



BSI Standards Publication

Solar energy systems for roofs - Requirements for structural connections to solar panels

National foreword

This Published Document is the UK implementation of CEN/TR 16999:2019.

The UK participation in its preparation was entrusted to Technical Committee B/542, Roofing and cladding products for discontinuous laying.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

© The British Standards Institution 2019
Published by BSI Standards Limited 2019

ISBN 978 0 580 89187 8

ICS 27.160

Compliance with a British Standard cannot confer immunity from legal obligations.

This Published Document was published under the authority of the Standards Policy and Strategy Committee on 31 March 2019.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

ICS 27.160

English Version

Solar energy systems for roofs - Requirements for structural connections to solar panels

Systèmes d'énergie solaire pour les toits : Exigences relatives aux raccordements des panneaux solaires à la charpente

Solare Energiesysteme für Dächer: Anforderungen an konstruktive Verbindungen zu Sonnenkollektoren

This Technical Report was approved by CEN on 26 November 2018. It has been drawn up by the Technical Committee CEN/TC 128.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Contents	Page
European foreword.....	7
Introduction	8
1 Scope.....	9
2 Normative references.....	9
3 Terms and definitions	10
4 Symbols.....	10
5 Configuration of solar panel installation.....	10
6 Design responsibility.....	10
7 Thermal solar collectors and PV solar panels	10
8 Principles of limit state structural design.....	11
8.1 General.....	11
8.2 Design situations	11
8.3 Ultimate limit state.....	11
8.4 Serviceability limit state.....	11
9 Determination of actions.....	11
9.1 Permanent actions (G)	11
9.2 Variable actions (Q).....	11
9.2.1 General.....	11
9.2.2 Imposed loads	12
9.2.3 Snow loads	12
9.2.4 Wind loads	12
9.2.5 Critical load combinations.....	13
9.2.6 Load combination factor ψ	13
9.2.7 Partial safety factors for actions.....	13
9.2.8 Consequence of structural failure.....	13
10 Structural resistance of connections.....	14
10.1 Configuration and type of connectors	14
10.2 Design by calculation	14
10.3 Design assisted by testing.....	14
11 Design for accidental action	15
12 Design for seismic action.....	15
Annex A (informative) Examples of connection design.....	17
A.1 Fixing hook for PV solar panels mounted above tiled roof.....	17
A.1.1 Description of the system.....	17
A.1.2 Climate zone.....	17
A.1.3 Loads.....	17
A.1.3.1 Dead loads.....	17

A.1.3.2 Imposed load	18
A.1.3.3 Wind and snow loads.....	18
A.1.3.4 Calculation of the wind load acting on the panels.....	18
A.1.3.5 Snow loads	19
A.1.3.6 Summary of loads acting on a single panel, in directions normal to the roof and down the roof	19
A.1.4 Factored load combinations for the ultimate limit state	20
A.1.5 Factored load combinations for the serviceability limit state.....	21
A.1.6 Structural resistance (by test).....	22
A.1.6.1 General.....	22
A.1.6.2 Characteristic Resistance	23
A.1.6.3 Safety factors and design resistance	24
A.1.6.3.1 General	24
A.1.6.3.2 Ultimate Limit State for characteristic resistance by test.....	24
A.1.6.3.3 Serviceability Limit State for resistance by test	24
A.1.6.3.4 Design structural resistance values:.....	24
A.1.7 Design verification – derivation of the number of hooks required	25
A.2 Thermal solar collector on flat roof stabilized with dead weight	27
A.2.1 Description of the system.....	27
A.2.2 Climate zone.....	27
A.2.3 Loads.....	27
A.2.3.1 Dead loads	27
A.2.3.2 Wind load at roof height Z	27
A.2.4 Ultimate load case for uplift and sliding.....	28
A.2.5 Serviceability limit state.....	28
A.2.6 Ultimate resistance to uplift and sliding	28
A.2.7 Design downward load on roof (concrete blocks + collector + downward wind + snow, excluding self weight of roof structureConcrete blocks: $14 \times 0,35 \times 1,35 = 6,62 \text{ kN}$ ($\gamma_G = 1,35$)	29
A.2.8 Verify the design load and compression strength of the aluminium member BD	30
A.2.8.1 Critical load case: Snow + downward wind	30
A.2.8.1.1 Snow: In accordance with EN 1991-1-3:	30
A.2.8.1.2 Wind: Downward pressure coefficient $c_{p,net} = +1,2$	30
A.2.8.1.3 Factored snow, wind and dead loads.....	30
A.2.8.2 Compression strength of member BD	33
A.2.9 Summary of design verification for compression member BD	34
A.3 Connections for an in-roof solar PV system.....	35

