The Scottish Government
Directorate for the Built Environment
Building Standards Division

BRE Scotland and Waterman Group

Risk assessment of structural impacts on buildings of solar hot water collectors and photovoltaic tiles and panels – final report

Date: March 2010

Report prepared by:
Julian Ridal and Dr Stephen Garvin, BRE Scotland
Frank Chambers and Jim Travers, Waterman Group

The opinions expressed in this report are those of the authors on behalf of their organisations

Report commissioned by:
Building Standards Division
Directorate for the Built Environment
Denholm House
Almondvale Business Park
Livingston
EH54 6GA

Tel: 01506 600 400
Fax: 01506 600 401
e-mail: buildingstandards@scotland.gsi.gov.uk
web: www.scotland.gov.uk/bsd

This report is published electronically to limit the use of paper, but photocopies will be provided on request to Building Standards Division.

Contents

1 Executive Summary

BRE and Waterman Group have been contracted by the Building Standards Division of the Built Environment Directorate, Scottish Government to undertake a research project on the risk assessment of the structural impacts on domestic and non-domestic buildings of solar hot water collectors and photovoltaic tiles and panels.

Information has been gathered on the following types of solar collectors:

- Solar thermal hot water collectors – flat plate, evacuated tube and tile type;

- Photovoltaics – crystalline and amorphous silicon types, as panels and tiles.

Data on the weight and dimensions of the various types of collectors as well as information on the types of support system (support frame and fixings for walls and roofs) have also been obtained. Structural assessments have been undertaken of the loads imposed when solar thermal hot water collectors and photovoltaics are attached to roofs and walls. A risk based approach has been developed for the installation of solar collectors to roofs and walls, and a number of case studies have been developed from actual installations. The conclusions drawn from the research are set out below.

Roofs

- Where a single row of photovoltaic panels or solar hot water collectors are fixed on a support frame over an existing roof tiles or slates, then there will be an increase in the dead load applied to the roof truss. These loads have been calculated to be within acceptable limits of safety for standard truss rafter roofs, particularly those fabricated by specialist timber roof manufacturers utilising metal punch plate connector plates.

- For mansard and older roof types, the loads may also be accommodated. However, as the variability of design is great, then each installation should be assessed on an individual basis, which may require a chartered engineer.

- Where multiple rows of photovoltaic panels or solar hot water collectors are fixed on a support frame over an existing pitched roof structure, a detailed assessment should be undertaken to assess the effects on the truss members and connections, which may require a chartered engineer.

- Replacing concrete tiles in a roof with "in-plane" solar thermal hot water collector or photovoltaic tiles will reduce the dead load on the rafters and consequently the roof will not require any additional strengthening. However, there may be some minor problems with wind uplift. Consequently truss holding down measures may be required.

- The effects of current levels of snow loading are accounted for routinely in the standard roof truss design for both panels and tiles.

- There may be some minor problems with wind uplift where solar thermal hot water tiles or photovoltaic tiles are fixed to individual roof trusses, so consequently truss holding down strengthening measures may be required.

Walls

- Solar thermal hot water heating panels and photovoltaic panels can be supported adequately on a range of wall constructions. This includes no-fines concrete, cavity walls, timber frame and steel frame construction types. However, as there is a wide range of variability in the design of most of these wall types, each wall should be assessed by a chartered engineer to ensure the adequacy of the construction.

- The majority of photovoltaic and solar water collector equipment is installed on roofs rather than walls. The residual risk from wall installations can be managed by involving a chartered engineer.

Fixings

- Solar thermal hot water collectors and photovoltaics should be fixed with durable fixings and supported by the structural members of roofs and walls.

Risk Assessment

- A risk assessment and risk management methodology for the safe installation of solar collectors and photovoltaics to roofs and walls has been developed. The risk assessment could be undertaken by an Approved Certifier of Design or an MCS Accredited Installer but may require the involvement of a chartered engineer to assess the structural integrity of roofs or walls.

Building Standards

- The fixing of solar collectors and photovoltaic panels to roofs and walls may involve structural alterations or modifications which must comply with Building Standards.

2 Introduction

BRE and Waterman Group have been contracted by the Building Standards Division (BSD) of the Built Environment Directorate, Scottish Government, to undertake a research project on the risk assessment of the structural impacts on domestic and non-domestic buildings of solar thermal hot water collectors and photovoltaic tiles and panels.

The need for the research was identified during a major revision to the Scottish Building Standards for Energy (see the recent consultations on Section 1 Structure, Section 6 Energy and Compliance on the BSD web site). A 30% reduction in carbon dioxide emissions from domestic and non-domestic buildings is required. This could lead to the increased use of renewable energy systems in new buildings. Existing buildings will need to address the use of renewable energy systems as well as improving insulation standards and the performance of services.

The main issue addressed by this research is to identify after installation of solar renewable technologies whether and how the changes in loadings may affect the structural requirements of the buildings. The report from this research project will help Building Standards Division understand the risks of using such low carbon equipment in typical Scottish properties.

The project objectives were set out by BSD as follows:

1. “To understand the significance of the changes in the loading on buildings where solar hot water collectors and photovoltaic tiles or panels are fitted to the walls or roofs of a range of common building structures in Scotland;

2. Once complete this risk assessment may be used to contribute towards providing supplementary guidance, for example in the Technical Handbooks;

3. The assessment should cover the full range of active solar systems and installation conditions;

4. The assessment should, where possible, quantify the potential additional loads that the structure of the building will be required to withstand as a result of the proposed installations and whether strengthening measures are likely to be necessary for typical construction forms. This may include uplift loads, especially where substantial areas of roof coverings are replaced or covered;

5. The assessment should also cover fixings methods and propose guidance that might be provided in relation to fixings.”

The risk assessment may be used by BSD to contribute towards providing supplementary guidance in the Technical Handbooks. Therefore the assessment covers the full range of active solar systems and installation conditions. It also, where possible, quantifies the potential additional loads that the structure will be required to withstand as a result of the proposed installations and whether or not strengthening measures are likely to be necessary for typical construction forms. This includes uplift loads, especially where substantial areas of roof coverings are replaced or covered.

3 Methodology

The methodology undertaken for the structural assessment involved the following:

- Gathering information on renewable technologies, including basic specifications of type, weight and dimensions selected from the range of equipment used. This will identify the appropriate worst case additional design loads arising from installation.

- Collecting building performance data for the specific types of walls and roofs.

- Undertaking an assessment of the safety of the buildings (roofs, walls and attachments) with respect to the impact of changes to loading arising from the installation of renewable technologies on the structural performance of the building and supporting structural elements.

3.1 Low carbon equipment

Information has been collected on various types of solar thermal hot water collectors and photovoltaic panels and tiles. The low carbon equipment information has been gathered from product data, which was sourced both from products used by installers in the Microgeneration Certification Scheme (MCS) and from product data obtained from manufacturer's literature.

3.1.1 Solar thermal hot water collectors

In Scotland, solar thermal hot water collectors are incorporated commonly on or in roofs but are mounted rarely on walls. There are three generic types of solar collectors, as follows:

- Flat plate collector

- Evacuated tubes collector

- Tile type solar collector.

A flat plate collector is a glazed box with a selective coated absorber plate, which is embedded with fluid channels. It allows good transmission of light to the cover and is highly insulated.

An evacuated tube collector is composed of a series of parallel glass tubes containing a vacuum to reduce heat losses. There are two types of evacuated tube, as follows:

- Heat pipe – each tube contains a sealed absorber circuit filled with working fluid that evaporates when heated by solar radiation. The vapour rises to the top of the tube and condenses in the manifold to the heat exchange fluid.

- Direct flow – each tube has a 'U' tube filled with the system circulation fluid. Heat is absorbed and carried away to the heat exchanger.

One type of tile solar collector is currently commercially available in the UK, which is used to replace existing tiles on roofs.

All solar thermal hot water collectors should meet the requirements of BS EN 12975 Part 2[1].

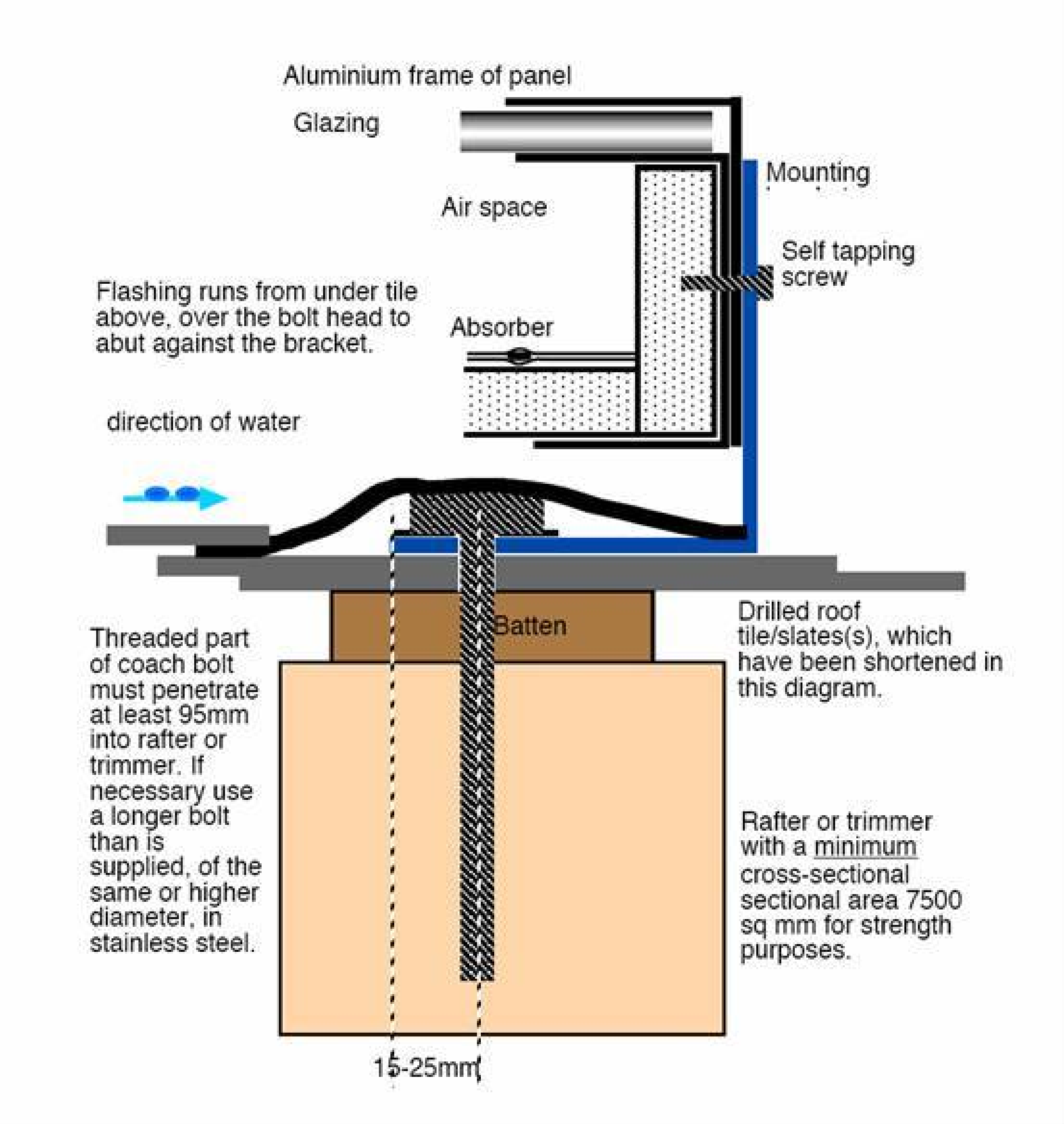
The number and area of solar thermal hot water collectors used in an installation is linked to the sizing of the capacity of the hot water cylinder, the dedicated solar volume and the daily hot water demand.

