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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

Reference number
ISO 13793:2001(E)

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of an identical text or by endorsement, at the latest by September 2001, and conflicting national standards shall be withdrawn at the latest by September 2001.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

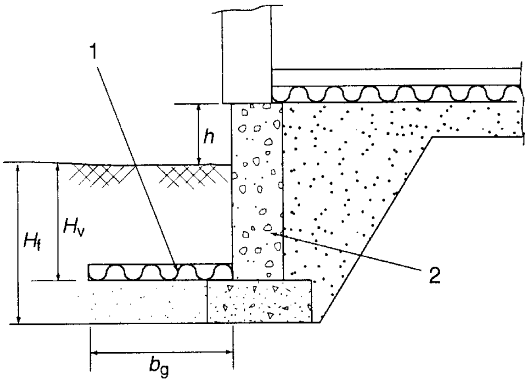
3.1.10
floor insulation position
height of lower surface of the floor insulation layer above external ground surface

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

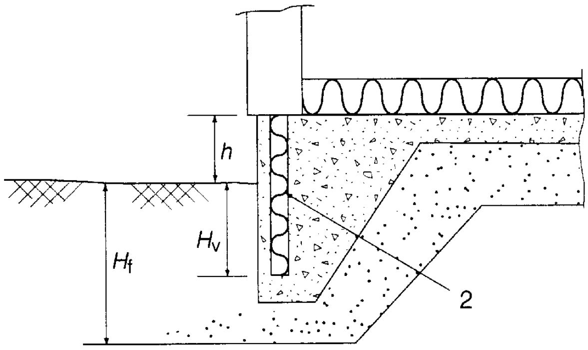
3.2 Symbols and units

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

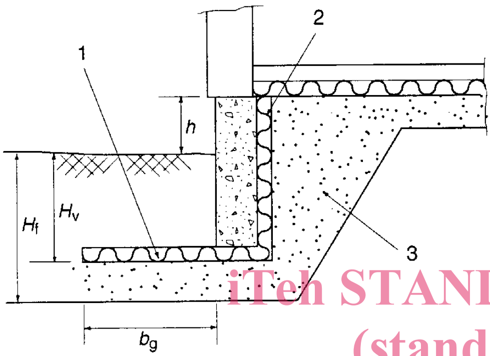
Symbol	Quantity	Unit
B	width (smaller dimension) of building	m
b_g	width of ground insulation, measured from outer limit of footing	m
b_{gc}	width of ground insulation at corner	m
b_{gw}	width of ground insulation along wall	m
F_d	design freezing index	K·h
F_n	freezing index which statistically is exceeded 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)	$m^2 \cdot K/W$
R_v	thermal resistance of vertical edge insulation	$m^2 \cdot K/W$
R_g	thermal resistance of ground insulation	$m^2 \cdot K/W$
R_{gc}	thermal resistance of ground insulation at corner	$m^2 \cdot K/W$
R_{gw}	thermal resistance of ground insulation along wall	$m^2 \cdot K/W$
$\overline{\theta}_e$	annual average external air temperature	°C
$\theta_{i,m}$	average internal air temperature in month m	°C



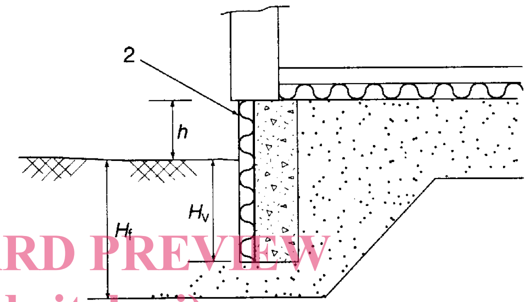
a) Lightweight concrete foundation wall with ground insulation



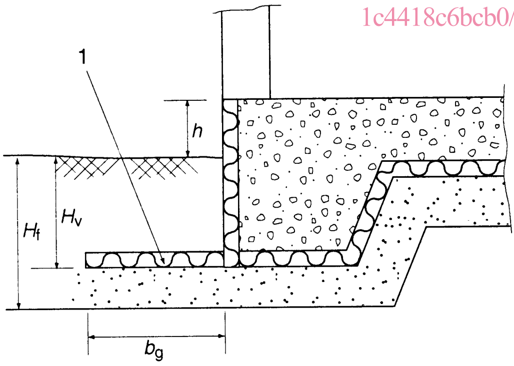
b) Floor slab with edge beam



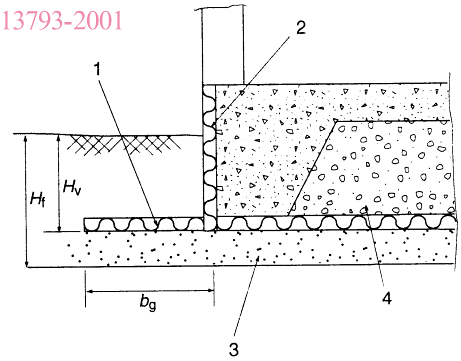
c) Concrete foundation wall with ground insulation and internal vertical edge insulation



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)	$C = 3 \times 10^6$ J/(m³·K)
heat capacity per volume (frozen)	$C_f = 1,9 \times 10^6$ J/(m³·K)
latent heat of freezing per cubic metre of soil	$L = 150 \times 10^6$ 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 $H_f < H_0$, 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 $\leq \theta_{i,m} <$ 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.