EUROPEAN STANDARD DRAFT
prEN ISO 13793
NORME EUROPEENNE

EUROPAISCHE NORM December
1994

ICS

Descriptors :

English version

Building foundations - Protection against frost heave (ISO/DIS 13793:1994)

Fondations des bitiments - Protection contre les poussees dues au gel (ISO/DIS 13793:1994)

Gebiudegrundungen - Schutz gegen Frosthebung (ISO/DIS 13793:1994)

This draft European Standard is submitted to the CEN members for parallel enquiry. It has been drawn up by Technical Committee CEN/TC 89.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CEN in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

CEN members are the national standards bodies of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

CEN

European Committee for Standardization Comite Europ6en de Normalisation
Europiisches Komitee fUr Normung

Central Secretariat: rue de Stassart 36, B-1050 Brussels

Ref. No. prEN ISO 13793:1_94 E

Contents

Foreword (CEN edition)

This European Standard was prepared by CENITC 89, *Thermal performance of buildings and building components,* under the Vienna Agreement between CEN and ISO as a common European and International Standard, It is identical to ISO :199x.

No existing European standard is superseded.

This standard is one of a series of standards for the design and evaluation of the thermal performance of buildings and building components.

Introduction

Frost heave can occur when there is frozen soil under the foundations. 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 depth of foundation necessary for structural reasons.

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

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 non frost-susceptible material before constructing the foundations.

A third option is to insulate the foundations so as to avoid frost penetrating below the foundations. This latter option is frequently the most economic in cold climates by allowing 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 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 < 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 design of building foundations so as to avoid damage resulting from frost heave.

It applies to buildings and foundations on frost-susceptible ground, and includes 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 standard incorporates by dated or undated reference, 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 standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

prEN 26946 -1 ISO/DIS 6946 /1	Building components and building elements - Thermal resistance and thermal transmittance - Calculation method
prEN 30456 ISO/DIS 30456	Building materials and products - Procedures for determining declared and design thermal values
prEN 32573 ISO/DIS 12573	Thermal bridges in building construction - Heat flows and surface temperatures - General calculation methods
ISO 7345	Thermal insulation - Physical quantities and definitions

3 Definitions, symbols and units

3.1 Definitions

The definitions in ISO 7345 apply, together with the following.

3.1.1 slab on ground: 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 (see figure 1).

3.1.4 ground insulation: Insulation placed horizontally (or nearly so) below ground, external to the building (see figure 1).

3.1.5 freezing Index: 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: The 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, as explained in annex A.

3.1.7 frost depth: Depth of penetration of frost into the ground.

3.1.8 foundation depth: Depth of the foundations below the outside ground level. If the foundations are put on a layer of well-drained, non frost-susceptible material, 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 give frost heave forces when frozen as part of the ground (see also annex C).

3.1.10 floor height: Height of lower surface of the floor insulation layer above external ground surface.

NOTE: If there is no insulation in the floor the floor height is measured from the floor surface.

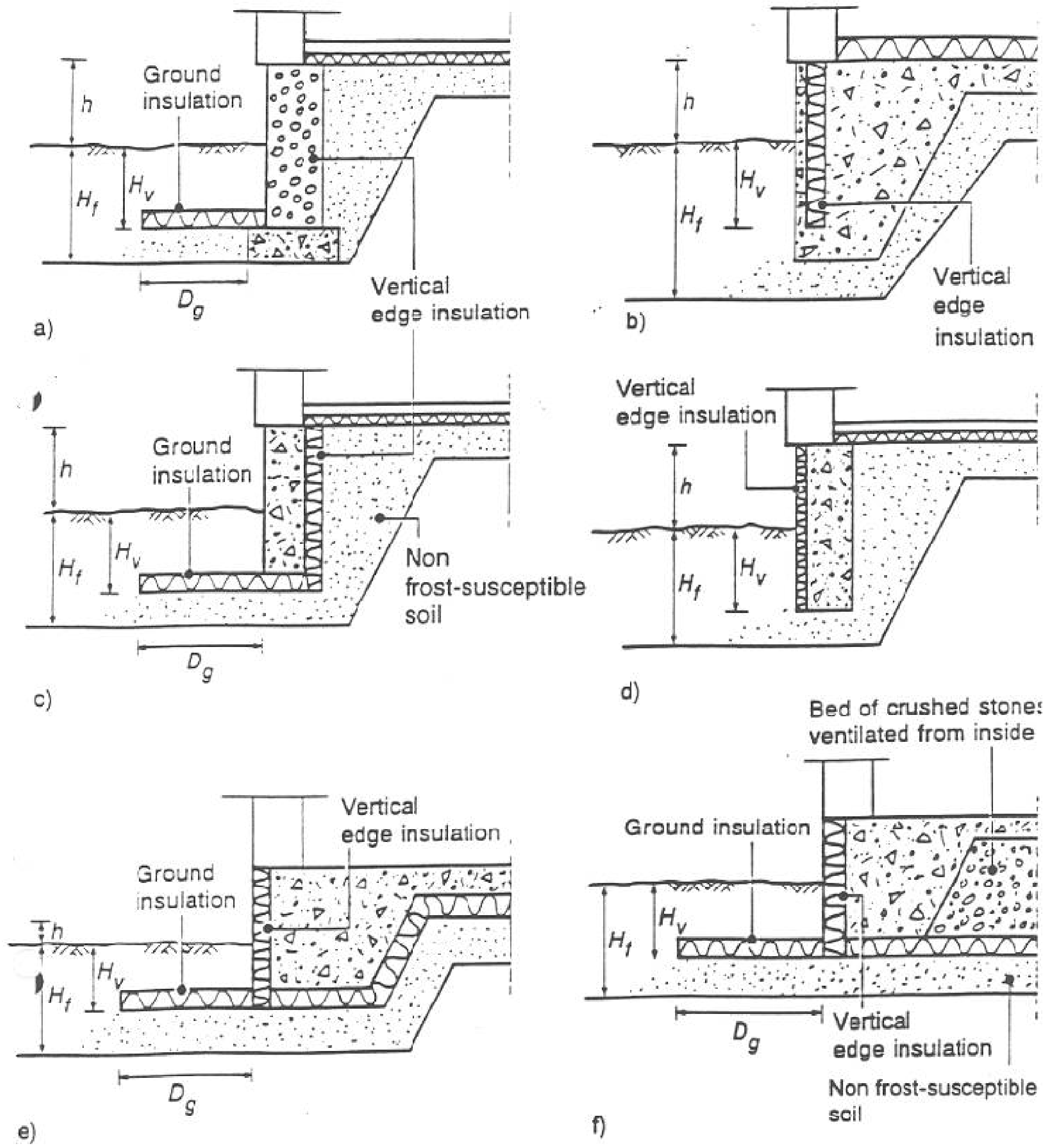

Figure 1 : Examples of vertical edge insulation and ground insulation in foundation structures

