

Greenhouses — Design and construction

Part 1: Commercial production greenhouses

National foreword

This British Standard is the UK implementation of EN 13031-1:2019, incorporating corrigendum September 2022. It supersedes BS EN 13031-1:2001, which is withdrawn.

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

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European foreword

This document (EN 13031-1:2019) has been prepared by Technical Committee CEN/TC 284 “Greenhouses”, the secretariat of which is held by NEN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by June 2020, and conflicting national standards shall be withdrawn at the latest by June 2020.

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.

This document will supersede EN 13031-1:2001.

National document: National choices are allowed in EN 13031-1 through:

- 5.2.3 for Design working life of the structure;
- 5.3.1 for Classification of Consequence Classes CC;
- 5.3.2 for Differentiation of Partial Factors;
- 5.3.3 and 10.3 for Combinations of actions and related ψ -coefficients;
- 5.3.4 for Reference Periods for related Probabilities of Exceedance;
- 10.2.2 and 10.2.3 for Adjustment Factors for Reference Periods according to 5.3.4;
- 10.2.2.6 for Temperature ranges for gutters and other structural components;
- 10.3 Combination of actions;
- Annex A for Glass design calculation;
- Annex B for Wind: Size Factors, Correlation Coefficients, Aerodynamic Coefficients;
- Annex C for Snow: Surface Material Coefficients, Thermal Coefficients, Shape Coefficients;
- Annex E for Earthquake: Classification of Importance Categories IC, Importance Factors γ_I , Return Periods, probabilities of Exceedance and Adjustment Factors;
- Annex F for Owner's manual and identification plate.

As a guidance, the recommended values in tables are shown in grey fields.

According to the CEN-CENELEC Internal Regulations, the national standards organisations of the following countries are bound to implement this European Standard: 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 the United Kingdom.

Introduction

Part 1 of this document relates specifically to commercial production greenhouses used for the professional production of plants (crops) where human occupancy is restricted to authorized personnel, concerning low levels in number and duration. Other parts of this European standard are to be prepared that relate to greenhouses where general access by the public is permitted (such as those in garden centres or expositions).

This document gives specific rules and information, such as load distributions, deformation criteria and limitations to tolerances, for structural design and construction of greenhouses to enable adequate structural safety.

The structural design is based on EN 1990 and the relevant parts of EN 1991 to EN 1999 (Eurocodes 1 to 9) regarding the general principles and basic requirements for actions, mechanical resistance and stability, serviceability and durability. National Application Documents (NAD) are considered.

Recommended values for structural design in this document are given in accordance with the classification of greenhouses in EN 1990. This takes into account, that for commercial production greenhouses the consequences and nature of failure and the importance for public safety are lower than for normal buildings. The design working life is small. The potential economic loss is limited to the owner and the impact on the environment is low.

Non-contradictory, complementary information is provided to account for the particular requirements, functions and forms of commercial production greenhouses that distinguish them from ordinary buildings. A distinguishing functional requirement is the optimization of solar radiation transmission to create and maintain an optimal environment for the growth of plants (crops). This has implications on the form and structural design of commercial greenhouses.

As rules and requirements of this standard may become adopted by other European standards, for example the Structural Eurocodes or codes for Glass in Building – Design of glass panes, these will be replaced by a reference to this document.

1 Scope

This document specifies principles and requirements for the mechanical resistance and stability, serviceability and durability for design and construction of commercial production greenhouse structures, including their foundations, irrespective of the material used, for the professional production of plants (crops).

Fire resistance-related aspects are not covered in this document.

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 572-1, *Glass in building — Basic soda lime silicate glass products — Part 1: Definitions and general physical and mechanical properties*

EN 572-6, *Glass in building — Basic soda lime silicate glass products — Part 6: Wired patterned glass*

EN 673, *Glass in building — Determination of thermal transmittance (U value) — Calculation method*

EN 1090-1, *Execution of steel structures and aluminium structures — Part 1: Requirements for conformity assessment of structural components*

EN 1096-1, *Glass in building — Coated glass — Part 1: Definitions and classification*

EN 1279-1, *Glass in Building — Insulating glass units — Part 1: Generalities, system description, rules for substitution, tolerances and visual quality*

EN 1990, *Eurocode — Basis of structural design*

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, *Eurocode 1 – Actions on structures — Part 1-3: General actions — Snow loads*

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

EN 1993-1-1, *Eurocode 3: Design of steel structures — Part 1-1: General rules and rules for buildings*

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

EN 12150-1, *Glass in building — Thermally toughened soda lime silicate safety glass — Part 1: Definition and description*

prEN 16612:2017, *Glass in building — Determination of the lateral load resistance of glass panes by calculation*

ISO 4355, *Bases for design of structures — Determination of snow loads on roofs*

EN ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation methods (ISO 6946)*

EN ISO 10077-1, *Thermal performance of windows, doors and shutters — Calculation of thermal transmittance – Part 1: General (ISO 10077-1)*

EN ISO 10077-2, *Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Part 2: Numerical method for frames (ISO 10077-2)*

EN ISO 12543-5, *Glass in building — Laminated glass and laminated safety glass — Part 5: Dimensions and edge finishing (ISO 12543-5)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1990, EN 1090-1 and the following 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>

3.1

greenhouse

building structure that optimizes solar radiation transmission used for plants requiring regulated climatic conditions

3.2

commercial production greenhouse

greenhouse (3.1) for professional production and/or protection of plants (crops), where human occupancy is restricted to authorized personnel, concerning low levels in number and duration

Note 1 to entry: Other persons shall be accompanied by authorized personnel.

3.3

clearance

free space in the rabbet, between the cut-size of a cladding panel and two opposite cladding bars

3.4

permanent opening

opening which cannot be closed under extreme wind conditions and which has a significant influence on the internal pressure

3.5

cladding

outer skin of roof and wall attached to the structural framework of the greenhouse

Note 1 to entry: It is made of panels of glass or plastic sheets or of plastic film and may include further metal components, such as cladding bars, ridge bar and gutter. The gutter can also be as well a component of the structural framework.

4 Symbols and abbreviations

Abbreviations:

NAD	National Application Documents, e.g. National Annex to Eurocode or Euronorm, also National Code or National Regulation by the Authority
SLS	serviceability limit states
ULS	ultimate limit states
NCR	non collapse requirements
DLS	damage limitation states
CC	consequence class
IC	earthquake importance category
Luv	windward side of the structure
Lee	leeward side of the structure
0°-Wind	wind direction perpendicular to ridge and gutter, side walls, inclined windward and leeward roof surface
90°-Wind	wind direction parallel to ridge and gutter, perpendicular to the gable walls

Symbols:

NOTE The following symbols used in this document are based on EN 1990, EN 1991 and EN 1998.

