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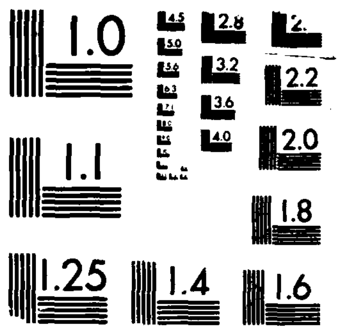

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FOUNDATION DESIGN AGAINST FROST ACTION IN EUROPE

Omar T. Farouki

March 1988

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FOUNDATION DESIGN AGAINST FROST ACTION

IN EUROPE

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LIST OF SYMBOLS

F	Freezing Index h^oC
F_d	Design Freezing Index
F_{100}	Maximum Freezing Index in 100 years
MAT	Mean Annual Temperature ^oC
T_{in}	Internal temperature in building ^oC
T_{out}	External air temperature ^oC
R_1	Themal resistance of floor insulation m^2K/W
R_2	Thermal resistance of foundation wall or edge beam insulation
R_3	Thermal resistance of ground insulation
R_i	Internal heat transfer resistance (inside air to floor surface)
R_t	Thermal resistance of the floor structure
R_j	Thermal resistance of the ground underlying the building
R_T	Total thermal resistance of the floor structure against the ground (i.e. including the effect of the underlying ground)
R_o	Thermal resistance of insulation layer
R_e	Thermal resistance of existing structure
U-value	Heat loss per unit area from part of a structure W/m^2K
	Thermal conductivity W/mK
h_o	Frost penetration depth in undisturbed ground
z_f	Frost penetration depth at a foundation
z_g	Foundation depth
h	height of top of foundation wall, or bottom of floor structure, above outside ground level (the pedestal height)
b	generally refers to width of ground insulation
t	generally refers to thickness of insulation

1. INTRODUCTION

Foundation design in areas of frost depends on the choice of an appropriate foundation depth and protection of the foundation from the effects of frost particularly where there is frost-susceptible soil in proximity. Harmful frost action arises under certain conditions. Frost must penetrate down to frost-susceptible soil and sufficient water must be available to feed ice lens formation in this soil at an adequate rate. Ice lenses produce forces that are usually directed at right angles to the frost front. These forces can be very large and lead to heaving of the entire foundation or parts of it as the soil freezes below. The magnitude of the heave forces cannot generally be determined. It is impractical to fully restrain heave and therefore one should design so that it does not take place at all. In practice this means that any frost-susceptible soil that can affect the foundation, must either not be allowed to freeze by use of insulation or it should be replaced by non-frost-susceptible material or that water is prevented from being supplied to the freezing front.

Frost damage can also arise from 'sidegrip' occasioned by the lateral shearing stress exerted by the freezing soil on adjacent foundations, such as foundation walls or strips, columns or posts. There is then a tendency for these to be lifted up by shearing forces acting along their side surfaces and this is counteracted by the weight of the foundation and the load it carries and also by anchorage below the frost line.

In certain cases freezing of frost-susceptible soils can produce horizontal forces causing the buckling of basement walls, retaining walls and the like. These forces are difficult to estimate and should be prevented from occurring by suitable design, by using insulation, by preventing capillary water from rising to the freezing front or, if possible, by lowering ground water level in the vicinity of the wall.

In the Scandinavian countries there have been many instances where foundations have been based at reduced depths and protected by use of insulation. A reduced depth is one that is shallower than the frost-free depth in undisturbed ground. Such a shallow depth has usually been used with 'light' buildings that exert only a small bearing pressure on the underlying ground. These include buildings of a large extent, such as warehouses, if the bearing pressure is sufficiently reduced by means of spread foundations. Heavy structures which exert large bearing pressures generally require deeper foundations extending to firm soil layers or to rock. The foundation depth is then usually greater than the frost-free depth and problems due to frost action do not arise.

In Sweden foundations with reduced depths had been built from around the 1920's and by 1975 about 50000 houses with 'slab-on-grade' had been built and generally functioned satisfactorily (Torgerson, 1975). They had a concrete slab more or less at grade level and an edge beam or foundation wall transferring the main building load to ground at a shallow depth. However, foundation depths for light buildings varied from a value of 0.25m all the way down to the full frost-free depth in undisturbed ground.

The Swedish Building Standards of 1967 (SBN 67) specified a foundation depth of 0.25m as a general rule for the whole country. However this was dependent on certain conditions being satisfied and local circumstances could necessitate a deeper foundation. Where frost-susceptible soil existed the foundation depth had to be increased sufficiently so that no damage occurred from frost heave or sidegrip. This meant that factors influencing frost penetration had to be considered and due regard given to any heat contribution from the building and to the soil's characteristics, ground water conditions, drainage and insulation measures. On this basis an assessment could be attempted to determine how much one could reduce the foundation depth in comparison with the frost-free depth in undisturbed ground.

The guidelines in SBN 67 were based partly on experience relating to a large number of completed constructions and also on certain temperature measurements and theoretical calculations, e.g., by Adamson and others in 1964. However the theoretical basis was somewhat unsatisfactory partly because of the difficulty at that time of mathematically analysing the problem of heat flow in the foundation soil area. Modern computer techniques enabled this problem to be solved in sufficient detail with the determination of temperature distribution related to different building designs and climatic conditions. The effects of various factors on frost penetration were assessed by Adamson et al (1971, 1973) and Adamson (1973). This eventually led to revision of SBN 67 to produce the 1980 version of the Swedish Building Standards, i.e. SBN 80.

Norwegian experience with slab-on-grade design came later than Swedish. Methods of construction based on a reduced foundation depth began to be used in Norway around 1950 and test houses with slab-on-grade foundations were built in 1955. A survey by Skaven-Haug (1961) of 432 Norwegian municipalities showed that the recommended minimum foundation depths varied from 0.75 m (in Kristiansund) to 1.88 m (in Finnmark) with a mean value about 1.45 m. Design of foundations with reduced depths was seen to offer economic advantages as regards savings due to easier and less costly foundation methods and possible economies in materials. In particular the economic advantages could be substantial in the case of an integrated multiple house development over a whole area especially if prefabricated techniques could be used as was done in the Skjetten development completed in 1972.

The limited Norwegian practical experience with light buildings was assessed around the late 1960's when 25 different designs of slab-on-grade construction with insulation were surveyed (Thue, 1973). These showed that there was no frost damage after occupation and heating of the buildings but slight damage occurred where there were connections to 'cold' auxiliary buildings or extensions, e.g., car ports. The most important conclusion from the survey was that it was essential to protect the construction operation and the foundation during the winter otherwise damage due to frost was liable to occur. Previous Swedish practical experience was also assessed, and although cases in Sweden showed rare occurrence of damages, one must bear in mind possible differences between Norway and Sweden as regards soil conditions and climatic effects. In Sweden, as in Norway, there were some damages associated with 'cold' accessories to heated buildings which could have been avoided by allowing free movement of the associated cold section. Also, in Sweden, there were cases of 'cold bridges' at the foundation-wall/floor/outer-wall connection in a heated house leading to excessive heat losses through the cold bridge with a consequent reduction in the floor temperature to an uncomfortable value.

The results of such surveys and assessments were taken into account in the Norwegian building guidelines which came into effect in 1970. Previous to that, in the building code regulations of 1949, the requirement was that foundations had to go down to the frost-free depth (in undeveloped ground during a hard winter) or to frost-resistant rock. There was no differentiation between foundations which received some heat from buildings such as houses and, on the other hand, foundations of 'cold' structures such as unheated buildings and bridges.

The Norwegian regulations which came into force in 1970 stipulated a demand on the performance of the structure. The foundations should be built so that no damage occurs from frost action, neither from heave nor from sidegrip arising from frost-susceptible soil. This implies that, as long as this requirement is satisfied, the foundation depth may be less than the frost-free depth in undisturbed ground. Additionally protection is required against the rise of moisture and water vapor into the building. Also the joint between the floor and the foundation wall and outer wall must not form a cold bridge.

The 1970 rules were based on fundamental principles and the requirement was a 'finished product' conforming to these principles while the decision process and detailed design were left to the engineer.

The change in the building regulations opened the way to non-traditional foundation designs. The basic idea in placing a foundation at a reduced depth is to arrange that the local frost penetration near the foundation is limited as a result of the heat escaping from the building and/or the heat released from the associated soil on cooling and freezing (known as 'soil heat'). This 'soil heat' is stored in the ground during the summer season and use of 'ground' insulation placed horizontally in the soil limits release of the soil heat to outside air during the cold season and so this heat is available to prevent the foundation area from getting too cold.

In the case of a heated house, the idea is to place adequate insulation at appropriate locations (e.g. at the foundation wall) so as to guide the escaping heat towards the base of the foundation, thereby preventing frost from penetrating near the base. To reduce the foundation depth it may also be necessary in certain cases to use artificial sources such as heating cables, but the economics of this would have to be justified.

Measures based on the ideas mentioned above would then ensure that no harmful effects arise from any frost-susceptible soil below the reduced frost penetration level. These concepts thus give protection from frost action and shallow foundations are also comparatively easy to carry out and can lead to cost savings. The result has been that shallow foundations are usually used in Norway at the present time for light buildings.

To develop a set of guidelines for design against frost action, the 'Frost I Jord' project was initiated in Norway around 1970 and continued until about 1976. The project was a co-ordinated venture the main participants being engineers at the Technical University in Trondheim and the Norwegian Building Research Institute (NBI) in Oslo but others, such as consulting engineers, had an input. The important results of Ad.mson and his co-workers in Sweden on foundations with a slab-on-grade and those with a crawl space were utilised and formed a basis for some of the results of the Frost I Jord project.

At the Institute for Building Technology (University of Trondheim) Thue (1974) considered that design against frost action can be approached on one of three levels. The first and simplest level is to produce a set of approved schematic designs for each of the four climatic zones in Norway. On the second level one develops a simplified procedure for calculations relating to a certain scheme. The user can quickly check whether a certain design solution is satisfactory from the thermal point of view. The third level is the highest and most complex method whereby the transient heat conduction equation is solved by a finite element computer technique with appropriate boundary conditions. This level of approach would apply to cases where a particularly high safety factor is required and it is important to go into great detail. It also applies to specific cases of complicated or extreme types of construction to which simpler methods are not applicable.

The computer programs developed by Thue are a powerful tool for the analysis of heat flow associated with foundations in the ground. They produce a plot of the isotherms in the soil around the foundation of a particular building under given climatic influences taking into account any heat contribution from the building, latent heat of fusion and the change in thermal conductivity of the soil on freezing. From the resulting location of the critical isotherm, the optimum insulation can be designed according to its material type, position, thickness and extent. The important criteria are the depth of frost penetration in the ground and the floor surface temperature inside the building.

The work of Thue and others at Trondheim was continued by Torgersen and others at NBI in Oslo and by consulting engineers like Algaard. The Frost I Jord project produced a series of publications bearing the same name and culminating with Frost I Jord, Nr 17, 1976. This number brought together all the previous theoretical and practical experience in an extensive and comprehensive report which is considered by Scandinavian engineers to be a reliable guide for design against frost action in soils. It contains chapters written by various experts on different aspects of foundation design.

Based on the results of the Frost I Jord project, NBI started publication in 1978 of a set of design sheets, the 'Byggdetaljer' ('Building Details'). These sheets also had an input from the Norwegian building industry and took into account comments on previous guidelines. The sheets contained guidelines that were revised as necessary, the latest appearing in modified form in 1987. They have been simplified and directed to the people doing the building work. They are not considered as law but are accepted by local authorities and the building industry as sensible and reliable guidelines to follow. They are widely used in Norway by engineers, architects and builders for reference and design in their offices and by engineers and contractors on building sites.

The 'Byggdetaljer' sheets propose guidelines that have a certain built-in safety factor. They were drawn up for general use and with their help one can save time and there is no need to carry out a design for a standard case on the basis of a computer program or by some other method. Computer programs can be very time-consuming and in Norway frost protection is based on the sheets and specific computer designs are very rare. Thus during 1987, the Norwegian Building Institute carried out only one computer test for a group of consultants who wanted a very close and detailed study of the heat loss in different slab-on-grade constructions for a school building (Torgersen, 1988).

Although there had been prior research on frost effects in Finland, particularly in the middle of the 1970's, the Finnish guidelines of 1979 on foundation design against frost action were largely based on the results of the Norwegian Frost I Jord project with some amendments to suit local conditions and parameters in Finland. With the exception of Lappland, the Frost I Jord results were found to be generally applicable to most of Finland. It was, however, found that more insulation thickness was required under Finnish conditions. The effect of installing insulation was to reduce frost damage but some designers or contractors did not follow the guidelines properly so that damages did occur in certain cases (Saarelainen, 1986).

On the basis of investigation of frost damages and experience with completed foundations, the 1979 guidelines were revised and new guidelines published in 1987 by the Geotechnical Laboratory of the Technical Research Center of Finland (VTT). This new 'code' amended the 1979 code and introduced some changes, in particular stressing the importance of continuous insulation under a foundation wall so that there is no cold bridge effect and the necessity for extra insulation at corners of structures. The 1987 code also referred to the mean snow cover during winter rather than the maximum snow depth, and suggested use of a reduction factor to allow for snow cover in

Economics of shallow foundations

Individual foundation cases may need to be investigated specifically to determine the most economic foundation. Thus in Austria the general preference is to place the foundation say 0.2 or 0.5m deeper using additional concrete rather than to use insulation. Contractors are not fond of using insulation because of the risks involved if it deteriorates with moisture uptake (Brandl, 1987). On the other hand, with the vast experience in using insulation in the Scandinavian countries, there is general confidence in its use and proper functioning over the life of a structure. The large economic savings due to multiple house developments such as the Skjetten project in Norway have been mentioned above.

In Finland it is estimated that a single private house, constructed with a slab-on-grade foundation and insulation, can entail a saving of 200 to 300 Finnish marks ($50 to $75) per square metre as compared with a foundation taken down to the frost-free depth in moraine (Saarelainen, 1986). The latter case would involve extra expense due to additional excavation costs and time involved and the expense of disposing of unwanted excavated material. The savings take into account the cost of the insulation and its placing. Considerable economies can thus result if a large development is carried out with many buildings involving similar multiple shallow foundations.

During the 1970's the slab-on-grade method came to be generally applied in Norway. As many as 50,000 to 100,000 houses have so far been built with shallow foundations ('Building Details' A 521.111, 1986). The economies have been considerable and the results very good.

2. DESIGN CRITERIA

2.1 FREEZING INDEX

The Freezing Index F at a locality represents the amount of frost occurring over a year and, in Scandinavia, is expressed as the product of degrees Celsius below $0^{o}C$ and the number of hours of frost conditions (10000 ^{o}Ch = 750 ^{o}F days). F varies from year to year and a suitable design value F_d needs to be chosen depending on the particular application.

In Norway the maximum F_d value used is F_{100} which is the maximum Freezing Index occurring in 100 years. Contours of this 'Maximum Freezing Index' are given for different parts of the country in Fig. 1. As explained in Chapter 5, lower values of F_d may be used in certain cases, e.g., F_{10}, F_5 or F_2 corresponding to the highest Freezing Index occurring in 10, 5 or 2 years respectively.

In Finland the maximum value of F_d used is F_{50} which may be found from Fig. 2 for a particular locality. Less stringent design values of F_{20}, F_{10}, F_5 or F_2 (Fig. 3) are sometimes used for particular applications.

The Swedish Standards (SBN 80) imply a maximum design Freezing Index of around F_{50} since the frost penetration depth h_o used in design (Section 2.4) corresponds roughly to the maximum frost depth in a fifty year period. Rather than using a Freezing Index, the Swedish Standards refer to four temperature zones in Sweden ranging from the coldest Zone 1 in the north of the country to the warmest Zone IV in the south (Fig. 4). Each zone does not have specific parameters like information on the mean temperature and length of winter. They are used, for example, in specifying wall and floor insulation required to achieve an acceptable indoor climate (Knutsson, 1988). In Norway such specifications (e.g., describing the highest acceptable heat loss through building parts) are now the same for the whole country. Previously four temperature zones were specified in the building code of 1981 (Torgersen, 1988).

In Denmark, a design Freezing Index of 12000 to 15000 $h^{o}C$ is chosen on the basis of the very severe winter of 1941-42 which corresponded to an occurrence of once or twice in a 100 year period (Porsvig, 1986)

Insulation placed horizontally in the ground, i.e., 'ground insulation', limits frost penetration and reduces the effective Freezing Index under the insulation. Fig. 5 shows the damping of the temperature distribution under the insulation. Correctly designed ground insulation should damp the temperature distribution so much that no frost occurs with harmful ice formation in the ground below the insulation.

2.2 MEAN ANNUAL TEMPERATURE

The Mean Annual Temperature (MAT) at a locality is important in connection with design of insulation placed in the ground outside the foundation (e.g. see chapter 5). MAT is a measure of the 'soil heat' stored in the ground over the summer warming period (Skaven-Haug, 1972). 'Ground insulation' retards loss of this heat and so frost penetration is reduced. MAT also influences the extent of frost heave, and MAT values are given in Fig. 6 for Norway and in Fig. 7 for Finland determined over the period 1931-60.

2.3 SOIL FROST SUSCEPTIBILITY

Soil frost susceptibility is generally based on grain size distribution with various classifications. For example there are three classes of susceptibility according to Swedish criteria. The Norwegian classification according to the State Road Board has four classes of susceptibility. In Austria frost susceptibility criteria are the same for building foundations as for road construction and have worked well over the last 15 years (Brandl, 1987).

Frost damage is often due to faulty or insufficient Ground Water Level measurement and more rarely to incorrect frost susceptibility classification (Eriksson et al, 1985). To reduce the risk of damage, a more detailed assessment of the foundation soil's frost susceptibility and the ground water conditions is required.

2.4 FROST PENETRATION

The frost penetration in free (i.e. undisturbed) ground h_o is an important design criterion and also the extent of its reduction by the effect of a building and its foundations. For Norway Fig. 8 shows the maximum frost depth in undisturbed sandy gravel without snow cover. Correction factors are applied for other materials as shown in Table 1, the factor for sandy gravel being taken as 1.0. No correction is usually made for the soil's water content although the effect of this could be significant in some cases.

TABLE 1
NORWAY
Correction Factor for Maximum Frost Depth (Fig 8)

Material	Correction factor
Stone	1.4
Sand/gravel	1.0
Silt	0.85
Clay	0.7
Turf	0.3

(from Algaard, 1976)

Fig. 9 from the Finnish guidelines (1987) gives a rough estimate of the expected frost depth in different soil types depending on the Freezing Index in the locality and the presence of snow cover. This cover is normally present almost all winter except for relatively short periods of variable melting in fall and spring. Due to uneven accumulation of snow at a building and its removal from trafficked areas, the effect of snow is not taken into account in design of building foundations. In Fig. 9 the natural snow cover corresponds to the average thickness of undisturbed snow cover in a given area (Saarelainen, 1988).

For no snow cover, Fig. 9 shows three curves for the frost depth applying to different soil types ranging from gravel (curve I) to clay (curve III). The effect of various thicknesses of natural snow cover in an average winter are shown only for soil II, i.e. silt and silty soils. For other soil types the frost depth can be estimated by multiplying the values for soil II by the coefficients in Table 2 (Finnish guidelines 1987) these being mean values for particular ground types. If more precise information is required, the designer must make local observations or more sophisticated analysis using the local soil profile, properties and thermal conditions.

TABLE 2

Finland

Conversion coefficients for frost depth
(Coefficient for silt is 1.00)

Ground type	Conversion coefficient
Rock	1.50
Sand, gravel and moraine	1.15
Silt	1.00
Clay	0.85
Turf	0.60

Fig. 9 was prepared on the basis of statistical treatment of actual frost depth observations, over a period exceeding 10 years, at various stations in Finland with known ground conditions, the snow cover being measured, (Saarelainen, 1988). The mean depth to ground water is about 1m in Finland and capillary rise is usually more than 0.5m. Hence the soil can usually be considered saturated almost up to ground surface. Apart from the degree of saturation other factors influencing frost depth are the geothermal gradient and the Mean Annual Temperature.

In determining the frost depth, Finnish practice uses 'silt' as the basis while Norwegian practice takes 'sandy gravel'. The Swedish Building Standards refer to natural layers of 'frost-susceptible friction soils' or 'moraines'. The 'maximum frost depth' h_o in these layers for various parts of Sweden is given in Fig. 10. This frost depth is the value occurring in a winter with 'particularly extensive' frost penetration. This is not clearly defined by the Swedish Standards but it is taken to mean the worst winter in 50 years (Knutsson, 1988). Fig. 10 applies to soil that is free of snow, without vegetation cover and does not receive any heat from a building, pipe etc. Also it is assumed that normal penetration of frost is not hindered, for example, on account of ground water lying near the ground surface. The values of h_o are considerably generalized. For soils with a small water content h_o would be larger while it would be smaller if the water content is larger.

A significant difference between Finnish and Norwegian design is that allowance is made in Finland for the effect of snow cover in connection with 'cold' structures. The 1987 Finnish guidelines give design values for the average snow depth in winter appropriate to different regions of Finland (Fig. 11). Using the average snow depth is considered better than applying the maximum snow depth as was done in the 1979 Finnish guidelines. The extent of snow cover may be used together with the design Freezing Index to estimate the frost depth from Fig. 9.

Where snow cover is to be neglected in Finland, the frost-free foundation depth can be found from Fig. 12. According to the guidelines, this figure applies to unheated structures such as stores, garages, sheds, masts, exterior staircases and supporting columns or walls. It gives the frost-free depth occurring once in 50 years for silt or silty sand or silty moraine (Soil II of Fig. 9).

In case one wishes to use a less stringent design Freezing Index, occurring once in a period of less than 50 years and the foundation soil is different from soil II, the corresponding F_d for a Finnish locality is first found from Fig. 3 and then applied to the appropriate (snowless) curve in Fig. 9 to determine the frost-free depth.

2.5 CRITICAL ISOTHERM

Since there is usually a significant depression of the freezing point of water in soil, Adamson et al (1973) suggested that the critical isotherm should be taken as that representing a temperature of $-1^{o}C$. At that temperature, it is not unusual to find some unfrozen water still present together with ice lenses that have formed in water-saturated soil. Ice lenses generally follow the isotherms and the forces produced are therefore mainly at right angles to the isotherms (Fig. 13) but they tend to incline towards the direction of least resistance.

Accordingly, in their analysis Adamson et al took the frost penetration depth as the vertical distance from the outside ground surface to the point of intersection of the $-1^{o}C$ isotherm with the downward extension of the inside edge of the foundation wall (i.e. intersection with the vertical x = 0 in Fig. 14). Whereas Thue (1974), working in Norway, originally used the $0^{o}C$ isotherm as the critical isotherm, the definitive Norwegian Frost I Jord report (Torgersen, 1976), followed Adamson in Sweden and fixed on the $-1^{o}C$ isotherm as the appropriate design isotherm. The requirement was stipulated that this isotherm should not penetrate under the foundation to an extent greater than one third the foundation width (Fig. 15). Only a very small amount of the frost-susceptible soil then freezes such that no damage is caused to the foundation. In Norway this criterion implies that the foundation depth will vary from about 0.4 m to about 1.2m from the mildest to the coldest region (up to a design Freezing Index of 60000 $h^{o}C$) where no ground insulation is used for extra protection.

Design practice in Finland is to regard the $0^{o}C$ isotherm as being critical and this introduces an extra safety factor as compared with Swedish or Norwegian practice. Fig. 16 shows the basic design principle or criterion used in Finland. As shown the $0^{o}C$ isotherm must not fall within the 2:1 load spread area beneath the foundation i.e. the prism formed by two boundaries the gradient of each being 2:1 (vertical to horizontal). Accordingly the soil in this area would not freeze and therefore there should be no adverse heave effects.

Whereas the Swedish criterion of Adamson et al (1973) requires that the $-1^{o}C$ isotherm should not penetrate beyond the <u>inner</u> edge of a foundation wall. the Finnish criterion specifies that the $0^{o}C$ isotherm should not penetrate beyond the <u>outer</u> edge of a foundation (Fig. 16a) or a foundation wall (Fig. 16b). This further limitation of the Finnish design method contributes to another increase in safety factor as compared with Swedish and Norwegian methods.

The Finnish guidelines (1987) give an example of a finite element method used to estimate the temperature distribution for a slab-on-grade foundation (Fig. 17). In the case illustrated the slab has increased insulation near the foundation wall which has inside insulation. Ground insulation is used with non-frost-susceptible material above and below it, while such material is also present below the floor and foundation wall. The heat flow analysis is based on non-stationary and non-linear conditions, the non-linearity being due to the generated heat of freezing. A computer program is used to calculate the temperature at the nodes of a typical finite element mesh for the boundary conditions shown, requiring:

(1) The dry unit weight and moisture content of the coarse material and that of the underlying soil from which the rate of production of latent heat of freezing is calculated.

(2) The specific heat and thermal conductivity of each material component in the model.

(3) An estimate of temperature conditions at the initial time point of the calculation procedure.

(4) The outside temperature conditions corresponding, for example, to the design winter.

(5) Other boundary conditions.

The isotherms can then be determined and, if the $0^{o}C$ isotherm has an unfavorable location, the insulation is increased and the analysis repeated.

2.6 FOUNDATION DEPTH

According to design in Norway, Sweden and Finland, Chapter 3 deals with foundation depths associated with slab-on-grade designs while Chapter 4 considers depths for foundations with crawl spaces.

In other European countries foundations are usually placed at the frost-free depth if the ground is frost-susceptible. Thus in Austria the general rule is that the foundation must be below the frost-free level with an added safety factor depending on the type of structure. The greater the sensitivity of the structure to frost effects, the deeper the foundation should be. Foundation depths have ranged from 1.2m (for a small house) to 2.2m. The local climate has a large effect and in one case there was 3m of frost. There is reluctance to use insulation to reduce the foundation depth (Brandl, 1987).

The specification in Czechoslovakia is also that the base of the foundation must be below the frost depth. The Standard prescribes a general minimum depth of foundation of 0.8m but this is increased to 1.2m in cohesive soils where the Ground Water Level is less than 2.0m below the surface. The minimum foundation depth is further extended to 1.4m below ground level if the soil is cohesive and liable to shrinkage (Prumstav Pardubice, 1987). On the other hand if the soil is non-frost-susceptible, the foundation depth can be a minimum of 0.4m. For regions in Czechoslovakia having a Freezing Index greater than 15000 h^{o}C, the foundation depth is to be increased from the general value of 0.8m specified by the Czech Standard (VUIS, 1987). Recently there have been attempts in Czechoslovakia to build foundations shallower than the Standard specification by designing thermal insulation for protection but no details are available.

The rule of thumb in West Germany, based on experience, states that the foundation depth should normally be 0.8m and this is extended to 1.2m in mountain areas. No thermal insulation appears to have been used in association with foundations (Jessberger, 1986).

The case of Denmark is interesting since it shows the lack of rationality in some procedures. According to Porsvig (1986) the foundations of old Danish buildings (of light construction in 1 or 2 stories) were carried out a hundred or more years ago with a foundation depth of 0.3 to 0.45m. Such buildings, that were not founded on deposits liable to settlement, have shown no signs of damage that can be attributed to frost heave of the foundations. A hundred years later Danish tradition changed so that foundations were placed deeper under the ground i.e. 0.6 to 0.9m. This perhaps resulted from the introduction of a new floor construction method, namely a foundation with crawl space. After the winter of 1941-42, the Danish Standards stated that the frost-free foundation depth should be 0.9m or more! However, while the statement is that this depth should normally be between 0.9 and 1.2m, depending on the soil's frost susceptibility, the actual depth used can be less if there is a heat contribution to the foundation soil or if insulation is placed or drainage measures applied. A smaller foundation depth is allowed with free-bearing foundation structures if there is no damage from freezing of the soil under the foundation. Notwithstanding these guidelines, it is understood in Danish practice that a designer is allowed to use a particular foundation method if it can be justified.

2.7 FACTOR OF SAFETY

In Swedish and Norwegian practice, the effect of snow cover is neglected and this builds in a safety factor in the design. This is also the case in Finnish design practice for heated buildings but allowance is made for the effect of snow cover in certain types of cold structure. Other factors that influence the safety factor in the design process are (Saarelainen, 1988):

(1) Selection of the probability level of the design winter at the location i.e. the design Freezing Index.

(2) Selection of the thermal conductivity value of the insulation material in use considering the risk of increasing moisture content in the long term and ageing effects of the insulation.

(3) Evaluation of the frost susceptibility of the local ground.

Because the effects of these may counteract each other, an extra safety margin has not been included in Finnish design, the probability being small that all risks are mobilized together. Design of structures is an art of varying uncertainty but there is no evidence to indicate failure of frost design in Finland. Rather, in the analysed damage cases, the thermal behavior agrees with the thermal analysis used in design.

3. SLAB-ON-GRADE FOUNDATION

3.1 PRINCIPLES

A slab-on-grade foundation has been increasingly used for light buildings because of its relative ease of construction and economy. It involves placing a slab, often of concrete (e.g., Fig. 18), more or less on existing ground or on suitable coarse material, with the associated foundation wall ('ringwall' i.e., perimeter wall) based above the frost level in undisturbed ground. With such a shallow foundation depth there is safety from frost action because frost penetration near the foundation can be reduced in one or more of three ways:

(1) By the heat escaping from the building (mainly through its floor), this heat being guided towards the foundation area as much as possible.

(2) By the use of external 'ground insulation', generally placed horizontally near the foundation wall, to limit the loss of 'soil heat' to the atmosphere and thereby reduce the depth of frost penetration at the foundation.

(3) By the use of an artificial heat source such as a heating cable.

Design against frost action in the case of slab-on-grade is closely interlinked with requirements for thermal insulation of the floor of the building (i.e., adequate floor surface temperature) and also requirements for protection of this floor against the effects of moisture and water vapor from the underlying soil.

A slab-on-grade foundation is generally one of two types depending on the way in which the weight of the bearing walls is transferred to the ground:

(a) A slab with thickened edges cast integrally (Fig. 19)

(b) Separate slab and foundation walls (Fig. 20).

In case (a) the interaction between the edge beam and the slab has the advantage of distributing the load over a greater area thus reducing the bearing pressure and consequent settlement. However the slab would be subject to great strain if the edge beam settles. In case (b) the slab can be entirely free of the foundation walls or it can be supported. Since there is no continuity between the slab and foundation walls, the slab undergoes less strain than in case (a).

Type (b) is simpler both with regard to construction and in statical terms. It is also better suited to allow for minor ground irregularities. In contrast to Sweden, most houses built in Norway as 'slab-on-grade' have been of type (b). The Swedish emphasis on type (a), the edge-reinforced slab, is partly because Sweden includes a number of low-lying areas containing extremely wet clay so that settlement is a very real problem and load spread is necessary. However the interaction between the slab and the thickened edge resulted sometimes in cracked slabs and special reinforcement was required to withstand the stresses due to considerable settlement. In Norway, on the other hand, normal slab reinforcement is sufficient and concrete foundation walls are generally 20cm thick with no footings, but foundation walls of clinker bricks are often used (Torgerson, 1975).

3.2 USE OF SLAB-ON-GRADE

The slab-on-grade foundation method can provide a shallow foundation where excavating for a deeper foundation would be more difficult or costly or could lead to drainage problems (e.g. arising from a high ground water level). In the past 10 to 20 years houses with shallow foundations in Norway have often been the only kind not to exceed the cost limits set by the Norwegian National Housing Bank. It is expected that, in the foreseeable future, the slab-on-grade method will be a major foundation method (Norwegian 'Building Details' A 521.111).

3.2.1 Site and terrain conditions

Founding a slab directly on existing ground requires practically flat terrain with a level difference under 0.5m. Any fill required must be well compacted so as to resist further compression later. Filling and compaction of frozen soils under winter conditions can cause large settlements during spring thaw.

Use of slab-on-grade is not suited to ground with marked differences in level. However, in steeply sloping ground it can be feasible and economical to build a combination slab-on-grade with basement (Fig. 21). In this way the foundation depth at the front edge is reduced. This can be done where the ground consists of soil or rock and results in a considerable extension of the usable floor area of the building.

In rocky ground, an economic foundation can be carried out by using compacted broken stone obtained from site blasting (Fig. 22). The particle size and gradation should be controlled to obtain a dense fill. With adapted cut/fill in sloping terrain, one can economise in the mass balance for each house such that earthwork is kept to a minimum.

In hilly terrain the slab-on-grade method could be feasible for large construction projects where a rational cut/fill technique can be followed to minimise earthworks as was done in the Skjetten development described below. As a result the amount of excavation was considerably less than with other types of foundation.

Soil conditions

Any topsoil and organic soil must be removed prior to the building operation. Small buildings, like small houses of one or two stories, can usually be supported on a foundation wall without footing. However, if the ground bearing capacity is too low, the need for a footing must be specially evaluated. With wet clay it may be necessary to spread the wall loading over a large area on the ground. As previously mentioned this can be achieved by casting the foundation wall and slab as one integral unit with reinforcement to get joint action (Fig. 23). Such a construction must be specially designed with regard to concrete thickness and required reinforcement.

In the case of wet underlying soil it is often necessary to use a separation layer between this soil and the drainage layer under the slab. The separation layer can consist of 50 to 100mm sand or a synthetic fiber mesh, acting as a filter to prevent the overlying drainage layer from being clogged up. Requirements regarding drainage layer and capillary break are given in Section 3.6.

An evaluation must be made to see if the soil is frost-susceptible because this has an influence on the foundation depth and the thermal insulation procedure, especially in a particularly cold area. In Norway a 'dry crust' layer occurs over large areas leading to special design considerations. It is a very hard top layer, usually clay or silty clay, with a thickness of 2 to 4m. It exhibits a system of fine cracks from drying and shrinkage and is often very susceptible to frost heaving (Torgersen, 1988).

3.2.2. The Skjetten development

The Skjetten development near Oslo is an example of a large scale project involving slab-on-grade foundations for many row houses (Eiesland, 1972). It was carried out in 1970-72 on an extensive site with undulating terrain. The ground level was optimally adjusted using a computer program to give cut or fill areas to get grades suitable for slab-on-grade foundations for the houses. The particular foundation design is shown in Fig. 24 where the slab consists of 80mm concrete lying on 150mm stabilised (i.e., cement bound) light expanded clay aggregate called 'Leca'. This has thermal insulation properties and also acts as a moisture and vapor barrier. It has an important function in the period after construction allowing the concrete slab to cure downwards after an impervious floor covering has been placed on the slab.

It is important in such foundations that there should be no cold bridge effect at the junction between the slab and a foundation wall. In this design a cold bridge was inhibited by placing 30mm cork insulation between the slab and the concrete foundation wall as shown in Fig. 24. Also a heating cable supplying 25 W/m was placed in the floor near the floor/wall joint.

Vertical insulation was placed on the inside of the foundation wall and consisted of 50mm of 'Rockwool' (a mineral wool). This insulation guides heat from the house down toward the foundation base. In spite of this, Faeroyvik (1972) pointed out there was still some cold bridge effect below the insulation which could be obviated by using designs such as in Fig. 25 and Fig. 26. In the Skjetten scheme, use of outside, instead of inside, insulation on the foundation wall was indeed considered. Although outside insulation would have been thermally more effective, it was rejected on practical grounds because of the difficulty of applying insulation protection to the particular Skjetten foundations with all the steps in level and the facade indentations.

The reduced foundation depths in the Skjetten scheme were calculated from a complicated formula taking into account the duration of the frost period, the inside temperature of the house, the thermal conductivities of frozen and unfrozen soil, latent heat and other factors. Construction continued in winter and detailed thermal studies were carried out to determine necessary protection in the cold period (Eiesland, 1972).

The development was carried out in an area where there was a considerable thickness of dry crust material in which traditional deeper foundations would have been more costly. The scheme gave substantial economic benefits but the design would require variation to suit the conditions of specific small schemes or individual houses.

3.3 FACTORS INFLUENCING FROST PENETRATION

As compared with undisturbed free ground, frost penetration at a slab-on-grade foundation (for a heated building) is less (Fig. 27) and its extent depends on a number of factors. These were investigated in Sweden by Adamson et al (1973) and in Norway by the Frost I Jord project that was partly based on the computer results of Thue (1973). The studies of Adamson et al applied to the two types shown in Fig. 28, but the Norwegian work reported by Torgersen (1976) involved theoretical analysis of type (b) i.e. a slab separate from the foundation walls.

<u>Climate</u>

In their computer analysis Adamson et al (1973) assumed the outside temperature T_o to vary as a cosine function according to Janson (1968):

$$T_o = T_m + T_a \cos wt \quad (2\pi w = 1 \text{ year})$$

where T_m = annual mean value of air temperature (over a 30 year period) and the amplitude T_a is determined so that the resulting Freezing Index equals F_{50}.

Different climatic conditions were considered covering the range of temperature zones I to IV in Sweden (Fig. 4). In one case the greatest frost penetration occurred four weeks after the lowest outside temperature (Fig. 29). The lowest outside temperature used in the calculations was $-16.7^{o}C$ for Haparanda (at the border with Finland).

The Frost I Jord report (Torgersen, 1976) considered a similar cosine outside temperature distribution and a distribution based on the mean daily temperature but giving the same Freezing Index (Fig. 30). Computer calculations showed that the resulting magnitude of the frost depth at a foundation was practically the same for each temperature distribution. It was deduced that the Freezing Index is the decisive parameter as regards the depth of frost penetration at a specific site. The climatic influence can therefore be represented by a local Freezing Index, while the Mean Annual Temperature plays only a small role in the case of a well-insulated slab-on-grade foundation. The Freezing Index for design is taken in Norway to be the greatest value in a 100 year period i.e. F_{100}.

Snow cover

In one case of their analysis, for example, Adamson et al found that natural snow cover reduced frost penetration from 0.5 m for snow-free ground to 0.0 m. However snow is often removed from areas near a building. The effect of snow is not taken into account in the design of slab-on-grade foundations for heated structures in Sweden, Norway or Finland. The presence of snow in practice provides an insulation effect and gives an increased safety factor.

Size of building

Adamson et al showed that frost penetration at a corner for a building with overall dimensions of 4 x 4m, was approximately the same as for a building of size 10 x 10m. In the middle of the facade (outer wall) frost penetration is insignificantly larger in the case of the smaller building. The results were thus applicable to buildings with a width (i.e. smaller dimension) equal to 4m or more. This agreed with the stipulation of the 1967 Swedish Building Standards concerning the application of certain design requirements to buildings with width of 4m at least. If a building is smaller it would need to be analysed specifically.

Floor insulation

The Swedish study of Adamson et al showed the effect of the floor insulation thermal resistance R_1 on the frost penetration z_f for two cases (Fig. 31). In one case there was no edge (or foundation wall) insulation (i.e. $R_2 = 0$) and in the other case the edge insulation had a thermal resistance R_2 of $1.08 m^2 K/W$. With more floor insulation the depth of frost penetration increases in each case because less heat escapes to the foundation area. Increase in R_1 from 1.0 to about $2.15m^2K/W$, however, causes only a small increase in the frost penetration. If R_1 is increased above $2.15m^2K/W$ there is an insignificant increase in frost penetration.

An uninsulated floor would give the best protection against frost but some insulation is necessary to provide a comfortable floor temperature. Fig. 32 illustrates the effect of removing floor insulation in a case where horizontal 'ground insulation' is used. Position c, without floor insulation, is much safer as regards possible frost damage to the foundation but would increase the heat loss requiring extra inside heat (Kløve and Thue, 1972).

Associated with frost-susceptible soils, the required thermal resistance of the floor insulation is in the region of 1.0 to $2.0m^2K/W$ depending on the climate. This is equivalent to about 40-80mm of expanded polystyrene. If the Freezing Index is 50000 h^oC an increase in floor insulation from 1.0 to $2.0m^2K/W$ means an increase of frost penetration of about 20% but with an energy savings (Torgersen, 1976).

Foundation wall insulation

Vertical foundation wall insulation is used to limit the heat loss from the building and particularly to help guide the heat towards the foundation base thus reducing the frost penetration as is evident from Fig. 31 by comparing the two curves. This reduction continues until the thermal resistance of the insulation R_2 increases to about $1m^2K/W$ (equivalent to about 40mm expanded polystyrene or 0.25m light clinker blocks). Adamson et al (1973) found that, if the insulation was increased further, there was no appreciable effect on the extent of frost penetration (Fig. 33). There is little point in having too high a value of R_2.

However the place where the insulation is put is significant. External insulation gives less frost penetration than insulation placed internally on a foundation wall. An advantage of inside insulation is that it does not need protection as does outside insulation. Also it is easier to retro-fit a building with inside insulation but space inside the building is lost.