The requirements for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar heating microgeneration systems are outlined in Microgeneration Installation Standard MIS 3001[2]. Alternative standards and guidance may be published in other countries and could be used as an alternative to those referenced in this report.

Solar collectors need a support system (support frame and fixings) (Figure 1). They should be ballasted adequately or fixed to a suitable structural member of the building. The support frame and fixings should be protected from corrosion for a typical life to first maintenance of at least 20 years. Either stainless steel number 1.4301 or 1.4401 to BS EN 10088 Part 1[3] or galvanised coating on mild steel as specified in BS EN ISO 14713[4] should be used. Different metals should be isolated from each other to prevent the risk of bimetallic corrosion.

The roof structure should be capable of withstanding the imposed static and wind loads before considering an installation[2]. For a pitched roof, a solar collector should have at least four fixings attached through the roof covering to the load bearing roof trusses and the weathertightness of the roof should not be compromised[5]. All roof penetrations for solar collectors, pipework, cables or support structure need to be sealed using purpose-made products capable of accommodating the movement and temperatures to which they will be subjected. Suitable sealing products include purpose-made roof tiles and flashings, examples are outlined in the Microgeneration Installation Standard, MIS 3001[2].

Figure 1: Fixing a solar collector to a pitched roof (not typical dimensions)



Data for solar collector products is given in tables 1 to 3. A brief summary of the data is as follows:

- Flat plate collectors: gross area range 2.03 m^2 to 3.01 m^2 weight range of 25.0 kg to 44.4 kg.
- Evacuated tube collectors (variable numbers of tubes): twenty tube collectors typical gross area range 2.84 m^2 to 2.99 m^2; weight range 50.3 kg to 60.0 kg. Thirty tube collectors typical have a gross area of 4.32 m^2 and a weight of 76.0 kg.
- Solar collector tile, gross area 0.39 m^2, weight 7kg.

From this review of solar collector products currently available in the marketplace worst case design loadings will be defined for each type of construction under consideration.

Table 1: Flat plate type solar hot water collector data

Type	Dimensions/m	Gross area/m^2	Aperture area/m^2	Absorber area/m^2	Mass of empty collector/kg	Example
F	2.434 x 1.235 x 0.140	3.01	2.65	2.49	25.0	Frame over roof covering
A	2.009 x 1.009 x 0.074	2.03	1.78	1.778	36.1	Ballasted framework on flat roof
D	2.039 x 1.139 x 0.080	2.32		2.14	44.4	Frame over roof covering

Table 2: Evacuated tubes type solar hot water collector data

Type	No of evacuated tubes	Dims / m	Gross area/m^2	Aperture area/m^2	area / m^2	Mass /kg	Example
B	20	2.005 x 1.418 x 0.097	2.84	2.01		50.3	Frame attached to pitched roof
C	30	2.127 x 2.031 x 0.043	4.32	3.17	3.07	76.0	Frame attached to pitched roof
E	20	1.730 x 1.730	2.99		2.20	60.0	Frame attached to pitched roof

Table 3: Tile type solar hot water collector data

Type	Gross area/m^2	Mass/kg
J	0.39	7

3.1.2 Photovoltaics

In Scotland, photovoltaics are incorporated commonly on or in roofs but are mounted rarely on walls. There are two generic types of photovoltaics, as follows:

- Crystalline silicon types (monocrystalline or polycrystalline) – to BS EN 61215[6].
- Amorphous silicon types (thin film) – to BS EN 61646[7].

Photovoltaics can be incorporated into buildings as either frame mounted photovoltaic modules or building integrated photovoltaic roof tiles. In Scotland, photovoltaics are mounted rarely on walls but are incorporated commonly on or in roofs.

On a pitched roof, a frame mounted photovoltaic module systems is mounted above the roof surface and is constructed from prefabricated elements designed to transfer the applied forces, such as self-weight, wind and snow, to the supporting structure (Figure 1). On flat roofs, the photovoltaic modules are mounted on an 'A' frame fixed to the structure supporting the flat roof or ballasted adequately.

For building integrated photovoltaic roof tile systems on pitched roofs, the photovoltaic tiles replace the roof tiles or slates and become an integral part of the roof and so need to maintain the weathertightness of the roof. All roof penetrations, such as PV modules, cables and support framework, should be sealed using purpose-made products capable of accommodating the movement and temperatures to which they will be subjected. Suitable sealing products include purpose-made roof tiles and flashings, examples are outlined in MIS 3002[8], although manufacturers of such products should be able to advise on product use. For flat roofs, the photovoltaic tiles are incorporated into the roof weatherproofing system in a similar way to roof lights. However, it is rare to integrate photovoltaic tiles into flat roofs[9].

The size and number of photovoltaic modules used will vary, depending on how much electricity is to be generated.

The requirements for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar photovoltaic (PV) microgeneration systems are outlined in Microgeneration Installation Standard MIS 3002[8]. Alternative standards and guidance may be published on other countries and could be used as an alternative to those referenced in this report.

Photovoltaic equipment needs a support system (support frame and fixings). It should be ballasted adequately or fixed to a suitable structural member. The support frame and fixings should be protected from corrosion for a typical life to first maintenance of at least 20 years. Either stainless steel number 1.4301 or 1.4401 to BS EN 10088 Part 1[3] or galvanised coating on mild steel as specified in EN ISO 14713[4] should be used. Different metals should be isolated from each other to prevent the risk of bimetallic corrosion. The roof structure should be capable of withstanding the imposed static and wind loads[8].

Data for typical photovoltaics are given in the tables 4 and 5. A brief summary of the data is as follows:

- Frame mounted photovoltaic: gross area range 1.38 m^2 to 1.68 m^2; weight range 17 kg to 22 kg.

- Photovoltaic slate: gross area 0.50 m^2; weight 5.1 kg.

- Photovoltaic tile: gross area 0.51 m^2; weight 8.0kg.

From this review of photovoltaic products currently available in the marketplace worst case design loadings will be defined for each type of construction under consideration.

Table 4: Frame mounted type photovoltaic data

(frame on pitched roof or a frame on flat roof)

Type	**Dimensions/m**	**Gross area/m^2**	**Mass/kg**	**Example**
G	1.658 x 0.834 x 0.045	1.38	17	Frame over roof covering
H	1.675 x 1.001 x 0.034	1.68	22	Frame over roof covering

Table 5: Tile type solar photovoltaic data

Type	Gross Dims/m	Gross area/ m^2	Individual unit mass/ kg	Mass as laid/ (kg/m^2)	Fixings
I (slate)	1.210 x 0.412 x 0.014	0.50	5.1	14.0	4 stainless steel screws with EPDM washers and 2 slate hooks per unit
J (tile)	1.220 x 0.420 x 0.030	0.51	8.0	19.7	4 x 4.5mm x 45mm self tapping stainless steel screws with EPDM washers

3.2 Construction types

The types of constructions and buildings considered are as follows:

1. Solid wall, mansard or semi-flat roof (pre-war) – top flat roof with a steep pitched lower roof, typically between 45° and 70°, leading to a wall without a cavity, brick/brick cavity wall and room in roof.

2. Brick/brick cavity wall with room in roof (inter war) – these generally have pitched roof containing loft space above brick/brick cavity construction;

3. Timber roof trusses (developed by the Timber Development Association (TDA)), bolted or with metal connector plates (1950s and 1960s) – pitched roof above brick/brick cavity wall construction;

4. No-fines construction (1950s to 1970s) – wall construction of concrete of coarse aggregate only (95% of aggregate sized between 10 and 20 mm), finished with pebble dash render on the outside and plasterboard on the inside;

5. Cavity wall construction (from 1970s to present) – lightweight blockwork wall with cavity and lightweight manufactured timber truss roof;

6. Timber framed construction (from 1980s to present) – timber framed and brick clad with lightweight manufactured timber truss roof;

7. Steel framed building – steel portal frame enclosed by profiled metal cladding; and

8. Steel framed building – steel frame enclosed with masonry cavity wall and with pitched or flat roofs.

3.2.1 Information collection

A range of design assessment conditions have been determined using previous experience, current and historic published guidelines on the building forms specified in the tender brief.

