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Thermal performance of buildings — Thermal design of foundations to avoid frost heave

Performance thermique des bâtiments — Conception thermique des fondations pour éviter les poussées dues au gel

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Foreword

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Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of member bodies casting a vote.

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International Standard ISO 13793 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 163, *Thermal insulation*, Subcommittee SC 2, *Calculation methods*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Throughout the text of this standard, read "...this European Standard..." to mean "...this International Standard...".

Annexes A, B and C form a normative part of this International Standard. Annexes D and E are for information only.

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Foreword

The text of EN ISO 13793:2001 has been prepared by Technical Committee CEN/TC *89 "Thermal performance of buildings and building components*", the secretariat of which is held by SIS***,*** in collaboration with Technical Committee ISO/TC 163 "*Thermal insulation*".

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of an identical text or by endorsement, at the latest by September 2001, and conflicting national standards shall be withdrawn at the latest by September 2001.

References to International Standards that have also been published as European Standards are given in normative annex ZA, which is an integral part of this European Standard.

Annexes A, B and C form an integral part of ISO 13793. Annexes D and E are for information only.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

Frost heave is the deformation of a building due to ice lenses in the ground below it, which can occur when soil freezes under the foundations or other structural members in contact with the soil. This is relevant to the design of building foundations in climates where the depth of penetration of frost into the ground may exceed the minimum foundation depth necessary for structural reasons.

Not all types of soil are susceptible to frost heave (this is discussed in annex D).

The risk of frost heave can be avoided in various ways. One is to have foundations deep enough so as to be below the frost penetration depth. Thus, special design procedures for frost heave are not necessary for buildings with basements extending more than the frost penetration depth below ground level (except to ensure the use of suitable backfill material that will not adfreeze to the basement wall).

Another possibility is to remove the frost-susceptible soil down to a depth below the frost penetration depth, and replace it with material that is non-susceptible to frost before constructing the foundations.

A third option is to insulate the foundations so as to avoid frost penetrating below the foundations. In cold climates the latter option is frequently the most economic as it allows shallower foundations, and this standard gives methods for determining the width, depth, thermal resistance and placement of insulation in the foundation region in order to reduce the risk of frost heave to a negligible level.

In unheated buildings the heat available from the building itself is less than with heated buildings, and more perimeter insulation is needed to protect the foundations.

The procedures in this standard are essentially those that have been used in the Nordic countries over many years, and have been found to be satisfactory in practice in preventing frost heave. They are based on the results of dynamic computer calculations, which took account of the annual temperature cycle, the heat capacity of the ground, the latent heat of freezing of water, etc., and which have been validated by experimental data from actual constructions.

The standard is concerned with ensuring that the ground below the foundation (if frost-susceptible) does not become frozen. In permafrost areas (annual average temperature less than 0 °C), the appropriate design may, by contrast, be based on maintaining the ground fully frozen for the whole year. That involves quite different solutions that are not considered in this standard.

1 Scope

This standard gives simplified procedures for the thermal design of building foundations so as to avoid the occurrence of frost heave.

It applies to foundations on frost-susceptible ground, and includes buildings with both slab-on-ground floors and suspended floors.

It covers heated and unheated buildings, but other situations requiring frost protection (for example roads, water pipes in the ground) are not included.

The standard is not applicable to cold stores and ice rinks.

The standard applies in climates where the annual average air temperature is above 0 °C, but does not apply in permafrost areas where the annual average air temperature is below 0 °C.

2 Normative references

This European Standard incorporates, by dated or undated references, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references, the latest editions of the publication referred to applies (including amendments).

ISO 6946	*Building components and building elements - Thermal resistance and thermal transmittance - Calculation method*
ISO 7345	*Thermal insulation - Physical quantities and definitions*
ISO 10211-1	*Thermal bridges in building construction - Heat flows and surface temperatures - Part 1: General calculation methods*
ISO 10456	*Building materials and products - Procedures for determining declared and design thermal values*

3 Definitions, symbols and units

3.1 Terms and definitions

For the purposes of this standard, the terms and definitions in ISO 7345 and the following apply.

3.1.1
slab on ground floor
floor construction directly on the ground over its whole area

3.1.2
suspended floor
floor construction in which the floor is held off the ground, resulting in an air void between the floor and the ground

NOTE This air void, also called underfloor space or crawl space, may be ventilated or unventilated, and does not form part of the habitable space.

3.1.3
vertical edge insulation
insulation placed vertically against the foundation internally and/or externally, or within the foundation itself

3.1.4
ground insulation
insulation placed horizontally (or nearly so) below ground, external to the building

NOTE See Figure 1.

3.1.5
freezing index
24 times the sum of the difference between 0°C and daily mean external air temperature, accumulated on a daily basis over the freezing season (including both positive and negative differences)

3.1.6 freezing season
period during which the mean daily external air temperature remains less than 0°C, together with any freezing/thawing periods at either end of this period if they result in net freezing

3.1.7
frost depth
depth of penetration of frost into the ground

3.1.8
foundation depth
depth of foundation below the outside ground level

NOTE If the foundations are put on a layer of well-drained material that is non-susceptible to frost, the thickness of such a layer may be included in the foundation depth.

3.1.9
frost-susceptible soil
soil of a type which may cause frost heave forces when frozen as part of the ground

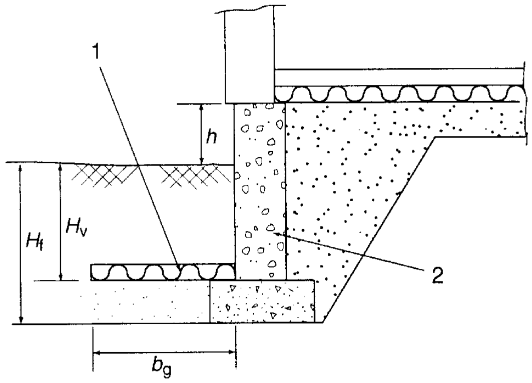
3.1.10
floor insulation position
height of lower surface of the floor insulation layer above external ground surface

NOTE If there is no insulation in the floor this quantity is measured from the floor surface.

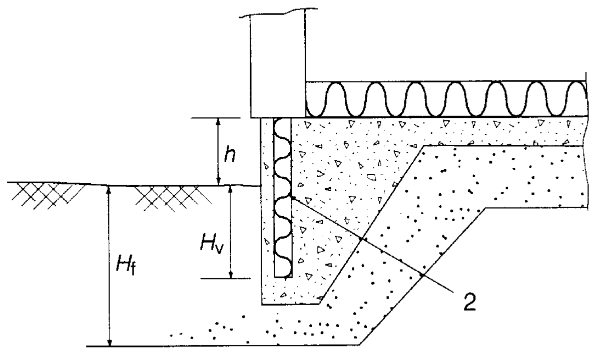
3.2 Symbols and units

The following is a list of the principal symbols used. Other symbols are defined where they are used within the text.

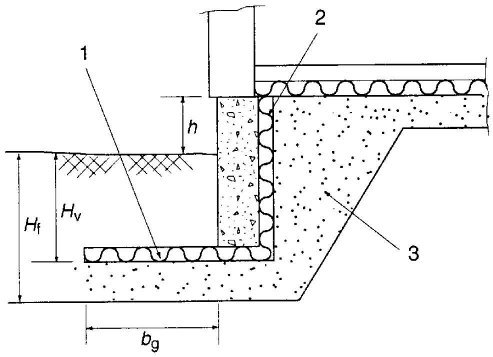
Symbol	Quantity	Unit
B	width (smaller dimension) of building	m
b_g	width of ground insulation, measured from outer limit of footing	m
b_{gc}	width of ground insulation at corner	m
b_{gw}	width of ground insulation along wall	m
F_d	design freezing index	K·h
F_n	freezing index which statistically is exceeded once in a period of *n* years	K·h
H_0	maximum frost depth in undisturbed, snow-free ground	m
H_f	foundation depth for walls	m
H_{fc}	foundation depth for corners	m
H_v	depth of vertical edge insulation	m
h	floor insulation position	m
L_c	length of corner insulation (measured along external surface of wall)	m
R_f	thermal resistance of floor construction (average value over the outer 1 m of floor)	m²·K/W
R_v	thermal resistance of vertical edge insulation	m²·K/W
R_g	thermal resistance of ground insulation	m²·K/W
R_{gc}	thermal resistance of ground insulation at corner	m²·K/W
R_{gw}	thermal resistance of ground insulation along wall	m²·K/W
$\overline{\theta}_e$	annual average external air temperature	°C
$\theta_{i,m}$	average internal air temperature in month *m*	°C



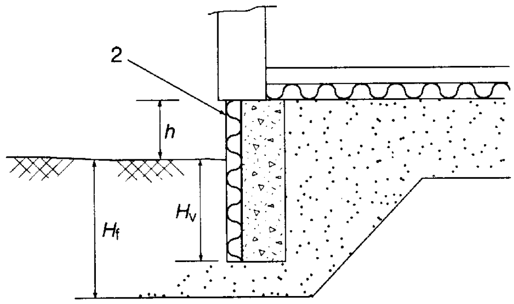
a) Lightweight concrete foundation wall with ground insulation



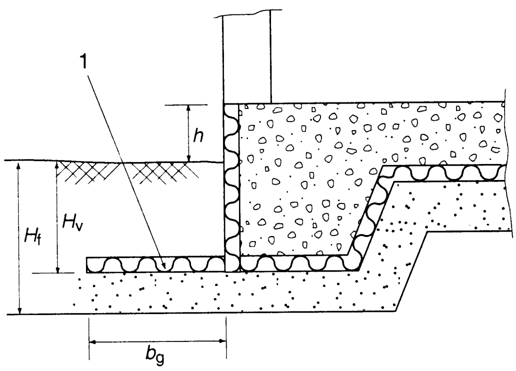
b) Floor slab with edge beam



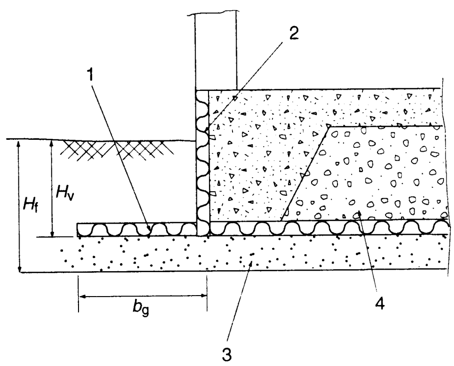
c) Concrete foundation wall with ground insulation and internal vertical edge insulation



d) Concrete foundation wall with external vertical edge insulation



e) Raft construction with ground insulation and vertical edge insulation



f) Raft construction over a bed of crushed stones (h < 0 in this case, so is not considered)

Key

1 Ground insulation

2 Vertical edge insulation

3 Non frost-susceptible soil

4 Bed of crush stones ventilated from inside

NOTE These are illustrations to show thermal principles and should not be considered as constructional details.

Figure 1 - Examples of vertical edge insulation and ground insulation in foundation structures

4 Design principles

Soil is fully frozen when all the water in it is frozen. This is assumed to have occurred when the temperature of the soil reaches -1 °C (see annex D). The data given in clauses 8 to 10 apply when the foundations are to be designed so that no fully frozen soil occurs below the foundation during the design winter. Alternative data based on a criterion of 0°C are given in annex C.