Thue (1974) showed that using inside insulation without floor insulation gave similar results to insulating the floor together with providing outside insulation. This means that the increase in heat loss through the perimeter resulting from moving insulation from the outside to the inside of a foundation wall is practically equal to the reduction in heat flow to the foundation resulting from insulating the floor.

The results of Adamson et al (1973) showed that a foundation wall composed of light clinker blocks reduced frost penetration in one case to 0.37m as compared with a penetration of 0.60m for a foundation wall of concrete or hollow concrete blocks. A concrete wall acts as a thermal bridge conducting heat to the side (outwards) rather than directing it down towards the foundation base thus leading to a greater frost penetration. The greater thermal resistance of a foundation wall composed of light clinker means that it may not require additional thermal insulation as does a foundation wall of concrete.

Height of foundation wall above ground level

The vertical distance from the floor surface of a building to the outside ground surface may be termed the pedestal height. If this height is increased, there is more exposure and more heat will be lost without benefitting the foundation. Frost penetration at the foundation therefore increases (e.g. Fig. 34) necessitating more insulation of the foundation wall. The edge or foundation wall should therefore not be made unneccessarily high.

In the Swedish Building Standards (SBN 80) it is stated that extra insulation of a foundation wall is required if the pedestal height is greater than 0.3m and that this height should not exceed 0.6m. The Norwegian Building Details (A 521.111) require special protection if the floor lies higher than 0.6m over outside ground. The Finnish guidelines (1987) also consider design for a pedestal height up to 0.6m with greater values requiring special treatment.

Ground insulation

Ground insulation placed horizontally (or, sometimes, obliquely) in the soil outside the foundation has a strong influence in reducing frost penetration by limiting release of 'soil heat'. Such insulation is therefore suitable especially for extra protection against frost at a corner of a building or near a cold section situated at an outer boundary. It is also desirable around the whole of the building in a specially cold climate requiring additional frost protection. The insulation width is usually up to 1.0m with a thermal resistance of 1.0 to 1.5m^2K/W. There is little point in overdesigning the ground insulation since this is not likely to cause much further reduction in frost penetration as shown by the computer results of Thue (1974).

At a corner of a building there is exposure to frost from two sides and frost penetration is consequently deeper than in the middle of an outer wall. Adamson et al (1973) showed that the penetration is often double or more at a corner and Fig. 35 exemplifies the increase in frost penetration as a function of distance from the corner. It was found that the corner effect disappeared completely for cases in southern Sweden at about 1 to 1.5m from a corner and in northern Sweden at about 2m from a corner. Extra ground insulation is thus required at corners particularly for places with a high Freezing Index and this is recognised in Swedish, Norwegian and Finnish guidelines.

Cold bridge effect

Fig. 36 shows an example of a foundation design which was much used in Finland because of its ease of construction. It resulted in many cases of frost damage during the severe winter of 1984-85 because frost penetrated under the foundation wall as can be seen from the position of the $0^{o}C$ isotherm. This resulted from the cold bridge effect occasioned by the fact that the insulation is not continuous under the concrete foundation wall. The damage could have been prevented by having designs such as shown in Fig. 37 or, in south Finland, by building the foundation wall of light expanded clay aggregate instead of concrete (Kivikoski, 1986). With a design as illustrated by Fig. 37, the cold bridge is broken and the $0^{o}C$ isotherm does not approach the bottom outer edge of the foundation wall.

3.4 THERMAL CONSIDERATIONS FOR BUILDING/FOUNDATION

Thermal insulation of the floor should be designed so that the floor temperature is not lower than $16^{o}C$. Too low a floor temperature would not be comfortable and could result in condensation at the surface of the floor. The floor surface temperature depends particularly on the inside temperature of the building and on the heat flow across the floor and other heat losses from the building walls and foundation walls.

To save energy there has been a tendency in recent years to lower the inside temperature below the guideline value assumed in design and this resulted in many damages. A lower inside temperature would require more floor insulation and/or a lower foundation depth.

3.4.1 Heat flow from a building

Adamson's study

Adamson (1973) reported the results of computations assuming non-stationary, and stationary, heat flow related to long rectangular buildings and to square buildings. Heat flows and floor temperatures were calculated for 19 two-dimensional cases applying to long buildings and for 14 three-dimensional cases applying to square buildings. In the latter heat flow downwards would not be confined to a vertical plane. The two types of slab-on-grade foundation shown in Fig. 28 were analysed. The inside temperature of the building was generally assumed to be 20^{o}C. The variables considered were geographical position (giving the outside temperature), floor slab insulation, insulation of 'bottom wall unit' (i.e., edge beam or foundation wall) and external horizontal ground insulation. The heat flow across the floor was analysed by a forward difference finite element method which gave the isotherms at a certain time after the lowest outside temperature.

In the case of long buildings the isotherms were represented for a vertical section parallel to the shortest dimension of the building. For square buildings the isotherms were those occurring in the vertical plane through a diagonal. The cases studied corresponded with those used in the studies of frost penetration (see Section 3.3) and required foundation depth (Section 3.5). The results of Adamson's computations based on stationary heat flow agreed well with those on the basis of non-stationary flow, within a zone about 1 metre from an external wall.

In the middle of the floor, heat flow was much higher in a square building than in a long building of the same width because of three-dimensional flow in the former case. Comparison of the combined thermal resistance values of the floor construction and underlying soil in the two cases, showed a considerably higher value in the case of the long building because heat has to travel a longer distance down from the middle of the floor and around the bottom of the foundation.

For a square building an illustration of the heat flow at different points of the floor is given by Table 3. This shows how the heat loss increases from the middle of the floor to an external wall. Heat loss also increases from the middle of an external wall to a corner.

TABLE 3

Greatest heat flow through floor surface in a square building
10x10m situated in Stockholm
Co-ordinates x and y are parallel to the sides
and measured from the center of the plan

y m	Greatest heat flow (W/m^2) at the point x,y				
x =	0.50	2.30	3.25	4.20	4.85 m
0.5	<u>3.1</u>	3.6	4.9	7.8	12.7
2.30	3.6	<u>4.3</u>	5.5	8.1	12.9
3.25	4.9	5.5	<u>6.4</u>	8.8	13.3
4.20	7.8	8.1	8.8	<u>10.8</u>	14.2
4.85	12.7	12.9	13.3	14.2	<u>16.4</u>

<u>Note</u>: Values which are underlined refer to a diagonal of the building

It was also shown that the thermal resistance between a point on the floor surface near an external wall and a point on the ground surface outside the building is practically independent of the boundary temperature in the ground and of the outside air temperature. This means that the results of the computations have wide general applicability.

<u>Frost I Jord project</u> (Torgersen, 1976)

In a typical Norwegian house with slab-on-grade construction the percentage heat losses during the cold season (the winter half of the year) are as shown in Fig. 38 and increase as the outside temperature drops. Only about 10 per cent of the total heat loss from the building is represented by the heat loss through the floor, the actual percentage depending on the effectiveness of the insulation of the house above ground. The heat loss through the floor passes through the ground below and rises towards the outside air by means of an approximately semi-circular path. The effect is to reduce the frost depth near the foundation as compared with the frost depth in undisturbed ground (Fig. 27). An important aspect of design is to use a floor insulation that will allow the requisite amount of heat to flow towards the foundation base, thereby reducing frost penetration under the foundation wall.

Some of the heat loss from the floor attempts to follow other paths such as through the floor/foundation-wall connection (where a 'cold bridge' could form) or further down across the foundation wall. Interruption of the possible cold bridge and adequate vertical insulation of the foundation wall would guide most of the heat lost from the floor to the underside of the foundation wall. Insulation of the foundation wall is described in Section 3.4.6. Additional protective measures could be installation of heating cables or heat ducts in the floor area near the connection with the foundation wall and/or placing horizontal ground insulation in the soil outside the wall to reduce frost penetration (Section 3.5).

Ground insulation inhibits the release of the 'soil heat' which is stored in the soil during the summer half of the year and is available to retard the downward advance of frost. As the outside temperature continues to drop below $0^{\circ}C$, the soil heat is gradually given up as the unfrozen soil cools, and when it freezes releasing latent heat, and as the frozen soil cools further. Compared to the soil heat, the geothermal heat from the earth's interior is insignificant. An idea of the relative magnitudes of the heat contributions is given by Fig. 39 which shows the importance of the latent heat given up on freezing.

Where there is frost-susceptible ground, approximately continuous heating of the building is assumed to take place in the cold season giving an inside temperature of $18^{\circ}C$. Heating can be reduced temporarily, e.g., when a 3 weeks' vacation is taken during winter, but the inside temperature in this case must be at least $5^{\circ}C$.

Heat flow from the floor of a building depends on the thermal resistance it encounters. Modern insulation material with a large thermal resistance can be used to reduce the heat flow. The underlying soil also has a certain thermal resistance depending on its properties and on the length of the heat flow path through it. As shown by Adamson (Table 3) the largest heat flow across a floor occurs near the outer walls because flow paths to the outside air are short. In the middle of the floor the heat flow is much less because heat has to traverse long distances through the ground before it can reach outside air. In this case the total thermal resistance along the heat flow path will be dominated by the ground's thermal resistance while floor insulation plays a smaller role. The effects of floor insulation may be seen by comparing Fig. 40 and Fig. 41. In Fig. 40, the insulation has a low thermal resistance and heat flow across it is therefore large. The floor surface temperature is reduced, but the frost boundary does not advance very deep at the foundation wall because of the effect of the large heat flow contribution from the floor. On the other hand in Fig. 41, the floor insulation has a large thermal resistance which restricts heat loss across it and thereby maintains a higher floor surface temperature. As a result the frost boundary advances deeper down at the foundation wall so that the foundation depth must be increased.

The starting-point in the slab-on-grade design process is to find the necessary floor insulation such that an acceptable floor surface temperature can be obtained. One must then make sure that the frost boundary does not advance too deep and that the chosen foundation design is not likely to be damaged by frost action.

A cold bridge at the junction floor/foundation-wall/outer-wall (Fig. 42) can lead to an uncomfortably cold floor. In forming these connections great care must be taken to assure interruption of a possible cold bridge and there must be air tightness.

A heating cable in the floor along an outer wall gives a comfortable floor temperature all the way out to that wall if the floor is well insulated. Insulation on its own would usually not suffice to produce a comfortable temperature in a floor strip within 0.3m of the outer wall (Fig. 43).

Danish heat flow analysis

From a recent investigation by the Thermal Insulation Laboratory (1982) in Denmark, Fig. 44 shows 2-dimensional heat losses through the floor and wall as compared with 1-dimensional heat flow determined according to the Danish Standards 418 (giving rules for calculating heat loss from buildings). The 2-dimensional heat loss, Q-2, may be almost three times the values indicated by the Danish Standards. By comparison the work of Adamson (1973) considered only 1-dimensional heat loss through the floor (and loss through the foundation wall) without apparently including heat loss through the building wall above the floor.

The Danish study was entitled 'The Low-Energy House Project' and analysed design of foundations for energy conservation houses. Different slab-on-grade foundation designs were studied as shown in Fig. 45 offering a variety of technical solutions to the problem of cold bridges. From about 1960 most single family houses in Denmark have been one-storey houses without basement and built with a slab-on-grade foundation. The connection floor/external wall/foundation-wall often resulted in a severe cold bridge. The traditional type of foundation for Danish slab-on-grade houses is shown in Fig. 46 and a construction that has recently been used is given in Fig. 47. (It has not been Danish practice to install external ground insulation).

For each of the designs in Fig. 45, computer calculations were made to obtain the 2-dimensional heat flow. The calculated values of Q-2 are shown in Fig. 48 for each of the designs together with the associated insulation. The results showed the considerable importance of effective vertical perimeter insulation extended to the correct depth. An illustration of this is a design shown in Fig. 49a which has an extremely well insulated floor but the heat loss is high due to continuous concrete between the slab and a foundation wall. In Fig. 49b there is an improvement resulting from the replacement of the unusually thick concrete slab by an ordinary 100mm slab. Separation of the floor slab from the inner part of the foundation wall by introducing mineral wool (Fig. 49c) gives a further slight reduction in heat loss. A more significant reduction results when the inner part of the foundation wall is replaced by blocks of expanded clay concrete (Fig. 49d). The resulting heat loss is only about half the original heat loss with the construction of Fig. 49a.

3.4.2 Internal heat transfer resistance

A very important thermal factor is the heat transfer resistance R_i (m^2K/W) affecting heat flow from inside air to the floor surface. The reciprocal of this is the heat transfer coefficient (W/m^2K) which Adamson (1973) stated was in fact lower (i.e., R_i was higher) than what was usually assumed in previous design calculations. Measurements showed that in corner rooms of single storey heated buildings, the heat transfer coefficient between room air and the floor surface was 1.5 to 2.5 W/m^2K. The lower value corresponds to R_i of $0.67m^2K/W$ and applies to the middle of the floor. The higher figure corresponds to R_i equal to $0.4m^2K/W$ and applies to the part near the corner of an external wall.

It is important to be able to determine the appropriate value of R_i because it influences the floor surface termperature markedly as shown in Table 4. This gives the temperature at different distances from an outer wall depending on the chosen value of R_i. The inside temperature is assumed to be 21^{o}C.

TABLE 4

Relationship between floor surface temperature and internal heat transfer resistance

	FLOOR TEMPERATURE °C		
Distance from outer wall mm	Internal Heat transfer resistance R_i 0.40	0.29	0.14 m^2K/W
0	11.6	13.0	15.3 °C
10	11.7	13.1	15.5
30	12.0	13.5	15.9
90	12.7	14.1	16.6
200	14.3	15.1	17.4
300	14.9	15.7	17.9
500	15.5	16.8	18.7
1000	17.8	18.7	19.9

Where there is little ventilation and doors are closed, R_i, may be as high as $0.65m^2K/W$ but with normal ventilation and heating R_i is about $0.40m^2K/W$. The Norwegian Standards (1986) NS 3031 gives a value of $0.13m^2K/W$ for R_i.

3.4.3 Effect of climate

In the Norwegian study reported by Torgersen (1976), related to the construction of Fig. 50, a computer study was made of the influence of changes in the outside air temperature on floor temperature at points 0.3m and 1.0m from an outer wall (Fig. 51). These results applied to the winter of 1965/66 in Oslo which was the coldest for 30 years and data for the mean air temperature over each 5 day period was input. The dotted curve represents a harmonic (cosine) curve for the outside air temperature. The two air temperature distributions are quite different but produce the same value of the Freezing Index F and the effects on the floor temperature variation are about the same. The conclusion is that it is sufficient to represent the climate's influence by the local Freezing Index which is the significant parameter whereas the Mean Annual Temperature has an insignificant influence on the floor temperature of a well-insulated slab.

The design Freezing Index is taken in Norway to be F_{100}, the maximum F value in a hundred year period.

3.4.4 Effect of insulation

The computer study of Adamson (1973) showed that edge beam or foundation wall insulation and floor insulation have a large influence on heat flow near the beam or wall and therefore also an important influence on the floor temperature.

Concrete slab with edge stiffening

Calculations of floor temperature were made for different cases where the floor slab insulation is laid above the slab (e.g. Fig. 52), cast into the slab (e.g. Fig. 53) or laid under the slab (e.g. Fig. 54). Taking comparable cases illustrated by these figures (cases 104, 143 and 171 respectively) the first case (insulation above the slab) gave the highest floor temperature near an external wall and the second case (insulation cast into the slab) gave the lowest floor temperature near the external wall. As expected the floor temperature decreases considerably towards an external wall. In one case, for example, the temperature dropped from 17.5°C at about 0.9m from an external wall to 8.2°C at this wall. The room occupation zone is assumed to begin 0.3m from an external wall and the temperature at this point should be at least 16°C for comfort. A heating cable producing 20W/m and placed near an external wall can give acceptable floor temperatures up to that wall (e.g. Fig. 43).

Concrete slab in combination with strip foundation

In the case of a concrete slab with separate foundation walls, the effects of thermal insulation laid on top or underneath the slab and of different wall constructions were also studied. The foundation walls were assumed to consist of either hollow concrete blocks or of lightweight clinker blocks on a concrete footing. An example with the latter type of foundation wall is shown in Fig. 55, where an external wall has brickwork facing and inner stud panels. A particular computation showed a drop in floor temperature from 18.3°C at about 0.8m from the external wall, down to 13.4°C at this wall. This is more favorable than the case mentioned above where the concrete slab has edge stiffening.

Ground insulation

The influence of ground insulation (e.g. placed as in Fig. 55) was also studied and found to be quite negligible in causing a rise in floor temperature.

3.4.5 Thermal insulation of floor

The floor thermal insulation and the ground's thermal resistance strongly influence the floor's surface temperature, but while a designer has little influence on the ground's thermal resistance, the floor thermal insulation can be prescribed to ensure a satisfactory floor temperature.

The necessary thickness of floor insulation is determined from the prescribed U-value of the floor construction (i.e., slab, covering and floor insulation). The requirements for U-values for slab-on-grade construction are given in Chapter 53 of the Norwegian Building Code for heated buildings (as reported by 'Building Details' A 521.111). The given requirements apply to a 1 metre wide field of the floor bordering along an outer wall, and also as the average for the whole floor. These requirements should be regarded as the minimum requirements for thermal insulation, and it can often pay to insulate better. To avoid problems with low floor temperature in colder regions of Norway, U-values are recommended in the 'Building Details' (A 521.111) as shown in Fig. 56. These values apply to buildings that are heated to at least 18°C. There are different curves depending on whether the underlying ground is clay, other fill or rock. The local Freezing Index is applied together with the appropriate curve to obtain the recommended U-value. (Fig. 1 shows the maximum Freezing Index in different parts of Norway).

Determination of insulation thickness according to Norwegian Standards

The required floor insulation can be determined according to the rules given in NS 3031 "Thermal Insulation. Calculation of Buildings' Energy and Power Requirements for Heating and Ventilation" (Norwegian Standards, 1986). This gives values for the average ground thermal resistance R_i depending on the type of ground (clay, rock or other) and the distance from an outer wall as shown in Table 5.

TABLE 5

THERMAL RESISTANCE OF THE GROUND R_i

Construction	Thermal Resistance R_i (m^2 K/W) Clay	Other Fill	Rock
'slab-on-grade' up to 0.6m above grade			
0 to 1m from an outer wall	1.1	0.9	0.5
1 to 3m " " " "	3.0	2.3	1.5
3 to 6m " " " "	4.2	3.2	2.2
Over 6m " " " "	6.0	4.8	3.5
Additional resistance for a floor of depth h(m) below grade	1.4h	h	0.7h

The total thermal resistance R_T for the construction against the ground is then calculated from the formula

$$R_T = R_i + R_t$$

where R_t is the thermal resistance of the composite floor structure against the ground. The floor structure will often consist of a floor cover and a slab with underlying plastic film and insulation. The slab may be homogeneous consisting of concrete or wood material but it could be of composite construction consisting, for example, of wood and mineral wool and including air spaces.

R_t is the thermal resistance of the composite floor from surface to surface and is expressed as

$$R_t = \Sigma R + \Sigma R_g$$

where R is the thermal resistance (m^2K/W) of a homogeneous plane material layer in the floor and R_g is the thermal resistance of an air space.

The thermal resistance R across a continuous homogeneous plane material layer is calculated according to the expression

$$R = \frac{d}{\lambda_p} \quad (m^2K/W)$$

where d is the material thickness (m) and λ_p is the practical value of the thermal conductivity (W/mK) for the material layer. NS 3031 gives tabulated values of the thermal conductivity of insulation materials and other materials that may be used. It also gives appropriate values for the thermal resistance of a 'plane unventilated air layer'.

In determining the thermal resistance of a floor construction that consists of homogeneous and non-homogeneous plane material layers, the composite construction is divided up into fields with heat flowing at right angles to each field, for example as shown in Fig. 57. Upper and lower bounds for the thermal resistance are then calculated and the mean value taken. The upper bound is calculated on the assumption that heat flow paths across the fields are parallel so that no heat crosses from one field to the next. The lower bound is based on the assumption that different materials in a layer 'blend together' i.e., that there is no thermal resistance between the different materials in a layer. Details of the procedure of calculation are given in NS 3031.

By using the rules indicated above, the total thermal resistance R_T of a slab-on-grade construction (including the effect of the underlying ground) can be calculated. This can be done for different fields of the floor according to the distance from an outer wall.

The U-value for the slab-on-grade construction is simply the reciprocal of R_T:

$$U = \frac{1}{R_T} \quad W/m^2K$$

and represents the heat flow per unit cross-sectional area per unit temperature difference along the flow path.

Fig. 56 gives recommended U-values for slab-on-grade with a building that is heated up to 18°C. Using the locality's maximum Freezing Index and the appropriate curve depending on the ground type, the recommended U-value is obtained. The floor insulation thickness can then be selected so that the total U-value of the slab-on-grade construction, calculated according to NS 3031 rules, is satisfactorily related to the recommended U-value from Fig. 56 (i.e. the allowable U-value is not exceeded).

Use of figures in Norwegian 'Building Details' (A 521.111)

A quick method of determining a suitable thickness for the floor insulation is simply to use the appropriate curve in the figure from the Building Details (Fig. 58). Each set of curves applies to a particular field of the floor relative to an outer wall. The given curves for different ground conditions are according to NS 3031. The curve for clay applies to pure clay while the middle curve should be used for other soil materials and for broken stone. The soil layer thickness below the floor must be at least 2.0m, and with smaller layer thickness over a rock underlayer one may interpolate between the curve for the actual soil type and that for rock. With a drainage layer under the floor consisting of at least 150mm crushed rock or coarse gravel, one can allow a thermal resistance of $0.2 m^2K/W$ which is equivalent to 8mm of floor insulation. The required floor insulation thickness obtained from Fig. 58 can then be reduced by 8mm.

In Fig. 58 it is assumed that the floor insulation is of polystyrene or mineral wool with a practical thermal conductivity of 0.036W/mK. It is also assumed that the thermal resistance of the foundation wall is at least $1.0m^2K/W$, for example a concrete foundation wall with at least 40mm polystyrene or mineral wool or a 250mm thick foundation wall consisting of blocks of light clinker. A 50mm concrete slab is assumed with a floor covering and plastic film underneath giving a joint thermal resistance of $0.11m^2K/W$.

For insulation material with a practical thermal conductivity λ_p different from 0.036W/mK, the insulation thickness t(mm) can be calculated from

$$t = t_o \lambda_p / 0.036$$

where t_o is the insulation thickness in accordance with Fig. 58.

Small house

It is normal in a small house to insulate the whole floor with the same insulation thickness. The Building Code demands a U-value not exceeding $0.3W/m^2K$ for a 1m wide border area of the floor along an outer wall. Table 6 (from 'Building Details') can be used to determine the required thickness of insulation and this is then applied in Fig. 58a to determine the U-value which should not exceed $0.3W/m^2K$.

TABLE 6

Floor insulation thicknesses (mm) satisfying regulations

Insulation material	Practical W/mK	Ground conditions Clay	Other fill	Rock
Polystyrene or mineral wool	0.036	50(40)	60(50)	70(60)
Loose light clinker	0.20	250	300	400

Table 6 gives values of insulation thicknesses of polystyrene and mineral wool that are satisfactory according to the regulations. Numbers in parenthesis apply to slab-on-grade constructions with at least 150mm thickness of drainage layer of crushed rock or coarse gravel under the insulation, the thickness of which can accordingly be reduced. In colder regions (Freezing Index above 40000h°C) the recommended insulation thicknesses should be increased by the amounts given in Table 7 to avoid a reduced floor temperature. This assumes sufficient foundation wall insulation as provided by a concrete foundation wall with at least 40mm polystyrene or mineral wool, or a foundation wall consisting of 250mm blocks of light clinker.

TABLE 7

Recommended increase in insulation thickness in colder regions (mm)

Ground type	Maximum Freezing Index 40000	50000	60000 h°C
Clay and other fill	0	10	20
Rock	10	20	30

Large buildings

For large buildings (width greater than 4m) the necessary thickness of floor insulation, in accordance with the required U-value for a 1m wide border area along an outer wall, is determined from Fig. 58. Also the average U-value for the whole floor should be checked against the actual requirement.

For a floor construction the average U-value can be calculated according to the formula:

$$U_m = \frac{A_aU_a+A_bU_b+A_cU_c+A_dU_d}{A_a+A_b+A_c+A_d}$$

where U_a, U_b, U_c and U_d are the U-values for the respective floor fields from Fig. 58 and A_a, A_b, A_c and A_d are the respective areas of these fields.

Swedish Standards SBN 80

SBN 80 simply states that the thermal resistance value of an outer edge strip of a floor construction (with no heat gains from heating pipes) should not exceed $3.3 m^2 K/W$. The normal U-value requirement for a slab-on-grade construction is $0.30\ W/m^2K$ and the maximum U-value is $0.40\ W/m^2K$. These values apply for the four temperature zones in Sweden. It may be noted that the maximum U-value is higher than the allowable value of $0.30\ W/m^2K$ specified in Norway.

Finnish guidelines

The Finnish guidelines (1987) give the maximum allowable U-value and minimum thermal resistance for a slab-on-grade foundation with a heated or partly heated room. As shown in Table 8 a maximum U-value of $0.36 W/m^2K$ is specified for all areas of the floor construction below a heated room (intermediate between the Norwegian and Swedish values). The specified thermal resistance of a slab-on-grade floor structure in Finland is higher for the 1m border area than for the inner part of the floor.

Comparison

The Norwegian method of determining the floor insulation thickness is more detailed since it takes into account the underlying foundation material and considers four areas of the floor according to their distance from an outer wall. However for a small house the same thickness of insulation is used over the whole floor in practice.

3.4.6 Foundation wall insulation

The effect of foundation wall insulation on frost penetration was described in Section 3.3 and on floor temperature in Section 3.4. Fig. 59 shows alternative locations of insulation as recommended by the Finnish guidelines (1987). The foundation wall itself may be made of material with

TABLE 8.

Maximum allowable U-value and minimum thermal resistance
Floor of heated and partly heated structures

Floor structure type		Max. allowable U-value W/m^2K		Thermal resistance m^2K/W	
		Heated room	Partly heated room	Heated room	Partly heated room
slab-on -grade	1m floor border area and 1m ground border area	0.36 (0.45)	0.45 (0.65)	2.6 (2.1)	2.1 (1.4)
	Other areas	0.36 (0.45)	0.45 (0.65)	1.4 (-)	0.9 (-)

Note: Values in brackets apply to industrial structures and warehouses.

(Finnish guidelines, 1987)

good insulation properties like light clinker blocks, or as referred to in Section 3.4.1, only the inner part of a foundation wall may be composed of such blocks (Fig. 49d).

The Swedish Building Standards SBN 80 gives approved values for the minimum thermal resistance of edge (or foundation wall) insulation associated with a slab-on-grade foundation as shown in Table 9.

TABLE 9

Approved least thermal resistance of edge insulation, m^2 K/W

	Temperature zones I and II	Temperature zones III and IV
Floor with heating along external wall	1.00	0.80
Floor without heating along external wall	1.60	1.20

The Norwegian 'Building Details' (A 521.111) requires the whole foundation wall to be insulated to obtain frost protection. The thickness of insulation depends on the locality's maximum Freezing Index (F_{100}) and on the pedestal height (i.e., height of floor surface above prepared ground level). Table 10 gives recommended thicknesses of insulation for a foundation wall of concrete insulated with expanded polystyrene or mineral wool. A foundation wall of 250mm light clinker blocks can be taken as equivalent to 40mm of polystyrene or mineral wool. If the insulation requirement according to Table 10 is larger than that, this type of foundation wall should be additionally insulated.

Examples of insulating foundation walls with inside and/or outside insulation are given in Fig. 60. One example shows a foundation wall built with light clinker blocks using inside insulation (Fig. 60b). Foundation wall insulation should consist of a board of polystyrene with density at least 20Kg/m^3 or a board of mineral wool with density of at least 90Kg/m^3.

TABLE 10

Necessary foundation wall insulation of expanded polystyrene or mineral wool Thicknesses are given in mm in the table.

Maximum Freezing Index h ^{o}C	Floor height above the ground mm 300 or less	450	600
30000 or less	40	50	60
40000	50	60	70
50000	60	70	80
60000	80	90	100

If the floor's height above the ground is more than 600mm, the foundation wall should be frost-protected according to the guidelines in 'Building Details' A 521.811

(from 'Building Details', A 521.111)

Ongoing Danish research

As part of the Danish energy research program, an analysis is being done of existing and future buildings' necessary foundation depth in relation to frost protection assuming (i) no foundation insulation, (ii) outside foundation insulation only and (iii) inside foundation insulation only. The analysis is based on the following conditions (Porsvig, 1986):

(1) Two typical foundation soils namely saturated moraine and partly saturated sand. These occur at foundation depths in about 70% of Denmark.
(2) A heated building insulated according to the present Danish Standards.
(3) A frost influence corresponding to an outside temperature variation like that of the winter of 1941-42.
(4) A constant soil temperature of about 8°C in 10m depth.

The project includes computer calculations of temperature conditions around part of a construction composed of outer wall-foundation-floor. The part of the outer wall considered is bounded by a horizontal section at a height of 1m above the floor level. The included floor surface is bounded by a vertical section at a distance of 2m from the internal face of the wall. The foundation depth is varied between 0.4m and 0.9m under the ground. The influence of a possible foundation insulation placed on the outside or the inside of the foundation is examined for both moraine and sand.

Provisional results

Using a foundation depth of 0.4m and with insulation at the inside of the foundation or without insulation, the 0°C isotherm is just near the foundation's outside edge. On the other hand the 0°C isotherm for the corresponding foundation, with insulation on the outside, is forced away from the foundation. This study confirms that outside insulation is more effective than inside insulation and shows that use of the existing Standards (DS 415) concerning frost-free foundation depth is much influenced by which side of the foundation wall is protected in the case of heated buildings. (Calculations for unheated buildings are still lacking).

Where the underlying soil properties relating to strength and deformation are so good that a smaller foundation depth is used, it would be possible to carry out the foundation with outside insulation. However such a measure would be in contradiction with existing practice and Porsvig (1986) suggested that it should be done only in cases where documented calculations of both temperature and deformation conditions are available. A saving in foundation concrete can then be set against expenses of extra calculations, checking and insulation material. This might be warranted where one is considering use of standard foundation designs for a number of industrial buildings at a foundation depth above the recommended frost-free depth.

3.5 FOUNDATION DEPTH AND GROUND INSULATION

3.5.1 Required foundation depth and ground insulation

The foundation depth is related to frost penetration which is significantly reduced by ground insulation (e.g. Fig. 61 shows a reduction from 1.0 to 0.6m). There must be an adequate foundation depth for protection against frost damage. The required foundation depth should take account of possible heave forces that can act if frost penetrates into saturated frost-susceptible soil. Ice lenses generally follow the isotherms and the heave forces produced are therefore mainly at right angles to the isotherms (Fig. 13) but they tend to incline towards the direction of least resistance.

Adamson et al (1973) and the Frost I Jord project assumed the $-1^{o}C$ isotherm to be critical as shown in Fig. 14. Above this isotherm the soil can be considered to be fully frozen and liable to produce frost heave if it is frost-susceptible.

In Fig. 62 region 'a' would be occupied by the foundation wall or slab edge and below it there is a drainage layer composed of non-frost-susceptible material of thickness 'b'. This layer is considered part of the foundation depth which thus extends a distance z_g that is nearly equal to the frost penetration depth z_f (the small hatched area in Fig. 62 being negligible). Thus in the case represented by Fig. 62, the frost heave force does not significantly affect the structural part of the foundation.

Reporting in the early 1970's, Adamson et al stated that in Sweden remarkably few cases of damage to floor structures placed on the ground could be related to frost heave in spite of considerable frost penetration during the winters of 1966 and 1970. The most common designs using edge-stiffened floor slabs had a foundation depth of 0.3 to 0.4m below the ground surface, including non-frost-susceptible drainage layers. The edge of the slab was usually well-reinforced with steel and could take any heave force.

Foundation depth for edge-stiffened concrete slabs

Case of floor slab without edge insulation (i.e. $R_2 = 0$).

Fig. 63 shows the occurrence of a large frozen area, and consequently a large heave force, at a corner of a square building with a foundation depth of 0.35m. At a distance of 0.8m from the corner there is much less frost penetration and the heave force is reduced considerably (Fig. 64). The corner effect may extend about a metre on either side and to counteract it the edge should be reinforced with top and bottom steel. This would be sufficient in Swedish temperature zones III and IV but in the colder zones I and II special measures may be necessary.

Case of slab with edge insulation

Where the edge is provided with insulation of thermal resistance R_2, there is considerable frost penetration under the foundation area at a corner as shown in Fig. 65. Again, this penetration is much less at a distance of 0.8m from the corner (Fig. 66). If the edge insulation is extended down 0.3m into the ground there is significantly less penetration in either case (Figs. 67 and 68).

Figs. 69 and 70 show that frost forces may act obliquely up at the slab's bottom. The upward force can be eliminated or reduced by supplying heat (Fig. 71) or installing ground insulation at a corner (Fig. 72).

Adamson et al suggested that in temperature zones I and II the edge should be insulated with insulation above the ground only, the thermal resistance R_2 of this insulation being approximately $1m^2K/W$.

Special measures at corners

SBN 67 required special measures against frost heave at corners, for example by providing heat from heating pipes in the building. However Adamson et al (1973) concluded from their study that normally no such measures are necessary. They suggested nevertheless that edge beams (or foundation walls) should be reinforced near corners to provide cantilever action in case underlying frost-susceptible soil is displaced as a result of frost heave forces. At projecting corners in Swedish zone I, particularly, the edge should be insulated along its whole height and extra heat supply (from heating pipes or electrical cables) or ground insulation may also be required.

Protruding parts of a foundation

The results of Adamson et al justified the requirement of SBN 67 that, for a protruding part of a construction, the foundation depth should be increased by an amount equal to the distance which the part projects outside an outer wall. In Fig. 73 the foundation depth has been increased by the protruding distance d (giving a total foundation depth of 0.35+d in metres) and frost conditions are more favorable than in Fig. 63 where the foundation depth is only 0.35m.

Room temperature

Adamson et al found that the required foundation depth is not particularly sensitive to small variations in room temperature, for example if it is reduced from 20°C to 10°C. They therefore suggested that the foundation depth of 0.35m can also be used where the room or space above a floor structure is heated to only 10°C if the total thermal resistance of the floor area next to an outer wall does not exceed $1.3m^2K/W$. Also ground insulation should be provided and special measures taken to counteract frost heave along the entire outer wall. However it was considered preferable to increase the foundation depth from 0.35m to 0.50m if the room or space had a minimum mean monthly temperature of 10°C during a hard winter.

3.5.2 Standards and Guidelines

SWEDEN

The general requirements of the Swedish Building Standards (SBN 80) are that if a building is to be founded on frost-susceptible soil and is to be protected against frost action, its foundation should be taken down at least to the lowest frost-free level which can be expected to occur during the assumed life of the building. This level should be determined taking into consideration climatic conditions and heat contribution from the soil ('soil heat') and from the building if it is permanently heated, and also with regard to the durability of thermal insulation used. In applying these requirements it should be assumed that buildings which are not intended for permanent use, for instance most holiday houses, may be unheated during winter months.

For a foundation slab underneath an external wall and projecting outside (or other projecting part of a construction), the specified foundation depth should be increased by the width of the slab (or extent of projection) outside the face of the wall. However, the foundation depth need not be made larger than $0.85h_o$ where h_o is the frost depth in undisturbed ground. The requirement for other projecting parts of a construction (e.g. external stairs) is that the specified foundation depth should be increased by the distance between the extremity of the part concerned and the external wall but need not be larger than h_o.

Particular requirements refer to a slab-on-grade construction associated with a heated building. The floor construction is assumed to have horizontal insulation such that the total thermal resistance in the outer edge strip is not greater than $3.3m^2K/W$ and there are no heat gains from heating pipes or the like cast into the construction. It is also assumed that the floor construction is situated underneath a room that has a minimum monthly mean temperature during cold winters of about 18^oC as for a habitable room. With such a structure the foundation depth should be 0.35m under the following conditions:

(1) The width of the building is at least 4m.

(2) Edge beams or foundation walls for buildings situated in temperature zones I and II should be provided with thermal insulation having a minimum thermal resistance of $1m^2K/W$ above ground surface. If the floor surface lies more than 0.3m above the ground surface outside the building, the edge beam or foundation wall should have a thermal resistance of at least $2m^2K/W$ in temperature zones I and II and at least $1m^2K/W$ in zones III and IV. However, the floor surface should not be situated higher than 0.6m above the ground surface outside the building.

(3) Special measures to counteract the risk of frost damage should be taken within a distance of 1m from external corners in contact with external air. An example of such a measure could be the provision of suitable ground insulation. However these special measures can be omitted under certain conditions, e.g. where the edge beam's thermal resistance is increased by 50% above the values given in point (2), but with a minimum thermal resistance of $1.5m^2K/W$.

If the least monthly mean temperature of the room during winter is about 10^oC, the foundation depth should be increased from the previously specified 0.35m to 0.50m.

NORWAY

With the change in the Norwegian building guidelines (1970), the requirement became simply that the foundations should be designed so that there would be no damage to the structure from frost action. It was no longer necessary in all cases to take the foundation down to the frost-free depth in undisturbed ground. For a typical slab-on-grade foundation, the isotherms are shown in Fig. 74 at the coldest time of the year for a certain locality (Torgersen, 1976). These isotherms were produced from computer calculations which take into account heat contribution to the foundation from the building. If the soil is frost-susceptible, there is danger of frost damage unless the foundation is taken down to a sufficient depth relative to the critical isotherm or other special precautions are taken.

The foundation depth and requirement for ground insulation are dependent on the locality's maximum Freezing Index F_{100}. Fig. 75 from the 'Building Details' (A 521.111) shows placing of ground insulation with an externally or internally insulated foundation wall. This design also applies to a masonry type foundation wall. An optional drainage layer, 100mm thick, under the foundation wall can be considered as part of the foundation depth.

The 'Building Details' specify that, with a Freezing Index up to 30000 $h^{o}C$, a foundation wall for a heated house can be based at 0.4m depth measured from prepared ground, without use of ground insulation. If the Freezing Index is larger it is necessary to have ground insulation as indicated in the following two points with associated figures and tables. Tables 11 and 12 are based on ground insulation of expanded polystyrene with a density of $30Kg/m^3$ and a thermal conductivity of 0.045W/mK. For extruded polystyrene the given thicknesses should be multiplied by 0.73 and for mineral wool by 1.45. A mineral wool board should be laid on a draining underlayer and should not be laid under the foundation wall or foundation.

(1) If ground insulation is used at a house corner or outside an unheated small room as shown in Fig. 76, the necessary foundation depth and ground insulation dimensions can be found from Table 11.

(2) If the minimum foundation depth of 0.4m is used and the Freezing Index is greater than 30000 $h^{o}C$, one should lay ground insulation along all walls as shown in Fig. 77. The dimensions of this ground insulation are determined according to Table 12.

With an unheated room in the corner of a house or with a large unheated room, the foundation wall should be frost-protected according to the regulations for unheated buildings described in Chapter 5. The same applies to a construction for a house which is in process or which is not yet heated before the cold season sets in.

FINLAND

Table 13 from the Finnish guidelines (1987) gives the frost-free foundation depth in frost-susceptible soil for a heated structure with a slab-on-grade foundation. The foundation depth depends on the Freezing Index and the location of the foundation, i.e., whether at a wall border or a corner area. The floor structure's thermal resistance is taken to be $4m^2K/W$ and the foundation wall is assumed to have outside insulation but no ground insulation is required.

Table 13 applies to normally present foundation fills with moisture content about 3-10%. Foundation depths smaller than those indicated in Table 13 can be used for finer-grained soils while greater depths should be used for coarser-grained soils and moraines. With natural clays or silts the moisture content can be quite high and it is essential to have outside foundation wall insulation to prevent a cold bridge from outside air to frost-susceptible soil.

TABLE 11

Minimum foundation depth in metres with ground insulation only at the corner and outside an unheated small room. If the foundation wall has inside insulation, the optional ground insulation must also be extended under the foundation wall.

Maximum Freezing Index h °C	Concrete insulated externally	Concrete internally insulated Light aggregate blocks Thickness 250mm	Necessary ground insuln. (polystyrene 30 Kg/m^3) at corner and room (t x B x L) in mm (see Fig. 37)
30000 or less	0.40	0.40	Ground insulation is not necessary
35000	0.40	0.50	50x500x100
40000	0.50	0.60	(polystyrene)
45000	0.60	0.70	
50000	0.70	0.85	50x500x1500
55000	0.85	1.05	(polystyrene)
60000	1.00	1.20	

(from 'Building Details', A 521.111)

TABLE 12

Necessary ground insulation with a foundation depth of 0.4m
If the foundation wall has inside insulation, the ground insulation, must also be extended under the foundation wall.

