# PV DOMESTIC FIELD TRIAL
# SECOND ANNUAL TECHNICAL REPORT

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BRE

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# EXECUTIVE SUMMARY

This report covers the DTI's solar photovoltaic domestic field trials over the period January to December 2002. It discusses installations by 8 projects on 12 locations, which have in general continued to go smoothly. The report also analyses cost data from the procurement activities for 9 projects over 13 locations, referring to a total capacity of 262kWp.

More sites use roof integrated module solutions from Pfleiderer and Redland this year and the installation costs of these sites is falling to as little as £0.10 per watt peak. As installer familiarity and specifier confidence increases with these products there is every indication these costs will fall further still. The use of pluggable 'MC' type connectors and factory fitted cable tails to these modules enables them to be fitted with little PV specialist training by most roofing contractors and this has certainly help reduce costs. The strings of installed modules still require simple testing for continuity, generally involving an electrician but this task could be given to a suitably trained roofer.

This year sees the first use of the ballast filled 'ConSole' mounting system for flat roofs, installed on the parapet walls at Hockerton. This system looks very promising for flat roof applications because it does not require mechanical fixing or roof penetrations in most cases. The consoles can be moved relatively easily, given sufficient cable length, for roof maintenance purposes.

The Geographical spread is also improving, with sites now located in Perthshire, North Wales, Belfast, Nottinghamshire and the North and South East. Coupled with the sites last year, this will enable a comparative map of generated yields for the whole country to be developed based on experience with real sites and local weather conditions.

Architectural Integration has also improved, with quite a diverse range of mounting solutions this year. Many sites are new build with integrated PV roofing components and others use a variety of modules on mounting frames. The first frame mounted module roof flush system has been installed at Steelstown.

There have been some module delivery slippages, with modules arriving sporadically in some cases. As the market continues to grow this situation is likely to improve but suppliers must be asked if they can meet realistic delivery schedules. Some modules need extra shrouds fitting to meet the requirements of the BS476 spread of flame test. It is hoped this will be conducted by the manufacturers for the UK market to remove the need for it to be performed under site conditions.

Most of the cost elements of installed PV systems have fallen since last year and this trend is likely to continue. This, coupled with the increasing market will reduce the generated cost of PV power, leading to the continuation of PV as power source in buildings.

Finally, a significant monitoring issue has been highlighted and recommendations have been made to reduce its potential impact on the filed trials.

## INTRODUCTION

The aim of the DTI photovoltaic (PV) domestic field trials (DFTs) is to use the design, construction and monitoring of the installations as a learning opportunity for utilities, building developers and other key players in the process of PV installation. The PV Domestic Field Trials have been running for over two years now and all of the first round installations are complete and operating. This year five new build sites are included, 5 are retrofit. Many of these sites have 6 or so dwellings and installations within them.

This report conveys some of the experiences involved in the design, construction and installation of the most recent twelve locations during 2002. This main intention of this report is to examine

- the different appearances of the systems,
- their architectural integration,
- the different fixing methods, and
- the relative cost effectiveness of these.

It is a technical report meant to inform those in the PV industry, architects, PV designers and those considering the available options for building integration of PV and some of the related installation pitfalls and costs.

Architectural integration and appearance of the systems continue to improve, with sites this year including specialist PV roofing products such as Sunslates and the module systems from Pfleiderer and Redland. Problems have been experienced in interfacing these products, made to European dimensions, to existing English roofing systems. The UK spread of flame test, BS476 has necessitated extra works to some module types to prevent fire spread. However, as the experience base of the installers develops these problems are easier to rectify and the costs are reduced accordingly.

The sites this year include a wide variety of fixing methods, from new build and retrofit roof integration to modules mounted on several types of mounting frame. In view of the need for ventilation to keep modules cool in summer, it will be interesting to see the relative performance of the roof integrated systems.

Monitoring is not covered extensively in this report due to lack of sufficient data to draw any meaningful conclusions. A monitoring issue has also come to light in that the on – board monitoring of one brand of inverter is not as accurate as first suggested when the trials began. In particular, the DC current is not measured but derived from the AC power, reducing the accuracy. In view of this, it is advisable to fit extra metering equipment to check the data validity.

The analysis of costs would suggest that most costs have reduced since the last annual technical report. In particular the installation and monitoring costs have all reduced. This may be a result of the greater number of 'standard' new build sites this time, the widening skills base and early identification of problems. Inverter cost has fallen slightly and module cost has risen slightly. Many of the sites experienced module delivery delays and this would suggest that more capacity is required from the manufacturers as UK and World demand increases.

## ARCHITECTURAL INTEGRATION

The subjectivity of the assessment of the degree of visual integration can be reduced by accepting agreed criteria for such assessment. The following architectural criteria are based on those formulated by IEA Task VII:

1. Architecturally pleasing (visually pleasing)
   The PV adds eye catching features to the design, is of an appropriate scale to that of the building, and fits in with the street, or the street with the local area.

2. Good composition between materials and colours.
   The contrast between shiny and matt surfaces is adequately dealt with. The colour and texture of the PV array is in harmony with other materials. Generally PV is bright and blue while the surrounding roof or walls are likely to be of rough texture and earthy colours, so matching of PV with colour and texture is likely to be unusual.

3. Fit with the building grid, fenestration and roof pitch.
   The sizing of the modules/tiles/cells matches that of other rectilinear features of the building. This includes the issue of how the shape of uncovered roof surrounding the modules fits the grid as well. It should also be considered from close-up and far-away perspectives. The PV installation is graded as better integrated if it is flush with the roof surface, unless the architectural intention is to enhance the salience of the PV.

4. Contextuality.
   The PV is in harmony with total image of the building (generally referring to the style at the time in which the building was constructed, historic or modern)

5. Detailing.
   Elegance of design detail. Simplicity of execution. Detail should be convincing.

The IEA list also includes consideration of how PV ‘completes’ the architecture, and scores for architectural innovation. These criteria will be loosely applied to the field trial sites.

**Machynlleth**

The developer of this site, Cantref, is a charitable Housing Association working with Welsh Assembly support. They are keen to follow a 'green' agenda and acquired the old Health Centre site in Machynlleth for housing, situated in a conservation area. Plans were approved for a brown field development to demolish the existing buildings and construct 8 flats and 2 bungalows for retired tenants. Planning approval was granted for roof integrated PV following debate over colour and visual presentation.

The design of the residences at Machynlleth had to recognise the neighbouring architectural context which was noted to be important for planning permission. The surrounding buildings have stone walls and slate roofs, typical for buildings in this area due to the availability of local materials. The town itself is picturesque and is now consciously promoting itself as a tourist destination, with many visiting The Dyfi Valley Eco project and The Centre for Alternative Technology (CAT).