A.3.1	Description of the system.....	35
A.3.2	Climate zone.....	35
A.3.3	Loads.....	35
A.3.3.1	Dead load.....	35
A.3.3.2	Imposed loads	35
A.3.3.3	Wind loads	35
A.3.3.3.1	General	35
A.3.3.3.2	External pressure coefficient	35
A.3.3.4	Snow loads	36
A.3.3.5	Thermal loads.....	36
A.3.4	Vector load components	37
A.3.5	Ultimate limit state load combinations.....	37
A.3.5.1	Ultimate limit state criteria.....	37
A.3.5.2	Load cases	37
A.3.5.3	Vectorial load.....	38
A.3.6	Serviceability limit state load combinations.....	39
A.3.6.1	Serviceability limit state criteria.....	39
A.3.7	Structural resistance of connections.....	39
A.3.7.1	Lower side of module.....	39
A.3.7.1.1	General	39
A.3.7.1.2	Axial load	39
A.3.7.1.3	Shear Load	40
A.3.7.2	Upper edge of module.....	41
A.3.8	Design verification (resistance $\geq$ loads)	42
A.3.8.1	Lower edge of module	42
A.3.8.2	Upper interlocking profile	43
A.4	Earthquake resistant design of solar PV panel connections	43
A.4.1	Description of the system.....	43
A.4.2	Seismic zone	43
A.4.3	Calculation of the seismic load acting on the panels	43
A.4.4	Seismic load and other loads acting on a single panel.....	45
A.4.5	Load Combination	45
Annex B (normative)	Supplementary information on wind actions	47
B.1	General.....	47
B.2	Terms and definitions (NEN 7250:2014/A1:2015 3.0)	47
B.2.1	back panel (NEN 7250:2014/A1:2015 3.1).....	47

B.2.2	building construction (NEN 7250:2014/A1:2015 3.2)	47
B.2.3	eave height (NEN 7250:2014/A1:2015 3.3)	47
B.2.4	photovoltaic element (NEN 7250:2014/A1:2015 3.4)	47
B.2.5	combined element (NEN 7250:2014/A1:2015 3.5)	47
B.2.6	closed substructure (NEN 7250:2014/A1:2015 3.6)	47
B.2.7	façade (NEN 7250:2014/A1:2015 3.7)	47
B.2.8	sloping roof (NEN 7250:2014/A1:2015 3.8)	48
B.2.9	high side (NEN 7250:2014/A1:2015 3.9)	48
B.2.10	mounting method (NEN 7250:2014/A1:2015 3.10)	48
B.2.11	mounting method 1 (NEN 7250:2014/A1:2015 3.11)	48
B.2.12	mounting method 2 (NEN 7250:2014/A1:2015 3.12)	49
B.2.13	mounting method 3 (NEN 7250:2014/A1:2015 3.13)	50
B.2.14	mounting method 4 (NEN 7250:2014/A1:2015 3.14)	51
B.2.15	mounting method 5 (NEN 7250:2014/A1:2015 3.15)	52
B.2.16	low side (NEN 7250:2014/A1:2015 3.16)	53
B.2.17	substructure (NEN 7250:2014/A1:2015 3.17)	53
B.2.18	open substructure (NEN 7250:2014/A1:2015 3.18)	53
B.2.19	flat roof (NEN 7250:2014/A1:2015 3.19)	53
B.2.20	thermal element (NEN 7250:2014/A1:2015 3.20)	53
B.2.21	external dividing construction (NEN 7250:2014/A1:2015 3.21)	54
B.2.22	solar element (NEN 7250:2014/A1:2015 3.22)	54
B.2.23	solar energy system (NEN 7250:2014/A1:2015 3.23)	54
B.3	Requirements for the construction (NEN 7250:2014/A1:2015 6)	54
B.3.1	General (NEN 7250:2014/A1:2015 6.1)	54
B.3.2	Wind load (NEN 7250:2014/A1:2015 6.2)	54
B.3.2.1	General (NEN 7250:2014/A1:2015 6.2.1)	54
B.3.2.2	Net pressure coefficient for mounting method 1 (NEN 7250:2014/A1:2015 6.2.2)	55
B.3.2.2.1	External pressure coefficient c_{pe} , mounting method 1 (NEN 7250:2014/A1:2015 6.2.2.1)	55
B.3.2.2.2	Internal pressure coefficient, c_{pi} , mounting method 1 (NEN 7250:2014/A1:2015 6.2.2.2)	55
B.3.2.2.3	Pressure equalization factor c_{eq} mounting method 1, sloping roof (NEN 6.2.2.3)	55
B.3.2.2.4	Pressure equalization factor c_{eq} , mounting method 1, wall (NEN 7250:2014/A1:2015 6.2.2.4)	57
B.3.2.3	Net pressure coefficients for mounting method 2 (NEN 7250:2014/A1:2015 6.2.3)	59
B.3.2.3.1	Net Pressure Coefficient, $c_{p,net}$, pitched roof, parallel (NEN 7250:2014/A1:2015 6.2.3.1)	59