Latin upper-case letters:

A	altitude of the building site above sea level in m
A_i	accidental action
A_k	characteristic value of accidental action
A_{gr}	ground area of the greenhouse
A_{ap}	aperture area of the greenhouse
A_{li}	light interception area of the greenhouse
B	width
B_{gh}	width of the greenhouse
C_{esl}	exceptional snow load coefficient
C_e	exposure coefficient
C_m	surface material coefficient
C_t	thermal coefficient
D	cross sectional dimension of the foundation hole
E	modulus of elasticity
F_{wire}	horizontal force per wire
G	shear modulus
$G_i; g_i$	permanent action
$G_k; g_k$	characteristic value of a permanent action

H	height of the greenhouse ridge above ground level
K	shape parameter dependent on the coefficient or variation of the maximum annual wind data (speed or pressure)
K_{FI}	consequence factor dependent on the consequence class
L	length; span
L_{gh}	length of the greenhouse
M	moment
N	normal or membrane force
P_1	annual probability of exceedance of variable or of earthquake actions
P_n	probability of exceedance of variable or of earthquake actions with reference to n years
$P_{T,50}$	target value of the probability of exceedance of the earthquake action with reference to $n = 50$ years and the associated return period $T_{NCR}(50)$
$Q_i; q_i$	variable action
$Q_k; q_k$	characteristic value of a variable action
R_T	thermal resistance of a component
R_{si}	internal surface resistance (surface to internal air)
$R_{si,sw}$	internal surface resistance for heat flow sideways
$R_{si,up}$	internal surface resistance for heat flow upwards
R_{se}	external surface resistance (surface to external air)
$R_{\lambda,j}$	thermal resistance of the material layer j
R_f	thermal resistance of the frame, e.g. glazing bars and gutter
$R_{g,k}$	thermal resistance of the gas space k
$R_{ts,m}$	thermal resistance of the (thermal) screen m
$T_{NCR}(n)$	target value for the earthquake return period in years for NCR in reference to n years
$T_{NCR}(50)$	target value for the earthquake return period in years for NCR in reference to 50 years
U	overall heat transmittance in $W/(m^2K)$
U_o	special heat transmittance in $W/(m^2K)$ for snowmelt conditions excluding the external heat transfer into the air
V	coefficient of variation of the annual maximum snow load

Latin lower-case letters:

a	largest span of a glass panel, distance between wires
a_{gR}	reference peak ground acceleration for earthquake
a_g	design ground acceleration for earthquake
b	smallest span of a glass panel; distance in width direction
b_{cb}	distance between the column bases
c	clearance; coefficient
c_{fr}	coefficient of friction

c_{pe}	aerodynamic coefficient for global external pressure
$c_{pe,L}$	aerodynamic coefficient for local external pressure
c_{pi}	aerodynamic coefficient for internal pressure
c_{prob}	probability factor the adjustment of the wind speed dependent on the return period n
c_s	size factor
c_{cor}	correlation factor
d	distance; diameter; depth
f_y	characteristic yield strength of steel
$f_{gl;d}$	design value of the ultimate bending strength of a glass pane
$f_{gl;u}$	characteristic value of the ultimate bending strength of a glass pane
$f(\alpha)$	roof angle function for the thermal coefficient C_t
$f(\theta_i)$	influence of the heating (internal air temperature) on the thermal coefficient C_t
$f(U_o)$	influence of the thermal transmittance of the glazing on the thermal coefficient C_t
$f(s_{k,n})$	influence of the snowfall rate (snow load) on the thermal coefficient C_t
$f_s(n)$	adjustment factor for the characteristic value of the snow load dependent on the reference period n
$f_w(n)$	adjustment factor for the characteristic value of the wind load dependent on the reference period n
$f_E(n)$	adjustment factor for the earthquake ground acceleration dependent on the reference period n
h	length of column (between foundation and gutter); height (usually above ground level)
h_e	eaves height above ground level
h_g	gutter height above ground level
h_r	roof height; for multi-span roofs also depth of the inner troughs
$h_{s,k}$	heat transfer coefficient of the gas space k
k	seismic coefficient
k_n	quantile of the negative inverse standard normal distribution for the annual probability $P_1(n)$ for a reference period of n years
k_{mod}	modification factor for the load duration for glass
k_{ed}	strength reduction factor dependent on the edge finish of glass panes
k_{sp}	strength reduction factor dependent on the surface profile of glass panes
l	span; distance in longitudinal direction
l_{cb}	distance between the column bases
n	number
n	return period in years
n_d	design working life in years
$p_{T,1}$	target value of the annual probability of failure

$p_{T,50}$	target value of the failure probability accumulated to a reference period of $n = 50$ years
s	section length; roof span
$s_{k,n}$	characteristic ground snow load for the reference period n
$s_{i,n,t}$	characteristic roof snow load for the location i , the shape coefficient μ_i , the reference period n , the exposure coefficient C_e and the thermal coefficient C_t (Note: for $C_t < 1$; $C_e = 1$)
$\min s_{1,n,t}$	minimum roof snow load with reference to the ground area in kN/m^2
t	thickness
t	load duration
t_{nom}	nominal thickness of the glass panel
t_{pl}	design value of thickness of the glass panel
u	displacement or deflection
v_{int}	intended fall of the gutter
v_m	mean wind velocity
$v_{b,0}$	fundamental value of the basic wind velocity
v_b	basic wind velocity
w	width; overall width of multi-span roof; wind pressure
z_e, z_i	reference height of a greenhouse above ground for external or internal wind pressure
z_s	reference height for the gust wind response of the greenhouse structure
z_{min}	minimum height (onset of the wind profile)

Greek upper-case letters:

Φ	cumulative distribution function of the standard normal distribution
Δ	deviation from the intended position
$\Delta\varphi$	deviation from intended inclination

Greek lower-case letters:

α	angle of roof pitch; measured from the horizontal; coefficient of thermal expansion
α_{cr}	second-order elastic critical load factor
α_u	second-order elastic-plastic critical load factor
α_H	intended angle between the foundations of side wall and gable wall
β	angle between the horizontal and the tangent of arched roofs ($\beta = 0^\circ = \text{horizontal tangent}$; $\beta = 90^\circ = \text{vertical tangent}$)
$\beta_{T,1}$	target value of the reliability index of the annual failure probability
$\beta_{T,50}$	target value of the failure probability accumulated to a reference period of $n = 50$ years
γ_F	partial factor for actions (including variations and model uncertainties)
γ_M	partial factor for resistance (general)
$\gamma_G, \gamma_Q, \gamma_A$	partial factor for actions: permanent, variable and accidental action
γ_I	importance factor for earthquake actions dependent on the importance category

$\gamma_{s, \text{equ}}$	equivalent mean snow density by weight in kN/m^3
λ_j	thermal conductivity in W/(mK) for a material layer j ; ($\lambda_{j, \text{sup}}$ - upper value; $\lambda_{j, \text{inf}}$ - lower value)
μ_i	shape coefficient at the location i for roof snow load distributions
θ	radial angle of an arched roof
θ_i	internal air temperature in $^{\circ}\text{C}$
θ_e	external air temperature in $^{\circ}\text{C}$
ρ	density
ν	Poisson ratio
φ	intended inclination
ϕ_x	rotation angle of the cladding bar
$\psi_{0;1;2}$	combination value, frequent value and quasi-permanent value of variable actions in load combinations

5 Basis of design for greenhouse structures

5.1 General

(1) Greenhouses shall be designed to have adequate structural resistance, serviceability and durability. Types and classes of greenhouses are specified in 5.2. Recommendations for the reliability of commercial production greenhouses are specified in 5.3.