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 bed of crushed stones *(h* < 0 in this case. so is not considered)

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
Dg	width of ground insulation. measured from outer limit of footing	m
Dgc	width of ground insulation at corner	m
Dgw	width of ground insulation along wall	m
Fd	design freezing index	K.h
Fn	freezing index which statistically is exceeded once in a period of *n* years	K.h
Ho	maximum frost depth in undisturbed. snow-free ground	m
Hf	foundation depth for walls	m
Hfc	foundation depth for corners	m
Hv	depth of vertical edge insulation	m
Lc	length of corner insulation (measured along external surface of wall)	m
Rf	thermal resistance of floor construction (average value over the outer 1 m of floor) .	m^2xK/W
Rv	thermal resistance of vertical edge insulation	m^2xK/W
Rg	thermal resistance of ground insulation	m^2xK/W
Rgc	thermal resistance of ground insulation at corner	m^2xK/W
Rgw	thermal resistance of ground insulation along wall	m^2xK/W
Te	annual average external air temperature	°C
Ti.m	average internal air temperature in month m	°C
h	floor height	m

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 C). The foundations are considered safe against frost heave when they are designed so that no fully frozen soil occurs below the foundation during the design winter.

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, non frost-susceptible material;

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 non frost susceptible layer below the foundations may be included in the foundation depth *Ht* 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:

a) by using the tables and graphical presentations in this standard (see clauses 8 to 10), or

b) by 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 should 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 should be designed to avoid adfreezing of the soil, thus preventing frost heave by transfer of shear forces, for example by having a layer of non frost-susceptible material 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 should 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.

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 should be made when assessing the design criterion.

5 Material properties

5.1 Properties of the ground

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

NOTE 1: Information about frost susceptibility is given in annex C.

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

thermal conductivity (unfrozen)	:	$\lambda = 1,5$ W/(m·K)
thermal conductivity (frozen)	:	$\lambda_f = 2,5$ W/(m·K)
heat capacity per unit volume (unfrozen)	:	$C = 3 \times 10^6$ J/(m³K)
heat capacity per unit volume (frozen)	:	$C_f = 1,9 \times 10^6$ J/(m³K)
latent heat of freezing per cubic metre of soil	:	$L = 150 \times 10^6$ J/m³
dry density	:	$\rho = 1350$ 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 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 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 prEN 30456 (ISO/DIS 10456) or obtained from tabulated values. The thermal resistance of products used below ground level should 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 should 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 should 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

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.

6.1 Design freezing index

The design freezing index F_d is expressed in terms of F_n, the value which has a 1 in *n* probability of being exceeded over a winter for the locality concerned, based on recorded meteorological data and calculated according to annex A. *Fn* may also be considered as the value of the freezing index that statistically will be exceeded once in *n* years.

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 (*eg* F_{20}, F_{10}, F_5, F_2) may be used.

6.2 Frost depth in undisturbed ground

The greatest depth of frost penetration in undisturbed ground (ie 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. Design values of maximum frost depth in undisturbed, homogeneous frost-susceptible ground without snow cover, *Ho*> may be found for different locations in maps or tables.

If H_O is not known, an approximate value may be calculated from the following formula:

$$H_O = \sqrt{\frac{7200\, F_d\, \lambda_f}{L + C\, \overline{T}_e}}$$

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 unit volume of soil, in J/m³;

C is the heat capacity of unfrozen soil per unit volume, in J/(m³K);

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

NOTE 1: If appropriate soil data are not given, use the data in 5.1.

NOTE 2: Equation (1) provides a conservative (ie maximum) estimate of the frost depth, because it is based on the air freezing index rather than the (ground) surface freezing index, and because it takes no account of geothermal heat.

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 ground, H_O.

If H_f = H_O> the foundations are adequately protected against frost heave and no special measures to insulate the foundations are required.

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

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

8 Heated buildings: Slab-on-ground floors

This clause applies to:

- buildings in which the average internal air temperature throughout the building in each month is at least 17°C (ie $T_{i,m}$ = 17°C for all *m);*

. buildings in which some parts are heated and some parts are unheated, provided that in the heated parts $T_{i,m}$ = 17°C for all m, and that the unheated parts are treated as described *in* 8.4;

. buildings in which 5°C = $T_{i,m}$ < 17°C with the modifications described in 8.7.

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

8.1 General principles

In all cases provide vertical edge insulation as described in 8.5.

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. Take the foundations to the depth given in 8.6.1 (a greater depth of foundation is needed at corners than along the rest of the walls).

2) Avoiding taking the foundations deeper at the corners by providing ground insulation only at the corners. The foundation depth is as for the walls in 1). See 8.6.2.

3) Using a restricted foundation depth (not less than 0,4 m), the same foundation depth all round building. Provide ground insulation all round the building, but increased at the corners. See 8.6.3.

The depth of the foundations and/or the extent of the ground insulation are determined by the design freezing index. F_d.

Design the floor insulation to give satisfactory floor temperatures and energy economy (ie 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.

8.2 Restrictions

8.2.1 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 all round the building.

8.2.2 Floor height

The foundation depths and frost insulation specified in this clause apply for floors with a height *h* above ground level not exceeding 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).

8.2.3 Thermal resistance of floor slab

The thermal resistance of the floor slab. R_f, includes any insulation layers above, below or within it, together with that of any floor covering.

If the thermal resistance of the floor slab 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 m^2xK/W. If $R_f > 5$ m^2xK/W. either undertake numerical calculations in accordance with annex B or use the procedures for unheated buildings (clause 10).

8.3 Ground insulation

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, D_g, D_{gw} *and* D_{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 D_g if the footing projects beyond the foundation wall. as in figure 1 a.

If ground insulation is used together with internal edge insulation, take care to avoid a thermal bridge by taking 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.

8.4 Unheated parts of a building

If some parts of a building are unheated, the procedures of 8.5 and 8.6 may be applied to the heated Parts, provided that the protection described in 8.4.1 or 8.4.2 (as appropriate) is applied to the unheated parts of the building.

