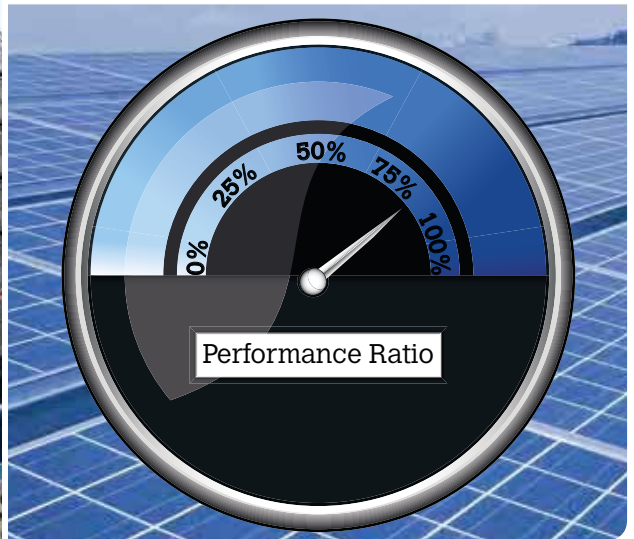


Performance of photovoltaic systems on non-domestic buildings

Steve Pester and Frances Crick





Performance of photovoltaic systems on non-domestic buildings

Steve Pester and Frances Crick

The research and writing for this publication has been funded by BRE Trust, the largest UK charity dedicated specifically to research and education in the built environment. BRE Trust uses the profits made by its trading companies to fund new research and education programmes that advance knowledge, innovation and communication for public benefit.

BRE Trust is a company limited by guarantee, registered in England and Wales (no. 3282856) and registered as a charity in England (no. 1092193) and in Scotland (no. SC039320).

Registered office: Bucknalls Lane, Garston, Watford, Herts WD25 9XX
Tel: +44 (0) 1923 664743
Email: secretary@bretrust.co.uk
www.bretrust.org.uk

IHS (NYSE: IHS) is the leading source of information, insight and analytics in critical areas that shape today's business landscape. Businesses and governments in more than 165 countries around the globe rely on the comprehensive content, expert independent analysis and flexible delivery methods of IHS to make high-impact decisions and develop strategies with speed and confidence. IHS is the exclusive publisher of BRE Trust publications.

IHS Global Ltd is a private limited company registered in England and Wales (no. 00788737).

Registered office: Willoughby Road, Bracknell, Berkshire RG12 8FB.
www.ihs.com

BRE Trust publications are available from:
www.brebookshop.com

or
IHS BRE Press
Willoughby Road
Bracknell
Berkshire RG12 8FB
Tel: +44 (0) 1344 328038
Fax: +44 (0) 1344 328005
Email: brepress@ihs.com

© IHS 2013. No part of this publication may be reproduced or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, or be stored in any retrieval system of any nature, without prior written permission of IHS. Requests to copy any part of this publication should be made to:

The Publisher
IHS BRE Press
Garston
Watford
Herts WD25 9XX
Tel: +44 (0) 1923 664761
Email: brepress@ihs.com

Printed using FSC or PEFC material from sustainable forests.

FB 60

First published 2013

ISBN 978-1-84806-231-3

This work draws strongly on information from both the UK Large Scale Field Trial and the UK Domestic Field Trial and the authors therefore gratefully acknowledge the information provided by these two sources. The authors would also like to acknowledge Stanhope plc for their support in the early stages of the BRE Trust research project from which this publication evolved.

This report has passed through several stages of evolution since the original research project concluded and the authors would like to thank BRE Trust for remaining supportive throughout this process.

Contributors to the BRE Trust research project from which this publication emerged are (in alphabetical order):

- Robert Burzynski
- Frances Crick
- David Forward
- Ben Howe
- Steve Pester

All URLs accessed September 2013. Any third-party URLs are given for information and reference purposes only and BRE Trust and IHS do not control or warrant the accuracy, relevance, availability, timeliness or completeness of the information contained on any third-party website. Inclusion of any third-party details or website is not intended to reflect their importance, nor is it intended to endorse any views expressed, products or services offered, nor the companies or organisations in question.

Any views expressed in this publication are not necessarily those of BRE Trust or IHS. BRE Trust and IHS have made every effort to ensure that the information and guidance in this publication were accurate when published, but can take no responsibility for the subsequent use of this information, nor for any errors or omissions it may contain. To the extent permitted by law, BRE Trust and IHS shall not be liable for any loss, damage or expense incurred by reliance on the information or any statement contained herein.