(2) Ultimate limit states shall be verified in accordance with Clause 6, and serviceability limit states in accordance with Clause 7.

(3) The greenhouse design shall meet the requirements for tolerance, durability, maintenance and repair given in Clause 8 and Clause 9.

5.2 Classes of greenhouse structures

5.2.1 General

Commercial production greenhouses are classified dependent on the tolerance to frame displacement of the cladding system as given in 5.2.2 and the design working life for the structure as given in 5.2.3.

NOTE The recommended classes, categories, values and procedures in 5.2, 5.3 and Clause 10 of EN 13031-1:2019 are applicable for the greenhouse design, if not otherwise specified in the National Annex to EN 13031-1.

5.2.2 Tolerance to frame displacements of the cladding system

(1) Greenhouses shall be designated as Type A or Type B depending upon the tolerance to frame displacements of the cladding system, as described in 5.2.2(2) to (4).

(2) Greenhouses in which the cladding system is not tolerant to frame displacements, resulting from the design actions, shall be designated as Type A. Type A greenhouses shall be designed by considering serviceability limit states (SLS) as well as ultimate limit states (ULS).

(3) Greenhouses in which the cladding system is tolerant to frame displacements, resulting from the design actions, may be designated as Type B. Type B greenhouses may be designed by considering ultimate limit states (ULS) only.

(4) In cases where only a part of the greenhouse cladding system is not tolerant to frame displacements, the greenhouse structure shall be designated as Type A. The local displacements of structural components directly carrying only parts of the cladding system, that are tolerant to frame displacements, need not be checked against serviceability limit state (SLS) criteria.

5.2.3 Design working life of the structure

(1) As indicated in EN 1990, commercial production greenhouses shall have a design working life dependent on the greenhouse type and use.

The life span of cladding (e.g. plastic film) may differ from the design working life, provided that the cladding can be exchanged in accordance with Clause 9.

(2) Greenhouses should be classified dependent on the design working life as shown in Table 1, where minimum values are given.

Table 1 — Recommendations for the classification of greenhouses (minimum values)

Type see 5.2.2	Commercial Production Greenhouse Class		
	Design working life n_d in years ^c		
	15 years	10 years	5 years
Type A	A15	–	–
Type B ^{a b}	B15	B10	B5

^a A design working life of 5 years may only be used for structures with limited service life, such as tunnels.

^b Where expensive plants (crops) and /or equipment are present in the greenhouse, the design working life should be not less than 10 years.

^c A design working life of at least 15 years shall be used for structures dedicated to technical areas (such as electric generator rooms, boiler rooms, storage areas, cold rooms, ferti-irrigation areas, water storage, packing areas, plants (crops) preparation areas, etc.) with low level of authorized personnel.

5.3 Reliability of commercial production greenhouses

5.3.1 General classification, recommendations

(1) According to EN 1990, commercial production greenhouses specified in 5.2.3 as Class A15 or Class B15, should be classified as structures of Consequence Class CC1.

(2) Commercial production greenhouses, specified in 5.2.3 as Class B10 and B5, should be classified as structures of Consequence Class CC0.

NOTE For commercial production greenhouses the consequences and nature of failure and the importance for public safety are lower than for normal buildings. There is no public access. Human access is restricted to authorized personnel, concerning low levels in number and duration. The potential economic loss is limited to the owner; the impact on the environment is low. The design working life is small. The statistical basis for the reliability differentiation in accordance with EN 1990 is given in Table 2.

5.3.2 Partial factors γ_F

(1) As indicated in EN 1990 the partial factors of actions γ_F may be modified using the recommended consequence factors K_{Fi} for actions in persistent and transient design situations:

$$\gamma_{F,i} = K_{Fi,i} \gamma_{F,i,CC2}$$

where

$K_{Fi,i}$ is the consequence factor for the consequence class according to Table 2;

$\gamma_{F,i}$ is the partial factor for the action i ;

$\gamma_{F,i,CC2}$ is the partial factor for the action i for the reference consequence class CC2, taken from EN 1990 and NAD.

(2) For the commercial production greenhouses classified in 5.3.1, the consequence factors based on EN 1990, should be taken as shown in Table 2.

Table 2 — Consequence factors for commercial production greenhouses

Persistent, transient and accidental design situations	Consequence Class		
ULS (reference period 50 years)	CC2 ^a	CC1	CC0
Target value of probability of failure for $n = 50$ years $p_{T,50}$ (Target value of reliability index $\beta_{T,50}$)	$5 \cdot 10^{-5}$ (3,8)	$5 \cdot 10^{-4}$ (3,3)	$5 \cdot 10^{-3}$ (2,6)
Target value of annual failure probability $p_{T,1} = 1 - (1 - p_{T,50})^{1/50}$ (Target value of reliability index $\beta_{T,1}$)	10^{-6} (4,7)	10^{-5} (4,2)	10^{-4} (3,7)
$K_{Fi,G}$ and $K_{Fi,Q}$ for permanent and variable actions	1	0,9	0,8
$K_{Fi,A}$ for accidental actions (without earthquake)	1	0,8	0,6
^a Basic reference values for $n = 50$ years, consequence class CC2 according to EN 1990.			

5.3.3 Combination coefficients

(1) In addition to general combinations of actions in ULS and SLS and the related combination coefficients that should be taken from EN 1990 and NAD, all design values of actions on greenhouses that may occur simultaneously shall be considered in combination. In verifying the serviceability and ultimate limit states, the effects of the most onerous combinations of design values of actions shall be considered.

(2) Values of ψ factors for wind and snow can be taken from EN 1990 + NAD. In case crop load is the leading variable action, the ψ factor for snow load may be taken as $\psi_{i,Qk2} = 0$ in case the thermal coefficient for the roof cladding can be taken as $C_t < 1$ (see Annex C, Table C.1). The recommended ψ factor for crop load is $\psi_{i,Qk3} = 1$ in all load combinations.

NOTE See Clause 10 of this standard for representative values of actions on greenhouses including recommendations for the definition of combinations of actions.

(3) Actions on greenhouses, which cannot occur simultaneously, for example, due to physical or functional reasons, should not be considered together in combinations.

(4) When wind action Q_{k1} and snow action Q_{k2} are to be considered in combination, from the wind action on the external surfaces, only the wall pressures and positive wind pressures on the roof should be taken into account.