8.4.1 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 *Lu* is given in terms of the design freezing index in table 1.

Table 1 : Maximum unheated length *Lu* for limited unheated parts

F_d(Kxh)	= 30 000	> 30000 to 40 000	> 40 000 to 50 000	= 50000
L_u (m)	4.0	3.5	3.0	2.0

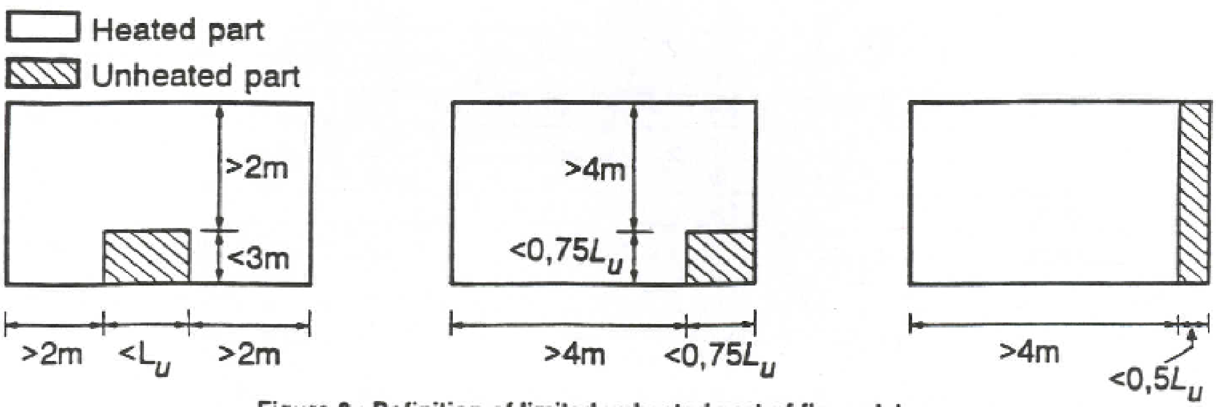

Figure 2 : Definition of limited unheated part of floor slab

NOTE: *Lu* 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 *Lu* in other cases. as shown in figure 2.

For limited unheated parts:

- insulate the floor of the unheated part as for unheated buildings according to 10.2:

- at the external perimeter of the unheated part and for *Le* to each side of it, use vertical edge insulation according to 8.5. together with frost protection as for corners according to 8.6, where values of *Le* are given as a function of the design freezing index in table 5:

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

8.4.2 Building with more extensive unheated parts

If any unheated part of the 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 *Le* where it adjoins the heated part, where values of *Le* are given as a function of the design freezing index in table 5.

8.5 Vertical edge insulation

Provide vertical edge insulation in all cases, of thermal resistance *Ry* 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*(m^2xK/W)*

	$0.0 < R_f = 1,0$		*1.0 < R_f = 2.6*		$2.6 < R_f = 5,0$ m^2xK/W	
F_d(Kxh)	*h* = 0,3	0,3 < *h* = 0.6	*h* = 0.3	0.3 < *h* = 0.6	*h* = 0.3	0.3 < *h* = 0,6
5 000	.	.	0.5	0.8	0.8	10
10 000	0.5	0.8	1.0	1.0	1.5	20
20 000	0.8	1,0	1.0	1.2	1.5	23
30 000	10	1,0	1,0	1,3	15	25
40 000	1.0	1,0	1.2	15	1.7	2.7
50 000	1.0	1,2	1.4	1.7	2.0	30
60 000	12	1.4	1,8	2.1	24	3.4
70 000	1,4	1,6	2.1	2,4	2.8	3.6

NOTE 1: Greater values of *Ry* 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 (eg 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 *Hy* 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 = 0.6 m. or the full depth of the foundations if less;

. with ground insulation H_v is the depth of the lower surface of the ground insulation.

8.6 Alternative foundation designs

The foundation design should comply with 8.5 and with one of the following alternatives.

8.6.1 Foundations with no ground insulation

The depth of the foundations should be:

- at the walls at least $H_{f,}$

- near the corners and at limited unheated parts for a distance *Le* from these places, at least the greater depth H_{fc} (if F_d > 30 000 Kxh),

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(Kxh)	H_f*(m)*	H_{fc} (m)	L_c (m)
30 000	0.35	0.35	-
> 30 000 to 35 000	0.40	0.60	10
> 35 000 to 40 000	0.50	0.80	1,0
> 40 000 to 45 000	0.60	1.00	15
> 45 000 to 50 000	0.75	1.30	15
> 50 000 to 55 000	0.90	1.60	15
> 55 000 to 60 000	1.10	1.80	2.0
> 60 000 to 65 000	1.30	2.00	2.0
> 65 000 to 70 000	1.50	2.20	25

8.6.2 Ground insulation only at corners

If F_d = 30 000 Kxh, ground insulation is not required.

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

The thermal resistance of the ground insulation should be at least 1,0 m_2xK/W, and its width should be D_{gc}, where values of D_{gc} are given in table 4. See also figure 3.

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

F_d(Kxh)	H_f*(m)*	D_{gc} (m)	L_c (m)
= 30 000	0.35	-	-
> 30 000 to 35 000	0.40	0,50	1.0
> 35 000 to 40 000	0,50	0.50	1,0
> 40 000 to 45 000	0.60	0.50	15
> 45 000 to 50 000	0.75	0,60	1.5
> 50 000 to 55 000	0.90	0.80	1,5
> 55 000 to 60 000	1.10	080	2.0
> 60 000 to 65 000	1,30	0.80	2.0
> 65 000 to 70 000	1.50	100	25

8.6.3 Ground Insulation all round building

If F_d = 30 000 Kxh, ground insulation is not required.

For greater values of F_d, the foundation depth can be reduced to not less than 0.4 m by placing ground insulation all round the building,

If F_d > 30000 Kxh, 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, D_{gc} of ground insulation near the comers using figure 4, according to the value of F_d

If F_d > 37 500 Kxh, ground insulation is also necessary along the walls. Select an appropriate combination of thermal resistance. R_{gc}. and width, D_{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 comers and unheated parts, The corner insulation applies for a distance *Le* as given in table 5,

See also figure 3.