B.3.2.3.2	Net Pressure Coefficient, $c_{p, net}$, pitched roof, not-parallel (NEN 7250:2014/A1:2015 6.2.3.2)	60
B.3.2.3.3	Net Pressure Coefficient, $c_{p, net}$, of Mounting method 2, façade (NEN 7250:2014/A1:2015 6.2.3.3)	61
B.3.2.3.4	Net Pressure coefficient $c_{p, net}$, for mounting method 2, flat roof (NEN 7250:2014/A1:2015 6.2.3.4)	61
B.3.2.4	Net pressure coefficient $c_{p, net}$, for mounting method 3 (NEN 7250:2014/A1:2015 6.2.4)	62
B.3.2.4.1	General (NEN 7250:2014/A1:2015 6.2.4.1)	62
B.3.2.4.2	Open support structure (NEN 7250:2014/A1:2015 6.2.4.2)	62
B.3.2.4.3	Closed under construction (NEN 7250:2014/A1:2015 6.2.4.3)	65
B.3.2.4.4	Load Zones (NEN 7250:2014/A1:2015 6.2.4.4)	66
B.3.2.4.5	Roof areas (NEN 7250:2014/A1:2015 6.2.4.5)	67
B.3.2.5	Net pressure coefficient mounting methods 4 and 5 (NEN 7250:2014/A1:2015 6.2.5)	69
B.3.3	Determination of the design value for wind load resistance of solar energy systems according to assembly method 1 and 2 by testing (research prototype) (NEN 7250:2014/A1:2015 11.2)	69
B.3.3.1	General (NEN 7250:2014/A1:2015 11.2.1)	69
B.3.3.2	Principle (NEN 7250:2014/A1:2015 11.2.2)	70
B.3.3.3	Sampling (NEN 7250:2014/A1:2015 11.2.3)	70
B.3.3.4	Test Conditions (NEN 7250:2014/A1:2015 11.2.4)	70
B.3.3.5	Specimen (NEN 7250:2014/A1:2015 11.2.5)	70
B.3.3.5.1	Test Samples (NEN 7250:2014/A1:2015 11.2.5.1)	70
B.3.3.5.2	Dimensions of the test specimen (NEN 7250:2014/A1:2015 11.2.5.2)	70
B.3.3.5.3	Number of tests (NEN 7250:2014/A1:2015 11.2.5.3)	70
B.3.3.5.4	Composition of the test piece (NEN 7250:2014/A1:2015 11.2.5.4)	70
B.3.3.5.5	Equipment and apparatus (NEN 7250:2014/A1:2015 11.2.6)	70
B.3.3.5.6	Test Procedure and evaluation (NEN 7250:2014/A1:2015 11.2.7)	70
	Bibliography	73

European foreword

This document (CEN/TR 16999:2019) has been prepared by Technical Committee CEN/TC 128 “Roof covering products for discontinuous laying and products for wall cladding”, the secretariat of which is held by NBN in co-operation with CEN/TC250 “Structural Eurocodes”, CEN/TC254 “Flexible sheets for waterproofing”; CEN/TC312 “Thermal solar systems and components” and CLC/TC82 “Solar photovoltaic energy systems”.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

Introduction

The following is a summary of the requirements for structural design of the structural connection between solar energy panels and the roof structure as detailed in this Technical Report.

- a) Type of solar panel: Thermal or photovoltaic solar panels which comply with the mechanical resistance requirements of EN 12975-1 (solar thermal collectors) or EN 61215 (solar PV panels).
- b) Determining of the loads and load combinations: self-weight of the solar panels and relevant imposed snow and wind actions in accordance with EN 1991-1-1, EN 1991-1-3 and EN 1991-1-4. Referring to French Standard NF P78-116 and Dutch Standard NEN 7250 for additional data on snow and wind loads on solar panels.
- c) Determining the design loads for the solar panels: multiplication of each of the loads by their respective partial factor γ_G or γ_Q for the ultimate limit state, and separately for the serviceability limit state in accordance with EN 1990.
- d) Identifying combinations of most unfavourable design loads which act together at the same time, for the ultimate and serviceability limit states. Modifying the loads by applying a load combination factor ψ to one of the two variable loads which act at the same time.
- e) Determining of the structural resistance of the connections between the solar panels and the roof structure in accordance with calculation methods of one or more of the following European Standards:

EN 1992 series to EN 1996 series, and EN 1999 series for the ultimate and serviceability limit states:
 - 1) For the serviceability limit state, determining of the resistance at the specified maximum deformation limiting the function of the connection;
or
 - 2) determine the resistance by serviceability and ultimate load tests.
- f) Verifying the design by confirming that the factored structural resistance is not less than the critical combinations of factored actions for both limit states.

Four examples of design calculations for different solar panel connections are given in Annex A.

1 Scope

This document provides guidance on the principles and requirements of structural design for the safety and serviceability of the structural connection between solar energy panels (thermal or photovoltaic) and the structure of flat or pitched roofs.

This document does not include requirements for:

- weather tightness of the roof, solar panels and connections;
- electrical, thermal or mechanical characteristics of the solar panels;
- precautions against fire of the installation.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 1990:2002, *Eurocode - Basis of structural design*¹⁾

EN 1991-1-1, *Eurocode 1: Actions on structures - Part 1-1: General actions - Densities, self-weight, imposed loads for buildings*

EN 1991-1-3:2003, *Eurocode 1 - Actions on structures - Part 1-3: General actions - Snow loads*

EN 1991-1-4:2005, *Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions*

EN 1992 (all parts), *Eurocode 2 - Design of concrete structures*

EN 1993 (all parts), *Eurocode 3 - Design of steel structures*

EN 1994 (all parts), *Eurocode 4 - Design of composite steel and concrete structures*

EN 1995 (all parts), *Eurocode 5 - Design of timber structures*

EN 1996 (all parts), *Eurocode 6 - Design of masonry structures*

EN 1998-1:2004, *Eurocode 8: Design of structures for earthquake resistance - Part 1: General rules, seismic actions and rules for buildings*²⁾

EN 1998 (all parts), *Eurocode 8: Design of structures for earthquake resistance*

EN 1999 (all parts), *Eurocode 9: Design of aluminium structures*

EN 1999-1-1:2007, *Eurocode 9: Design of aluminium structures - Part 1-1: General structural rules*³⁾

1) This document is impacted by the amendment EN 1990:2002/A1:2005.