This design condition may be achieved in one of four ways:

1) arranging for the foundation depth to be greater than the depth at which fully frozen soil occurs;

2) removing frost-susceptible soil from below where the foundations will be built, to the same depth as mentioned in 1), and replacing this with well-drained material that is non-susceptible to frost;

3) insulating the foundations to reduce heat loss from the soil below the foundations so as to keep this soil unfrozen;

4) using heat loss from the building, or special heating measures, to keep the soil below the foundations unfrozen.

For the purposes of this standard, 1) and 2) are equivalent and are covered in clause 7. Furthermore, the solution adopted can be a combination of 2), 3) and 4). Thus, the thickness of any layer below the foundations that is non-susceptible to frost may be included in the foundation depth H_f when using this standard to decide whether frost protection measures are necessary and, if so, what insulation is needed.

NOTE 1 If option 4) is chosen, a combination with 3) is usually necessary to restrict heat loss.

The insulation required by options 3) and 4) can be determined by:

a) using the tables and graphical presentations in this standard (see clause 8, 9 or 10, depending on the type of building), or

b) undertaking numerical calculations conforming with the principles given in annex B.

It is also permissible to use a combination of a) and b), for example determination of insulation required at corners by a) and (two-dimensional) numerical calculations to determine the insulation required elsewhere.

Heat emission from floor heating systems, heating cables in the ground, or similar, is not allowed for in the design procedures of clauses 8 to 10. Numerical calculations shall be undertaken when such heat emission is to be considered.

NOTE 2 If the design procedures of clauses 8 to 10 are applied to such situations, there will be an additional margin of safety as regards frost heave, but perhaps additional heat loss.

The foundations shall be designed to avoid adfreezing of the soil, thus preventing frost heave by transfer of shear forces, for example by having a layer of material that is non-susceptible to frost adjacent to the walls of the foundation or basement.

If the building envelope is not completed and/or the building is not heated before the frost season, additional insulation measures shall be undertaken to protect the foundations.

NOTE 3 One way of achieving such additional protection is to design the foundations as for unheated buildings using a design freezing index for non-permanent structures (see 6.1).

The parameters relevant to frost protection are:

- climate, especially freezing index and annual average temperature;
- frost susceptibility of the soil;
- thermal properties of the ground, both frozen and unfrozen;
- insulation of the floor;
- internal temperature in the building;
- the geometry, and especially the overall dimensions, of the building, and the type of foundation used.

NOTE 4 Snow cover has the effect of reducing the frost penetration depth, but since snow cover cannot be assured for design purposes, no allowance for it is made when assessing the design criterion.

Some examples are illustrated in Figure 1.

5 Material properties

5.1 Properties of the ground

The ground shall be considered to be frost-susceptible unless otherwise established by geotechnical examination.

NOTE 1 Information about frost susceptibility is given in annex D.

This standard is based on homogeneous ground consisting of frost-susceptible soil with the following properties:

thermal conductivity (unfrozen)	λ = 1,5 W/(m·K)
thermal conductivity (frozen)	λ_f = 2,5 W/(m·K)
heat capacity per volume (unfrozen)	C = 3 × 10^6 J/(m³·K)
heat capacity per volume (frozen)	C_f = 1,9 × 10^6 J/(m³·K)
latent heat of freezing per cubic metre of soil	L = 150 × 10^6 J/m³
dry density	ρ = 1350 kg/m³
water content (saturation degree = 90 %)	w = 450 kg/m³

For most types of frost-susceptible soils, the frost penetration depth adjacent to a building differs little from that determined using the above values. If, however, the actual soil properties are considerably different from those listed above, numerical calculations in accordance with annex B should be undertaken.

NOTE 2 As a general rule, the design data in clauses 8 to 10 can be applied for soils with dry density in the range 1100 kg/m³ to 1600 kg/m³ and with water saturation exceeding 80 %.

NOTE 3 When ground insulation is used, the relevant properties are those of the soil in the vicinity of the building. If ground insulation is not used, the properties of the backfill may be significant, especially if the backfill zone is relatively wide. Backfill (which is well-drained to avoid adfreezing) can increase the frost penetration depth locally due to absence of water in the soil and its associated latent heat.

5.2 Properties of building materials

For the thermal resistance of any building product, use the appropriate design value, either calculated according to ISO 10456 or obtained from tabulated values. The thermal resistance of products used below ground level shall reflect the moisture conditions of the application.

NOTE Moisture conditions may be affected by whether or not the building is heated, and are often more severe adjacent to unheated buildings.

If thermal conductivity is quoted, obtain the thermal resistance as the thickness divided by thermal conductivity. The thickness used shall allow for any compression of the product, if applicable.

Ensure that any insulation material subject to compressive load has adequate compressive strength and deformation characteristics.

If ground insulation is necessary for the protection, measures shall be taken to ensure that it is not damaged or removed after completion of the building. Inform the user of the building of the presence and location of the ground insulation and of its purpose.

6 Climatic data

6.1 Design freezing index

The insulation required for frost protection depends on the severity of the design winter, expressed in terms of the freezing index together with the annual average external air temperature.

The design freezing index F_d is expressed in terms of F_n, the value of the freezing index which statistically is exceeded once in n years for the locality concerned, based on recorded meteorological data and calculated according to annex A. F_n has a 1 in n probability of being exceeded in a given winter.

Having selected the value of n, obtain F_n from tables or maps covering the locality concerned.

The appropriate value of n is related to the expected lifetime of the building and the sensitivity of the building to frost heave.

For permanent structures use F_{100} or F_{50}.

NOTE For practical purposes F_{100} and F_{50} can be considered to be equivalent, as the difference between them is very small, and either may be used (depending on availability).

For the design of buildings that can tolerate some movement, or for non-permanent buildings, a lower freezing index (e.g. F_{20}, F_{10}, F_5) may be used.

6.2 Frost depth in undisturbed ground

The greatest depth of frost penetration in undisturbed ground (i.e. ground unprotected by buildings, snow cover or vegetation) depends on the climate (freezing index and annual average air temperature) and on the thermal properties of the ground.

NOTE Design values of maximum frost depth in undisturbed, homogeneous frost-susceptible ground without snow cover, H_0, may be found for some locations in national maps or tables.

If H_0 is not known, an approximate value may be calculated from the following equation:

$$H_0 = \sqrt{\frac{7200\, F_d\, \lambda_f}{L + C\,\bar{\theta}_e}} \qquad (1)$$

where

F_d is the design freezing index, in K·h;

λ_f is the thermal conductivity of frozen soil, in W/(m·K);

L is the latent heat of freezing of water in the soil per volume of soil, in J/m³;

C is the heat capacity of unfrozen soil per volume, in J/(m³·K);

$\bar{\theta}_e$ is the annual average external air temperature, in °C.

If appropriate soil data are not given, use the data in 5.1.

7 Foundation depth greater than frost depth in undisturbed ground

The foundations of any building can be designed so that the foundation depth, H_f, is at least the maximum frost depth in undisturbed snow-free ground, H_0.

If $H_f \geq H_0$, the foundations are adequately protected against frost heave and neither edge insulation nor ground insulation is required.

If the foundations are on a layer of well-drained material that is non-susceptible to frost, the thickness of such a layer may be included in H_f.

NOTE For climates with F_d < 2000 K·h this condition applies for depth of foundation of 0,45 m or greater.

If $H_f < H_o$, consult clauses 8 to 10 or undertake numerical calculations according to annex B.

8 Slab-on-ground floors for heated buildings

8.1 Applicability

This clause applies to foundations for which $H_f < H_0$ and to:

a) buildings in which the average internal air temperature throughout the building in each month is at least 17 °C (i.e. $\theta_{i,m} \geq 17$ °C for all *m*);

b) buildings in which some parts are heated and some parts are unheated, provided that in the heated parts $\theta_{i,m} \geq 17$ °C for all *m*, and that the unheated parts are treated as described in 8.5;

c) buildings in which 5 °C ≤ $\theta_{i,m} < 17$ °C with the modifications described in 8.8.

If $\theta_{i,m} < 5$ °C in any month, the frost protection of the foundations should be designed as for unheated buildings (see clause 10).

For data based on a design criterion of 0 °C below the foundations, see annex C.

8.2 General principles

In all cases, provide vertical edge insulation as specified in 8.6.

Heat from the building raises the ground temperature less at corners than along the sides of the building. Therefore additional measures may be needed at corners, either by having deeper foundations at the corners or by having additional insulation there.

This clause provides three options for achieving the necessary frost protection:

1) using vertical edge insulation only, with no ground insulation: excavate the foundations to the depth given in 8.7.1 (a greater foundation depth is needed at corners than along the rest of the walls);

2) using ground insulation only at the corners, to avoid increasing the foundation depth at the corners: the foundation depth is as for the walls in 1), see 8.7.2;

3) using a restricted foundation depth (not less than 0,4 m), with the same foundation depth all round the building: provide ground insulation all round the building, but increased at the corners, see 8.7.3.

The foundation depth and/or the extent of the ground insulation is determined by the design freezing index, F_d.

Design the floor insulation to give satisfactory floor temperatures and energy economy (i.e. independently of the frost heave problem).

NOTE The use of vertical edge insulation and ground insulation increases floor surface temperatures and decreases heat loss at the edge of the floor.

8.3 Restrictions

8.3.1 Building width

The foundation depths and frost insulation specified in this clause apply to buildings with a width *B* of at least 4 m.

If *B* < 4 m the foundations should be designed, either in depth or in provision of ground insulation, according to the procedures given for corners, but applied all round the building.

8.3.2 Floor insulation position

The foundation depths and frost insulation specified in this clause apply to floors for which the floor insulation position *h* does not exceed 0,6 m.

If *h* > 0,6 m, either undertake numerical calculations in accordance with annex B or use the procedures for unheated buildings (clause 10).

8.3.3 Thermal resistance of floor slab

The thermal resistance of the floor construction, R_f, is the total thermal resistance between the floor surface and the soil. It includes any insulation layers above, below or within it, together with that of any floor covering.

If the thermal resistance of the floor construction varies over its area, take R_f as the average value over the outer 1 m of floor.

The foundation depths and frost insulation specified in this clause apply to slabs with R_f not exceeding 5 m²·K/W. If R_f > 5 m²·K/W, either undertake numerical calculations in accordance with annex B or use the procedures for unheated buildings (clause 10).

8.4 Ground insulation

Ground insulation shall be protected against risk of mechanical damage. The top surface of any ground insulation should be at least 300 mm below ground level, unless covered by paving in which case the depth may be reduced to 200 mm.

The data given on the width of ground insulation, b_g, b_{gw} and b_{gc}, assume that this width is measured from the outermost face of the foundation.

> NOTE It may be necessary for the total width of the ground insulation to be greater than b_g, if the footing projects beyond the foundation wall, as in Figure 1a.

If ground insulation is used together with internal edge insulation, take care to avoid a thermal bridge by continuing the ground insulation beneath the foundation to meet the vertical edge insulation (see Figure 1c).

Ensure that ground insulation is continuous with no gaps, that it is adequately protected from excessive moisture by roof overhangs, sound guttering arrangements, etc. and that it is placed on a drainage layer.