(5) Combination coefficients for crop action Q_{k3} depend on the type of plants (crops) and the production method. If not otherwise specified, they can be classified as long-term variable loads.

If required by type of plants (crops) or the production method, snow loads should be combined with crop action Q_{k3} .

(6) Concentrated vertical action Q_{k4} due to maintenance or repair on the roof does not have to be combined with wind or snow action, if the roof is not accessed during extreme wind or snow events (roof category H): $\psi_{i,Qk4} = 0$.

(7) For concentrated vertical action Q_{k4} due to repair and for exceptional snow action the Serviceability Limit State (SLS) need not be considered.

5.3.4 Basis for actions on greenhouses

(1) In accordance with EN 1990, all actions and influences likely to occur during the design working life of the greenhouse shall be considered. In the following clauses this is adapted for greenhouses.

(2) The reference periods, return periods (recurrence intervals) and annual probabilities of exceedance for determining the characteristic values of the variable actions to be used in the design of each Class of greenhouse can be taken from Table 3, where minimum values are given.

The return period for actions “n” should not be taken less than the design working life “ n_d ”.

Table 3 — Reference periods for variable actions and probabilities of exceedance

Consequence Class	CC1	CC0	
Greenhouse Class	A15 and B15	B10	B5
Reference period for actions n in years	15	10	5
Annual probability of exceedance of actions	0,065	0,095	0,18
$P_1 \approx 1 - e^{(-1/n)}$ for n – reference period in years	(6,5 %)	(9,5 %)	(18 %)
Probability of exceedance of actions during the reference period n in years	$P_n \approx 1 - (1 - P_1)^n = 0,63$ (63 %)		
Adjustment factors $f_w(n)$ and $f_s(n)$ for the characteristic values of variable wind and snow actions, taking into account the reference period and annual probability of exceedance, are recommended in 10.2.2.1 and 10.2.2.2.			

6 Ultimate limit states

6.1 General

(1) The structural capacity of Type A and Type B greenhouses, determined in accordance with 6.2 or 6.3, shall be such, that the ultimate limit states are not exceeded under the design values of actions determined in accordance with Clause 10 of this standard.

(2) Clamping connections that operate by friction between structural members shall be able to transmit the ultimate limit state design forces without slipping.

6.2 Design calculations

(1) The design for the ultimate limit states shall be performed in accordance with the relevant parts of EN 1992 to EN 1999 and their NAD unless otherwise specified in this standard.

(2) Annex A of this standard can be applied for glass cladding.

The Eurocode does not contain design calculation methods for glass yet. In the absence of national regulations, which have to be used for commercial production greenhouses, Annex A should be applied.

(3) Annex D of this standard provides non-contradictory complementary information for steel arches.

NOTE EN 1993-1-1 does not contain detailed design calculation methods for greenhouse arches. In Annex D a design calculation method is given based on research results and tests on tubular steel arches for film plastic covered greenhouse tunnels.

(4) The material and product properties shall conform to the relevant parts of EN 1992 to EN 1999 and to Annex A of this standard for the glass cladding.

(5) Other materials and products may be used, if it can be demonstrated that the design is suitable for the intended purpose and leads to safe results.

6.3 Testing

The structural capacity may be determined by testing, provided that the tests and the evaluation are performed in accordance with the procedures described in Annex D of EN 1990.

7 Serviceability limit states

7.1 General

(1) The serviceability of Type A greenhouses, determined in accordance with 7.2 or 7.3, shall be such that the serviceability limit states with respect to displacements and deflections, presented in Clause 11, are not exceeded under actions determined in accordance with Clause 10 of this standard.

7.2 Design calculations

(1) The design calculation for serviceability limit states should be performed in accordance with the relevant parts of EN 1992 to EN 1999.

(2) If material and product properties do not conform to the relevant parts of EN 1992 to EN 1999, it has to be demonstrated, that the design using other materials or products is suitable for the intended purpose and leads to safe results.

7.3 Testing

The serviceability properties may be determined by testing, provided that the tests and the evaluation are performed in accordance with Annex D of EN 1990.