	Ground insulation (polystyrene 30 Kg/m^3)	
Maximum Freezing Index h °C	At corner: thickness, breadth and length (t . B . L) in mm	Along a long wall thickness and breadth (t . b) in mm
30000 or less	Not necessary	Not necessary
35000	50x500x1000	50x250
40000	50x750z1000	50x250
45000	50x750x1500	50x250
50000	80x750x1500	50x500
55000	80x1000x1500	80x500, 50x750
60000	80x1000x2000	80x750

(from 'Building Details', A 521.111)

TABLE 13.

Heated structures (inside temperature $\geq 17^{\circ}C$)
frost-free foundation depth in frost-susceptible soil.

Foundation construction	Foundation part	Frost-free foundation depth m		
		Freezing Index F_{50} h°C		
		35 000	50 000	65 000
slab-on-grade floor structure thermal resistance	wall border	1.0/1.2	1.3/1.5	1.6/1.9
$4m^2K/W$ insulation outside foundation-wall	corner	1.3/1.6	1.6/2.0	2.0/2.4
slab-on-grade floor structure thermal resistance	wall border	0.9/1.1	1.2/1.4	1.6/1.9
$3m^2K/W$ insulation outside foundation-wall	corner	1.2/1.5	1.6/2.0	2.0/2.3

Notes: It is assumed that the building's width is at least 4m and that the ground surface by the side of the structure is snowless.
Smaller foundation depths can be used for fine-grained soils and greater depths for coarse-grained soils and moraines. Intermediate values can be interpolated.

(Finnish guidelines, 1987)

If the foundation depth to be used is less than the frost-free depth, ground insulation is required with thermal resistance depending on the chosen foundation depth and the local design Freezing Index as shown in Fig. 78. These design curves refer to a slab-on-grade foundation with the following conditions based on the Swedish and Norwegian work:

(1) The inside temperature is at least $17^{o}C$.

(2) The building's width is at least 4m.

(3) There is no snow on the ground next to the building.

(4) The pedestal height is not more than 0.6m above grade.

(5) The foundation wall is well insulated so as to provide a thermal resistance of at least 1 m^2K/W.

(6) The border strip of the floor structure near outside walls has a thermal resistance of 2.6 m^2K/W.

(7) The width of ground insulation is 0.8 to 1.0m.

The guidelines state that at exterior corners 40% additional insulation should be provided over a distance of 1.5m from a corner. This can consist, for example, of 70mm thickness of insulation placed at a corner compared to 50mm thickness along an outer wall. Lack of this extra insulation has resulted in many frost damages in Finland due to:

(1) less snow cover at a corner because it is particularly exposed to the action of wind which blows the snow away,

(2) the $0^{o}C$ isotherm being lower at a corner on account of its greater exposure to the outside climate.

COMPARISON

The Swedish Standards do not appear to give any recommendations about the design of ground insulation but leave that to the judgement of the engineer. The Norwegian and Finnish guidelines give a more detailed procedure with recommended insulation depending on the Freezing Index and foundation depth. The Finnish recommendations are based on the Frost I Jord project and the ground insulation's thermal resistance from Fig. 78 needs to be converted to a requisite thickness of insulation material used, e.g., polystyrene. The Norwegian guidelines are more detailed as they differentiate between a foundation wall insulated externally and one insulated internally. The inside temperature assumed in the Finnish case is slightly less, i.e., at least $17^{\circ}C$ is specified instead of $18^{\circ}C$ as in the codes of Norway and Sweden.

3.5.3 Ground insulation material and protection

According to the Norwegian 'Building Details' (A 521.111), as horizontal ground insulation outside a foundation wall one should use boards of extruded polystyrene or of expanded polystyrene with density at least $30Kg/m^3$ or boards of mineral wool with density at least $140Kg/m^3$. Under a loaded foundation wall one should not use boards of mineral wool. Expanded polystyrene with density at least $30Kg/m^3$ can normally be used in the construction of a small house without basement. Extruded polystyrene has the largest compressive strength and should be used where a large load is expected.

For maximum thermal efficiency, ground insulation should be placed as near the ground surface as possible (Knutsson, 1986). However this could result in damage by inadvertent digging for gardening purposes as has frequently happened.

The Finnish guidelines (1987) recommends placing ground insulation on a sand bedding and, if it is near the surface, protecting it by a concrete slab of thickness 50-70mm. With no such protection the ground insulation must be placed at least 0.30m deep and protected with a plate of asbestos cement or water-resistant plywood (Chapter 9). This cover, which should be inclined away from the foundation wall, limits possible damage to the insulation by plants and loss of insulation effect by water intake. During the construction process care must be taken to prevent access of water to the ground insulation before protection is applied.

In Finland, an alternative to insulation material like polystyrene or mineral wool is light gravel which is placed on a sand bed that is nearly level and covered with plastic insulating paper or with some plastic coating. Over this a thin layer of sand is placed and on top of this is placed a protective cover if required. If the thickness of fill that is placed on top of the light gravel is less than 0.15m, the layer of insulation has to be protected, where damage may occur, with building panels or by stabilization with cement (VTT, 1974).

3.5.4 Heating cable design

If a heating cable is used it can be located as shown in Fig. 79 according to the Finnish guidelines. Table 14 gives the required power for a heating cable used without ground insulation depending on the design Freezing Index, the allowable frost depth and the position of foundation wall insulation. This table applies to conditions where the inside temperature is at least $5^{o}C$ and where the thermal resistance of the floor structure is 2.6 m^2K/W.

TABLE 14

Necessary cable power for frost protection

Foundation wall insulation	Allowable frost depth m	Cable power without ground insulation, W/m Freezing Index h°C 35 000	50 000	65 000
Insulation placed outside	0.5	10	15	20
	1.0	5	5	5
Insulation placed inside or across the bottom	0.5	15	20	30
	1.5	10	10	15

The heating cable is extended the full length of the foundation wall and covered with sand free of stones. Care must be taken not to damage the cable during the filling operation. The cable is controlled with one or more thermostats and the temperature sensor is located in an area where the depth of frost is greatest (VTT, 1974).

3.6 PROTECTION AGAINST MOISTURE FROM THE GROUND

Problems have arisen from transfer and accumulation of moisture, such as suction upwards and condensation of moisture in the construction with danger of corrosion, rot and destruction of the floor covering. There is also the possibility of damage to the building due to differential movements produced by shrinkage, swelling and frost heave.

According to the Norwegian 'Building Details' (A 521.111) a floor construction should be protected against moisture from the ground by means of the following layers:

(1) A drainage layer under the construction consisting of at least 100mm crushed rock or coarse gravel.

(2) A capillary barrier layer that stops suction of water upward. This should consist of boards of polystyrene or stiff mineral wool. A layer of broken rock, crushed stone or coarse gravel may not act well as a capillary break if it contains dust and fine material. Because of this, it is recommended that the layer thickness be at least 400mm and it would simultaneously act as a drainage layer.

(3) A layer acting as a vapor barrier which is specially important in buildings with a large width. Between the concrete slab and the insulation is laid a plastic film, thickness 0.2mm, at a location above the capillary suction level. It acts as a block against moisture in the form of water vapor from the ground.

A plastic film that is laid under the thermal insulation can involve considerable collection of moisture in the insulation layer during construction, in the form of precipitation and possibly casting water, in the period between the laying of the film and completing casting of the slab. If the film is placed under a concrete slab it is very important that the slab should be allowed to cure first before a moisture-proof covering is put on it.

(4) A separation layer between underlying wet ground and the drainage layer. The separation layer should consist of specially made synthetic fiber mesh and this hinders infiltration of soil material into the overlying drainage layer.

Examples of moisture protection of slab-on-grade are shown in Fig. 80.

3.7 SLAB-ON-GRADE CONSTRUCTION

The following are types of slab-on-grade constructions proposed by the Norwegian 'Building Details' (A 521.111):

Concrete slab

Constructions with a concrete slab and associated foundation details are illustrated in Figures 81, 82 and 83.

Slab insulation of polystyrene or mineral wool has an effect like a capillary breaking layer that will prevent upward suction of moisture to the concrete slab. Under the insulation it is therefore sufficient to have a 100mm thick drainage layer of material without a special requirement for it to have a capillary breaking property. Slab insulation of light clinker, however, is doubtful as a capillary breaking layer. Under such insulation, a capillary breaking layer [illegible] 0mm crushed rock or coarse gravel is specified.

A concrete slab which is taking load just from non-bearing walls and usual house furnishings is usually cast in a thickness of 50 to 70mm. A slab with a larger loading must be specially designed.

Floating floor

Figures 84 and 85 show examples of floors constructed of wood boards on polystyrene insulation. The wood material can be wood fiber board, wood chipboard or plywood. The insulation layer is laid on a concrete slab or sand layer set out precisely to give a sufficiently level floor. At least 100mm of drainage material is required but there is no need for this to have capillary breaking properties.

Wood-surfaced floor

Fig. 86 shows a wood-surfaced floor which is a composite of wood joists and mineral wool in between. A concrete slab, at least 50mm thick, is cast as an underlayer and suitably reinforced. This type of floor should not be used in combination with a foundation wall that is insulated on the inside, on account of the danger of condensate against the plastic film closest to the outer wall. The wood-surfaced floor on sleepers can consist of 21mm floorboard, 22mm chipboard or 19mm plywood. The use of a drainage and capillary breaking layer consisting of at least 150mm crushed stone or coarse material is specified.

3.8 THERMAL INSULATION MATERIALS

The Norwegian 'Building Details' (A 521.111) specify thermal insulation as follows:

Floor insulation

Under a concrete slab is required a sheet of polystyrene with density at least 20Kg/m^3, a sheet of mineral wool with density at least 90Kg/m^3 or lightweight clinker that is loose, cement-stabilised or wrapped in special plastic sacks. Under a floating floor of wood fiber or chipboard, a board of polystyrene should be used with density of at least 30Kg/m^3.

Foundation wall insulation

This should consist of boards of polystyrene with density at least 20Kg/m^3 or boards of mineral wool with density at least 90Kg/m^3.

4. FOUNDATIONS WITH CRAWL SPACE OR BASEMENT

4.1 INTRODUCTION

A foundation with crawl space (Fig. 87) is suited to the same ground conditions as a slab-on-grade, but the former can be more easily adjusted to slightly hilly rocky terrain and to sloping sites. The method gives a relatively low building cost and can be relatively easily adjusted to own house building. However crawl spaces have given rise to a large number of problems such as decay in the floor structure, etc. Storage areas must be built on level ground and the imposed loading acts as an additional load on the ground if the ground in the crawl area is not located lower than outside.

In Sweden foundations with crawl spaces have been used from time immemorial, in the form of a free-bearing floor structure on plinths or ground walls. However from around 1900 houses were mostly constructed with basements and this became the dominant method by the beginning of the Second World War. After this war there was a renaissance in the construction of foundations without basements until about 40% of the number of houses and other light buildings were being constructed in this manner.

In Norway foundations with crawl spaces have been used for a long time but building methods have changed particularly because crawl spaces have been exposed to moisture and rot damage. Since the war use of crawl space or basement foundations, and often combinations of these, has been dominant in the case of light buildings. Crawl spaces have been mostly used for extensions and accessory buildings and under a suspended floor of a house in sloping ground. In connection with crawl spaces, wood-beams with mineral wool insulation are almost always used and a foundation wall of concrete or of light expanded clay aggregate (leca) blocks.

There are two general types of crawl space, i.e., 'cold' and 'warm'. The former is a crawl space that is ventilated with outside air (Fig. 88) whereas the latter is ventilated with inside air (Fig. 89). A 'warm' crawl space has been little used and an unventilated crawl space should not be built.

A crawl space foundation can be adjusted to variations in the terrain and is well suited to gently undulating conditions. It is particularly well suited to non-frost-susceptible ground and rocky ground. It can, however, be suitable in weak ground where an excavation is in any case necessary to remove some of the soil. In such cases construction of a basement would often be preferable to acquire additional usable inside area for the house. Where there are particularly steep slopes, a basement with slab-on-grade at the back of the house can be combined with a crawl space near the front (Fig. 90), although such a design can give problems with respect to ventilation of the crawl space area (Fig. 91).

On nearly flat sites, it is rarely an advantage to use a crawl space together with, for example, a slab-on-grade. A crawl space could involve a lower depth of foundation with increased loading and also moisture problems can frequently arise.

In wet climates there has been much moisture damage to the floor area above a crawl space. The supply of moisture can be limited by:

(1) shaping the ground with a slope away from the building.

(2) draining the crawl space if it is lower than the outside ground.

(3) covering the ground in the crawl space area with a plastic film.

Figure 92 shows a design with a foundation wall cast in concrete.

There should be adequate protection against possible frost damage. The ground wall and foundation with crawl space should be designed so that no damage occurs from frost heave, sideways frost pressure or uplift from frost sidegrip.

A comprehensive study of crawl space foundations was carried out at Lund Technical University in Sweden by Adamson and others. The results of this study (Adamson et al, 1971 and Adamson, 1972) formed the basis for revisions of relevant sections of the Swedish Standards SBN 69 to produce SBN 80. The study also gave an input into the Norwegian Frost I Jord project.

4.2 HEAT FLOW CONDITIONS

The frost depth at a foundation wall for a 'cold' ventilated crawl space under a heated building will be less than the frost depth in snow-less undisturbed ground. Depending on the floor insulation, heat is led through the floor structure down to the crawl space and thus contributes to keep the crawl space temperature higher than the outside temperature. The heat loss from the foundation wall's inner and outer side is reduced and the frost depth decreases since heat is concentrated at the foundation bottom area.

As long as the crawl space temperature is over $0^{o}C$, heat from the crawl space is led to the freezing zone and slows down frost penetration (Fig. 93). The effectiveness of this depends on a balance between heat from the floor and heat losses from the crawl space through ventilation. In cold, and moderately cold, regions the crawl space temperature with regular ventilation and good overlying floor insulation could fall below $0^{o}C$ in critical winters. Heat flow from the crawl space to the frost front would then cease and only 'soil heat' contributes to the foundation area. Because of the low crawl space temperature the frost depth at a 'cold' crawl space under a heated building will be considerably larger than in the case of a slab-on-grade construction. On the other hand a 'warm' crawl space would have an associated frost penetration that is similar to the case of a slab-on-grade.

Relevant crawl space parameters are indicated in Fig. 87. They include the U-value of the floor structure and that of the foundation wall, the pedestal height h (height of floor bottom above outside ground), the foundation depth z_g and the ventilation rate v as well as the outside climate.

4.3 FROST PENETRATION

Depending on various factors Adamson et al (1971) and Adamson (1972) charted the heat flow conditions and determined the frost penetration related to crawl spaces on the basis of extensive computer calculations for long buildings and for square buildings subject to various outside climates.

<u>Geometric factors</u>

Fig. 94 shows isotherms for a long building, 10m wide, which can be compared with those for a square building 10 x 10m (Fig. 95), at the time of maximum frost penetration with no snow cover, the same parameters being assumed in each case. The vertical broken lines in these figures represent the boundary of a foundation wall of 0.2m thickness. The intersection of this boundary with the assumed critical $-1^{o}C$ isotherm was taken to give the required foundation depth. This depth was greater for the square building being about 0.9m as compared with about 0.5m for the long building.

For a square building frost penetration was deeper at an outside corner (e.g. 0.9m depth) than in the middle of an external wall (e.g. 0.7m). This corner effect was significant only within a distance of 0.5m to 1m (in a horizontal plane) from the corner.

There was less frost penetration in the middle of the facade of a long building (e.g. 0.55m depth) compared with the penetration in the middle of a square building's external wall (e.g. 0.7m), since heat loss through the foundation wall is greater in the latter case because of the three dimensional effect and because of more exposure. The floor insulation, foundation wall insulation and crawl space ventilation were assumed to be equal in each case.

<u>Other factors</u>

As may be expected, increased insulation of the floor or increased ventilation of the crawl space, reduced the temperature in the crawl space during winter and increased frost penetration. Thus, in the case of a long building an increase in the U-value of the floor from 0.41 to $0.58 W/m^2K$ increased the frost penetration from 0.65 to 0.7m at a constant ventilation rate of $0.5 m^3/m^2$. For a long building having a floor with a U-value of $0.407\ W/m^2K$, increase in ventilation rate from 0.5 to $2 m^3/m^2$, increased frost penetration from 0.7m to 0.95m.

A reduction in room temperature above the crawl space from 20^oC to 10^oC increased frost penetration from 0.45m to 0.65m. On the other hand, ground level in the crawl space had no influence on frost penetration and, therefore, on the required foundation depth.

4.4 FLOOR TEMPERATURE AND THERMAL INSULATION

With regard to thermal insulation the Norwegian Building Code places a limitation on the U-value of a floor structure depending on the particular climatic zone. According to Algaard (1976) this value is rather high as it implies too large a heat loss being allowed to take place through the floor. It might be more appropriate to have a lower U-value by using more insulation to improve the floor temperature and for better heat economy. This would then give a lower temperature in the crawl space and require a larger foundation depth with frost-susceptible soil.

Similarly to the case of a floor with slab-on-grade, the requirement should be that the lowest surface temperature on the floor over the crawl space is 17.5^oC with an indoor temperature of 21^oC (Algaard, 1976). Also the connection between the foundation wall, outer wall and floor structure should be made in such a way that there is no damaging cold bridge or moisture leakage that can considerably reduce the floor temperature along the outer wall. The necessary thermal insulation for the floor structure can then be determined on the basis of these requirements and taking into consideration crawl space ventilation, the heat transfer resistance R_i between inside air and the floor surface (Section 3.4.2) and estimates of the lowest crawl space temperature.

According to the Frost I Jord project the Freezing Index F_{100} is used as the design 'frost load' and Fig. 96 gives the relationship between F_d (design value) and the necessary heat transfer coefficient (U-value) or its reciprocal, the thermal resistance R_t, for the floor structure, to obtain a minimum of 17.5°C on the floor. This is a recommendation rather than a requirement. For crawl spaces under unheated, or sporadically heated, buildings (cabins, etc.) the situation is different and depends on whether they are to be used for extended occupation.

The Norwegian 'Building Details' (A 521.203) specifies highest allowable U-values for a floor structure of 0.30, 0.45 or 0.6W/m^{2}K at inside temperature 18°C and higher, 10-18°C or 0-10°C respectively. These values apply to a floor against an unheated crawl space with outside ventilation and total area of ventilation openings less than 0.2m^2 per 100m^2 of ground area. The distance from the floor structure to the ground under the house must not be less than 0.3m.

In the Swedish Standards (SBN 80) two U-values of the floor structure are tabulated i.e. 0.25 and 0.50W/m^{2}K (Table 17) with the possibility of interpolation to determine the corresponding foundation depth. The Finnish guidelines (1987) gives Table 15 which specifies maximum allowable U-values of 0.22 and 0.45W/m^{2}K applicable respectively to a floor for a heated room and a partly heated room above a crawl space. In the case of industrial buildings the respective values are 0.36 and 0.65W/m^{2}K.

TABLE 15

Maximum allowable U-value and minimum thermal resistance
for floor structure
of heated and partly heated buildings with crawl space.

	Max. allowable U-value W/m^2K		Thermal resistance m^2K/W	
	Heated room	Partly heated room	Heated room	Partly heated room
Residences	0.22	0.45	4.55	2.2
Industrial	0.36	0.65	2.8	1.5

4.5 FOUNDATION DEPTH

(a) Foundation in non-frost-susceptible ground

According to the Norwegian 'Building Details' (A 521.203), in non-frost-susceptible ground the foundation depth may be small, the practical minimum being about 0.3m under prepared ground (Fig. 97). For less important buildings the foundation may be set directly on sufficiently firm ground (Algaard, 1976).

(b) 'Frost-free depth'

For frost-susceptible soil, the Norwegian 'Building Details' specify that the foundation wall should be based at the particular locality's 'frost-free depth' in undisturbed ground. The frost depth from the Chart (Fig. 8) for Norway is corrected depending on the local soil type but no correction is made for water content. The correction factor is 0.85 for silt and 0.7 for clay and the smaller depth thus obtained gives a saving in excavation work and ground wall material.

The foundation depth based on the Chart is deeper than necessary for heated buildings but it is right and necessary for cold or sporadically heated buildings and for crawl spaces that are especially well ventilated (in the latter case one approaches the principles for 'open' foundations (Chapter 6). In such a crawl space, there will also be frost penetration on the inside of the foundation wall and then one must check both for the maximum frost depth and for uplift by sidegrip (Fig. 98). With frost penetration down both sides of the foundation wall, sidegrip can become considerable and the resulting uplift force can be estimated on the basis of Table 16. If the total uplift force is larger than the total weight carried by the foundation wall, it must be anchored under the maximum frost depth or its surface coated with bitumen (at least 2mm) or epoxy to reduce the sidegrip (Algaard, 1976).

(c) Reduced foundation depth

A heated building provides a certain amount of heat through its floor to the foundation area so that the required foundation depth is less than the frost depth h_o in undisturbed ground. Procedures of design with reduced foundation depth are based on the work done in Sweden by Adamson et al (1971 and other publications) and on the Swedish Building Standards. An underlying drainage layer of gravel is considered part of the foundation. The ground around the building is assumed to have no snow cover and the crawl space temperature to be above 0^oC.

Swedish Building Standards

According to SBN 80 the foundation depth can be determined from h_o by applying a reduction factor β found from Table 17.

TABLE 16

Values for the lifting force (KN) transmitted by sidegrip to unprotected piles or piers with diameter 200 to 350mm in dry crust clay

	LIFTING FORCE WITH SIDEGRIP, KN,		
	Freezing Index h °C		
Material	10000	30000	50000
Steel	50	100	140
Wood	30	50	60
Concrete	30	80	100
Concrete wall per metre length	25	40	50

(values serve as a guide)

(from Torgersen, 1976)

TABLE 17

Reduction factor β with respect to frost penetration depth for a foundation construction below a heated building with a floor construction above an enclosed crawl space ventilated by outside air

Temperature zone	Thermal transfer coefficient of floor construction U - value W/m^2K	Reduction factor β for facades at distances greater than 1m from external corners: Long building*	Short building	Near external corners, up to 1m from the corner
I and II	0.50	0.3	0.4	0.4
	0.25	0.5	0.6	0.6
III and IV	0.50	0.2	0.3	0.3
	0.25	0.4	0.5	0.5

* A long building is one with length more than 3 times its width.

Use of Table 17 requires the following conditions:

(1) The width of the building is at least 4m.

(2) Rooms or premises situated above the floor, with the exception of single small spaces, regularly have a temperature of at least 18°C during the heating season.

(3) The layer of insulating material on the ground surface inside the ventilated crawl space has a maximum thermal resistance of $0.5m^2K/W$.

(4) The part of the foundation wall above external ground surface has a minimum thermal resistance of $1.1m^2K/W$ in temperature zones I and II, and $0.9m^2K/W$ in zones III and IV. However, if the underside of the floor construction is higher than 0.6m above the ground surface outside the foundation wall, a higher thermal resistance should be selected. Its value should be such that the total quantity of heat passing through the foundation wall is not greater than the quantity of heat passing through a foundation wall 0.6m above grade and with the thermal resistance specified above.

(5) The ventilation rate is $1m^3$ per m^2 of floor area per hour. When the ventilation rate is as much as $3m^3/m^2h$, the tabulated values of β should be increased by 0.1. For intermediate ventilation rates, linear interpolation should be applied. (With regard to ventilation requirements and calculation of ventilation areas, reference is made to section 32 : 3222 of SBN 1980).

Frost I Jord procedure

Similar assumptions were used in the Frost I Jord procedure with the following differences. In the case of point (2) it was noted that an occasional drop in temperature from the usual $17^{\circ}C$ (instead of $18^{\circ}C$ in Sweden) to about $10^{\circ}C$ over a couple of weeks would not have an appreciable influence on frost penetration. Also, corresponding to point (3) it is specified that the ground in the crawl space must not be thermally insulated. The minimum thermal insulation requirements for the foundation wall, point (4), are also different in this case and have to be in accordance with the Norwegian Building Code's requirements for a basement wall against outside air. If the foundation wall is higher than 0.6m above outside ground, more insulation is required. With regard to point (5), the assumption is simply 'adequate ventilation'.

The Frost I Jord calculation procedure for determining the minimum foundation depth is based on an outside temperature varying harmonically according to a cosine function. This gives approximately the same frost penetration as an actual temperature variation with the same Freezing Index (Section 3.3). The steps in the procedure are as follows:

(1) The local design Freezing Index is determined: $F_d = F_{100}$.

(2) The foundation wall's U-value is checked to see that it satisfies the Building Code's requirement concerning a basement wall

If the foundation wall height is greater than 0.6m above grade, the U-value is multiplied by 0.6/h.

(3) The floor structure's U-value is checked to see that it conforms to the Building Code's requirements.To obtain a satisfactory surface temperature on the floor, one uses recommended values from Fig. 96.

The building ground is examined to see if it is frost-susceptible or not.The necessary foundation depth z_g is determined:

(a) On frost-susceptible ground:

z_g is determined depending on F_{100}, the floor structure's U-value and soil type A or B (Fig. 99). Soil A includes the finest friction soils such as silty sand and sandy silt. Soil B includes impervious and moist cohesive soils.

(b) On non-frost-susceptible ground:

$z_g \geqslant 0.3$m, or less in exceptional cases.

Outside ground insulation will have a large effect on frost penetration but this is not taken into consideration in determining the necessary foundation depth according to the Swedish Standards or the Frost I Jord procedure. The Finnish guidelines take the thermal resistance of ground insulation into account.

Finnish guidelines

The Finnish guidelines (1987) assume a width of ground insulation between 0.8 and 1.0m taking the $0^{o}C$ isotherm as being critical whereas the $-1^{o}C$ isotherm is chosen as such in the Swedish and Norwegian methods. Otherwise the Finnish guidelines are based on similar assumptions to those of the Swedish Standards with the following differences:

Point (2): The inside temperature of the room above the crawl space is assumed to be at least 17°C.

Point (4): The foundation wall is assumed to be 'well insulated' for at least 0.3-0.5m below ground level but the value of its thermal resistance is not specified.

Point (5): The ventilation rate is assumed to be not greater than 0.6Litres/m^2s which is equivalent to $2m^3/m^2h$.

Also the thermal resistance of the floor structure is specified in the Finnish guidelines as $4.5m^2K/W$ whereas the Swedish Standards specify the U-value of the floor structure between 0.25 and 0.50 W/m^2K.

Based on the above assumptions, the Finnish guidelines enable the required foundation depth to be determined from Fig. 100 depending on the local design Freezing Index and the thermal resistance of the ground insulation to be used. Table 18 from the Finnish guidelines gives an alternative specification for the frost-free foundation depth in frost-susceptible soil.

Where buildings are partially heated to an inside temperature between 5°C and 17°C, the foundation depth found from Fig. 100 is increased by 0.2m to 0.4m.

Norwegian 'Building Details'

According to the Norwegian 'Building Details' (A 521.203), even on frost-susceptible soil, the foundation depth can be reduced to 0.3m if insulation is laid under a foundation wall (Fig. 101). This is most practicable in relatively mild climates where moderate insulation thicknesses can be used. The necessary insulation thickness is given in Table 19 depending on the locality's Freezing Index F_{100} and Mean Annual Temperature. The assumed insulation is expanded polystyrene with density of 30 kg/m^3.

TABLE 18

Heated structure (inside temperature $\geqslant 17^{o}C$)
with crawl space
Frost-free foundation depth in frost-susceptible soil

Specification	Foundation part	Frost-free foundation depth m Freezing Index F_{50} $h^{o}C$ 35000	 50000	 65000
Floor structure thermal resistance $4.5 m^2 K/W$ and crawl space ventilation rate 0.6 Litres/$m^2 s$	wall border	1.1/1.4	1.4/1.8	1.8/2.2
	corner	1.4/1.8	1.7/2.2	2.1/2.6

Note: It is assumed that the building's width is at least 4m and that there is no snow cover by the side of the building.

(Finnish guidelines, 1987)

TABLE 19

Insulation thickness t (mm)

MEAN ANNUAL TEMPERATURE °C	Freezing Index F_{100} h°C 5000	10000	20000	30000
3			80	120
5	40	40	80	120
7	40	40	60	100
B (m) (See Fig. 101)	0.5	0.5	0.75	1.0
b (m) (" " ")	0.5	0.5	0.5	0.75

In the case of a cold crawl space with ventilation openings not exceeding the recommendation of the Norwegian 'Building Details' (0.2m^2 per 100 m^2 of ground area), the air temperature inside the crawl space will be appreciably higher than outside air temperature. Accordingly a design Freezing Index of F_2 may be used in determining the required width 'b' of insulation extending <u>inwards</u> from the foundation wall. The width of insulation extending <u>outwards</u>, 'B', is still determined according to F_{100} (Dow Chemical, 1987).

4.6 FOUNDATION WALL INSULATION

The Norwegian Building Code does not place a requirement on thermal insulation of the foundation wall of a crawl space. Heat loss through the foundation wall can be considerable and in buildings for normal occupation the foundation wall should be insulated (Algaard, 1976). All estimates of the recommended thermal insulation for the floor structure (Fig. 96) and necessary foundation depth (Fig. 99) assume that the foundation wall insulation is not worse than the Building Code's requirement for a basement wall against outside air. By increasing the insulation of a foundation wall, the crawl space temperature will rise somewhat and that will improve conditions with regard to the floor temperature and the frost depth at the foundation wall. Where the floor structure has a low U-value it is particularly important to improve insulation of the foundation wall to keep the crawl space temperature up and

If a foundation wall has a height h over the ground greater than 0.6m, heat loss through the wall increases beyond what is assumed in the Building Code's recommendation, and the greatest allowable U-value of the basement wall is multiplied by a factor of 0.6/h (Algaard, 1976).

The Swedish Standards SBN 80, in association with Table 17 (Section 4.5), quotes minimum values for the thermal resistance of a foundation wall ranging from $0.9 m^2 K/W$ to $1.1 m^2 K/W$ depending on the climate. The recommendation is that these values should be increased (but the amount is not specified) if the pedestal height h is more than 0.6m. In such a case the Finnish guidelines (1987) recommend the minimum thermal resistance R of the foundation wall be obtained from the expression:

$$R = R_{0.6}\ (h/0.6)$$

where $R_{0.6}$ is the thermal resistance of a wall with pedestal height of 0.6m.

For a foundation wall consisting of material that is not thermally insulating, e.g., concrete, the thermal insulation should be placed on the <u>outside</u> because that gives the best protection against frost penetration through the foundation wall.

A cold bridge should not be allowed to form as exists in the top illustration of Fig. 102. This cold bridge can be broken by extending the ground insulation under the foundation wall so that this insulation contacts the vertical insulation in the middle of the foundation wall as in the lower illustration (Fig. 102). The effect is to shift the position of the $0^{o}C$ isotherm more favorably so that it does not penetrate inwards below the foundation wall. A further advantage is that less width (1.2m) of ground insulation is required instead of the former width of 1.5m.

4.7 THERMAL INSULATION OF BASEMENT WALLS

The Norwegian Building Code gives certain maximum allowable U-values for outer walls or basement walls depending on the inside temperature. These U-values are 0.30, 0.60 and $0.80 W/m^2K$ for inside temperature of 18^oC and above, 10-18^oC, and 0-10^oC respectively.

As an example of how the U-value may be determined, design curves are given here for a concrete basement wall externally insulated with 'styrofoam' (an extruded polystyrene product). The average U-value depends on the height of the wall, the insulation thickness, the type of soil behind the wall and the height of this soil. Three types of ground are considered: (I) loose material, (II) clay and (III) rock. Fig. 103 applies to a wall 2.5m high with varying soil height H. If extra insulation thickness is used under the ground, the U-value can be determined from Fig. 104. For a basement wall with height up to 6m and a fixed top level 0.5m above the ground, Fig. 105 gives the U-value with the same insulation thickness above and under the ground.

For use in thermal design of a basement, NS 3031 (Norwegian Standards, 1986) gives the values in Table 20 for the thermal resistance R_j of the ground (see Section 3.4.5) depending on the type of ground.

TABLE 20

Thermal resistance of the ground
R_j, m^2K/W

Construction	Fill materials Clay	Fill materials Other	Rock
Basement outer wall with fill height H (m) above the basement floor	0.7H	0.5H	0.35H

4.8 DRAINAGE AND THERMAL INSULATION

The usual drainage method is to use a layer of sand or gravel to replace any existing cohesive soil just behind the wall (Fig. 106). If, instead of this, a layer of plastic or mineral wool is placed, it will hinder sidegrip on the wall. With a plastic layer, however, frost-susceptible soil would lie near the wall and can still give horizontal pressure on the wall. The imperviousness of the plastic can lead to inadequate drainage so that the soil remains frost active.

A layer of mineral wool, for example on the outside of a Leca-wall, acts as a large addition to the thermal insulation so that heat from the basement to the soil outside is considerably reduced. As a result there could be a deeper frost penetration than with gravel drainage and frost-active soil would be nearer to the basement wall. Also the mineral wool requires sufficient stiffness to take any acting horizontal pressure. Because of these problems one should consider removing some of the frost-susceptible soil and replacing it with non-frost-susceptible material together with some insulation (e.g. Fig. 107).

In Norway drainage board is sometimes used as a combined basement wall drainage and thermal insulation. This board can consist of 'rockwool' (a mineral wool), of 100 Kg/m^3 density, or polystyrene with an open structure or with grooves (Torgersen, 1988). Other proprietary materials are used in Sweden such as 'Pordran' consisting of nearly uniform 'styropor' pellets of medium gravel size held together with a binder. A plate of this material is 6.5cm thick with a porosity of around 35% allowing movement of water through it in liquid or vapor form. As shown in Fig. 108 the pordran is covered with a synthetic fiber mesh called 'fiberduk' which prevents access of fine soil particles. The protective combination, placed on the outside of a basement wall, has good thermal insulating properties and allows drying of the basement wall outwards thus preventing moisture accumulation in it due to upward suction from the ground. Adequate drainage behind the wall is also facilitated. Similarly in Finland basement walls are usually protected with an outside thermally insulating plate and a drainage layer.

Experience shows that most of the damages from frost action occur in the construction period during the cold season or in the first winter after construction. This is probably because the drainage system has not yet managed to drain the soil sufficiently and, as a result, there are more favorable conditions for frost action causing larger horizontal frost pressure. Also frost tends to penetrate deeper where soil is exposed during the construction operation and protection measures, such as covering by 'winter material', should be considered.

4.9 FOUNDATION OF BASEMENTS

The Swedish Standards (SBN 80) give a reduction factor β (Table 21) for determining the foundation depth for an uninsulated floor construction laid on the ground such as a basement floor.

TABLE 21

Reduction factor for uninsulated floor construction laid on the ground

Lowest monthly mean temperature during the winter in a room with uninsulated floor construction	about $0^{\circ}C$	about $10^{\circ}C$
Reduction factor β	0.6	0.3

In Finland, foundations of basements normally reach frost-free depth but if the basement is founded above this level, its foundations should be insulated in the normal manner (Saarelainen, 1988). With a cold basement, foundation conditions and designs can be similar to those for unheated structures and to foundations on piers or piles. If, on the other hand, a basement is heated and insulated to provide habitable space, the construction becomes like a slab-on-grade and should be designed accordingly.

4.10 FROST PROBLEMS

Frost problems with a basement construction are generally smaller than when there is no basement. The temperature in the basement is generally over $0^{o}C$ and the foundation is usually below the frost depth. So the risk of frost under the foundation is negligible in practice. However unfavorable conditions can give rise to sidegrip and horizontal frost pressure on a basement wall. Also indoor temperatures can decrease if part of the basement is exposed to outside air.

A basement exposed to winter air is extremely vulnerable to frost. Not only is there a short distance to the foundation but, if there is soil along the whole height of an outside wall, there is danger from horizontal frost pressure if the soil freezes on account of the very cold conditions inside the basement. While care has generally been taken as regards frost-protection of a basement's foundation to hinder under-freezing, there has been negligence in frost-protecting basement walls exposed to winter air. Fig. 109 shows a recommended design where the floor slab bears on a drainage layer and the walls are insulated internally with additional insulation between an outside wall and existing soil.

Sidegrip

Generally sidegrip is not a big problem with a basement construction. It often happens that soil next to a basement wall shrinks and fissures form especially near the top of the wall. This reduces the sidegrip that the soil could exert on freezing but water should not be allowed to percolate into the fissures since on freezing it can grip the wall.

Some damages have been observed particularly with walls built of blocks with defective vertical joints. Sidegrip can be prevented by using a coarse grained drainage material outside the basement wall e.g. 0.5m of dry gravel. This provides separation from frozen existing soil or fill so that any upward heave force is not transmitted to the wall. Alternatively a tar coating on the wall could reduce the shear between frozen soil and the wall surface (Saarelainen, 1988).

Horizontal frost pressure

If a basement wall is properly insulated and there is level homogeneous ground outside, the freezing front is horizontal and any heave force acts vertically upwards. If the ground is steeply sloping, there can be a significant horizontal frost force. There is no doubt that this has caused a number of damages as basement walls were pressed inwards (Nordgård, 1972). However while damages caused by horizontal frost pressure have occurred in Norway, for example, they have not been frequent (Torgersen, 1988).

If the ground on one side of a house is sloping towards the house, it is evident that the direction of frost uplift can have a horizontal component acting on the wall (Fig. 110). Even with flat ground, where snow has been shifted away from a house, it is possible to have an inclined frost force (Fig. 111). Because there is no insulating effect from snow near the house, the frost depth is lower in this region and the frost front is curved as shown. The frost force is conveyed to the wall through the frozen mass.

It is often difficult to differentiate between frost pressure and normal lateral earth pressure. Whereas the latter can be estimated, horizontal frost pressure cannot. It would be difficult to design a wall as regards frost pressure and the best solution is to design so as to prevent frost pressure from developing. This can be done by providing adequate drainage behind the wall to prevent water accumulating. A drainage layer of coarse material (gravel or crushed stone) can be placed outside the wall as previously mentioned. Also the ground can be sloped downwards away from the wall and/or horizontal ground insulation placed outside the wall to limit frost penetration (Torgersen, 1988).

Local uplift force

Usually a basement wall consists of internally insulated cast-in-place concrete or it is built of blocks of expanded clay aggregate. The latter type is so weak that, if there is a local uplift force under its foundation, this could lead to a fracture in the wall. A cast wall can usually be reinforced so that a moderate uplift will not cause any damage to the wall other than some distortion. However even a small distortion can lead to problems in the overlying house. Again, it is better to have a good design against frost pressure developing rather than to try to solve such a problem with increased reinforcement.

5. FROST PROTECTION OF UNHEATED BUILDINGS

5.1 INTRODUCTION

This chapter is concerned with frost protection of the foundations of unheated (i.e., 'cold') structures that may be associated with frost-susceptible soil. It includes frost protection of separate foundations, such as wall ('strip') and column ('point') foundations exposed to frost. The general objective is to ensure that damaging frost heave does not occur. As opposed to heated buildings where heat flow from the building is utilised in foundation design, the protection of cold structures relies on the available 'soil heat' which has been stored in the ground during summer. Frost protection is based on using insulation to reduce the upward loss of this soil heat and thereby to prevent frost from penetrating down to the frost-susceptible ground below (Fig. 112). The protection under a building consists of a layer of insulation placed on a drainage layer. The drainage layer consists of coarse material that is not frost-susceptible.

The methods described are generally based on the Frost I Jord project. They can be applied to frost protection of a slab-on-grade, and, in general, to foundations for various types of unheated structures such as industrial buildings, warehouses, garages, outhouses and shacks. These methods can also be applied to an unheated section, or a large room, of an otherwise heated building, to a small unheated room in a corner of a heated building or to a heated building the floor of which lies higher than 0.6m above exposed ground. Frost protection of special structures, such as exterior staircases, is included.

Frost protection of foundations can also be done in other ways:

(1) Placin the foundation at the traditional frost-free depth. The economics of this might have to be considered in comparison with other methods. The Swedish Building Standards SBN 80 simply states that a foundation construction below a building with a

temperature not appreciably higher than that of the outside air should be taken down to the frost-free depth h_o below the ground surface according to Fig. 10. This applies, for example, to foundations below entirely unheated buildings and below buildings with an 'open' foundation on piers (Chapter 6) and to staircases and retaining walls outside buildings.

(2) Replacement of frost-susceptible material down to the traditional frost-free depth. This method would normally be used only if the frost-susceptible material requires to be moved for some other reason as well.

(3) Using artificial heat sources such as heating cables, heat pipes or warm air. This is very energy consuming if it is not combined with *insulation*. It is also risky for permanent structures because the heat supply could fail during critical periods. It should therefore not be used in permanent structures except in emergencies although it could be feasible during winter construction.