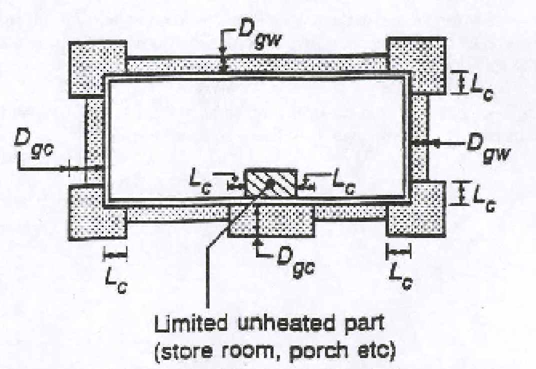

Figure 3 : Width of ground insulation

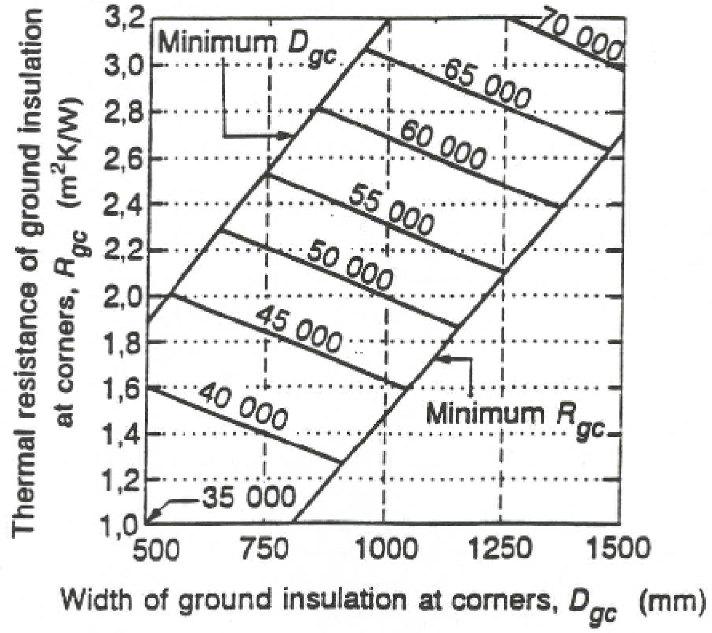

Figure 4 : Width and thermal resistance of ground insulation at corners and limited unheated parts, for slab-on-ground floor with $H_f \leq 0,4$ m

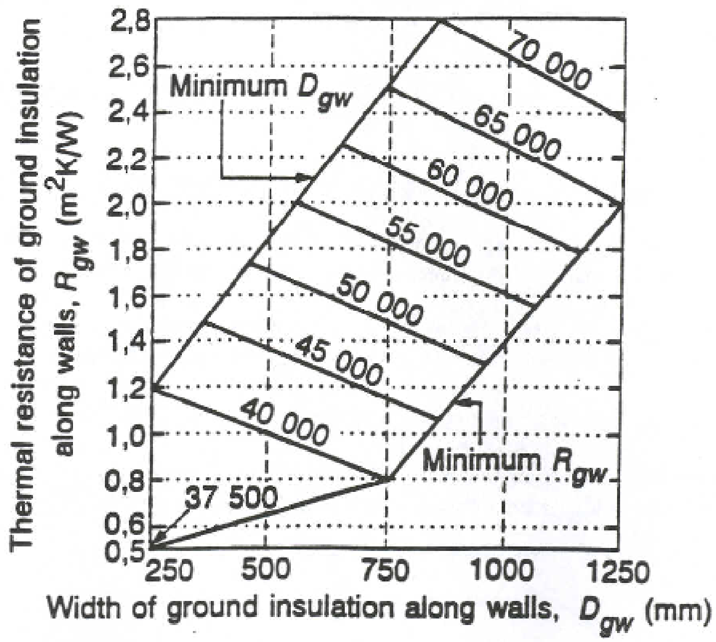

Figure 5 : Width and thermal resistance of ground insulation along walls, for slab-on-ground floor with $H_f \leq 0,4$ m

Table 5 : Length of corner insulation

F_d(Kxh)	L_C (m)
= 30000	-
> 30 000 to 35 000	1.0
> 35 000 to 40 000	1.0
> 40 000 to 45 000	15
> 45 000 to 50 000	1.5
> 50 000 to 55 000	1.5
> 55 000 to 60 000	2.0
> 60 000 to 65 000	2.0
> 65 000 to 70 000	2.5

8.7 Buildings with low internal temperature

For poorly heated buildings with 5°C = $T_{i,m}$ < 17°C, the values in 8.6.3 can be used if H_f is at least 0.6 m instead of 0.4 m.

Alternatively increase the values of *Ht* in table 3 or table 4 by 0.2 m.

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

9 Heated buildings: Suspended floors

9.1 Heated underfloor space

The same procedures as for slab-on-ground floors, using the values of the parameters in clause 8, can be used for:

a) Suspended floors in which the underfloor space is unventilated and airtight, 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 8.5;

- R_f, taken as the sum of the thermal resistance of the suspended pari of the floor and the thermal resistance of the insulation on the base of the underfloor space, does not exceed 5.0 m^2xK/W.

b) Suspended floors in which the underfloor space is 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 8.5;

- R_f, taken as the thermal resistance of the insulation on the base of the underfloor space, does not exceed 5.0 rrJ2.KJW.

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

9.2 Underfloor space ventilated with outside air

The foundations may be designed either without ground insulation according to 9.2.1 or 9.2.2 (as appropriate), or with ground insulation according to 9.2.3, 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 m^2xK/W.

4) The thermal resistance of the suspended part of the floor does not exceed 8 m^2xK/W (without ground insulation) or 5 m^2xK/W (with ground insulation).

5) The thermal resistance of the foundation wall above the outside ground level is not less that 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 then 0.6 m above the outside ground level, this thermal resistance is to be increased such that the total quantity of heat passing through the foundation wall above 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 m^3 per square metre of floor slab per hour.

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 thennal resistance of foundation walls above ground and of vertical edge insulation below ground for suspended floors

F_d(Kxh)	R_v (m^2xK/W)
= 5 000	05
> 5000 to 10000	08
> 10 000 to 20 000	10
> 20 000 to 30 000	10
> 30 000 to 40 000	1.0
> 40 000 to 50 000	12
> 50 000 to 60 000	14
> 60 000 to 70 000	1,6

9.2.1 Foundations with no ground insulation: long buildings

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

The depth of the foundations should be, depending on the design freezing index, the maximum ventilation rate of the underfloor space, and the thermal resistance of the suspended floor:

- 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.