8.5 Unheated parts of a building

8.5.1 General

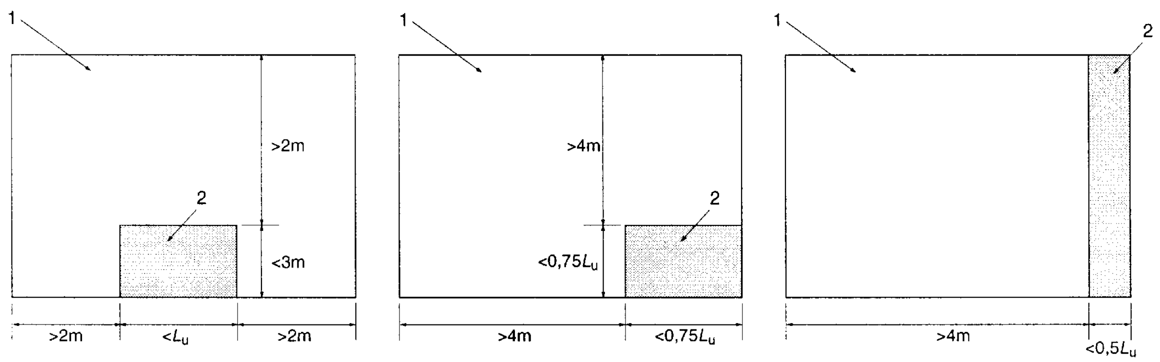
If some parts of a building are unheated, the procedures of 8.6 and 8.7 may be applied to the heated parts, provided that the protection described in 8.5.2 or 8.5.3 (as appropriate) is applied to the unheated parts of the building.

8.5.2 Building with limited unheated parts

The unheated parts of a building may be regarded as limited if their dimensions do not exceed those indicated in Figure 2, where the parameter L_u is given as a function of the design freezing index in Table 1.

Table 1 - Maximum unheated length L_u for limited unheated parts

F_d (K·h)	≤ 30 000	> 30 000 to 40 000	> 40 000 to 50 000	> 50 000
L_u (m)	3,0	2,5	2,0	1,5



Key

1 Heated part

2 Unheated part

Figure 2 - Definition of limited unheated part of floor slab

NOTE L_u is the maximum length of an unheated part which is surrounded on three sides by heated areas of the building. The maximum length is less than L_u in other cases, as shown in Figure 2.

For limited unheated parts:

- insulate the floor of the unheated part so that the thermal resistance of the floor is at least to the minimum ground resistance, R_g, for unheated buildings according to 10.2 (Table 11 or Table 12);

- at the external perimeter of the unheated part, use vertical edge insulation according to 8.6;

- if the unheated part is surrounded on three sides by heated areas of the building (Figure 2a): use frost protection as for corners according to 8.7 at the external perimeter of the unheated part and for a distance L_c to each side of it, where values of L_c are given as a function of the design freezing index in Table 5;

- if the unheated part is surrounded on only one or two sides by heated areas of the building (Figures 2b and 2c): at the external perimeter of the unheated part and for a distance L_c to each side of it, use ground insulation of width $0{,}5b_g$, with b_g according to 10.2 (Table 10), of thermal resistance R_g as for unheated buildings according to 10.2 (Table 11 or Table 12), where values of L_c are given as a function of the design freezing index in Table 5;

- avoid thermal bridges at the internal perimeter of the unheated part.

8.5.3 Building with more extensive unheated parts

If any unheated part of a building cannot be regarded as limited because its dimensions exceed those indicated in Figure 2, regard the heated and the unheated parts as separate buildings and design the foundations accordingly, continuing the design for the unheated part for a distance L_c where it adjoins the heated part, where values of L_c are given as a function of the design freezing index in Table 5.

8.6 Vertical edge insulation

In all cases, provide vertical edge insulation, of thermal resistance R_v at least that given in Table 2. Use linear interpolation to obtain intermediate values.

Table 2 - Minimum thermal resistance of vertical edge insulation for slab-on-ground floors, R_v (in m²·K/W)

R_f in m²·K/W, h in m

F_d K·h	$0{,}0 < R_f \le 1{,}0$		$1{,}0 < R_f \le 2{,}6$		$2{,}6 < R_f \le 5{,}0$	
	$h \le 0{,}3$	$0{,}3 < h \le 0{,}6$	$h \le 0{,}3$	$0{,}3 < h \le 0{,}6$	$h \le 0{,}3$	$0{,}3 < h \le 0{,}6$
5 000	-	-	0,5	0,8	0,8	1,0
10 000	0,5	0,8	1,0	1,0	1,5	2,0
20 000	0,8	1,0	1,0	1,2	1,5	2,3
30 000	1,0	1,0	1,0	1,3	1,5	2,5
40 000	1,0	1,0	1,2	1,5	1,7	2,7
50 000	1,0	1,2	1,4	1,7	2,0	3,0
60 000	1,2	1,4	1,8	2,1	2,4	3,4
70 000	1,4	1,6	2,1	2,4	2,8	3,6

NOTE 1 Greater values of R_v than those shown in Table 2 may be appropriate for reasons of minimum floor surface temperatures or restriction of heat loss.

The necessary vertical edge insulation can be obtained by using a foundation material with low thermal conductivity (e.g. lightweight concrete), or by using a layer of insulation material external to, within or internal to the foundation wall or beam.

NOTE 2 Although external insulation is preferable from the point of view of frost protection, the data given cover all the above alternatives.

Vertical edge insulation should extend from the top of the slab insulation to a depth H_v below ground level, taking care to avoid a thermal bridge between the slab insulation, the wall insulation and the vertical edge insulation, where:

- with no ground insulation, $H_v \geq 0,6$ m or the full foundation depth if less;
- with ground insulation, H_v is the depth of the lower surface of the ground insulation.

8.7 Alternative foundation designs

The foundation design should comply with 8.6 and with one of the following alternatives.

8.7.1 Foundations with no ground insulation

The foundation depth should be:

- at the walls, at least H_f;
- near the corners and at limited unheated parts for a distance L_c from these places, at least the greater depth H_{fc} (if F_d > 30 000 K·h);

where the values of H_f, H_{fc} and L_c are given in Table 3 as a function of the design freezing index.

Table 3 - Foundation depth for slab-on-ground floor without ground insulation

F_d K·h	H_f m	H_{fc} m	L_c m
$F_d \leq$ 30 000	0,35	0,35	-
30 000 < $F_d \leq$ 35 000	0,40	0,60	1,0
35 000 < $F_d \leq$ 40 000	0,50	0,80	1,0
40 000 < $F_d \leq$ 45 000	0,60	1,00	1,5
45 000 < $F_d \leq$ 50 000	0,75	1,30	1,5
50 000 < $F_d \leq$ 55 000	0,90	1,60	1,5
55 000 < $F_d \leq$ 60 000	1,10	1,80	2,0
60 000 < $F_d \leq$ 65 000	1,30	2,00	2,0
65 000 < $F_d \leq$ 70 000	1,50	2,20	2,5

8.7.2 Ground insulation only at corners

If $F_d \leq$ 30 000 K·h, ground insulation is not required.

For greater values of F_d, the foundation depth shall be at least H_f all round the building, and ground insulation shall be used near corners and at limited unheated parts for a distance L_c from these places, where the values of H_f and L_c are given in Table 4.

The thermal resistance of the ground insulation shall be at least 1,0 m²·K/W, and its width shall be b_{gc}, values of b_{gc} being given in Table 4. See also Figure 3.

Table 4 - Foundation depth and corner insulation for slab-on-ground floor

F_d K·h	H_f m	b_{gc} m	L_c m
$F_d \leq$ 30 000	0,35	-	-
30 000 < $F_d \leq$ 35 000	0,40	0,50	1,0
35 000 < $F_d \leq$ 40 000	0,50	0,50	1,0
40 000 < $F_d \leq$ 45 000	0,60	0,50	1,5
45 000 < $F_d \leq$ 50 000	0,75	0,60	1,5
50 000 < $F_d \leq$ 55 000	0,90	0,80	1,5
55 000 < $F_d \leq$ 60 000	1,10	0,80	2,0
60 000 < $F_d \leq$ 65 000	1,30	0,80	2,0
65 000 < $F_d \leq$ 70 000	1,50	1,00	2,5

8.7.3 Ground insulation all round the building

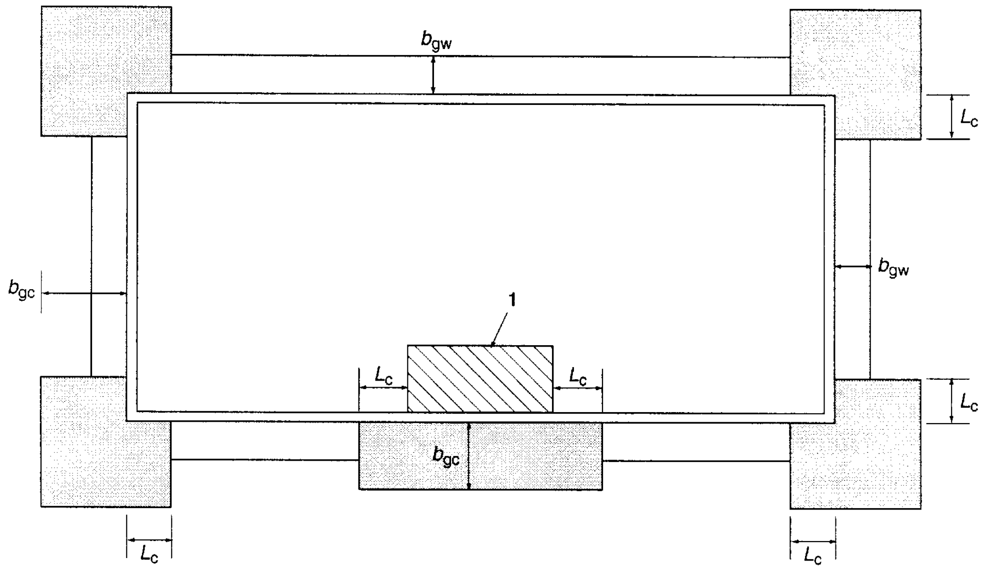
If $F_d \leq$ 30 000 K·h, ground insulation is not required.

For greater values of F_d, the foundation depth may be reduced to not less than 0,4 m by placing ground insulation all round the building.

If F_d > 30 000 K·h, ground insulation is necessary near corners and at limited unheated parts, for a distance L_c from these places as given in Table 5. Select an appropriate combination of thermal resistance, R_{gc}, and width, b_{gc}, of ground insulation near the corners using Figure 4, according to the value of F_d.

If F_d > 37 500 K·h, ground insulation is also necessary along the walls. Select an appropriate combination of thermal resistance, R_{gw}, and width, b_{gw}, of ground insulation along the walls using Figure 5, according to the value of F_d. Then use Figure 4 to determine the greater ground insulation needed near the corners and unheated parts. The corner insulation applies for a distance L_c as given in Table 5.

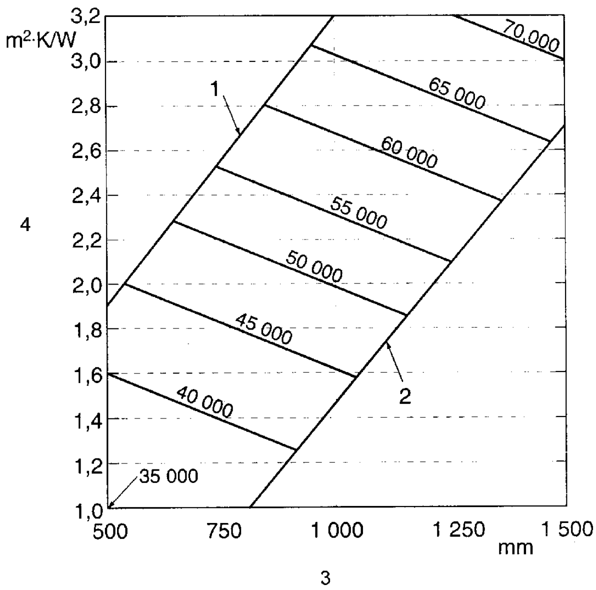
See also Figure 3.