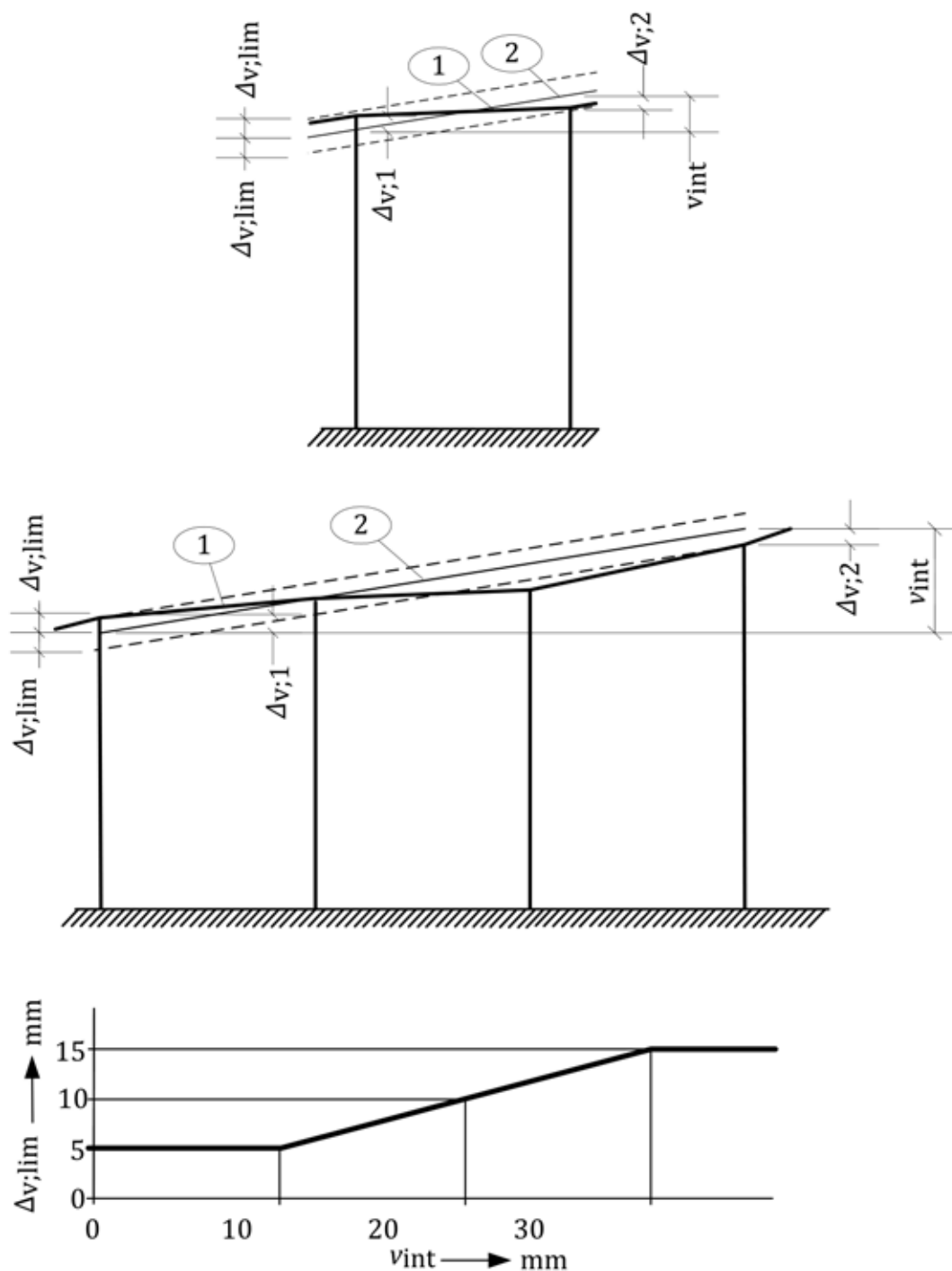
8 Tolerances

8.1 General

(1) The design calculation methods for greenhouses are only valid if the greenhouse structure conforms to 8.1, 8.2 and 8.3.

(2) The vertical deviation Δ_v from the intended position of the gutter at column ends shall be not more than $\Delta_{v,lim}$, where $\Delta_{v,lim}$ is equal to half the intended gradient v_{int} of the gutter per span, with a minimum upper limit of 5 mm and a maximum upper limit of 15 mm (see Figure 1).

NOTE The above requirement is fulfilled when $\Delta_v \leq \Delta_{v;\text{lim}}$, in any position on the gutter, for a segment of at least 3 times the gutter span (gutter span is the distance between two adjacent columns).



Key

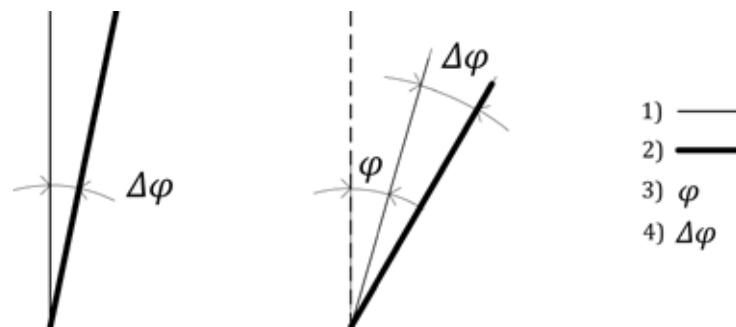
- 1 actual position
- 2 intended position

Figure 1 — Limit for the vertical deviation from the intended position of the gutter at column ends

(3) The deviation from the intended inclination of columns in any direction shall be not more than $1/200$ or $20/h$, whichever is smaller, where h is the column length measured between foundation and gutter in mm (see Figure 2).

For the deviation from the intended inclination, the influence of thermal actions may be taken into account.

The influence of thermal actions should be specified taking into account the temperature under which the components are made and the neutral temperature for the measuring instrument used (for both aspects, the temperature can regularly be taken as 20 °C).



Key

- 1) intended position in design
- 2) actual position
- 3) intended inclination
- 4) deviation from the intended inclination

Figure 2 — Deviation from the intended inclination of a column

(4) The deviation from the intended inclination of a foundation pile shall be not more than $1/50$.

(5) The position of the prefabricated foundation pile within the foundation hole shall be such that (see Figure 3):

- its centre lies within a circle with a radius equal to $D/5$ or 100 mm of the centre of the foundation hole, whichever is less;
- the distance between any edge of the pile and the edge of the foundation hole is at least 50 mm or $D/8$, whichever is larger;
- where D is the diameter of the foundation.

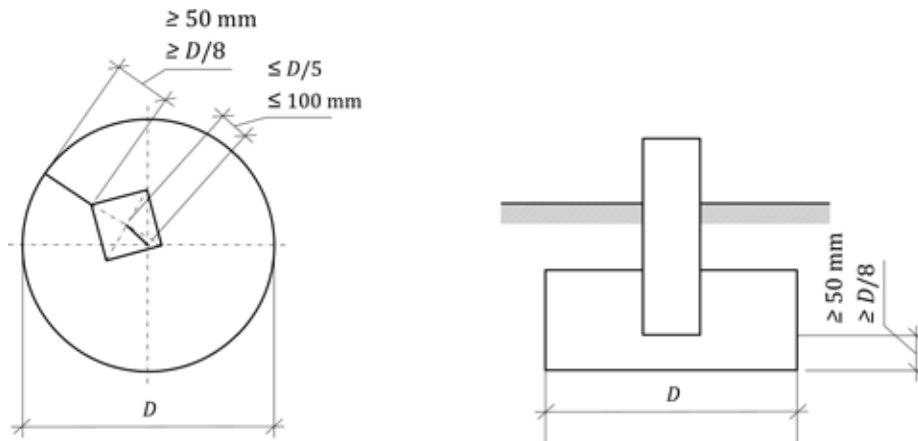


Figure 3 — Position of the prefabricated foundation pile within the foundation hole

(6) Tolerances of glass panels made of basic soda-lime silicate glass according to EN 572-1 – EN 572-6, not coated or coated in accordance with EN 1096-1, shall be as follows:

a) Single glass panels

The tolerance on nominal dimensions for thickness, length and width shall be as follows:

- annealed glass (float glass and drawn sheet glass also known as normal flat glass, patterned glass and wired glass) shall conform to EN 572-1 – EN 572-6;
- thermally toughened safety glass shall conform to EN 12150-1.

The tolerance on nominal dimensions for length and width of annealed glass may deviate from the values mentioned in EN 572-1 – EN 572-6, but shall be taken not less than:

- ± 1 mm for float and drawn sheet glass;
- ± 2 mm for patterned glass;
- ± 3 mm for wired glass.

b) Laminated glass

The tolerance on nominal dimensions for thickness, length and width shall conform to EN ISO 12543-5.

The tolerance on nominal dimensions for length and width may deviate from the values mentioned in EN ISO 12543-5, but shall be taken not less than ± 3 mm.

c) Insulating glass units

The tolerance on nominal dimensions for thickness, length and width shall conform to EN 1279-1.

The tolerance on nominal dimensions for length and width may deviate from the values mentioned in EN 1279-1, but shall be taken not less than ± 2 mm.