The types of loads being considered are as follows:

- Static or dead load – additional weight of the solar collector attached to the roof or wall;

- Wind load – forces exerted when wind passes between the roof and the solar collectors; and

- Snow load – additional load imposed by snow lying on top of the solar collector attached to the roof. Typically where individual solar collectors are fixed to existing roof structures the effects of snow drifting will not be significant and would normally be accommodated within the normal snow loads considered, however for all other installations a detailed assessment of snow loading should be assessed.

The additional loading from the photovoltaic cells and solar hot water collectors have been compared to the loads applied in the original typical structural designs and the increase or decrease in critical member and connection forces defined for the original design condition. In the original designs critical members will be loaded or stressed to a large proportion of their 100% capacity at which required factors of safety would have been achieved.

In order to establish a straightforward method of assessing, critical or affected members should not be loaded to more than 100% of their design capacity as a consequence of increased loading from solar collector products. Should applied additional loads result in member forces or stresses that exceed 100% of the original design capacity, then the intended factors of safety will be reduced.

4 Results

The results from the structural assessment are provided in this section. Tables 6 to 7 summarise the result of the structural assessments carried out. These assessments considered the effects of the application of additional (or reduced) dead and live loading resulting from the installation of photovoltaic panels and solar collectors to the roof or wall construction under consideration.

The results provided in this section address the impact of various types of photovoltaic tiles and panels and solar thermal hot water collectors fixed to construction types (numbered as section 3 and briefing document) as follows:

1. Solid wall, mansard or semi-flat roof (pre-war).

2. Brick/brick cavity wall with room in roof (inter war);

3. Timber roof trusses (developed by the Timber Development Association (TDA)), bolted or with metal connector plates (1950s and 1960s) – pitched roof above brick/brick cavity wall construction;

4. No-fines construction (1950s to 1970s) – wall construction of concrete of coarse aggregate only (95% of aggregate sized between 10 and 20 mm), finished with pebble dash render on the outside and plasterboard on the inside;

5. Cavity wall construction (from 1970s to present) – lightweight blockwork wall with cavity and lightweight manufactured timber truss roof;

6. Timber framed cavity wall construction with lightweight manufactured timber truss roof (from 1980s to present);

7. Steel framed building – steel portal frame enclosed by profiled metal cladding; and

8. Steel framed building - steel frame enclosed with masonry cavity wall and with pitched or flat roof.

These construction types were selected for appraisal and analysis as they are likely to feature where a major proportion of solar renewable energy installations are undertaken in the future.

4.1 Loads from renewable technologies

4.1.1 Solar thermal hot water heating collector loads

The additional loads applied to the roof structure were calculated from data sheets giving the weights and dimensions of the equipment, which, when considered together combined to produce the following additional distributed loads (see tables 1, 2 and 3 for details):

Type A	0.19 kN/m^2
Type B	0.19 kN/m^2
Type C	0.19 kN/m^2
Type D	0.20 $kN.m^2$
Type E	0.22 N/m^2
Type F	0.90 kN/m^2

The weight of the water and glycol mixture within the solar thermal hot water collectors has been taken into account in the assessments.

4.1.2 Photovoltaic panel and tile loads

The additional panel loadings applied to the structure were calculated from relevant equipment data sheets which provided the weights and dimensions of the panel or tile. The applied additional distributed loadings for the design assessment purposes were calculated as follows: (see tables 4 and 5 for details)

Type G	0.12 kN/m^2
Type H	0.13 kN/m^2
Type I	0.14 kN/m^2
Type J	0.19 kN/m^2

Panel types G and H are panels to be constructed above the existing roof finish (known as on-roof panels) and are therefore an increase to the existing loads.

Panels I and J are designed to replace the existing roof tiles (known as in-roof panels) and represent a decrease to the original loading.

4.2 Performance of construction types

4.2.1 Solid wall, mansard or semi-flat roof (pre-war)

Mansard roof frames were typically constructed on-site using loose timbers and not as factory produced prefabricated assemblies as is the case with modern timber trusses (considered later). As such, the connections of the individual members will vary greatly as does the location within the frames of the internal web members.

It is not possible to assess a mansard roof construction as there are no standard or even typical frame types. Such frames are different in their construction as they are supported on external cavity walls and are additionally supported at the internal wall locations. Solid walls should be assessed by a chartered engineer on a case by case basis.

4.2.2 Brick/brick cavity wall with room in roof (inter war)

Room-in-roof trusses were typically constructed on-site using loose timbers and not as factory produced prefabricated assemblies as is the case with modern timber trusses. As such the connections of the individual members vary greatly as does the location within the frame of the vertical (oxters) and horizontal (collars) internal members. Often the internal oxters and collars are half notched at their ends and fixed to the rafters and ceiling ties by one or two nails relying on the bearing onto the notch to transfer the compression forces. In other instances the oxters and collars are simply through bolted to the rafter and ceiling tie via a single bolt.

The room in roof construction cannot be assessed in the same way as standard proprietary roof trusses, which are considered in some detail later, as it is not possible to undertake an assessment of a typical room in a roof frame. Such frames are different in their construction as they are supported on external cavity walls and may additionally be supported on the internal wall locations. However by considering the individual components it should be possible to establish criteria to allow a similar assessment method. This type of roof structure is generally found in older properties particularly in bungalows as it is subject to alteration and strengthening to enable use of the attic space for accommodation. The assessment of typical loadings and frame arrangements indicates that like proprietary roof trusses room in a roof, frames should be capable of supporting the photovoltaic panels without significant additional strengthening. However, in order to ensure compliance of the frame members and joints each individual case should be risk assessed.

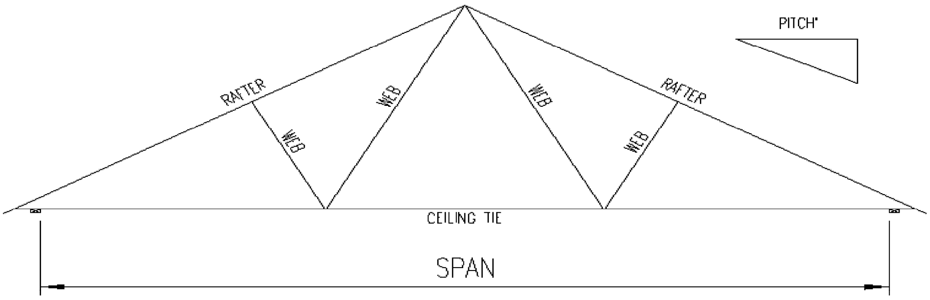
4.2.3 Timber roof trusses (TDA), bolted or with metal connector plates (1950s and 1960s) – pitched roof above brick/brick cavity wall construction

4.2.3.1 Detailed Truss Assessment

In order to undertake a detailed assessment of timber roof trusses a range of truss sizes and pitches as indicated in table 6 were considered. Assistance was provided by MiTech Industries through their truss design software in undertaking this detailed analysis. These assessments have been based on standard fink trusses with a single span and symmetrical pitch which consider a single row of photovoltaic panels and solar collectors applied on one side of the truss only, as shown in figure 2 and a typical roof make-up, as shown in figure 3.

Table 6 - Basic Truss Profile

Span (mm)	Pitch (degrees)	Timber Grade	Member		
			Rafter (mm)	Ceiling Tie (mm)	Internal Web (mm)
8000	30	TR26	97 x 35	97 x 35	72 x 35
	35	TR26	97 x 35	97 x 35	72 x 35
	40	TR26	97 x 35	97 x 35	72 x 35
9000	30	TR26	122 x 35	97 x 35	72 x 35
	35	TR26	97 x 35	97 x 35	72 x 35
	40	TR26	97 x 35	97 x 35	72 x 35
9000	30	TR26	122 x 35	122 x 35	72 x 35
	35	TR26	122 x 35	122 x 35	72 x 35
	40	TR26	122 x 35	122 x 35	72 x 35



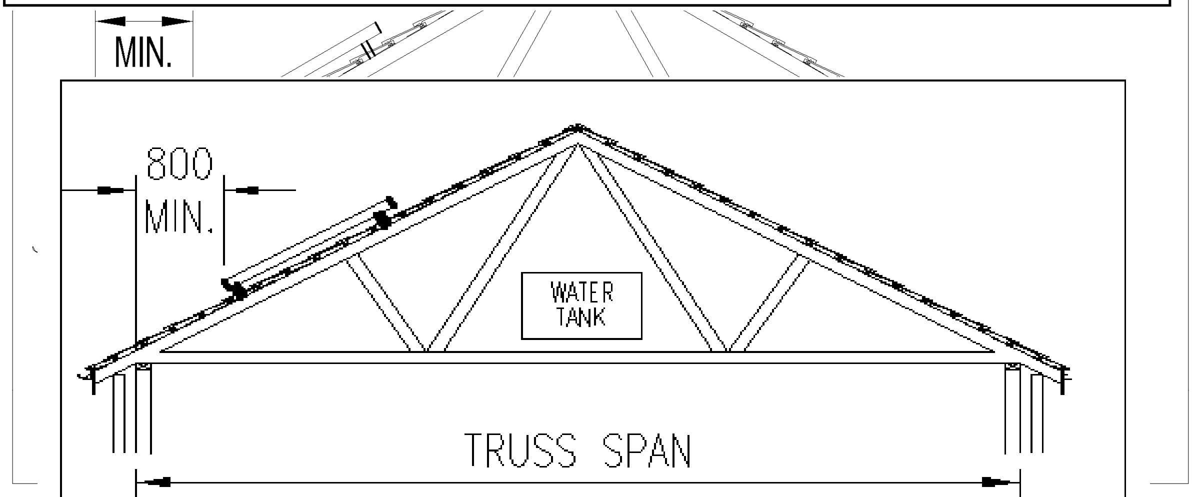


Fig 2. TYPICAL SECTION SHOWING TYPICAL PANEL LOCATIONS

1. CONCRETE TILE SLATES
2. SLATING BATTENS
3. UNDERLAY
4. TRUSS/RAFTER AT 600 CENTRES
5. SARKING BOARD

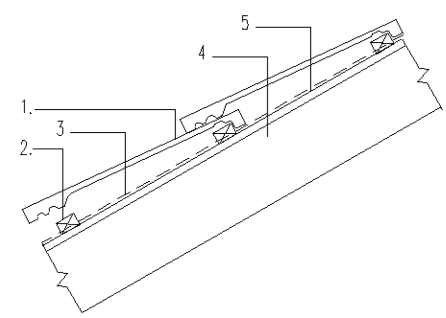


Fig. 3 TYPICAL ROOF MAKE UP WITH SARKING BOARD

In order to undertake the detailed assessment of the impact of installing photovoltaic panels and solar collectors onto existing pitched roofs it is necessary to first model the trusses based on typical design loading parameters including truss span, roof pitch, roof dead and imposed loads and a typical wind load. For the purpose of this analysis a basic wind speed of 24m/s has been adopted. The design is then reanalysed with the base outputs such as member size, joint size and details "frozen" into the design and the additional loads then applied.

