Guide to installation of renewable energy systems on roofs of residential buildings

NHBC Foundation
Housing research in partnership with BRE Trust

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July 2011

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FOREWORD

Growing consumer awareness about the impact of climate change, higher costs of generating heat and power by conventional means, and the introduction of the Code for Sustainable Homes, Feed-in Tariffs and the Renewable Heat Incentive have all contributed to an increase in the uptake of roof-mounted microgeneration systems such as photovoltaic, solar thermal, and perhaps to a lesser extent, microwind turbines. Disappointingly this increase has also resulted in an escalation of wind-induced failures and rainwater penetration through the roof envelope.

This guide reviews various roof-mounted microgeneration technologies and considers the main reasons for such failures, including poor design of installation and bad workmanship. It is essential that systems can both resist the anticipated wind forces and safely transmit these back to the building structure, and that roof-mounted systems are weather-resistant and do not compromise the existing building envelope by allowing rainwater to enter or damage the fabric of the building.

This publication provides practical guidance on the installation of roof-mounted renewable energy systems and complements existing guidance contained in other sources including the NHBC Standards Chapter 3.1 Low or zero carbon technologies and the Microgeneration Certification Scheme standards.

As we head towards the zero carbon future for new homes, and address the huge challenge of reducing energy consumption and achieving carbon compliance in our homes, it is clear that satisfactory installation of renewable energy systems is essential in order to avoid problems that will impact adversely on consumers, and in the process undermine the credibility of new low and zero carbon technology.

I hope that you will find the guide both useful and informative.

Rt. Hon. Nick Raynsford MP
Chairman, NHBC Foundation

ABOUT THE NHBC FOUNDATION

The NHBC Foundation was established in 2006 by the NHBC in partnership with the BRE Trust. Its purpose is to deliver high-quality research and practical guidance to help the industry meet its considerable challenges.

Since its inception, the NHBC Foundation's work has focused primarily on the sustainability agenda and the challenges of the government's 2016 zero carbon homes target. Research has included a review of microgeneration and renewable energy techniques and the groundbreaking research on zero carbon and what it means to homeowners and housebuilders.

The NHBC Foundation is also involved in a programme of positive engagement with government, development agencies, academics and other key stakeholders, focusing on current and pressing issues relevant to the industry.

Further details on the latest output from the NHBC Foundation can be found at www.nhbcfoundation.org.

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Professor Steve Wilcox, Centre for Housing Policy, University of York

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1 Introduction

There are a number of drivers that are leading to an increasing rate of installation of renewable energy systems in residential buildings; these include increased consumer awareness of the impact of climate change, the increasing costs of generating heat and power by conventional means, the introduction in 2006 of the Code for Sustainable Homes, the Feed-in Tariffs introduced in May 2010 and the Renewable Heat Incentive scheme introduced in 2011 and which will be extended to residential installations in 2012. This has led to a surge in popularity of microgeneration systems such as photovoltaic (PV), solar thermal, and microwind turbines installed on residential buildings in the UK. In turn this has led to cases of wind-induced failures and rainwater penetration through the roof envelope. This can be due to a number of reasons including poor design and bad workmanship, but a main contributing factor is that there are no British or European standards for the installation of these products on buildings, although the individual microgeneration systems are themselves well regulated.

PV, solar thermal and microwind turbines are installed on or above roofs where they can be exposed to harsh environmental conditions such as strong winds and driving rain. It is an essential requirement that these systems can both resist the wind forces and safely transmit these forces back to the building structure. It is also essential that roof-mounted systems are weather-resistant and do not compromise the existing building envelope by allowing rainwater to enter or damage the fabric of the building.

PV, solar thermal and microwind turbines are all regulated by a range of British and European standards which ensure that they are ‘fit for purpose’. In the UK, there is also the Microgeneration Certification Scheme (MCS) which is an initiative to drive the Government’s carbon and energy strategies and to provide consumer confidence that renewable technology products and installers meet, and continue to meet, robust standards. The MCS covers product and installer certification schemes for a wide range of microgeneration technologies including PV, solar thermal and microwind turbines.

However, there are currently no European or British standards that regulate the mechanical installation of PV, solar thermal or microwind turbines on buildings to ensure they are resistant to wind and rain action. General requirements for the installation of these technologies are given in the *NHBC Standards Chapter 3.1 Low or zero carbon technologies*[1]; guidance is also given in the MCS Product Certification Scheme Requirements[2,3,4]. For example, the MCS guidance[3] states that the installation instructions shall give '*full instructions of how the module is to be installed to provide a weatherproof installation (ie details of any flashing or sealing kits and how these are fitted to the module and to the adjoining roof covering)*'. However, it is left to the manufacturer or installer to provide this guidance, generally based on ad hoc testing and/or experience. Because of the lack of authoritative guidance, there are inevitably some failures; either wind induced or from rain penetration through the roof envelope.

The purpose of this guide is to give best practice advice on wind- and weather-resistant installation of PV, solar thermal and microwind turbines on residential buildings. It includes examples of good and bad installation practice and detailed guidance on design for wind loading.

This guide is not intended to replace accredited learning to National Occupational Standards.

2 General good practice during installation

General good roofing practice should always be followed when installing renewable energy systems on roofs.

The PV, solar thermal or microwind turbine system should be fully defined at the design stage, including coordination of the assembly sequence of all system components. The chosen system should be self-consistent and all components must be designed to work together. Special consideration must be given to the adequacy of fixings or anchors to ensure that they can resist the wind loads and any other imposed loading. Wind speeds and hence wind loads, vary throughout the UK and are influenced by the roof height, roof pitch, building orientation, topography, etc. Therefore, a design that is suitable for one roof shape or house type might not be suitable for a different roof. For example, a fixing system that is suitable for use in London might not be adequate for use in northern England or Scotland without the use of larger members or additional fixings. A check should always be carried out to ensure that the system is suitable for the specific wind conditions at the site.

The specifications of the roof covering and roof weatherproofing system should always be taken into account when planning an installation. In particular, it is important to ensure that the thermal insulation, weathertightness, ventilation and structural stability are not compromised by the installation. Roofs of residential buildings in the UK are mainly of single lap tiles (concrete or clay, flat or profiled) (Figure 1) or double lapped tiles (concrete or clay) (Figure 2) or slates (natural or man-made). These different types of roof covering pose different installation problems and a solution for a single lapped covering might not be suitable for a double lapped covering.

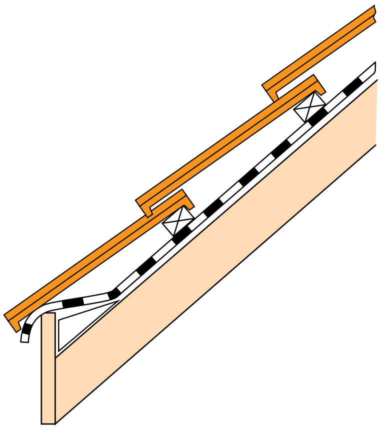

Figure 1 Single lap roof tiles.

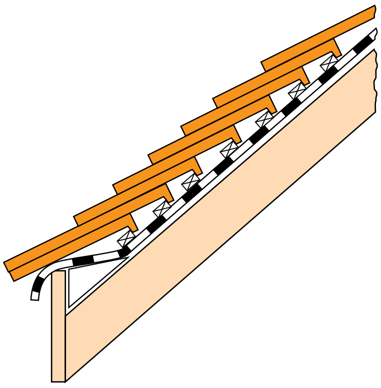

Figure 2 Double lap roof tiles.

For slating and tiling work, the minimum standards are covered by BS 5534 *Code of practice for slating and tiling (including shingles)*[5], BS 8000-6 *Workmanship on building sites. Code of practice for slating and tiling of roofs and claddings*[6] and NHBC Standards. General information on roofing and good roofing practice is given in the BRE publication *Roofs and roofing*[7]. Technical Bulletins produced by the National Federation of Roofing Contractors are also a recognised source of good industry practice. A full list of the relevant standards applicable to roofing is provided in Table 1.

Table 1

British Standards applicable to roofing

BS 5534	Code of practice for slating and tiling (including shingles)
BS 1202	Specification for nails (Part 1: Steel nails, Part 2: Copper nails, Part 3: Aluminium nails)
BS 1449-1	Steel plate, sheet and strip – Part 1: Carbon and carbon-manganese plate, sheet and strip
BS 1554	Specification for stainless and heat-resisting steel round wire
BS 5268-2	Structural use of timber – Part 2: Code of practice for permissible stress design, materials and workmanship
BS 6100-1.3.2	Glossary of building and civil engineering terms, Part 1: General and miscellaneous – Section 1.3: Parts of construction works – Subsection 1.3.3: Roofs and roofing
BS 6229	Code of practice for flat roofs with continuously supported coverings
BS 6399	Loading for buildings (all parts)
BS 6651	Code of practice for protection of structures against lightning
BS 8000-6	Workmanship on building sites – Code of practice for slating and tiling of roofs and claddings
BS 8417	Preservation of timber – Recommendations
BS EN 485-1	Aluminium and aluminium alloys – Sheet, strip and plate (parts 1, 2 and 4)
BS EN 517	Prefabricated accessories for roofing – Roof safety hooks
BS EN 988	Zinc and zinc alloys – Specification for rolled flat products for building
BS EN 1172	Copper and copper alloys – Sheet strip for building purposes
BS EN 10048	Hot rolled narrow steel strip – Tolerances on dimensions and shape
BS EN 10258	Cold rolled stainless steel narrow strip and cut lengths – Tolerances on dimensions and shape
BS EN 12588	Lead and lead alloys – Rolled lead sheet for building purposes
BS EN ISO 1461	Hot dip galvanised coatings on fabricated iron and steel articles – Specification and test methods
BS EN1991-1-4	Eurocode 1: Actions on structures: Part 1-4: General actions – Wind actions

Any penetrations through the roof envelope or walls, such as fixings or cables and pipes should be sealed using appropriate standard or custom-made flashings or kits. Sealants or mastic alone should not be used. Where tiles are cut or trimmed, for example, to allow installation of a roof hook, the gaps around the hook should be no larger than those naturally occurring between the roof tiles.

General good practice for installations requires that:

- an appropriate scaffold or working platform must be erected when working at height on a roof
- an appropriate system of mechanical lifting should be provided. Flat plate solar thermal panels can weigh up to 80 kg each
- when installing an integrated PV or solar thermal system, the underlay should always be checked for tears or other signs of damage and replaced as necessary. If the underlay is damaged, it will not provide an effective air barrier which could lead to increased wind loads on the installed system
- the condition of existing roof timbers should always be carefully inspected to ensure that the rafters and battens provide a suitable substrate for the fixing and can resist the additional wind loads. Existing battens might not be as large as modern battens and they might need to be reinforced or replaced
- when installing systems close to the ridge, there is a chance that ridge tiles could be loosened. If this is likely, then the ridge tiles should be removed and refixed on completion
- consideration should always be given to the need for maintenance of the renewable energy system or the surrounding roof. For example, if a roof has a life expectancy of less than the system being installed, this could require the system having to be removed and reinstalled in the future
- when installing flashings, it might be necessary to adapt the tiles, particularly some types of profiled tiles, to improve the fit of the flashing, see Figures 3 and 4
- note that any adaptations to tiles should not compromise the weathering properties, and where lead flashings are formed in situ, they must conform to the minimum standards issued by the Lead Sheet Association (LSA)
- PV and solar thermal systems should be installed in locations where they will get full sunlight and not be shaded; see Figure 5 for an example of an undesirable installation
- microwind turbines installed on buildings should where possible be mounted above the ridge or the highest part of the building to maximise the available wind resource.