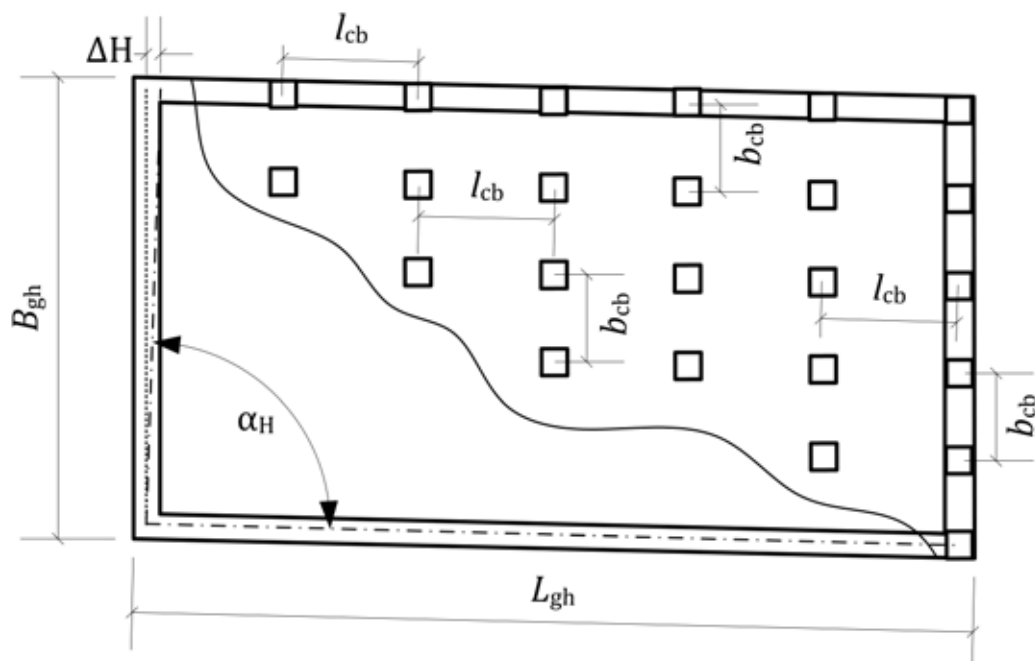
(7) Fabrication tolerances of structural steel components shall be in accordance with EN 1090-1.

8.2 Tolerances specific to Type A greenhouses

(1) The deviation in the dimensions and horizontal spacing between column bases shall be not more than the values given in Table 4.

Table 4 — Maximum allowable deviations in the horizontal distance

Dimensions, spacing (see Figure 4)	Maximum deviation
Distance between column bases in direction of the length l_{cb} and width b_{cb}	15 mm
Total length of the greenhouse L_{gh}	$\frac{1}{3000} L_{gh}$ or 30 mm, whichever is greater
Total width of the greenhouse B_{gh}	$\frac{1}{3000} B_{gh}$ or 30 mm, whichever is greater
Rectangularity of the plan: measured over the B_{gh} distance of the deviation ΔH in relation to α_H	$\frac{1}{3000} B_{gh}$ or 15 mm, whichever is greater



Key

B_{gh} width of the greenhouse

b_{cb} distance between column bases in direction of the width of the greenhouse

L_{gh} length of the greenhouse

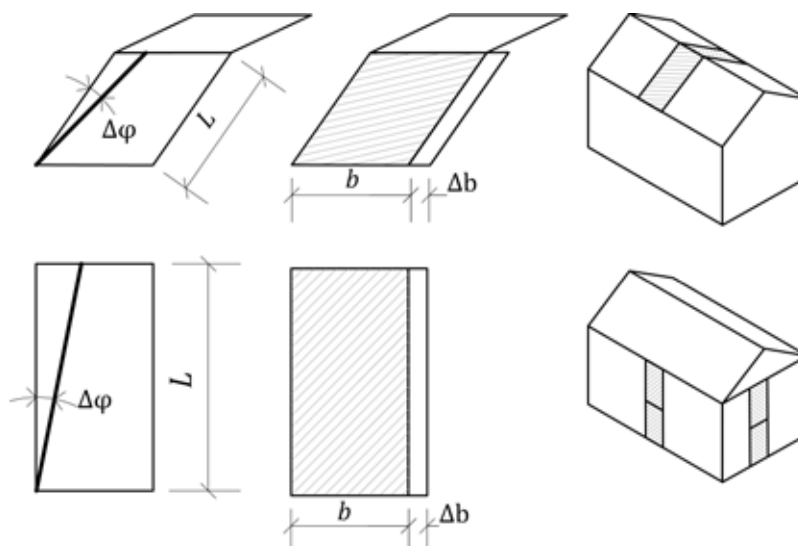
l_{cb} distance between column bases in the longitudinal direction of the greenhouse

α_H intended angle between the foundation of the side wall and the foundation of the gable wall

Figure 4 — Dimensions and horizontal spacing between column bases

(2) The deviation from the intended inclination of cladding bars in the plane of the cladding $\Delta\varphi$ shall be not more than $1/150$ or $12/L$, whichever is smaller, where L is the span of the cladding bar in mm (see Figure 5).

(3) The average deviation Δb from the intended centre-to-centre distance b of the cladding bars along the bar shall be no more than the value of the tolerance on the nominal dimensions for length and width of the cladding panels (see Figure 5).



Key

$\Delta\varphi$ deviation from intended inclination

Δb deviation from intended distance

L span of the cladding bar

b centre-to-centre distance of cladding bars

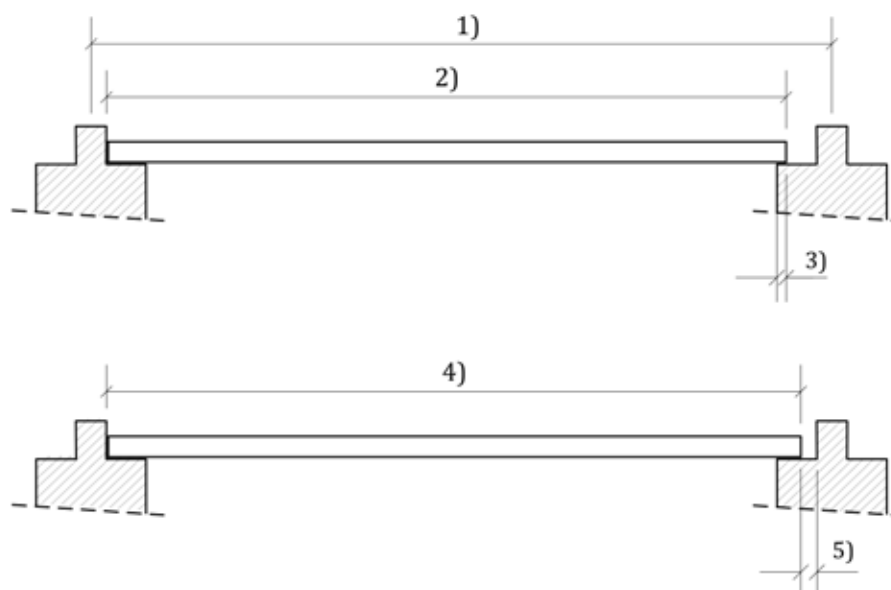
Figure 5 — Deviation from the intended position of cladding bars

(4) During installation of cladding panels, the cladding bars shall be positioned in a way that damage to the cladding panels is avoided. This can be achieved by having a clearance of at least 1 mm to pass any relevant part of the cladding bars.