Top chord Dead	0.785 kN/m²	(slope)
Man Load (top chord)	0.900 kN	(vertical)
Snow load	0.750 kN/m²	(plan)
Bottom chord Dead	0.250 kN/m²	(slope)
Bottom chord Imposed	0.250 kN/m²	(slope)
Man load (bottom)	0.900 kN	(vertical)

300 litre water tank supported by 3 trusses = 0.98kN/m²
(midspan of the bottom chord)

Basic wind speed	24m/s
Distance to sea	25km
Altitude	60m

The wind load criteria have been considered as typical values for assessment purposes only.

If any of the foregoing; truss geometry, dead or imposed loads or basic wind speed etc. were to be revised then the base 'frozen' data may be changed which could affect the assessment.

Although the base design would be altered by changes to the base input data it is not considered that this would greatly affect the assessment as the truss would be initially be designed to meet this data and the increase loading applied from the array would have a similar impact to the typical design conditions considered.

On completion of the individual truss analysis the design member sizes and connector sizes provided from this initial assessment were again frozen and the additional loading from the collector or panel added to the standard load. The analysis was then recalculated to establish the impact of this additional loading on the truss members and joints.

4.2.3.2 Solar thermal hot water heating collectors

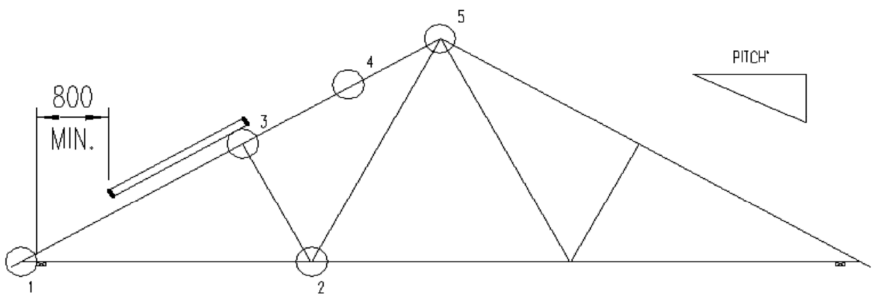
For solar collector types A to F an assessment has been made by considering the increased load applied to the standard truss design and the results are presented in Table 7.

Table 7 - Truss Analysis Results

Span (mm)	Pitch	Equipment Type	Member			Joint				
			Rafter	Ceiling Tie	Web	1	2	3	4	5
8000	30	Photovoltaic	●	●	●	●	○	○	●	●
		Solar Collector	●	●	●	●	○	○	●	●
	35	Photovoltaic	●	●	●	●	○	●	●	●
		Solar Collector	●	●	●	●	○	●	●	●
	40	Photovoltaic	●	●	●	○	○	●	●	●
		Solar Collector	●	●	●	○	○	●	●	●
9000	30	Photovoltaic	●	●	●	●	○	●	●	●
		Solar Collector	●	●	●	●	○	●	●	●
	35	Photovoltaic	●	●	●	●	○	●	●	●
		Solar Collector	●	●	●	●	○	●	●	●
	40	Photovoltaic	●	●	●	●	○	●	●	●
		Solar Collector	●	●	●	●	○	●	●	●
9000	30	Photovoltaic	●	●	●	●	○	●	●	○
		Solar Collector	●	●	●	●	○	●	●	○
	35	Photovoltaic	●	●	●	●	○	●	●	●
		Solar Collector	●	●	●	●	○	●	●	●
	40	Photovoltaic	●	●	●	●	○	●	●	●
		Solar Collector	●	●	●	●	○	●	●	●

● - Denotes member/joint pass

○ - Denotes pass within acceptable tolerances. Joint overstress less than 3%



It is clear that whilst the individual members (rafters, ceiling ties and webs) are within their stress capacities there are a number of occasions where the member joints have exceeded their normal design stress by up to 3%. In all cases the connector plate fixing the internal web member to the ceiling tie was shown to become marginally overstressed. It is understood from tests conducted by TRADA that the plate connectors have a factor of safety of 2.2. In addition the design analysis software (by MiTech Industries) allows for the connector design to incorporate a 5 mm misalignment tolerance which then discards any fixings within 5 mm of the timber edge. This can reduce the actual capacity of the connector plate considered in the design.

Taking the above points into consideration and the degree of joint overstress, it is considered that these are within acceptable limits.

It should be noted however, that whilst theoretical failures have been noted in the plate connectors that these have been based on the initial design utilising the smallest plate connector available for that design condition. This may not necessarily be the connectors utilised in the actual truss installation as not all truss manufacturers supply the standard plate sizes. It should also be noted that whilst there is a small overstressing of the truss components, typically the trusses will be designed for a standard rafter dead load of 0.785 kN/m^2 [10]. Typically concrete interlocking roof tiles tend to be in the range 0.54 kN/m^2 to 0.65 kN/m^2 and there is therefore a degree of additional capacity built into the design of the trusses.

4.2.3.3 Photovoltaic Panels

The results of the outcome of the truss assessments undertaken, based on the loading parameters described in section 4.2.3.1, are tabulated in table 7.

It is clear that whilst the individual members (rafters, ceiling ties and webs) are within their stress capacities there are a number of occasions where the member joints have exceeded their normal design stress by up to 3%. In all cases the connector plate fixing the internal web member to the ceiling tie was shown to become marginally overstressed. It is understood from tests conducted by TRADA the plate connectors have a factor of safety of 2.2. In addition the design analysis software (by MiTech Industries) allows for the connector design to incorporate a 5 mm misalignment tolerance which then discards any fixings within 5 mm of the timber edge which can reduce the actual capacity of the connector plate considered in the design.

As a result of the above and the degree of joint overstress it is considered that these are within acceptable limits.

It should further be noted however, that whilst theoretical failures have been noted in the plate connectors that these have been based on the initial design utilising the smallest plate connector available for that design condition. This may not necessarily be the connectors utilised in the actual truss design as not all truss manufacturers supply the standard plate sizes. It should also be noted that whilst there is a small overstressing of the truss components, typically the trusses will be designed for a standard rafter dead load of 0.785 kN/m^2 [10]. Typically concrete interlocking roof tiles tend to be in the range 0.54 kN/m^2 to 0.65 kN/m^2 and there is therefore a degree of additional capacity built into the design of the trusses.

4.2.3.4 Photovoltaic Tiles

For the tile replacement panels types I and J, the maximum additional distributed load is calculated as 0.19 kN/m^2. This compares with the standard load for a typical concrete roof tile of 0.54 kN/m^2 and 0.65 kN/m^2 and therefore represents a reduction in the rafter loading when replacing the concrete tile by the photovoltaic tile. Such a reduction if applied over one side of a truss (solar panels are normally only positioned on one side of a pitched roof) area may present a problem for the roof assessment in the wind uplift design condition. However it is unlikely that the overall reduced dead load arising from the extent of a single row of photovoltaic tile installation on a typical roof would negatively impact on the design of the truss members and joints. Consideration may have to be given to increasing the provision of truss holding down mechanisms.

Whilst the effects of snow on photovoltaic panels and solar collectors should not result in an increase in the overall truss loading consideration has been given to the change in load pattern onto the trusses where the load will now be applied as point loads through the fixings onto the roof truss. Based on the parameters outlined in figure 2 there should be no adverse effects on the individual truss members or to the truss frame itself.

4.2.3.5 Summary

Comparing the analyses against the original design indicates the following:

- Where photovoltaic panels, types G and H are to be fixed over the existing fabric then there will be an increase in the loading applied to the truss members. The degree of additional loading against the original loadings indicate that the increased stresses on the individual timber members (rafters, ceiling tie, webs) are within acceptable limits for the truss configurations considered. There are increases in the connection loadings which may be in excess of the connector plate capacities. However these are considered to be within acceptable limits and are deemed satisfactory.

- The loadings of the replacement photovoltaic tiles, types I and J, are less than the concrete tiles that they replace and as such they can be considered as acceptable without any additional strengthening. It is envisaged that the scale of replacement tiles on the domestic properties is likely to be of limited extent. However there may be some minor problems with the wind uplift condition and consideration should be given to the truss holding down arrangements local to the trusses affected and installation of additional restraint as considered appropriate.

- Similar to photovoltaic panels, types G and H, solar thermal hot water heating collectors, types A to F, are mounted over the existing fabric and fixed through the roof finishes directly to the timber roof trusses. There will be an increase in the loading applied to the truss members. The degree of additional loading indicates that the increased stresses on the individual timber members (rafters, ceiling tie, webs) are within acceptable limits for the truss configurations considered. There are increases in the connection loadings which may be in excess of the connector plate capacities. However these are considered to be within acceptable tolerances and are deemed satisfactory.

4.2.3.6 Roof Fixings

Photovoltaics are described as in-roof construction and on-roof construction, where the panels replace the existing roof tiles and where panels are mounted above the existing tiles on a sub-frame respectively.

Typically in-roof panels are supplied with an integrated surround which is fixed directly to the roof structure whereas the on-roof panels are fitted to a steel sub-frame which in turn is fixed through the roof tiles onto the roof structure (see figure 1).