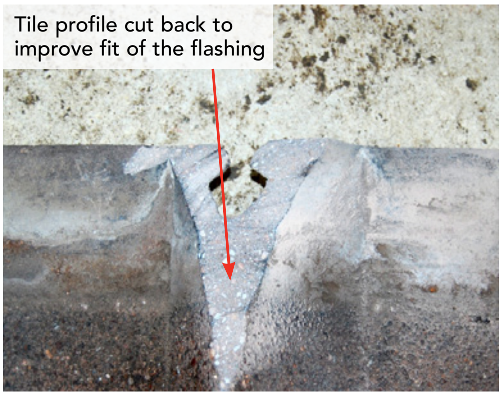

Figure 3 Tile trimmed for easier flashing.

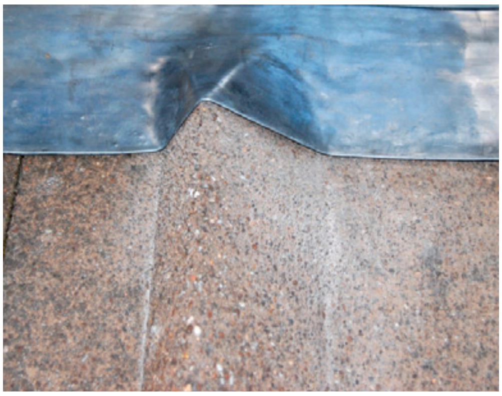

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Figure 4 Flashing in place on trimmed tile.


On a south facing roof but behind a chimney

Shaded by trees

Figure 5 Examples of unsuitable locations for solar systems.

All applicable regulations and directives must be met in full for the appropriate microgeneration technology. Different regulations might apply in England and Wales, Scotland and Northern Ireland. Some guidance on applicable regulations is given in the appropriate MCS guidance documents[2, 3, 4]. Installation of PV, solar thermal and microwind turbines will vary depending on the individual product. Specific installation instructions should be available from the manufacturer or supplier.

General good practice guidance for solar thermal, PV and micro wind is given in the following publications:

- The Energy Saving Trust (EST) publication CE 131 *Solar water heating systems – guidance for professionals, conventional indirect models*[8] gives advice on solar thermal installations.
- The DTI guide *Photovoltaics in buildings – Guide to the installation of PV systems,* 2nd edition, 2006 (DTI publication DTI/pub URN 06/1972)[9] gives advice on PV installations.
- The EST publication CE 72 *Installing small wind-powered electricity generating systems*[10] gives advice on installation of microwind turbines.

All work, and working practices, must be in compliance with all relevant Health and Safety regulations. A risk assessment should be carried out for each individual installation before work on site is commenced.

Anyone carrying out the installation of PV, solar thermal or microwind systems should be trained and competent at general construction site practice and should also have specific training or competence appropriate to the type of renewable technology. MCS installation standards give requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of PV[11], solar[12] and microwind turbine systems[13].

PV and solar thermal systems should not be installed in locations where they will be shaded for long periods of time; Figure 5 shows an installation in an unsuitable location. Microwind turbines should ideally be located so that they are not sheltered from the prevailing wind direction which is generally south west.

The British Standards shown in Table 1 are relevant for roofing and some or all of these will also be relevant to the installation of roof-mounted renewable energy technologies.

3 Photovoltaic systems

3.1 Overview of PV in the UK

There is a total installed PV capacity in the UK of 29.6 MW[14]. This represents a 31% (7.1 MW) increase in capacity between 2008 and 2009. However, in comparison with other European countries, this is a very small total installed capacity, for example, in France, the installed PV capacity increased by over 250 MW during 2009 and in Germany, the increase was over 3800 MW. Table 2 gives details of the installed PV power capacity in 2009 for a range of countries.

The majority of UK PV installed capacity is grid connected and approximately 72% of the installed capacity in 2008 was supported by grant funding through the Low Carbon Buildings Programme and other grant schemes.

There are many different types of roof-mounted PV systems in use in the UK. Some have been designed specifically for UK roof construction and practice whilst others are imported systems originally designed for use in other countries. This can lead to confusion and, in some cases, inadequate installation has resulted in failures under wind action or rain penetration. Guidance exists for electrical installation of PV systems[15, 16, 17] but there is little equivalent guidance for mechanical installation.

3.2 Installation

There are two main types of PV installation: integrated into the roof surface, often referred to as Building-Integrated Photovoltaic (BIPV) systems or mounted above the existing roof covering, also referred to as stand-off systems. There are a number of sub-categories of both types defined according to the size of the PV modules, design, installation requirements, type of fixing, etc. BRE DG 495[18] gives more details. Integrated systems are usually installed on new buildings, whereas above-roof systems are generally installed as retrofit systems, although there are no technical barriers to the use of either type of system in new or existing roofs.

Table 2

PV power capacity in participating IEA PVPS countries during 2009[14]

Country*	Cumulative off-grid PV capacity** (kW)		Cumulative grid-connected PV capacity (kW)		Cumulative installed PV power (kW)	Cumulative installed per capita (W/Capital)	PV power installed during 2009 (kW)	Grid-connected PV power installed during 2009 (kW)
	Domestic	Non-domestic	Distributed	Centralised				
Australia	40 770	43 140	97 210	2530	183 650	8,3	79 130	68 570
Austria	3605		48 991		52 596	6,4	20 209	19 961
Canada	15 190	20 010	12 250	47 120	94 570	2,8	61 850	54 140
Denmark	165	375	4025	0	4565	0,8	1300	1200
France	23 000		407 000 installed/ 269 000 connected		43 000	6,7	250 000	250 000
Germany	45 000		9 800 000		9 845 000	119,6	3 845 000	3 840 000
Israel	2644	260	21 611	14	24 529	3,4	21 500	21 000
Italy	5000	8000	656 800	511 500	1 181 300	20,3	723 000	723 000
Japan	2635	91 998	2 521 792	10 740	2 627 165	20,7	482 976	479 152
Korea	983	4960	93 300	342 672	441 917	9,1	84 400	84 400
Malaysia	10 000		1063	0	11 063	0,4	2287	287
Mexico	18 037	5687	1296	0	25 020	0,2	3270	796
The Netherlands	5000		58 169	4338	67 507	4,1	10 669	10 578
Norway	8080	450	132	0	8662	1,9	320	0
Portugal	3050		99 150		102 200	9,5	34 250	34 150
Spain	31 000		3 492 000		3 523 000	76,1	60 000	60 000
Sweden	4448	721	3535	60	8764	1,0	854	516
Switzerland	4000		67 040	2560	73 600	9,7	25 700	25 500
Turkey	1000	3500	500	0	5000	0,1	1000	100
UK	620	1125	27 845	0	29 590	0,4	7077	6922
USA	154 000	256 000	1 101 600	130 000	1 641 600	5,3	473 100	433 100
Estimated totals for all IEA PVPS countries (MW)	**837**		**19 543**		**20 381**		**6188**	**6113**

Reproduced with permission from IEA PVPS International Energy Agency Photovoltaic Power Systems Programme.

In all cases, special care has to be taken to ensure that the exterior waterproof envelope of the roof is not compromised which could lead to leaks and rain penetration. In particular, where fixings, cables and pipes penetrate the roof, they should be installed using appropriate standard manufactured parts wherever possible or where standard parts are not available, then purpose-made proprietary mountings and penetration sealing should be used. The following sections provide guidance on achieving a weathertight installation. The Annex gives guidance on design for wind loading.

3.2.1 Roof-integrated PV systems

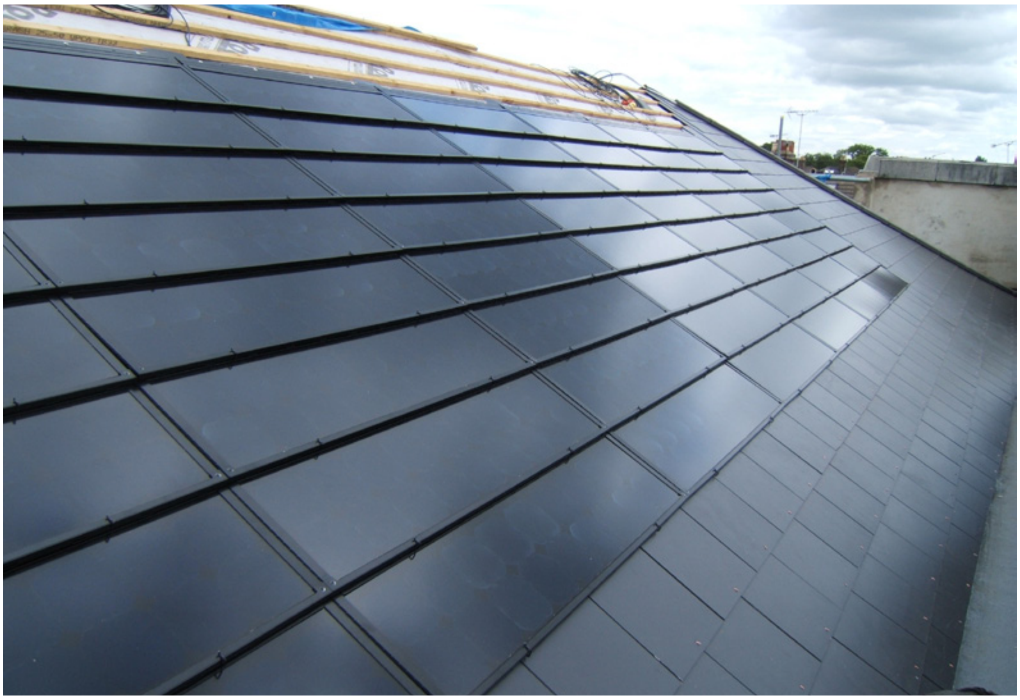
There are a wide range of types of roof-integrated PV systems in use in the UK; they can range from interlocking small format PV tiles and slates through to large format laminate systems. All roof-integrated PV systems must perform the dual function of generating power whilst also providing a weatherproof covering to the building. It is essential therefore that the PV system is weatherproof and has adequate durability to maintain its weathertightness throughout its expected lifetime. It is also essential that integrated

PV systems provide a weatherproof seal at the interface with the existing roof covering because this is where there is the greatest potential for problems from rain and wind driven rain to occur.

Another issue which can lead to problems with water ingress is the need to provide adequate ventilation to the underside of the integrated PV system. This can be achieved by increasing the air gap beneath the system or by providing external ventilation. Where external ventilation is used, it is essential to ensure that no rainwater can leak through the ventilation grilles. The ideal free air gap beneath the roof covering is 50 mm, although 25 mm is generally acceptable (see BS 5534[5] and BRE's *Thermal insulation: Avoiding risks*[19]).

Small format tile and slate PV modules

These systems are generally used on tile or slate pitched roofs. They can be either single or multiple tiles or slates, and can be either interlocking or non-interlocking and are generally designed to integrate with particular types of roof tiles or slates. A typical example is shown in Figure 6.



© D Chambers

Figure 6 PV solar slate designed to interface with existing slates without additional flashing.

The potential sources of leakage with small format tile and slate PV units are:

- through the head or side laps of the PV tiles and slates
- at the top of the array at the junction with the ridge tile or top course of tiles or slates
- at the sides of the array at the junction with the existing roof tiles or slates
- at the bottom of the array.

For interlocking PV tiles, providing the PV tile side and head locks are designed correctly, then the interlocking PV tiles should be as rain-resistant as the existing roof covering and providing the interlocks are compatible with the existing roof tiles, then they should not leak at the interfaces with the existing tiles. However, care should be taken to ensure that the interlocks of PV tiles are well-matched with the existing roof covering. This is especially important for retrofit systems where a wide range of roof tiles could be used. For new build systems or where the whole roof is being replaced, then the correct roof tiles can be specified.