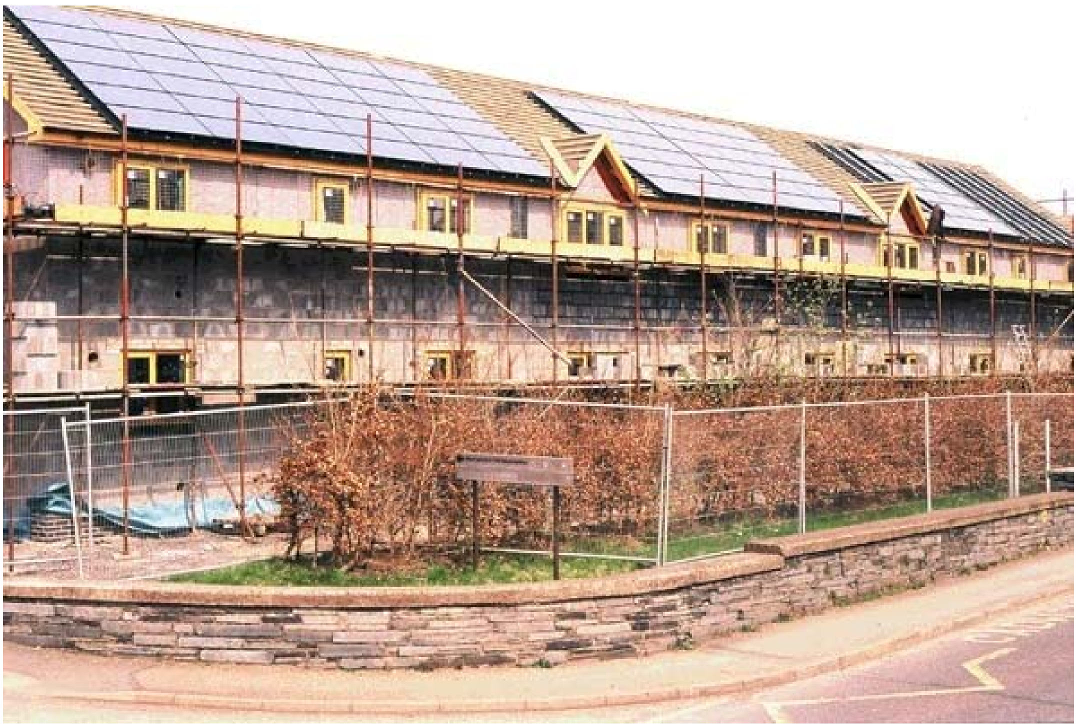

Fig.1: The Machynlleth development under construction. (Dulas)

The buildings themselves are rather large and imposing but, standing back from the road and built largely with traditional materials, they blend in well with the neighbourhood. The roof itself is from local slate and the PV is intended to match this as much as possible. Shiny aluminium is not visible since the frames and mountings are coloured black.

As is usual with roofs like this the squareness of the PV array does not fit in well with the shape of the roof. The dormer roofs introduce a difficult angle to accommodate the PV arrays, shown above the entrance doors in Fig. 2. Generally the only option for the PV designer is too allow more space around the array so the lines bordering the roof and the array are not forced too closely together. As this reduces the size and yield of the PV, the designer has to balance conflicting aims. At Machynlleth the balance has shifted in favour of yield.

Fig. 2: The bungalows showing gap in PV array above entrances (BRE).

In terms of texture and colour, PV fits better with slate than with other non-metallic roofing materials. It will often look the colour of the slate depending on the sky colour. The angle of view also has a large effect on the contrast presented to the viewer. In figure 3, the far left array blends sympathetically with the slate, the array to the right reveals its blue colour and the grain structure of the modules adds texture to an otherwise plane surface.

Fig. 3: Changing appearance of the module with viewing angle.

**Pinehurst**

This development is part of estate refurbishment, and is new build to replace five houses that were considered beyond economic repair . In order to integrate successfully, the new houses were built to a style sympathetic to the surrounding houses and those they replaced. The entire estate uses red or grey concrete roofing tiles with a double roman profile, similar to that of modern Redland equivalents. The Redland PV system was therefore selected to blend with the choice of roof tiles. The success of this is illustrated in figure 4, showing the roof of the existing buildings to the left and right.

Fig.4: The new build block on the existing Pinehurst estate (BRE).

Figure 5 shows the flushness of the modules with the roof, almost hidden clips and the resulting uncluttered lines afforded by the Redland system, giving a neat well-designed appearance to the roofs.

The most obvious integration issue is the contrast in colour between the red tiles and the blue PV modules. This was deliberate so as to accentuate the PV and produce an eye-catching installation. However, with short front gardens the viewing angle from the street is so acute the modules do not appear such bright blue, while the colour of the tiles will moderate with age as can be seen from the neighbouring houses.


Fig. 5: The Redland roof integrated PV system (BRE).

Rooflights also caused problems of visual integration, shown in Figure 6. A cursory glance suggests the PV reaches to the roof light edges and is level with the tops. Closer inspection reveals a slightly unequal in-fill of cut tiles to the roof light edges to integrate with the fixed length modules. In these circumstances all that can be done is to make the shapes around the rooflights look as balanced as possible.


Fig. 6: Integration of roof windows at Pinehurst (BRE).

**Broughton Leys – Bloor Homes**

This is a new housing development on the outskirts of Milton Keynes. The design won an architectural award, partly for incorporating energy saving features. There are a range of town houses, terraces and semi-detached houses scattered in various orientations. As such, there is no particular character to which the PV houses must conform.

The dark coloured Terra Piatta tiles do not present a contrast with the Pfleiderer modules. The integration system hides all mounting parts and presents clean horizontal lines to the observer very much in keeping with the look of the tiles themselves. The architectural intention was that the PV would not be very noticeable and this can be seen in the site pictures such as Fig 7. The roofs are square which helps the designer place the arrays evenly on the roofs.

Under the PV tiles a row of vent tiles are included to increase the air flow past the modules to keep them cool during the summer months. This adds texture to the roof and encourages the careful eye to look further.

Fig.7: Pfleiderer roof integrated PV at Broughton Leys (BRE).

The Pfleiderer modules are quite large, displacing six ordinary tiles (fig 7). Nevertheless they fit in well with the grid of the roof since they are just one tile deep, accentuating the horizontal lines.

Using European tiles presents its own problems, due to dimensions unusual to the UK. They had to be cut to avoid overlapping the guttering, leaving an orange edge exposed to the viewer at ground level which then had to be painted black.

Fig.8: Close up Pfleiderer Terra Piatta solar tiles and vent tiles below (BRE).

Figure 8 shows the roofing system close up. (Note the air vents tiles to reduce the operating temperature.) The design detail is very good but partially spoiled by the complication of having to fix a stainless steel shroud which surrounds the cells and protects the plastic frame from the possibility of catching fire. On their own the modules failed the spread of flame test (BS476). They were re-tested with the steel surround and passed.  This adds an extra step to the installation process which could be better carried out in the factory.