Solar hot water collectors are fixed to the roof structure on a steel sub-frame similar to the on-roof photovoltaic panels (see figure 1).

Photovoltaic panels and solar collectors should be placed on the roof on standard trusses, two tiles length from any gable ladders and should be placed on the slope with at least two tiles above the panel fixings to the ridge. To accommodate fixings to the structure and to allow for the internal cabling, a horizontal dimension of approximately 800mm should be provided to the bottom of the panel measured from the truss support point (refer figure 2).

Consideration has been given to the effects of wind on the equipment and trusses particularly where the panels are mounted above the truss finishes. Guidance is given in BRE Digest 489, *Wind loads on roof based photovoltaic systems*[11], which considers a number of conditions including altitude, topography and wind zone to simplify the wind uplift loads. The wind load has been assessed for zone iii (Scotland) only as zones i and ii are outwith the Scottish area and zone iv requires special consideration and assessment, see table 8.

Table 8 - Simplified Wind Uplift

Altitude (m)	Topography	Zone*	Dynamic Wind Pressure, qs	Wind Load (Uplift) (kN/m2)
A < 100	Not Significant	iii	1.386	-1.8
	Significant	iii	2.442	-3.18
100 < A < 200	Not Significant	iii	1.65	-2.15
	Significant	iii	2.788	-3.62
200 < A < 300	Not Significant	iii	1.936	-2.52
	Significant	iii	3.157	-4.1

The above figures are based on a module placed above the roof tiles at less than 300mm. Where the height of the module above the roof finishes exceeds 300mm the wind uplift figures can be reduced by approx 46%.
Zones i and ii have not been considered for Scotland.
* Where zone iv is to be considered then a full assessment of the wind loads will be necessary.

Using the loadings derived in table 8 it is possible to establish the minimum number of fixings of various sizes required per m^2 based on the wind uplift loads. The results are given in table 9.

Table 9 - Screw Fixings

Screw Size (mm)	Withdrawl Load (kN)	Min. No. Fixings (per m2)	Shear/Lateral Load(kN)	Min. No. Fixings (Per m2)
3.00	0.378*	11	0.320**	13
3.50	0.427*	10	0.440**	10
4.00	0.473*	9	0.560**	8
4.50	0.522*	8	0.710**	6
5.00	0.700*	6	0.880**	5

* Minimum pointside penetration into timber rafter 35mm.
** Max pointside penetration into side of timber rafter 30mm.

It is assumed that the panels will be fitted top and bottom and will be connected either directly to the side of the timber trusses or to the top face of dwangs/noggins fitted between the rafter members. There will be an equivalent number of fixings through the rafter and into the end of the dwang/noggin (refer figures 4 and 5 for details of fixings).

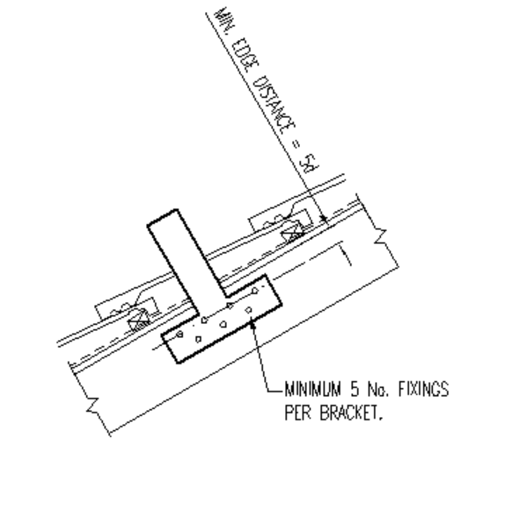


Fig 4 TYPICAL SIDE FIXING OF SUPPORT BRACKET

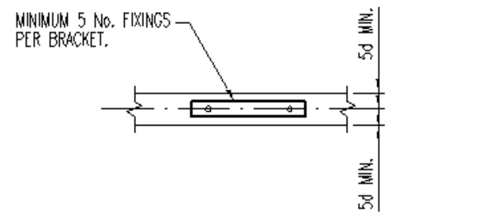


Fig. 5 TYPICAL TOP FIXING OF SUPPORT BRACKET

4.2.4 No-fines construction

No-fines concrete houses constructed in the 1960's and 1970's comprise solid concrete external walls.

Where panels are to be mounted vertically and directly onto the face of the gable wall they will be fitted to support rails which in turn will then be fixed to the wall.

As a minimum the panels would be fitted to the wall with a support rail at the top and bottom of the panel which in turn should be fixed directly onto the wall, see figure 6.

For load sharing purposes good practice dictates that an array should be fixed using a minimum of five fixings.

Panels should be located beyond the reach of door and window openings.

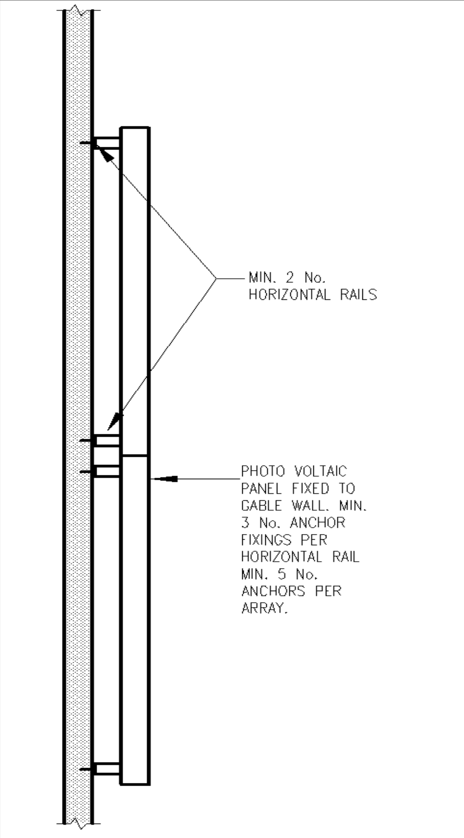


Fig 6.

Where panels are to be supported at an angle they will be mounted on a sub-frame (similar to those supplied with roof mounted ballasted panels) which should be fixed to the wall via horizontal support rails with a minimum of one rail top and one rail bottom, see figure 7.

Again for load sharing purposes good practice dictates that an array should be fixed using a minimum of five fixings.

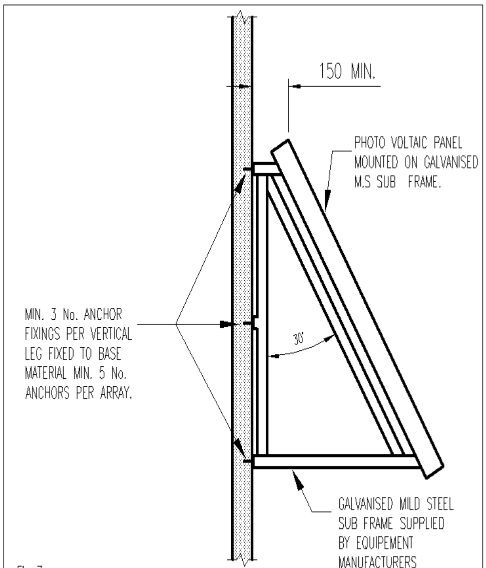


Fig 7.

Assessment has been made of the above noted photovoltaic panels and solar collectors utilising the simplified wind loads derived in table 8, applicable in Scotland[11]. Considering the heaviest equipment as being the type C solar collector then the maximum shear load to be resisted would be 0.76 kN for a single panel. However for wind analysis then the most onerous condition would be that of a photovoltaic panel which has a solid surface as opposed to a solar collector which is a series of tubes with voids between them. In this case, utilising the loads provided in table 8, fixings would be required to resist a maximum design load of 4.1 kN/m² applied to the face of the panel.

As the wind loads are greater than the panel dead load and for solid concrete walls a ratio of four 10mm diameter fixings per square metre should prove adequate for the majority of conditions. (minimum 5 no. fixings per array)

Whilst this form of construction is generally considered to be robust and capable of accommodating adaptations, it is anticipated that any alteration or modification to the structure including the mounting of heavy photovoltaic panel or solar collectors will require individual assessment.

4.2.5 Cavity wall construction (from 1970s to present)

Typically there are two types of cavity wall constructions which have been constructed since the 1970’s as follows;

- Cavity wall construction traditionally comprises brickwork inner and outer leaves with a cavity width of approximately 50mm. Wall ties were normally positioned at approximately 900mm horizontal and 450mm vertical centres. Wall ties were normally wire ties. The density of the inner and outer leaves, their interconnection to internal cross-walls together with the cavity width and provision of the cavity wall ties all contribute to the load capacity of the wall.

- Cavity wall construction with a blockwork inner leaf and an outer leaf of either rendered blockwork or brickwork. Cavity widths vary with recent designs using cavities of up to 120mm to accommodate insulation. Cavity wall ties vary and may be galvanised or stainless wire or flat pate ties positioned at 900mm horizontal and 450mm vertical centres. The density of the inner leaf in this construction can vary from lightweight block with a density of approximately 600kg/m^3 to a medium dense block with a density of up to 1400kg/m^3 (in some cases dense block may be utilised). The density of the inner and outer leaves, their interconnection to internal cross-walls together with the cavity width and provision of the cavity wall ties will all contribute to the load capacity of the wall.

Where panels are to be mounted either vertically and directly onto the face of the wall or at an angle to the wall they will be fitted first to rails which in turn are fixed to the wall. As a minimum the panels would be fitted to the wall with a support rail at the top and bottom of the panel which in turn should be fixed directly onto the wall, see figures 6 and 7. Panels should be located beyond the reach of door and window openings.

A structural assessment has been made of the renewable energy panels utilising the simplified wind loads derived in table 8, applicable in Scotland[11]. Considering the heaviest equipment as being the type C solar collector then the maximum shear load to be resisted would be 0.76 kN for a single panel. However for wind analysis then the most onerous condition would be that of a photovoltaic panel which has a solid surface as opposed to a solar collector which is a series of tubes with voids between. In this case, utilising the loads provided in table 8, fixings would be required to resist a maximum design load of 4.1 kN/m^2 applied to the face of the panel.