Key

1 Limited unheated part (store room, porch etc)

Figure 3 - Width of ground insulation



Key

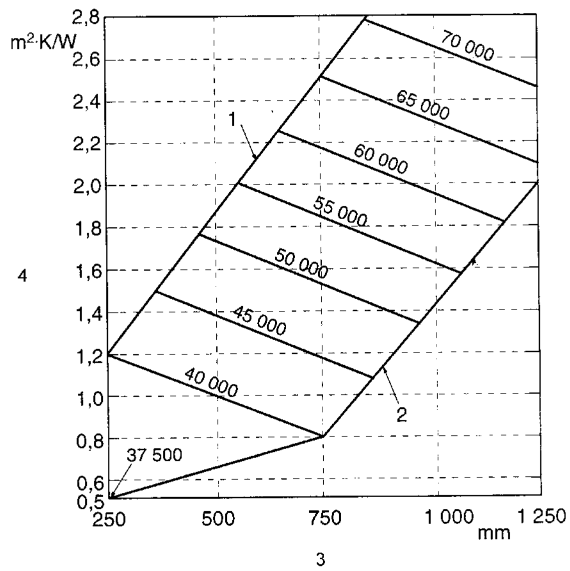
1 Minimum b_{gc}

2 Minimum R_{gc}

3 Width of ground insulation at corners, b_{gc}

4 Thermal resistance of ground insulation at corners, R_{gc}

Figure 4 - Width and thermal resistance of ground insulation at corners and limited unheated parts, for slab-on-ground floor with $H_f \leq 0{,}4$ m



Key

1 Minimum b_{gw}

2 Minimum R_{gw}

3 Width of ground insulation along walls, b_{gw}

4 Thermal resistance of ground insulation along walls, R_{gw}

Figure 5 - Width and thermal resistance of ground insulation along walls, for slab-on-ground floor with $H_f \leq 0{,}4$ m

Table 5 - Length of corner insulation

F_d K·h	L_c m
$F_d \leq 30\ 000$	-
$30\ 000 < F_d \leq 35\ 000$	1,0
$35\ 000 < F_d \leq 40\ 000$	1,0
$40\ 000 < F_d \leq 45\ 000$	1,5
$45\ 000 < F_d \leq 50\ 000$	1,5
$50\ 000 < F_d \leq 55\ 000$	1,5
$55\ 000 < F_d \leq 60\ 000$	2,0
$60\ 000 < F_d \leq 65\ 000$	2,0
$65\ 000 < F_d \leq 70\ 000$	2,5

8.8 Buildings with low internal temperature

For poorly heated buildings with 5° C ≤ $\theta_{i,m}$ < 17 °C, the values in 8.7.3 may be used if H_f is at least 0,6 m instead of 0,4 m.

Alternatively increase the values of H_f in Table 3 or Table 4 by 0,2 m.

If $\theta_{i,m}$ < 5 °C in any month, the frost protection of the foundations shall be designed as for unheated buildings (see clause 10).

9 Suspended floors for heated buildings

9.1 Heated underfloor space

This clause applies to foundations for which $H_f < H_o$.

The same procedures as for slab-on-ground floors, using the values of the parameters in clause 8, can be used for suspended floors in which the underfloor space is either unventilated and airtight or ventilated by the internal air, provided that:

- the walls of the underfloor space are insulated, with thermal resistance at least R_v as given in Table 2, and this insulation is continued below ground as specified in 8.6;

- R_f, taken as the sum of the thermal resistance of the suspended part of the floor and that of the insulation on the base of the underfloor space, does not exceed 5,0 m²·K/W.

Ensure that the foundation walls are properly sealed to restrict air leakage.

9.2 Underfloor space ventilated with outside air

9.2.1 General

The foundations may be designed either without ground insulation according to 9.2.2 or 9.2.3 (as appropriate), or with ground insulation according to 9.2.4, subject to the following restrictions.

1) The width of the building, *B*, is at least 4 m.

2) The average internal air temperature in each month in all parts of the building is not less than 17 °C.

3) The thermal resistance of any insulation on the ground surface at the base of the underfloor space does not exceed 0,5 m²·K/W.

4) The thermal resistance of the suspended part of the floor does not exceed 8 m²·K/W (without ground insulation) or 5 m²·K/W (with ground insulation).

5) The thermal resistance of the foundation wall above the outside ground level is not less than the appropriate value in Table 6 when the bottom of the floor construction is situated at a height not more than 0,6 m above the outside ground level.

   If the bottom of the floor construction is situated higher than 0,6 m above the outside ground level, this thermal resistance is to be increased such that the total heat flow rate passing through the foundation wall above the outside ground level does not exceed that of a 0,6 m high wall having the thermal resistance specified in Table 6.

6) Vertical edge insulation of thermal resistance at least that specified in Table 6 is applied to a depth of at least 0,6 m if there is no ground insulation, or to the lower surface of the ground insulation if ground insulation is present.

7) The ventilation rate of the underfloor space does not exceed 2 m³ per square metre of floor slab per hour.

   NOTE A method of estimating the ventilation rate is given in EN ISO 13370, *Thermal performance of buildings - Heat transfer via the ground - Calculation methods.*

If any of the above conditions are not met, either design the foundations as for unheated buildings in accordance with clause 10 or undertake numerical calculations in accordance with annex B.

Table 6 - Minimum thermal resistance of foundation walls above ground and of vertical edge insulation below ground for suspended floors

F_d K·h	R_v m²·K/W
$F_d \leq 5\ 000$	0,5
$5\ 000 < F_d \leq 10\ 000$	0,8
$10\ 000 < F_d \leq 20\ 000$	1,0
$20\ 000 < F_d \leq 30\ 000$	1,0
$30\ 000 < F_d \leq 40\ 000$	1,0
$40\ 000 < F_d \leq 50\ 000$	1,2
$50\ 000 < F_d \leq 60\ 000$	1,4
$60\ 000 < F_d \leq 70\ 000$	1,6

9.2.2 Foundations with no ground insulation : long buildings

A long building is one whose length is more than three times its width.

Depending on the design freezing index, the maximum ventilation rate of the underfloor space, and the thermal resistance of the suspended floor, the foundation depth shall be:

- at the walls, at least that in Table 7;
- near the corners for a distance L_c from the corners, at least the greater depth given in Table 8;

where values of L_c are given in Table 5 as a function of the design freezing index. Linear interpolation may be used in Tables 7 and 8 for other values of R_f.

Table 7 - Foundation depth, in metres, for suspended floors: walls of long buildings

Design freezing index F_d K·h	**Ventilation rate** m³/m²h					
	1			2		
	R_f m²·K/W			R_f m²·K/W		
	2	4	8	2	4	8
$F_d \leq 5\ 000$	a)	a)	0,50	a)	0,40	0,55
$5\ 000 < F_d \leq 10\ 000$	a)	0,45	0,70	a)	0,55	0,80
$10\ 000 < F_d \leq 15\ 000$	a)	0,55	0,85	0,45	0,70	0,95
$15\ 000 < F_d \leq 20\ 000$	a)	0,65	0,95	0,50	0,80	1,15
$20\ 000 < F_d \leq 25\ 000$	0,35	0,75	1,10	0,60	0,90	1,25
$25\ 000 < F_d \leq 30\ 000$	0,50	0,85	1,25	0,70	1,00	1,35
$30\ 000 < F_d \leq 35\ 000$	0,60	1,00	1,40	0,80	1,20	1,60
$35\ 000 < F_d \leq 40\ 000$	0,70	1,15	1,60	0,90	1,35	1,80
$40\ 000 < F_d \leq 45\ 000$	0,75	1,25	1,75	1,00	1,50	2,00
$45\ 000 < F_d \leq 50\ 000$	0,85	1,40	1,90	1,10	1,65	2,20
$50\ 000 < F_d \leq 55\ 000$	0,90	1,50	2,05	1,20	1,75	2,35
$55\ 000 < F_d \leq 60\ 000$	0,95	1,60	2,20	1,25	1,90	2,50
$60\ 000 < F_d \leq 65\ 000$	1,05	1,70	2,35	1,35	2,05	2,60
$65\ 000 < F_d \leq 70\ 000$	1,10	1,80	2,50	1,45	2,15	2,70
a) indicates less than 0,35						

9.2.3 Foundations with no ground insulation : short buildings

A short building is one whose length is not more than three times its width.

The foundation depth shall be at least that given in Table 8 all round the building.

NOTE The greater depth is needed all round short buildings because, for a given width, these have greater loss (per square metre of floor area) through the ground and through the walls of the underfloor space, compared with a long building, resulting in a lower temperature in the underfloor space.

Table 8 - Foundation depth (in metres) for suspended floors: short buildings and corners of long buildings

Design freezing index F_d K·h	**Ventilation rate** m³/(m²·h)					
	1			2		
	R_f m²·K/W			R_f m²·K/W		
	2	4	8	2	4	8
$F_d \leq 5\,000$	a)	0,40	0,55	a)	0,50	0,65
$5\,000 < F_d \leq 10\,000$	a)	0,55	0,80	0,45	0,70	0,90
$10\,000 < F_d \leq 15\,000$	0,45	0,70	0,95	0,55	0,85	1,10
$15\,000 < F_d \leq 20\,000$	0,50	0,80	1,15	0,65	0,95	1,30
$20\,000 < F_d \leq 25\,000$	0,60	0,90	1,25	0,75	1,10	1,45
$25\,000 < F_d \leq 30\,000$	0,70	1,00	1,35	0,85	1,25	1,60
$30\,000 < F_d \leq 35\,000$	0,80	1,20	1,60	1,00	1,40	1,80
$35\,000 < F_d \leq 40\,000$	0,90	1,35	1,80	1,15	1,60	2,05
$40\,000 < F_d \leq 45\,000$	1,00	1,50	2,00	1,25	1,75	2,25
$45\,000 < F_d \leq 50\,000$	1,10	1,65	2,20	1,40	1,90	2,40
$50\,000 < F_d \leq 55\,000$	1,20	1,75	2,35	1,50	2,05	2,50
$55\,000 < F_d \leq 60\,000$	1,25	1,90	2,50	1,60	2,20	2,60
$60\,000 < F_d \leq 65\,000$	1,35	2,05	2,60	1,70	2,35	2,70
$65\,000 < F_d \leq 70\,000$	1,45	2,15	2,70	1,80	2,50	2,80
a) indicates less than 0,35						

9.2.4 Foundations with ground insulation

The foundation depth (all round the building) shall be at least that given in Table 9.

The data apply for $R_f \leq 5$ m²·K/W. Ground insulation of width $b_g \geq 1{,}0$ m is applied all round the building, having thermal resistance R_{gw} along the walls, and R_{gc} at the corners and for a distance L_c from each corner, where values of L_c are given in Table 5.