In terms of functional integration it could be expected that PV would only be installed on houses which are already energy efficient. These houses scored an NHER rating of 10 with 100mm. cavity insulation, two zone heating, 3-400 mm. insulated lofts, low-E Argon filled glass, and condensing boilers. Such efficient housing is new to Bloor, but they have not experienced any problems with installing these features, or the PV.

**Perthshire**

The Perthshire Housing Association project consists of two types of modules installed at three different sites, and includes a mix of new build and retrofit. The sites are Glen Lyon, Pitlochry and Bankfoot. Originally all the PV capacity was to have been installed at a single site, but planners did not like the density of PV which caused Perthshire Housing Association to reallocate some of the PV to other sites and experiment with two types of modules and retrofit.

Glen Lyon

At Glen Lyon (2-4 Inverar Cottages) Atlantic Solar Sunslates are installed on a semi-detached bungalow.

The choice of sunslates means the PV is very unobtrusive as the original roofing material was slate, and the colour of the PV is dark, having fibre cement backing material. Most of the roof is covered by the sunslates with a line of real slates along the top and bottom, and a few along the sides.

Fig.9: Typical PV roof on Glen Lyon site (BRE).

Fig. 9 shows the integration of the sunslates and the existing slates. Note the irradiance sensor above the front door for the monitoring equipment. This is a replacement roof so the sunslates are a similar height to ordinary slates, preserving the roof line.


Fig.10: Sunslates and Dormer (BRE).

Figure 10 reveals the treatment of the dormer roof. Although the sunslates are of a similar size to ordinary slates, the integration around the dormer is a little disappointing since the border of slate either side is unequal. Once again this situation will always be a trade off between performance and what is pleasing to the eye, the left hand side gap being larger so as to avoid problems of shadow. It is perhaps unfortunate that more design effort was not placed on centering the array around the dormer and maintaining the angle of the edge of the array parallel with that of the roof angles, even if performance were sacrificed slightly.

Pitlochry

The Pitlochry site is a new build development of flats around a courtyard located at East Moulin Road.. The south-facing roof has Pfleiderer modules and Terra Piatta tiles which will serve 15 of the flats. These are designed to interlock together and match each other. Figure 11 shows the location.


Fig. 11: The Pitlochry development (Perthshire HA).


Fig.12: Detail of dormer (Perthshire HA)

Figure 12 shows good integration of colour, texture and shape using the Pfleiderer system The edge of the modules shows up more strongly, which accentuates the horizontal lines. The Black stainless steel shields around the edge of the modules fit the colour of the tiles and modules. The shrouds are fitted on site to meet the requirements for spread of flame, as in Broughton Leys.

**Pleasant Court**

This is a retrofit installation carried out during refurbishment of a three storey, late 1960s block of flats. Other works include gas central heating and double glazing.

The surface-mounted PV is installed on the south-facing side of the roof, so these modules are not visible from the street (Figure 13).

Fig.13: Rear view showing PV roof (BRE)

Although neighbouring flats can see the PV array from some balconies, these are some distance away so this is not problematic.

The modules are surface mounted on a frame so a clearance of some 50mm is provided for ventilation to keep the modules cool, shown in Figure 14.

Fig.14: Detail of module / roof clearance (BRE).

The arrays are well centred and visually balanced. The bright aluminium frame calls attention to them, and the glass surface of the modules contrasts with the texture and colour of the roof tiles. The scale of the arrays is quite large (32m x 3m) but is not excessive for the size of roof, each consisting of 96 Astropower AP-120 modules of monocrystalline silicon.

## Berwickshire

The Berwickshire Housing Association project includes retrofit and new installation:

1. At Coldstream, retrofit installation of 24 modules on each of 6 semi detached houses (Level 2) and retrofit installation of 24 modules on each of 6 terraced houses (A3)
2. At Ayton, retrofit of 24 modules on each of 4 newly-built houses (Lawfield)
3. At Ayton, installation of 24 modules on a newly-built low energy house (Level 3 - Beanburn). At this site the PV modules are retrofitted on top of the new roof.

Coldstream

Figure 15 shows the complete installation. The tiles here are rather discoloured, which forms a contrast with the new and shiny PV modules. The contrast is not unsightly though, since the PV puts a hi-tech gloss on otherwise plain roofs. This contrast could have been either enhanced or reduced by selection of the material for the surround, which in this case is black. Were it blue or aluminium it would have complemented the module frames, producing a more striking effect.

With the black surround the clearance between the modules and the roof tiles appears smaller than the 50mm that it is. Flushness with the roof plane is usually considered an important parameter of visual integration, but it is expensive to achieve with retrofit. This installation achieves a good compromise of visual integration and an acceptable amount of ventilation for the modules. The dark edges frame the PV array effectively but do not draw attention to the air gap.

Fig.15: Retrofit PV arrays at Coldstram (BRE)

The area of the arrays is such that they actually reduce the roof clutter, and they are well placed in the centre of the roof. The design intention is not to conceal the PV, and the arrays are sufficiently large that they stand beside the other building elements, such as doors and windows, in their own right. The individual modules have a similar size and shape to the windows.

Ayton, Lawfield

Lawfield is also a retrofit, but on newer properties so the tiles are not as discoloured. This serves to enhance the contrast between the PV and the roof. Visual integration is not so important here as the south sides of the houses face a field. These houses have heat pumps, which collect heat from a sunspace on the south-facing wall.

Fig.16: Retrofit PV arrays at newer houses in Lawfield, Ayton (BRE).

Fig. 16 shows the rear facing array. The texture complements that of the sunspaces to the left and right. With the black edge frame, the clearance between roof and modules is less noticeable.

Ayton, Beanburn (Level 3)

This new-build low-energy house is constructed using pre-fabricated ‘breather wall’ panels and timber frame. It features solar thermal hot water, controlled ventilation with heat exchanger, passive solar heating incorporating automatic vents and blinds, and grey water re-cycling. With 48 PV modules installed, it has double the area of the other houses in this project.

It stands alone on the site, which has given the architect more liberty to depart from the conventional materials and appearances of the surrounding houses. The outside walls are of blue-painted wood, which have a resonance with the colour of the PV array.

Fig.17: The newly-built low energy house at Beanburn, Ayton.

The sun space glass roof and the PV fill the major part of the roof area, with most of south-facing roof being glass finished. This minimises the contrasting texture which is normal with photovoltaics on a roof- it is unusual for an entire roof to be finished in PV. This eliminates the problem of keeping the margins of the roof (the part which is not PV, but tiles, slates, or sheet) in visual balance.