For PV slates and non-interlocking PV tiles, the rain resistance is provided by the overlap between the PV elements and the existing roof covering. Providing the head and side laps follow European or National rules (see BS 5534) for tiles and slates, then the PV slates and tiles should be rain-resistant. However, at the interface with the existing roof covering, special seals or flashings may be required.

In some cases, it may be necessary to provide a larger air space beneath the PV tile or slate to increase the ventilation and hence the cooling. This can be easily done using counter battens and does not affect the weathertightness of the roof or the PV units. Counter battens should comply with the requirements of BS 5534, but note that counter battens if used must be applied to the whole roof covering not just to the area where the PV units are installed.

Large format PV modules, laminates and tiles

These systems are generally used on pitched roofs with tiles, slates or metal cladding. They range from large format tiles and slates to laminate and modules on self-supporting sub-frames to PV modules bonded to metal pans. A typical example is shown in Figure 7.

The potential sources of rain leakage with large format module systems are:

- between adjacent PV modules
- at the sides, top and bottom of the array where they join the existing roof.

Large format PV tiles are generally interlocking or overlapping units; the main sources of leakage with these are at the interface with the existing roof covering.

Laminate and module systems generally use special seals and/or capping strips to make a weatherproof seal between adjacent modules. The main source of leakage with these systems is at the interfaces with the existing roof where product-specific flashings are required. Figures 8 and 9 show typical top and bottom flashing details.

© PV Systems

Figure 7 Integrated PV module system.

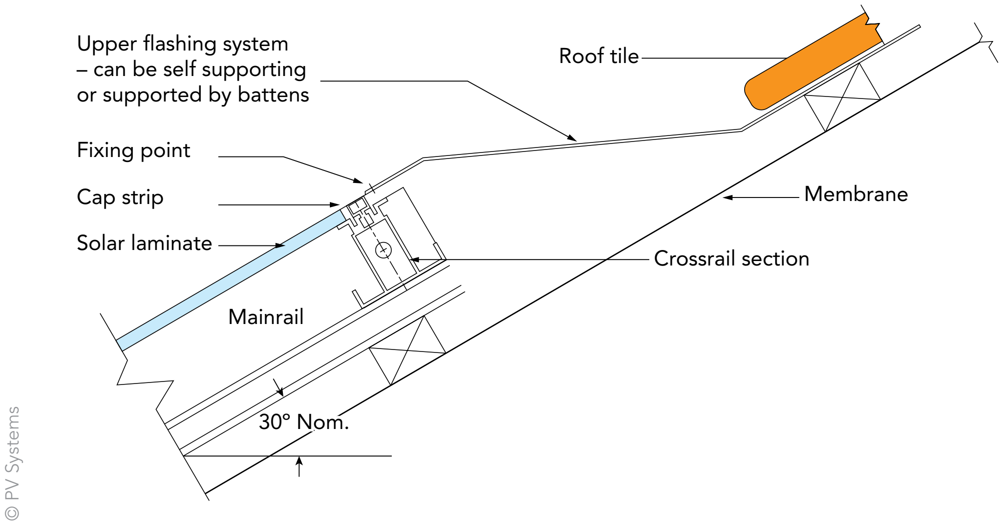


Figure 8 Typical flashing detail at the top of an integrated PV system.

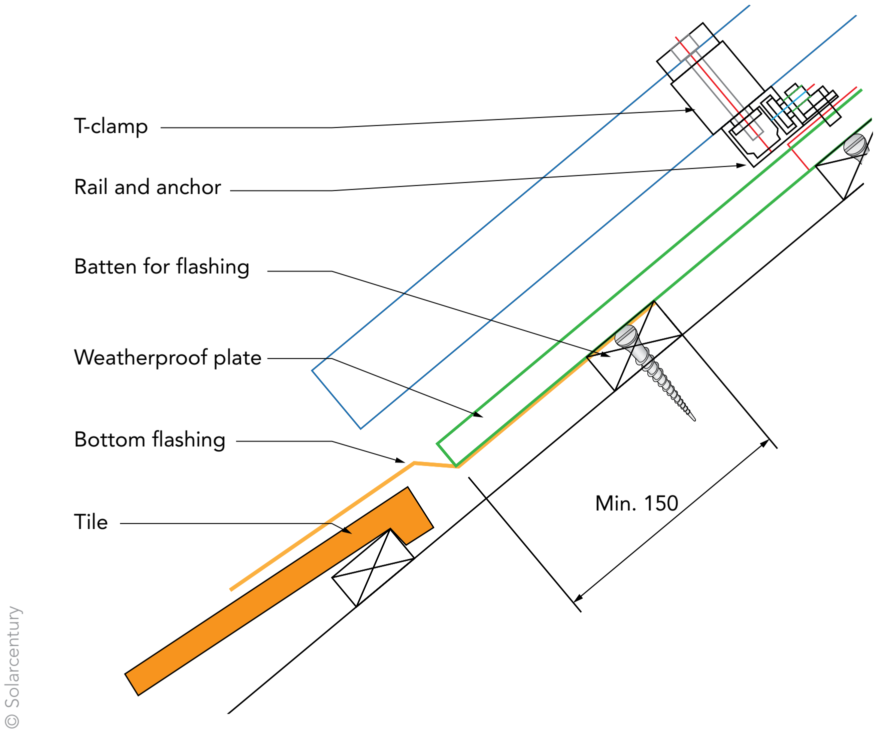


Figure 9 Typical bottom flashing detail for a module system with backing plates.

Integrated systems with weathertight under-roof

These are PV systems where the modules sit above a proprietary under-roof system which provides the weathertight barrier and perimeter flashings are used to provide the interface to the roof covering. Such systems have proprietary fixing points built into the weatherproof under-roof.

The potential sources of rain leakage with these PV systems are:

- at the sides, top and bottom of the under-roof system where it joins the existing roof
- between the elements of the under-roof system.

Figure 10 shows a typical weathertight under-roof system. This figure also shows details of edge and bottom flashings and fixing points for the module mounting rails. For the purposes of wind loading, these systems should be treated as above-roof systems because the underside of the PV modules is fully exposed to wind action.

3.2.2 Above-roof PV systems

Systems mounted on pitched roofs

Above-roof PV systems mounted over the top of pitched roofs usually comprise modules attached to a frame which is fixed to the roof. The frame is designed to transfer the applied forces (ie self-weight, wind and snow loads) to the supporting roof structure. Various types and sizes of PV modules can be used with stand-off systems. A typical example is shown in Figure 11.

Above-roof PV systems are not required to provide a weatherproof covering for the roof, therefore any rain ingress into or between the modules will not affect the underlying roof, although of course, this could seriously affect the performance of the PV system.

The potential sources of rain leakage on roofs with above-roof PV systems are:

- at the fixing points used to attach the system to the roof structure
- where the electrical connections penetrate through the roof
- possibly beneath the bottom edge of large arrays of PV modules where high levels of run-off rainwater from the modules can be concentrated.

It is important to ensure that there is sufficient gap between the system and the roof covering to allow for free drainage of the rainwater.

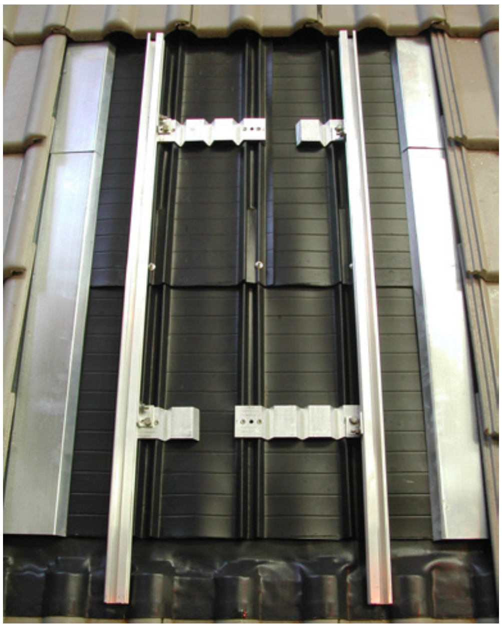


Figure 10 Proprietary weathertight under-roof system showing edge flashings and module fixing points.

© AST Roofing

Figure 11 Above-roof PV system.

Fixings of above-roof systems are of three main types:

- hook fixings which penetrate between the tiles and fix to rafters or occasionally to the battens
- proprietary tiles or slates with built-in fixing points
- bolt-through fixings which penetrate through the tiles (generally used with double lap tiles and slates).

Hook fixings

The hook fixing is the most common fixing type on roofs with single lap tiles since removing a tile exposes the roof structure allowing easy fixing of the hook, as shown in Figure 12. Figure 13 shows examples of hook fixings.

Single lap tile lifted to allow hook to be installed

Hook fixing with tile in place

© Ecoskies

Figure 12 Easy fixing of the hook.

Hook for plain tiles

Standard roof hook for interlocking tiles

Adjustable roof hook for interlocking tiles

© Solarcentury

Figure 13 Examples of hook fixings.

There is a European Standard BS EN 517:2006[20] for roof safety hooks. These hooks are similar in some ways to the hook fixings used with PV systems. This Standard gives information on materials and methods for fixing hooks to the roof structure as well as test methods for static, dynamic and fatigue loading. It is likely that much of this Standard will be applicable to the design of hook fixings used with above-roof PV systems.

Problems can occur with hook fixings due to inadequate design or installation which can cause the roof to leak. These problems can include hooks which deflect under wind load, lifting surrounding roofing elements, hooks which increase the gap between tiles (Figure 14) and hooks which interfere with the adjacent tiles causing them to break under wind or snow loads or from workers walking on the roof (Figure 15). Where tiles are notched to accommodate hooks, the size of the notch should not create excessive gaps larger than those that naturally exist between tiles (Figure 16).

It is good practice to use stainless steel hooks (eg stainless steel number 1.4301 or 1.4401 to BS EN 10088-1) (with a minimum thickness of 5 to 6 mm) for corrosion resistance and to avoid excessive deflection under wind action. On profiled tiles, hooks should usually be installed in the tile trough and notched to avoid increasing the tile gapping.

Roof hooks for use in mainland Europe often have fixing holes designed to suit the larger rafters common in these countries. These hooks might not fit the narrower roof timbers generally used in the UK without modification. Another consideration with some hooks is that they are designed for use with large screw fixings in excess of 8 mm diameter. BS 5268-2[21] specifies that the minimum distance from predrilled holes to the edge of the timber is five screw diameters. Typical UK rafters are 35 to 50 mm wide which could preclude the use of such large fixings, or could require evidence that the fixings are adequate. A common solution to this problem is to use noggins – timber cross members fixed between the rafters.

Hook fixings are more difficult to install with double lapped tiles (plain tiles) and slates since the underlying roof structure is not exposed by lifting the top tile or slate. Hook fixings can be used with double lapped roof elements although this will require the roof elements to be cut to accommodate the hook and an appropriate flashing installed to ensure the fixing is weathertight. Figures 17 and 18 show examples of weather-resistant sealing methods around hook fixings on plain tiles and slates.

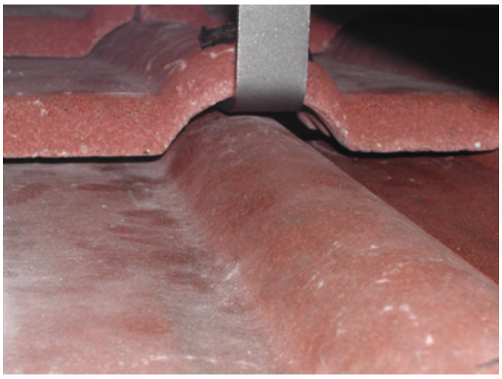


Figure 14 Hook fixing at top of tile profile increasing the tile gaps (not recommended).