(4) Casting a stiff foundation that can limit frost heave. The foundation then acts as a unit and is subject to a reduced amount of heave. For example this method has been used in Norway with small unheated storage buildings (say 3x3m). Because of the rigid foundation, the door can be closed and opened without problems. The building and foundation go up and down during the year. In spring, the building tilts because thawing occurs faster on the sunny side (Torgersen, 1988).

5.2 FROST LOAD

The necessary frost protection depends on the local winter climate as expressed by the local design Freezing Index F_d and the Mean Annual Temperature (MAT) which produce the 'frost load'. The MAT is important because it can affect the extent of heaving. The Freezing Index at a place can have different magnitudes depending on its statistical probability of occurrence in a given period of years i.e. F_{100}, F_{10}, F_5 and F_2.

NORWAY

Values of the Freezing Index together with the Mean Annual Temperature are tabulated for different districts ('kommune') in Norway. The district's 'maximum Freezing Index' is in practice taken as the greatest value of F in one hundred years i.e. F_{100}. The design Freezing Index, F_d, for a particular frost-protection requirement in a particular district, is chosen from among F_{100}, F_{10}, F_5 and F_2 tabulated for that district depending on (Algaard, 1976):

(1) What is to be frost-protected e.g. a foundation or floor. The consequences of possible frost heave should be assessed and the sensitivity of the construction to heave taken into account. F_d can be different for a foundation wall and a floor of the same building (Fig. 113).

(2) The number of winters over which the frost protection should be effective, i.e. whether the structure is permanent or temp[illegible] The likelihood for a certain Freezing Index to occur [illegible] estimated.

(3) The degree of experienced inspection. This [illegible] to the construction period.

(4) Whether the air temperature indoors is high[illegible]

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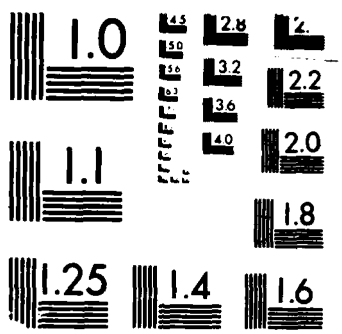

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if the value of the Freezing Index inside is expected to be lower than outside. This is likely for an unheated building that is insulated and closed particularly if it has windows giving considerable sun radiation. This is an uncertain factor but it can be important.

(5) Whether the surface temperature at the site and the effective frost load are significantly different from the air's temperature and Freezing Index.

With regard to point (5), radiation from an uncovered horizontal surface can increase F by 7000-8000 $h^{o}C$, but snow cover reduces F and other factors also tend to reduce F, thus usually providing an adequate safety margin. Table 22 gives guidelines for choosing the design Freezing Index F_d.

The tabulated values of the Freezing Index for a Norwegian district may require adjustment for a particular location depending on its local influencing factors such as the elevation, slope and 'open-ness'. The locality may be some distance from the nearest meteorological station from which the tabulated values are derived. The local Freezing Index may therefore vary significantly and require a larger thickness of insulation.

At places with a low MAT($+1^{o}C$ and lower) there is little effective heat content in the soil, i.e. utilisable 'soil heat'. So the demand for insulation is quite large if one does not also make use of the freezing heat by allowing part of the soil to freeze. To avoid frost heave in such cases a sufficiently thick layer of moist protecting material (sand, gravel) is laid under the insulation and its water content gives additional heat on freezing. The frost resistance of such a layer is proportional to its thickness and moisture content. If the MAT is $0^{o}C$ or lower (as in mountain areas and in Finnmark) one cannot use the methods for frost protection described here since permafrost conditions are approached.

TABLE 22
Guidelines for choice of F_d for frost-protection of construction and ground, permanently or in building period.

FROST-PROTECTION OBJECTIVE	DESIGN FREEZING INDEX F_d, h°C Foundation wall	Floor
'Permanent' construction exposed to outside climate $F_d = F_{out}$	F_{10} to F_{100} Building construction must be evaluated	0 to F_{100} Use requirement and floor type must be evaluated.
Unheated, but closed and insulated building $F_{in} < F_{out}$	($F_d = F_{out}$) F_{10} to F_{100}	($F_d < F_{out}$) 0 to F_{10} Frost load, use requirement and floor type must be evaluated.
Insulated, frost-free building Inside temperature $\geq 0°C$ i.e. $F_{in} = 0$	($F_d = F_{out}$) F_{10} to F_{100}	0
Frost protection of construction in the building period to prevent frost heave: Construction's frost sensitivity and ground's frost susceptibility must be evaluated	F_5 (F_2, F_{10})	
Frost protection of building ground to prevent: - Frost heave: Soil and risk must be evaluated - A thick frost crust:soil, digging equipment and risk must be evaluated	F_2 (F_5)	

Probability that Freezing Index should be F_d	With F_d as:
50%	F_2
80%	F_5
90%	F_{10}
99%	F_{100}

(from Algaard, 1976)

The 'Building Details' (A 521.111) state that frost protection of permanent structures should normally be designed according to the local maximum Freezing Index i.e. F_{100}. This would give full protection without harmful movements in the structure from the action of frost. However, if the structure can tolerate a certain amount of heave, a smaller Freezing Index may be used in the design ,e.g. F_{10}, F_5 or F_2. Table 23 relates to lightweight houses made of wood and gives the expected maximum frost heave (that the structure can tolerate) and its frequency of occurrence corresponding to the selected design Freezing Index. The values in this table were estimated from experience and calculation. They give an idea of the maximum frost heave with soils that have high or medium frost susceptibility and differential heaves of that order of magnitude can also arise. These values, however, must be regarded as site specific so that they may not be a good guide for other circumstances. Prediction of amount of frost heave is still at an early stage.

A floor directly on grade can be considered to tolerate some frost heave depending on type of construction and functional conditions. A concrete floor designed for large loads and heavy traffic should not be exposed to frost heave. An asphaltic floor can tolerate moderate deformation while a floor of gravel or earth (as, for example, in a car port or open shack) can be just as fit for use with normal frost heave.

If a building is to have a life of several years, the design Freezing Index should not be different from the usual probability value for the locality since F_{100} can appear at any time (Algaard, 1976).

Cottages and other buildings that are sporadically heated will have a lower indoor Freezing Index depending on the length of the heating period. However one must be very careful before reducing F_d because a few short heating periods in the winter can, in practice, have little influence on the design requirements.

TABLE 23

Maximum frost heave (mm)			
	Maximum frost heave occurring on average one winter in a		
Design Freezing Index h °C	100 year period	10 year period	5 year period
F_{100}	-	-	-
F_{10}	10-20	-	-
F_5	30-40	20-30	-
F_2	40-50	30-40	10-20

(from 'Building Details', A 521.811)

In buildings where the inside temperature in the winter half of the year is never lower than $0^{o}C$, the 'Building Details' (A 521.111) state that there is no need for frost protection of the floor. For such buildings the foundation wall can be frost protected using F_{10} as the design value.

It is very important to note that the foundation wall and the outer walls of a building are always exposed to the outside climate irrespective of whether the frost load indoors on the floor is lower than outdoors or not.

FINLAND

In Finland F_{50} is usually chosen as the design Freezing Index for cold structures except in special cases. For example F_{20} may be used where structures can withstand some differential movement due to frost heave as in the case of buildings composed of wood or light aggregate.

For a particular locality in Finland the value of F_{50} is determined from Fig. 2 and a corresponding reduction factor is applied as obtained from Fig. 114. Use of a reduced F_d is a new procedure in Finnish design applying to cold structures and it allows for the insulating effect of snow cover which is practically always present in winter. This Finnish practice is significantly different from Norwegian design which does not take snow cover into account.

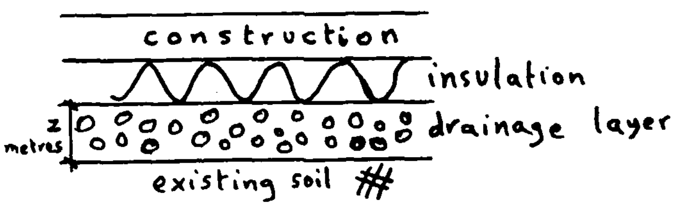
5.3 NECESSARY THERMAL INSULATION

Table 24 from the Frost I Jord project can be used to determine the least thermal resistance R_o of the insulation layer according to the design Freezing Index F_d and the Mean Annual Temperature MAT (Algaard, 1976). The values can be interpolated for intermediate magnitudes of F_d and MAT. The necessary thermal resistance R_o depends on the thickness and type

TABLE 24

Necessary thermal resistance R_o with frost insulation to prevent frost heave under cold insulated structures. R_o is a function of the design Freezing Index, Mean Annual temperature and type and thickness of frost-protecting layer between the insulation and frost-susceptible ground.

Design Freezing Index F_d h°C		10 000	20 000			30 000				40 000			50 000	
Mean Annual Temperature °C		(all)	2	3	4–7	1	2	3	4–6	1	2	3–4	1	2
Frost-protecting layer between insulation and underground Type	Thickness z,m	Insulation's minimum thermal resistance R_o, m^2K/W												
	0.1–0.2	0.8	1.6	1.4	1.2	3.2	2.6	2.2	2.0	4.2	3.5	2.8	(5.0)	(4.0)
GRAVEL	0.4	0.5	1.2	1.0	0.8	2.5	2.0	1.6	1.4	3.5	2.8	2.2	(4.0)	(3.2)
COARSE SAND	0.6	0.3	0.8	0.6	0.5	1.7	1.4	1.0	0.8	2.5	2.0	1.6	3.0	2.4
(ρ_d = 1700 kg/m^3)	0.8	0	0.6	0.4	0.3	1.4	1.1	0.8	0.7	2.1	1.6	1.3	2.5	1.9
(w = 8%)	1.0	0	0.4	0.3	0.2	1.0	0.7	0.6	0.5	1.6	1.2	1.0	1.8	1.4



(from Algaard, 1976)

of frost-protecting material placed between the insulation and the frost-susceptible soil below. A high water content in the protecting material gives a high contribution of freezing heat and will delay frost penetration. In Table 24 calculations have been based on the use of a layer of sand/gravel with a moisture content of 8% by weight. A drier layer of crushed stone would give a greater thickness requirement.

The given values for R_o will allow frost to penetrate a little into the frost-susceptible underlayer without giving rise to significant frost heave. The first line in Table 24, z = 0.1 - 0.2m, is used if there is only a draining or capillary breaking layer of minimum thickness under the insulation. With a drainage layer of larger thickness, the corresponding value of R_o can be found from Table 24 according to appropriate values of F_d and MAT.

5.3.1 Finnish guidelines

Based on Table 24, the Finnish guidelines propose the use of Table 25 which is similar but has an additional column corresponding to a Freezing Index of 60000h^{o}C and greater. Table 25 also has an additional row applying to the use of 1.5m thickness of non-frost-susceptible material. The Mean Annual Temperature for a Finnish locality is obtained from Fig. 7 and the design Freezing Index is the reduced value allowing for snow cover as explained in Section 5.2. The required thermal resistance R_o of the insulation can then be determined according to the chosen thickness of the non-frost-susceptible layer to be placed under it. The idea of using this layer is to prevent the 0^{o}C isotherm from penetrating further down into underlying frost-susceptible soil. The part of the insulation extending outside the foundation is the 'ground insulation' with a width 'b'.

TABLE 25

Thermal resistance of ground insulation
for protection of cold structures.

Design Freezing Index h °C	20 000			30 000				40 000			50 000		≥ 60 000
MAT °C	÷2	÷3	≥ ÷4	÷1	÷2	÷3	≥ ÷4	÷1	÷2	÷3 ... ÷4	÷1	÷2	0 ... ÷1
Thickness of non-frost-susceptible layer (below ground insulation) m	Ground insulation's Thermal resistance R_o m^2K/W												
0,2	1,6	1,4	1,2	3,2	2,6	2,2	1,8	(4,2)	3,5	2,8	x	(4,6)	x
0,4	1,4	1,1	0,8	2,6	2,1	1,7	1,4	3,5	2,8	2,2	(4,6)	3,8	x
0,6	1,0	0,7	0,5	2,1	1,7	1,3	1,0	2,6	2,2	1,6	3,8	2,9	(5,0)
0,8	0,6	0,4	0,3	1,7	1,3	1,0	0,7	2,2	1,6	1,3	2,9	2,2	3,8
1,0	0,4	0,3	0,2	1,3	1,0	0,7	0,5	1,6	1,2	1,0	2,2	1,7	2,8
1,5	0	0	0	0,8	0,6	0,4	0,2	1,0	0,7	0,5	1,4	1,0	1,8

X foundation depth should be increased.

( ) in general, increase of foundation depth is more profitable.

(Finnish guidelines, 1987)

Having found the required thermal resistance of the ground insulation from Table 25 and knowing its thermal conductivity, its necessary thickness can be determined. The required width 'b' of this ground insulation is then found from Fig. 115 depending on the depth of the insulation below the ground surface and the design Freezing Index. Fig. 116 shows typical examples of the positioning of ground insulation, determined as above, to protect a slab, a foundation wall and a column or pier.

Ground insulation must always be located over a layer of non-frost-susceptible material with a thickness of at least 0.2m. This drainage layer protects the overlying insulation material against capillary flow from the ground below and tends to keep the frost front a relatively long period in non-frost-susceptible material, thus smoothing and reducing frost heave outside the foundation perimeter (Saarelainen, 1988).

The effect on the calculated temperature distribution of placing insulation at different locations is shown in Fig. 117. In the upper illustration 0.34m of sand underlies the foundation wall whereas in the lower case insulation is placed directly below the wall with 0.2m of sand underlying. The $0^{o}C$ isotherm has a more favorable (i.e. higher) location in the latter case because of the position of the insulation. Had the foundation wall been composed of expanded clay aggregate instead of concrete, the upper case would have been satisfactory because of the higher thermal resistance of the light aggregate material.

Ground insulation as shown in Fig. 117 can consist of insulation material like a board of extruded polystyrene or of a light gravel layer (composed of expanded clay aggregate) of such a thickness as to give an equivalent thermal resistance R_o. If a polystyrene insulation board is used, it is first laid on a drainage bed and then covered with a protective layer of sand, for example. To prevent surface runoff from getting to the insulation, the ground surface should be sloped away and covered with a soil

5.3.2 Norwegian 'Building Details'

The design process developed in the Frost I Jord project was taken a step further by the Norwegian 'Building Details' (A 521.811) which gives required thicknesses of expanded polystyrene insulation and underlying drainage layer (Table 26). Various combinations of thicknesses of these layers have an equivalent effect and may be used corresponding to a particular design Freezing Index and Mean Annual Temperature. The specification is that frost protection can be carried out with thermal insulation, a combination of thermal insulation and an underlying layer of drainage material that is not frost-susceptible, or with coarse drainage material alone. Under a floor there must always be a drainage layer with at least 100mm thickness (Fig. 118) consisting of coarse gravel or crushed stone. Such a layer should also be laid under mineral wool used as ground insulation.

Table 26 gives the inter-related thicknesses with expanded polystyrene as insulation. If another insulation material is used, the insulation thickness from this table is multiplied by the appropriate correction factor from Table 27, which also indicates the necessary moisture protection requirements. With use of extruded polystyrene, such as 'styrofoam', the necessary insulation thickness may also be found directly from Fig. 136 as a function of the design (air) Freezing Index and Mean Annual Temperature.

Under favorable snow conditions, a snow cover outside a cold building will give a thermal insulation effect. In practice, however, it would be highly uncertain what thickness of snow to use in calculations. Therefore, according to the 'Building Details', no allowance should be made for snow in design of frost protection for cold buildings.

TABLE 26

Frost protection with expanded polystyrene and underlying drainage material

Design Freezing Index h °C	Mean Annual Temp. °C	Necessary layer, given in m of drainage material under insulation of expanded polystyrene in the following thicknesses (given in mm) $\boxed{0}$	40	50	$\boxed{60}$	80	$\boxed{100}$	120	150 insulation
	1 drainage layer	0,6	0						
3000 and less	3	0,5	0						
	5	0,4	0						
	7	0,4	0						
	1	0,8	0						
5 000	3	0,7	0						
	5	0,6	0						
	7	0,5	0						
	1	1,2	0,1	0					
10 000	3	1,1	0						
	5	0,9	0						
	7	0,8	0						
	1	1,9	0,8	0,6	0,5	0,3	0,1	0	
20 000	3	1,6	0,4	0,3	0,2	0			
	5	1,4	0,3	0,2	0,1	0			
	7	1,3	0,2	0,1	0				
	1	2,3	1,2	1,1	0,9	0,7	0,4	0,3	0,1
$\boxed{30\ 000}$	3	1,9	0,8	0,7	0,6	0,3	0,1	0	
	$\boxed{5}$	$\boxed{1,8}$	0,7	0,6	$\boxed{0,4}$	0,2	$\boxed{0}$		
	7	1,7	0,6	0,5	0,3	0,1	0		
	1	2,6	1,5	1,3	1,2	0,9	0,7	0,5	0,4
40 000	3	2,2	1,2	1,0	0,9	0,6	0,4	0,3	0,1
	5	2,1	1,1	0,9	0,8	0,5	0,3	0,2	0
50 000	1	2,8	1,7	1,5	1,4	1,1	0,9	0,7	0,6
	3	2,6	1,5	1,3	1,2	0,9	0,7	0,5	0,4

Example: For a Freezing Index of 30000 h°C and MAT of 5°C one can obtain frost protection with, for example:

(a) 1.8m drainage material

(b) 60mm polystyrene and 0.4m drainage material

(c) 100mm polystyrene

See the framed values in the Table

(from 'Building Details', A 521.811)

TABLE 27. Correction factor for insulation thickness given in Table 26 with use of other insulation materials. Necessary moisture-protection of the insulation is also shown.
(from 'Building Details', A 521.811)

Insulation material	Insulation thickness in Table 26 multiplied by	Moisture protection
Extruded polystyrene	0.85	None
Expanded polystyrene Density 20 Kg/m^3 Density 30 Kg/m^3	 1.4 1.0 (basis)	 Overlying plastic film
Mineral wool Density at least 150 Kg/m^3	 2.0	 0.1m thick drainage layer
Light aggregate	3.5	Wrapped in plastic bag

Insulated floor and foundation wall

The floor and foundation wall in unheated buildings must be frost-protected if frost heave cannot be tolerated. Figures 119 to 124 give examples of frost protection which consists of thermal insulation and an underlying layer of drainage material. These must be extended over a distance 'b' beyond the foundation wall. Table 28 gives values of 'b' depending on the maximum Freezing Index F_{100}. It is very important that no frost-susceptible material is placed within the foundation wall area. At an exterior corner. extra insulation must be provided as shown in Fig. 125.

TABLE 28

Necessary insulation width outside a foundation wall

Maximum Freezing Index h ^oC	10000	20000	30000	40000	50000	60000
Necessary insulation width outside foundation wall b. metres	0.50	0.75	1.00	1.25	1.50	1.50

If some frost penetration in the floor can be allowed, the foundation wall would be exposed to frost from the inside as well as from the outside. The insulation thickness calculated for the outside of the foundation wall, must then also be extended a distance 'b' in towards the floor (Algaard. 1976). If frost penetration in the floor is large, the rules given in the following section for insulation of a foundation wall should be followed because conditions would then approach those for a 'strip' foundation.

In buildings where the inside temperature in the winter half of the year is always above 0°C, the 'Building Details' allow no frost protection of the floor as shown in Fig. 126. The required width 'b' of insulation outside the foundation wall and the extra insulation at the corner are found from Table 28. The thickness of the insulation and underlying drainage layer are designed according to Table 26 using F_{10}. To avoid condensation on the floor at the outer wall, any cold bridge effect between the floor and the foundation wall should be broken by insulation.

Care must be taken that no cold bridges are formed such as illustrated in Figs. 127 and 128. The insulation must form a continuous layer over or under both floor and foundation without any cold bridges that can give local frost penetration (Algaard, 1976).

There must be adequate protection for an unheated part, or large unheated room, of an otherwise heated building or of a small unheated room in an external corner of such a building. If the inside temperature in such an unheated room can be lower than $0^{o}C$, it should be frost-protected according to Table 28 and its associated requirements, with the possibility of omitting the floor insulation as in Fig. 126.

If the floor in a heated room lies higher than 0.6m over outside ground, the foundation wall should be protected as in Fig. 126 and the floor insulation designed as for heated buildings.

Insulating wall foundations

In the case of a foundation which is less than 4m in width, there will be appreciable heat loss towards the sides as well as in the vertical direction. The necessary width of insulation is then larger and found from Table 29. At a corner the insulation width is even greater (Table 30) corresponding with the value for a column or 'point' foundation (Algaard, 1976).

The 'Building Details' specify that where a floor can accept frost heave, i.e., there is a small tolerance demand, it is sufficient to insulate the foundation for the outer walls, and for any inner walls, with no floor insulation being necessary. This can be the case in structures with a gravel floor and also in those with an asphaltic floor when the ground is not particularly frost-susceptible. This is also the case with foundations for 'levegger' (shelter walls) and atrium walls, groundwall strips as in 'open foundations' (Chapter 6), foundation walls with crawl spaces for unheated buildings, foundations for small shacks, garages, etc.

Figures 129 to 131 show examples of frost protection of wall or 'strip' foundations. Table 29 gives the necessary width 'b' of insulation outside the foundation while Fig. 132 shows how a corner should be insulated. The thicknesses of insulation and drainage layer are designed according to Table 26 and its associated directions (usually using F_{100}).

TABLE 29
Necessary insulation width for protection of a foundation wall

Maximum Freezing Index h^oC	10000	20000	30000	40000	50000	60000
Necessary insulation width b on each side of foundation wall in metres	0.50	0.75	1.00	1.50	2.00	2.50

This foundation method is thus appropriate when a foundation wall is to be frost-protected, leaving the floor uninsulated or where a building has a free-bearing insulated floor on groundwall strips bearing on frost-susceptible soil. In the latter case, insulation is required between the strips and the underlying soil (Algaard, 1976).

Fig. 133 shows alternative treatments of a retaining wall. Where part of the backfill material is frost-susceptible, a vertical insulation layer of thickness d is required behind the wall as well as a minimum thickness of 100mm of drainage material. The extruded polystyrene insulation ('styrofoam') under the wall need only be extended a reduced distance b' beyond the inner edge of the footing such that the sum of the breadth and height from free air to the foundation is equal to the place's frost depth in sand and gravel (from Fig. 8).

Insulating 'point' foundations

In the case of a cold building with an uninsulated floor, a 'point' or column foundation must be specially frost-protected. The same applies to a heated or cold building with an 'open' foundation (free-bearing floor) on piers and to small unheated structures, such as shacks, with width less than 4m. Column foundations or piers can be frost-protected as shown in Figs. 134 and 135. The 'Building Details' give Table 30 showing the distance 'b' the insulation must be extended outside the foundation area and around it.

TABLE 30

Necessary insulation width for protection of a column foundation

Maximum Freezing Index h°C	10000	20000	30000	40000	50000	60000
Necessary insulation width b outside foundation in metres	0.75	1.10	1.50	2.25	3.00	3.75

The width and thickness of insulation and the thickness of drainage layer are designed according to Table 26 and associated guidelines. As compared with Table 29 for strip foundations, Table 30 specifies 50% more insulation width owing to the small amount of 'soil heat' stored under column insulation as compared to heat loss along the periphery of a column foundation. Frost protection of column foundations requires disproportionately more insulation, especially in colder regions. It often pays to frost protect a column or row of columns with a continuous horizontal insulation area as for wall foundations.

The minimum thickness of 'styrofoam' insulation can be found from Fig. 136. F_{100} is used for permanent structures but, for less critical structures, a smaller insulation thickness may be used corresponding to a lower F_d.

5.3.3 Cold part or projection of a structure

Cold parts of, or adjuncts to, heated structures require special treatment, because of their tendency for differential movement (e.g. Fig. 137). The cold part or adjunct can be allowed separate freedom of movement or frost protected adequately.

The Swedish Building Standards SBN 80 specifies that, for part of a construction outside an external wall, the foundation depth, applying to a foundation with a crawl space or basement, should be increased by a distance between the extremity of the part concerned and the outer face of the external wall.

According to the Finnish guidelines, foundations for cold parts or projections of an otherwise heated structure can be thermally insulated as shown in Section A-A of Fig. 138. This can apply to cases such as a foundation wall extension, an exterior staircase, a column supporting a balcony, a porch, an unheated garage etc. The design Freezing Index is chosen to be F_{50} as for 'cold' structures in Finland.

Insulation of the following auxiliary cold constructions is described in the Norwegian 'Building Details' (A 521.811).

An exterior staircase for a basement

At an outside staircase for a basement, one should insulate under the whole staircase and up along the staircase wall on the outside against earth fill. There can additionally be horizontal insulation outside the top of the staircase corner as shown in Fig. 139. The breadth 'b' of the insulation is obtained from Table 29 and the thicknesses of the insulation and drainage layer are designed according to Table 26.

The ground slope may be utilized instead of a staircase wall, extending the insulation layer under the staircase base 1 m outside the base.

An entrance staircase

A foundation for an entrance staircase can be frost protected as shown in Fig. 140, with an insulation width 'b' as given by Table 29. The thicknesses of the insulation and drainage layer are designed with the help of Table 26. Such a 'cold' adjunct to a heated building must be suitably frost protected if the adjunct is 'tied' to the building as in this illustration.

Closed-in entrance

Fig. 141 shows frost protection of a closed-in entrance area. The width of insulation is obtained from Table 29, and the thicknesses of insulation and drainage layer are designed using Table 26.

A garage ramp

At a garage entrance, the foundation must be frost protected as shown in Figs. 142 and 143. The insulation width 'b' is given in Table 29 and is extended 1m beyond the garage door on each side. The thicknesses of the insulation and drainage layer are designed according to Table 26. Beyond the end of the insulation, a marked swelling due to frost will appear in the ramp. This can be smoothed out by the use of, for example, a layer of loose light aggregate over a distance of a couple of metres beyond the insulation. The thickness of this layer should decrease uniformly from 200mm, for example, to zero. Alternatively the thickness of the insulation can be reduced.

5.4 VARIABLE HEAT/COLD BUILDINGS

For buildings that are only sporadically heated (assembly halls, cabins, outhouses, etc.) or that may later be permanently heated, the floor and foundation wall may be designed according to the requirements for floor temperature in the case of heated buildings. The connection between the floor and foundation wall should not form a cold bridge and vertical insulation is required on the outside or inside of a foundation wall.

Figs. 144a and 144b show design types that are suited both for heated and cold buildings, giving acceptable floor temperatures in heated buildings when the floor and foundation wall insulation are designed according to Chapter 3. Fig. 144c is satisfactory with regard to frost penetration but unsuitable for heated buildings without vertical foundation wall insulation. Heating cables may be necessary as a supplement.

6. DESIGN WITH OPEN FOUNDATIONS

Foundations are considered 'open' when there is free air circulation under the building. This section considers open foundation design using groundwall strips, piles or piers. Open foundation methods involve little interference with the existing terrain and drainage provisions are unnecessary. They can be used with practically all terrain and ground conditions but are especially suitable in hilly ground (Fig. 145). The free distance between the ground and the building's floor structure should be at least 300 mm. At the entrance to a building, water and sewer pipes must be frost-free ('Building Details' A 521.304).

6.1 BACKGROUND FROM FROST I JORD PROJECT (Torgersen, 1976)

There is no special problem from moisture under the floor structure (wood frame) of a basement but the floor should be insulated especially well. The recommended U-values for the floor structure are shown in Fig. 146 to give a surface temperature of the floor equal to 17.5°C. They depend on a design outside temperature equal to the lowest average temperature in a three day period, i.e., the lowest average temperature for three successive days found from meteorological data in a 30-year period.

The foundation should be extended to the minimum frost-free depth or to bedrock if it is not placed on insulation according to the directions given in Chapter 5. The foundation should be protected against frost uplift due to sidegrip and the building's side stability should be checked.

6.1.1 Frost damage

In frost-susceptible soil there are two possible causes of frost damage with open foundations, i.e. frost under the foundation and sidegrip (Fig. 147).

Frost under the foundation

Frost penetrates under the foundation and the ice lenses formed exert upward heave forces. As mentioned this can be prevented by placing insulation under the foundation or by extending the foundation to the frost-free depth.

Sidegrip

Although there may be no frost under the foundation, soil can freeze firmly on the foundation's side surface and this sidegrip gives a lifting force. If this force is greater than the load from the building, the foundation must be anchored under the frost zone. The anchoring can be achieved by expanding the cross-sectional area of the foundation with a larger footing under the frost zone (in the case of a groundwall strip or pier, Fig. 148). It is also possible to extend the foundation under the frost zone so that friction between the foundation and the soil gives sufficient anchoring (in the case of a pile). Also the sidegrip can in certain cases be reduced by coating the side surface in the frost zone with bitumen or epoxy.

Lifting forces from sidegrip increase with the Freezing Index but not proportionally. The maximum lifting force acts in the period when the outside temperature is decreasing most rapidly. The force usually increases with increasing diameter of pier and frost depth but there is no direct proportionality. The maximum lifting force does not necessarily act when the frost depth is a maximum.

Based on the report of Andresen (1975), Table 16 gives guidelines for the lifting force from sidegrip on piles or piers in dry crust clay. The values represent the lifting force in KN per pile or pier (or KN per metre of concrete wall) depending on the design Freezing Index which in Norway is chosen as F_{100}. In a silt soil the lifting force is estimated to be about half the given values for a Freezing Index of 10000h^{o}C and one third for a Freezing Index of 50000h^{o}C. With use of a coating of bitumen (at least 2mm) or epoxy on the pile or pier, the values in Table 16 may be reduced by 40% if there is dry material in the frost zone. For silt soils it is doubtful whether bitumen protection has some effect because of the large rate of heave and epoxy should be used in such a case.

6.1.2 Groundwall strips

Groundwall strips are well suited where the ground is not frost-susceptible. A house or building is founded on groundwall strips under the load-bearing walls along its longer side (Fig. 149). On firm ground that is not frost-susceptible, the groundwall strips are extended 0.3-0.5m under the ground.

In frost-susceptible soil the strips must be placed on insulation (designed according to Tables 26 and 29) at a depth of 0.3-0.4m or extended down to the frost-free depth (or to rock). In the latter case the foundation must be anchored against sidegrip when the lifting force is greater than the load from the building. It could then be more advantageous to use piers or piles.

6.1.3 Piles

Bored piles can be used instead of piers. Boring can be done quickly and cheaply with a special boring rig in cohesive soil without large stones. It is possible to bore in frozen ground in winter and the piles can be cast in place.

Driven piles for a small house are generally costly and seldom used. However in certain cases where the depth to bearing ground was larger than 3-4 m, driven piles were used instead of piers.

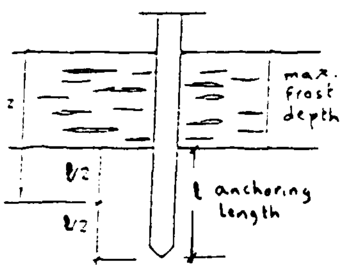
Piles must be anchored against lifting forces arising from frost sidegrip. It is usual to extend piles to such a distance below the frost-free depth that friction between the pile and surrounding soil gives sufficient anchoring. The reduced lifting force is determined by subtracting the load carried by the pile from the lifting force. Table 31 gives values of friction in different soils for calculating the anchoring effect. The reduced lifting force divided by the friction and the pile's circumference gives the necessary anchoring length under the frost-free depth.

TABLE 31.

Friction between a pile and the under the frost zone.

(z is given in metres)

(from Torgersen, 1976).



Soil	Friction kN/m^2
Very wet clay	50 - 125
wet clay	125 - 250
medium stiff clay to dry crust clay	250
silt (frost-susceptible friction material)	40(z) (z is shown in sketch)

6.1.4 Piers

Each pier should carry approximately the same load from the house. A pier can be cast in place or a prefabricated pier placed in an excavated hole that is later backfilled. To get a good anchoring effect, material that can be well compacted should be used as backfill, e.g., dry crust, sand, gravel or moraine material.

A pier's footing must be so large that its share of the load from the house can be conveyed to the underlying ground without the allowable bearing pressure being exceeded. The self weight of the pier should be included in the pier load. Using this and the allowable bearing pressure of the ground, the pier dimension b can be found from Fig. 150.

If the ground is frost-susceptible, one must then check that the pier is not lifted by sidegrip. The appropriate value for the lifting force is obtained from Table 16 and this is reduced by the total pier load. Fig. 151 may then be used to determine the necessary footing area depending on the locality's maximum frost penetration and the reduced lifting force.

Apart from increasing the footing area, other measures that can be taken in designing against sidegrip are:

(1) to smear the pier with bitumen or epoxy to decrease the lifting force,

(2) to reduce the number of piers so that a pier's share of the total load increases and this also requires a larger footing area.

As the pier is anchored against sidegrip, it has to withstand a tensile force equivalent to the reduced lifting force. The pier reinforcement is anchored in the footing. The latter is designed for a uniformly distributed stress equivalent to the reduced lifting force divided by the footing area (minus the pier's cross-section) giving the necessary reinforcement in the footing's upper edge. Reinforcement is also necessary at the bottom edge of the footing to take the uniformly distributed bearing pressure.

6.2 'BUILDING DETAILS' GUIDELINES FOR CONCRETE PIERS

The Norwegian 'Building Details' (A 521.304) shows mainly cast-in-place piers but also applies in principle to prefabricated piers.

Practical details

The hole for the pier and optional footing foundation must be dug down to rock or other ground with good bearing capacity at frost-free depth. The side stability of a pier depends on proper compaction of the backfill material around it. In the case where frost-susceptible soil exists giving sidegrip, it is particularly important that the backfill material over the pier footing is well compacted (Fig. 152). This necessitates the use of crushed rock, sand, gravel, etc.

In frost-susceptible soil, the 'Building Details' specifies that a lubricating coat at least 3mm thick should be applied on a pier's surface under the ground down to the frost-free depth. This coat can consist of bitumen with a penetration of 80-100 or of epoxy resin-paint. The latter should be used in silty soil. The long term effect of such lubrication is little known.

On flat sites the ground under the house should be elevated in relation to the outside level and a grade should be formed sloping away from the house to lead surface water away (Fig. 153).

Wind load on the house must be transferred to the ground. This requires the floor structure and walls to be anchored to the beams that are in turn anchored to the piers and footings. (Fig. 154).

Design

Load distribution over the pier depends on the distance between the piers, the distance between the pier rows and whether the structure on top is free-bearing or not. The distance between piers should be so large that the ground pressure is allowable and reasonable beam dimensions are obtained. Placing piers under bearing walls as shown in Fig. 155 gives approximately the same load in each pier.

For design against sidegrip, Table 32 is proposed by the 'Building Details' to obtain the necessary size of a pier footing. The design load is the 'specific load', i.e., the load carried by a pier including its self-weight. Table 32 applies to piers with diameter of 350mm and less. It gives the width for a square footing in metres.

In addition a footing must be designed to take the net upward force that is equivalent to the difference between the upward force on the unloaded pier and the apparent specific load of the pier. The pier must also be designed for such a tensile force.

If the pier is smeared with bitumen or epoxy, the values in Table 32 for the lifting force from sidegrip on the unloaded pier are divided by 2.

Example of design with Table 32

Without lubricant coating on pier

F = 30000 $h^{o}C$
Specific load = 30 KN gives a pier footing 0.85m x 0.85m (Table 32), and a lifting force on the unloaded pier of 80 KN
Net lifting force = 80 - 30 = 50 KN

With lubricant

F = 30000 $h^{o}C$
Specific load = 30 KN
Lifting force from sidegrip is halved = 80/2 = 40 KN
Net upward force becomes 40 - 30 = 10 KN
This equals a specific load of 70 KN without lubricant because the net upward force is 80 - 70 = 10 KN (Table 32 applies to piers without lubricant)
F = 30000 $h^{o}C$, specific load = 70 KN giving a footing of 0.50 m x 0.50 m (Table 32).

TABLE 32

Necessary size in metres of square pier footing for anchoring against frost sidegrip

Design Freezing Index	Frost-free Depth	Lifting Force on Unloaded column	Specific load kN									
h °C	m	kN	0	10	20	30	40	50	60	70	80	90
10 000	1,0	30	0.85	0.70	0.55							
20 000	1.5	60	1.00	0.95	0,85	0,75	0,65	0.50				
30 000	2.0	80	1.05	1.00	0.95	0,85	0,80	0,70	0.60	0.50		
40 000	2.5	90	1.00	0.95	0.95	0.85	0,80	0.75	0.60	0.55	0.50	
50 000	3.0	100	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.60	0.55	0.45

(from "Building Details', A 521.304)

7. FROST PROTECTION DURING WINTER CONSTRUCTION

7.1 INTRODUCTION

For economic and other reasons, building operations cannot be limited to the summer half of the year. Construction needs to take place over the winter period in spite of the considerable extra cost owing to snow clearance, the need to thaw frozen soil, frost protection of building ground and construction, heating of concrete, etc. A log book should be kept noting each working day's highest and lowest temperature, precipitation and any frost protection that has been carried out or changed (Eriksson et al, 1985).

Winter construction entails the most severe problems because there is no heat contribution from the inside of a building and the construction is 'open' and exposed to the climate. Most frost damages have occurred in the building period and frost protection of foundations during this period is essential to hinder frost heave in the building ground and under the floor and foundations of a building. Structures with vertical walls (e.g., basement wall, buttressed wall, etc.) can be damaged from horizontal frost forces and the soil directly outside these must be kept free from horizontally advancing frost (Fig. 156). It is also necessary to limit frost penetration in excavated and fill material. Fill should not be mixed with snow and ice lumps since these can melt later and lead to large settlement.

If the building ground is frost-susceptible and the construction can be damaged by frost,then the ground under the construction must be kept frost free to prevent damage from frost heave or from settlement after frozen soil melts. To protect against frost damage one possible measure is to replace frost-susceptible soil with material that is not frost-susceptible but this could be costly and is feasible if there is also another motivation such as having to backfill behind walls. The common protection measure is to reduce the 'frost load' on the ground and the construction by covering with insulation. This may be combined with an artificial heat supply if economically justified.

An insulated floor will often be able to prevent frost in the underlying frost-susceptible soil, especially in a relatively mild area but in colder regions insulation of the floor and foundation wall have to be increased. Also, depending on the climate, horizontal ground insulation may have to be laid under a foundation wall and up to a certain distance outside it.

A slab-on-grade that is adequately insulated with ground insulation under and outside a foundation wall and that is built before frost comes, can spend the winter without other special frost protection measures such that construction can continue at any time in the winter half of the year. It often requires only a relatively small increase in insulation to give frost protection in the construction period. Frost protection of a floor and foundation wall based on insulation and cover on the top side of the floor increases the cost and is not very suitable when the building is being built, i.e., if the construction is in progress ('Building Details' A 521.111).

7.2 DESIGN FREEZING INDEX

One is usually concerned with frost protection for one winter season or perhaps part of a season. 'Cold' constructions that must be protected for more than a couple of winters require insulation as for permanently unheated buildings (Chapter 5).

The design Freezing Index, F_d, is less than for a permanent structure and can vary considerably depending on the protection objective and the consequences of underdesign. Generally frost protection of foundations and stiff floor constructions requires a larger safety factor than frost protection of excavated and fill materials. For foundations and 'slab-on-grade', F_d is chosen as F_5 but can be increased to F_{10} if the consequences of possible frost heave are larger. Possible snow during construction can give considerable extra safety. Under exceptional conditions F_2 can be used, e.g., when the consequences of frost heave are small or the soil is only a little frost-susceptible.

If frost protection is to take place only for part of a winter, F_d can be chosen to equal the Freezing Index over that actual period. This has to be estimated for a particular locality and one should allow for a three week uncertainty as to the beginning or end of the frost season. The partial design Freezing Index is estimated from Fig. 157 or similar.

7.3 NECESSARY THERMAL INSULATION

Foundations and groundwalls must be adequately insulated if backfilling is not carried out right away. Basement walls and other vertical boundaries against soil can also be strongly exposed to frost damage in the building period and should be frost protected.

Frost I Jord project

According to the Frost I Jord project (Algaard 1976) the problem can be tackled in two ways:

(1) the construction is covered with the necessary additional insulation no later than the beginning of the frost season.

(2) the construction is carried out with a sufficiently thick general insulation layer.

In each procedure all sections of the construction must be checked so that the thermal resistance R of the insulation is everywhere larger than the necessary thermal resistance R_o. If the construction is provided with an inbuilt insulation layer (i.e. as a fixed component) placed a sufficient time before the frost season starts, R_o can be found by the same method as for unheated buildings from Table 24 depending on F_d, MAT and the thickness of the underlying drainage layer. If this thickness varies at different sections, one must take that into account to achieve the minimum thermal resistance required.