Table 9 - Foundation depth, in metres, for suspended floors with ground insulation

R_{gw} (m²·K/W)	0,0	0,5	1,0	1,5	2,0	2,5	3,0
R_{gc} (m²·K/W)	0,0	0,7	1,4	2,1	2,8	3,5	4,2
F_d K·h							
$F_d \le 20\,000$	0,80	0,35	a)	a)	a)	a)	a)
$20\,000 < F_d \le 25\,000$	0,90	0,50	a)	a)	a)	a)	a)
$25\,000 < F_d \le 30\,000$	1,00	0,70	0,35	a)	a)	a)	a)
$30\,000 < F_d \le 35\,000$	1,20	0,90	0,60	0,35	a)	a)	a)
$35\,000 < F_d \le 40\,000$	1,35	1,15	0,90	0,60	0,35	a)	a)
$40\,000 < F_d \le 45\,000$	1,50	1,35	1,10	0,85	0,55	0,35	a)
$45\,000 < F_d \le 50\,000$	1,65	1,45	1,25	1,00	0,75	0,50	0,35
$50\,000 < F_d \le 55\,000$	1,75	1,55	1,35	1,15	0,90	0,65	0,45
$55\,000 < F_d \le 60\,000$	1,90	1,65	1,45	1,30	1,05	0,85	0,60
$60\,000 < F_d \le 65\,000$	2,00	1,80	1,60	1,40	1,20	0,95	0,75
$65\,000 < F_d \le 70\,000$	2,15	1,90	1,70	1,50	1,30	1,05	0,90

a) indicates less than 0,35

10 Unheated buildings

10.1 General

This clause applies to foundations for which $H_f < H_0$ and to:

a) buildings which are unheated;

b) buildings in which the monthly average internal air temperature in any month of the year may fall below 5 °C.

NOTE The data given apply to climates for which the average annual air temperature is not less than 1 °C. For annual average air temperature in the range 0 to 1°C, frost insulation can be designed by undertaking numerical calculations in accordance with annex B.

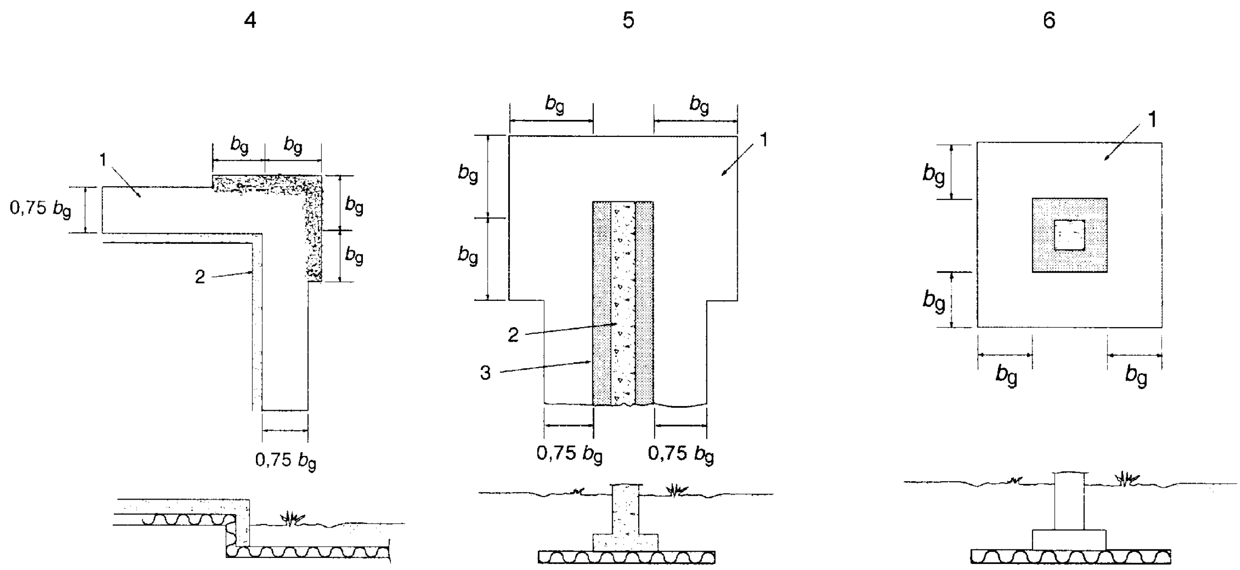
10.2 Without ground insulation

If ground insulation is not used, the foundation depth (including any layer of material that is non-susceptible to frost beneath the foundation) shall be at least the maximum frost depth in undisturbed ground, in accordance with clause 7.

10.3 With ground insulation

The foundation depth may be reduced to less than that required in 10.2 by having a continuous insulation layer beneath the foundations and extending to each side of the foundation. If frost heave will damage the floor, the insulation layer should continue under the whole floor. See Figure 6.

NOTE 1 The insulation is continued beneath the foundations to prevent them acting as a thermal bridge.



Key

1 Ground insulation

2 Foundation wall

3 Foundation base

4 Slab-on-ground

5 Foundation wall

6 Column

Figure 6 - Width of ground insulation for unheated buildings

The necessary thermal resistance, R_g, and width, b_g, of the insulation depends on:

- the design freezing index, F_d;
- the annual average external air temperature, $\overline{T}_e$;
- the foundation depth.

Determine the width b_g from Table 10 according to the design freezing index, F_d. Linear interpolation may be used for intermediate values of F_d.

Table 10 - Width of ground insulation for unheated building

F_d K·h	10 000	20 000	30 000	40 000	50 000	60 000	70 000
b_g m	0,75	1,20	1,60	2,00	2,40	2,75	3,10

For small foundations and near corners of larger foundations, the insulation shall extend at least b_g from the foundation. For whole buildings, or for strip foundations of length at least 3 m, the insulation width may be reduced to 0,75 b_g at distances greater than b_g from the corner or end of the foundation: see Figure 6.

Determine the minimum thermal resistance of the ground insulation, R_g, from Table 11 for foundations at least 0,4 m deep, or from Table 12 for foundations at least 1,0 m deep. Linear interpolation may be used in these tables for intermediate values, and linear interpolation may also be used between Tables 11 and 12 for foundation depths intermediate between 0,4 m and 1,0 m.

NOTE 2 The same value of R_g applies along walls and at corners.

NOTE 3 Values of thermal resistance greater than 5,0 m²·K/W in Table 11 have been put in brackets to indicate that it will usually be a more viable option to increase the foundation depth.

NOTE 4 If F_d ≥ 60 000 K·h, a foundation depth of 0,4 m is not sufficient and should be increased.

Table 11 - Minimum thermal resistance of ground insulation, R_g (m²·K/W) for unheated buildings with H_f = 0,4 m

F_d K·h	$\bar{\theta}_e$ °C				
	1	2	3	4	≥ 5
≤ 10 000	-	-	-	1,1	1,1
20 000	-	1,8	1,6	1,5	1,3
30 000	3,5	2,9	2,5	2,1	1,9
40 000	4,5	3,8	3,3	2,8	-
50 000	(5,6)	4,7	4,1	-	-
60 000	(6,7)	(5,7)	-	-	-

Table 12 - Minimum thermal resistance of ground insulation, R_g (m²·K/W) for unheated buildings with H_f = 1,0 m

F_d K·h	$\bar{\theta}_e$ °C				
	1	2	3	4	≥ 5
≤ 10 000	-	-	-	0,0	0,0
20 000	-	0,7	0,5	0,4	0,4
30 000	1,8	1,3	1,1	0,8	0,6
40 000	2,3	1,8	1,5	1,2	-
50 000	3,1	2,4	2,0	-	-
60 000	3,9	3,0	-	-	-
70 000	4,8	-	-	-	-

Protect the insulation layer as follows:

a) place a layer of well-drained material that is non-susceptible to frost at least 100 mm thick beneath the insulation;

b) above the insulation, arrange a protective cover consisting of:

- under the foundations and within the building, at least 50 mm of concrete or similar;
- outside the building, at least 300 mm of soil, unless covered by paving in which case the soil thickness may be reduced to 200 mm;

c) place the insulation above the maximum level of the ground water Table.

10.4 Additional material that is non-susceptible to frost beneath insulation

The minimum thermal resistance of the ground insulation, R_g, specified in 10.3 may be reduced by having a layer of material that is non-susceptible to frost beneath the insulation of thickness greater than 100 mm.

R_g may be reduced by 0,2 m²·K/W per 100 mm increase in the thickness of this layer above 100 mm.

10.5 Additional soil cover above insulation

The minimum thermal resistance of the ground insulation, R_g, and its minimum width, b_g, specified in 10.3 may both be reduced by having a layer of soil above the insulation of thickness greater than 300 mm.

R_g may be reduced by 0,1 m²·K/W per 100 mm increase in thickness of soil cover above 300 mm.

b_g may be reduced by 0,1 m per 100 mm increase in thickness of soil cover above 300 mm.

NOTE The increase in soil cover can be limited by the requirement to keep the insulation above the water Table (see 10.2).

Annex A
(normative)

Definition and calculation of freezing index

A.1 General

This annex gives the method of calculation of the design freezing index F_d from meteorological records of daily mean external air temperatures for the locality concerned.

A.2 defines the calculation of the freezing index, F, for one particular winter. The design data given in clauses 8 to 10 are based on F_n, the freezing index which statistically is exceeded once in n years, e.g. F_{10}, F_{50}, F_{100}. These values may be obtained from a set of individual values of F calculated for several winters using the statistical treatment described in A.3.

A.2 Calculation of freezing index for one winter

The freezing index is the 24 times sum of the difference between freezing point and the daily mean external air temperature:

$$F = 24 \sum_j \left(\theta_f - \theta_{d,j} \right) \quad \text{(A.1)}$$

where

F is the freezing index for one winter, in K·h;

θ_f is equal to 0°C;

$\theta_{d,j}$ is the daily mean external air temperature for day j, in °C;

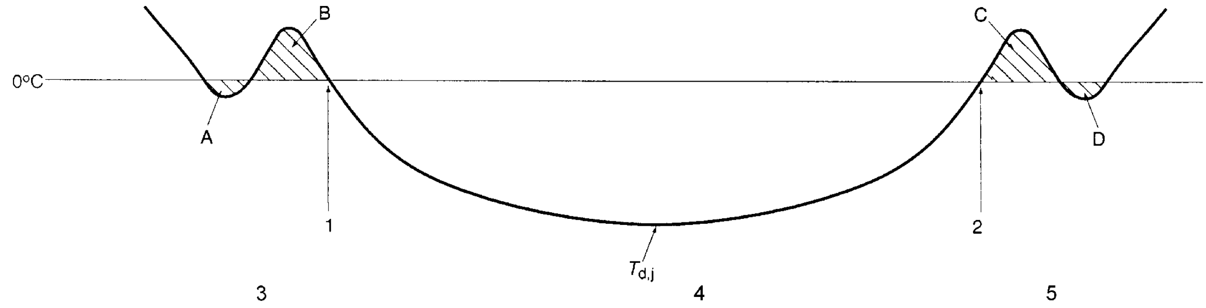
and the sum includes all days in the freezing season (as defined below).

The daily mean external air temperature may be obtained as the average of several readings, or as the average of the maximum and minimum values, for the day in question.

Both positive and negative differences, within the freezing season, are included in the accumulation of equation (A.1). A negative difference (daily mean temperature above 0 °C) implies some thawing of the ground, which serves to reduce the frost penetration in the ground.

For the purposes of the summation in equation (A.1) the freezing season starts at the point from which the accumulation remains always positive throughout the winter. With reference to Figure A.1, there is initially some freezing as a result of the area marked A, followed by complete thawing as a result of the area marked B since this is greater than area A. The accumulation therefore starts after this. In Figure A.2, area A is greater than area B, so the thawing is not complete and the accumulation starts earlier as indicated on that Figure.