Figure 15 Tile damage caused because the tile was not notched around the hook.

Figure 16 Single lap tile notched for hook fixing (note that the gap around the hook is similar to that between the tiles).

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Figure 17 Cut plain tiles with a weatherproof flashing around the hook fixing.

© Sundog

Figure 18 Cut natural slate with a weatherproof flashing around the hook fixing.

Solar support tiles

Proprietary fixing systems are available for mounting PV (and solar thermal systems) on to tile or slated roofs. These systems include metal tiles with the fixing point directly attached to the tile or metal support posts which are securely fixed back to the roof structure and sealed with a flashing panel designed to seal around the support post and integrate with the surrounding roof tiles. These systems can be universal systems designed to fit a range of tiles (Figure 19a) or products designed to fit specific tile types (Figure 19b). These systems can provide a robust and weathertight solution which does not create gaps or lift the surrounding roof tiles under wind loading. Such systems can be used for solar thermal collectors as well as PV modules.

(a) Universal design

(b) Tile specific solution

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© Monier

Figure 19 Examples of solar support tiles.

Bolt-through fixings

Bolt-through fixings are not recommended because they can damage or weaken the roof tiles or slates, they can increase the loads on the roof covering, and they are difficult to seal. This is especially true for double lapped products such as slates and plain tiles because the holes for the fixings must be drilled through two roofing elements (Figure 2), the lower of which cannot be seen or inspected for damage and cannot be easily sealed. In some cases, drilling holes in tiles or slates will invalidate the tile/slate manufacturer's warranty for that area of the roof.

Figures 20 and 21 show examples of bolt-through fixings. Figure 22 shows an example of a bolt-through fixing relying on mastic alone for the weathertight seal.

Figure 20 Bolt-through fixing on a plain tile roof (not recommended).

Figure 21 Bolt-through hook fixing on a slate roof (not recommended).

Figure 22 Example of a non-durable weather seal around a bolt-through fixing (should not be used).

Roof penetrations

With above-roof systems, attention should be given to ensuring that penetrations through the roof for the routing of power cables are waterproof. This can best be provided using purpose-made tiles or flashings (Figure 23). Mastic or sealants alone should not be relied on to provide a weathertight seal.

© Ecoskies

© Klober

Figure 23 Purpose designed tiles to provide a weathertight entry for power cables.

PV systems mounted on flat roofs

PV modules on flat roofs are generally mounted on sloping frames which can be mounted on free standing bases (usually loaded with additional ballast) or fixed directly to the roof structure and incorporated into the roof waterproofing system. Ballasted systems will increase the dead loads on the roof; an assessment of the structural adequacy of the roof structure should be made. Figure 24 shows a typical PV installation on a flat roof.

The only sources of rain leakage with these systems are where there are penetrations through the roof waterproofing layer. It is always good practice to avoid such penetrations because they are generally hard to seal and inspection is often difficult.

In some cases, PV systems can be integrated directly into flat roofs (Figure 25), although this is not common because the efficiency of PV modules is reduced because the optimum angle relative to the sun is not achieved. Where PV systems are integrated into flat roofs, the rain penetration issues could require special consideration because the rainwater will be in contact with the roof for longer periods due to the slower rate of run-off.

© Solarcentury

Figure 24 PV arrays mounted on a flat roof.

Figure 25 PV system integrated into a flat roof.

4 Solar thermal systems

4.1 Overview of solar thermal systems in the UK

Solar thermal systems have been commercially available since the 1800s. However, the UK market is still very small, representing only 2% of the European solar thermal market, see Table 3[22, 23]. In the UK in 2010, there was about 573 220 m^2 of installed solar thermal capacity. This represents an equivalent solar thermal capacity of about 401 MW. The solar thermal market increased by approximately 8% during 2010. Growth is expected to continue increasing for the next decade[23], especially as now that the new Renewable Heat Incentive scheme has been launched.

Solar thermal systems come in a variety of configurations. Each differs in design, cost, performance, and level of complexity. A solar water heating system usually consists of a hot water storage tank, a solar collector that absorbs solar energy, a back-up energy source, and (for forced circulation systems), a pump and controls. Most solar thermal installations in the UK are of the forced circulation type; passive systems which require a water tank integrated into or located above a solar collector are generally only suitable for warmer climates where there is little risk of freezing.

Table 3

European solar thermal market size in terms of solar thermal capacity and collector area[22, 23]

	In operation		Market (newly installed)						Annual evaluation of the market
	2010		2008	2009	2010				2010/2009
	Total glazed		Total glazed	Total glazed	Flat plate	Vacuum collectors	Total glazed		Total glazed
	m^2	KW(th)	m^2	m^2	m^2	m^2	m^2	kW(th)	%
Austria	3 836 509	2 685 556	347 703	356 166	279 898	268 093	11 805	195 929	-21.4
Belgium	328 148	229 703	62 200	50 700	38 301	31 306	6995	26 811	-24.5
Bulgaria	105 300	73 710	25 500	8000	8400	7750	650	5880	-
Cyprus	715 022	500 515	60 000	34 709	30 713	28 931	1782	21 499	-11.5
Czech Republic	308 376	215 863	35 000	51 669	86 000	70 000	16 000	60 200	66.4
Denmark	525 146	367 602	33 000	54 500	58 100	57 700	400	40 670	6.6
Estonia	2920	2044	500	450	500	100	400	350	-
Finland	32 923	23 046	4100	4000	6000	4000	2000	4200	-
France	1 573 900	1 101 730	313 000	265 000	256 000	247 000	9000	179 200	-3.4
Germany	13 824 000	9 676 800	2 100 000	1 615 000	1 150 000	1 035 000	115 000	805 000	-28.8
Greece	4 084 200	2 858 940	298 000	206 000	214 000	212 500	1500	149 800	3.9
Hungary	149 814	104 870	32 000	22 000	21 000	14 700	6300	14 700	-4.5
Ireland	131 489	92 042	43 610	32 221	24 918	14 525	10 393	17 443	-22.7
Italy	2 671 730	1 870 211	500 000	475 000	490 000	427 500	62 500	343 000	3.2
Latvia	1940	1358	210	180	200	100	100	140	-
Lithuania	2400	1680	300	200	200	50	150	140	-
Luxemburg	31 600	22 120	3600	4700	4500	3500	1000	3150	-
Malta	45 860	32 102	6000	5500	5000	5000	0	3500	-
The Netherlands	447 595	313 317	25 000	45 260	40 834	40 834	0	28 584	-9.8
Poland	655 890	459 123	129 632	144 308	145 906	110 480	35 426	102 134	1.1
Portugal	672 697	470 888	86 820	173 762	182 271	182 018	253	127 590	4.9
Romania	104 700	73 290	8000	14 900	15 500	8500	7000	10 850	-
Slovakia	121 750	85 225	13 500	13 500	15 000	12 800	2200	10 500	11.1
Slovenia	175 300	122 710	16 000	22 000	19 000	15 000	4000	13 300	-13.6
Spain	2 106 866	1 474 806	433 000	391 000	336 800	315 300	21 500	235 760	-13.9
Sweden	323 735	226 615	26 813	21 309	20 699	13 567	7132	14 489	-2.9
Switzerland	895 492	626 844	112 833	145 640	140 000	130 000	10 000	98 000	-3.9
UK	573 220	401 254	81 000	89 100	105 200	75 600	29 600	73 640	18.1
EU27 + Switzerland	34 448 521	24 113 964	4 797 321	4 246 774	3 694 940	-	-	2 586 458	-13.0

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4.2 Installation

Solar thermal systems are generally heavier per m^2 than PV systems due to the weight of the heat conducting fluid and pipe work. Therefore, the structural stability of the roof will need to be assessed. An assessment should be made during the site survey to determine the type and construction of the roof to assess its structural strength. The weight of the collectors is less of a concern for integrated systems as the weight per m^2 of the collectors is generally of the same order as typical concrete roof tiles. Wind and snow loading on the collector can significantly increase the overall loading on the roof. Modern truss rafter constructions are computer designed to minimise the number of trusses and the size of the timbers required. They tend to have less capacity to take additional load and more care should be exercised when assessing loading. Roofs that have special constructions, eg hip and valley, or that have rafters cut for roof lights should be treated with even greater care and the location of the collectors kept away from potentially weaker areas. The following sections provide guidance on achieving a weathertight installation. The Annex gives guidance on design for wind loading.

4.2.1 Above-roof solar thermal mounting systems

There are two main types of above-roof solar collectors: flat plate (Figure 26), which consists of a flat copper plate painted black with water tubes attached to the absorber plate, and evacuated tube collectors (Figure 27), which consist of a series of tubes that contain a heat pipe to absorb solar energy and transfer it to a liquid medium.


© Baxi

Figure 26 Flat plate solar collector.


© Klober

Figure 27 Evacuated tube solar collector.

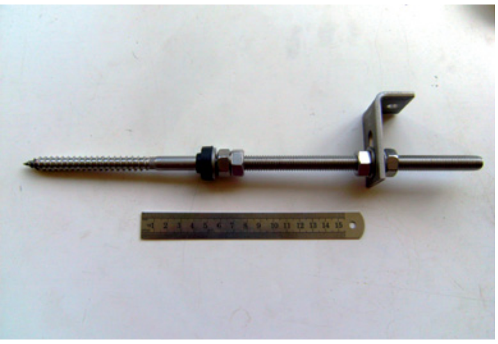

Figure 28 Bolt fixing for solar thermal system.

Above roof solar thermal collectors are generally mounted using hook or bolt-through fixings; these can be similar to those used on PV systems although the fixings tend to be of heavier construction to support the higher dead loads (Figure 28). The same sources of leakage and the precautions and solutions also apply to solar thermal systems, however, the roof penetrations needed for solar thermal systems can be larger than for PV systems and need special care. MIS 3001[12] gives the following advice:

> *'in all circumstances the building's weather tightness must be maintained. Holes drilled through roofing felt and/or roof tiles/slates sealed with mastic or silicone sealant are not considered durable. Purpose-made roof tiles and flashings for the routing of pipes from a collector are examples of durable solutions'.*

Figure 29 shows examples of poorly sealed roof penetrations and Figure 30 shows an example of good practice. Penetrations through the sarking layer should be sealed using proprietary sealing rings or other purpose-made seals. Figure 31 shows an example of an unsealed and a sealed sarking penetration.

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Figure 29 Examples of poorly sealed roof penetrations.

© Monier

Figure 30 Example of weathertight penetration using a modified roof tile.

Good practice – sealed penetration

Bad practice – unsealed penetration

© Klober

© Nigel Cherry

Figure 31 Examples of good and bad practice with underlay penetrations.

4.2.2 Roof-integrated mounting systems

At present, only flat plate collectors are integrated into the roof. The collector essentially becomes part of the weatherproof layer of the roof. This requires a high standard of materials and workmanship to provide durability comparable to standard roofing such as tiles and slates. Usually collectors will only be integrated into new-build or major refurbishment jobs as the degree of disturbance to an existing roof and the additional cost are not justifiable in a retrofit application. On a new-build roof, the collector will be installed on top of the rafters or tile battens and then flashed in situ using proprietary flashings. Generally, a header flashing will divert the flow of water coming down the roof over the top of the collector or around it onto the side flashings. The bottom edge is finished with a flashing to redirect the flow of the water onto the slates or tiles underneath (Figure 32). Hydraulic connections are often concealed behind the flashing and so are not exposed to the weather which removes the need for weathertight seals around the penetrations.

© Viridian

Figure 32 Integrated flat plate solar collectors with slates and profiled tiles.