**Hockerton Housing Partnership**

HHP aims to live as a sustainable community incorporating environmental, economic and social aspects. The development consists of five privately owned ultra-low energy houses incorporating a large number of energy efficient measures. These include the earth sheltered design with insulated turf roof and heavyweight structure to even out temperature fluctuations. A south facing sunspace collects solar gain to help heat the building and, via a heat pump, hot water. HHP receives many visitors and is very well publicised.

The PV system comprises 90 BP Solar 85Wp modules.

Fig. 18: PV modules mounted on ballast filled consoles above parapet wall (HHP).

This installation is unique in that the modules are mounted on consoles that simply sit on the parapet wall at the top of the sunspaces. It is a retrofit installation involving no penetration of the building fabric or the roof structure since the cables pass through a ventilation shaft. Approx 75kg of ballast is loose filled into each console, with the PV module bolted directly to the top. The ballast ensures the modules stay fixed.

In terms of architectural integration, this installation surpasses many others since the PV seems to complement the sunspace to the extent the building would look deficient without it. The angle of the PV modules is similar to that of the sunspace; this presumably having also been designed to increase the energy harnessed.

## Steelstown Energy Programme

This is a new build development at Killybrack Road, Omagh, of 25 low-cost three bedroom houses, part of an estate of 80. The chosen properties have unshaded south facing roofs making them particularly suitable for PV installation. 25 systems will be installed, giving a total capacity of 51kWp.

The PV arrays are unusual in that they are roof integrated using modules on a pre-assembled structural frame. EPDM gaskets form a water seal between the modules to prevent rain ingress.

Fig. 19: PV arrays are integrated into the south-facing roof using the PV systems "RIS" system.

The roof integrated mounting system means the modules are almost flush with the plane of the roof and are visually part of the building design. The colour of the cells blends well with the roof tiles, the aluminium frames complement the horizon colour and draw attention to the PV.

The arrays in Figure 19 are well centred on the dwelling roof and equally spaced either side of the chimneys - this is interesting from a functional point of view as both are linked with energy production for the houses. Once again, the visual appearance of the modules depends upon the angle of view.

## COMPARISON OF INSTALLATION METHODS

All examples called for different methods of installation, training, and different levels of design input. The detail of design has an important effect on the smoothness of the installation process.

### Machynlleth

The PV system consists of 7 blocks of arrays feeding 8 Fronius inverters connected to the mains at the 3-phase distribution board. Modules are framed, blue-backed Astropower 120Wp specials with hidden support to meet the visual requirements of planners.

The modules are mounted on an Intersole tray system, which is designed to make a weatherproof join to a variety of types of tiles and slates. This system promises to be capable of mating a wide variety of modules to a wide variety of roofing materials. The recycled plastic from which the Intersoles are made can be easily cut to match any sizing requirements of the roofing elements or modules, and the rippled edges channel water away from the joins as well as providing an interlocking means with the adjacent tiles or slates. This universal nature makes this an interesting system with many potential applications.

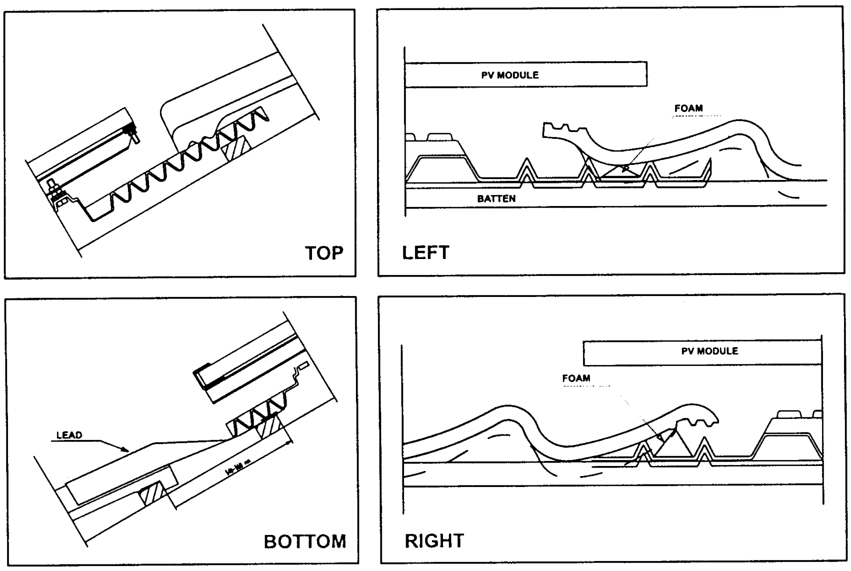


Fig. 20: Detail of Intersole Trays from manufacturer data.

In practice the Intersoles proved more difficult to use than expected. This difficulty arose from the means of attaching the modules to the Intersoles rather than in the interface with the slates. The first installations had to be dismantled, and thus took much more time than later ones, due to the need of assembling the system in the correct order. If the fixing stud was not completely tight when it came to attach the module, access to the required nut was impossible. The installers, Dulas, decided to attach extra locknuts to ensure the brackets and studs did not become loose. This added extra complexity to the fixing stud assembly.