The wind loads are greater than the panel dead load and this should be the principal governing load.

Due to the wide variety of base materials to which the panels can be fixed and the support conditions of the walls themselves it is not possible to determine a single fixing type to suit all conditions. However, for clay bricks then a ratio of four 10mm diameter fixings per square metre should prove adequate for the majority of conditions. (minimum 5 no. fixings per array)

To ensure the integrity of the wall as a whole and to ensure that the additional loads are adequately distributed to both leaves it may be necessary to install remedial wall ties through the outer leaf directly into the inner leaf to ensure adequate connectivity between the outer and inner wall elements.

Installation of panels onto masonry cavity walls should be assessed on an individual basis. A structural inspection and assessment together with a risk assessment should be undertaken for each situation. The assessment would consider the size and strength of the base material, the condition of the components and wall ties. It is recommended that pull out tests be undertaken to establish the suitability and capacity of the mechanical fixings to the wall.

4.2.6 Timber framed construction (1980s to present) – timber framed and brick clad with lightweight manufactured timber truss roof

Timber frame construction comprises a timber frame inner leaf typically comprising timber studs at 600mm centres spanning between floors with a plywood sheathing board to the cavity face, with a brick or rendered blockwork outer leaf. Typically studs will range from 89 mm deep to 150 mm deep depending on the site conditions and thermal performance requirements.

In timber frame construction the timber elements are normally designed to accommodate most of the vertical and horizontal loads with the outer leaf having limited load bearing capacity.

Where panels are to be mounted either vertically and directly onto the face of the wall or at an angle to the wall they will be fitted first to rails which in turn are fixed to the wall. As a minimum the panels would be fitted to the wall with a support rail at the top and bottom of the panel which in turn should be fixed directly onto the wall, see figures 6 and 7. Panels should be located beyond the reach of door and window openings.

A structural evaluation has been carried out of the renewable energy panels using the simplified wind loads derived in table 8, applicable in Scotland[11]. Considering the heaviest equipment as being the type C solar collector then the maximum shear load to be resisted would be 0.76 kN. However for wind analysis then the most onerous condition would be that of a photovoltaic panel which has a solid surface as opposed to a solar collector which is a series of tubes with voids. In this case, utilising the loads provided in table 8, fixings would be required to resist a maximum force of 4.1 kN/m² applied to the face of the panel.

Due to the wide variety of base materials to which the panels can be fixed and the support conditions of the walls themselves it is not possible to determine a single fixing type to suit all conditions. However, for clay bricks or concrete blocks then a ratio of three 10mm diameter fixings per square metre should prove adequate for the majority of conditions. As the timber inner leaf is the main load-bearing structural element in this form of construction it may be necessary to install remedial wall ties through the outer leaf directly into the timber studs to connect the outer and inner wall elements to ensure the loads are transmitted to the inner load-bearing timber frame.

4.2.7 Steel portal framed building with profiled metal cladding

This form of construction traditionally comprises hot rolled steel columns and rafter sections at centres of between 4.5 m and 7.5 m. External profiled metal cladding is supported on either lightweight cold formed metal rails or lightweight mild steel angle rails supported on sheeting rails and purlins spanning horizontally between the main portal frame columns.

Where panels are to be mounted either vertically and directly onto the face of the cladding frame or at an angle to the cladding frame they will be fitted first to rails which in turn are fixed to the frame. As a minimum the panels would be fitted to the cladding frame with a support rail at the top and bottom of the panel which in turn should be fixed directly onto the wall, see appendix 4, figures 5 and 6. Panels should be located beyond the reach of door and window openings.

A structural assessment has been made of the renewable energy panels utilising the simplified wind loads derived in table 4.3, applicable in Scotland[11]. It may be possible in some cases for panels to be fitted directly onto the secondary sheeting rails however in most cases it is assumed that the scale of the installation may be such that a secondary sub-frame fixing will be required to be fixed directly between adjacent columns and rafters. Additional strengthening may also be required.

It is considered that photovoltaic panels and solar collectors may be adequately supported on steel framed buildings. However the form of construction and condition of the cladding frame and fixings should be examined and assessed as to their capacity to support the specific equipment.

4.2.8 Steel framed building with masonry cavity walls

These buildings normally comprise hot rolled steel columns supporting lightweight steel trusses. Columns are normally located at between 4.5 m and 6.0 m with the external masonry cavity walls tied to the main columns.

Where panels are to be mounted either vertically and directly onto the face of the wall or at an angle to the wall they will be fitted first to rails which in turn are fixed to the wall. As a minimum the panels would be fitted to the wall with a support rail at the top and bottom of the panel which in turn should be fixed directly onto the wall, see figures 6 and 7. Panels should be located beyond the reach of door and window openings.

Where panels are to be mounted onto the roof they will be fitted to rails which in turn will then be fixed to the frame. As a minimum the panels would be fitted to the cladding rails/purlins with a support rail at the top and bottom of the panel however in most cases it is assumed that the scale of the installation may be such that a secondary sub-frame fixing will be required to be fixed directly between adjacent roof frames rafters. Additional strengthening may also be required.

A structural evaluation of the renewable energy panels has been completed using the simplified wind loads derived in table 8[11]. It may be possible in some cases for panels to be fitted directly onto the secondary sheeting rails. However in most cases it is assumed that the scale of the installation may be such that a secondary sub-frame fixing will be required to be fixed directly between adjacent columns. Additional strengthening may also be required.

It is considered that photovoltaic panels and solar collectors may be adequately supported on steel framed buildings. However the form of construction and condition of the cladding frame and fixings should be examined and assessed as to their capacity and suitability to support the specific equipment.

5 Risk assessment and risk management

A simple risk based approach has been developed to consider the safe installation of photovoltaic and solar collector technology. The approach includes both risk assessment and risk management actions. The general approach is given in this section and examples of specific hazards and risks are also given.

The risk assessment methodology developed uses a hazard-event-consequence approach as opposed to alternatives such as source-pathway-receptor.

In the case of photovoltaics and solar collectors the possible hazards include the following:

- Quality of workmanship or condition of wall or roof, such as roof trusses or wall ties;
- Weight of solar renewable technologies;
- Poor quality and/or durability of the support frame and fixings;

Relevant events include the following:

- Failure of fixing(s);
- Extreme weather events, such as strong winds and heavy snow loadings;
- Solar renewable technologies being pulled off a wall or roof;
- Collapse of a wall or roof.

Possible consequences could include the following:

- Damage to adjacent buildings or vehicles due to impact by falling or flying equipment or collapsed wall or roof;
- Serious injury or fatalities to humans.

5.1 Risk assessment

Risk assessment is a process for identifying, registering and quantifying the risks associated with a specific process. Risk assessment involves identification and assessment of hazards followed by a risk analysis. The terms commonly used in risk assessment are as follows:

- Harm – an adverse effect on a person, such as an illness or injury, such as being crushed by a falling solar collector or a collapsing gable wall;
- Hazard – a potential cause of harm to a person, such as a solar collector insecurely attached to a pitched roof;

- Hazardous situation – exposure of a person to a hazard, such as their proximity to a solar collector poorly attached to a gable wall above.

The risk associated with a hazard is the product of the severity of harm caused and the likelihood of harm occurring, i.e. as follows:

Risk = Severity x Likelihood

A value needs to be assigned to each of risk, severity and likelihood for any installation. Severity of harm caused can be categorised and given a value, as follows:

- Low - minor injury or illness;
- Medium – short-term injury or disability;
- High – fatality, major injury or serious long-term disability.

Likelihood of harm occurring can be categorised and given a value, as follows:

- Low – unlikely to occur;
- Medium – possible to occur;
- High – likely to occur.

As the risk is the product of severity and likelihood, both a low severity and a low likelihood implies that the risk is also correspondingly low. As the Risk value increases then the risk is correspondingly higher and there is a need for risk management actions to be undertaken.

5.2 Risk management

This stage follows on from risk assessment. It is a process for managing the identified risks down to an acceptable level. If the risk is higher than Very Low, then some risk management action is required. The following gives a guide as to the relevance of the Risk value to the actions required:

- Very low - no action typically required other than ensuring that the installation is carried out correctly.
- Low - actions would include assessing the structure and determining a specific fixing methodology.
- Medium - carry out strengthening work on the roof or wall.
- High - possibly avoid the installation on the particular roof or wall, or change the type of technology being used.

Risks can generally be managed in the following ways:

- Risk removal or elimination – the best option, where it is possible;

- Risk avoidance – the next best option, avoid the risk by following another course of action such as undertaking a different process;

- Risk reduction – if the risk cannot be removed or avoided, reduce it by appropriate means such as changing the method of working;

- Risk minimisation – a minimised risk may be acceptable, but this is the least desirable option.

5.3 Risk process

Assessing and managing the risks of installing low carbon panels to pitched roofs or walls of different construction includes a number of stages. Information should be gathered and recorded appropriately to defend decision making throughout the process.

5.3.1 Risk assessment process

The risk assessment process will involve the following stages:

Hazard identification and assessment steps

1. Assess the condition of the roof or wall by visual inspection or through testing. Determine the location and design of structural members for installation and fixing of the equipment.

2. Determine the weight and area of solar collector or photovoltaic panel and compare with the weight of roof tiles, if removing them.

3. Assess the buildings location, proximity to roads, other property and other information that would affect a failure.

4. Determine which structural components the equipment will be supported by and fixed to.

5. Determine the fixings requirements, including number per square metre, type and installation instructions.

6. Make preliminary assessment of potential results should a failure occur.

7. For roofs and walls, other than for a standard trussed roof (post 1971), determine the dead load, wind load and snow load for solar collector and whether or not the roof can withstand them.

Risk analysis

8. Determine the Risk value by estimating the severity and likelihood of something going wrong.

The use of tiles rather than panels will not normally give rise to structural performance issues. However, the roof should still be assessed for its condition and repair work carried out as necessary.