2) This document is impacted by the amendment EN 1998-1:2004/A1:2013.

3) This document is impacted by the amendments EN 1999-1-1:2007/A1:2009 and EN 1999-1-1:2007/A2:2013.

3 Terms and definitions

For the purposes of this document, the terms and definitions for structural design given in EN 1990, the EN 1991 series, the EN 1992 series, the EN 1993 series, the EN 1994 series, the EN 1995 series, the EN 1996 series, the EN 1998 series, and the EN 1999 series apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

4 Symbols

For the purposes of this document, the symbols for structural design given in EN 1990, the EN 1991 series, the EN 1992 series, the EN 1993 series, the EN 1994 series, the EN 1995 series, the EN 1996 series, the EN 1998 series, and the EN 1999 series apply.

5 Configuration of solar panel installation

The configuration of solar panel installations is classified by the method of mounting on the roof structure, as given in Annex B.

6 Design responsibility

The designer should ensure that:

- the choice of the structural system and the design of the structural connections are made by appropriately qualified and experienced personnel;
- adequate supervision and quality control are provided in design offices, factories and on site;
- the structure will be adequately maintained;
- the structure will be used according to the design assumptions;
- the building structure can safely support the solar panels according to Eurocode standards of design; building retrofitted with solar panels should also be checked.

7 Thermal solar collectors and PV solar panels

Thermal solar collectors and PV solar panels are collectively called solar panels in this Technical Report.

Thermal solar collectors should comply with EN 12975-1, according to the manufacturer's declared requirements.

PV solar panels should comply with the requirements of EN 61215 or EN 61646.

The structural resistance of the body of solar panels is not considered in this Technical Report. It is assumed that their structural resistance is adequate. Attention is drawn to high snow loads in certain areas of Central and Northern Europe (see EN 1991-1-3:2003, Annex C), acting together with downward wind loads, which should be compared with the structural resistance of solar panels determined by 'mechanical load tests' incorporating adequate safety factors.

8 Principles of limit state structural design

8.1 General

Structural design should be carried out according to the principles of limit states of EN 1990. The ultimate limit state and the serviceability limit state should both be considered, for relevant design situations.

For each limit state:

- the design value of an action is its characteristic value multiplied by the appropriate partial safety factor for the action;
- the design value of the resistance is its characteristic value divided by the appropriate partial safety factor for the material, which should be not less than the design value of the action.

8.2 Design situations

Design situations to be considered are actions which are:

- persistent (conditions of normal use, from dead loads, wind and snow loads, and other imposed loads);
- induced loads from thermal action due to temperature variation (e.g. for mounting beams of solar panels);
- transient loads (e.g. during execution or repair);
- accidental actions (for exceptional conditions e.g. explosion, impact, disproportionate consequence of local failure);
- seismic actions (in seismic locations only).

The most unfavourable combinations of actions which act together at the same time should be considered in design. They may include loads which are applied in different directions.

8.3 Ultimate limit state

The ultimate limit state concerns the safety of people and/or the structure when failure of the structure occurs by excessive deformation, transformation into a mechanism or loss of stability.

8.4 Serviceability limit state

The serviceability limit state concerns the deformation, vibration or damage of the structure under normal use which affect its function, appearance, or discomfort to people.

9 Determination of actions

9.1 Permanent actions (G)

The characteristic value of self-weight of the solar panel and its structural connection should be taken as its mean value.

Indirect actions, e.g. caused by irreversible deformation, are also classed as permanent actions.

9.2 Variable actions (Q)

9.2.1 General

Variable actions are imposed loads, wind and snow loads, and loads induced by thermal movement (e.g. for mounting beams).

The characteristic load values for snow and wind speeds may vary with location and may be given in National Annexes to the standard.

9.2.2 Imposed loads

Imposed loads are in accordance with EN 1991-1-1.

9.2.3 Snow loads

9.2.3.1 General

Snow loads are in accordance with EN 1991-1-3 and the relevant National Annex. Supplementary information on increased snow load on solar panels at the eaves of pitched roofs in climatic conditions where melting, sliding and re-freezing of snow can occur, is given in NF P78-116 (for France only).

9.2.3.2 Return period

The ground snow load value may be adjusted according to the return period adopted (see EN 1991-1-3:2003, Annex D), if specified by the National Annex. The return period may be based on the expected design life of the solar panel connections.

9.2.3.3 Sliding snow loads on pitched roofs

Sliding snow loads which act on the framework and connections of solar panels which project above the pitched roof surface should be determined according to EN 1991-1-3:2003, 6.4. They may occur at the same time as vertical snow loads and snow drift loads. Solar panel elements are not designed to resist sliding snow load.

To protect solar panels projecting above the roof surface from heavy sliding snow loads from a long length of pitched roof, snow guards are recommended to be installed up-slope of the solar panels. Where the projected height of the solar panels is greater than that of the snow guard, snow drift loads should be assumed to act on the difference in projected height.

9.2.4 Wind loads

9.2.4.1 General

The modelling of wind velocity and peak velocity pressure is given in EN 1991-1-4. For site-specific data on climatic information, wind speed distribution maps and altitudes, refer to the relevant National Annex to EN 1991-1-4.

The dynamic pressure of the wind should be derived in accordance with EN 1991-1-4 based on the peak velocity pressure. The characteristic wind load is the dynamic pressure modified by terrain, height and wind pressure coefficients according to the shape and orientation of the structure.