9.2.2 Foundations with no ground insulation: short buildings

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

The depth of the foundations should be at least that given in table 8 all round the building.

NOTE: The greater depth is needed all round short buildings because 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 7 : Foundation depth (in metres) for suspended floors: walls of long buildings

ventilation rate (m^3/m^2h):	1			2		
R_f (m^2xK/W):	2	4	8	2	4	8
F_d (Kxh):						
= 5 000	.)	.)	0,50	.)	0,40	055
> 5000 to 10000	.)	045	0.70	.)	0.55	0,80
> 10000 to 15000	.)	0,55	0.85	0.45	0.70	095
> 15000 to 20 000	.)	065	0.95	050	0.80	115
> 20 000 to 25 000	0.35	0,75	110	0.60	0.90	125
> 25 000 to 30 000	0,50	085	1.25	0.70	1.00	135
> 30 000 to 35 000	0.60	-1,00	140	0,80	1.20	160
> 35 000 to 40 000	0,70	1,15	1,60	0.90	1.35	180
> 40 000 to 45 000	0.75	125	175	1.00	1.50	200
> 45 000 to 50 000	0,85	140	1.90	1.10	1.65	220
> 50 000 to 55000	0,90	150	2.05	120	1.75	2.35
> 55000 to 60 000	0,95	1.60	2.20	1.25	1.90	250
> 60 000 to 65 000	1.05	1.70	2.35	1.35	2.05	2.60
> 65 000 to 70 000	1,10	1.80	2.50	145	215	2.70
	.) indicates less than 0.35					

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

ventilation rate (m^3/m^2h):	1			2		
R_f (m^2xK/W):	2	4	8	2	4	8
F_d (Kxh):						
= 5000	.)	0.40	0.55	.)	0.50	0.65
> 5000 to 10000	.)	055	0.80	0.45	0.70	090
> 10 000 to 15000	0.45	0.70	0.95	055	0.85	1.10
> 15000 to 20 000	0.50	080	1,15	0.65	0.95	1.30
> 20 000 to 25 000	0.60	0.90	1.25	0.75	1.10	145
> 25 000 to 30 000	0.70	100	1.35	0,85	1.25	160
> 30 000 to 35 000	0.80	1.20	1.60	1.00	1.40	1.80
> 35 000 to 40 000	0.90	1.35	180	115	1.60	2.05
> 40 000 to 45 000	1,00	150	2,00	1.25	1.75	2.25
> 45 000 to 50 000	110	1.65	2.20	140	190	240
> 50 000 to 55 000	1.20	1.75	2.35	1.50	2.05	250
> 55 000 to 60 000	1,25	1.90	2.50	1.60	2.20	2.60
> 60 000 to 65 000	1.35	2,05	2.60	1.70	2.35	270
> 65 000 to 70 000	1.45	2.15	2.70	1.80	2.50	2.80
	.) indicates less than 0.35					

9.2.3 Foundations with ground Insulation

The depth of the foundations (all round the building) should be at least that given in table 9.

The data apply for R_f = 5 m^{2}xK/W. Ground insulation of width D_g = 1,0 m is applied all round 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 floor with ground insulation

Rgw (m^{2}xK/W):	0,0	0,5	1,0	1,5	2,0	2,5	3,0
Rgc (m^{2}xK/W):	0,0	0.7	1,4	2,1	2,8	3,5	4,2
F_d (Kxh):			..				
= 20000	0,80	0,35	-)	-)	-)	-)	-)
> 20 000 to 25 000	090	0,50	-)	-)	-)	-)	-)
> 25 000 to 30 000	1.00	0.70	0.35	-)	-)	-)	-)
> 30 000 to 35 000	1,20	090	060	035	-)	-)	-)
> 35 000 to 40 000	1,35	1,15	0,90	0.60	035	-)	-)
> 40 000 to 45 000	1.50	1,35	1.10	0,85	055	035	-)
> 45 000 to 50 000	1.65	145	1,25	100	075	0.50	035
> 50 000 to 55 000	1,75	1.55	1,35	1.15	0,90	0.65	045
> 55 000 to 60 000	1,90	1,65	145	1,30	105	0.85	060
> 60 000 to 65 000	2,00	1,80	1.60	140	120	0.95	075
> 65 000 to 70 000	2,15	1,90	1,70	150	130	1,05	0.90
	-) indicates less than 0,35						

10 Unheated buildings

This clause applies 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.

10.1 Without ground insulation

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

10.2 With ground Insulation

The foundation depth can be reduced to less than that required in 10.1 by having a continuous insulation layer beneath the foundations and which extends to a width *Og* 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.

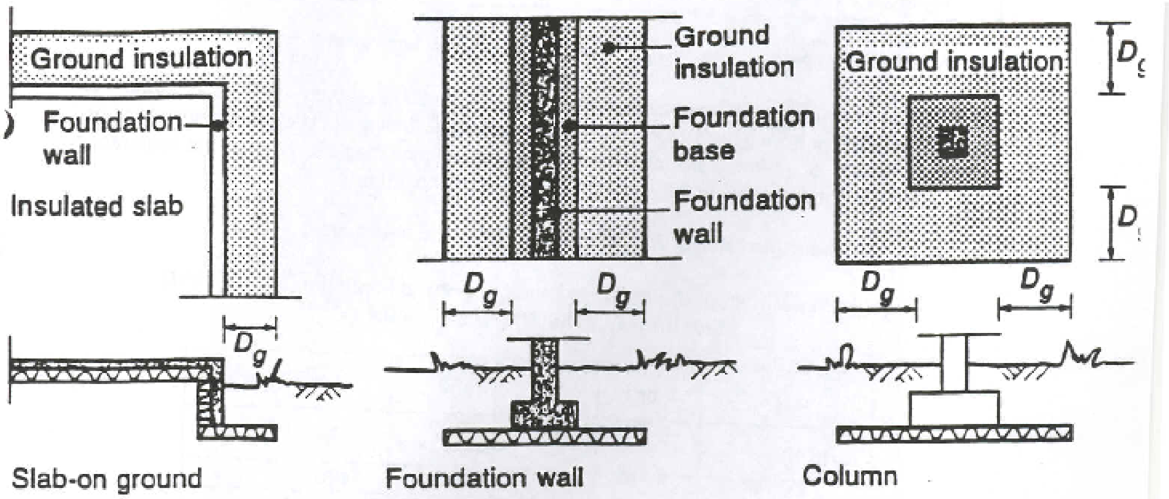

Figure 6 : Width of ground insulation for unheated buildings

Protect the insulation layer as follows:

a) place a layer of well-drained, non frost-susceptible material at least 150 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 reinforced 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.