The freezing season ends at the point which results in the largest total accumulation for the winter. If a short thawing period is followed by a larger freezing period both are included, while if a thawing period is followed by a lesser freezing period neither is included, as illustrated in Figures A.1 and A.2.

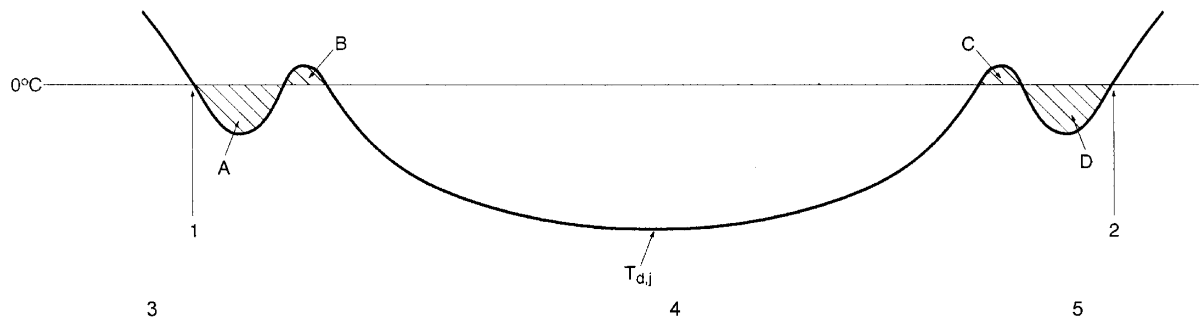


Key

1 Start
2 End
3 Autumn
4 Winter
5 Spring

NOTE Area B > area A, and area C > area D

Figure A.1 - Illustration of the limits of the freezing season (first example)



Key

1 Start
2 End
3 Autumn
4 Winter
5 Spring

NOTE Area B < area A, and area C < area D

Figure A.2 - Illustration of the limits of the freezing season (second example)

NOTE 1 In the past, freezing indexes have sometimes been calculated including only positive differences in equation (A.1), i.e. ignoring the effect of thawing periods. Tables or maps of freezing indexes calculated on that basis, which give higher values of F than as defined above and so a greater margin of safety, may be used for the purposes of this standard. On the other hand an accumulation on the basis of average monthly temperatures can significantly underestimate the true freezing index and such data should not be used.

NOTE 2 An alternative, and equivalent, method of obtaining the freezing index is to plot the cumulative difference between daily mean temperature and freezing point against time for a complete 12-month period (from midsummer to midsummer). The freezing index is then the largest difference between maximum and minimum turning points on this curve.

NOTE 3 Freezing in the ground depends on the ground surface temperature. However, because air temperatures are more readily available than ground surface temperatures, this standard uses the air freezing index, i.e. the freezing index calculated from external air temperatures, as the design parameter. In most cases the use of air temperatures provides a safety margin because factors such as the presence of vegetation and snow cover, and solar radiation, result in ground surface temperatures being higher than air temperatures. However the opposite may apply for snow-free surfaces in permanent sun shadow, for which ground surface temperatures can be lower as a result of radiation to clear skies.

A.3 Statistical determination of design freezing index

The design freezing index, F_n, is the freezing index that statistically is exceeded once in *n* years. This implies that the probability that the freezing index in any one winter exceeds F_n is $1/n$.

NOTE 1 The appropriate value of *n* should be decided upon with regard to the level of safety that is required for the building in question. Parameters to consider are the expected lifetime of the structure, the sensitivity of the type of structure to frost heave, etc. For permanent buildings *n* is normally chosen as 50 years or 100 years.

NOTE 2 *n* is referred to as the return period, i.e. the average number of years between successive occurrences of freezing indexes greater than F_n.

The design freezing index for a given location is obtained from a set of freezing indexes F_i, calculated as described in A.2, of *m* winters at the location. Whenever possible, the value of *m* should not be less than 20. The use of data from *m* consecutive, or nearly consecutive, winters is recommended.

Use a statistical distribution that realistically reflects extreme events. The Gumbel distribution (see A.4) has been found to be suitable for many climates, and is recommended in the absence of specific information for the locality concerned.

A.4 Use of the Gumbel distribution

Calculate the average freezing index, $\overline{F}$, using (A.2) and the standard deviation, s_F, using (A.3):

$$\overline{F} = \frac{\sum F_i}{m} \qquad \text{(A.2)}$$

$$s_F = \sqrt{\frac{\sum \left(F_i - \overline{F}\right)^2}{m-1}} \qquad \text{(A.3)}$$

where

$i = 1,2,.....,m$

The design freezing index is then given by (A.4):

$$F_n = \overline{F} + \frac{s_F}{s_y}\left(y_n - \overline{y}\right) \qquad \text{(A.4)}$$

where *y* denotes the reduced variable in the Gumbel distribution.

Obtain the appropriate values of $\bar{y}$ and s_y from Table A.1 corresponding to the number *m* of individual values of F_i used in the calculation.

Obtain the value of y_n from Table A.2 corresponding to the value of *n* chosen for the design.

Table A.1 - Values of $\bar{y}$ and s_y

m	$\bar{y}$	s_y	*m*	$\bar{y}$	s_y
10	0,50	0,95	50	0,55	1,16
15	0,51	1,02	60	0,55	1,17
20	0,52	1,06	70	0,55	1,19
25	0,53	1,09	80	0,56	1,19
30	0,54	1,11	90	0,56	1,20
40	0,54	1,14	100	0,56	1,21

Table A.2 - Values of y_n

n	5	10	20	50	100
y_n	1,50	2,25	2,97	3,90	4,60

NOTE For further information about the Gumbel distribution, see [1] and [2] in Bibliography.

Annex B
(normative)
Numerical calculations

B.1 General

The general case of frost penetration into the ground adjacent to buildings or structures is a three-dimensional, time-dependent, non-linear heat transfer problem, which can be modelled using suitable numerical techniques (for example finite differences or finite elements).

The design procedures given in this standard are based on such numerical calculations for buildings on homogeneous ground consisting of frost-susceptible soil with properties as given in 5.1, and with other conditions as described in B.2.

The procedures described in clauses 8 to 10 will give adequate frost protection of foundations in most cases. If, however, the soil properties differ substantially from those given in 5.1 (in particular if the dry density of the soil is outside the range 1100 kg/m³ to 1600 kg/m³ or if the water saturation is less than 80 %), numerical calculations according to B.2 shall be undertaken.

> NOTE The calculated soil temperatures adjacent to the building are increasingly sensitive to the precise values of the soil properties as the freezing index increases, as the internal temperature decreases, and as the floor insulation increases.

Numerical calculations which conform with B.2 may be used as an alternative to the tables and graphs given in this standard.

B.2 Conditions for numerical calculations

B.2.1 Subdivision of the geometrical model

The geometrical model of the ground is subdivided in such a way that the subdivisions are smallest near to the edge of the floor, and gradually increasing in size to much larger subdivisions near the truncation planes. The criteria given in ISO 10211-1 for judging whether sufficient subdivisions have been used (related to the calculation of heat flows and surface temperatures) are recommended.

B.2.2 Dimensions of the ground

The following minimum dimensions of the ground define the truncation planes in the geometrical model:

- in the horizontal direction inside the building: 0,5 *B*;
- in the horizontal direction outside the building: 2,5 *B*;
- in the vertical direction below ground level: 2,5 *B*;

where *B* is the width (smaller dimension) of the floor.

B.2.3 Three- or two-dimensional calculations

If the smaller dimension of the floor does not exceed 4 m, three-dimensional calculations shall be used. For other cases, the frost conditions along the walls can be judged from two-dimensional calculations with the building width set equal to the smaller dimension of the floor. The frost conditions at corners should then be judged from three-dimensional calculations or by using the appropriate tables and graphs in the standard.

B.2.4 Boundary conditions

For two-dimensional calculations, there is a vertical symmetry plane mid-way across the floor, which is taken as an adiabatic boundary (so that one half of the building is modelled). For three-dimensional calculations on a rectangular building, there are two vertical symmetry planes mid-way across the floor in each direction, which are taken as adiabatic boundaries (so that one quarter of the building is modelled).

Outside the building, the vertical truncation plane is taken as an adiabatic boundary.

The horizontal truncation plane in the ground is taken as an adiabatic boundary.

Surface resistances as specified in ISO 6946 apply at the inside floor surface and at the outside ground surface.

B.2.5 Thermal properties

For the thermal properties of the ground:

a) if known, use values for the actual location, allowing for the normal moisture content;

b) otherwise, use the values specified in 5.1.

When water in the soil freezes or melts, there is a change in the heat capacity per volume and in the thermal conductivity of the soil, and the latent heat of the water in the soil is released during freezing. Numerical calculations should allow for these effects.

The latent heat of water in the soil may be treated as an apparent increase in the heat capacity of the soil over a temperature interval of 1 K below 0 °C. Soil at a temperature of -1 °C or below is considered as fully frozen.

For materials other than the ground, use values according to 5.2.

B.2.6 Design external temperature

Use a sinusoidal variation of external temperature given by (B.1):

$$\theta_{\mathrm{e}} = \overline{\theta}_{\mathrm{e}} + \hat{\theta}_{\mathrm{e}} \cos\left(2\pi t / t_{\mathrm{p}}\right) \qquad \text{(B.1)}$$

where

θ_e is the external air temperature at time t, in °C;

$\overline{\theta}_e$ is the annual average external air temperature, in °C;

$\hat{\theta}_e$ is the amplitude of the sinusoidal variation, in K;

t_p is one year expressed in seconds ($3,15 \times 10^7$ s).

$\hat{\theta}_e$ is chosen such that the integral of (B.1) below 0 °C over a year gives the correct design freezing index F_d (see 6,1).

In order to start the calculation of the design year with an appropriate temperature distribution in the ground:

- the initial conditions should be the annual average external air temperature throughout the ground;

- the calculation period should extend over two consecutive design years, with the results being taken from the second year.

B.2.7 Design criterion

The foundation design is considered to be protected against frost heave when no fully frozen soil occurs below the foundation during the design winter, i.e. the temperature remains above -1 °C under the whole of the base of the foundation. This can be done by examining the maximum penetration of the -1 °C isotherm towards the base of the foundation. An example of such an isothermal plot is shown in Figure B.1.