Pressure coefficients for roofs of certain building configurations are given in EN 1991-1-4. Information from the Dutch Standard NEN 7250:2014/A1:2015 on pressure coefficients for various mounting configurations of solar panels on roofs and façades is given in Annex B.

The effect of wind loads on the roof surface with solar panels installed above it should be considered.

9.2.4.2 Return period

The wind speed may be adjusted according to the return period adopted (see EN 1991-1-4), which is normally assumed to be not less than 25 years, unless otherwise specified by the National Annex.

9.2.5 Critical load combinations

The following are load combinations which may act together at the same time on solar panels and their connections:

- dead load + imposed load;
- dead load + snow load (including sliding snow for pitched roofs) + wind (downward);
- dead load + wind load (upward);
- loads induced by thermal action [for mounting beams].

The most unfavourable load combinations in magnitude and load direction should be adopted for design.

9.2.6 Load combination factor ψ

Where the leading variable action occurs at the same time as other variable actions, the value of the other variable actions may be reduced by multiplying by combination factors ψ (See EN 1990 and design examples in A.1 and A.2).

9.2.7 Partial safety factors for actions

The design value of an action is the characteristic value multiplied by partial safety factor γ_G or γ_Q .

For the ultimate limit state:

- permanent actions: in favourable load combination $\gamma_G = 1,0$;
- in equilibrium condition, e.g. dead load solely providing stability $\gamma_G = 0,9$;
- in unfavourable load combination $\gamma_G = 1,35$;
- variable actions: $\gamma_Q = 1,50$.

Where design is assisted by wind tunnel testing using an appropriate model of the structure and of the natural wind (see EN 1991-1-4), the value of γ_Q for wind action may be taken as 1,35.

For the serviceability limit state:

- permanent and variable actions, $\gamma_G = 1,0$; $\gamma_Q = 1,0$.

9.2.8 Consequence of structural failure

Where permitted nationally, solar panels installed on buildings in normal conditions of use may be designated with a consequence class CC1 (EN 1990:2002, Table B.1) corresponding to Reliability Class RC1.

For RC1, a multiplying consequence factor $K_{FI} = 0,9$ should be applied to unfavourable actions (ultimate limit state only).

For installations requiring consideration of higher risk, see EN 1990:2002, B.3.

10 Structural resistance of connections

10.1 Configuration and type of connectors

The arrangement in number, position and spacing of connectors to solar panels should be not less favourable than the arrangement adopted in the mechanical load test for the body of the solar panel.

10.2 Design by calculation

The structural resistance should be determined by calculation in accordance with one or more Eurocodes the EN 1992 series, the EN 1993 series, the EN 1994 series, the EN 1995 series, the EN 1996 series and the EN 1999 series, for both the ultimate and serviceability limit states, to support adequately the most unfavourable load combinations.

The design resistance is the lesser of the characteristic strength at the ultimate limit state, or at the serviceability limit state, divided by a material partial factor γ_M .

Values of γ_M at the ultimate limit state are specified in the relevant Eurocode for structural materials: the EN 1992 series, the EN 1993 series, the EN 1994 series, the EN 1995 series, the EN 1996 series and the EN 1999 series (see design examples in Annex A). The value of γ_M for the serviceability limit state is 1,0.

10.3 Design assisted by testing

In accordance with EN 1990:2002, Annex D, design may be based on a combination of tests and calculations.

Testing to determine the resistance of the structure or part of the structure may be carried out, for example, in the following circumstances if:

- adequate calculation models are not available;
- a large number of components are to be used;
- it is necessary to confirm, by control checks, assumptions made in the design.

Test specimens should be specified or obtained by sampling in such a way as to represent the conditions of the real structure, and to obtain a statistically representative sample.

The rate of loading should where possible reflect actual conditions. Where the material of the structure has significant time dependent effects on strength and deformation (e.g. timber – see EN 1995-1-1), the test results should be modified to take into account the difference in load durations between testing and the design conditions. Tests should be continued until failure occurs, recording load increments and deflections.

The characteristic strength should be the 5 % characteristic value based statistically on the Normal Distribution of a population of test results (EN 1990:2002, Table D1). The minimum population of tests results should be 3.

The design resistance value for the ultimate load condition is the characteristic value divided by $\gamma_M > 1, 0$. Values of γ_M vary according to the type of structural material (See relevant Eurocode: EN 1990, the EN 1991 series, the EN 1992 series, the EN 1993 series, the EN 1994 series, the EN 1995 series, the EN 1996 series, the EN 1998 series, or the EN 1999 series).

The design resistance at the limit of serviceability should also be the 5 % characteristic value.

The design resistance at the limit of serviceability is the characteristic value divided by $\gamma_M = 1,0$.

The minimum design resistance is the lesser of the ultimate load and serviceability conditions.