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

- the design freezing index. F_d.

- the annual average external air temperature. T_e.
- the depth of the foundations.

Determine the minimum width D_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: Minimum width of ground Insulation for unheated building

F_d(Kxh)	10000	20 000	30 000	40 000	50 000	60 000	70 000
D_g (m)	0.75	1.20	1.60	2.00	2.40	2.75	3.10

NOTE 2: The same value of D_g applies along walls and at comers.

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 3: The same value of R_g applies along walls and at corners.

Table 11 : Minimum thermal resistance of ground Insulation, R_g (m^{2}xK/W) for unheated building with H_f= 0,4 m

T_e (C°):	0 or 1	2	3	4	= 5
F_d(Kxh):					
= 10000	-	.	-	1.0	1.0
20 000	-	17	15	14	1.2
30 000	3,4	2.8	2.4	2.0	18
40 000	44	37	3.2	27	.
50 000	(5.5\	46	40	.	.
60 000	(6.6\	(56\	.	.	.

NOTE 4: Values of thermal resistance greater than 5.0 m^{2}xK/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 5: IF F_d = 60 000 Kxh a foundation depth of 0.4 m is not sufficient and should be increased.

Table 12 : Minimum thermal resistance of ground insulation, R_g (m^{2}xK/W) for unheated building with Ht = 1,0 m

T_e (°C):	0 or 1	2	3	4	5
F_d (Kxh):					
= 10 000	-	-	-	0.0	0.0
20 000	-	0.6	0.4	0.3	0.3
30 000	1,7	1.2	1.0	0.7	0.5
40 000	2.2	1.7	1.4	1.1	-
50 000	3.0	2.3	1,9	-	-
60 000	3.8	2,9	-	-	-
70 000	4.7	-	-	-	-

10.3 Additional non frost-susceptible material beneath insulation

The minimum thermal resistance of the ground insulation, R_g specified in 10.2 may be reduced by having a layer of non frost-susceptible material beneath the insulation of thickness greater than 150 mm.

R_g may be reduced by 0,2 m^{2}xK/W per 100 mm increase in the thickness of this layer above 150 mm.

10.4 Additional soil cover above insulation

The minimum thermal resistance of the ground insulation, R_g, and its minimum width, D_g specified in 10.2 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 m^{2}xK/W per 100 mm increase in thickness of soil cover above 300 mm.

D_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

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

A.1 Calculation of freezing index for one winter

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

$$F = 24 \sum_j \left(T_f - T_{d,j}\right)$$

where:

- F is the freezing index for one winter. in Kxh:
- T_f is 0°C;
- $T_{d,j}$ 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.

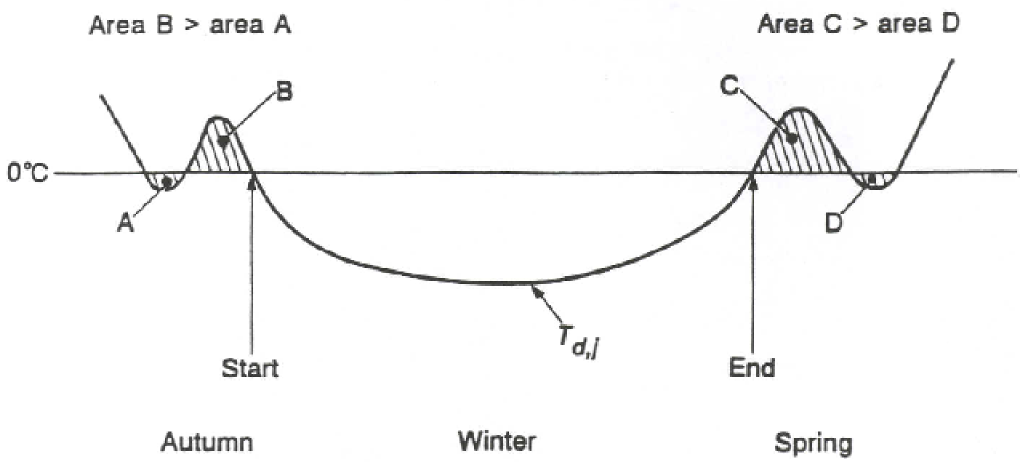

Figure A.1 : Illustration of the limits of the freezing season (first example).

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 through 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.

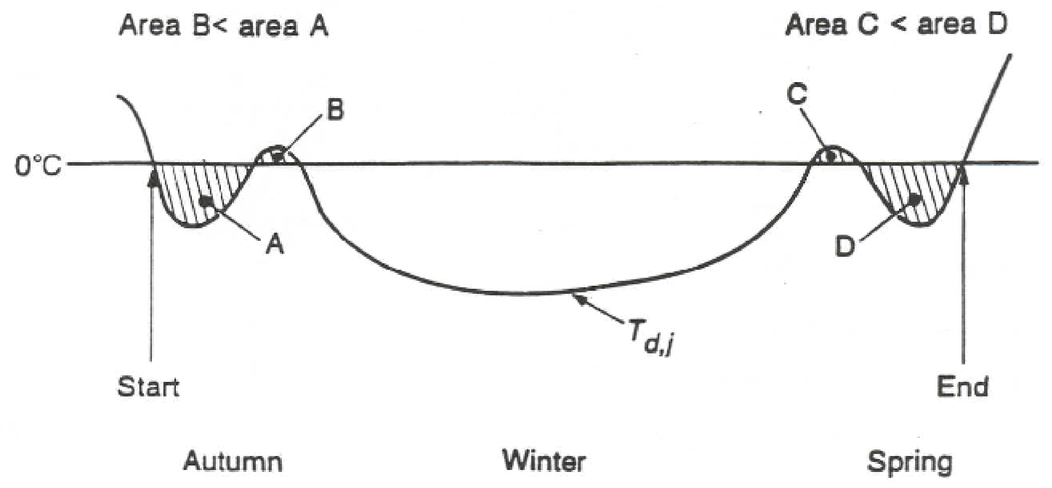

Figure A.2 : Illustration of the limits of the freezing season (second example).