(5) Cladding panels in installed condition shall conform to the following requirements to the support widths and clearances (see Figure 6):

- The distance between the edge of the cladding panel and the further edge of the supporting face of the cladding bar shall be at least 5 mm on average, but nowhere less than 1 mm in any position of the cladding panel. This condition shall be checked taking into account the position of the panel on the cladding bars, the tolerances on the nominal dimensions for length and width of the cladding panel, the tolerance on the position of the cladding bars and the deformations under actions in accordance with Clause 10 of this standard.
- The value of the clearance between two opposite cladding bars and the according cladding panel shall be taken in such a way that the cladding panel will not be cramped between cladding bars. This condition shall be checked taking into account the tolerances on the nominal dimensions for length and width of the cladding panel, the position of the cladding bars and the deformations under actions in accordance with Clause 10 of this standard.

NOTE For the position of the cladding bars it is allowed to take the nominal position provided that the design of the connections of the cladding bars to the supporting structure allows the cladding bars to shift to their nominal position after erection.



Key

- 1) nominal distance + limit for deviation (see 8.2(5))
- 2) nominal dimension cladding panel – tolerance
- 3) edge cover
- 4) nominal dimension cladding panel + tolerance
- 5) clearance

Figure 6 — Requirements for the support widths and clearances of cladding panels

8.3 Tolerances specific to Type B greenhouses

(1) The deviations in the dimensions and horizontal spacing between column bases shall not exceed the values given in Table 5.

Table 5 — Maximum allowable deviations in horizontal distances

Dimensions, spacing (see Figure 4)	Maximum deviation
Distance between column bases in both directions, length and width	30 mm
Total length of the greenhouse L_{gh}	$\frac{1}{1500} L_{gh}$ or 60 mm, whichever is greater
Total width of the greenhouse B_{gh}	$\frac{1}{1500} B_{gh}$ or 60 mm, whichever is greater

(2) For arches of Type B5 greenhouses, the deviation from the intended inclination of the arch-plane shall not be more than 1/50.

NOTE These larger tolerances are allowed because larger imperfections are used in the design. For arches a calculation method taking into account larger imperfections is described in Annex D of this standard.

9 Durability, maintenance and repair

9.1 General

The design calculation methods for greenhouses are only valid if the greenhouse structure conforms to 9.2. 9.3 is related to considerations for safe execution of maintenance and repair.

9.2 Durability

Greenhouse structures shall be protected against corrosion and deterioration in such a way that the structural safety is maintained for a period of not less than the design working life as specified in 5.2.3 of this standard.

9.3 Maintenance and repair

(1) Concentrated loads on the cladding need to be avoided.

Persons may not step on cladding panels for any reason whatsoever and should not access and/or should not be on the roof without a safe system for the transportation of people.

(2) Systems should be devised to avoid hazardous situations during access onto and movements across the roof for humans as well as for the transportation of heavy materials and equipment required for cleaning, maintenance or repair.

(3) In order to reduce the overall hazards involved in roof working, bulk materials, heavy components and equipment required for repairs should either be moved to the location of the repair inside the greenhouse and then lifted through the roof, or be transported over the roof on a special device.

(4) For the use of those working on the greenhouse roofs, greenhouse manufacturers shall supply a detailed manual of greenhouse specifications including service and maintenance loads considered in the design, in connection with instructions to avoid a concentration of materials on the roof (see Annex F and Annex G of this standard).

(5) Design criteria for the accessibility of the greenhouses, e.g. roof access, workways, walkways, or ladders on roofs, are not a normative part of this standard. The specifications given in the informative Annex G are recommendations.

10 Actions on greenhouses

10.1 General

(1) Actions shall be taken from the relevant parts of the Eurocode EN 1991 to EN 1998 and their NAD. Greenhouse specific actions, also to be considered, are given in the following clauses.

NOTE In accordance with EN 1990, the actions on greenhouses are indicated with upper-case letters “G” for permanent loads, “Q” for variable loads and “A” for accidental loads. To indicate the uniformly distributed shape of loads, also the corresponding lower-case letters “g” and “q” are used.

(2) Characteristic values of variable actions may be adjusted to the reference period for the design working life of classified greenhouses according to 5.3.4.

10.2 Representative values of actions

10.2.1 Permanent actions

10.2.1.1 Self-weight G_{k1}

(1) Permanent actions are actions due to the self-weight of structural and non-structural elements, excluding the installations even if they are permanently present.

(2) Characteristic values of the self-weight of construction elements shall be assessed in accordance with EN 1991-1-1.

10.2.1.2 Permanently-present installation actions G_{k2}

(1) Permanently-present installation actions are actions due to permanently installed equipment such as that for heating, cooling, lighting, shading, irrigation and ventilation.

(2) Characteristic values of the self-weight of fixed equipment shall be assessed in accordance with EN 1991-1-1.

(3) For Class A15 and Class B15 greenhouses the characteristic actions due to installations for heating, shading, cooling, lighting and ventilation shall be taken not less than $\min g_{k2} = 0,07 \text{ kN/m}^2$ on plan area.

In combination with wind action upwards (lift) on the greenhouse roof also $g_{k2} = 0 \text{ kN/m}^2$ should be considered.

(4) The characteristic value of the actions due to mains supply and return heating pipes shall be taken as the self-weight of the pipes when filled.

(5) Where greenhouse structures support horizontal wires and cables of shading and irrigation equipment, the effects of the forces resulting from the system and use of these wires and cables shall be taken into account, see also 10.2.2.3.

NOTE The following forces in horizontal wires and cables are taken as a lower limit:

- shading systems:
 - o supporting wires (polyester, nylon): 150 N per wire;
 - o supporting wires (steel): 500 N per wire;
 - o pull wire/ pull cable (steel): 1 000 N (prestress) + 50 N per connected section, per wire/cable;
- irrigation equipment:
 - o supporting wires (steel): 1 250 N per wire.

10.2.2 Variable actions

10.2.2.1 Wind actions Q_{k1}

(1) Characteristic values of wind actions shall be calculated in accordance with EN 1991-1-4 and the NAD.

(2) Annex B: this standard provides complementary information for 10.2.2.1 to take into account special properties of greenhouse structures, such as:

- reference height z_e for greenhouses;
- size effect on the gust wind response of greenhouses with a very large floor area;
- correlation of windward-leeward pressures for walls and greenhouse roofs;
- aerodynamic pressure coefficients for special greenhouse structures with smooth cladding such as, for example, film, plastic or glass.