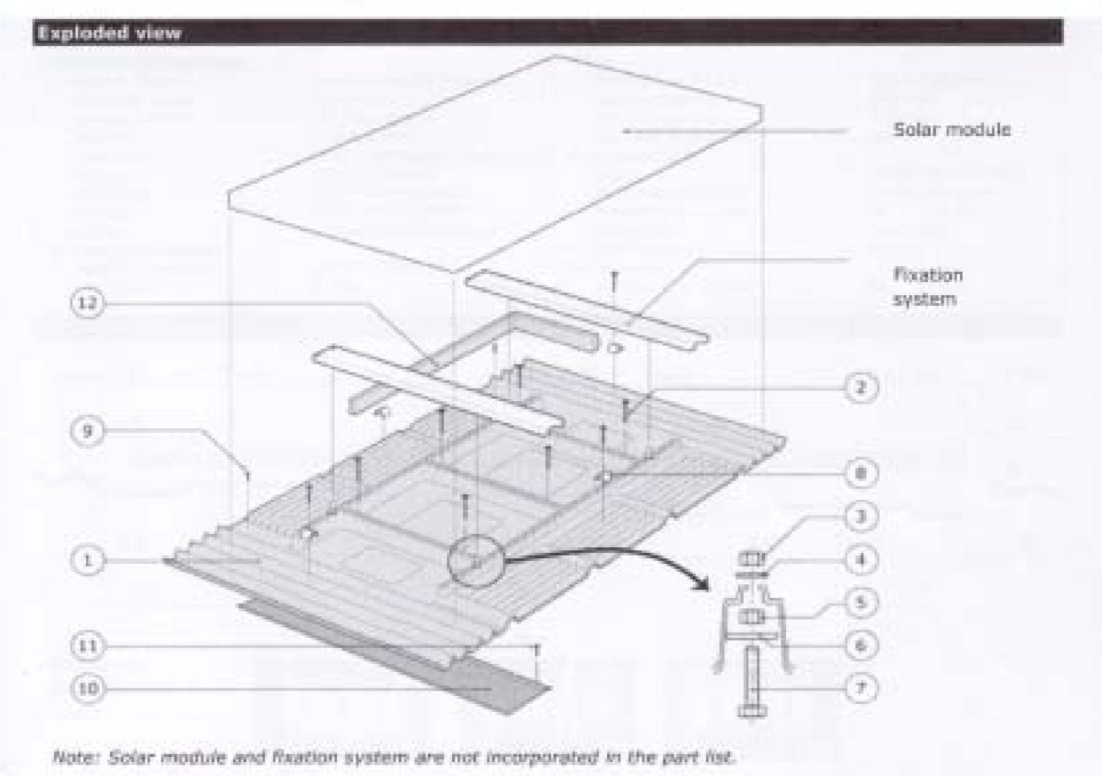

Fig. 21: An exploded view of the Intersole system. Note the fixing bolt detail (Manufacturer data).

In order to make the slates flush with the modules, an extra batten had to be installed underneath the slates to raise them to the same height. The profile of the Intersoles would suggest they are primarily for a profiled tile roof. Under the Intersoles only a single batten was required.

The Intersoles require screwing to the studs through a ridge in their profile, which ensures no water entry. They took more time to install than the modules, even though they are easier to handle. Once the order of assembly was established the installation time was reduced by a half. Figure 21 shows a single stud for attaching the modules. In practice this consisted of two studs connected by a plate, a total of 5 nuts per fixing and 532 fixings altogether. No parts list was provided by the manufacturer.

An L-shaped bracket is used to join the Interflex rails to the Intersole base units. As Dutch battens are thicker than British practice, the wood screws were found to be too long, which could have penetrated battens and the sarking felt, leaving potential moisture ingress. This was recognised and shorter screws were used accordingly.

## Pinehurst

Installing the Redland mounting system was generally straightforward. On the first roof roofers put the felt between the counter battens and the battens instead of underneath both, reducing the ventilation air gap. It is worth emphasising to roofers the correct sequence of the counter battening as this will be unusual practice to them. The battens at Pinehurst had to be re-done but did not add significant delay (see Fig.22).

Fig. 22: Counter battens (verticals) installed correctly for cooling, beneath battens

CDS Sun Dog tried both fixed price and hourly rate contract. The roofing work cost about twice as much as a normal roof under the former, but even more under the hourly rate contract. Until roofers become used to working with PV they will probably give inflated prices for its installation, but this is still likely to cost less than an hourly rate basis.

The roofers connected the modules as they progressed using the Multi-Contact (MC) connections which are touch-safe, reliable and need no tools, being already fitted to the modules. Prior to this the PV contractor, Sundog, had installed the main DC cables. Sundog returned to test the continuity of the strings after the modules were installed and before the scaffolding came down.

The connections were made as straightforward as possible by installing the modules in columns to form a string from bottom to top. The strings comprised ten or twelve modules depending on the site. The presence of an odd number of rooflights introduced complexities in the wiring as the end-of-string modules were not always able to be located on the top or bottom rows.

Fig. 23: Plastic trays for weatherproofing with modules fitted on top

Figure 23 shows the installation process. The installation is a two stage process: first the proprietary plastic tray is fitted which meshes in with the Redland tiles. This ensures weather tightness of the assembly and back ventilation. Secondly, the modules' multicontact connections are connected together and clipped into place. One potential concern for some installers is that access to failed panels or to connectors for testing is only possible by removing the panels from the top down. The figure below shows the finished installation.

Fig. 24: The finished installation at Pinehurst (BRE).

**Broughton Leys**

Broughton Leys uses the Pfleiderer module system. The solar tiles interlock easily with other Terra Piatta clay tiles, though not with conventional British concrete tiles due to different dimensions. Thought has to be given to the ridges where they meet and on this site the lowest row of tiles needed cutting to meet the gutter properly. This exposed the red clay edge of the tiles that had to be painted black to match the roof.

Fig. 26: The complete Pfleiderer module (Solar Century)

The picture above shows the Pfleiderer modules. Note the water channels to the sides, and profiled top edge to interface with other modules and conventional roof tiles from the Terra Piatta range. Each solar tile takes the place of six others. The electrical connections are MC plugs, factory fitted. With very little training from Solar Century, the roofers were able to make the connections between the tiles.

The sequence of installation is from the base up, with each module top edge being screwed to the battens

- Tiling is carried out below and to the right of the array.
- First module is laid on battens and dc cable is connected to output cable using push fit MC plugs
- The module is screwed through the tray to the battens in three places
- The second and subsequent modules are connected using MC plugs and screwed down.
- The module tray interlocks with adjacent modules and tiles for a weatherproof join.
- The final MC plug from the top of the array feeds into the output cable to the inverter.

Re-battening had to be done on some of the first installations to take the different sized clay tiles. This was at a modest cost (about £200) and is part of a reasonable learning curve for a new construction process.

One extra task that increased installation time involved the fitting of a stainless steel shroud to edge of the modules. This is necessary for the modules to meet the spread-of-flame requirements under British buiilding regulations.

**Perthshire**

Sunslates - Glen Lyon

Fig. 27: Atlantic Solar Sun Slates being installed (Solar Century).

The sunslates look very similar to slate as the backing material is fibre and fibre cement slates are already a familiar roofing material. The installation process is different however. Sarking (board and felt) is installed first, then counterbattens, then battens as is usual Scottish practice. However, the Sunslates have to be installed row by row to enable the electrical connections side to side. A normal slate roof would be installed in diagonal lines to enable the roofers to work to their side, rather than face down the roof and work on the slate below.

This was a retrofit job meaning the electrical and roofing work could progress simultaneously. At the same time an innovative solar PV powered heat recovery / ventilation system was installed. It collects heated air from below the sarking and blows it into the dwelling. Although the houses were occupied, there were no access problems as the tenants were well informed through the HA using meetings and newsletter publicity. They welcomed the installation of PV.

Extra scaffolding was required: two towers and edge protection.

Braisby, the roofer employed for this work, tested the continuity as they connected the sunslates, having been trained on-the-job by Solar Century. Although the installation time was about twice that of an ordinary roof, the roofers committed themselves to a fixed price contract.

The installation steps and relevant diagrams are the same as for Montagu Road in the first annual technical report. Since the sunslates are laid in rows electrical connections are made between adjoining tiles. It is important to test the continuity of the string at the end of a row before the next row up is laid. This necessitates having an electrician on site or a suitably trained roofer to test continuity using a multimeter. In a typical string the open circuit voltage can be in the region of 150 – 200Vdc so suitable safety precautions should be taken.