5.3.2 Risk management process

The risk assessment process should use the Risk value to indicate the actions to be undertaken. This is specific to particular installations, but a range of risk management actions are given in Table 5.1 below for roofs and walls.

Hazard or Risk for Roofs	**Risk assessment action**	**Risk management action**
Deterioration of roof trusses	Assess condition of existing roof	Strengthen existing roof or incorporate solar collector into design of new roof
Alterations to the roof construction, such as re-roofing with a heavier roof covering, altering roof trusses to create a room in roof or incorporate windows	Assess condition of roof trusses	Strengthen or replace roof trusses
Deterioration of frame or fixings	Assess condition of frame and fixings	Use required number of fixings of stainless or galvanised steel
Increased wind loading	Assess condition of roof, frame, fixings and solar collector	Use fit for purpose solar collector, frame and fixings
Increased snow loading	Assess condition of roof, frame, fixings and solar collector	Use fit for purpose solar collector, frame and fixings
Hazard or Risk for Walls	**Risk assessment action**	**Risk management action**
Deterioration of existing wall such as wall ties.	Assess condition of existing wall including wall ties.	Repair or strengthen existing wall
Alteration to original wall construction	Assess condition of wall	Strengthen wall if necessary
Deterioration of frame or fixings	Assess condition of frame and fixings	Use required number of fixings of stainless or galvanised steel
Increased wind loading	Assess condition of wall, frame, fixings and solar collector	Use fit for purpose solar collector, frame and fixings
Increased snow loading	Assess condition of wall, frame, fixings and solar collector	Use fit for purpose solar collector, frame and fixings

Table 5.1: Summary of hazards, assessment and management for installations on roofs and walls

5.4 Risk reporting

A simple risk assessment report should be completed for each installation of the equipment. In order to ensure that the report is not unduly onerous and a significant cost the report should be limited to one page and be in a standard format.

The report should cover the following:

- Description of hazards and their significance
- Risk value
- Risk management action

The report should describe who undertook the risk assessment and whether or not they were a chartered engineer or accredited installer of renewable energy panels.

The use of a chartered engineer who is qualified to undertake the assessment of risk and structural assessment is an important component of a proper risk assessment. The chartered engineer should be involved where the design, construction and condition of the roof or wall cannot be readily determined or is non-standard. Alternatively an Approved Certifier of Design or an MCS Accredited Installer could complete a risk assessment.

6 Case studies

Case studies have been prepared using data obtained in the course of the research. The case studies have focussed upon roofs as few actual cases of photovoltaics and solar thermal hot water collectors being installed on walls have been found. The case studies set out the construction type, structural performance assessment, the low carbon technology used and the risk assessment and risk management aspects.

The four case studies are as follows:

- Photovoltaic array attached to a pitched slate roof;
- Evacuated tubes solar thermal hot water collector attached to ‘A’ frame;
- Flat plate solar thermal hot water collector attached to a pitched tiled roof;
- Flat plate solar thermal hot water collector attached to a partition wall in an inner sun space.

Case study 1: Photovoltaic array attached to pitched, slated roof

Construction type	**Structural performance assessment**
The property was a detached house with solid stone walls and a pitched, slated roof in a rural location.	The photovoltaic panel weighed 21.5kg/m^2. The loading capacity of the roof was calculated to be 180kg/m^2. The photovoltaic array and its fixings was designed to withstand wind loadings (an uplift force of 6464N and a downward acting force of 4972N).
Low carbon technology	**Risk assessment and Risk management**
The photovoltaic array was composed of 18 photovoltaic panels. The array was mounted on a stainless steel frame 150mm above the pitched, slated roof.	The roof was considered sufficiently strong to support the photovoltaic array and support frame.

Case study 2: Evacuated tubes solar thermal hot water collector attached to 'A' frame

Construction type	**Structural performance assessment**
The property was a steel framed office building in an urban location.	The solar thermal hot water collector weighed 75 kg and had a surface area of $3m^2$, so dead loading of $25kg/m^2$. The tilted metal frame was designed to support the solar collector.
Low carbon technology	**Risk assessment and Risk management**
The solar thermal hot water collector was composed of 30 evacuated tubes. These were mounted on an aluminium secondary tilted frame on a stainless steel primary tilted frame.	The frame was considered sufficiently strong to support the solar thermal hot water collector.

Case study 3: Flat plate solar thermal hot water collector attached to pitched tiled roof

Construction type	**Structural performance assessment**
The property was a detached house with brick – brick cavity walls and a pitched, tiled roof in a semi-rural location.	The solar thermal hot water collector weighed 40kg and had a gross area of 2.75m^2, so dead loading of 14.5kg/m^2.
Low carbon technology	**Risk assessment and risk management**
The solar thermal hot water collector was composed of a flat plate. It was mounted on horizontal bars fixed to the roof trusses, with lead flashings used to keep the roof weathertight.	The roof was considered sufficiently strong to support the solar thermal hot water collector.

Case study 4: Flat plate solar thermal hot water collector attached to a partition wall in an internal sun space

Construction type	**Structural performance assessment**
The property was a one and half storey detached house. The construction was timber framed, single-skin, partition wall, insulated pitched roof and insulated solid ground floor.	The solar panel has an area of $3.12m^2$ and an approximate weight of 30kg. The panel was on an aluminium support frame and attached to the partition wall using stainless steel coach bolts that penetrated 95mm into the wall. Being internal, the solar panel was not subjected to wind loads or snow loads, just its dead load.
Low carbon technology	**Risk assessment and Risk management**
There was a sun space in the upper floor and roof space. There was a flat plate solar thermal hot water collector attached to an internal partition wall.	The wall was considered sufficiently strong to support the flat plate solar thermal hot water collector.

7 Discussion

The research has focussed upon the structural performance of photovoltaic panels and solar thermal hot water collectors when applied to different types of construction, either to a wall or roof. The different types of construction are all commonly found in Scotland. However, it is not always possible to define a typical or standard form of the construction and therefore consideration of one form of the construction may be misleading. There are standard roof truss details and wall construction that are typical and therefore a reasonable estimate can be given of the additional loads and structural safety. Such results could be applied across the majority of roof and wall designs.

Information and data has been gathered on the range and types of solar thermal hot water collectors and photovoltaic panels. Structural assessments have been undertaken of the loads imposed when solar thermal hot water collectors and photovoltaics are attached to roofs and walls. The likely dead or stationary load, wind load and snow load have been considered. In general, roofs and walls can withstand these loads and so support solar thermal hot water collector panels and tiles and photovoltaic panels and tiles.

It is worth noting that experience of the installation of equipment in Scotland has been obtained through the Micro-generation Certification Scheme (MCS). This has included where solar thermal hot water collector panels and photovoltaic panels were installed on pitched slated or tiled roofs. The panels were generally installed on support frames above the roof which were fixed to and supported by the load bearing roof trusses. The condition of existing pitched roofs needs to be determined in many cases by a visual inspection of the roof trusses in the loft space. The Micro-generation Certification Scheme is administered by 10 certification bodies.

Few real examples have been found in Scotland where solar thermal hot water collectors and photovoltaic panels were attached to walls. When considering attaching a collector to an existing wall, the condition of the wall, particularly of wall ties, needs to be determined using techniques such as pull-off tests by a competent person such a chartered engineer.

7.1 Construction types

The range of construction types has been considered in this project, including some specific wall and roof types.

7.1.1 Roofs

Roof truss design is sufficiently standard that the results of the structural assessment can be considered as applicable to a wide range of roofs. A structural assessment of loading a standard timber roof truss with an example solar renewable technology has been undertaken. Other roof types are not of a standard design and therefore the applicability of results to a wide range of roofs is not possible. In these cases a basic assessment of the structural performance is made in the report.

The mansard roof construction and room in roof constructions cannot be assessed as a typical frame type as all such frames are different in their construction as they are supported on an external cavity wall. They are additionally supported at the internal wall locations, however by considering the individual components it should be possible to establish criteria to allow an assessment to be undertaken. The basic assessment of typical loadings and frame arrangements indicates that these roofs should be capable of supporting the photovoltaic panels without significant additional strengthening.

For standard roof trusses where photovoltaic panels or solar water collectors are used then there will be an increase in the loading applied to the truss members. The degree of additional loading indicates that the increased stresses on the individual timber members (rafters, ceiling tie and webs) are within acceptable limits for the truss configurations considered. There will be increases in the member connection loadings which may be in excess of the connector plate capacities. Although there may be cases of theoretical failures in the metal plate connectors, for the trusses in the case studies, these have been assessed to be within acceptable limits and are deemed to be satisfactory.

The loadings of the replacement photovoltaic or solar collector tiles are less than the concrete tiles that they replace and as such they can be considered as acceptable without any additional strengthening. The scale of replacement tiles on the domestic properties is likely to be of limited extent. However there may be some minor problems with the wind uplift condition and the installation of additional restraint may be required.

7.1.2 Walls

Assessment has been made of walls with photovoltaic panels and solar collectors installed on external walls utilising the zone iii loadings from the simplified wind loads derived in table 4.3, applicable in Scotland[11]. Where a location of the structure to which the equipment is to be fixed is outwith the parameters of this guidance document then a full wind assessment should be undertaken.

For solid concrete no-fines walls a ratio of four 10mm diameter fixings per square metre should prove adequate for the majority of conditions. However, any alterations to this form of construction are normally required by Building Standards Departments to be certified by a qualified structural engineer.

For cavity walls there is a wide variety of base materials to which the panels can be fixed and the support conditions of the walls themselves. It is not therefore possible to determine a single fixing type to suit all conditions. To ensure the integrity of the wall it may be necessary to install remedial wall ties through the outer leaf directly into the inner leaf to ensure adequate connectivity between the outer and inner leaves. For timber frame, it may be necessary to install remedial wall ties through the outer leaf directly into the timber studs to ensure adequate connectivity between the outer and inner leaves.