NOTE 1: In the past freezing indexes have sometimes been calculated including only positive differences in equation (A.1), ie ignoring the effect of thawing periods. Tables or maps of freezing index 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 mid-summer to mid-summer). The freezing index is then the largest difference between maximum and minimum turning points on this curve.

NOTE 3: In this standard the air freezing index. ie the freezing index calculated from external air temperatures, is used as the design parameter. This is because air temperatures are more readily available than ground surface temperatures. Differences between air and surface temperatures may be caused by vegetation, snow cover, radiation, evaporation, etc. The precise effect of these factors is not readily quantified but the air freezing index is normally somewhat higher than the surface freezing index, making it a conservative choice, which is appropriate for design purposes.

A.2 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 anyone winter exceeds F_n is *1/n.*

NOTE 1: The appropriate value of *n* should be decided upon having 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 or 100 years.

NOTE 2: *n* is referred to as the return period, that is 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_j, calculated as described in A.1, of *m* winters at the location. 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.3) has been found to be suitable for many climates, and is recommended in the absence of specific information for the locality concerned.

A.3 Use of the Gumbel distribution

Calculate the average freezing index *F* and the standard deviation S_F follows:

$$\overline{F} = \frac{\sum F_i}{m} \qquad i = 1,2,.....m \qquad \text{(A.2)}$$

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

The design freezing index is then given by

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

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

Obtain the appropriate values of y and S_y from table A.1 corresponding to the number m of individual values of F_j 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 *y* and *Sy*

m	y	S_y	m	y	S_y
10	050	0.95	50	0.55	116
15	0.51	1.02	60	0.55	117
20	0.52	1.06	70	0.55	119
25	0.53	109	80	0.56	119
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	2	5	10	20	50	100
Y_n	0.37	1.50	2.25	2.97	3.90	4.60

Further information about the Gumbel distribution may be found in:

- E J Gumbel. Statistics of extremes. Columbia University Press. New York. 1958. (In English)

- R S Heiersted. Statistisk bestemmelse ay klimapAkjenninger (Statistical treatment of climatic loads on constructions), Frost i jord. 19. December 1977. (In Norwegian).

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 modeled 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 to 1600 kg/m^3 or if the water saturation is less than 80%), numerical calculations according to B.2 should 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 to B.2 may be used as an alternative to the tables and graphs given in this standard.

B.2 Conditions for numerical calculations

Subdivision of the geometrical model

The geometrical model of the ground is sub-divided in such a way that the sub-divisions are smallest near to the edge of the floor, and gradually increasing in size to much larger sub-divisions near the truncation planes. The criteria given in prEN 32573 (ISO/DIS 12573) for judging whether sufficient subdivisions have been used (related to the calculation of heat flows and surface temperatures) are recommended.

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.

Three- or two-dimensional calculations
If the smaller dimension of the floor is s 4 m, three-dimensional calculations should 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.

Boundary conditions

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

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 prEN 26946.1 (ISO/DIS 6946/1) apply at the inside floor surface and at the outside ground surface.

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 unit 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.

Design external temperature

Use a sinusoidal variation of external temperature according to

$$T_e = \overline{T}_e + \hat{T}_e \cos\left(2\pi t / t_p\right) \qquad \text{(B.1)}$$

where: *Te* is the external air temperature (°C) at time *t,* in s:

Te is the annual average external air temperature, in GC;

^Te is the amplitude of the sinusoidal variation, in K;

tp is one year expressed in seconds (3.15 x 107 s).

^Te 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 calculation period should extend at least one year before the design year.

Design criterion

The foundation design is considered safe against frost heave when no fully frozen soil occurs below the foundation during the design winter, ie 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.

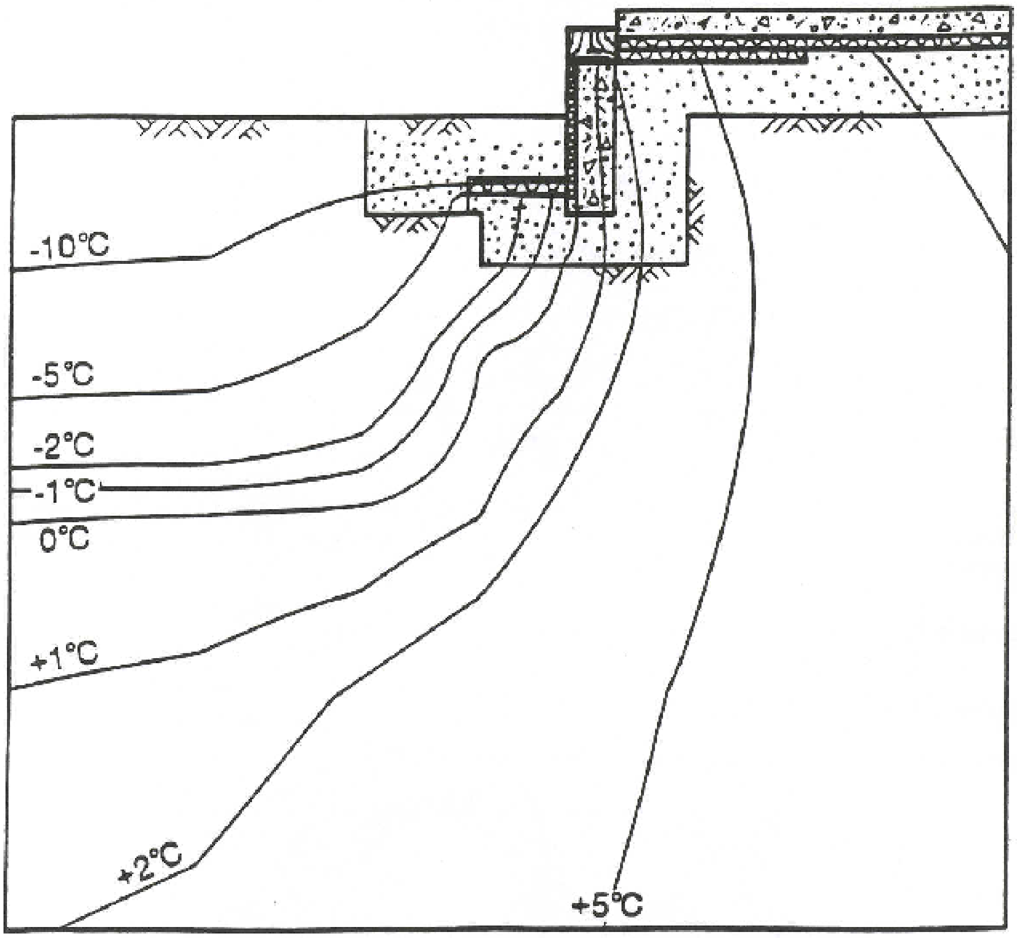

Figure B.1 : Illustration of isotherms in the ground near a foundation

Annex C (Informative)