Pfleiderer - Pitlochry

The addition of PV under the field trial came late in the building programme. The developer, Stuart Mill Homes, did not want the PV in the contract which was regarded as burdensome, creating contractual difficulties and a surcharge from them of about £8k. for the contract variation.

Marley, a roofing contractor, is installing the Pfleiderer modules while the main electrical contractor is doing the electrical work. Marley roofers were trained by Solar Century after carrying out a selection process which ensured the roofers were motivated about PV and informed about the environmental benefits. This included a general session followed by on-the-job training.

Marley test the tiles on the roof and then test entire strings, having been provided with a form to fill out with the voltages. They are aware that string voltages can be high, and that they should take appropriate precautions.

The modules require a shroud to be fitted for the BS spread of flame test. The roofers mastic the shroud to the modules as soon as they are unpacked. This was regarded by the roofers as tedious and unnecessary, and the reason for complete fabrication not having been carried out in the factory had to be explained to them.

Installation time was estimated at 75 – 100% more than an ordinary roof, however this would be less if the shroud were fitted in the factory. Deliveries from Germany came out of hours, and modules were simply left on site unsecured.

The installation steps were the same as for the Pfleiderer system at Broughton Leys.

**Pleasant Court**

This site used the Unistrut mounting frame system, installed by Nottingham City Building Works electricians and joiners. This was unconventional work for them, but they were enthusiastic.

Joiners screwed support brackets (solar hooks) in place, to which they attached the vertical Unistrut. Tiles had to be lifted to fit the hooks which was no problem. The joists for screwing the brackets into were a bit thinner than usual, the tiled sloping roof itself being a retrofit about ten years ago to upgrade a flat roof. The Unistrut had to be packed out from some of the brackets with spacers (washers) so as to get it perfectly straight, otherwise waves would have shown on the large glazed surface. Overall the five joiners fitting the brackets and Unistrut took about 1.5 days.

Afterwards, electricians installed the horizontal AluTec frame members and the modules themselves, as well as the wiring. The Swiss-patented AluTec system permits the fast dropping in of the modules and the simple removal or replacement of them, but has to be installed with some precision. The modules were raised on a scissor lift and tested and connected on the roof. The team of electricians took 2-3 days to fix the Alutec and 1-2 days for the modules.

Some of the panels had polarised MC connectors the wrong way round. Electricians suggested they would test the panels before they were lifted up in future, as they had to take down twelve when the above problem was identified.

This site used full scaffold and edge protection. As this is retrofit, access was sometimes a problem. Fortunately the inverters were in the common roof space and other refurbishment works were going on (double-glazing and central heating). This meant the need for access to the flats was minimised, and tenants were more than usually patient with granting work access.

Fig. 28: Detail photograph showing modules and Alutec frame (BRE).

## Berwickshire

The UniStrut mounting frame system is used at all 3 sites in Berwickshire. Roof tiles at Ayton and Coldstream are the same but with much older versions used at Coldstream and many already broken. The overlap and thickness dimensions of the tiles were forwarded to BP Solar who fabricated the fixing hooks.

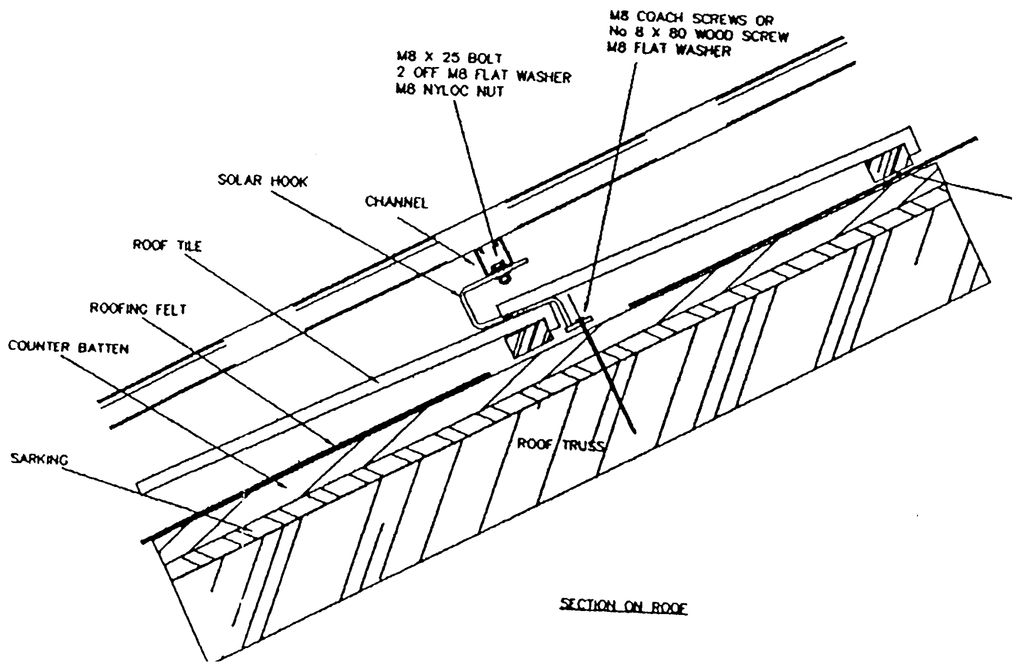


Fig. 29: Section of Scottish practice roof, mounting hook and Unistrut module frame (BHA)

Scottish practice is different to English because of the greater wind and infiltration resistance required. Rather than battens above felt, there is sarking (ply and felt) under counterbattens under battens (see diagram). Therefore the solar hooks had to be made to different dimensions.

Fig. 29 shows a typical Scottish practice roof cross section, with sarking board and felt. This requires a longer fixing bolt for the hooks - 80mm coach bolts into the trusses, which are at 600mm spacing. There are 12 modules and 12 hooks on each house (except the level 3 house at Ayton). The roofs with steeper slopes had every tile clipped. All this reflects the need for greater wind resistance.

Some of the newer timbers were bowed which could make alignments and centering more difficult. However, tolerances are generous, unlike Alutec, for example, (which quote 2mm). Once the fixing hooks are installed, the bottom horizontal Unistrut, defining the bottom of the frame, is centered on the roof and attached to the hooks. Then the right side vertical Unistrut is installed square, followed by the rest of the Unistrut frame. This arrangement can be seen in Figure 30.

Finally the modules are attached to the Unistrut using diamond fasteners and the edging is fixed. This improves the colour of the edge, hiding the Unistrut, and reduces the apparent height of the array above the roof.

Fig. 30: Installing the Unistrut frame to the roof hooks (BRE).

Aerials in the roof spaces at Coldstream stopped working due to the modules severely restricting signal strength, rectified by mounting externally. This is unfortunate consequence as it increases roof clutter, but essential to maintain continuity of TV reception.