5 Building-mounted microwind turbines

5.1 Overview of building-mounted microwind turbines in the UK

Small or microwind turbines have been available for several decades and are in widespread use today, with more than 150 000 machines installed and operated worldwide. However, fewer wind turbines have been sold in the UK than other countries such as the USA. By the end of 2011, there are expected to be approximately 11 500 microwind turbines installed in the UK (turbines with power output in the range 0.0 to 1.5 kW). Table 4[23] shows the UK deployment of small wind and microwind turbines since 2005, including free standing and building-mounted installations.

In theory, small scale wind energy has the potential to generate 41.3 TW of electricity and save 17.8 Mt CO_2 in the UK annually[24]. However, given the current costs of small wind turbines and electricity prices, it is realistic to suggest that only a small proportion of these figures could actually be achieved in the UK. If 10% of households installed turbines, up to 1.5 TW could be generated and 0.6 Mt CO_2 saved. Relative to the total UK electricity consumption and emissions from power generation, these figures are fairly low.

5.1.1 Types of domestic microwind turbines

There are two basic types of wind turbine available for domestic use, the more common horizontal axis wind turbines (HAWTs) (Figure 33), and vertical axis wind turbines (VAWTs) (Figure 34). The horizontal axis turbine consists of a propeller-type rotor and often a tail vane to continuously point the turbine in the direction of the wind. The vertical axis turbine is omnidirectional and so does not require a tail vane.

Roof-mounted turbines are typically smaller than mast-mounted systems and can be installed on the roof or side of a house where there is a suitable wind source. These are often around 1 to 2 kW in size. For larger industrial and commercial buildings, turbine capacities typically increase to 50 kW and can be up to 15 m in diameter, mounted at a hub height of 25 m[25].

Table 4

UK deployment of microwind turbines since 2005[23]

	UK 2005	Total 2005	UK 2006	Total 2006	UK 2007	Total 2007	UK 2008	Total 2008	UK 2009	Total 2009	UK 2010	Total 2010	UK 2011	Total 2011
Number of deployed units in that year														
0-1.5kW	992	3032	1943	4567	3147	6021	2796	5745	2524	6686	2036	5247	2647	7582
1.5-10kW	155	193	269	330	601	646	575	792	602	851	332	494	1075	1552
10-20kW	13	17	15	16	20	28	65	103	125	161	416	435	969	1173
20-50kW	3	3	5	5	19	19	17	17	24	24	22	22	11	11
50-100kW	0	0	0	0	0	0	0	0	5	5	47	47	140	140
Total	1163	3245	2232	4918	3459	6714	3453	6657	3280	7727	2853	6245	4842	10 458
System application														
On-grid	165	205	705	745	1644	1763	1387	1848	1240	2298	1002	1853	2654	5814
Off-grid	998	3040	1523	4173	2143	4951	2066	4809	2040	5429	1851	4392	2188	4644
System setup														
Building mounted	2	2	380	384	1054	1091	663	853	333	1194	113	542	255	795
Free standing	1161	3243	1852	4534	2733	5623	2790	5804	2947	6533	2740	5703	4617	9663
System design														
HAWT	1163	3245	2224	4910	3747	6674	3355	6557	3142	7579	2804	6194	4574	10 090
VAWT	0	0	8	8	40	40	98	100	138	148	49	51	268	368
Sales (£ thousands)														
0-1.5 kW	573	1678	2425	3923	3713	5595	3033	5359	2648	6590	1779	5513	2300	9517
1.5-10 kW	1301	1612	3093	3745	7663	8133	8001	9862	7969	10 692	5673	7676	21 767	33 477
10-20 kW	251	317	261	321	399	759	1515	2545	3455	4375	12 232	12 832	32 847	32 847
20-50 kW	235	235	292	292	1920	1920	1200	1200	2156	2156	1430	1430	715	715
50-100 kW	0	0	0	0	0	0	0	0	895	895	8160	8160	20 600	20 600
Total	2360	3842	6071	8281	13 695	16 407	13 749	18 966	17 123	24 708	29 274	35 611	78 229	97 156

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Figure 33 Horizontal axis turbine.

Figure 34 Vertical axis turbine.

5.2 Installation

No standards and little publicly available information are available on installation of microwind turbines on to buildings. Most manufacturers provide installation advice but this has not generally been peer reviewed and it is not clear how the fixing types have been arrived at or whether these are based on structural calculations or testing. Some general information on installing small mast mounted wind turbines is given in the EST guide CE 72[10]. Much of the information is also applicable to building-mounted turbines.

The expected maximum working lifetime of a microwind turbine is approximately 20 years, however, this can be reduced by lack of maintenance or damage. Testing has been carried out by BRE on microwind turbines to assess the performance of fixings into masonry walls when subjected to dynamic gust wind loading on the turbine. These tests showed that there was a tendency for bolted fixings to work loose when subjected to a relatively small number of strong wind gusts. It was found that fixing bolts could 'back-out' or the wall plugs could pull-out. This was found to occur on fixings into mortar joints as well as those into brickwork.

Masonry walls can effectively resist compressive (vertically downwards) forces, however, they have less resistance to tensile forces caused by lateral loads. Wind turbines mounted on to facades will generate lateral loads. The fixing of wind turbine support brackets into masonry walls (and other wall types) should be given special consideration to ensure that they are capable of withstanding the applied lateral and dynamic wind loads and resulting vibration and movement over the lifetime of the installation. Figure 35 shows a microwind turbine installation on a gable wall where the fixings holding the top bracket have failed.

It is important that routine maintenance checks as recommended by the supplier/installer are carried out and, in particular, that all fixings are regularly inspected. The mounting brackets should also be resistant to corrosion and ideally made from stainless or galvanised steel, eg stainless steel number 1.4301 or 1.4401 to BS EN 10088-1[26] or galvanised coating on mild steel as specified in EN ISO 14713:1999[27] for the appropriate environment.

All fixings, brackets, guys and turnbuckles should be capable of withstanding both the static and dynamic wind forces and should be provided with the means to avoid and prevent loosening of the fixings to ensure that the turbine is securely fixed to the building. Some manufacturers recommend installing resilient pads with the brackets to dampen vibrations from the turbine.

A suitable maintenance schedule should be in place to provide regular inspection of the turbine and its fixings.


© Encraft

Figure 35 Failure of a microwind turbine fixing bracket into a masonry wall.

5.2.1 Turbines attached to building walls

On domestic dwellings, turbines are generally mounted on a pole fixed to an external wall with brackets. The number, size and type of brackets used will vary according to the size of the turbine, the wind loads on the turbine, the wall substrate, etc. The turbine manufacturer will normally advise on the appropriate type of mounting bracket to use. Figure 36 shows two fixing arrangements for building-mounted microwind turbines.

© Encraft

Figure 36 Typical microwind turbine wall fixing brackets.

The turbine should be mounted sufficiently high to project above the roof of the building so that the blades are at least 0.5 m above the roofline. This is recommended to take advantage of higher wind speeds and to minimise the influence of turbulence generated by the building.

When installing a microwind turbine to a building with a pitched roof, the turbine is usually fitted to the gable end above the ridge line unless there are windows in the wall. Turbines fitted on gable ends require the shortest pole length to reach the required height. However, the apex of the gable end wall is potentially a weak region and an assessment of its structural adequacy should be carried out before installing brackets in this area. If there is no suitable gable end wall, then a very tall pole may be needed to reach a height above the building where there is a sufficient wind resource. This will increase the wind loads and could require a more robust pole and/or more robust brackets. BRE Information Paper 4/08[28] gives more information on optimising the location of wind turbines on pitched roofs.

Microwind turbines should not generally be installed on chimney stacks. Chimneys are not constructed to take the weight of the turbines and the resultant wind loads. Chimneys on older buildings may be even weaker because of the effects of mortar erosion due to flue gases. If a chimney is no longer in use on a building, it could possibly be reinforced to take the loads from a wind turbine[29] but specialist advice should be obtained from a structural engineer.

5.2.2 Roof-mounted microwind turbines

Microwind turbines can also be fixed on the roof or through the roof via a steel frame located in the loft, although this is relatively unusual and requires special consideration of the waterproofing (Figure 37). The turbine pole is attached to a rigid framework in the loft which will need to be securely fixed to the building structure. The hole through the roof created for the pole will require a purpose-designed flexible flashing to ensure that it is weathertight and can accommodate movement of the mounting pole. Expert advice should be sought with regard to the possibility of noise and vibration issues for these types of installation.

5.2.3 Turbines mounted on flat roofs

Turbines on flat roofs can be mechanically fixed, ballasted or guyed. Ballasted systems (Figure 38) do not affect the weathertightness of the roof. However, careful consideration of the wind loads is required for ballasted systems and checks should be made for overturning and sliding. A safety factor should be included to account for uncertainties in the assessment of the wind loading due to the wind speed-up effects over the roof of the building. A safety factor of 3.0 is recommended. Ballasted systems will increase the dead loads on the roof; an assessment of the structural adequacy of the roof structure should be made.

Figure 37 Wind turbine mounted through the roof.

© Encraft

Figure 38 Microwind turbines installed on a flat roof.

Where turbines are mechanically fixed to the roof, then special attention should be given to ensuring that the penetrations are waterproof. Turbines can also be restrained using guys fixed back to the structure. The guy anchor points should be assessed to ensure that they are able to withstand the dynamic and static wind loads. Again special attention should be given to any penetrations through the waterproof envelop of the roof.

BRE Information Paper 8/09[30] gives more information on optimising the location of wind turbines on flat roofed buildings.

5.2.4 Noise and vibration from wind turbines

Airborne noise is not generally an issue with small modern wind turbines. In general, if the noise level from the wind turbine is 10 dB above the background noise level, then it is likely to give rise to complaint, if it is 5 dB above the background noise level, then it would be marginal and if it is 10 dB below the background noise level, then it is unlikely to give rise to complaint. In conditions with little or no wind, the typical background noise levels range from about 35 dB(A) in isolated areas to 50 dB(A) in built-up urban areas. Background noise levels increase with wind speed and are likely to be within the range 37 dB(A) at 4 m/s to 70 dB(A) at 18 m/s (where 4 to 18 m/s is the typical operating range for microwind turbines). Microwind turbines that comply with the British Wind Energy Association *Small wind turbine performance and safety standard*[31] will have a 'noise label' which can be used to assess the potential noise emission level at a particular distance from the turbine.

A microwind turbine mounted on a pole attached to a building will vibrate in the wind and these vibrations may be transmitted into the structure through the mounting brackets. The level of vibration transmitted will depend on the type and size of the turbine and the materials and structure of the building. Anti-vibration mounts or resilient pads can be used to minimise these effects; manufacturers should be able to provide specific advice for their products.

Some general information on noise and vibration can be found in *Small wind energy systems*[32].

5.2.5 Wind speeds and wind loads

Microwind turbines typically start to generate power at wind speeds above about 4 m/s. EST suggests that a microwind turbine may not be viable where the typical mean wind speed is below 4.5 m/s, since the amount of energy generated would not justify the capital cost[10].

The UK has a good wind source and severe winds can occur occasionally, therefore it is important to ensure that the turbine and mounting system is safe in extreme winds. EST suggests that the turbine and mast should be rated to withstand an average wind speed of 35 m/s over a 10-minute period without any damage to its operation. The wind turbine and its support structure should also be designed to withstand a gust of at least 50 m/s without suffering from any mechanical or structural damage that might result in parts of the turbine falling to the ground[10]. However, a check should be made for the specific installation because the design wind speed can exceed 50 m/s in some parts of the UK, particularly if the turbine is mounted on the top of a tall building. BS EN 61400-2[33] gives specific guidance for the design of microwind turbines for wind loading and a simplified methodology is included in the Annex of this publication.