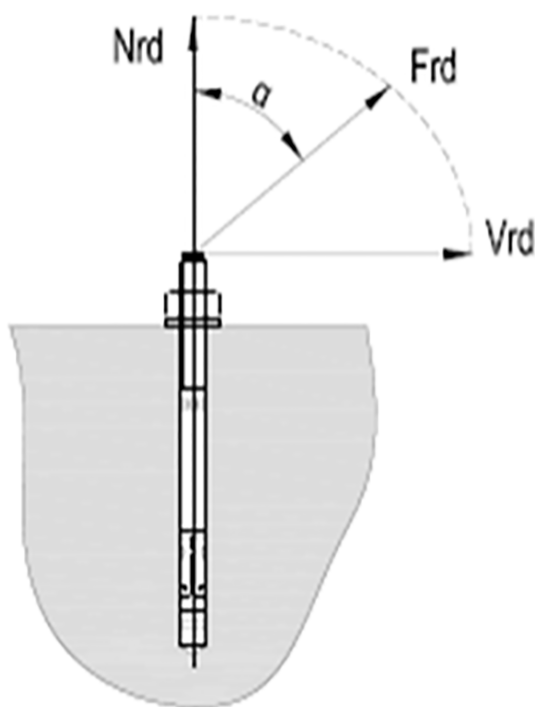


Figure 1 — Resultant value for the load

Where separate tests are carried out on two loads each acting in different directions, the resultant value for the loads acting together may be obtained vectorally by Formula (1):

$$F_{rd} = \frac{1}{\sqrt{(\cos[\alpha / V_{rd}])^2 + (\sin[\alpha / N_{rd}])^2}} \quad (1)$$

where

N_{rd} is the design resistance of the anchor point acting normal to the roof;

V_{rd} is the design resistance of the anchor point acting parallel to the roof;

F_{rd} is the resultant design resistance acting at an angle α .

For a test method to determine the wind uplift resistance, see B.4.2.

11 Design for accidental action

Solar panel installations normally would not induce progressive collapse of the building to which they are attached, therefore no special measures are required against accidental actions for the structural connections.

In exceptional conditions of high consequence of failure, EN 1991-1-7 provides design advice.

12 Design for seismic action

Design for seismic action should be in accordance with the EN 1998 series and is required only in earthquake areas as indicated in relevant National Annexes to the EN 1998 series, or in national building regulations.

National seismic design requirements and standards should also be adopted. The design should validate both seismic and non-seismic design situations.

Solar panels connected to the roof structure should normally be regarded as 'non-structural elements' or 'appendages' of buildings as defined in the EN 1998 series.

Unless otherwise specified, the effect of seismic action may be determined by applying to the non-structural element a horizontal force F_a , defined in the EN 1998 series as:

$$F_a = S_a W_a \gamma_a / g_a \quad (2)$$

$$S_a = \alpha S \left(3(1 + z/H) / (1 + (1 - T_a/T_i)^2) - 0,5 \right) \text{ but } S_a \geq \alpha S \quad (3)$$

where

- F_a is the horizontal seismic force, acting at the centre of mass of the non-structural elements in the most unfavourable direction;
- W_a is the weight of the element;
- S_a is the seismic coefficient for non-structural elements, defined in Formula (3);
- γ_a is the importance factor of the element, taken as 1,0;
- q_a is the behaviour factor of the element, taken as 1,0;
- α is the ratio of the design ground acceleration on type A ground, a_g , to the acceleration of gravity g ;
- S is the soil factor;
- T_a is the fundamental vibration period of the non-structural element;
- T_i is the fundamental vibration period of the building in the relevant direction;
- z is the height of the non-structural element above the level of application of the seismic action (foundation or top of a rigid basement);
- H is the building height measured from the foundation or from top of a rigid basement.

Annex A (informative)

Examples of connection design

A.1 Fixing hook for PV solar panels mounted above tiled roof

A.1.1 Description of the system

A solar roof hook is used to connect solar panels above a covering of roof tiles. Different generic types of connection are shown in Figure A.1. The base of the roof hooks in Figure A.1 (a) and (b) are screwed to the rafters. The hook then passes around the roof tiles, usually via the headlap of the tiles. In order to facilitate this, the weather bars of the roof tiles are hand modified so that the roof hook passes around the tiles without increasing the gapping of the roof tiles and hence without influencing the weather-tightness of the roof. If necessary a durable foam rubber strip is added around the hook for weather-tightness. Other types of roof hook shown in Figure A.1(c) may replace a roof tile with a metal tile having an integral metal upstand. An additional strengthening batten is then added.

The top section of the hook clamps to a mounting rail system which in turn secures the solar panels. A minimum of two mounting rails are required per solar panel and several hooks may be required per panel.

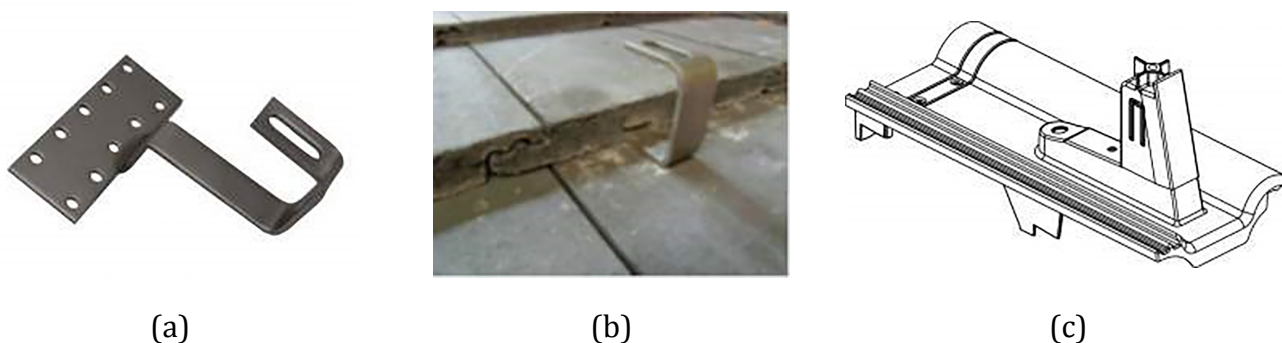


Figure A.1 — Generic solar roof hook designs

The design determines how many hooks are required per solar panel to safely resist the roof load. Failure is classified as actual failure of one or more parts of the system (ultimate limit state) or serviceability failure (serviceability limit state). Examples of serviceability failure are: 1) breakage of roof tiles and 2) excessive permanent deflection of the roof tiles affecting the weather-tightness of the roof.