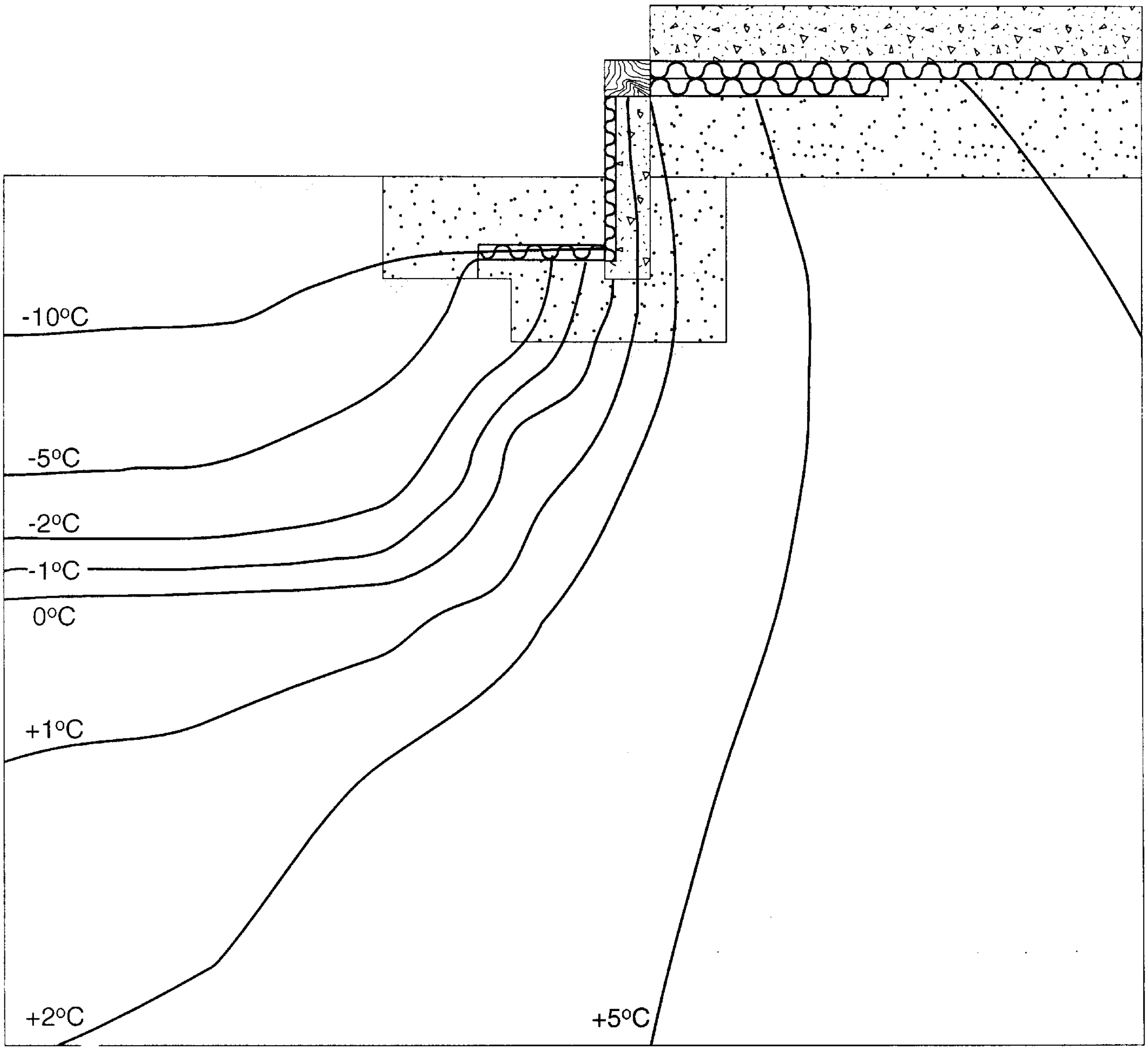


Figure B.1 - Illustration of isotherms in the ground near a foundation

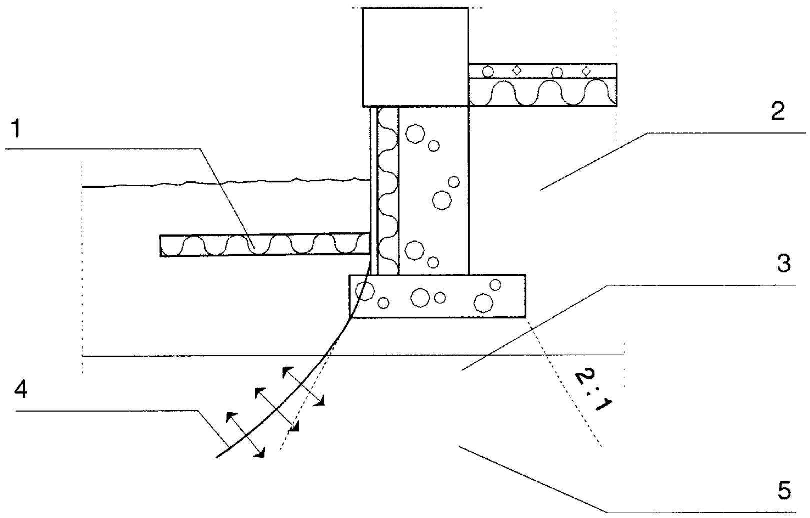
Annex C

(normative)

Design data for slab-on-ground floors based on 0 °C criterion

C.1 Introduction

This annex provides data for the design of shallow foundations for slab-on-ground floors, when the design condition is that the 0 °C isotherm does not penetrate below a 2:1 load spread area beneath the foundation (see Figure C.1).



Key

1 Ground insulation
2 Non frost-susceptible fill
3 Zone of stress influence
4 0 °C isotherm
5 Frost-susceptible soil

Figure C.1 - Frost protection based on 0 °C isotherm

C.2 Heated buildings

C.2.1 Foundations with no ground insulation

The design should conform with 8.3.1, 8.3.2, 8.3.3 and 8.6, and instead of 8.7.1 it should conform with the following.

The foundation depth should be:

- at the walls, at least H_f;
- near the corners and at limited unheated parts for a distance L_c from these places, at least the greater depth H_{fc};

where the values of H_f, H_{fc} and L_c are given as a function of the design freezing index in Table C.1 for fine-grained soils (silt and clay) and in Table C.2 for coarse-grained soils (frost-susceptible sand and moraine). Linear interpolation may be used in these tables for intermediate values of F_d.

Table C.1 - Foundation depth for slab-on-ground floor without ground insulation: fine-grained soils

F_d K·h	H_f m	H_{fc} m	L_c m
35 000	1,00	1,30	1,5
40 000	1,10	1,40	1,5
45 000	1,20	1,50	1,5
50 000	1,30	1,60	1,5
55 000	1,40	1,70	2,0
60 000	1,50	1,85	2,0
65 000	1,60	2,00	2,5
70 000	1,75	2,15	2,5
75 000	1,90	2,30	2,5

Table C.2 - Foundation depth for slab-on-ground floor without ground insulation: coarse-grained soils

F_d K·h	H_f m	H_{fc} m	L_c m
35 000	1,20	1,60	1,5
40 000	1,30	1,70	1,5
45 000	1,40	1,80	1,5
50 000	1,50	2,00	1,5
55 000	1,60	2,10	2,0
60 000	1,70	2,25	2,0
65 000	1,80	2,40	2,5
70 000	2,05	2,55	2,5
75 000	2,20	2,70	2,5

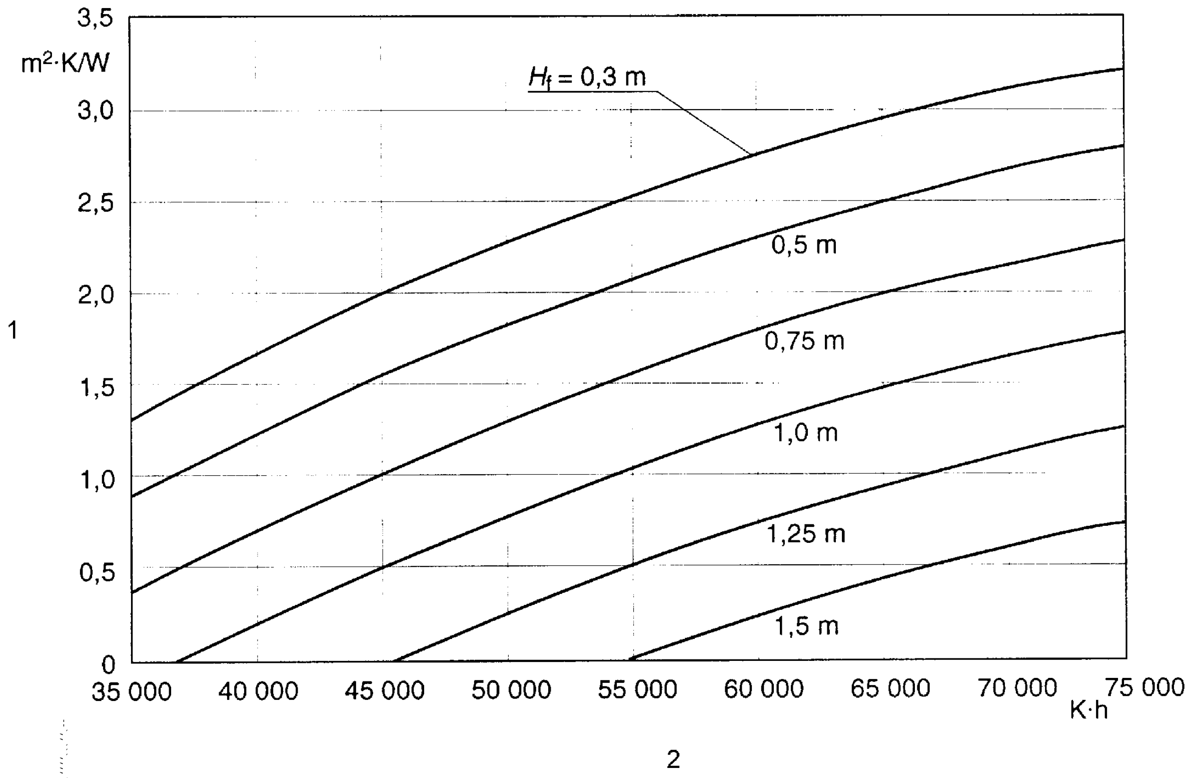
C.2.2 Ground insulation all round the building

The design should conform with 8.3.1, 8.3.2, 8.3.3 and 8.6, and instead of 8.7.3 it should conform with the following. The data apply when the thermal resistance of the floor slab is less than 5 m²·K/W.

The width of the ground insulation b_c, along the walls and at corners, should be at least 0,8 m.

Determine the minimum thermal resistance of the ground insulation along the walls, R_{gw}, according to the foundation depth H_f and the design freezing index F_d from Figure C.2.

At corners the thermal resistance of the ground insulation should be 40 % greater than along the walls, for a distance L_c (from Table C.1 or C.2) from each corner.



Key

1 Thermal resistance of ground insulation along walls, R_{gw}

2 Design freezing index, F_d

Thermal resistance of floor slab $R_f < 5{,}0$ $m^2 \cdot K/W$

Figure C.2 - Thermal resistance of ground insulation along walls

C.3 Buildings with low internal temperature

For poorly heated buildings with 5°C ≤ $\theta_{i,m}$ < 17°C, the values of H_f and H_{fc} in Table C.1 should be increased by 0,3 m.

If $\theta_{i,m}$ < 5 °C in any month, the frost protection of the foundations shall be designed as for unheated buildings (see clause 10).