6 Product and installation standards and test methods for microgeneration systems

Mandates are given by the European Committee for Standardization (CEN) for the harmonisation of standards for roof coverings. In most cases, these standards are intended for conventional building products, and do not specifically apply to microgeneration systems. There are a number of aspects in which microgeneration systems may differ from standard roofing products:

- PV and roof-mounted wind turbines generate power, requiring electrical installation
- solar thermal systems generate hot water so must comply with plumbing regulations
- microgeneration systems might have to comply with Construction Products Directive
- microgeneration systems might have to comply with Low Voltage Directive
- microgeneration systems might have to comply with the Directive on Electromagnetic Compatibility.

The UK and all countries in Europe have their own building regulations, which are mainly built on the same philosophy: that buildings must be safe for their users and their environment, they must provide a healthy atmosphere and preferably use little energy and no toxic materials.

In most countries, direct reference is made to the Construction Products Directive, which lays down the essential requirements for buildings to guarantee that the materials used fit their purpose.

6.1 PV systems

The product and installation standards specific for PV modules when used in the UK are:

- MCS 005: *Product certification scheme requirements: Solar photovoltaic modules*[3]
- MIS 3002: *Microgeneration installation standard: Requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of solar photovoltaic (PV) microgeneration systems*[11]
- MCS 012: *Product certification scheme requirements: Pitched roof installation kits*[34]
- BS EN 61215 *Crystalline silicon terrestrial photovoltaic (PV) modules. Design qualification and type approval*[35]
- BS EN 61646 *Thin-film terrestrial photovoltaic (PV) modules. Design qualification and type approval*[36].

MCS 005 provides third-party assessment and approval of companies who wish to demonstrate that their solar PV modules meet and continue to meet the requirements of BS EN 61215 or BS EN 61646.

MIS 3002 specifies the requirements of the MCS for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar PV microgeneration systems for permanent buildings.

MCS 012 specifies the test procedures which shall be used to demonstrate the performance of roof integrated and above-roof PV and solar thermal modules and/or their installation kits fixed to pitched roofs under the action of:

- wind loads – resistance to wind uplift forces
- fire – resistance to external fire
- rainfall and wind driven rain – weather-tightness.

BS EN 61215 and BS EN 61646 give requirements and test methods to determine the electrical and thermal characteristics of PV modules and to show, as far as possible within reasonable constraints of cost and time, that the module is capable of withstanding long-term operation in general open-air climates.

6.1.1 Tests to assess the wind uplift performance of PV systems

MCS 012 includes a test based on BS EN 14437:2004[37] for assessing the wind uplift performance of PV systems. This test requires a module (or pair of modules if they share the same fixings) to be fixed to a simulated roof structure at a pitch of 45° as it would be fixed in practice. Figure 39 shows a PV system being tested to MCS 012. The module is tested until failure which is defined as:

a) breakage of the mechanical fixing between the roofing element and the structure

b) pulling out or breakage of the connection of the mechanical fixing to the roof

c) breakage of covering elements

d) a maximum displacement of 75 mm on any roofing element which exposes the under-roof

e) a residual displacement of 5 mm on any roofing element which exposes the under-roof.

A characteristic value of uplift resistance is determined from the measured failure load and a safety factor applied dependent on the failure mechanism. The characteristic uplift resistance is then related to the design wind load calculated for the particular installation. Providing the design wind load at the site is less than the characteristic uplift resistance from this test, then the PV system can safely be used at this site. If the wind load at the site exceeds the characteristic uplift resistance then the PV system cannot be used unless its uplift resistance is increased (for example by increasing the number of fixings) so that it exceeds the design wind load for the site. The Annex gives a simplified method for assessing the wind load on PV systems in the UK.

MCS 012 allows alternative wind uplift tests to be used provided that they give equivalent or conservative values of resistance to wind uplift.

BS EN 61215 and BS EN 61646 include a mechanical load test which requires a load of 2400 Pa to be applied for 1 h to each side of the PV module. For modules in areas where heavy snowfall is expected, the downward acting load may be increased to 5400 Pa. These tests are intended to assess the performance of a single module under simulated wind and snow loads. Because a module has passed these mechanical load tests does not necessarily mean that when the module is installed on a roof it can be assumed to be able to resist a wind load of 2400 Pa. This is because the module or its fixings might exceed the MCS maximum or residual deflection criteria at this load, or the actual roof substrate might be weaker than that used in the test, or the number of fixings might differ from those used in the test. Also in practice, the module is likely to be installed in an array where a single fixing could be holding down two or more modules, in which case this could be the weakest link. Tests to BS EN 61215 and BS EN 61646 are normally only carried out on a single module.

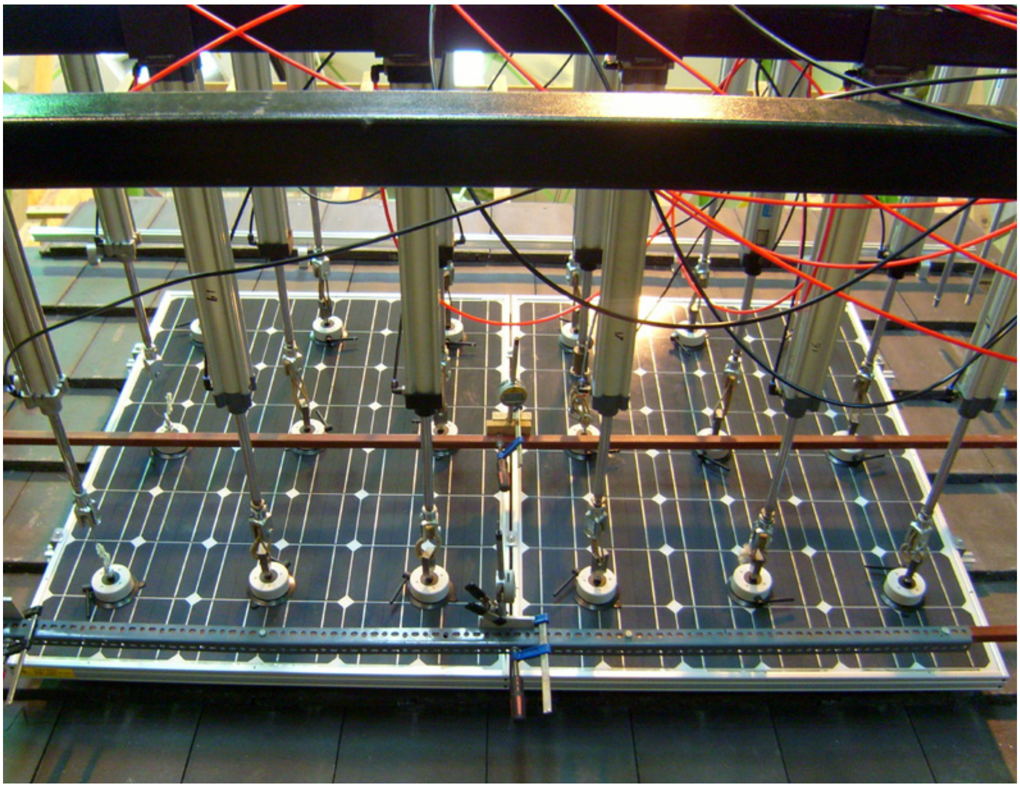

Figure 39 A PV system being tested to the MCS 012 wind uplift test method.

6.1.2 Tests to assess the rain and driving rain performance of PV systems

MCS 012 includes a test based on prEN15601[38] for assessing the rain and driving rain performance of PV systems. For this test, the specimen is installed on a simulated roof. For integrated systems, the surrounding roof covering and flashings must be included. Where a single flashing kit is specified for use with more than one generic class of roof covering, then the class representing the worst case shall be tested. If the worst class is not certain then other generic classes shall also be tested. The test must include all representative joints or interfaces, such as joints between modules and top, bottom and side interfaces with the existing roof covering. The test includes a deluge test (heavy rain with no wind) and a wind driven rain test for systems where the PV installation creates unprotected gaps larger than those that exist in the original roof or where it is possible that gaps could open up under wind action. Above-roof systems do not normally need to be tested for driving rain performance. Tests are also required on any roof penetrations, such as cable entry points, and also for penetrations through the underlay.

The performance of the PV installation in the rain and/or wind driven rain test must be at least as good as the performance of the surrounding roof covering on its own at the same roof pitch. Figure 40 shows a PV system being tested using the MCS 012 driving rain test.

Figure 40 PV solar slates ready for testing to the MCS 012 driving rain test method.

6.2 Solar thermal systems

The product and installation standards specific for PV modules are:

- MCS 004: *Product certification scheme requirements: Solar collectors*[2]
- MIS 3001: *Microgeneration installation standard: Requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of solar heating microgeneration systems*[12]
- MCS 012: *Product certification scheme requirements: Pitched roof installation kits*[33]
- BS EN 12975-1:2006 *Thermal solar systems and components. Solar collectors. General requirements*[39] and BS EN 12975-2:2006 *Thermal solar systems and components. Solar collectors. Test methods*[40]
- BS EN 12976-1: *Thermal solar systems and components. Factory made systems. General requirements*[41].

MCS 004 provides third-party assessment and approval of companies who wish to demonstrate that their solar collector meets, and continues to meet, the requirements of BS EN 12975-1:2006 or BS EN 12976-1:2006.

MIS 3001 specifies the requirements of the MCS for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar heating systems to supply domestic hot water, space heating and swimming pools for permanent buildings.

MCS 012 specifies the test procedures which shall be used to demonstrate the performance of roof-integrated and above-roof PV and solar thermal modules and/or their installation kits fixed to pitched roofs under the action of:

- wind loads – resistance to wind uplift forces (see Section 6.1.1)
- fire – resistance to external fire
- rainfall and wind driven rain – weather-tightness (see Section 6.1.2).

BS EN 12975-2 specifies test methods for validating the durability, reliability and safety requirements for liquid heating collectors.

6.2.1 Tests to assess the wind uplift and driving rain performance of solar thermal systems

The tests given in MCS 012 also apply to solar thermal systems; see Sections 6.1.1 and 6.1.2 for details of these test methods. Roof penetrations for water pipe entry must be tested for rain penetration if exposed. All water pipe entries through the underlay should also be tested (Figure 41).

BS EN 12975-2 includes a rain penetration test but this is for the solar collector in isolation and does not test the collector as mounted on the roof with fixings and flashings.

BS EN 12975-2 also includes a mechanical loading test which requires the collector to be loaded under positive and negative pressure to a minimum pressure of ±1000 Pa. The design wind load in the UK will often exceed 1000 Pa. Failure of the collector in these tests is defined as destruction of the cover or a permanent deformation exceeding 0.5% of the length of the collector, this deflection criterion is different from that used in MCS 012. The BS EN 12975-2 tests are only carried out on a single module so if the modules are installed in such a way that two or more share a common fixing, then the test results will not be applicable.

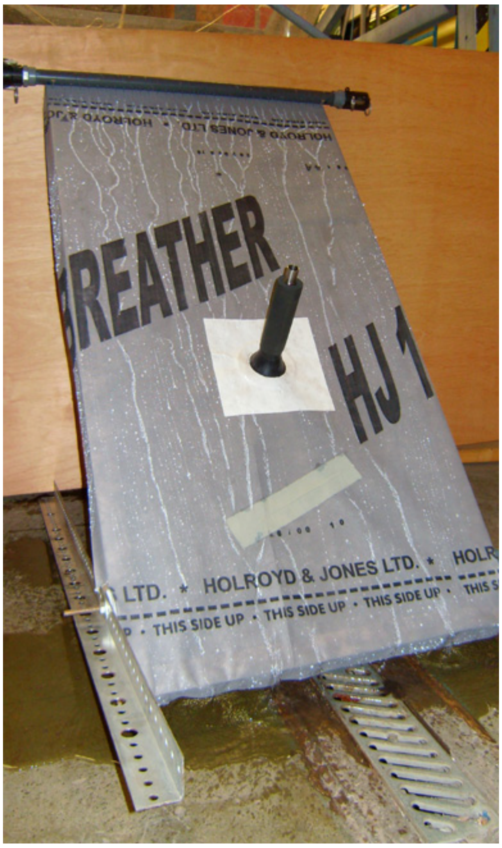

Figure 41 MSC 012 rain resistance test for underlay penetration.