This example considers a roof with rafter pitch of 30°, with the solar panels fixed above the roof using the hook design shown in Figure A.1 (a) and (b), parallel to the rafters and with a clearance of $\leq 300\text{mm}$ between the panels and the roof covering.

A.1.2 Climate zone

The solar roof hooks are to be used in the German market.

A.1.3 Loads

A.1.3.1 Dead loads

The panels each have an area of 1,386 m². The combined self-weight of the panels and rails is 18,5 kg/m².

A.1.3.2 Imposed load

An imposed concentrated load of $Q_k = 1,0 \text{ kN}$ will be considered (see 9.2.1). This design load simulates the weight of a person working on the panels. Since it is not customary to walk on solar panels this is considered to be an accidental load. Furthermore, this load is unlikely to occur in combination with significant snow or wind loads. It is will therefore be considered to act only in conjunction with the dead weight of the system. The imposed load shall be applied at the most severe position.

A.1.3.3 Wind and snow loads

The once in 50 year wind and snow loads are derived for the site or region in Germany using data from the following Eurocodes, together with the relevant National Annex.

EN 1991-1-3, *Actions on structures – Part 1-3: General Actions – Snow Loads* (National Annex: DIN EN 1991-1-3/NA)

EN 1991-1-4, *Actions on structures – Part 1-4: General Actions – Wind Loads* (National Annex: DIN EN 1991-1-4/NA)

NOTE Some member states permit the use of average return periods of less than once in 50 years. Consult the National Annexes for details.

Initially these are used to calculate the design wind pressure, q_p , and the characteristic snow load, S_k . The following values, Table A.1, have been derived for this example and cover a range of areas in Germany, including the North Sea coast where wind loads are highest but snow loads are modest and also including the southern parts of Germany where snow loads are high, while wind loads are lower.

Table A.1 — Example values of characteristic wind pressure and characteristic snow load

WIND			SNOW		
Zone	Building height	q_p (N/m ²)	Zone	Altitude (m)	S_k (kN/m ²)
Zone 3 incl coast	≤ 10m	1050	Zone 2	≤ 250	0,85
Zone 2, inland	≤ 10m	800	Zone 2	≤ 400	1,21
Zone 2, inland	≤ 10m	650	Zone 2a	≤ 1000	5,68

In the following calculations the second of these conditions will be used (shown in bold, $q_p = 800 \text{ N/m}^2$, $S_k = 1,21 \text{ kN/m}^2$). In practice a range of conditions would be calculated.

A.1.3.4 Calculation of the wind load acting on the panels

For the good understanding of this document the following is repeated:

q_p = once in 50 year wind pressure based on a short duration gust at 10m height over flat open ground. Other ground roughness values, distances from the sea, building heights or the presence of topography will influence this value.

The (unfactored) wind load acting on the panel, normal to the surface is calculated as follows:

$$F = q_p \times c_{p,net} \times A \quad (\text{A.1})$$

where

F is the windload;

$c_{p,net}$ is the net pressure coefficient or force coefficient;

A is the area of the solar panel.

Negative values signify a force acting upward normal to the roof. Positive values signify a force acting downward normal to the roof. In this example, values have been taken from NEN 7250:2014/A1:2015 (see Annex B, B.3.2.3.1). The roof zones referred to in Table A.2 are those from EN 1991-1-4. Zone F relates to the eaves corner areas (largest suction loads), Zone H&I are central areas.

Table A.2 — Values of $c_{p,net}$ and the calculated wind loads

	Uplift Loads		Down loads	
	Roof Zones F	Roof Zones H&I	Roof Zones F	Roof Zones H&I
$c_{p,net}$ values for a clearance $\leq 300\text{mm}$	- 2,0	-0,5	1,0	0,70
F / A (Pa)	1600	560	800	560
F (N)	-2218	-776	1109	776

This example will consider only roof zones F (eaves corners). In reality all the roof zones would also be considered where the solar panels cover a large area of the roof.

A.1.3.5 Snow loads

For the good understanding of this document the reader is reminded that S_k is a characteristic value, which shall be multiplied by several factors taken from the Eurocode EN 1991-1-3 and its National Annex. The result is then the once in 50 year snow load acting as if the roof was horizontal.

$$S = \mu_i \times C_e \times C_t \times S_k \quad (\text{A.2})$$

where

- μ_i is the shape coefficient, depending on the roof geometry and pitch. (e.g. for a normal duo-pitch roof at 30° $\mu_i = 0,8$; at 60° $\mu_i = 0$);
- C_e is the topography factor (take as 1,0 for 'normal' topography.) For sheltered sites $C_e = 1,2$; for windswept sites $C_e = 0,8$; in this example $C_e = 1,0$;
- C_t is the thermal coefficient, taking into account reduced loads due to heat transmission (where applicable). A value of $C_t = 1,0$ has been used.