(3) For wind loads based on a Gumbel distribution of the maximum annual wind data, e.g. speed, with the probabilistic parameters K and n , the adjustment factor $f_w(n)$ can be used:

$$f_w(n) = c_{\text{prob}}^2 = \left\{ \frac{\left[1 - K \ln \frac{1}{n} \right]^n}{\left[1 - K \ln \frac{1}{50} \right]^n} \right\}^2$$

where

- c_{prob} is the probability factor for the adjustment of the wind speed;
- n is the reference period for the design working life, see 5.3.4;
- K is the shape parameter dependent on the coefficient of variation V of the maximum annual wind data;
- n is the exponent of the probability function.

The probabilistic parameters for the distribution can be taken from NAD of EN 1991-1-4 or from other competent sources. If nothing else is available, the recommendation from EN 1991-1-4 can be taken:

$K = 0,2$ and $n = 0,5$, for a coefficient of variation of $V = \frac{\pi}{\sqrt{6 \left(0,577216 + \frac{1}{K} \right)}} = 0,23$ of the wind pressure

using a Gumbel distribution.

10.2.2.2 Snow actions Q_{k2}

(1) Characteristic values of snow actions shall be calculated in accordance with EN 1991-1-3 and NAD.

(2) For characteristic snow loads on the ground $s_{k,50}$ based on a Gumbel or a Lognormal distribution of the annual maximum snow loads, the adjustment factor $f_s(n)$ can be used: $s_{k,n} = f_s(n) s_{k,50}$.

- Gumbel:
$$f_s(n) = \frac{1 - V \frac{\sqrt{6}}{\pi} \left(\ln \frac{1}{n} + 0,577216 \right)}{1 + 2,6V} \quad \text{or}$$
- Lognormal:
$$f_s(n) = e^{(k_n - k_{50}) \sqrt{\ln(1+V^2)}}$$
 as indicated in NAD

where

- n is the reference period for the design working life, see 5.3.4;
- k_n is the quantile value of the negative inverse standard normal distribution:
 $k_n = -\Phi^{-1}(P_1(n))$ with the annual probability of exceedance $P_1(n)$ according to 5.3.4, Table 3;
- k_{50} is the reference quantile value for $n = 50$ years: $k_{50} = k_n(50) = 2,06$;
- V is the coefficient of variation of the annual maximum snow loads.

The coefficient of variation can be taken from NAD of EN 1991-1-3. Otherwise meteorological guidance should be sought. If the snow load is to be reduced ($f_s(n) < 1$), the minimum value of V is relevant. If nothing else is available, $\min V = 0,315$. The value $\min V = 0,315$ is related to the partial factor of $\gamma_{cc2} = 1,5$ as a target. If any other target is used, the value $\min V$ may be adapted.

(3) Annex C of this standard provides non-contradictory, complementary information for special conditions of greenhouse use and the properties of the structures, such as:

- Shape coefficients for sliding and accumulation of roof snow for greenhouses with smooth cladding, with or without heat transfer through the cladding.
- Thermal coefficients C_t for the reduction of roof snow due to melting for greenhouses with transparent, heat transmitting cladding ($U_o \geq 1 \text{ W/(m}^2\text{K)}$) and controlled heating ($\min \theta_i >> 5 \text{ }^\circ\text{C}$).

10.2.2.3 Crop actions Q_{k3}

(1) Crop actions are actions due to plants (crops) supported by or hanging from the structure.

(2) Characteristic values of the self-weight of plants (crops), containers and the growing medium shall be assessed in accordance with EN 1991-1-1. Crop actions may be considered to act vertically and uniformly distributed.

Permanent loads from irrigation systems, crop growing gutters, containers, growing medium, etc. should not be considered as crop actions Q_{k3} but as permanently-present installation actions G_{k2} according to 10.2.1.2

(3) Crop actions q_{k3} shall not be taken less than the minimum values given in Table 6.

Table 6 — Minimum values for crop actions q_{k3} and related installation actions g_{k2}

Crop	Minimum value for crop actions $\min q_{k3}$ in kN/m ²	Minimum value for crop growing gutters, containers, growing medium, etc. $\min g_{k2}$ in kN/m ²
Strawberries	0,05	0,25
Tomatoes, cucumber	0,20 ^a	0,13
Bell peppers	0,12	0,15
Other vegetables	0,15	0,13
^a For tomatoes and cucumber in greenhouses Type B5 the minimum value for crop actions $\min q_{k3}$ can be taken as $q_{k3} = 0,15 \text{ kN/m}^2$		

(4) Where crops hang on horizontal wires, allowance should be made for the wire forces:

NOTE The horizontal force per wire can be taken as:

$$F_{\text{wire}} = q_{k3} a \frac{l_{\text{wire,sup}}^2}{8u_{\text{wire}}}$$

where

F_{wire} is the value of the horizontal force per wire;

q_{k3} is the characteristic crop action;

a is the distance between the wires;

$l_{\text{wire,sup}}$ is the distance between the wire supports (section length);

u_{wire}

is the deflection of the loaded wire.

Recommended values: $l_{\text{wire},u}/30$ at a design value of $q_{k3} = 0,15 \text{ kN/m}^2$.

The horizontal force per wire should be calculated by taking into account the effect of displacements of the greenhouse structure due to thermal influences.

10.2.2.4 Concentrated vertical action Q_{k4}

(1) Concentrated vertical actions arise from maintenance and repair operations.

(2) Minimum values of concentrated vertical actions which shall be taken to act over a surface area of 100 mm by 100 mm, or over a length of 100 mm and over the full width of a structural member narrower than 100 mm, are given in Table 7.

Table 7 — Minimum values for concentrated vertical action

Concentrated vertical action	Minimum value for concentrated vertical action min Q_{k4} in kN
Action on the gutter	1,5
Action on the structural frame	1,0
Action on a secondary component, such as a cladding bar or ridge bar	0,35 ^a
^a For Class A15 greenhouses only. For single-span roofs without gutter, Q_{k4} may be taken equal to 0.	

10.2.2.5 Incidentally-present installation actions Q_{k5}

(1) Incidentally-present installation actions are actions of variable magnitude due to mobile equipment such as gantries running on rails supported by the structure, and cleaning equipment running along the roof, including service personnel.

(2) Characteristic values of actions for moveable installations shall be assessed from data provided by the manufacturer, such as details about the load transfer, self-weight of the complete equipment and load carrying capacity. Braking and acceleration forces of transportation equipment should also be taken into account.

10.2.2.6 Thermal actions Q_{k6}

(1) Thermal actions are actions due to climatic and operational temperature differences and changes.

(2) In accordance with EN 1991-1-5 and NAD thermal actions need to be taken into account for structures and structural components, which are not tolerant to movements and /or stress caused by thermal actions.

(3) For greenhouses the characteristic values of thermal actions shall be derived from the differences in temperature that can occur within a 24 h period. In the absence of specific national regulations (NAD) for greenhouses, the characteristic values of the temperature ranges for moderate European climate can be taken from Table 8.