6.3 Microwind turbines

The product and installation standards specific for PV modules are:

- MCS 006: *Microgeneration certification scheme: Product certification scheme requirements. Micro and small wind turbines*[4]
- MIS 3003: *Microgeneration installation standard: Requirements for contractors undertaking the supply, design, installation, set to work commissioning and handover of micro and small wind turbine systems*[13]
- British Wind Energy Association – *Small wind turbine performance and safety standard*[31]
- EST CE 72 – *Installing small wind-powered electricity generating systems: Guidance for installers and specifiers*[10].

MCS 006 provides third-party assessment and approval of companies who wish to demonstrate that their micro and small wind turbines with rated electrical power outputs up to 50 kW (measured at a wind speed of 11.0 m/s) meet and continue to meet the requirements of the British Wind Energy Association *Small wind turbine performance and safety standard*[31].

MIS 3003 specifies the requirements for contractors undertaking the supply, design, installation, set to work, commissioning and handover of micro and small wind turbine systems located on dedicated free-standing or guyed towers or building mounted. For the purposes of MIS 3003, micro and small wind turbines are defined as those having an electrical output in the range 0.3 to 50 kW (measured at a wind speed of 11.0 m/s).

MIS 3003 requires the installation to be carried out according to the EST publication CE 72 *Installing small wind-powered electricity generating systems*[10]. However, CE 72 does not include guidance for fixing turbines to buildings. MIS 3003 gives the following advice '*For wind turbines mounted directly on a building, in addition to section 3.1 of CE 72, the fixing method used shall not compromise the weather resistance or structural integrity of the building. If there is any doubt, a structural engineer must be consulted.*'

The RenewableUK (formally known as the British Wind Energy Association) *Small wind turbine performance and safety standard*[31] excludes the design of the turbine support structure and refers to BS EN 61400-2:2006[33] for the design of the turbine against wind loads. This standard is for turbines with a swept area of up to 200 m^2; typical micro turbines installed on buildings have a swept area from about 2 m^2 up to about 20 m^2. Calculations of wind loading on a turbine using BS EN 61400-2 can be quite complex. The Annex gives a simplified method for determining wind loads on building-mounted microwind turbines.

ANNEX

Simplified method for determining wind loads on roof-mounted photovoltaic, solar thermal and microwind turbines

A.1 Simplified method for PV and solar thermal systems

The simplified methodology presented in this Annex can be used to determine the peak wind loads acting on PV and solar thermal systems. This approach is based on the peak velocity pressures derived from BS EN 1991-1-4[42] and its UK National Annex (NA). Example calculations are given in Section A.2.

Steps for calculating wind uplift pressure on PV and solar thermal systems:

1) Determine wind speed zone for the site from Figure A1.

2) Read peak velocity pressure q_p for the appropriate building height from Table A1.

3) Apply correction factors for orography and site altitude (for sites at altitude ≤100m no correction is required) (see notes to Table A1).

4) Determine the net wind pressure coefficient c_p for the particular installation. Note that c_p may be given directly for some types of installations (such as above-roof systems), whilst for integrated systems, it may be necessary to determine separately the external pressure coefficient c_{pe} acting on the external surface of the system, and the internal pressure coefficient c_{pi} acting on the underside of the system. Where external and internal pressure coefficients are obtained separately, the net pressure coefficient can be obtained from $c_p = c_{pe} - c_{pi}$.

5) Calculate the wind pressure, *w*, in Pascals from equation A1 (see BS EN 1991-1-4 for more details):

   $$w = q_p \, c_p \, S_F \text{ (Pa)} \qquad \text{(A1)}$$

   where S_F is the safety factor. A suggested value is $S_F = 1.5$.

   Note that the value of the net pressure coefficient c_p can depend on a number of factors including roof type, roof pitch and distance from the edge of the roof. In general, the pressure coefficients will fall into one of four categories depending on the type of PV or solar thermal system:

   (i) Integrated nominally airtight systems where the PV or solar thermal modules form the weathertight roof covering.

   (ii) Air permeable arrays of PV or solar thermal tiles or slates integrated into pitched roofs.

   (iii) Systems mounted above the roof where there is a clear gap beneath the roof and the modules.

   (iv) Systems mounted on flat roofs.

   Pressure coefficients for Type (i) systems can be obtained directly from EN 1991-1-4 and the UK National Annex (NA) to EN 1991-1-4, for the appropriate roof type and roof pitch (provided that the modules do not protrude above the surface of the roof by more than 100 mm).

Pressure coefficients for Type (ii) systems can be obtained from BS 5534[5] by treating the system as roof tiles.

Pressure coefficients for Type (iii) and Type (iv) systems can be obtained from BRE DG 489[43] or from test data. Ballasted Type (iv) systems will also need to be assessed for sliding and overturning.

A.2 Example calculations of wind loads on PV and solar thermal systems

Example 1 – Solar thermal system mounted above the roof away from the roof edges (Type iii system)

Assumptions: Site is in London >2 km into the city and >20 km from the sea
Site altitude = 20 m
Topography not significant
Building height = 10 m (to ridge)
Duo pitch roof with pitch angle 30°

Step no:

1) Locate site on Figure A1 – site is in Zone 1 = **22 m/s**
2) Read q_p from Table A1 = **763 Pa**
3) Orography and site altitude correction factors not required
4) Obtain value of c_p from BRE DG 489 = **–1.3**
5) Obtain uplift pressure, *w*, acting on the solar thermal system from equation A1
   $w = q_p \times c_p \times S_F = 763 \times -1.3 \times 1.5 =$ **–1488 Pa**

Example 2 – Integrated nominally airtight PV system covering the whole roof (Type i system)

Assumptions: Site is on the outskirts of Sheffield in country terrain
>20 km from the sea
Site altitude = 180 m
Topography not significant
Building height = 8 m (to ridge)
Duo pitch roof with pitch angle 30°

Step no:

1) Locate site on Figure A1 – site is in Zone 2 = **24 m/s**
2) Read q_p from Table A1 = **965 Pa** (interpolated for a building height of 8 m)
3) Obtain altitude correction for an altitude of 180 m = 1.16 (see note 2 of Table A1)
4) Correct q_p for altitude = 965 x 1.16 = **1119 Pa**
5) Obtain worst case value of $c_{p,e}$ from the UK NA to EN1991-1-4 = **–1.2** (Table NA7a and Table NA7b of the UK NA, this value is appropriate for modules close to the roof edge; $c_{p,e}$ values near the centre of the roof will be smaller)
6) Obtain value of $c_{p,i}$ from EN1991-1-4 clause 7.2.9 = **0.0** (this is a conservative value obtained using equation 7.3 of EN1991-1-4 for typical roof permeabilities and should be generally applicable to most pitched roofs)
7) $c_p = c_{pe} - c_{pi} = -1.2 - 0 =$ **–1.2**
8) Obtain uplift pressure, *w*, acting on the PV system from equation A1
   $w = q_p \times c_p \times S_F = 1119 \times -1.2 \times 1.5 =$ **–2014 Pa**

A.3 Simplified method for wind loads on microwind turbines

The simplified methodology presented in this Annex can be used to determine the peak wind loads acting on microwind turbines and their fixing brackets. This approach is based on the simplified approach given in Section 7.4 of BS EN 61400-2[33] with the addition of extra terms to account for the dynamic response of the microwind turbine and mounting pole. BS EN 61400-2 gives two load cases that need to be considered when determining the loads on a mounting bracket caused by a microwind turbine. These are Load case H: parked wind loading for a 1:50 year gust wind speed and Load case I: parked wind loading maximum exposure for a 1:1 year gust wind speed. Example calculations are given in Section A.4.

Load case H is based on the peak gust wind speed V_{e50} with a recurrence interval of 50 years and assumes that the turbine is parked in the normal way and will face into the wind. Load case I is based on the peak gust wind speed V_{e1} with a recurrence interval of 1 year and assumes that the turbine is subjected to wind from the most unfavourable wind direction (where $V_{e1} = 0.75V_{e50}$). Load cases H and I should both be checked and the most onerous thrust load used.

Load case H has two approaches for determining the thrust load depending on whether the rotor is parked or spinning. The choice of approach for load case H will depend on the turbine operating characteristics. It should be noted that there can be large differences in thrust loads on a parked or spinning rotor. If there is any doubt about whether the rotor is parked at V_{e50} then it is recommended that both load cases be considered, ie steps 4a and 4b below.

Steps for calculating wind loads on microwind turbines:

1) Determine wind speed zone for the site from Figure A1.

2) Read peak velocity pressure q_p for the hub height of turbine from Table A1.

3) Apply correction factors for orography and site altitude (see notes to Table A1).

4a) Assess load case H for a rotor which is parked during extreme winds: calculate the peak wind load $\hat{F}$, in Newtons, and bending moment $\hat{M}$ in Newton metres, acting on the turbine and pole using equations A2 and A3:

$$\hat{F} = q_p \times A_1 \times [4.3 + 3.7 \times (A_2 + A_3)] \tag{A2}$$

$$\hat{M} = q_p \times A_1 \times L \times [4.3 + 1.9A_2 + 3.7A_3] \tag{A3}$$

where:

A_1 is the total maximum projected area of all of the turbine blades (m^2)
A_2 is the ratio of $L \times d / A_1$
A_3 is the ratio of A_{hub}/A_1
L is the length of the turbine mounting pole measured from hub to top mounting bracket (m)
d is the diameter of the mounting pole (m)
A_{hub} is the projected area of the turbine hub (m^2)

4b) Assess load case H for a rotor which is spinning during extreme winds: calculate the peak wind load $\hat{F}$, in Newtons, and bending moment $\hat{M}$ acting on the turbine and pole using equations A4 and A5:

$$\hat{F} = q_p \times A_1 [\lambda_{e50}^2 + 3.7 \times (A_2 + A_3)] \tag{A4}$$

$$\hat{M} = q_p \times A_1 \times L \times [\lambda_{e50}^2 + 1.9A_2 + 3.7A_3] \tag{A5}$$

where:

λ_{e50}^2 is the tip speed ratio

5) Assess load case I for a rotor which is parked and subjected to the most unfavourable wind direction: calculate the peak wind load $\hat{F}$, in Newtons, and bending moment $\hat{M}$ acting on the turbine and pole using equations A6 and A7:

$$\hat{F} = 0.56 q_{p} \times A_{1} [4.3 + 3.7 \times (A_{2} + A_{3}) + 4.3 A_{4}] \qquad \text{(A6)}$$

$$\hat{M} = 0.56 q_{p} \times A_{1} \times L \times [4.3 + 1.9 A_{2} + 3.7 A_{3} + 4.3 A_{4}] \qquad \text{(A7)}$$

where:

A_4 is the ratio of A_{tail}/A_1

A_{tail} is the projected area of the turbine tail (m^2)

Note that the values of A_{hub} and A_{tail} are the projected areas perpendicular to the approaching wind direction.

Equations A2 to A7 are based on a simplified methodology developed by BRE. More details will be published in a forthcoming BRE report[44].