These values give:

$$S_{\mu=0,8} = 0,968 \text{ kN/m}^2 \quad (\text{A.3})$$

The snow load acting vertically on a solar panel is then:

$$S_L = S_{\mu=0,8} \times A \times \cos\alpha = 1162 \text{ N} \quad (\text{A.4})$$

where

α = roof pitch = 30° in this example.

A.1.3.6 Summary of loads acting on a single panel, in directions normal to the roof and down the roof

These are derived by multiplying the loads by $\sin 30^\circ$ or $\cos 30^\circ$, as appropriate. See Table A.3.

Table A.3 — Loads acting on a single panel (N)

	Force vertical to the roof		Force down the roof	
	Based on wind uplift	Based on wind downward load	Based on wind uplift	Based on wind downward load
Imposed load (N)	866	866	500	500
Dead load (N)	218	218	126	126
Snow load (N)	1006	1006	581	581
Wind load (N)	-2218	1109	0	0

The sign convention is +ve for downward load, -ve for upward load.

A.1.4 Factored load combinations for the ultimate limit state

Based on EN 1990:2002, 9.2.4, Tables A1.1 and A1.2, the following load cases are considered. These include the appropriate load combination factors and load side partial safety factors.

- Load Case 0: [1,35 x Dead Load + 0,9 × 1,50 x Imposed load]
- Load Case 1: [1,35 x Dead Load + 0,9 × 1,50 x Snow Load]
- Load Case 2: [1,35 x Dead Load + 0,9 × 1,50 x Wind Load]
- Load Case 3: [1,35 x Dead Load + 0,9 × 1,50 (Wind Load + 0,5 Snow Load)]
- Load Case 4: [1,35 x Dead Load + 0,9 × 1,50 (Snow Load + 0,6 Wind Load)]
- Load Case 5: [1,0 x Dead Load + 0,9 × 1,50 x Wind Suction]

NOTE The partial safety factor for dead load (a permanent action) is 1,35 when the dead load acts in the same direction as variable actions (snow and downward wind loads) and 1,0 when the permanent load relieves the variable load (for example wind uplift).

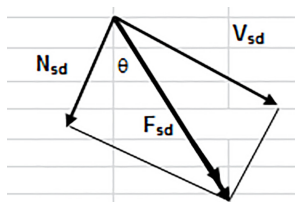
In some cases thermal effects shall also be considered. Such a case is the use of long rail lengths and extremes of temperature, Load case 1, for example, then becomes: Load case 1: [1,35 × (Dead Load) + 0,9 × 1,50 × (ψ1 x Snow Load + ψ2 x Thermal Load)] Two cases shall be considered: ψ1 = 1,0 with ψ2 = 0,6 and ψ1 = 0,5 (for site altitudes H ≤ 1000m), with ψ2 = 1,0. Thermal effects are not included in this example.

The factor of 0,9 in each load case is the K_{FI} consequence factor described in EN 1990:2002, 11.2.7. These loads occur in orthogonal pairs and can be combined into a single resultant load by vector addition.

$$F_{sd} = \sqrt{(V_{sd}^2 + N_{sd}^2)} \quad (A.5)$$

$$\tan \theta = \frac{V_{sd}}{N_{sd}} \quad (A.6)$$

These resulting values of F_{sd} are later compared against effective resistance values derived by measurement (see Figure A.2).

**Key**

N_{sd} = force on the anchor point acting normal to the roof

V_{sd} = force on the anchor point acting parallel to the roof

F_{sd} = resultant force, acting at an angle θ

Figure A.2 — Resulting force F_{sd}

The values are summarized below and have been derived for each load case.

Table A.4 — Resultant force acting on the solar hooks – ultimate limit state calculations

Load case	Wind load acting upwards normal to roof					Wind load acting downwards normal to roof				
	N_{sd} (N)	V_{sd} (N)	F_{sd} (N)	θ°	Dominant load	N_{sd} (N)	V_{sd} (N)	F_{sd} (N)	θ°	Dominant load
LC 0 ^a	1463	845	1690	30,0	Normal Down	1463	845	1690	30,0	Normal down
LC 1	1652	954	1908	30,0	Normal down	1652	954	1908	30,0	Normal down
LC 2	-2776	126	2779	-2,60	Normal up	1791	170	1799	5,4	Normal down
LC 3	-2097	518	2160	-13,9	Normal up	2470	562	2533	12,8	Normal down
LC 4	79	910	914	-85,0	Parallel down	2401	954	2583	21,7	Normal down
LC 5	-2776	126	2779	-2,6	Normal up	1791	170	1799	5,4	Normal down
^a LC 0 assumes both dead load and imposed loads are taken by a single roof hook.										

A.1.5 Factored load combinations for the serviceability limit state

The load cases are the same as those in A.1.4 except that all load side partial safety factors have the value of 1,0 and K_{FI} does not apply and therefore also defaults to 1,0 (See 9.2.7).

Load Case 0: Dead Load + Imposed load

Load Case 1: Dead Load + Snow Load

Load Case 2: Dead Load + Wind Load

Load Case 3: Dead Load + (Wind Load + 0,5 Snow Load)]

Load Case 4: Dead Load + (Snow Load + 0,6 Wind Load)]