Overall, this is a simple and effective fixing method for tiled roofs which have limited overlap. The height above the roof of the finished array is not excessive. The same method of installation is used at all sites; Lawfield, Beanburn and Coldstream.

**Hockerton Housing Partnership**

This is probably one of the simplest installation methods. The PV modules are bolted to Econergy’s ‘ConSole’ plastic trays designed for installation on flat roofs. There are 6 sizes of ConSole available and Hockerton uses size 3.1.

This method is potentially a cost effective solution for flat roofs and has the advantage no roof penetration is required for mounting. Further, since the devices are not bolted down they can be moved relatively easily for roof maintenance etc.

Each console is part filled with approximately 75kg of stone ballast and it would be essential to ascertain that the flat roof can withstand this loading. At Hockerton, this was done using unskilled labour, a shovel and wheelbarrow and the consoles are located at the top of the parapet wall / concrete roof junction so the loading was not problematic. In buildings with weaker structures and wider spans such as a 1960s system built school for example, careful assessment of the loading may be required.

The next photograph shows the consoles installed on the parapet wall with the stone chipping filling for ballast. The ballast has been levelled off, and dc cabling installed and irradiance sensors for monitoring equipment have been installed. (Note the flanges to the console edges for interfacing to a wide variety of module types.) Each module was secured to the console using 4 M6 bolts and washers. The material is easily drilled to accept fixing bolts.

Fig. 31: Consoles ready for panel installation.

**Steelstown**

As shown earlier in Fig 19, this site has roof integrated framed PV modules mounted on a ‘RIS’ frame by PV Systems. The frame consists of sectional mainrails and crossrails, preformed to provide strength and constant height support for the BP585 modules.

The system is mounted on familiar roofing – battens over Tyvek on conventional roofing timbers. Because the system is roof integrated, the modules sit lower in the roof than would be the case if a conventional frame were mounted on roof hooks with the air gap underneath.

Each module is surrounded by an EPDM gasket for weather resistance and the modules are laid onto the frame. A cap strip further seals the join between the modules. Side flashings of preformed aluminium sheet interface end mainrail with the profiled roofing tiles.

Similarly, the upper flashing is made from aluminium sheet and forms a U shape over the array. Lower flashing is similar. The flashing system is therefore similar to that of a Velux or Colt type roof window.

## COST BREAKDOWN

Table 1 shows the costs per Wp taken from the procurement reports available at 31 December 2002, for nine projects over 13 locations.

| **Site type:** | Newbuild tile integrated | New build modules on frame | Retrofit tile integrated | Newbuild tile integrated | Newbuild tile integrated | Retrofit module - console | Newbuild tile integrated | Rertofit modules on frame | Retrofit modules on frame | Retrofit modules on new build | Retrofit modules on frame | Retrofit modules with other works | New build tile integrated | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location no. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | |
| **Costs: £/Wp:** | | | | | | | | | | | | | | |
| Installed total cost | 8.39 | 5.34 | 9.69 | 10.20 | 8.01 | 6.65 | 7.06 | 6.29 | 6.51 | 5.99 | 7.32 | 5.43 | 6.75 | 7.20 |
| Module Installation | 0.54 | 1.40 | 0.48 | 0.95 | 0.73 | 0.55 | 0.07 | 0.76 | 0.77 | 0.46 | 1.37 | 0.62 | 0.72 | 0.72 |
| Electrical Installation | 0.56 | 0.66 | 0.45 | 0.58 | 0.68 | 0.98 | 0.36 | 1.54 | 1.58 | 1.54 | 0.83 | 0.78 | 1.46 | 0.92 |
| Monitoring | 0.69 | 0.23 | 0.46 | 0.38 | 0.45 | 1.34 | 0.88 | 0.94 | 1.11 | 0.94 | 1.12 | 0.23 | 0.60 | 0.72 |
| Inverter cost | 0.50 | 0.46 | 0.43 | 0.65 | 0.41 | 0.79 | 0.67 | 0.46 | 0.46 | 0.46 | 0.77 | 0.43 | 0.44 | 0.53 |
| Module cost | 6.10 | 2.59 | 7.88 | 7.64 | 5.74 | 2.99 | 5.07 | 2.59 | 2.59 | 2.59 | 3.24 | 3.37 | 3.53 | 4.30 |

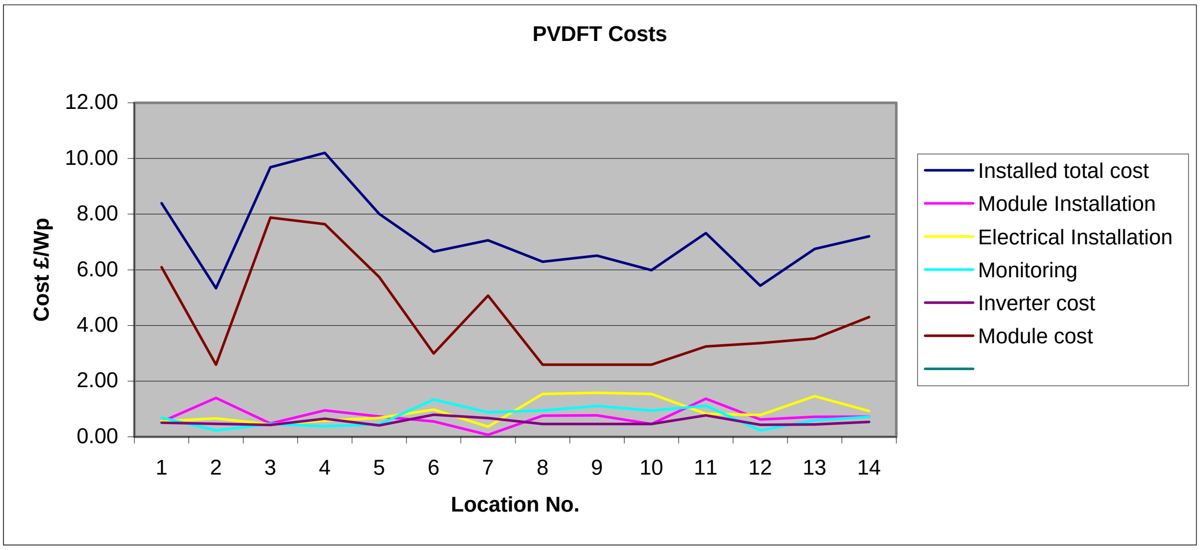


Table 1: Costs from procurement reports received from January to December 2002.

For comparison, the average costs are compared with those from the first annual technical report in Table 2. However please note that, especially for last year's report, the project costs are not equal to the sum of the parts, due to difficulty in disengaging items such as consumer metering or design costs from the overall PV cost.

| Cost Analysis | Module Installation £/Wp | Electrical Installation £/Wp | Monitoring £/Wp | Inverter cost £/Wp | Module and frame cost £/Wp | Total Project £/Wp |
|---|---|---|---|---|---|---|
| Average 1st report | 1.00 | 0.51 | 1.42 | 0.59 | 4.40 | 7.47 |
| Average 2nd report | 0.72 | 0.92 | 0.72 | 0.53 | 4.30 | 7.20 |

Table 2: Comparison of costs in this Annual Report with those in the Annual Report for 2001.