Front cover photographs:

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)

Contents

Executive summary	v
<hr/>	
1 Introduction	1
1.1 Background to PV systems	1
1.1.1 What is PV and how does it work?	1
1.1.2 Why is PV important?	2
1.2 Defining the performance of PV systems	4
1.2.1 Power rating	4
1.2.2 Energy yield	4
1.2.3 Metrics	4
1.3 Predicting the performance of PV systems: simulation programs	5
<hr/>	
2 Location and building factors	6
2.1 Geographic location	6
2.1.1 Solar resource: annual solar radiation	6
2.1.2 Ambient temperature	6
2.2 Mounting and building design options	6
2.2.1 Array orientation and tilt angles	8
2.2.2 Shading	9
<hr/>	
3 PV module characteristics	12
3.1 PV materials	12
3.1.1 Spectral effects and light levels	12
3.1.2 Operating temperature	13
3.1.3 Degradation	13
3.2 Selecting modules for a project	14
3.2.1 Module quality	14
3.2.2 Manufacturers' warranties	14
3.2.3 Power tolerances	14
<hr/>	
4 System design and installation factors	16
4.1 Common design issues	16
4.1.1 DC circuit design	16
4.1.2 Mismatch of modules	16
4.1.3 Inverters	16
4.1.4 Cabling, switches and junction boxes	18
4.1.5 Status displays and monitoring	18
4.2 Installation and commissioning	19
<hr/>	
5 Operational factors	20
5.1 Soiling and shading during operation	20
5.2 Grid interaction	20
5.3 Inverter breakdowns	20
5.4 System monitoring and user interface	21

6	Summary of factors that affect PV performance	22
7	Performance data and case studies	23
7.1	Summary of LSFT performance data	23
7.2	Is the performance of PV systems improving?	24
7.2.1	Data from Germany	24
7.2.2	UK scenarios	24
7.2.3	Sunlight at the end of the tunnel?	25
7.3	Case studies	26
7.3.1	Columba Centre, Islay (LSFT)	26
7.3.2	Mont-Cenis Academy, Herne Sodingen, Germany	28
7.3.3	Solar Office, Doxford International	29
7.3.4	Zuckerman Institute for Connective Environmental Research (ZICER), University of East Anglia (LFST)	34
8	Summary of lessons learned	37
9	PV system costs, feed-in tariffs and carbon savings	38
9.1	Historical system costs	38
9.1.1	Cost trends	38
9.2	Feed-in tariffs	38
9.2.1	What are FITs?	39
9.2.2	The UK FITs	39
9.3	Energy payback and carbon savings	40
9.3.1	Energy payback	40
9.3.2	Cost of carbon saved	41
	Appendix A: Further information on PV materials and performance	42
	Basic categories	42
	A word about junctions	42
	Silicon materials	43
	Non-silicon materials	44
	Recent developments	45
	Outlook for thin-film technologies	45
	Appendix B: Building-integrated mounting methods	46
	Roof-integrated systems	46
	Facade systems	48
	Solar shading devices	50
	Appendix C: Testing and certification	51
	Product certification	51
	Installer certification	52
	References	53

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.



BRE Connect Online

Build on your foundation of **knowledge** and **expertise**

WHAT IS BRE CONNECT ONLINE?

BRE Connect Online gives you **access to the unrivalled expertise and insight of BRE** – the UK's leading centre of excellence on the built environment. BRE Connect Online is an **annual subscription service** from IHS BRE Press giving online access to **over 1700 BRE titles**

WHAT DO I GET?

ALL NEW AND PUBLISHED BRE TITLES

700 books, reports and guides – research, innovation, best practice and case studies, including:

- The Green Guide to Specification
- Designing quality buildings
- Foundations, basements and external works
- Roofs and roofing
- Site layout planning for daylight and sunlight

250 Digests – authoritative state-of-the-art reviews

600 Information Papers – BRE research and how to apply it in practice

150 Good Building and Repair Guides – illustrated practical guides to good building and repair work

AND MUCH MORE ...

MORE THAN 50 NEW TITLES, INCLUDING:

- A technical guide to district heating
- Design of durable concrete structures
- Designing for future climate change
- Energy-efficient refurbishment
- Energy surveys and audits
- External fire spread
- Putting a price on sustainability: an update
- Radon solutions in homes
- Security glazing
- The essential guide to retail lighting



bre

All this for an annual subscription of only **£399** + VAT
Call now on +44 (0) 1344 328038 to find out more or arrange a free trial

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.

Related titles from IHS BRE Press

Lessons learned from community-based microgeneration projects: the impact of renewable energy capital grant schemes

FB 43

Renewable energy technologies: key factors for successful installations

AP 287

Wind loads on roof-based photovoltaic systems

DG 489

Building-integrated photovoltaic systems: challenges and opportunities for manufacturers and specifiers

IP 11/12



IHS BRE Press, Willoughby Road
Bracknell, Berkshire RG12 8FB
www.brebookshop.com

FB 60

ISBN 978-1-84806-231-3



9 781848 062313