Annex D

(informative)

Frost susceptibility of the ground

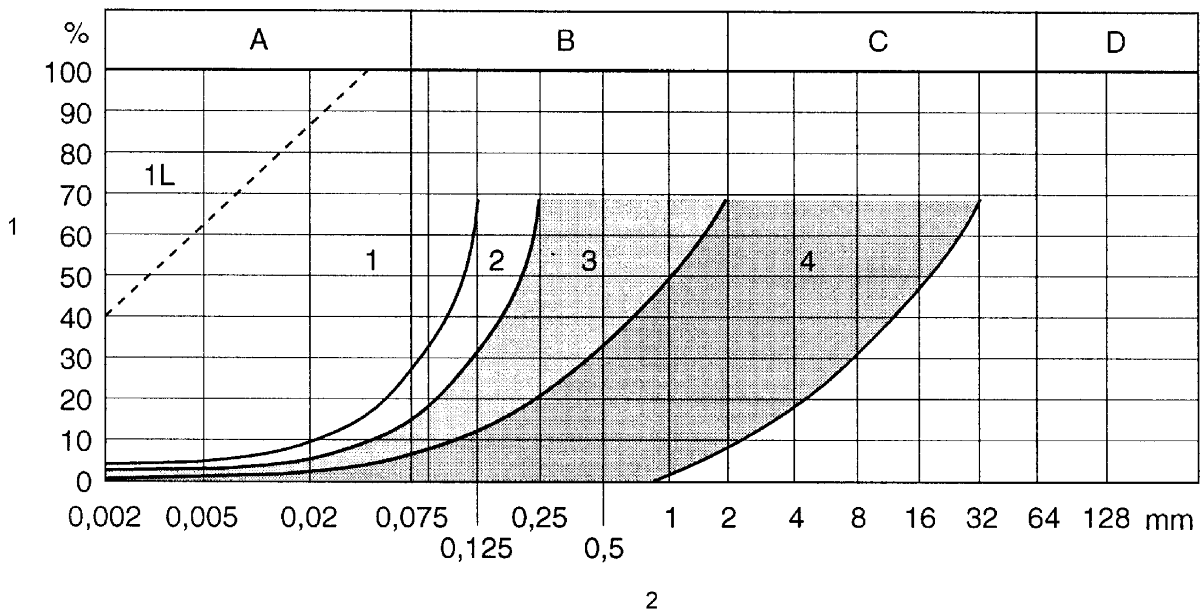
To what extent the ground is susceptible to frost depends both on the properties of the soil material and on local conditions, such as layering and ground water level. Normally a high ground water level, water-containing layers or a mixture of coarse and fine soil layers increases the risk of frost heave.

Frost heave occurs when ice-layers (ice lenses) are created during freezing of the soil below the foundation. This implies a sufficient supply of ground water and sufficiently high capilliarity and permeability of the soil. Thus soils with a high content of silt or clay are those giving the greatest risk of frost heave. These types are considered frost-susceptible.

Fat clay (clay content > 40 %) is less susceptible to frost heave due to its low hydraulic conductivity.

In general, a geotechnical examination of the ground conditions at the building site to the depth of frost penetration is necessary.

A rough assessment of the frost susceptibility of a soil can be obtained on the basis of grain size distribution, as illustrated in Figure D.1, which shows the percentage of grains passing through sieves of different sizes.



Key

1 % through sieve
2 Size of sieve
A Silt
B Sand
C Gravel
D Stones

Figure D.1 - Estimation of frost susceptibility of the basis of grain size distribution

With reference to Figure D.1:

1) if the grain size distribution is such that grains of size less than 0,02 mm comprise less than 3 % of the soil, the soil is normally non-susceptible to frost;

2) if the grain size curve lies completely within region 1, the soil is always frost-susceptible (except for the "fat clay" region 1L where the frost susceptibility is low);

3) if the grain size curve falls completely inside regions 2, 3 or 4, the soil is non-susceptible to frost, provided that in the case of region 2 the capillary rise is also checked and is less than 1 m;

4) if the lower part of the grain size curve permanently passes the boundary of the next region on the finer side, the soil is frost-susceptible;

5) it is necessary to examine borderline cases using more exact methods.

The grain size distribution can be used in this way to classify the soil as either frost-susceptible or non-susceptible to frost. Borderline cases which do not fall precisely into either of these two limiting classifications should either be regarded as frost-susceptible for the purposes of design, or the frost susceptibility should be determined by laboratory tests or by representative frost-heave observations *in-situ*.

Further information about frost susceptibility and testing methods may be found in [3] to [6] in Bibliography.

Annex E

(informative)

Worked examples

The procedures given in the standard are illustrated for a building 12 m long and 8 m wide in the following climate:

- design freezing index F_{50} = 47 000 K·h,

- annual mean external temperature $\overline{\theta}_e$ = 1,5 °C.

E.1 No frost insulation

The foundation depth is to be at least the maximum frost depth, according to clause 7. Using equation (1),

$$H_0 = \sqrt{\frac{7200 \times 47\,000 \times 2{,}5}{(150 + 3 \times 1{,}5) \times 10^6}} = 2{,}34 \text{ m}$$

The foundation depth is therefore 2,34 m (all round the building). This depth applies irrespective of any insulation of the floor. It is valid for both heated and unheated buildings, and for both slab-on-ground floors and suspended floors (although, in the case of a slab-on-ground floor below an unheated building, the slab itself would not be protected against frost heave damage).

E.2 Slab-on-ground floor using frost insulation

The floor will be insulated with all-over insulation of thermal resistance R_f = 3,0 m²·K/W.

a) Using vertical edge insulation only

Using Table 2, the thermal resistance of the vertical edge insulation will be at least 1,9 m²·K/W (interpolating between 1,7 m²·K/W and 2,0 m²·K/W), extending to at least 0,6 m below ground level.

The minimum foundation depth is then found using Table 3:

- along the walls, 0,75 m;

- for a distance of 1,5 m from each corner, 1,30 m.

b) Ground insulation at corners

Vertical edge insulation, of resistance at least 1,9 m²·K/W, is applied all round the building, extending to at least 0,6 m below ground level, as in a). From Table 4, the foundation depth is 0,75 m all round the building, and ground insulation 0,6 m wide of thermal resistance 1,0 m²·K/W is applied over a distance of 1,5 m from each corner.

c) Ground insulation all round the building

Using 8.6.3, the foundation depth can be 0,4 m all round the building, provided that:

- vertical edge insulation of thermal resistance not less that 1,9 m²·K/W is applied all round the building, as in a) and b), but in this case extending to the lower surface of the ground insulation (typically 0,3 m to 0,4 m);

- along the walls, ground insulation is applied: to use Figure 5, either the thermal resistance of the ground insulation or its width is chosen (within the limits indicated on Figure 5), and the other parameter is determined from the Figure; suppose that ground insulation of thermal resistance 1,4 m²·K/W will be used: in that case using Figure 5 its width is to be at least 650 mm;

- near the corners additional ground insulation is needed: again, either its thermal resistance or its width can be chosen; suppose that ground insulation of thermal resistance 2,0 m²·K/W will be used near the corners: then using Figure 4 its width is to be at least 800 mm, and from Table 5 the corner insulation is to be continued for 1,5 m from each corner.

Figure E.1 illustrates the design for this case.

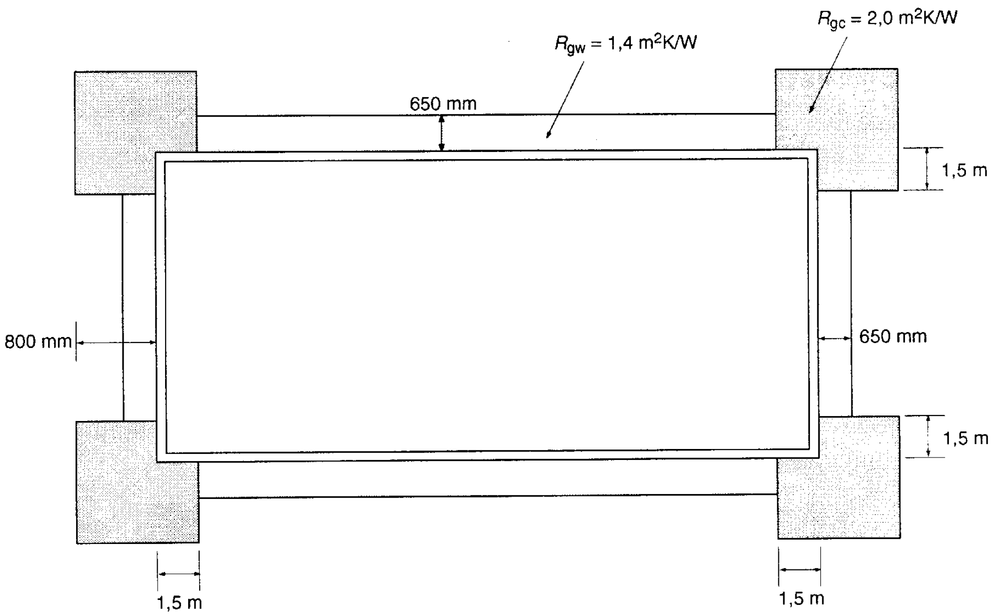


Figure E.1 - Illustration of the foundation insulation for example E.2 c)

E.3 Suspended floor

a) Using vertical edge insulation only

From Table 6, the thermal resistance of the foundation walls above ground, and of vertical edge insulation below ground, is to be at least 1,2 m²·K/W, extending to at least 0,6 m below ground. The length of the building is less than three times its width, so it is regarded as short. From Table 8 the foundation depth is:

- 1,10 m for R_f = 2 m²·K/W

- 1,65 m for R_f = 4 m²·K/W

and interpolation between these values for R_f = 3 m²·K/W gives a minimum foundation depth of 1,40 m all round the building.

b) Using ground insulation

Vertical edge insulation, of thermal resistance at least 1,2 m²·K/W, is applied all round the building, as in a), but in this case extending to the lower surface of the ground insulation. Different possibilities can then be deduced from Table 9:

- for a foundation depth of 1,25 m (all round the building), the ground insulation is 1,0 m wide and its thermal resistance is at least 1,0 m²·K/W along the walls and 1,4 m²·K/W within 1,5 m from each corner;

- for a foundation depth of 0,50 m (all round the building), the ground insulation is 1,0 m wide and its thermal resistance is at least 2,5 m²·K/W along the walls and 3,5 m²·K/W within 1,5 m from each corner.

E.4 Unheated building using frost insulation

If the building may be unheated during the winter, the design of the foundation is in accordance with the data in clause 10.

From Table 10, the width of the ground insulation needs to be at least 2,28 m (interpolating between 2,00 m and 2,40 m).

The annual mean external air temperature is 1,5°C: the column for 1°C in Tables 11 and 12 will be used to provide a safety margin.

For a foundation depth of H_f = 0,4 m, R_g = 5,3 m²·K/W by interpolation between freezing indexes of 40 000 and 50 000 in Table 11.

For a foundation depth of H_f = 1,0 m, R_g = 2,9 m²·K/W by interpolation between freezing indexes of 40 000 and 50 000 in Table 12.

The necessary thermal resistance of ground insulation for intermediate foundation depths can be obtained by linear interpolation between the values of 5,3 m²·K/W and 2,9 m²·K/W. Thus, for a foundation depth of 0,6 m, R_g will be at least 4,5 m²·K/W.

For unheated buildings, the same ground insulation (in terms of both width and thermal resistance) is placed all round the building.

Bibliography

[1] E J Gumbel. *Statistics of extremes*. Columbia University Press, New York, 1958. (In English).

[2] R S Heiersted. *Statistisk bestemmelse av klimapåkjenninger* (Statistical treatment of climatic loads on constructions), Frost i jord, 19, December 1977. (In Norwegian).

[3] ENV 1997-2. *Eurocode 7: Geotechnical design – Part 2: Design assisted by laboratory testing*.

[4] *Report of ISSMFE Technical Committee on Frost (TC-8)*, International Society of Soil Mechanics and Foundation Engineering, 1989. (In English).

[5] *Pohjarakennusohjeet* (Instructions for ground construction), publication RIL 121-1988, Finnish Union of Civil Engineers, Helsinki, 1988. (In Finnish).

[6] *Talonrakennuksen Routasuojausohjeet* (Instructions for frost protection in building construction), Technical Research Centre of Finland, Helsinki, 1987. (In Finnish).

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