BS EN 61400-2: Section: 7.8 Table 7 recommends a safety factor of 3.0 be used with the simplified load calculation method and 1.35 with aeroelastic modelling. The simplified approach above is based on a full dynamic analysis, hence a safety factor of 1.35 should be applied to the forces and moments obtained from Equations A2 to A7 to give values for use in design.

Equations A2 to A7 can be used provided:

1) The critical damping ratio of the turbine/pole system is at least 3% (measurements by BRE showed that this is likely to be appropriate for common microwind turbine/pole combinations).

2) The turbine has three or more blades.

3) The aspect ratio of the blades (ie the turbine blade length divided by the mean chord[1]) is less than 7.3.

A.4 Example calculations of wind loads on a microwind turbine

Example 1 – Microwind turbine attached to a house in a rural location close to Falmouth at a height of 12 m above ground level

Assumptions: Site is 1 km from the sea
Site altitude = 20 m
Height of turbine above ground level = 12 m
Number of blades, $B = 3$
Blade radius, $R = 0.6$ m
Projected area of single blade, $A_{proj,B} = 0.042\ m^2$
Area of tail, $A_{tail} = 0.162\ m^2$
Hub radius, $r_{hub} = 0.09$ m
Hub length, $l_{hub} = 0.33$ m
Mounting pole length, $L = 2$ m (measured from top of uppermost bracket)
Mounting pole outside diameter, $d = 0.048$ m
Turbine is parked (stationary) during extreme winds

$A_1 = 3 \times 0.042 = 0.126\ m^2$ (projected area of all turbine blades)
$A_2 = Ld/A_1 = 2 \times 0.048/0.126 = 0.76$
$A_3 = A_{hub}/A_1 = \pi \times 0.09^2/0.126 = 0.20$ (wind on to the front of the turbine – Load case H)
$A_3 = A_{hub}/A_1 = 0.18 \times 0.33/0.126 = 0.47$ (wind on to the side of the turbine – Load case I)
$A_4 = A_{tail}/A_1 = 0.162/0.126 = 1.29$

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[1] The chord is the distance between the leading edge and the trailing edge of a blade. The chord of a wind turbine blade can vary significantly between the turbine root and the tip. The mean chord is the average chord calculated over the length of the blade.

Step no:

1) Locate site on Figure A1 – site is in Zone 3 = **26 m/s.**

2) Read q_p from Table A1 = **1456 Pa** (interpolated for a height of 12 m).

3) Orography and altitude correction factors not required.

4) Obtain $\hat{F}$ and $\hat{M}$ from equations A2 and A3 (Load case H):
= 1456 x 0.126 x (4.3 + 3.7 x (0.76 + 0.2)) = **1441 N**
= 1456 x 0.126 x 2 x (4.3 + (1.9 x 0.76) + (3.7 x 0.2)) = **2379 Nm**

5) Obtain $\hat{F}$ and $\hat{M}$ from equations A6 and A7 (Load case I):
$\hat{F}$ = 1456 x 0.56 x 0.126 x (4.3 + 3.7 x (0.76 + 0.47) + 4.3 x 1.29) = **1479 N**
$\hat{M}$ = 1456 x 0.56 x 0.126 x 2 x (4.3 + (1.9 x 0.76) + (3.7 x 0.47) + (4.3 x 1.29)) = **2677 Nm**

6) Obtain worst case maximum force and moment from load cases H and I:
Worst case maximum force $\hat{F}$ = **1479 N**
Worst case maximum moment $\hat{M}$ = **2677 Nm**

7) Calculate maximum force and maximum moment on the mounting bracket by applying a safety factor of 1.35:
Maximum bracket force = 1479 x 1.35 = **1997 N**
Maximum bracket bending moment = 2677 x 135 = **3614 Nm**

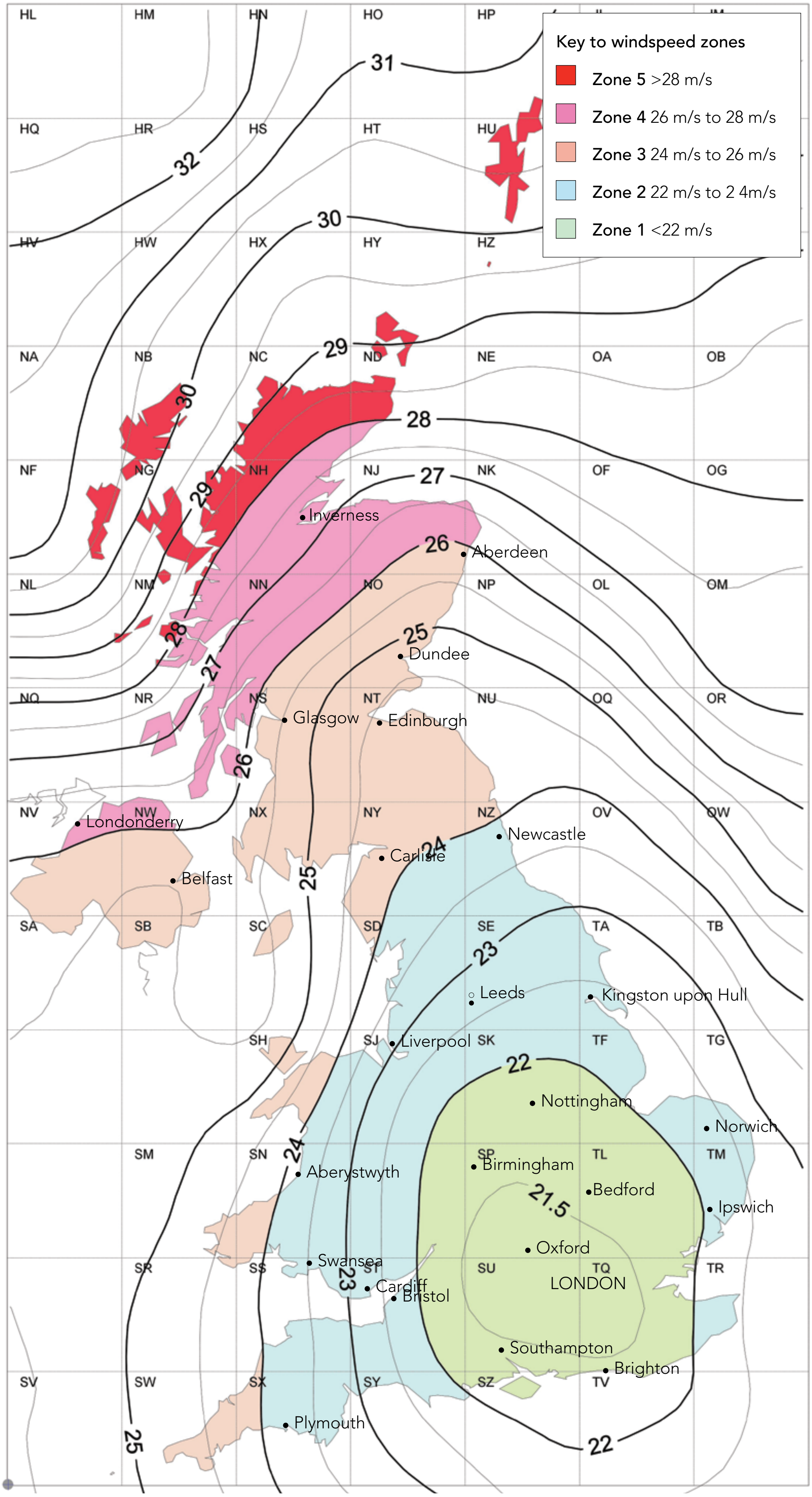

Figure A1 Map of basic mean wind velocity over UK.

Table A1

Peak velocity pressures (q_p) in Pascals (Pa)

Zone	Height	Distance from sea in country terrain			Distance from sea in town terrain		
	(m)	2 km	20 km	>20 km	2 km	20 km	>20 km
1	5	869	783	718	688	620	569
1	10	1009	955	872	883	836	763
1	15	1094	1062	977	1012	982	904
1	20	1122	1108	1017	1066	1052	966
1	25	1166	1166	1072	1137	1137	1045
2	5	1034	931	854	819	738	677
2	10	1201	1136	1038	1050	994	908
2	15	1302	1264	1163	1204	1169	1075
2	20	1335	1318	1210	1268	1253	1149
2	25	1388	1388	1276	1353	1353	1244
3	5	1213	1093	1003	961	866	794
3	10	1409	1334	1218	1233	1167	1066
3	15	1527	1483	1364	1413	1372	1262
3	20	1567	1547	1420	1489	1470	1349
3	25	1629	1629	1498	1588	1588	1460
4	5	1407	1268	1163	1115	1004	921
4	10	1634	1547	1413	1430	1353	1236
4	15	1772	1720	1582	1639	1591	1464
4	20	1817	1795	1647	1726	1705	1565
4	25	1889	1889	1737	1842	1842	1694
5	5	1703	1534	1407	1349	1215	1115
5	10	1977	1872	1710	1730	1638	1496
5	15	2144	2081	1915	1983	1925	1771
5	20	2199	2171	1993	2089	2063	1893
5	25	2286	2286	2102	2229	2229	2049

Notes

1. The altitude correction factor increases by 20% for every 100 m increase in site altitude above 100 m.
   For example, for a site altitude of 180 m the altitude correction factor is (180-100)/100 * 0.2 = 0.16, therefore multiply the value in Table A1 by 1.16.
2. Site altitude is measured relative to mean sea level
3. For building heights greater than 25 m, use EN 1991-1-4 and UK National Annex
4. The values given in Table A1 do not include any safety factors
5. Sites in town less than 300 m from the edge of the town should be assumed to be in country terrain
6. Where a site is closer than 1 km to an inland area of water which extends more than 1 km in the wind direction, the distance to sea should be taken as <2 km
7. For sites more than halfway up a hill where orography is significant, the following corrections should be made:
   For hill slopes = 0.1, multiply the pressures in Table A1 by 1.2
   For hill slopes = 0.2, multiply the pressures in Table A by 1.45
   For hill slopes = 0.3, multiply the pressures in Table A by 1.7
8. Interpolation may be used in Table A1
9. A more accurate (less onerous) assessment of peak velocity pressure can be obtained using EN1991-1-4 and the UK National Annex

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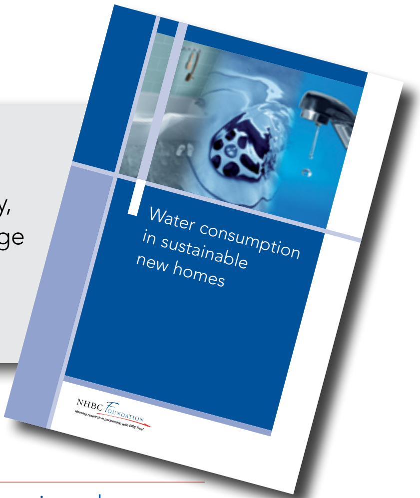

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Guide to installation of renewable energy systems on roofs of residential buildings

There has been a surge in popularity of installing microgeneration systems such as photovoltaics, solar thermal and microwind turbines since the introduction of the Code for Sustainable Homes, Feed-in Tariffs and the Renewable Heat Incentive scheme. However, there are no European or British standards that regulate their mechanical installation on buildings to ensure resistance to wind and rain action.

This guide provides best practice advice on wind- and water-resistant installation of photovoltaics, solar thermal and microwind turbines on residential buildings.

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The NHBC Foundation has been established by NHBC in partnership with the BRE Trust. It facilitates research and development, technology and knowledge sharing, and the capture of industry best practice. The NHBC Foundation promotes best practice to help builders, developers and the industry as it responds to the country's wider housing needs. The NHBC Foundation carries out practical, high quality research where it is needed most, particularly in areas such as building standards and processes. It also supports house builders in developing strong relationships with their customers.

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