If a construction is not adequately insulated and is to be covered with insulation when winter begins, some of the heat content in the soil would already have been lost and the insulation requirement to hinder frost penetration becomes somewhat larger than otherwise. R_o values are then determined from Table 33 depending on F_d, MAT and the allowable frost depth in the underlying layer.

For an insulated foundation and floor construction, the additional insulation ΔR necessary for winter cover is found by subtracting the existing thermal resistance R_e from the necessary value R_o:

$$\Delta R = R_o - R_e \quad m^2K/W$$

One should be specially aware that a foundation wall and floor are often planned with different thermal resistances R_e and that R_e also can vary for different parts of the floor. The winter covering must then be adjusted such that the sum of the effective thermal resistances is always larger or equal to the necessary R_o from Table 24 or Table 33.

In the case of a construction consisting of both insulated and uninsulated areas against frost-susceptible soil, the winter cover for its uninsulated part should as a rule be determined on the basis of the R_o value from Table 33.

Floors and foundations for heated buildings are designed to have a certain border insulation along the foundation wall and a certain floor insulation for the outer and inner fields of the floor (Chapter 3). The inside part of the floor can be uninsulated but it is usually given the same insulation as the outer or inner field. In colder regions, a foundation

TABLE 33.

Necessary thermal resistance R_o with frost insulation for winter covering of uninsulated construction and building ground. The table assumes that the insulation is placed no later than the beginning of the frost season.

Design Freezing Index F_{dim} h°C		10 000	20 000				30 000				40 000		
Mean Annual Temperature °C		(all)	1.0	2.0	3.0	4–7	1.0	2.0	3.0	4–6	1.0	2.0	3–4
SOIL	Allowable frost depth m	Insulation's minimum thermal resistance R_o, m^2K/W											
CLAY, SILT	0.1	1.0	2.5	2.2	2.0	1.8	3.8	3.5	3.3	3.0	–	–	5.0
(ρ_d = 1500 kg/m³)	0.3	0.6	1.4	1.2	1.1	1.0	2.4	2.0	1.7	1.5	3.5	3.2	3.0
(w = 20%)	0.5	0.3	0.9	0.7	0.6	0.5	1.4	1.2	1.1	1.0	2.0	1.8	1.6
SAND, GRAVEL	0.1	1.5	3.9	3.2	2.8	2.5	6.0	4.8	4.3	4.0	–	–	–
(ρ_d = 1700 kg/m³)	0.3	1.0	2.8	2.3	2.0	1.8	4.5	3.6	3.0	2.8	–	4.8	4.0
(w = 8%)	0.5	0.5	2.2	1.6	1.3	1.2	3.3	2.7	2.2	2.0	4.5	3.8	3.0

(from Algaard, 1976)

wall must additionally be frost protected with horizontal outside ground insulation if a reduced foundation depth is to be used. Such a slab-on-grade construction that is exposed to frost in the building period should be designed against frost penetration and frost heave during this period:

(1) The necessary thermal resistance R_o is found from Table 24 for the insulated part of the floor and for the foundation wall. If large parts of the floor are uninsulated, Table 33 is used for these.

(2) The necessary width of insulation outside the floor and that outside the foundation wall are determined from Table 28 and Table 29 respectively.

(3) The difference ΔR between the necessary thermal resistance R_o and the existing thermal resistance R_e is calculated for all sections.

(4) The necessary type and thickness of the additional insulation is determined according to the ΔR required.

If it is likely that the foundation and floor construction will remain unheated over the winter, it is often cheaper to design them so that winter cover becomes unnecessary. This requires that:

(1) the insulation in the floor and with the foundation provides everywhere a thermal resistance at least equal to R_o from Table 24.

(2) the insulation is continuous in the floor and over/under the foundation extending a distance 'b' outside the outer edge of the construction (according to Table 28, 29 or 30 depending on the type of foundation).

If the second requirement is fulfilled, the thermal resistance as required in the use situation for the foundation wall and floor (according to Chapter 3) will be sufficient to fulfill the first requirement for the greatest part of Norway. This is because, among other things, the design Freezing Index for frost protection in the building period (F_5 or F_{10}) is lower than for the use situation (F_{100}).

Compared with insulation under a concrete slab of a building, for example, special care is required to protect a separate insulation used as winter cover which could otherwise be ruined. In planning a construction it is important, therefore, that thought be given to conditions during winter building. It can be more economical to lay in extra insulation permanently in the structure in preference to using separate winter cover with its attendant trouble and risk.

There is often a high cost of making up 'winter material' for covering floors and foundations. In Norway there is a good supply of natural insulation materials that can give reasonable frost protection such as straw, chips, etc., but these materials are bulky and need later to be removed. Snow cover gives an uncertain frost protection and should only be used outside the foundation and floor.

<u>Finnish guidelines</u> (1987)

In Finland the guidelines propose Table 34 for determining the necessary thermal resistance R_o of ground insulation to be applied for protection of a construction. This insulation must be applied no later than the beginning of the frost period and it depends on the design Freezing Index, the Mean Annual Temperature and the allowable frost penetration in the particular soil type below the insulation. Table 34 is based on the Frost I Jord project (Table 33) with extra values added for Finnish conditions corresponding to a Freezing Index of 50000 h^oC. Another difference is that the Finnish Table recommends an increase in the foundation depth where there is a cross or bracket.

TABLE 34

Thermal resistance of insulation
for protection of building ground
(It is assumed that the insulation
is placed no later than the start
of the frost season).

Design Freezing Index K°C		10000	20000				30000				40000			50000	
MAT °C		any temp.	-1	-2	-3	≥-4	-1	-2	-3	≥-4	-1	-2	≥-3	-1	-2
Soil	Allowable Frost depth m	Ground insulation's Thermal resistance R_o m^2K/W													
clay silt w = 20%	0.1	1.0	2.5	2.2	2.0	1.8	3.8	3.5	3.3	3.0	x	x	(5.0)	x	x
	0.3	0.6	1.4	1.2	1.1	1.0	2.4	2.0	1.7	1.5	3.5	3.2	3.0	(5.0)	(4.6)
	0.5	0.3	0.9	0.7	0.6	0.5	1.4	1.2	1.1	1.0	2.0	1.8	1.6	2.9	2.7
sand gravel w = 8%	0.1	1.5	3.9	3.2	2.8	2.5	x	(4.8)	(4.3)	4.0	x	x	x	x	x
	0.3	1.0	2.8	2.3	2.0	1.8	(4.5)	3.6	3.0	2.8	x	(4.8)	4.0	x	x
	0.5	0.6	2.2	1.6	1.3	1.2	3.3	2.7	2.2	2.0	(4.5)	3.8	3.0	x	(5.0)

X foundation depth should be increased

( ) in general, increase of foundation depth is more profitable.

(Finnish guidelines, 1987)

Norwegian 'Building Details'

The 'Building Details' (A 521.111) specify frost protection by thermal insulation and optionally an underlying layer of free-draining material. Under the floor construction there should always be a layer of draining material of at least 100mm. In practice a considerably thicker layer is often used.

Fig. 158 shows the necessary thickness if the insulation used is expanded polystyrene with a density of $30Kg/m^3$ and a thermal conductivity of 0.045W/mK. This aplies to a foundation such as shown in Fig. 159. For extruded polystyrene the given thickness should be multiplied by 0.73 and for mineral wool by 1.45. A board of mineral wool must be laid on a permeable underlayer and must not be laid under the foundation wall or other parts of the foundation.

The insulation thickness in Fig. 158 can be reduced if there is a drainage layer of sand, gravel or crushed stone under the construction. This can be considered to justify an approximate reduction of 10mm of expanded polystyrene per 100mm of drainage layer. Fig. 159 shows the inter-related thicknesses of insulation (t) and drainage layer (d) at different places in the construction. The necessary width, 'b', of the ground insulation outside the foundation wall, shown in Fig. 159, is given in Table 35.

TABLE 35

Necessary insulation width (b) outside the foundation wall

Design Freezing Index h°C	10000	20000	30000	40000	50000	60000
Necessary insulation width outside the foundation wall b, in metres	0.50	0.75	1.00	1.25	1.50	1.50

7.4 SOME PRACTICAL MEASURES (Thue, 1972)

It is generally more favorable to proceed with both digging and foundation work before the frost period and then arrange for effective covering until the construction work is taken up again. Once a basement wall has been finished, it should be protected against sidegrip, horizontal frost forces and freezing under the foundation. In general it will be necessary to insulate the basement floor either with loose, laid-on insulation or with insulation built in the floor. If one is not going to backfill outside the wall, insulation must be placed at the back of the wall.

A point that is often overlooked is that a concrete structure in soil with a high section exposed to the outside air, will act as a strong cold bridge. This could lead to the formation of ice lenses (with consequent heave) locally under a basement wall, for example, in spite of the construction being otherwise very well insulated. The effect of cold bridges can be eliminated by covering the wall or by bringing heat in to the critical zone. It would also be advantageous to draw the floor insulation some distance over the wall.

In the case of foundations at a reduced depth, the danger from sidegrip is small, but the risk from under-freezing is correspondingly large. Such constructions, especially a slab-on-grade, can be protected relatively easily by means of thermal insulation and possibly an artificial heat supply as well. If heating cables are used to supply extra heat, they can either be laid loosely under the insulation (and used again on another occasion) or cast near the bottom of the foundation where the heat supply is most necessary.

The slab-on-grade design shown in Fig. 160 has the advantage that the insulation gives protection during the whole of the construction period and continues to be used after the house is occupied. One must, of course, use insulation material that can withstand the loading from the foundation wall. The insulation must be extended outside the foundation wall and a cold bridge near the foundation-wall/floor/outer-wall connections must not be allowed to form.

Piers are usually taken down below the frost-free depth and built quickly. So there will seldom be problems with them in theory in the construction period if one backfills around them as quickly as possible (Fig. 161).

The materials used for covering the construction are generally mechanically weak and can be damaged by people and machines. The building site and protection measures utilized must be managed properly and additional protection supplied according to requirements to guarantee a sufficient safety factor. In particular the measures should be adjusted to the local climate and based on practical experience.

7.5 FROST PROTECTION OF BUILDING GROUND

Frost protection of building ground is carried out by use of insulation on the ground to keep it wholly or partly frost-free until excavation and/or building work can be carried out. Insulation hinders the loss of 'soil heat' and thus limits frost penetration. The allowable thickness of the frozen soil layer depends on the digging equipment. For equipment worked by hand the frozen material should not be thicker than 0.1 m, while with a digging machine the frozen layer can be 0.2 to 0.3 m thick.

Frost I Jord Project

The effect of insulation on frost penetration in the ground can be judged from the results of a computer analysis of the heat flow conditions (Thue, 1972). The calculations were done for the cold Oslo winter of 1965/66 assuming a silt with a moisture content of 30%. The $0^{o}C$ isotherm was computed at 3 time points i.e. January 20, February 9 and March 1 1966.

Fig. 162 represents the case of undisturbed ground with no insulation on it. Fig. 163 shows the considerable improvement in conditions when an insulation strip 9.20m wide is placed on the surface, with a thickness of 50mm and a thermal conductivity of 0.046W/mK. The result is a reduction in frost depth from about 1.0m to about 0.3-0.4m. It is also seen that the ground should be insulated about 1.0m outside the area it is desired to keep frost-free.

If the insulation thickness is increased from 50 to 100mm as in Fig. 164, there is only a small additional reduction in the frost depth. The analysis also showed that it is important to maintain the protection as long as possible while the winter work is going on, because removing the insulation results in a rapid frost penetration.

The necessary thermal resistance R_o of insulation cover can be determined from Table 33 according to the design Freezing Index and the Mean Annual Temperature. If the objective is to hinder frost heave, one calculates on the basis of a permitted frost penetration of about 0.1m down into frost-susceptible soil. In this case the first line in Table 33 corresponding to 'CLAY, SILT' is used, the insulation lying directly on the ground. If a layer of frost-protecting material is to be placed between the insulation and the ground underneath, R_o can be found from the section of Table 33 corresponding to 'SAND, GRAVEL' using the 'Allowable frost depth' as the effective layer thickness plus 0.2-0.3m (Algaard, 1976).

If the objective is to hinder too thick a frost layer, one uses the R_o value from Table 33 as read to the right of the frost depth that can be allowed in the actual soil. There may be large variations in the effective frost depth, and if there is a possibility of larger frost penetration than assumed, the insulation amount should be increased.

In order to get a frost layer that is thin enough to break with usual hand equipment, about 0.1m, one must choose the highest line for each soil type in Table 33. If heavy digging equipment is available, the frost layer thickness can be 0.3m and R_o becomes less.

Norwegian 'Building Details' (A 513.121)

In insulating ground before carrying out foundation work, the insulation thickness should be chosen so that the ground stays frost-free as much as possible. If the ground is not insulated, or is very badly insulated, the frozen soil layer can become so thick that special methods must be used if digging is to be done in the winter half of the year. These include boring and blasting, ripping up, use of ice breakers and thawing procedures.

Insulation must be laid out on the ground before the frost season begins, preferably before the daily average temperature stays, on the average, lower than the local Mean Annual Temperature. Otherwise frost would draw out a large amount of the available soil heat.

It is very important that ground operations are well planned so that the required protection is obtained. The insulated area must be closed to traffic so that the insulation is not damaged or comes out of place. The insulation must be protected against being blown off and against cold air blowing in. This can be accomplished by loading the insulation appropriately.

Table 36 gives values for the necessary insulation thickness of 'winter material' corresponding to various thicknesses of acceptable frozen crust. The winter material consists of impregnated mineral wool encapsulated in plastic foil. The foil holds the mineral wool in place and protects it against moisture that can reduce its insulation effect. The material is normally supplied in 30mm and 50mm thicknesses.

In place of winter material, loose dry straw may be used but with a thickness 2 to 5 times as large as that required for winter material. If the

TABLE 36.

Necessary insulation thickness with use of winter material

Design Freezing Index, h °C		5 000	10 000	20 000				30 000				40 000		
Place's Mean Annual Temp °C				4–7	3	2	1	4–6	3	2	1	3–4	2	1
Soil	Frozen crust thickness m	Necessary thickness of winter material* mm												
Sand, gravel	0,1	20	50	80	90	100	130	120	140	–	–	–	–	–
	0,3	10	30	60	70	80	100	100	110	130	–	160	–	–
	0,5	10	20	50	50	60	80	80	80	100	130	120	150	–
silt silty moraine	0,1	20	50	70	80	90	110	110	130	160	–	–	–	–
	0,3	10	30	50	60	70	80	80	90	110	150	–	–	–
	0,5	10	20	40	40	50	60	60	70	80	100	100	120	170
clay clayey moraine	0,1	20	40	60	60	70	80	100	110	120	140	170	200	–
	0,3	10	20	40	40	50	50	60	70	80	90	100	120	130
	0,5	0	10	30	30	40	40	50	50	60	60	70	80	90

Note: *Can consist of impregnated mineral wool encapsulated in plastic foil.

(from 'Building Details", A 513.121)

straw is pressed together the thickness should be 6 to 10 times as large as that of winter material. If other insulation material is used its thickness is found by multiplying the thickness for winter material by the ratio between the thermal conductivity of the used material and that of the 'winter material' (0.04 W/mK).

In choosing the design Freezing Index, one must consider the consequences of having a thicker frozen crust under the insulation than planned if the winter is colder than assumed. The insulation and its cover should be extended 1.0 to 1.5 m beyond the area that is to be frost-protected as shown in Fig. 165.

When excavating in insulated soil in winter, it is very important that the insulation is removed just locally as digging continues. Otherwise there is a risk that troublesome frozen earth forms while digging is in progress. With digging in building ground one must also take care that the ground is not exposed to frost so that frozen earth forms. The building excavation must therefore be covered with insulating material after each digging operation. The excavated material that is to be used for backfilling later in the winter should be covered similarly.

8. RETAINING WALLS AND BRIDGE FOUNDATIONS

8.1 FROST FORCES ON WALLS

Theoretically lateral forces due to frost heave on retaining walls can be enormous and this is confirmed by laboratory tests. However with these it is difficult to simulate various factors such as characteristics of the freezing front, variation of overburden pressure, rate of heat removal, soil consolidation and water flow (Andersland and Anderson, 1978). In practice it is found that lateral forces are usually much smaller.

For a given case the magnitude of the horizontal frost force on a wall is difficult to ascertain and thus to allow for in design. Also it is often difficult to separate forces due to frost action from other forces owing to ordinary earth pressure. Fig. 166 shows results of measurements of frost forces against different types of sheet piles and a proposal for design based on these observations (Eggestad, 1982). This design is based on limited data but it applies to frost forces whereas some other methods do not separate between frost forces and other forces from earth pressure.

The following factors influence frost forces on sheet piles (Eggestad, 1982):

<u>The structure's stiffness</u>

Under similar conditions of backfill material, Freezing Index and time lapse, a stiffer wall with internal steel reinforcement entails a significantly larger frost force. This is because the stiffer wall would provide a greater reaction against increasing thickness of ice lens formation.

<u>The soil's firmness</u>

In principle the formation of an approximately vertical ice layer behind a wall changes the pressure build-up from the active condition through the 'at rest' state to the passive state (as a higher limit). Therefore a firmer soil would result in a larger force on the wall than a softer soil.

Soil's frost-susceptibility

With regard to the soil's frost-susceptibility, two factors act against each other. Thus a larger grain size, e.g., silt as compared with clay, leads to a greater permeability and hence faster ice-layer formation. This should give a larger frost force in a given period. On the other hand, the maximum possible frost force is considerably less in a silt than in a clay. It is uncertain which of these effects would dominate in practice.

Magnitude of Freezing Index

If the possibility of deformation can be neglected, full frost pressure would be obtained with a small Freezing Index. However there will, in practice, be some deformation in the structure and in the earth mass. The frost force against the structure will therefore be strongly dependent on the Freezing Index.

8.2 DESIGN FOR FROST PROTECTION

As shown in Fig. 167 frost protection of retaining walls and bridge foundations, against horizontal and vertical forces, may be carried out by using non-frost-susceptible backfill material and/or some insulation material such as extruded polystyrene. In this way the frost forces can be avoided in practice. Also an important effect of granular fill material is to ensure good drainage and a low Ground Water Level. The required thickness h of frost-protecting granular layer depends on the design Freezing Index F_d. Thus for a retaining wall with height less than 2.5m, the thickness h is specified as h_{10} corresponding to F_d equal to F_{10} (Statens Vegvesen, 1980). For retaining walls with greater height, the thickness of the frost-protecting layer is specified as h_{100} corresponding to F_{100}. Values of h_{10} and h_{100} are tabulated for every district in Norway.

Insulation may have to be used if there is not sufficient space behind a wall for the requisite thickness of non-frost-susceptible material. If a structure is to be insulated, it is often useful to attempt to sketch in the $0^{o}C$ isotherm location at successive times. This should give an idea of the type and direction of frost force acting. It is, however, difficult to provide a standard recipe on frost protection of retaining wall and bridge foundations and each case generally requires specific evaluation (Pedersen, 1976)

For retaining walls the most suitable insulation is extruded polystyrene with a minimum thickness of 45mm where the wall height is less than 2.5m or 75mm thickness otherwise. Other possible insulation materials are foamglass and light clinker (expanded clay) but these may be too uneconomic for smaller walls while being suitable for bridge foundations (Statens Vegvesen, 1980). In the case of a pile foundation, insulation is placed over the foundation ensuring that the shortest route of frost to the underside of the foundation is at least h_{100} (Fig. 168).

For temporary sheet pile walls, use of insulation may not be the simplest or cheapest method and local heating behind the sheet pile may be more effective. With anchored sheet piles it may be necessary to relieve the anchor stay as the frost force on the pile increases (Eggestad, 1982). For specially sensitive conditions it is also a good idea to keep a check on the temperature and measure the force on a back-anchored sheet pile (Eriksson et al 1985).

9. INSULATION PROPERTIES AND USE

Insulation has the effect of restricting heat flow across it and thereby causing an appreciable temperature difference from one side to the other (e.g., Fig. 169). Proper use of insulation materials with foundations is important and this problem is still being tackled. In this connection the early work on the performance of various insulation materials, carried out by engineers concerned with Scandinavian railroads, was of great value in assessing the behavior of insulation under different conditions.

9.1 PROPERTIES AND USE CONDITIONS

Important properties of insulation used in frost protection are its thermal conductivity, durability under use conditions, resistance to water uptake and load-bearing capacity.

Properties of insulating materials used in Norway are given in Table 37. The required insulation thickness can be determined from Fig. 170 depending on the material's thermal conductivity and the required thermal resistance in use. Thermal conductivity increases with water uptake and to prevent absorption of moisture, the material can be protected by a moisture membrane. Also the thickness of material should not be less than a given value depending on type of insulation and where it is used. For example using half the thickness of extruded polystyrene makes its moisture uptake potential four times as great. To avoid uneconomic thicknesses certain limitations should be placed on a material's moisture uptake in use. Under unfavorable moisture conditions most insulation materials should be protected against uptake.

Expanded polystyrene, in particular, is liable to take up moisture during use leading to a reduction in its insulating effect. Extruded polystyrene is more reliable in this respect and is therefore often used in spite of being three times as costly as expanded polystyrene. With expanded clay there could be a risk of convection but it can safely be used in heated buildings (Saarelainen, 1986).

TABLE 37

Insulating materials' density, compressive strength and thermal conductivity

Material	Dry Density kg/m^2	Compressive strength (5% deformation) kN/m^2	Thermal conductivity in dry material at - 5°C W/mK
Expanded clay			
Bulk			
Embedded in plastic	400		0.12
Expanded poly-	20	100	
styrene	30	150	0.033
(Bead board)	40	250	
Extruded polystyrene			
Styrofoam HI	40	350	
Styrofoam RM	35	250	
Styrofoam HD 300	50-60	700	0.025
Styrodur 3000	30	300	
Styrodur 4000	40	400	
Styrodur 5000	60	800	
Polyurethane	35	250	0.02-0.03
Foamglass	125	450	
	135	600	0.047
Mineral wool	40	18-30 (10%)	0.035
	150-200		0.034-0.036

(from Saetersdal and Refsdal, 1986)

Use of mineral wool (e.g. 'Rockwool') can be expensive and there is a tendency of this material to absorb moisture with consequent reduction in its insulating effect. Under certain conditions, mineral wool can be easily kept dry, for example when it is used at the wall of a heated structure where the heat flow is from the inside to the outside and remains stationary (Algaard, 1986).

Under an impervious concrete floor of a cold building, the moisture content of underlying insulation changes with the season. The conditions are similar to those occurring under a road with asphaltic surface. On the other hand, under an 'open' floor of crushed stone or gravel, moisture content decreases gradually and therefore moisture influence on underlying insulation will be somewhat less than with an impervious floor. This implies a less stringent limitation on the insulation's moisture uptake in the case of an 'open' floor or cover. Various possible arrangements of floor layers with insulation are shown in Fig. 171.

Moisture conditions with unheated floor and foundation follow seasonal temperature and moisture variation. Conditions are different from the situation under a floor in a heated building where heat flow is directed downwards the whole year. Different values for thermal conductivity of the same insulating material apply in those different use conditions.

The required service life is also an important factor. Thus if a life of 100 years is required for extruded polystyrene used with a retaining wall, as in Norway, the minimum insulation thickness would be 75mm (Statens Vegvesen, 1980). For purposes of design one should consider laboratory measurements of the thermal conductivity of the dry material and then estimate how this can be expected to increase under the specific conditions of field use. It is suggested that an estimate might be made of the time for the dry material to pick up 20% moisture and the resulting reduction in insulation effect (Refsdal, 1986).

In Finland 50 years is considered as insulation design life and possible insulation materials are polystyrene (extruded or expanded), polyurethane, polyethylene, light gravel and mineral wool. The Finnish guidelines (1987) give recommended thermal conductivity design values for insulation in practical cases depending on type and density of the insulation and use conditions (Figs. 172-175). For temporary use the thermal conductivity is lower and assumed constant over time. With permanent use the thermal conductivity increases, and the insulating effect decreases, if the conditions of use are adverse. There are three boundary lines in each of Figs. 172-175 representing 'good', 'average' and 'severe' conditions of use.

The relative insulating ability of other materials often used in building construction is shown in Table 38 which gives the density and thermal conductivity of these materials.

Ground insulation and its placement

Ground insulation should have a high resistance to vapor diffusion and, in particular, should resist rotting and attack from acids in the soil.

Care needs to be taken in installing and protecting ground insulation as illustrated by the Finnish guidelines in Figs. 176 and 177. Sand is placed in the foundation trench and can be compacted by vibration (Fig. 176, diag. 2). Proper drainage below the foundation is essential and the illustrations show a drainage pipe under the outside edge of the footing. At corners 40% more insulation is required as shown in Fig. 176, diagram 6. This can consist, for example, of 70mm thickness of insulation placed at a corner compared to 50mm thickness along an outer wall. The extra amount is applied over a distance of 1.5m from the corner. Diagrams 7 and 8 (Fig. 176) show how sand, or other non-frost-susceptible material, should be placed above and below ground insulation. There should be no digging or tampering with the

TABLE 38
Properties of materials used
in building construction

Material	Density Kg/m^3	Thermal conductivity at 10 °C W/mK
Concrete	1900-2300	1.5 - 2.5
Expanded concrete	400-650	
Expanded clay blocks		
above ground	650	0.20-0.24
under ground	650	0.25
Tiles	1700	0.7
Asphalt, hot mix	2100	1.0-1.5
Spruce, pine	500	0.15
Wallboard	400-600	0.12-0.14
Glass	2600	0.8
Snow: new	100	0.1
porous, dry	200	0.25
old	200-300	0.25

(from Saetersdal and Refsdal, 1986)

soil outside the finished building because this could damage ground insulation. Fig. 177 shows how ground insulation can be protected in certain cases by means of a concrete slab (50 to 70mm thick), a sheet of asbestos cement, water-resistant plywood or asphalt surfacing.

9.2 EXAMPLES OF INSULATION USE

The following examples are taken from Swedish practical applications as recommended by insulation manfuacturers. Commonly used insulation materials are polystyrene (extruded and expanded) and mineral wool. Mineral wool can be rock fiber board or glass fiber board but the latter is not used in contact with soil.

(a) Slab-on-grade construction

Fig. 178 shows use of insulation with two types of slab-on-grade construction. Continuous insulation below, and along the inside or outside, of the foundation wall is essential to prevent cold bridge formation. Conventional slab insulation as shown in Fig. 179(a) invites a cold bridge and is more difficult to construct than continuous insulation as in Fig. 179(b). The latter also acts as a more effective moisture barrier. It may be noted that mineral wool is not used where the bearing pressure is high, i.e. under an edge or foundation wall.

Fig. 180 shows a concrete slab with overlying polystyrene insulation and a foundation wall of light expanded clay aggregate with ground insulation of mineral wool. Another recommended design by a different manufacturer is illustrated in Fig. 181(a). This shows two layers of extruded polystyrene placed between a concrete floor and an edge-expanded concrete slab. Underneath the slab there is extruded polystyrene insulation which is extended externally to form ground insulation. The recommended thickness of this insulation can be determined from Fig. 181(b) depending on the region of Sweden.

(b) Foundation with crawl space

An example of insulation of a foundation with crawl space is given in Fig. 182. Mineral wool is placed on the inside of the leca foundation wall. A plastic film is placed on the ground, as a moisture barrier, with a layer of sand overlying.

(c) Foundations for 'cold' structures

Fig. 183 shows alternative placing of extruded polystyrene insulation used with a narrow strip foundation.

The manufacturer's recommended values of extruded polystyrene thickness and the insulation's necessary extension width 'b' outside a raft, a narrow strip or a pier foundation, are given in Fig. 184 depending on the location in Sweden and its associated frost depth h_o. It is stated that for each 0.5m lowering of the foundation depth, the insulation thickness may be decreased by 10mm. The excavation bottom should be levelled using non-frost-susceptible material (sand, gravel or fine macadam) with 100-200mm thickness. According to the manufacturer, this design ensures that there is no heave in the construction even if heave in the surrounding ground is appreciable.

(d) Ground insulation

Placing ground insulation raises the 0^oC isotherm (Fig. 185a) and manufacturer's recommended thicknesses for use of mineral wool and extruded polystyrene are shown in Fig. 185b applying to different regions in Sweden.

9.3 RETROFIT OF INSULATION

The Norwegian 'Building Details' give designs for incorporating insulation in a building after it has been in use for a period, i.e. 'retrofit' procedure. The purpose is to decrease heat loss from various structural parts which means their U-value is reduced. For example Sheet A 523.212 shows procedure applying to outer walls made of concrete or built masonry. These can be fitted on their outside with a suitable thickness of mineral wool board to reduce the U-value to what is required.

In Denmark retrofitting has been done to solve problems of frost heave in connection with old buildings having small foundation depths. A computer program has been used at the Danish Geotechnical Institute to calculate the associated position of the $0^{\circ}C$ isotherm and to determine how insulation may be placed to raise this isotherm (Porsvig, 1986). The Danish Geotechnical Institute has also made computer calculations related to other completed foundations where a mistake was discovered in the foundation design after use of the building. The necessary outside insulation to rectify the design was accordingly determined.

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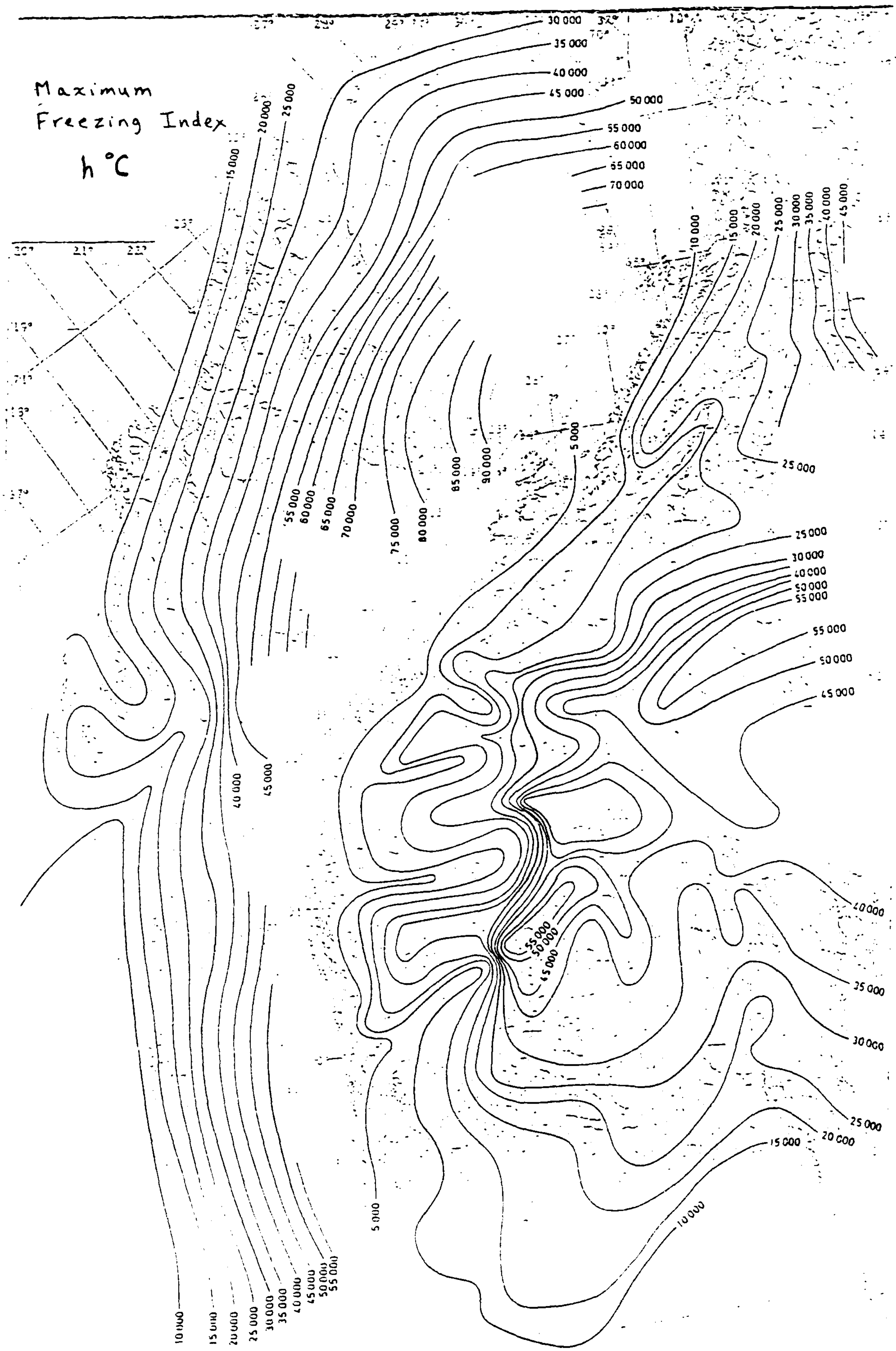

Fig. 1 Maximum Freezing Index contours in Norway

(from 'Building Details' A 521.111)

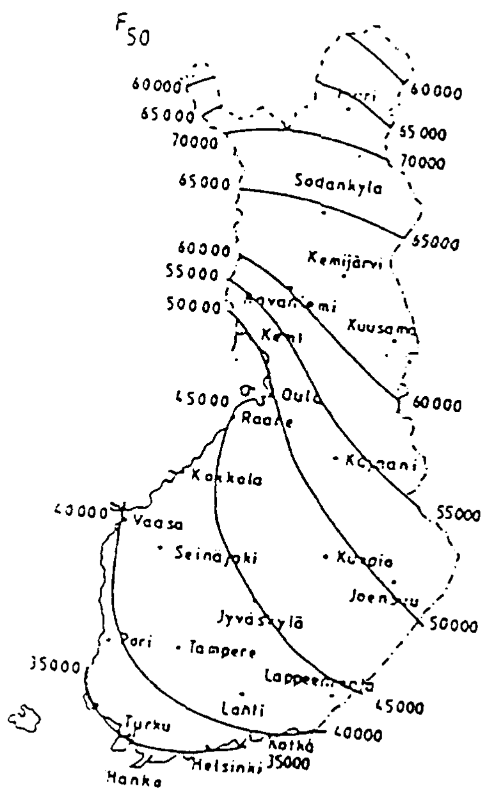

Fig. 2 Freezing Index F_{50}. h ^{o}C
i.e. once in 50 years

(Finnish guidelines, 1987)

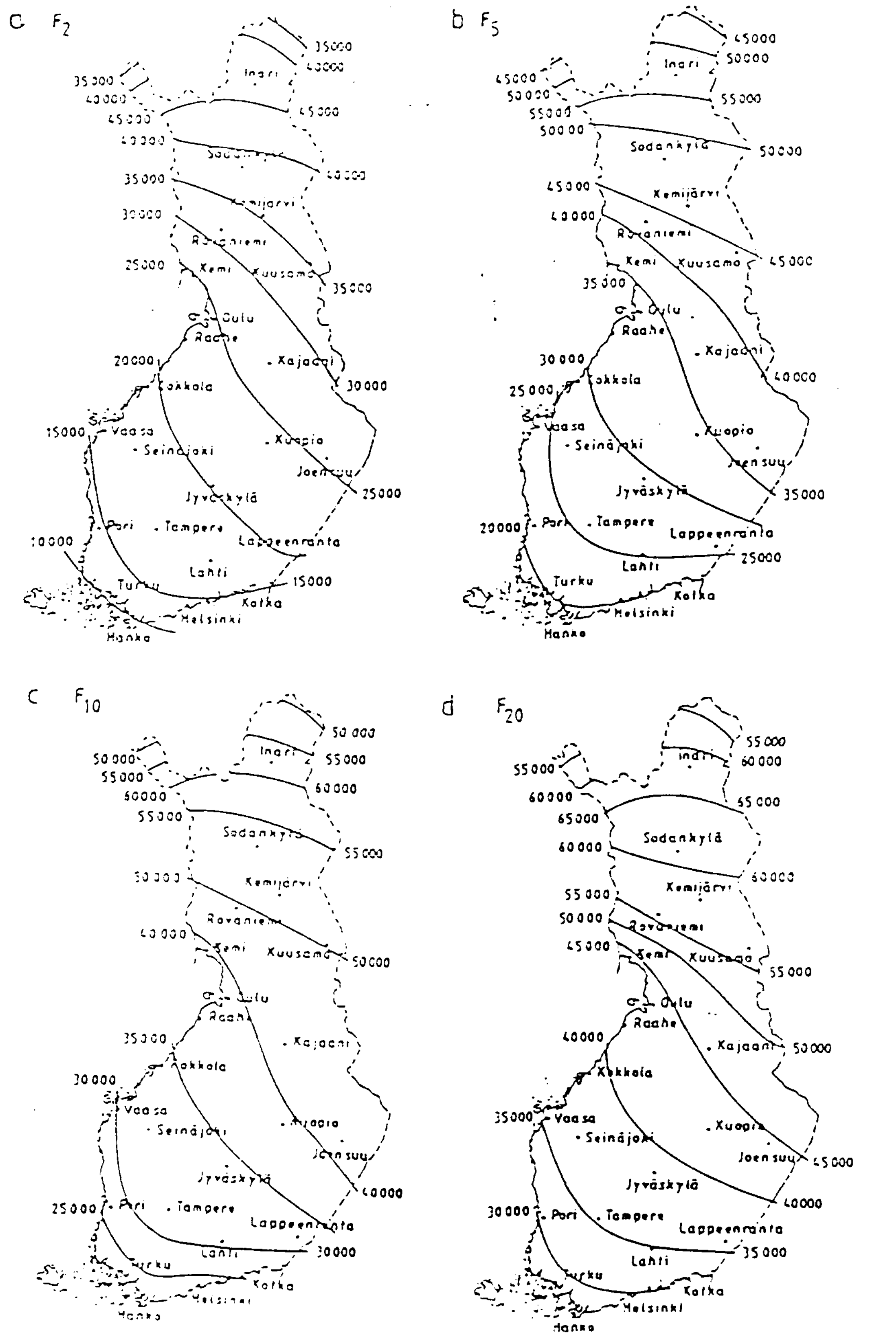

Fig. 3 Freezing Index, h°C

(a) F_2, once in 2 years (b) F_5, once in 5 years

(b) F_{10}, once in 10 years (d) F_{20}, once in 20 years

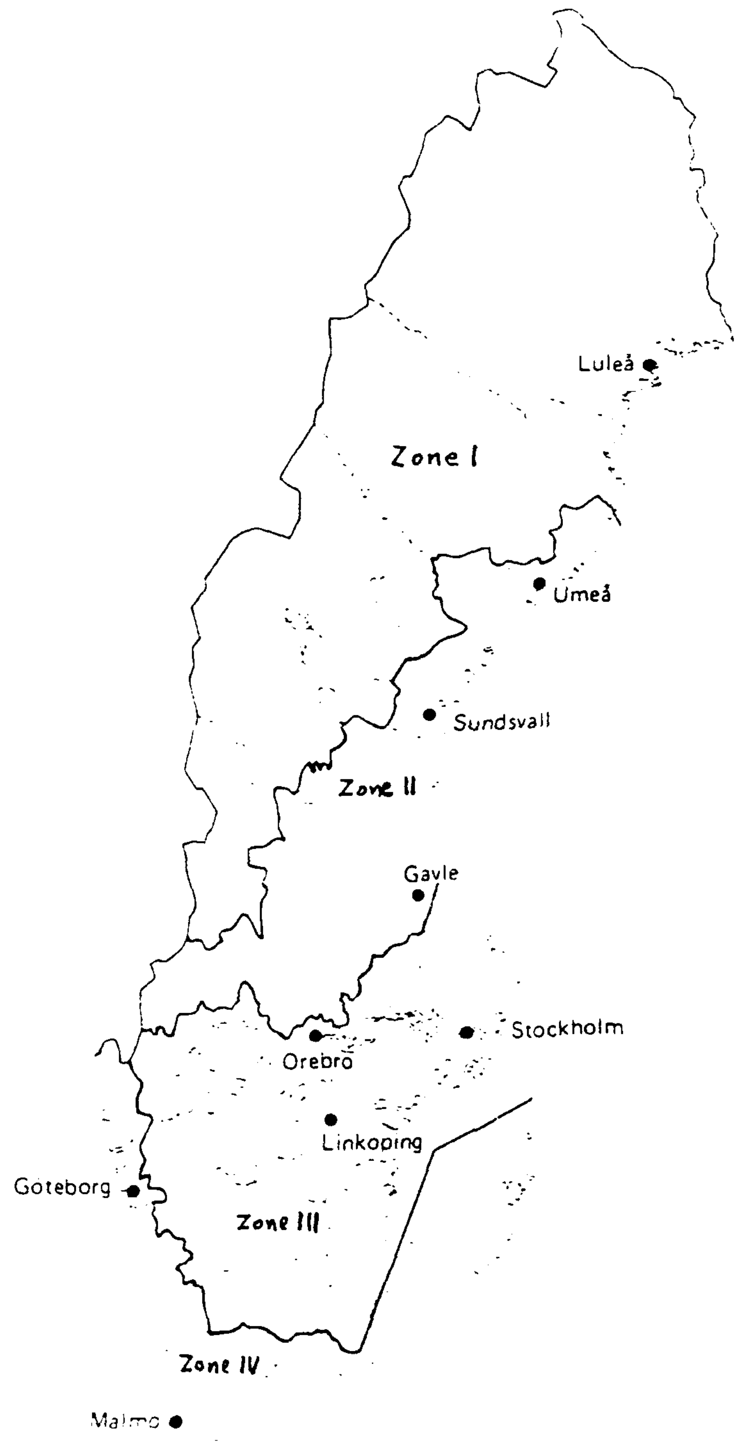

Fig. 4 Temperature zones in Sweden.