Photovoltaic panels and solar collectors may be adequately supported on steel framed buildings. However the form of construction and condition of the wall materials and fixings should be examined to assess their capacity and suitability to support the specific equipment. They may also be adequately supported on steel framed buildings with masonry cavity walls. In steel framed buildings with masonry walls to ensure the integrity of the wall it may be necessary to install remedial wall ties through the outer leaf directly into the inner leaf to ensure adequate connectivity between the wall elements. It may be possible for panels to be fitted directly onto the secondary sheeting rails within the roof. However in most cases it is assumed that the scale of the installation may be such that a secondary sub-frame fixing will be required to be fixed directly between adjacent columns.

7.1.3 Fixings

Using the loadings derived in table 4.3 it is possible to establish the number of fixings of various sizes required per m^2 based on the wind uplift loads. Solar thermal hot water collectors and photovoltaics need to be fixed with durable fixings and supported by structural members of roofs and walls. It is assumed that the panels will be fitted top and bottom and will be connected either directly to the side of the timber trusses or to the top face of dwangs/noggins fitted between the rafter members. There will be an equivalent number of fixings through the rafter and into the end of the dwang/noggin.

7.1.4 Risk Assessment

A risk assessment and risk management methodology for the safe installation of solar thermal hot water collectors and photovoltaic panels to roofs and walls has been developed.

As detailed earlier in this section different types of construction are highly variable in the design and construction of the roof or the wall. It is possible for some of the larger span steel frames for example, to have a gap between structural frame sections that is greater than the size of the micro-renewable equipment. In such a case the installation may be placed either directly onto a structural member or end up placed between them.

It is necessary for these issues to be identified through the risk assessment. A chartered engineer should then be required to undertake the structural performance assessment and to issue guidance to the installer on location on the building and fixing requirements. For standard roof trusses the condition of the roof should be assessed. However, if the roof is in good condition then there is unlikely to be a need to engage a chartered engineer and the installer should use the manufacturer's recommendations on installation and fixings.

Competent installers should be used for all installations. Currently competent installers need to be certified under a Micro-generation Certification Scheme[2,8], administered by Gemserve and supported by the UK Department of Energy and Climate Change (DECC) as no other alternative schemes exist currently.

7.1.5 Micro-renewable technology

The research has considered the installation of photovoltaics and solar water collectors. The majority of these types of systems are installed as panels onto roofs in Scotland. There are few examples of these technologies as wall mounted systems, but there does remain the possibility that the wall of buildings could be used. Both roofs and walls use frames as a base to fix the technology to the building.

As a result of the need to reduce carbon emissions and to address energy efficiency there is likely to be greater use of photovoltaic and solar collector panels over the next few years. Installations will take place on new buildings where the design can take account of all relevant factors. However, for existing buildings it is necessary to know details of the construction before proceeding with the installation.

Manufacturers should make available relevant information on issues such weight, size and fixing requirements from which a chartered engineer or approved installer of photovoltaics or solar panels can determine the suitability of the construction to accommodate the loads from the equipment.

8 Conclusions

Research has been undertaken on the structural performance of photovoltaic and solar water collector equipment when installed to existing roofs and walls. A range of construction types have been included in the assessments and the following points are concluded:

Roofs

- Where a single row of photovoltaic panels or solar hot water collectors are fixed on a support frame over existing roof tiles or slates, then there will be an increase in the dead load applied to the roof truss. These loads have been calculated to be within acceptable limits of safety for standard truss rafter roofs, particularly those fabricated by specialist timber truss manufacturers utilising metal punch plate connector plates.

- For mansard and older roof types the loads may also be accommodated. However, as the variability of design is great then each installation should be assessed on an individual basis, which may require a chartered engineer.

- Where multiple rows of photovoltaic panels or solar hot water collectors are fixed on a support frame over an existing pitched roof structure, a detailed assessment should be undertaken to assess the effects on the truss members and connections, which may require a chartered engineer.

- Replacing concrete tiles in a roof with “in-plane” solar thermal hot water collector tiles or photovoltaic tiles will reduce the dead load on the rafters and consequently the roof will not require any additional strengthening. However, there may be some minor problems with wind uplift. Consequently truss holding down strengthening measures may be required.

- The effects of current levels of snow loading are accounted for routinely in the standard roof truss design for both panels and tiles.

- There may be some minor problems with wind uplift where solar thermal hot water tiles or photovoltaic tiles are fixed to individual roof trusses, so consequently truss holding down strengthening measures may be required.

Walls

- Solar thermal hot water heating panels and photovoltaic panels may be supported adequately on a range of wall constructions including no-fines concrete, cavity walls, timber frame and steel frame construction types. However, as there is a wide range of variability in the design of most of these wall types, each wall should be assessed by a chartered engineer to ensure the adequacy of the construction.

- The majority of photovoltaic and solar water collector equipment is installed on roofs rather than walls. The residual risk from wall installations can be managed by involving a chartered engineer.

Fixings

- Solar thermal hot water collectors and photovoltaic panels should be fixed with durable fixings and supported by the structural members of roofs and walls.

Risk Assessment

- A risk assessment and risk management methodology for the safe installation of solar collectors and photovoltaics to roofs and walls has been developed. The risk assessment could be undertaken by an Approved Certifier of Design or an MCS Accredited Installer but may require the involvement of a chartered engineer to assess the structural integrity of roofs or walls.

Building Standards

- The fixing of solar collectors and photovoltaic panels to roofs and walls may involve structural alterations or modifications which must comply with Building Standards.

9 Recommendations

The following recommendations are made:

Modern Roofs

- Where concrete tiles in a roof are to be replaced with a single row of “in-plane” photovoltaic tiles this will reduce the dead load on the rafters and so the roof will not require any additional strengthening. Consideration should be given to assure sufficient holding down straps are present.

- Where concrete tiles are to be replaced with a two or more rows of photovoltaic tiles a detailed assessment should be undertaken to assess the wind uplift criteria.

- Where multiple rows of solar hot water collectors or photovoltaic panels are fixed on a support frame over the existing pitched roof structure a detailed assessment should be undertaken by a chartered engineer to assess the effects on the truss members and connections.

Older Roofs

- Due to the variable nature and configuration of older roof trusses and frames a detailed assessment should be undertaken by a chartered engineer to assess the effects on the truss members and connections from the additional loadings imposed by the solar hot water collectors or photovoltaic panels.

Walls

- Adding solar hot water collectors or photovoltaic panels will induce additional loads into the wall from the self weight (dead load) of the equipment and frame together with additional imposed loads from wind and snow. A detailed assessment should be undertaken by a chartered engineer to assess the condition of the wall and its components and the effects on the wall from the additional loading.

Fixings

- Durable fixings should be provided to fix solar hot water collectors and photovoltaic panels to roofs and walls which should be specified by a chartered engineer or certified installer.

Risk Assessment

- Solar hot water collectors and photovoltaic panels are large heavy objects which are normally located on roofs or high on walls. Considerable damage can be inflicted were these to become detached and it is recommended therefore that each installation be assessed by a chartered engineer, an Approved Certifier of Design or a MCS Accredited Installer and that a risk assessment be carried out to ensure a suitable installation.

Technology

- Solar thermal hot water collector panels, tiles and slates should be installed on roofs and walls using the following guidance or equivalent standards where they exist:

    a. Microgeneration Installation Standard MIS 3001, Requirements for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar heating microgeneration systems, Issue 1.5, Department of Energy and Climate Change, London, UK, February 2009;

    b. EST CE131, Solar water heating systems – guidance for professionals – conventional models, Energy Savings Trust, London, UK, March 2006.

- Photovoltaic panels, tiles and slates should be installed on roofs and walls using the following guidance or equivalent standards where they exist:

    a. Microgeneration Installation Standard MIS 3002, Requirements for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar photovoltaic (PV) microgeneration systems, Issue 1.5, Department of Energy and Climate Change, London, UK, February 2009;

    b. Building Research Establishment, Digest 489, Wind loads on roof-based photovoltaic systems, BRE, Watford, UK, August 2004;

    c. Building Research Establishment, Digest 495, Mechanical installation of roof-mounted photovoltaic systems, BRE, Watford, UK, September 2005.

Further work

It is recommended that the following additional issues should be addressed:

1. Altered roofs and walls – bridling of rafters for incorporating Velux type windows
    - re-roofing with a heavier roof covering
    - loft conversions.
2. Climate change implications – potentially greater wind loads and greater snow loads.
3. Incorporating microwind turbines on to buildings.

10 References

1. British Standards Institution, BS EN 12975, Thermal solar systems and components – Solar collectors – Part 2 - Test methods, BSI, London, UK, 2006.

2. Department of Energy and Climate Change, Microgeneration Installation Standard, MIS 3001, Requirements for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar heating microgeneration systems, Issue 1.6, DECC, London, UK, October 2009.

3. British Standards Institution, BS EN 10088 - Stainless steels – Part 1 - List of stainless steels, BSI, London, UK, 2005.

4. British Standards Institution, BS EN ISO 14713, Protection against corrosion of iron and steel structures – zinc and aluminium coatings – guidelines, BSI, London, UK, 1999.

5. Energy Saving Trust, CE 131, Solar water heating systems – guidance for professionals, conventional indirect models, EST, London, UK, March 2006.

6. British Standards Institution, BS EN 61215, Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval, BSI, London, UK, 2005.

7. British Standards Institution, BS EN 61646, Thin film terrestrial photovoltaic (PV) modules – Design qualification and type approval, BSI, London, UK, 1997.

8. Department of Energy and Climate Change, Microgeneration Installation Standard, MIS 3002, Requirements for contractors undertaking the supply, design, installation, set to work, commissioning and handover of solar photovoltaic (PV) microgeneration systems, Issue 1.5, DECC, London, UK, February 2009.

9. Building Research Establishment, Digest 495, Mechanical installation of roof-mounted photovoltaic systems, BRE, Watford, UK, 2005.

10. British Standards Institution, BS 648, Schedule of weights of building materials, British Standards Institute, London, UK, 1964.

11. Building Research Establishment, Digest 489, Wind loads on roof based photovoltaic systems, BRE, Watford, UK, 2004.