Frost susceptibility of the ground

Frost heave of foundations occurs when the following conditions are met:

- they are built on frost-susceptible soil;

- there is a sufficient supply of water to this soil;

- there is freezing of the soil below the foundation,

Frost-susceptible soil is ground which expands when water contained within it freezes,

In general a geotechnical examination of the ground conditions at the building site to the depth of frost penetration is necessary to assess the 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. This implies sufficient supply of ground water and sufficiently high capillarity and permeability of the soil. Thus soils with a high content of silt or clay are those giving the greatest risk of frost heave.

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

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

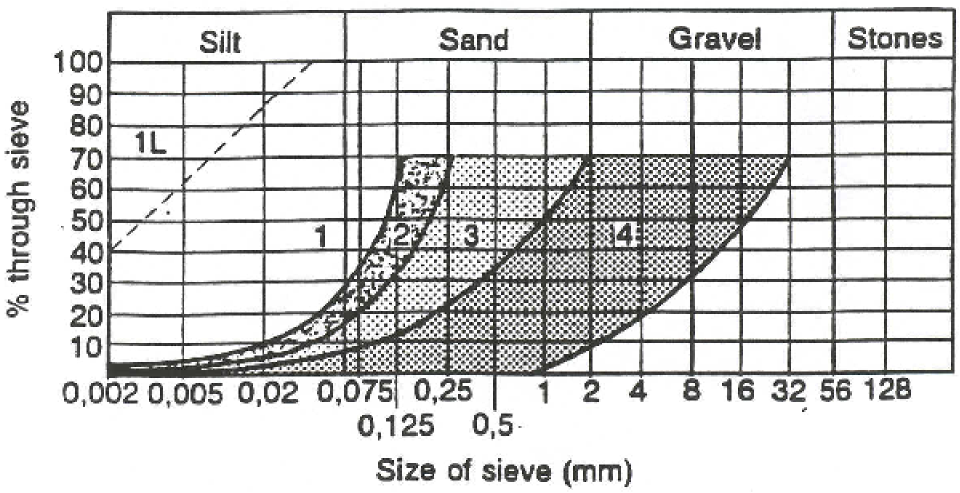

Figure C.1 : Estimation of frost susceptibility of the basis of grain size distribution.

With reference to figure C.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 frost-susceptible, 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 frost-susceptible. 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 institute.

Further information about frost susceptibility and testing methods may be found in:

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

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

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

Annex D (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 *Fso* - 47000 K'h,

- annual mean extemal temperature Te -1,5°C.

D.1 No frost insulation

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

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

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 and suspended floors (although in the case of a slab-on-ground below an unheated building the slab itself would not be protected against frost heave damage).

D.2 Slab-on-ground using frost insulation

The floor will be insulated with all-over insulation of thermal resistance R_f - 3.0 m2.KJW.

a) Using vertical edge insulation only

Using table 2, the thermal resistance of the vertical edge insulation is to be at least 1.9 m^2xK/W (interpolating between 1,7 and 2,0 m^2xK/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 m^2xK/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 m^2xK/W is applied over a distance of 1,5 m from each corner.

c) Ground Insulation all round the building

Using 8.5.3, 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 m^2xK/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 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 the figure), and the other parameter is determined from the figure. Suppose that ground insulation of thermal resistance 1,4 rn^2xK/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 rn^2xK/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 D.1 illustrates the design for this case.

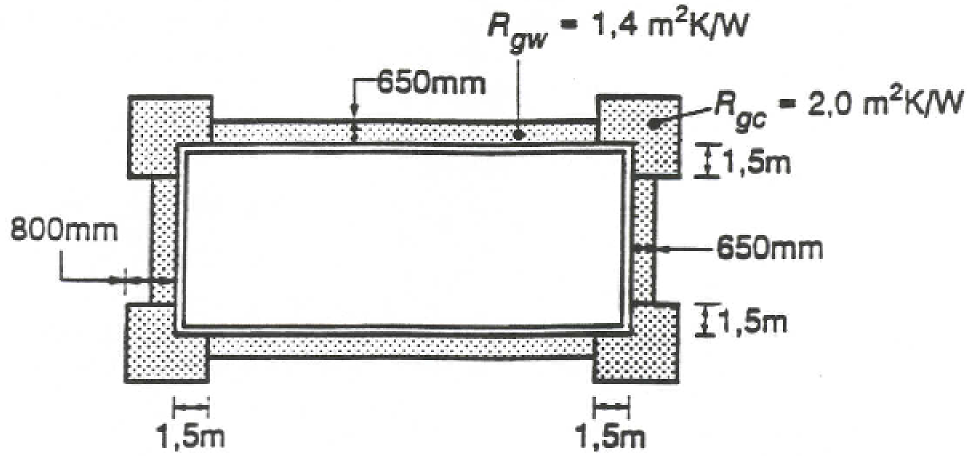

Figure D.1 : Illustration of the foundation insulation for example D.2 c)

D.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 m^2xK/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 m^2xK/W

- 1,65 m for $R_{f =}$ 4 m^2xK/W

and interpolation between these values for R_f - 3 m^2xK/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 m^2xK/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 are then 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 m^2xK/W along the walls and 1,4 m^2xK/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 m^2xK/W along the walls and 3.5 m^2xK/W within 1,5 m from each corner;

D.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 is to be at least 2,28 m (interpolating between 2,00 and 2.40 m).

The annual mean external air temperature is 1,5°C: the column "0 or 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= 5.2 m^2xK/W by interpolation between freezing indexes of 45 000 and 50 000 in table 11.

For a foundation depth of H_f = 1,0 m. R_g = 2.8 m^2xK/W by interpolation between freezing indexes of 45 000 and 50 000 in table 12.

The necessary thermal resistance of ground insulation for intermediate foundation depths can be obtained by linear interpolation between these values of 5.2 and 2.8 m^2xK/W. Thus for a foundation depth of 0,6 m, R_g is to be at least 4,4 m^2xK/W.

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