(SBN 80)

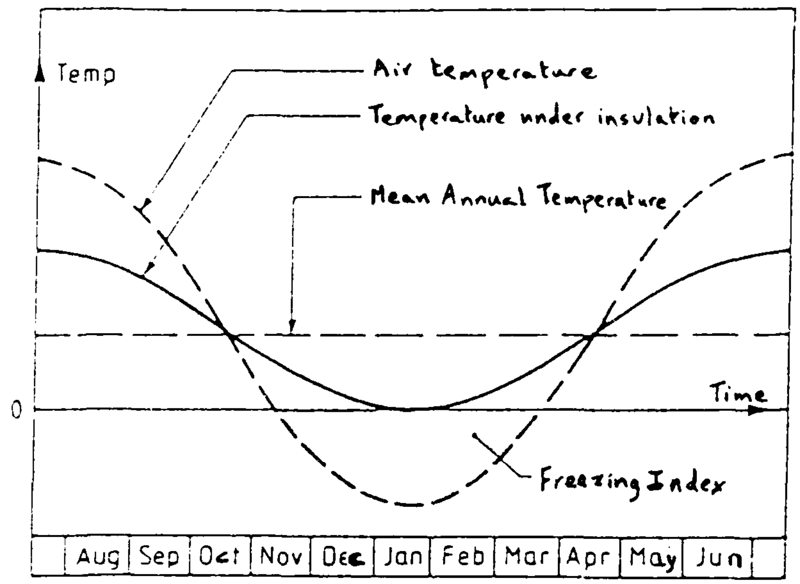

Fig. 5 Damping of temperature distribution in the ground by insulation.

('Building Details', A 521.811).

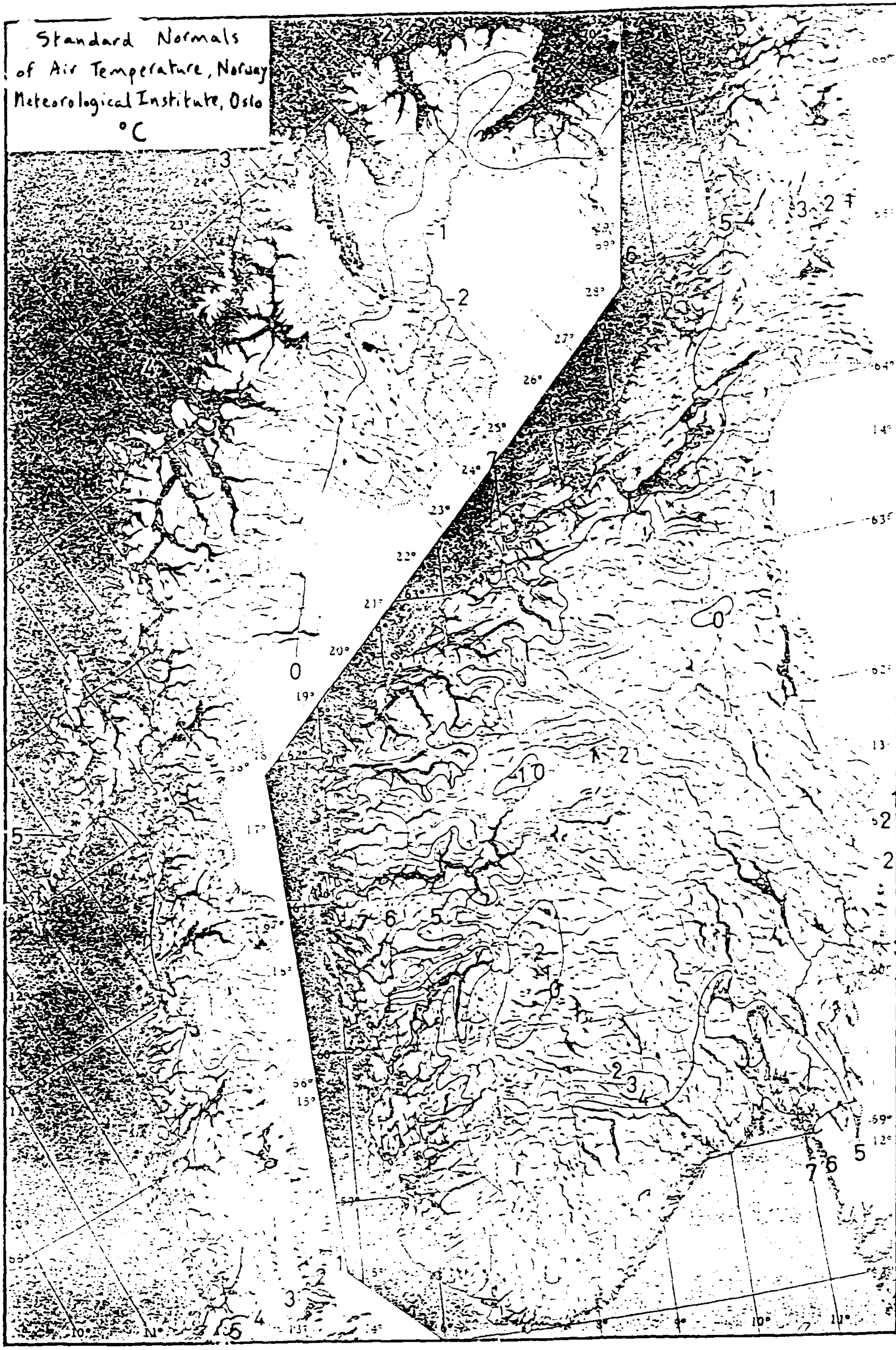

Fig. 6 Mean Annual Temperature. Norway (1931-6)

(Frost I Jord, 1976)

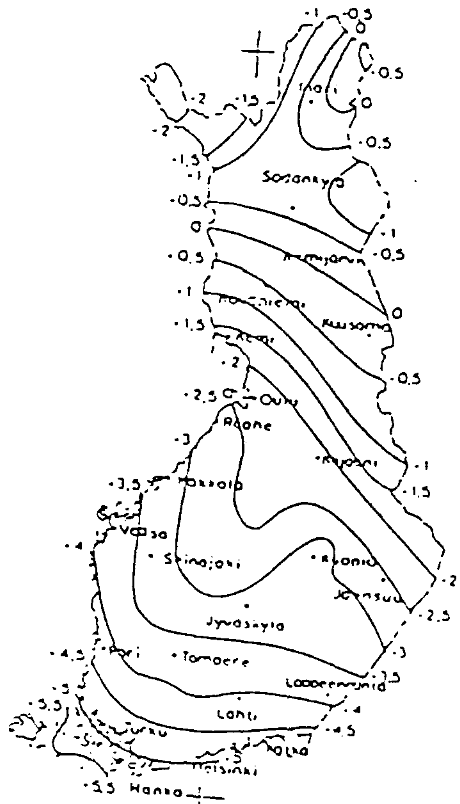

Fig. 7 Mean Annual Temperature ($^{\circ}C$), period 1931-60.

(Finnish guidelines, 1987)

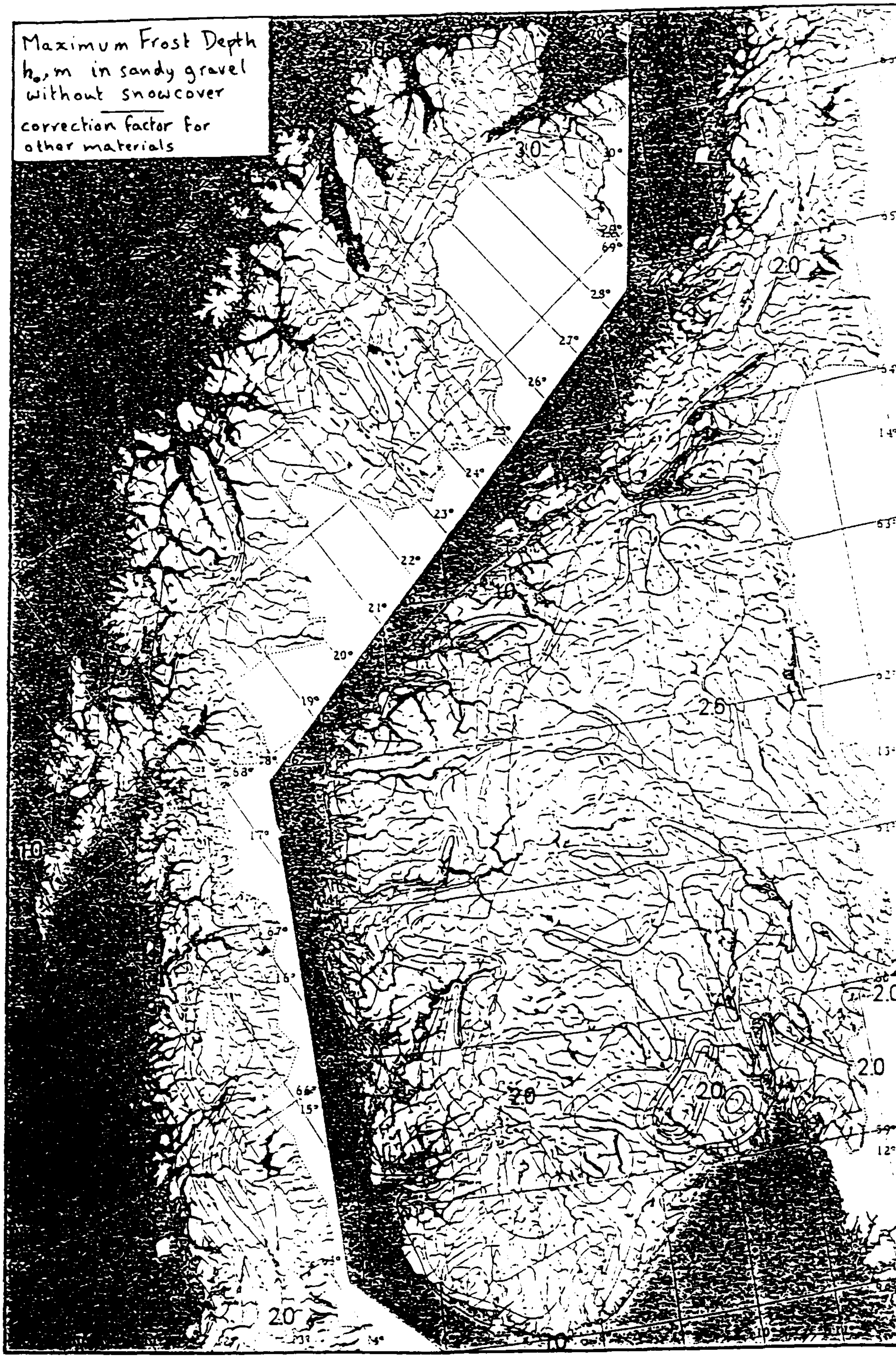

Fig. 8 Maximum Frost Depth Contours in Norway
(from Frost I Jord, 1976)

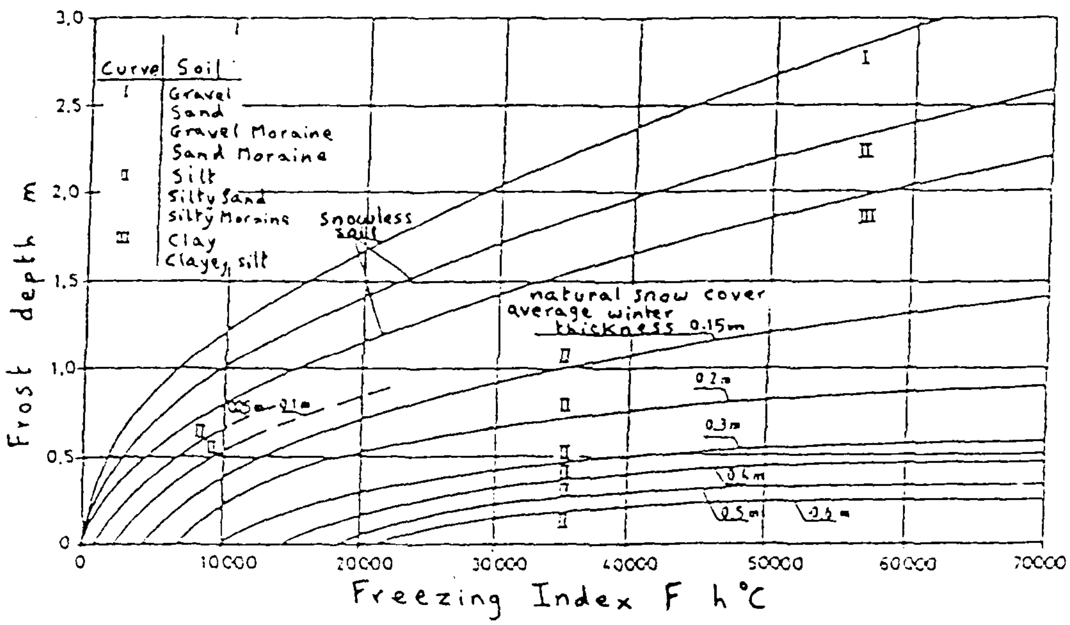

Fig. 9 Influence on Frost depth of Freezing Index and snow cover thickness.

(Finnish guidelines, 1987)

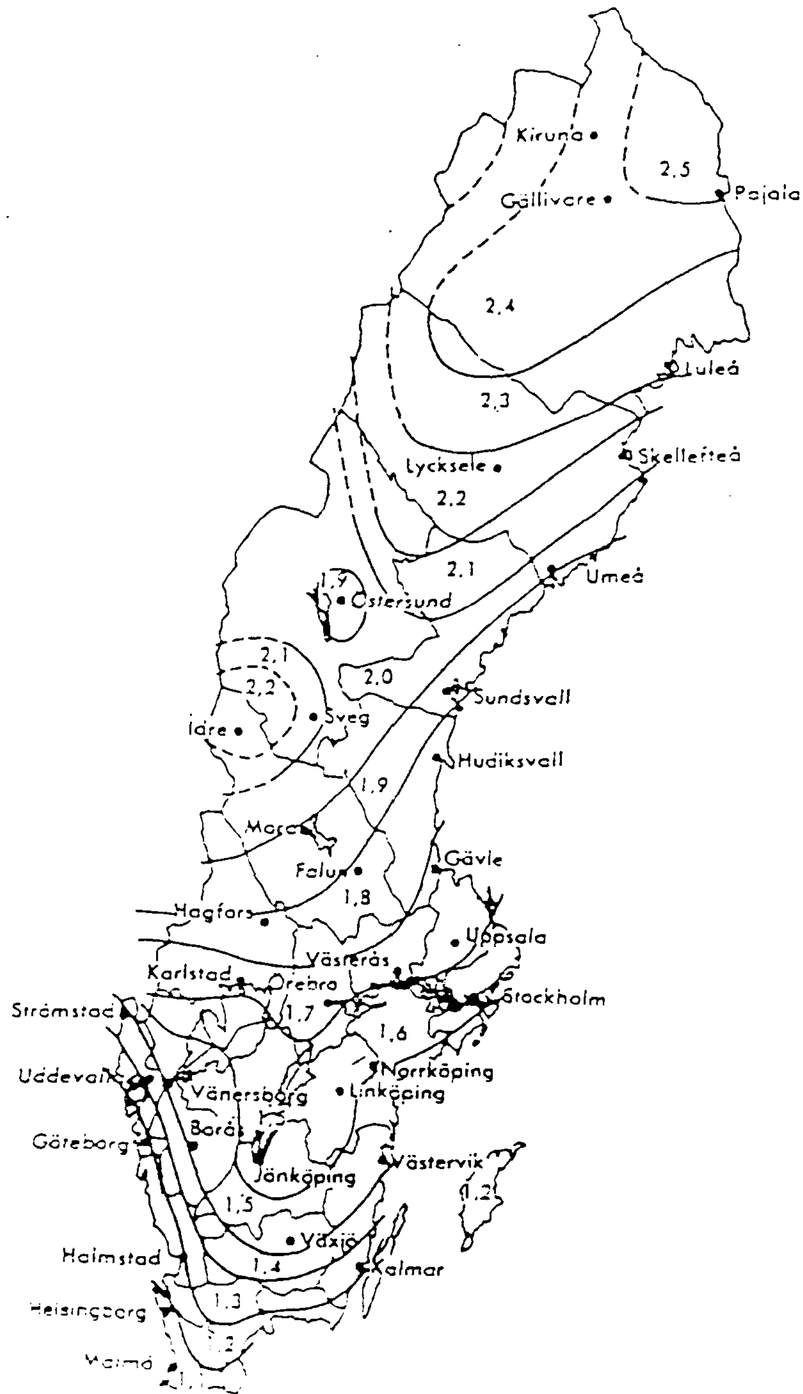

Fig. 10 Frost penetration depth h_o (metres) in frost-susceptible soil (from SBN 80)

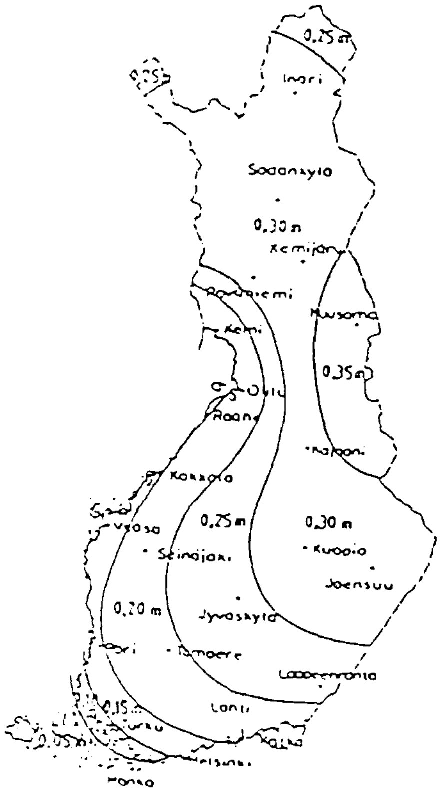

Fig. 11 Design values for mean snow depth over winter.

(Finnish guidelines, 1987)

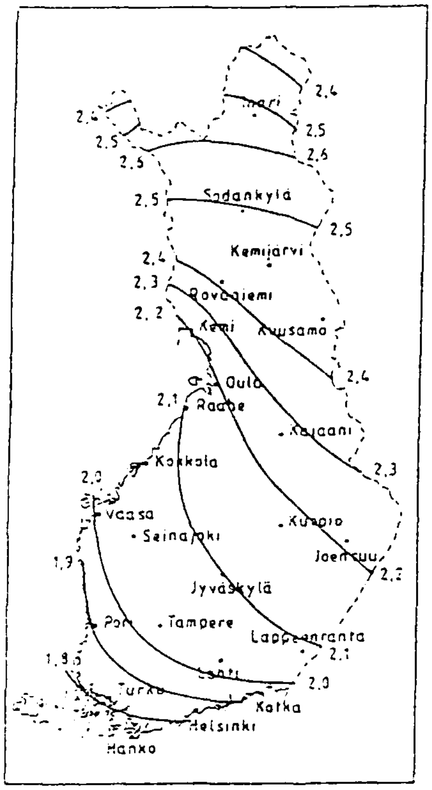

Fig. 12 Average frost-free depth (m) for foundations of cold structures on frost-susceptible soils, neglecting snow cover effect.

(Finnish guidelines, 1987)

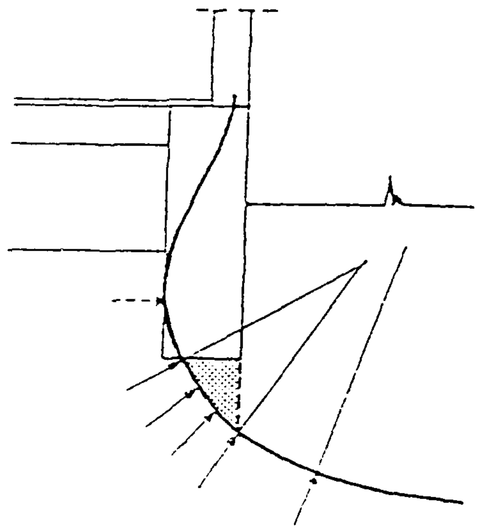

Fig. 13 Heave forces are assumed to act at right angles to the frost front.

(from Kløve and Thue, 1972)

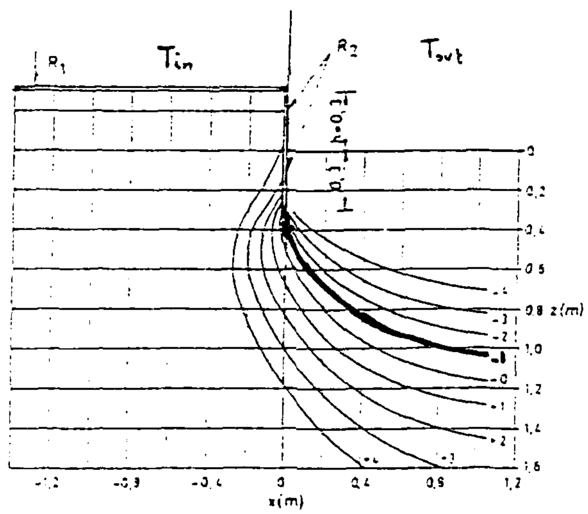

Fig. 14 $-1^{o}C$ isotherm is taken as being the critical isotherm, and its intersection with x = 0 (inside boundary of foundation wall) gives the assumed frost penetration depth.

(DIAG. 46 of Adamson et al, 1973)

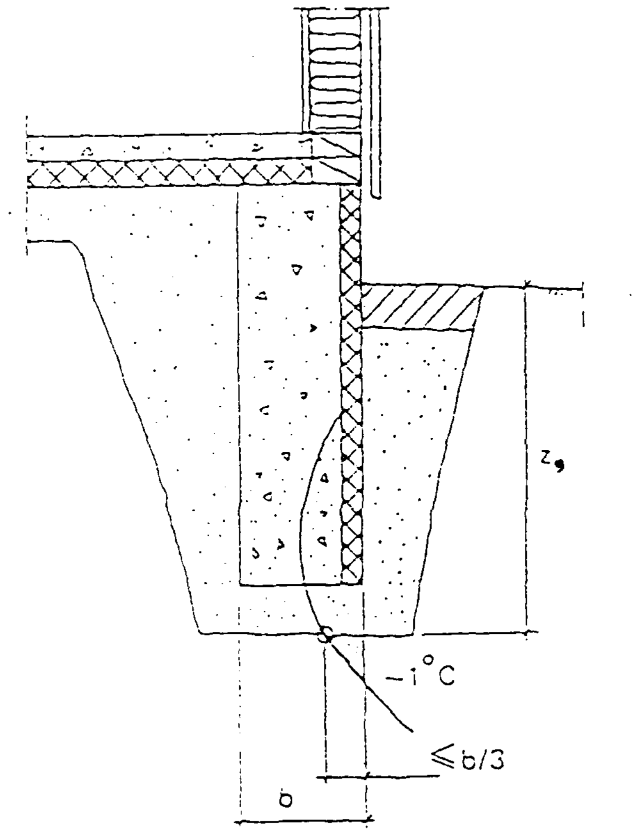

Fig. 15 Frost criterion and definition of foundation depth z_g.

(from Torgersen, 1976)

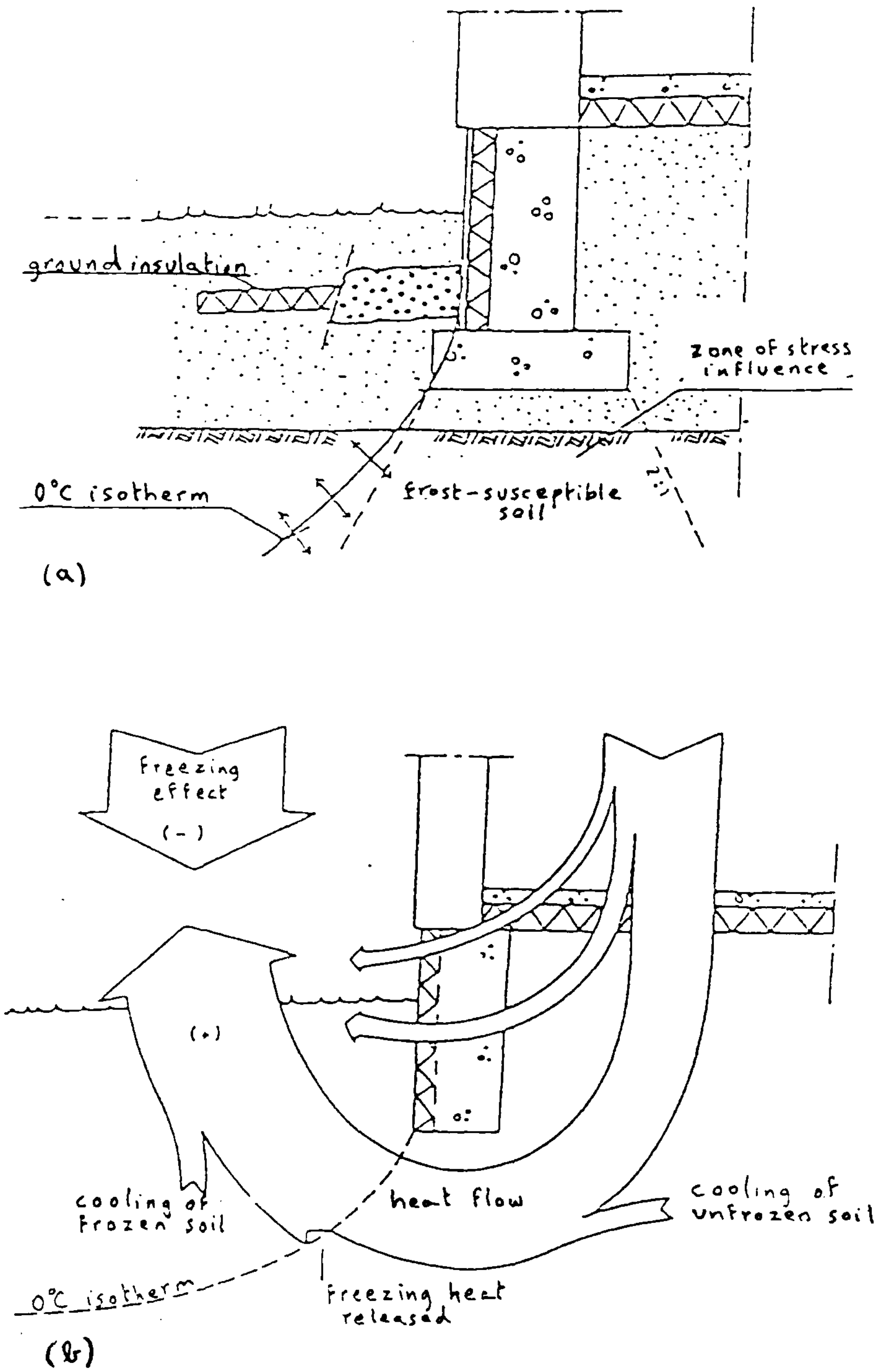

Fig. 16 Frost protection principle in Finland
0 °C isotherm limitation.

(Finnish guidelines, 1987).

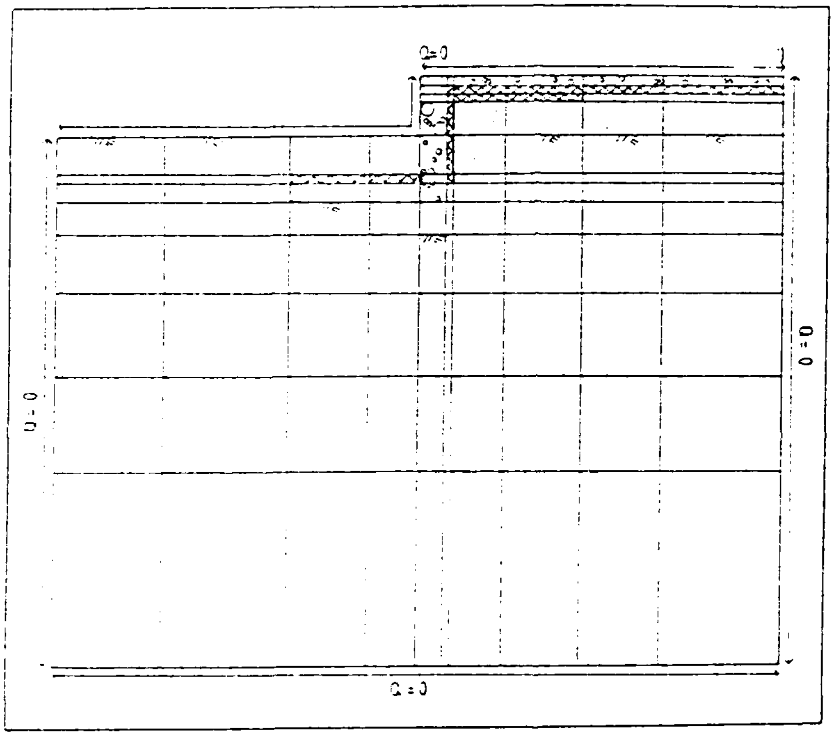

Fig. 17 Example of finite element mesh
for isotherm determination.

(Finnish guidelines, 1987)

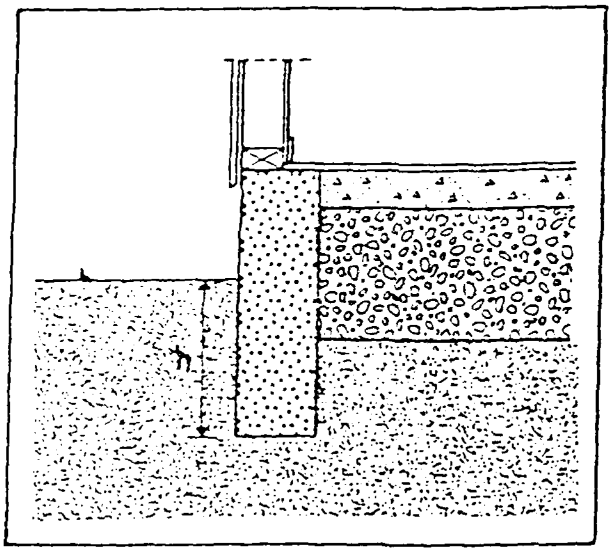

Fig. 18 'Slab-on-grade' foundation.
Shallow foundation depth h.
(from Kløve and Thue, 1972)

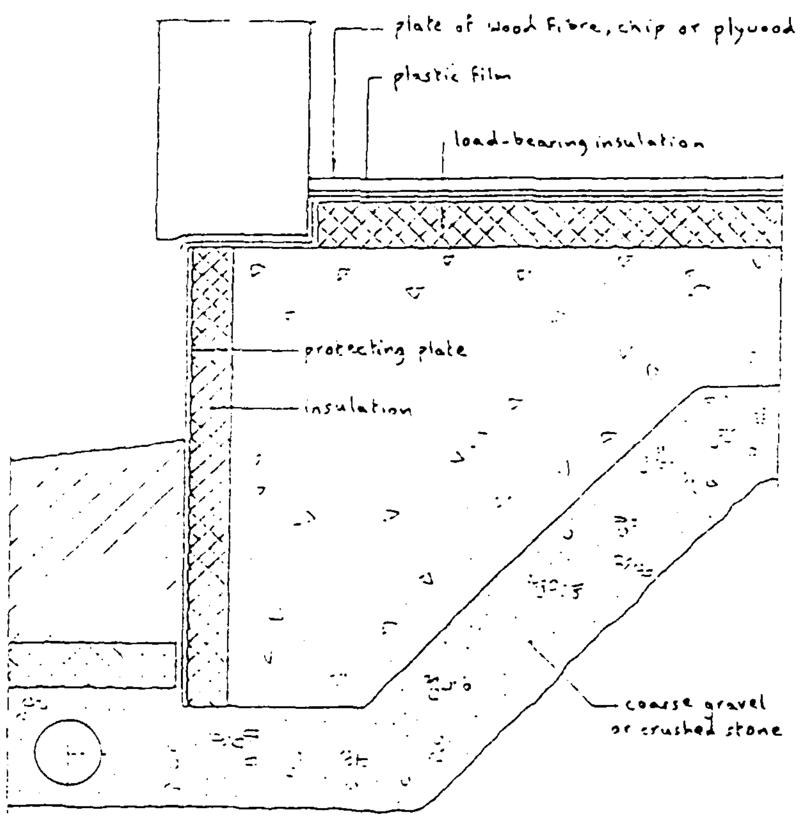

Fig. 19 Example of 'slab-on-grade' with edge-expanded concrete slab. Such a slab gives more load spread with poor foundation conditions.

(from 'Building Details', A 521.011)

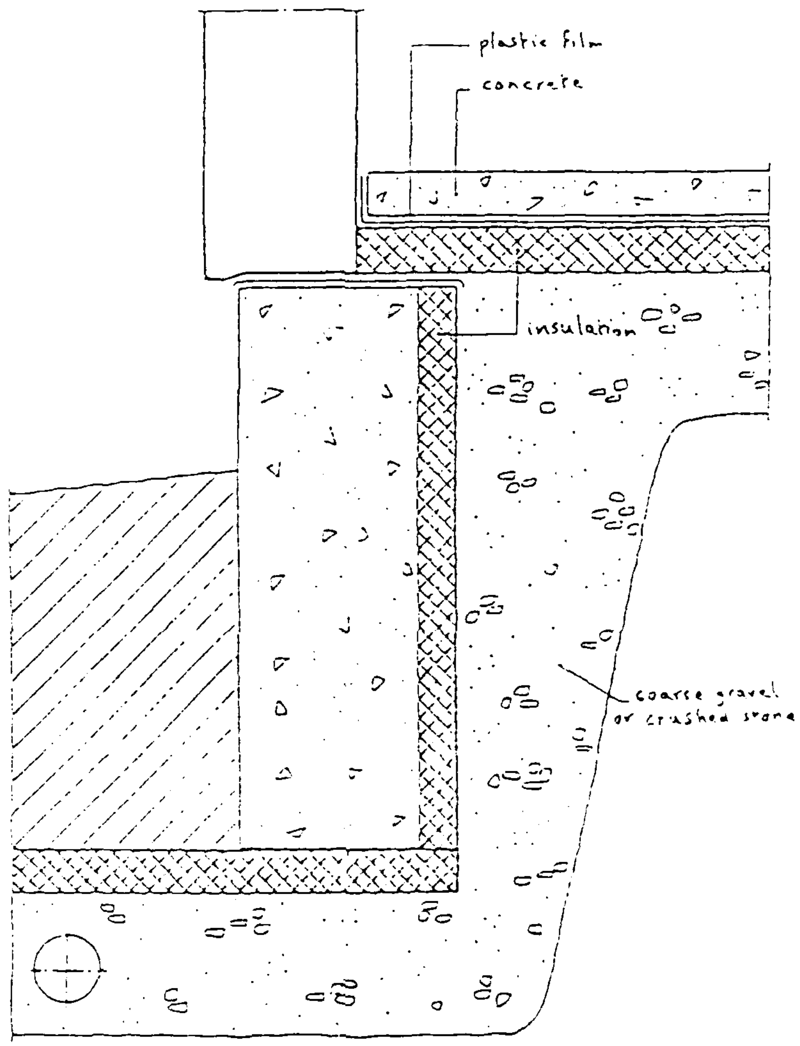

Fig. 20 Example of slab-on-grade' with separate foundation-wall and slab

(from 'Building Details', A 521.011)

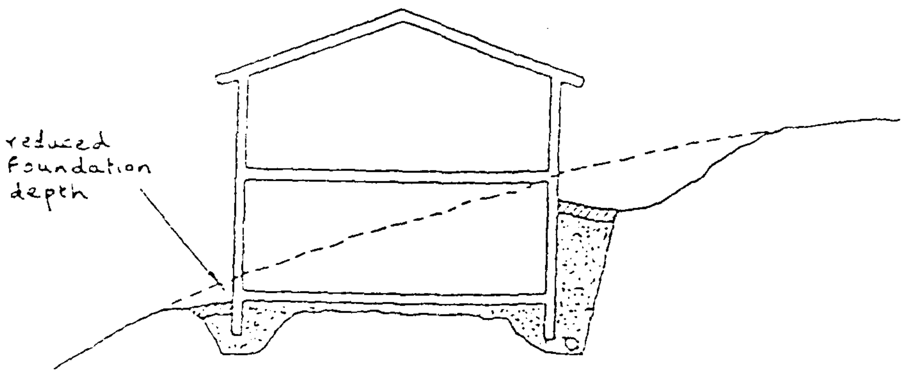

Fig. 21 Combination basement/ground foundation in sloping terrain

('Building Details', A 521.111)

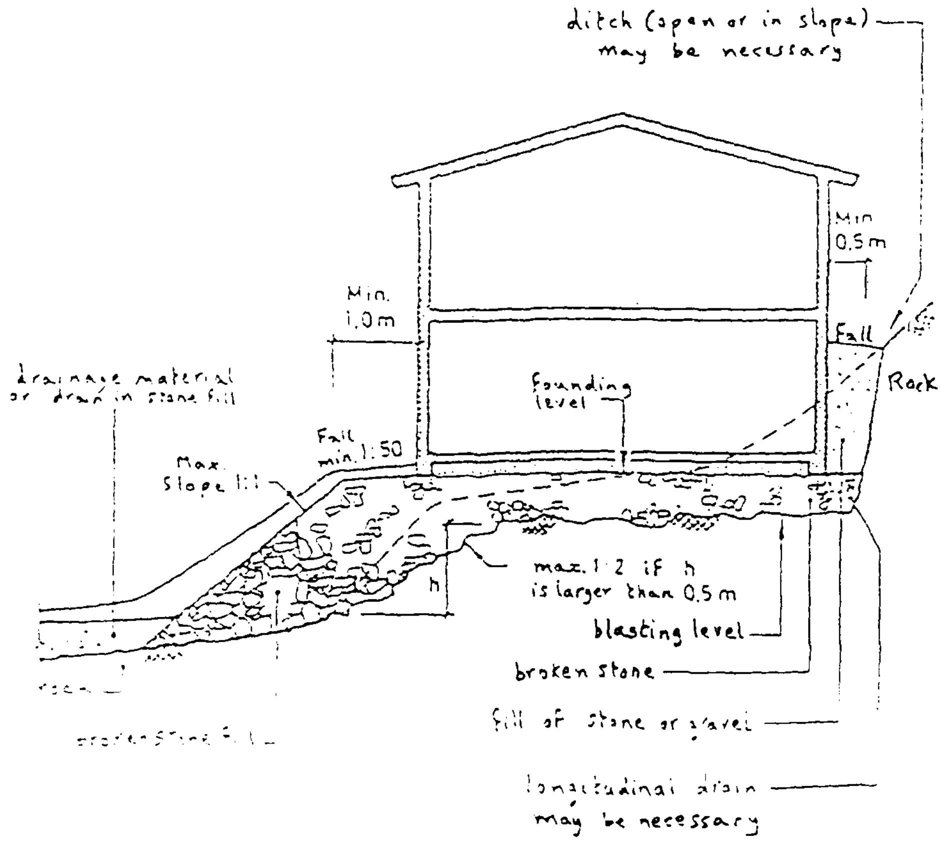

Fig. 22 House on broken stone fill in sloping terrain.