Table 2 shows that most of the cost elements of installed PV systems have fallen since last year. Last years costs were based on data from only six locations, against this years' thirteen locations.

Module installation cost has fallen dramatically; this may be attributed to an increasing knowledge base and familiarity amongst installer. There are relatively more new build sites this year and this can offer significant cost reductions over retrofit since the costs of site works, storage and scaffolding etc are shared by other works. This is certainly the case with locations 10 and 12, where the scaffold was also used for other refurbishment work so the cost was not borne entirely, if at all, by the PV installation.

Monitoring costs are less than half of those last year. This may be attributed to more installer familiarity and the fact the trial is moving significantly down the learning curve – many electricians and designers were unfamiliar with the metering technology employed. Conversely, electrical installation costs have approximately doubled. One site certainly experienced more outlay due to all the generation being routed to a central point, requiring extra switchgear and a G59 relay. It is also possible and would appear from some procurement reports that monitoring equipment cabling is charged as electrical installation in some cases. For first fix and cable routing it makes sense to combine these operations, since the same staff may carry them out on site, making the costing of data cable installation a bit of a grey area. There is certainly a large variation in the monitoring equipment costs.

The site visits and photographs show a great correlation in the layout of inverter, isolation and monitoring equipment and further savings could probably be effected if an assembled board pre-wired for installation on sites were developed. This would effect savings over site manufacture due to familiarity and better working environment reducing the time taken and reduced material wastage.

Module cost has fallen, albeit slightly. It is hoped that as demand for PV modules increases the costs will fall due to economies of scale. The peak on the graph contained in Table 1 is due to the higher module cost used at that particular site. These modules are self contained with each having their own cable and MC connector and this is reflected in their cost.

The use of roof integrated modules such as the Redland and Pfleiderer systems is more predominant this year and these components are more similar to traditional roofing products. This is reflected in the sometimes very low installation cost – as low as £0.10 per peak Watt installed. As the use of these products becomes more widespread and the installer base increases we may see this cost fall further still. The use of pluggable MC type connectors removes the need for traditional terminations on the roof and enables the panels to be fitted by roofing contractors rather than those with specialist electrical knowledge.

Modules mounted on frames are reasonably priced too – with one site using a novel roof integrated module system based on manufactured frame struts. The use of ConSoles also looks promising for flat roofs and this site features at the lower end of installation costs. Ease of access to the site afforded by the sloping roof has undoubtedly helped to keep costs down here.

## MONITORING

All of the sites have comprehensive metering fitted, not only to measure the PV power generated but also that consumed in the dwelling. Many of the sites using Sunnyboy inverters use the on-board metering to measure the DC current and voltage as well as the AC generated power.

However, it has been revealed that the SunnyBoy inverter does not actually measure the DC current but derives it from an algorithm based on the AC output. This has implications for the academic performance analysis since it is not possible to assess the inverter efficiency, particularly at part load where losses may be significant.

At the start of the field trial, it was understood that they did measure DC current to an accuracy of 4%. In fact the monitoring specification has already been altered in order to accommodate this 4% accuracy, as it had originally required 2%. In view of the number of sites with this equipment fitted, deciding the best way forward was a matter of discussion between various members of the DFT2 Scheme Management Consortium (Nicola Pearsall (NPAC), Chris Martin (EMC), and Ian Butterss (BRE)).

To investigate system performances, it is necessary to investigate not only the overall system losses, but also where those losses occur. The ability to do this is much reduced if we cannot separate the performance of the two main components, namely the PV array and the inverter. We cannot do that without reliable measurements of the DC output of the array and the AC output from the inverter.

Work done to confirm Sunnyboy measurements by the Environmental Change Unit at the University of Oxford leads us to believe that, while the inverter measurement may be slightly inaccurate, it is consistently so across different units of the model. It is therefore only necessary to cross-check a sample number of inverters and apply correction factors based on those sample readings to all the systems on a site.

The work by The Environmental Change Unit also indicated that the AC power readings made by the Sunnyboys were better than 2% accurate at full power. However, they were reading 15% low at 150W, i.e. at low but significant light levels, where the inverter is meant to be operating at peak efficiency. Therefore it would be useful to cross-check the AC readings made by the inverters with an independent AC power meter.

Hence, it would be desirable if the DFT sites could fit extra AC and DC metering equipment to verify the accuracy of the metering currently used. To draw a parallel with the heating industry, the SEDBUK boiler efficiency database compiles a list of the seasonal in- use efficiency of domestic boilers. It is possible that a similar database may be desired for a growing PV market to show the relative efficiencies of components under real weather operating conditions. In the boiler case, this has generated a competitive spirit among manufacturers to achieve ever greater efficiency. If a similar scenario were to happen with PV, the output from PV arrays could only increase as a result of improved conversion efficiency. Improved metering would enable this to be carried out more effectively.

At the time of writing  many of the newer sites have yet to be commissioned and so it is not proposed to comment on outputs from sites at this stage.

## CONCLUSION

This report has examined the different appearances of the systems, their architectural integration, the different fixing methods, and the relative cost effectiveness of these.

Architectural integration and appearance of the systems continue to improve, with sites this year including specialist PV roofing products such as Sunslates and the module systems from Pfleiderer and Redland. Problems have been experienced in interfacing these products, made to European dimensions, to existing English roofing systems. The UK spread of flame test, BS476 has necessitated extra works to some module types to prevent fire spread. However, as the experience base of the installers develops these problems are easier to rectify and the costs are reduced accordingly.

The sites this year include a wide variety of fixing methods, from new build and retrofit roof integration to modules mounted on several types of mounting frame. In view of the need for ventilation to keep modules cool in summer, it will be interesting to see the relative performance of the roof integrated systems.

Monitoring is not covered extensively in this report due to lack of sufficient data to draw any meaningful conclusions. A monitoring issue has also come to light in that the on – board monitoring of one brand of inverter is not as accurate as first suggested when the trials began. In particular, the DC current is not measured but derived from the AC power, reducing the accuracy. In view of this, it is advisable to fit extra metering equipment to check the data validity.

The analysis of costs would suggest that most costs have reduced since the last annual technical report. In particular the installation and monitoring costs have all reduced. This may be a result of the greater number of 'standard' new build sites this time, the widening skills base and early identification of problems. Inverter cost has fallen slightly and module cost has risen slightly. Many of the sites experienced module delivery delays and this would suggest that more capacity is required from the manufacturers as UK and World demand increases.