('Building Details', A 521.111)

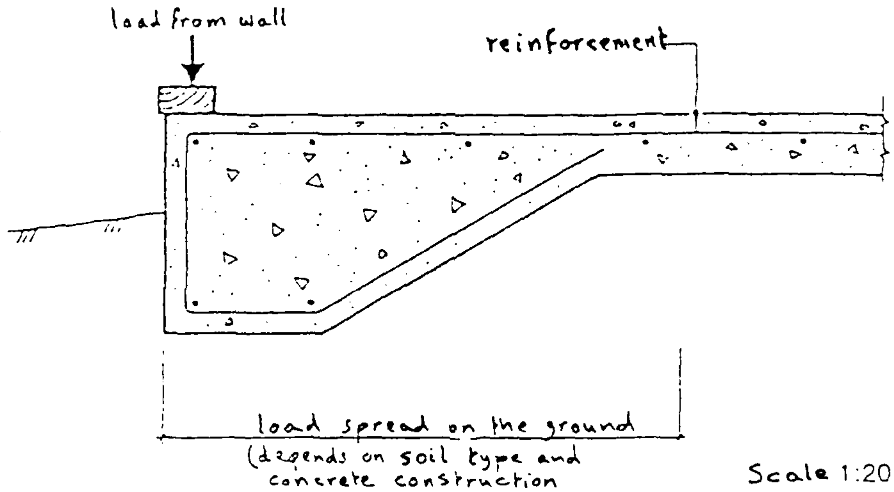

Fig. 23 If the foundation and slab are cast as one unit and reinforced, they will act together and distribute the wall loading over a larger breadth on wet ground.

(from 'Building Detils', A 521.111)

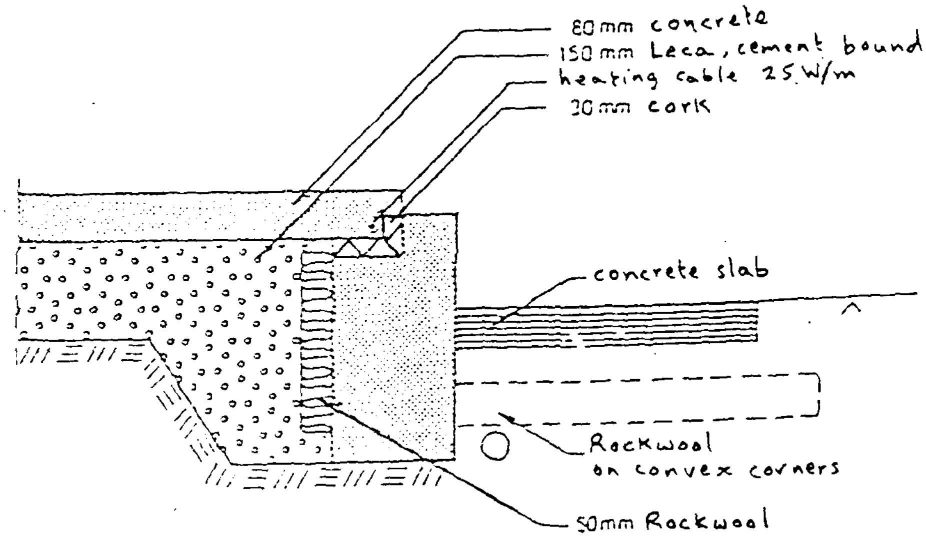

Fig. 24 Slab-on-grade design used in the Skjetten development.

(from Eiesland, 1972)

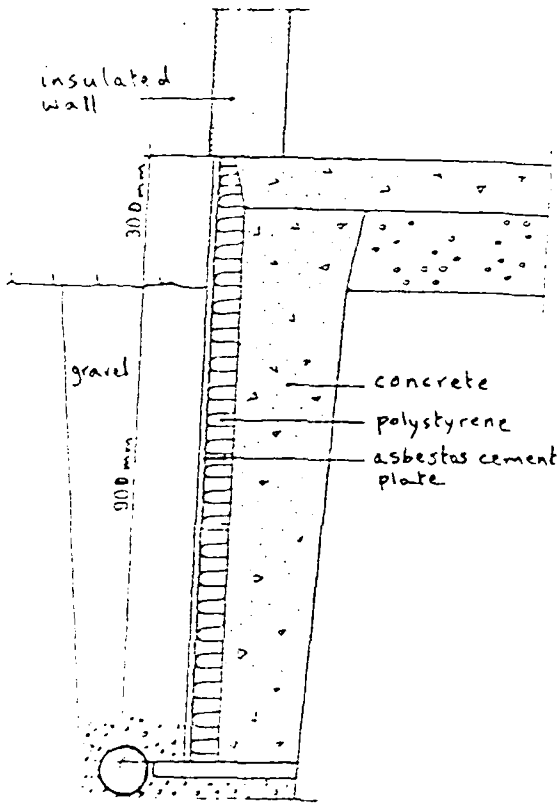

Fig. 25 Outside insulation on the foundation wall guides heat down to the foundation. There is no cold bridge effect.

(from Faeroyvik, 1972)

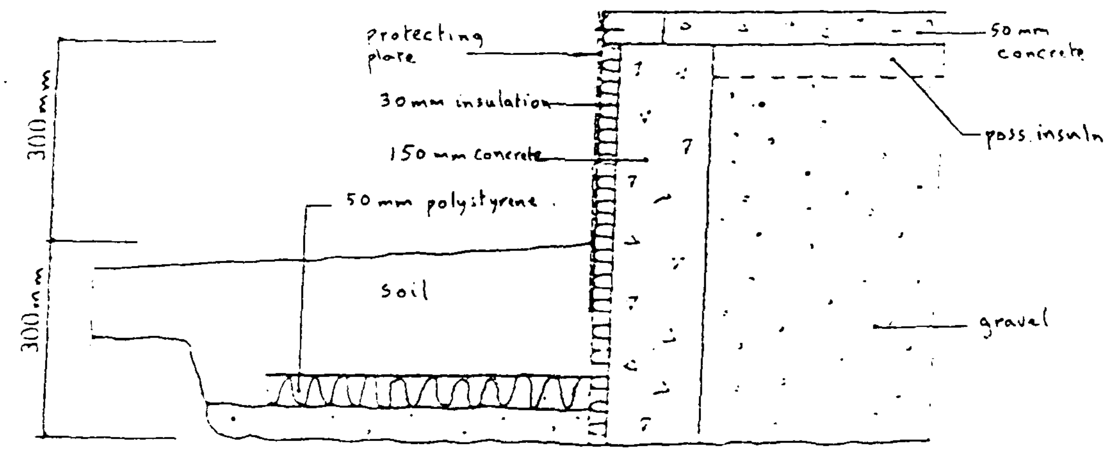

Fig. 26 Use of horizontal ground insulation to keep frost away from the foundation.

(from Faeroyvik, 1972)

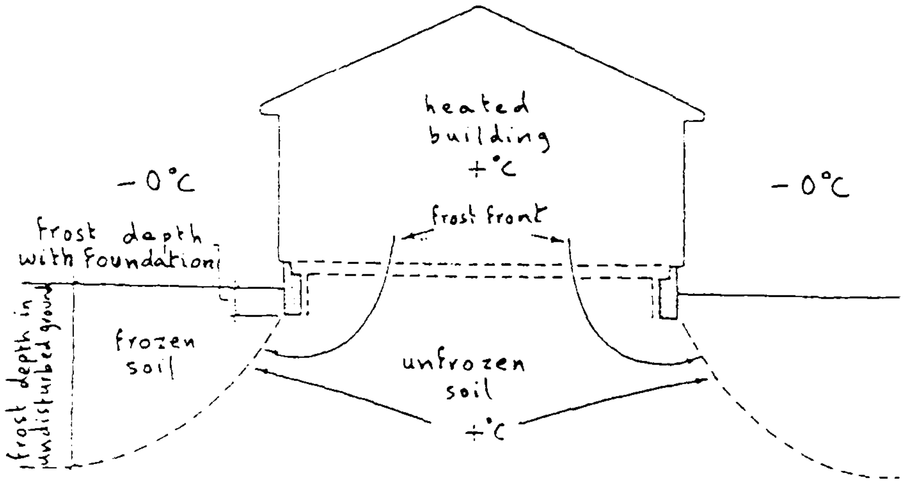

Fig. 27 Frost penetration at heated building
(from 'Building Details', A 521.111)

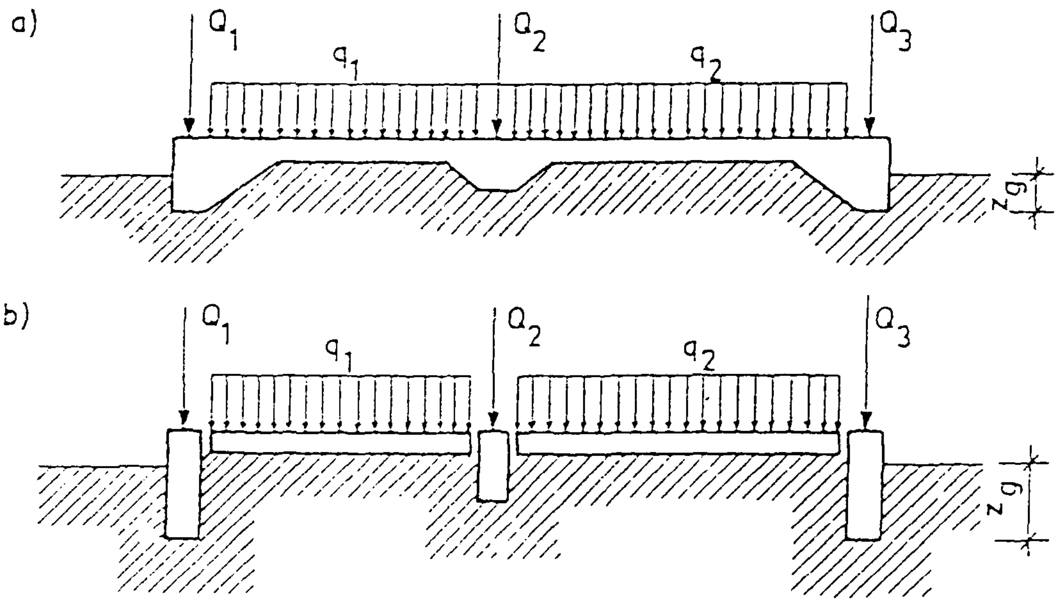

Fig. 28 Floor slab laid on the ground in the form of

(a) integral slab stiffened at the edges

(b) slab with edge beams taking wall loads

(Fig. 1 of Adamson et al, 1973)

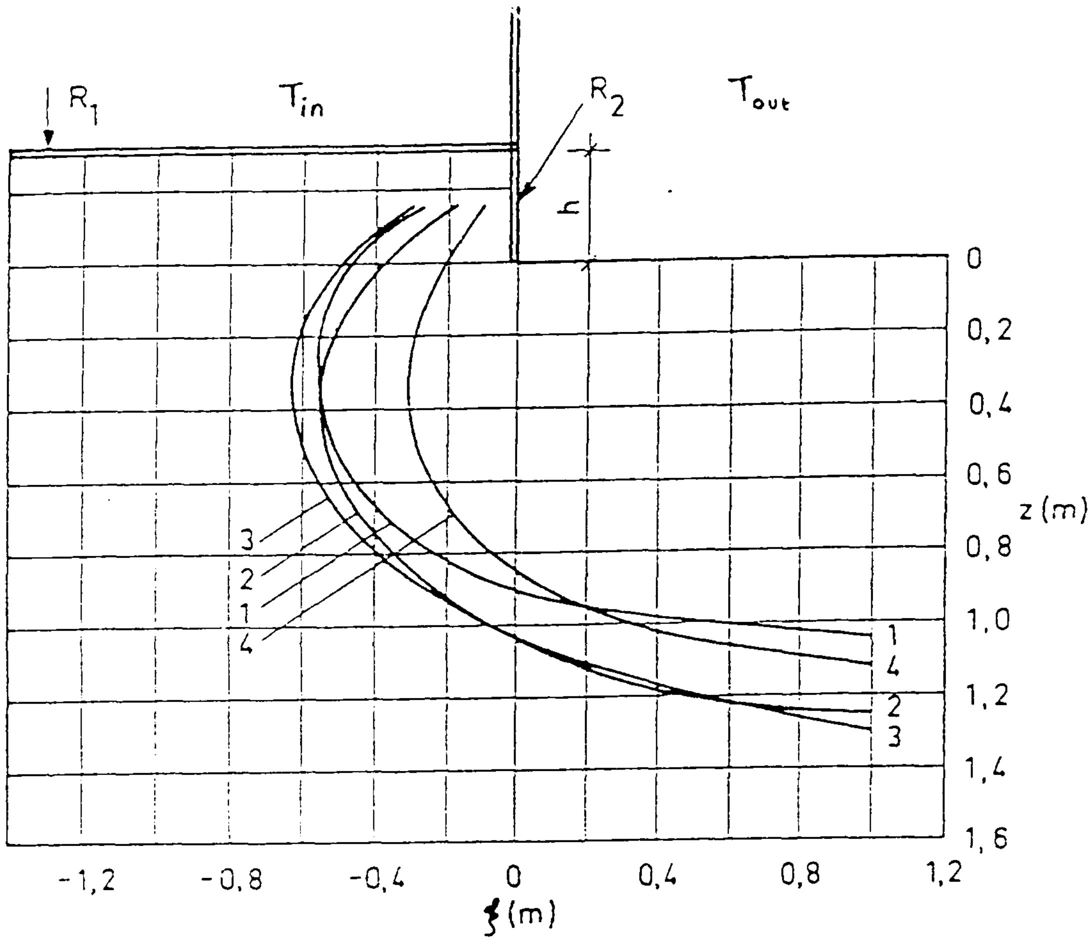

Fig. 29 Position of the -1°C isotherm at different times

Line 1: 2 weeks after the lowest outside temperature (T_{out}=-12.5°C)

Line 2: 4 weeks " " " " " (T_{out}=-11.0°C)

Line 3: 6 weeks " " " " " (T_{out}=-8.0°C)

Line 4: 9 weeks " " " " " (T_{out}=-3.7°C)

(Fig. 7 of Adamson et al, 1973)

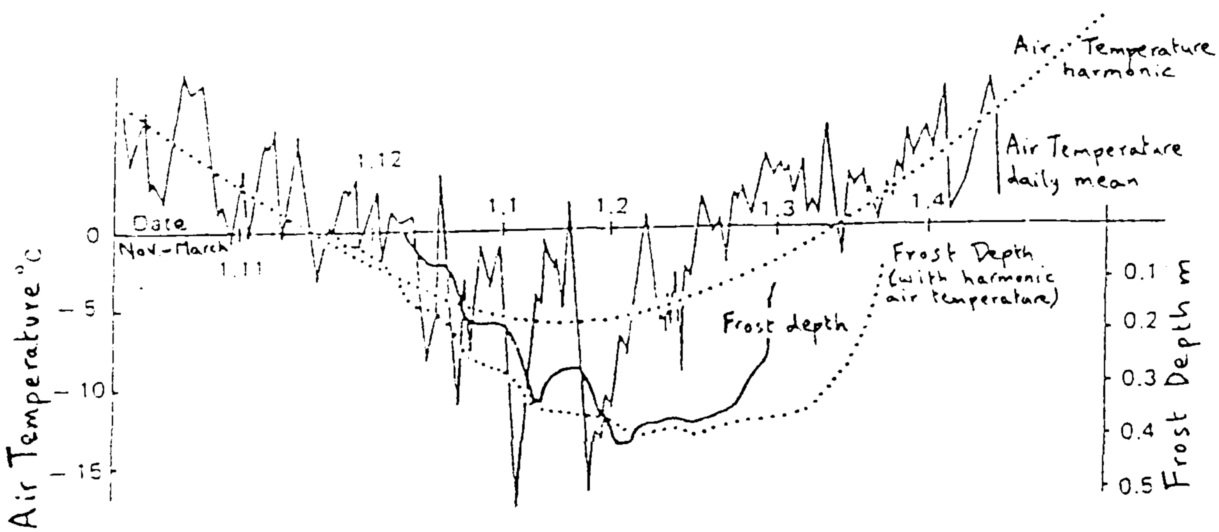

Fig. 30 Relationship between outside temperature variation and frost penetration at a foundation.

(from Torgersen, 1976)

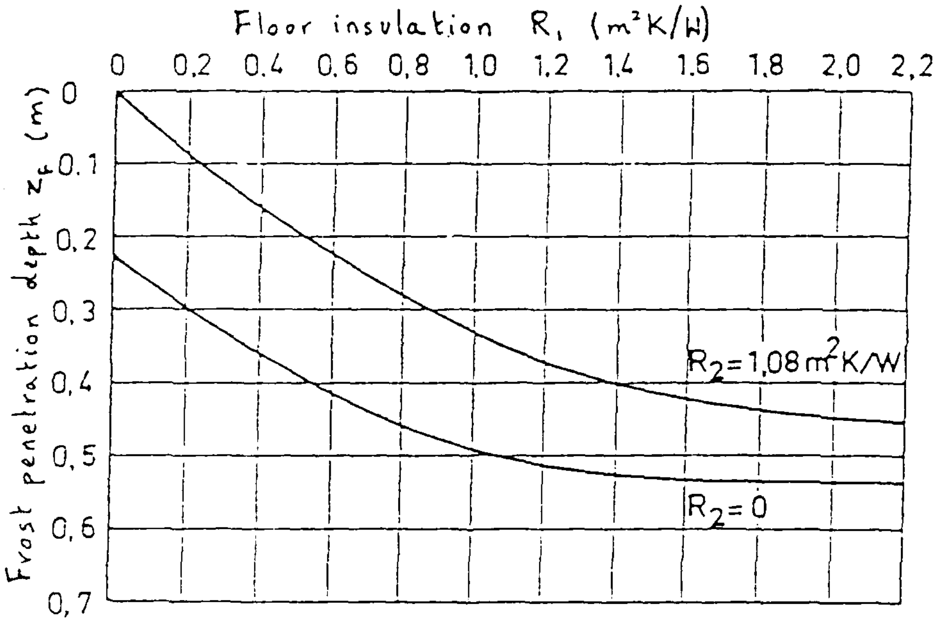

Fig. 31 Influence of floor insulation R_1 on frost penetration depth. Computation for Örebro. Insulation R_2 of the foundation wall applies to its part above ground. Pedestal height = 0.3m.

(Fig. 14 of Adamson et al, 1973)

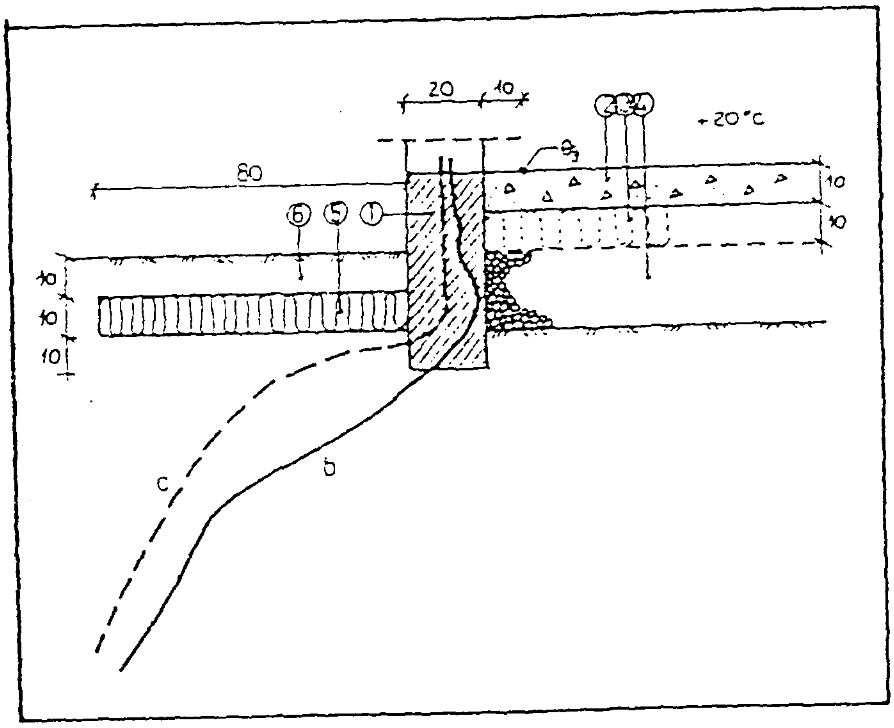

Fig. 32 0°C isotherm shifts from
b to c when floor insulation is removed.

(from Kløve and Thue, 1972)

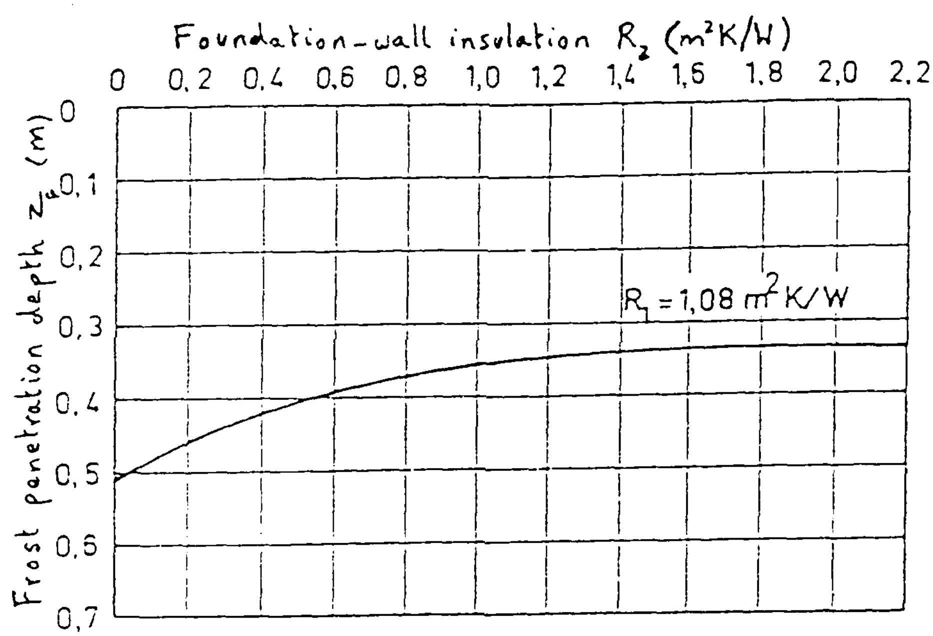

Fig. 33 Influence of foundation wall insulation R_2 on frost penetration. Computation for Örebro. Floor insulation $R_1 = 1.08 m^2K/W$. Insulation on foundation wall is placed only above ground. Pedestal height = 0.3m.

(Fig. 15 of Adamson et al, 1973)

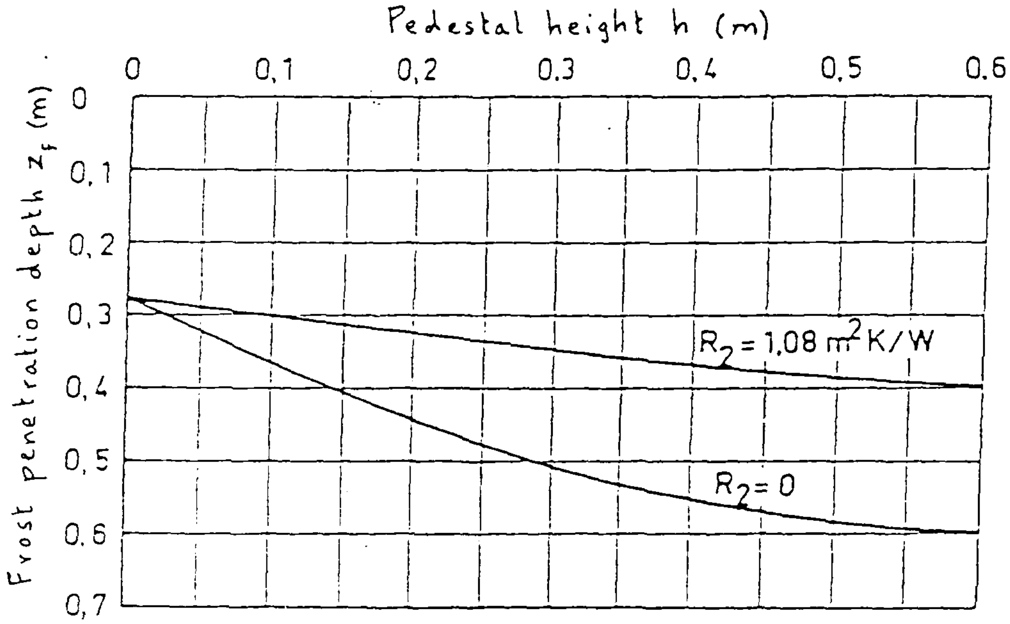

Fig. 34 Influence of pedestal height h on frost penetration depth. Computation for Örebro. Floor insulation $R_1 = 1.08 m^2K/W$. Insulation R_2 on foundation wall is placed only above ground.

(Fig. 16 of Adamson et al, 1973)

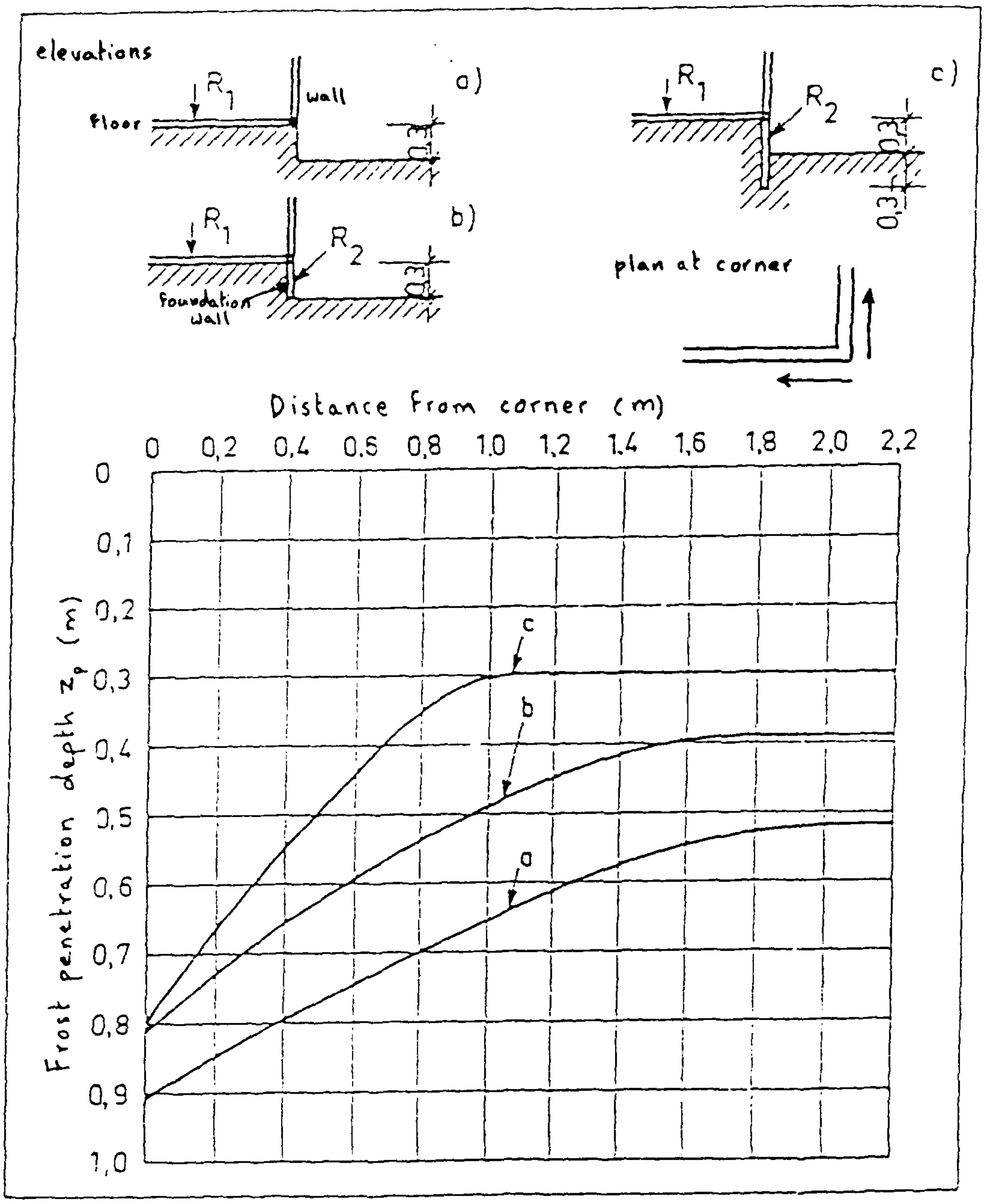

Fig. 35 Frost penetration depth as a function of the distance from a corner.
Computation for Stockholm conditions (R_1 = 1.08m^2K/W = R_2)

(Fig. 10 of Adamson et al, 1973)

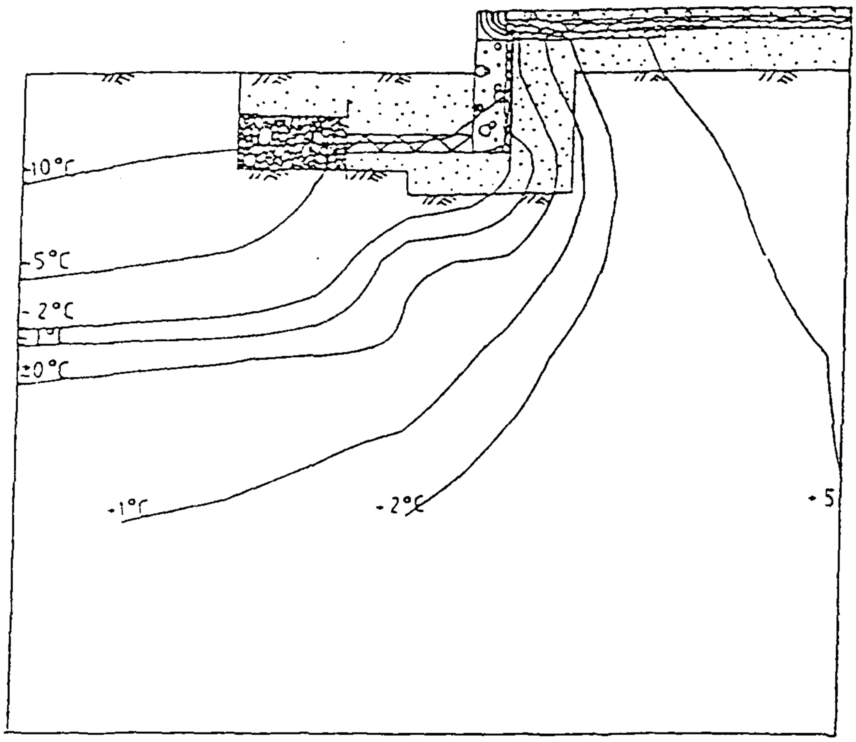

Fig. 36 Cold bridge effect with a concrete foundation wall.
Isotherms with Freezing Index = 57000 h°C,
foundation depth = 0.5m and
floor structure thermal resistance = 2.0m^{2}K/W.

(Finnish guidelines, 1987)

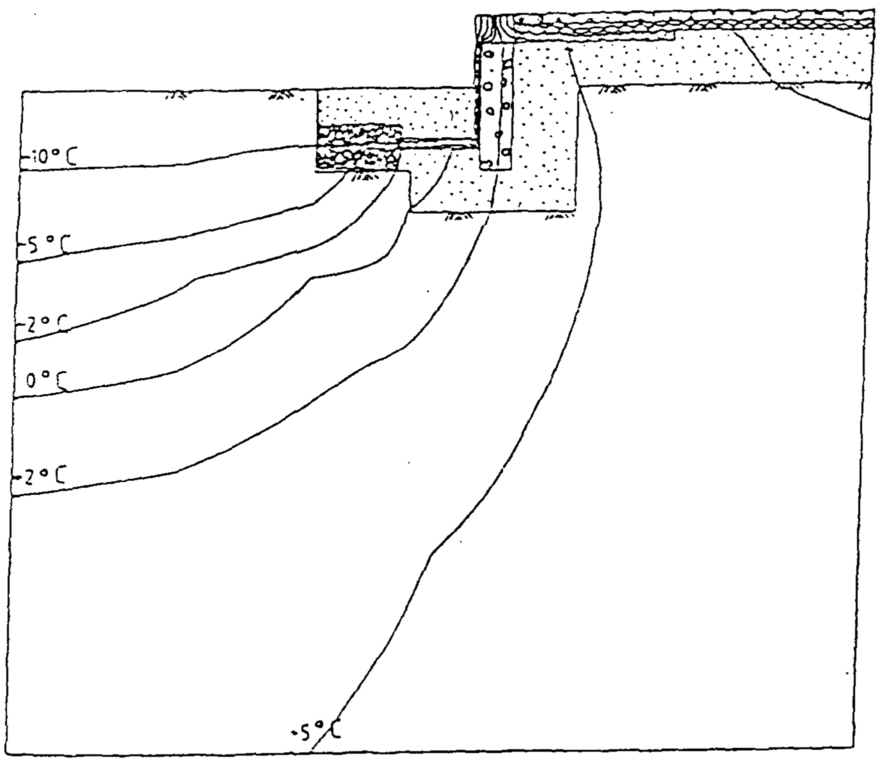

Fig. 37 Isotherms for slab-on-grade foundation.
Freezing Index = 37000 h°C, foundation depth = 0.5m
floor structure thermal resistance = 1.0 m^2K/W

(Finnish guidelines, 1987)

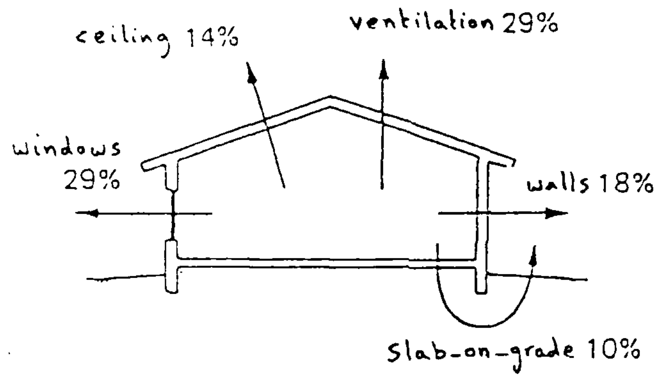

Fig. 38 Heat losses from a house with slab-on-grade foundation

(from Algaard, 1976)

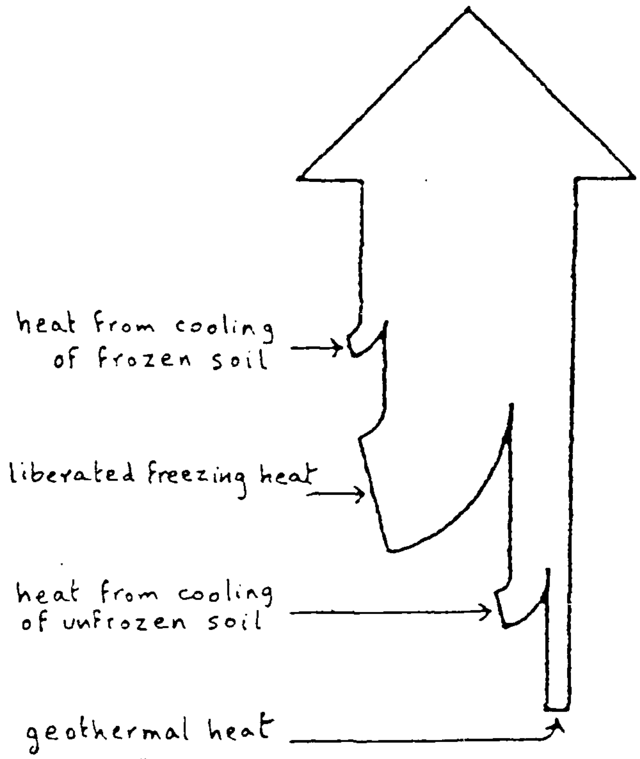

Fig. 39 Heat loss from the ground during the freezing process.

(from Kløve and Thue, 1972)

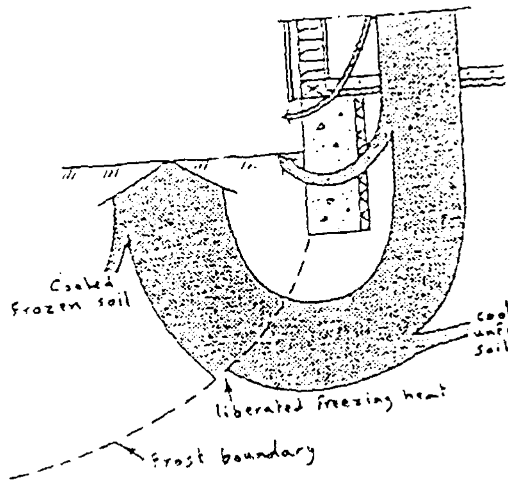

Fig. 40 A poorly insulated floor gives a lower floor temperature but some heat to frost-protect the foundation wall.

(from Torgersen, 1976)

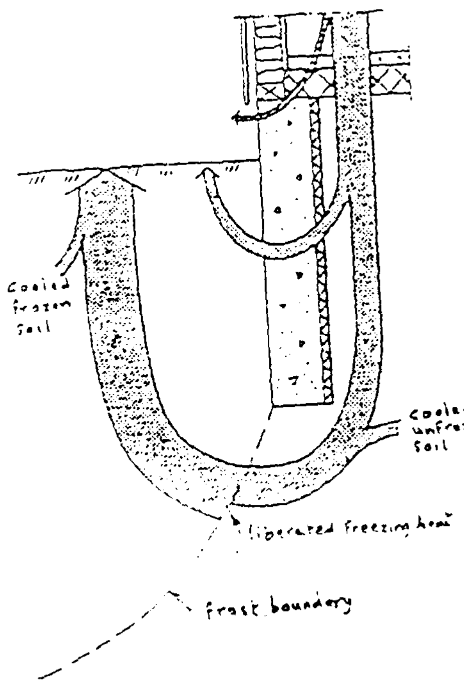

Fig. 41 A well insulated floor gives a higher floor temperature but little heat to frost-protect the foundation wall.

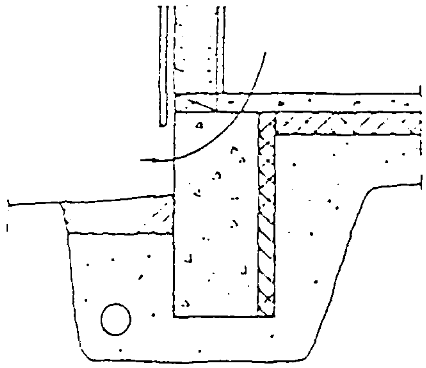

Fig. 42 A cold bridge ives an uncomfortable floor temperature and must therefore be avoided.

(from Torgersen, 1976)

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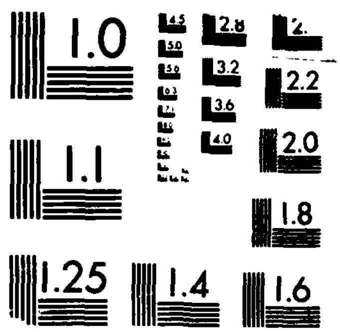

MICROCOPY RESOLUTION TEST CHART

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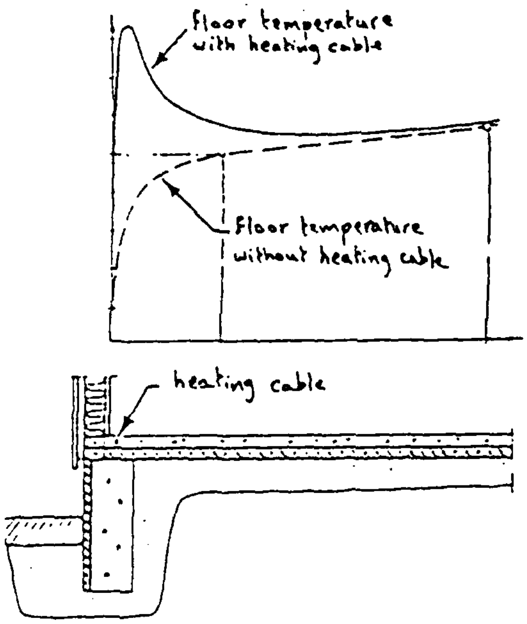


Fig. 43 A heating cable in the floor gives a satisfactory floor temperature up to the outer wall.

(from Torgersen, 1976)

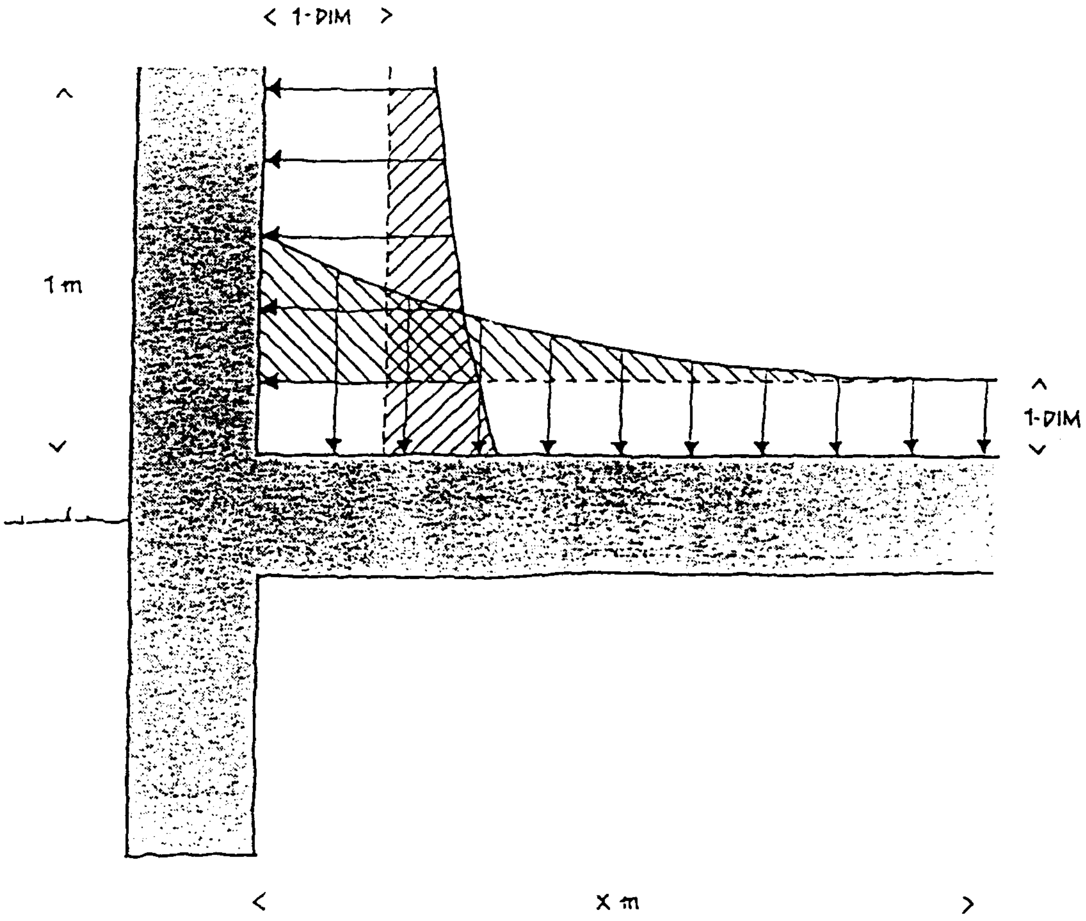


Fig 44 Heat flow through floor and wall.
(from Thermal Insulation Laboratory, 1982)

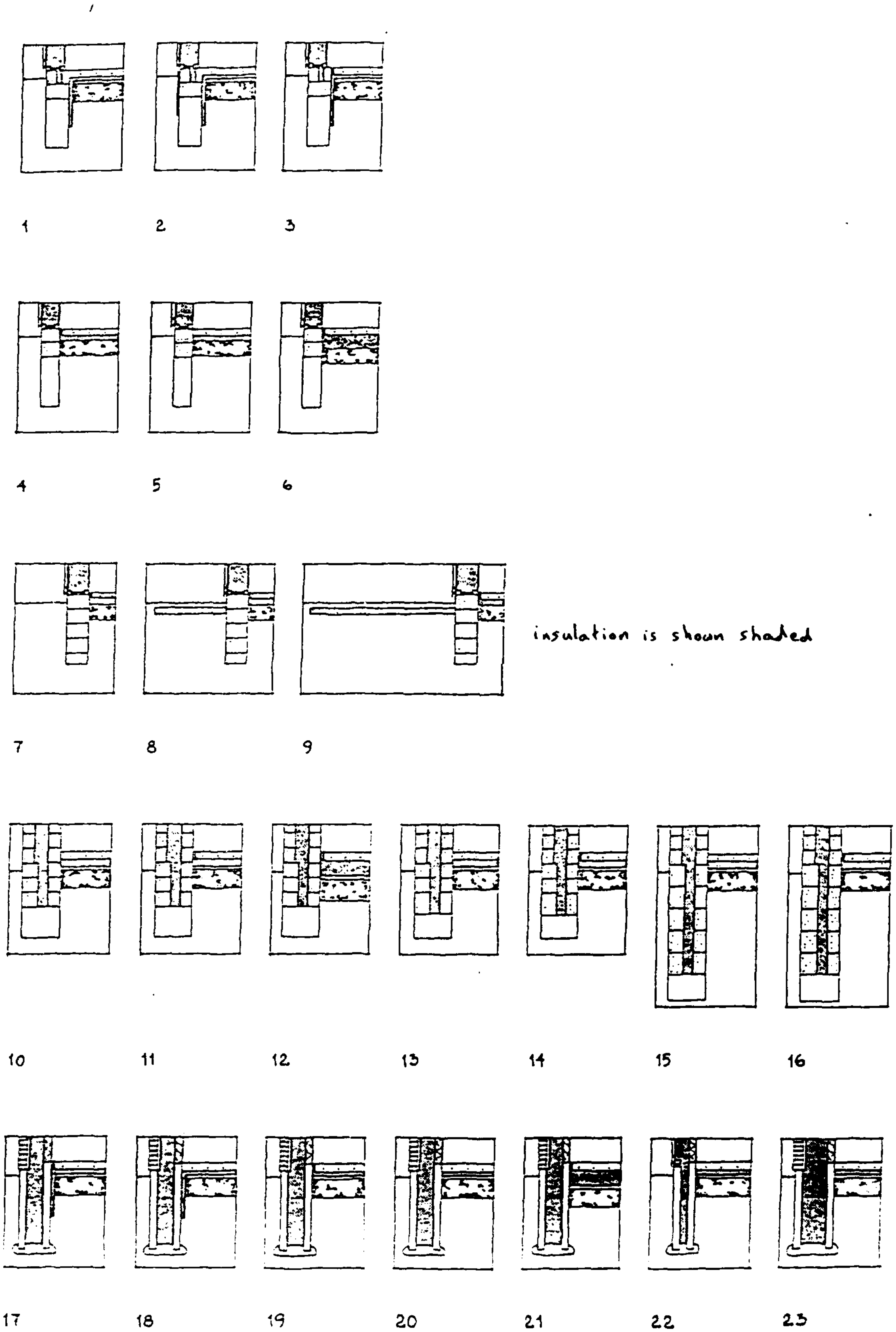


Fig. 45 Foundation designs investigated
(from Thermal Insulation Laboratory, 1982)

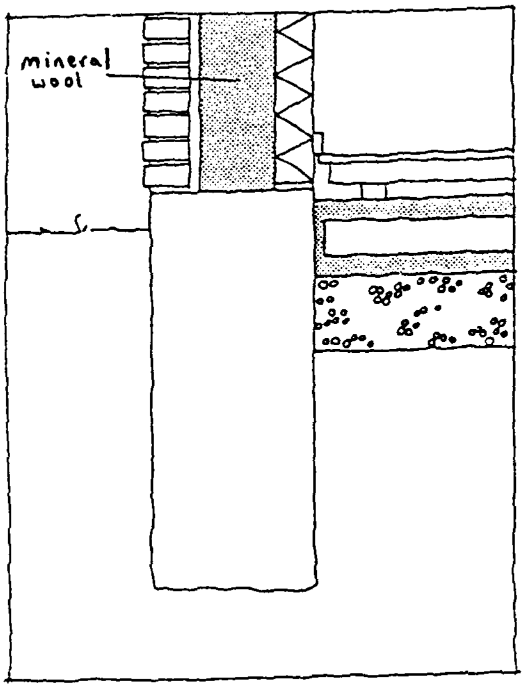


Fig. 46 Traditional Danish 'slab-on-grade' house foundation
(from Thermal Insulation Laboratory, 1982)

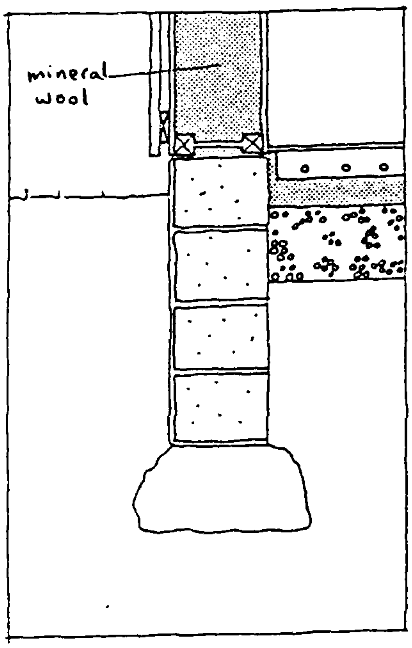
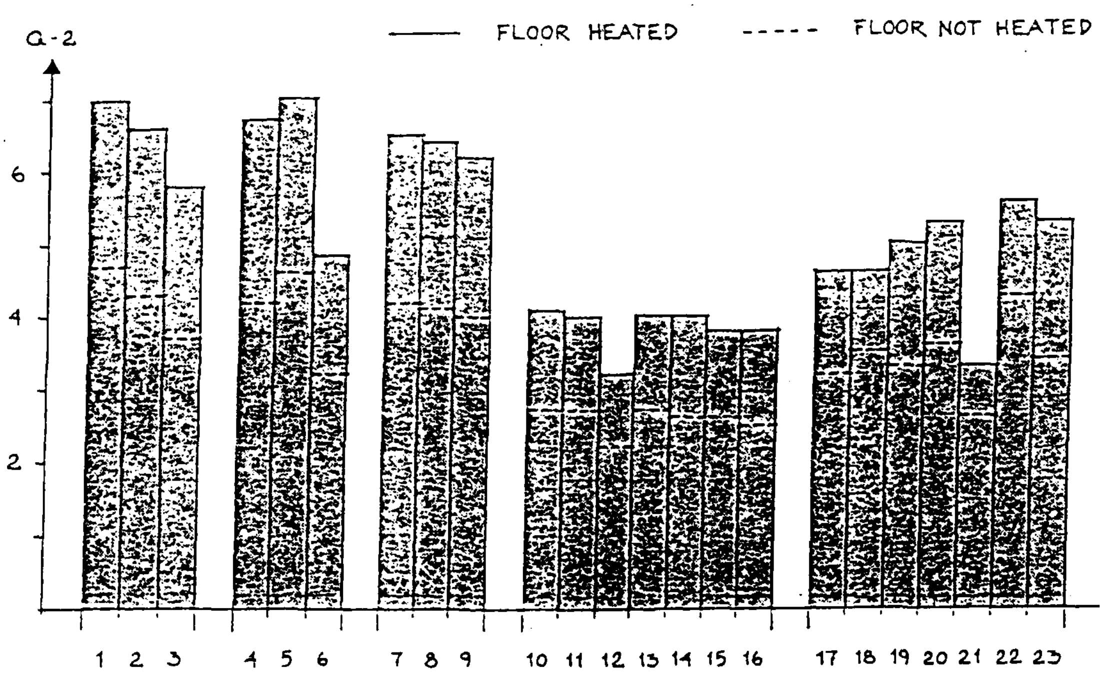


Fig. 47 Foundation wall of expanded clay blocks
(from Thermal Insulation Laboratory, 1982)



Model no	Vertical insulation *)			Horizontal floor **) insulation	Horizontal perimeter insulation	Sep. floor slab	Q-2 (Floor heated)	Q-2 (Floor not heated)
	Ext	Int	In cavity					
[NO]	[mm]	[mm]	[mm]	[mm]	[mm]	[NO]	[W/m²]	[W/m²]
1	-	50	T 75/H 200	50	-	No	7.0	4.7
2	30	50	T 75/H 200	50	-	No	6.6	4.3
3	-	50	T 75/H 200	50	-	Yes	5.8	3.7
4	-	-	-	75	-	Yes	6.7	4.2
5	-	-	-	75	-	No	7.0	4.6
6	-	-	-	200	-	Yes	4.8	3.2
7	-	-	-	75	-	Yes	6.5	4.2
8	-	-	-	75	W 1000/T 100	Yes	6.4	4.1
9	-	-	-	75	W 2000/T 100	Yes	6.2	4.0
10	-	-	T 130/H 600	100	-	No	4.1	2.7
11	-	-	T 130/H 600	100	-	Yes	4.0	2.7
12	-	-	T 130/H 600	200	-	Yes	3.2	2.2
13	-	-	T 130/H 700	100	-	No	4.0	2.7
14	-	-	T 130/H 700	100	-	Yes	4.0	2.6
15	-	-	T 130/H 1500	100	-	No	3.8	2.6
16	-	-	T 130/H 1500	100	-	Yes	3.8	2.5
17	-	50	T 225/H 1000	50	-	Yes	4.6	3.2
18	-	50	T 225/H 1000	50	-	No	4.6	3.5
19	-	-	T 225/H 1000	50	-	Yes	5.0	3.3
20	-	-	T 225/H 1000	50	-	No	5.3	3.6
21	-	-	T 225/H 1000	200	-	Yes	3.3	2.6
22	-	-	T 100/H 1000	50	-	No	5.6	4.3
23	-	-	T 325/H 1000	50	-	No	5.3	3.4

T = Thickness t_{int} = [illegible]°C t_{ext} = [illegible]°C t_{floor} = 32.0°C t_{earth} = 8.0°C

H = Height *) = Mineral wool or cellular plastics

W = Width **) = *) on top of 200-250 mm expanded clay clinkers

Fig. 48 Results of heat flow analysis
(from Thermal Insulation Laboratory, 1982)

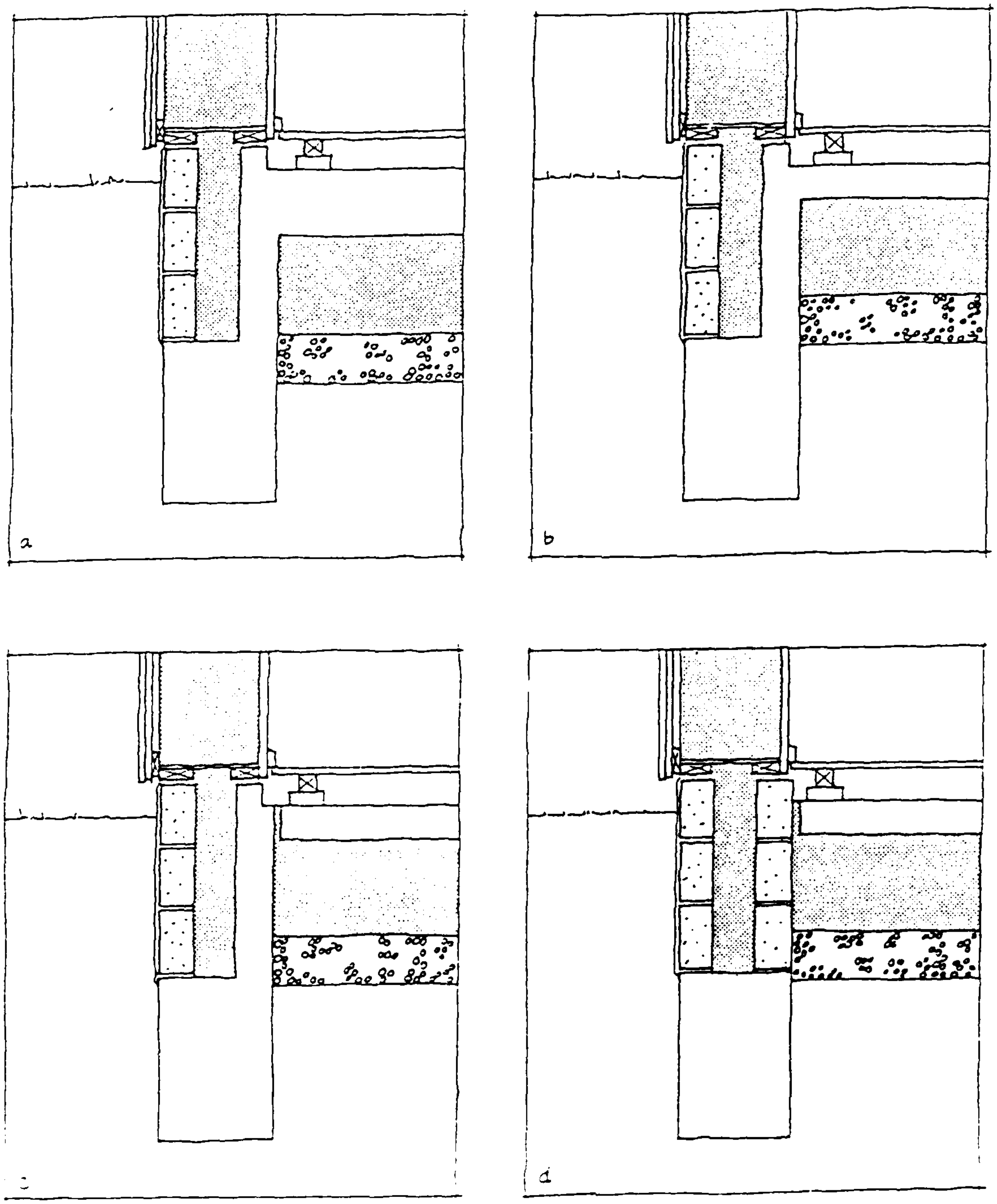


Fig. 49 A house foundation (a) and three progressively improved versions (from Thermal Insulation Laboratory, 1982)

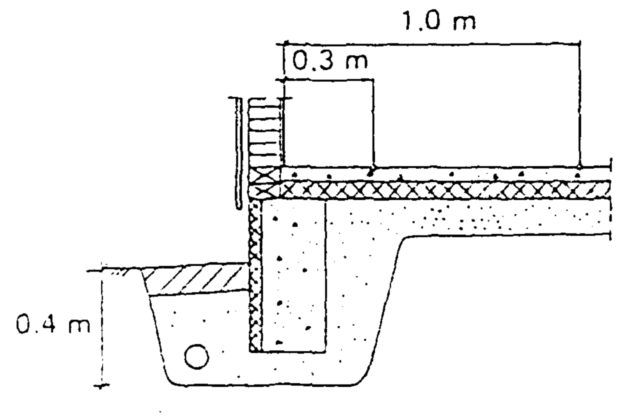


Fig. 50 'Slab-on-grade' construction on which computer analysis of floor temperature is based.

(from Torgersen, 1976)

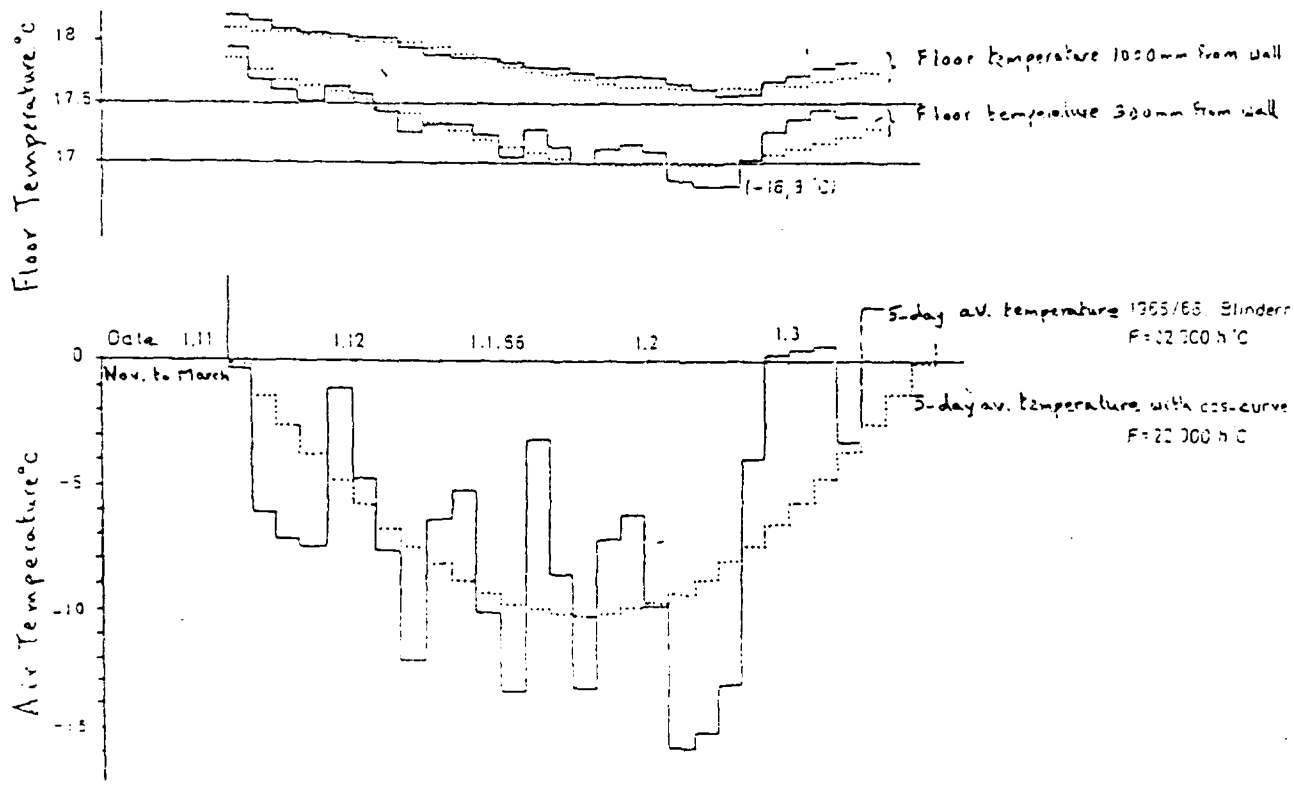
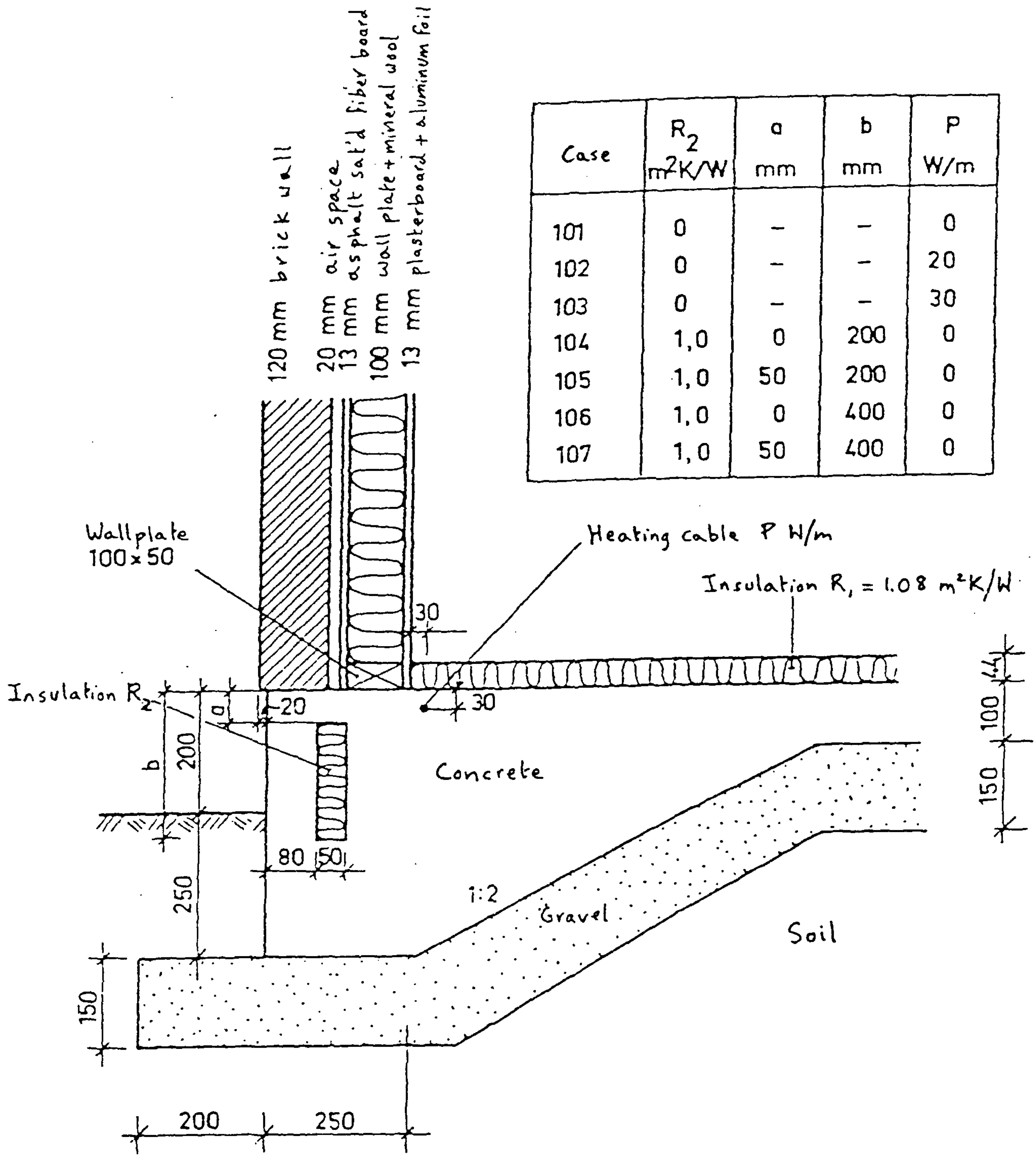


Fig. 51 Effect of variation in air temperature on floor temperature at points 0.3m and 1.0m from outer wall.

(from Torgersen, 1976)



Case	R_2 m²K/W	a mm	b mm	P W/m
101	0	–	–	0
102	0	–	–	20
103	0	–	–	30
104	1,0	0	200	0
105	1,0	50	200	0
106	1,0	0	400	0
107	1,0	50	400	0

Fig. 52 Edge-stiffened concrete slab with insulation on top of slab (Fig. 3.1 of Adamson, 1973)

Case	c mm	λ_1 W/mK	R_2 m^2K/W	a mm	b mm	P W/m
141	65	0,06	0	–	–	0
142	65	0,06	0	–	–	20
143	65	0,06	1,0	0	200	0
144	65	0,06	1,0	50	200	0
145	65	0,06	1,0	50	400	0
146	140	0,13	1,0	–	–	0
147	140	0,13	1,0	–	–	20
148	140	0,13	1,0	0	200	0
149	140	0,13	1,0	50	200	0

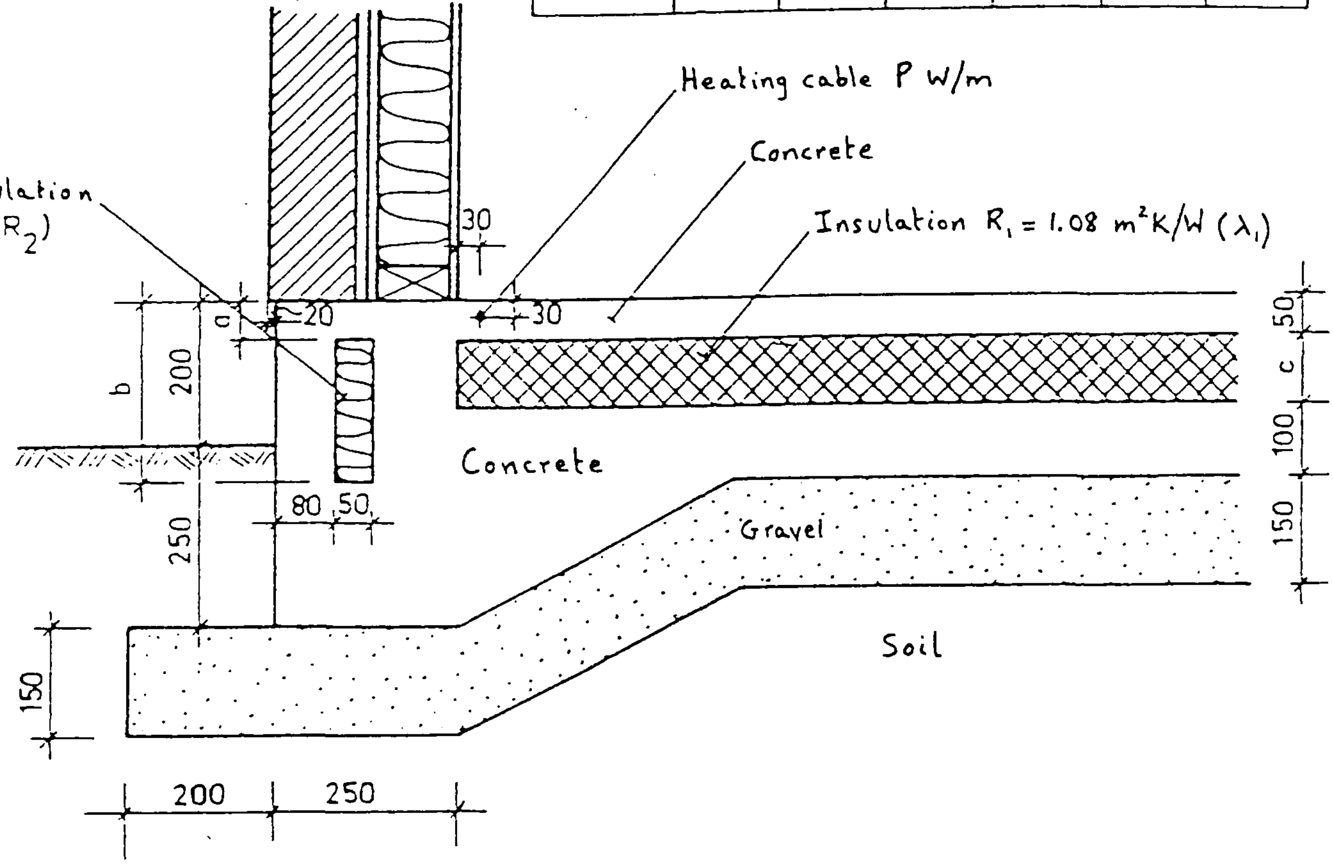
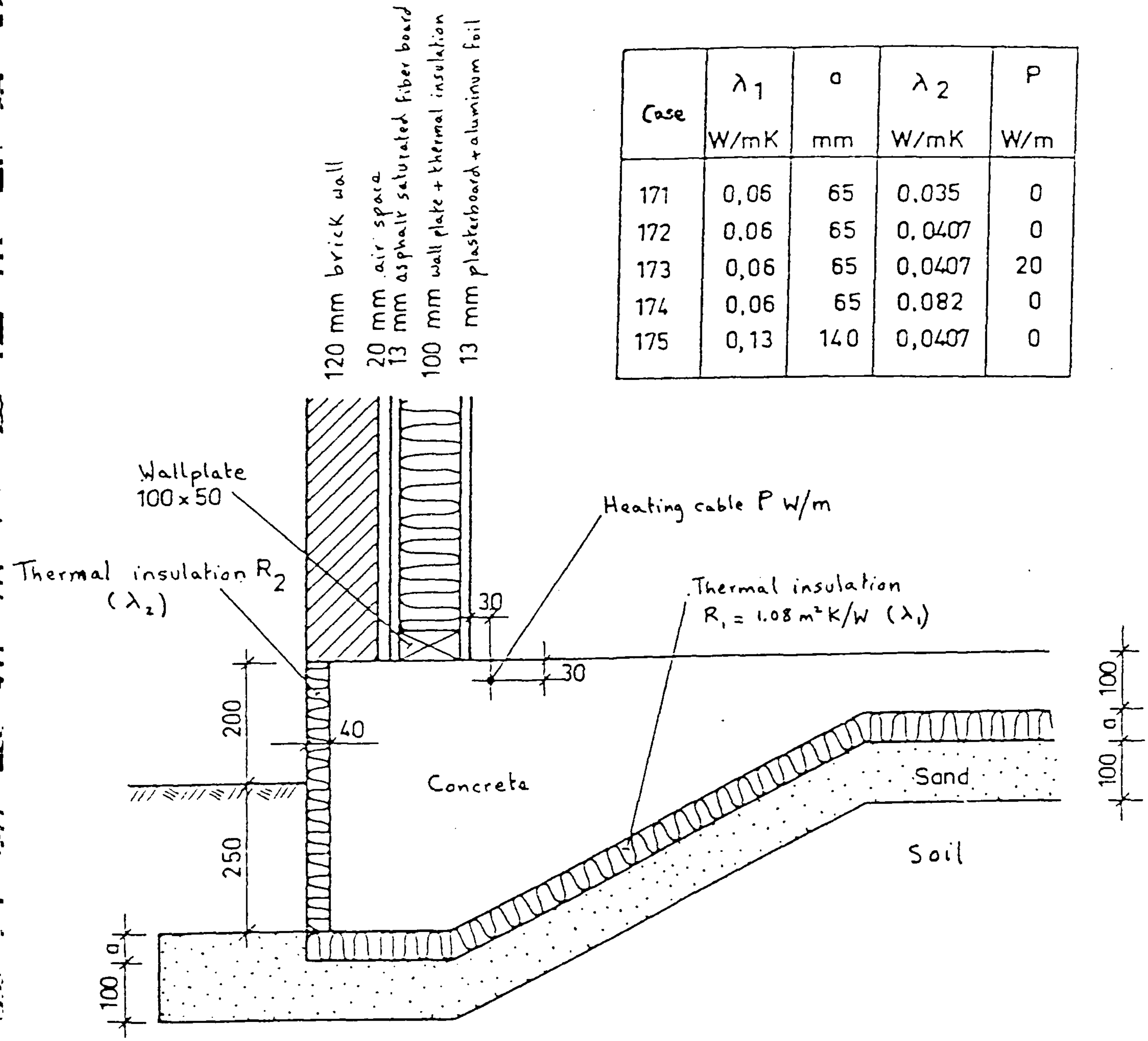


Fig. 53 Edge-stiffened concrete slab with insulation cast into slab (Fig. 3.4 of Adamson, 1973)



Case	λ_1 W/mK	a mm	λ_2 W/mK	P W/m
171	0,06	65	0.035	0
172	0.06	65	0.0407	0
173	0,06	65	0,0407	20
174	0,06	65	0.082	0
175	0,13	140	0,0407	0

Fig. 54 Edge-stiffened concrete slab with insulation under slab (Fig. 3.7 of Adamson, 1973)

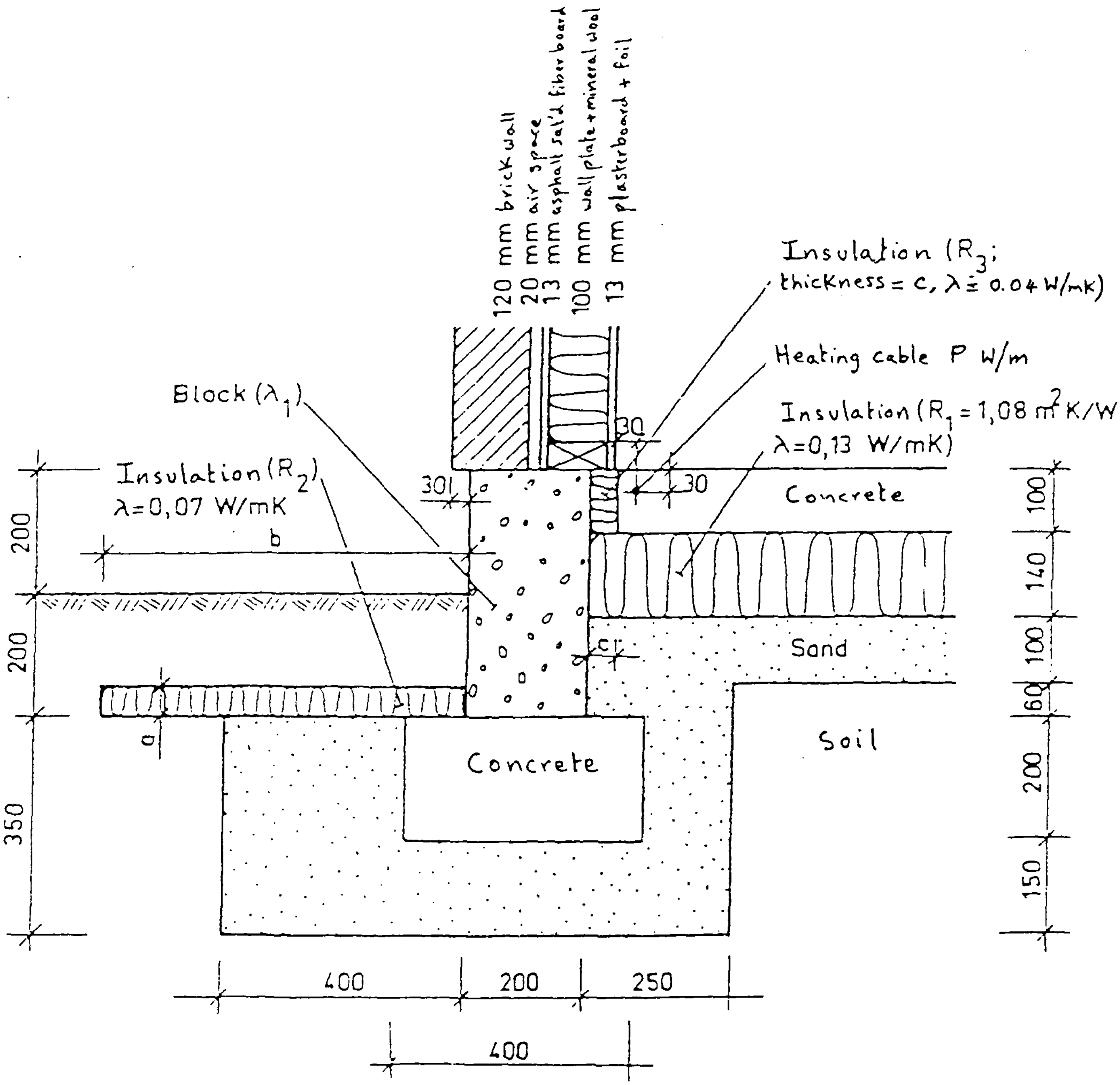


Fig. 55 Concrete slab with foundation wall of lightweight clinker blocks on concrete footing. Ground insulation.
(Fig. 4.5 of Adamson, 1973)

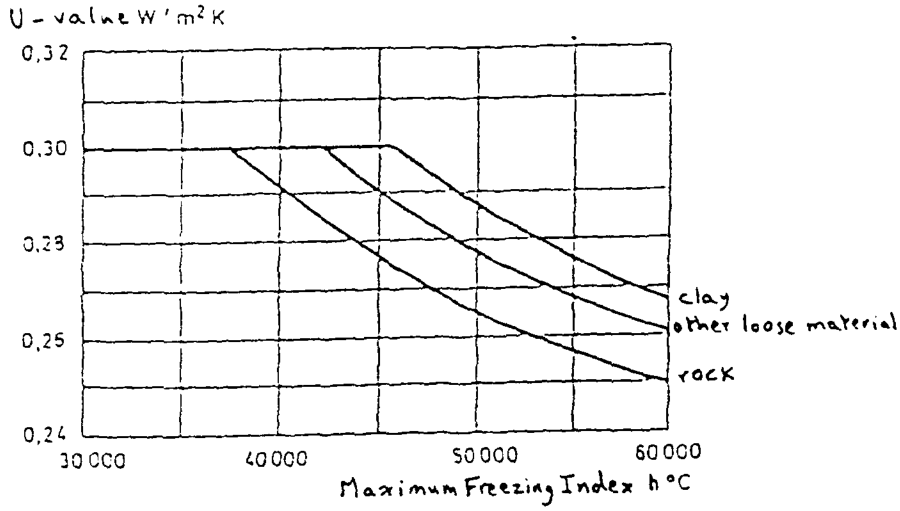


Fig. 56 Recommended U -values for slab-on-grade with a building that is heated to at least 18°C

(from 'Building Details', A 521.111)

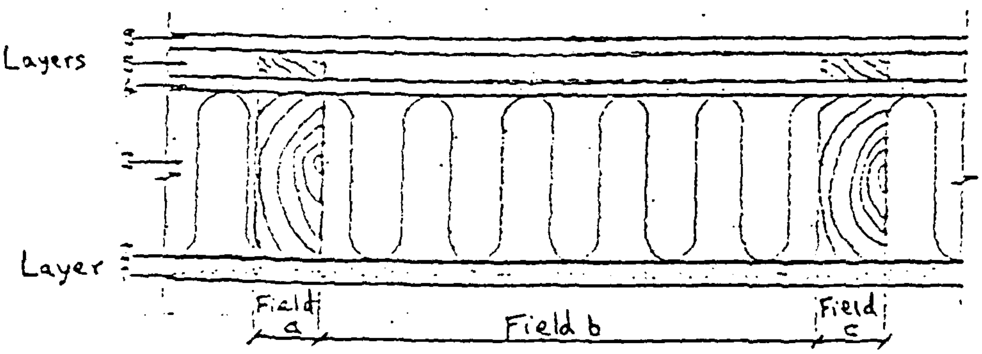


Fig. 57 Division of a construction into layers and fields

(from Norwegian Standard NS 3031)

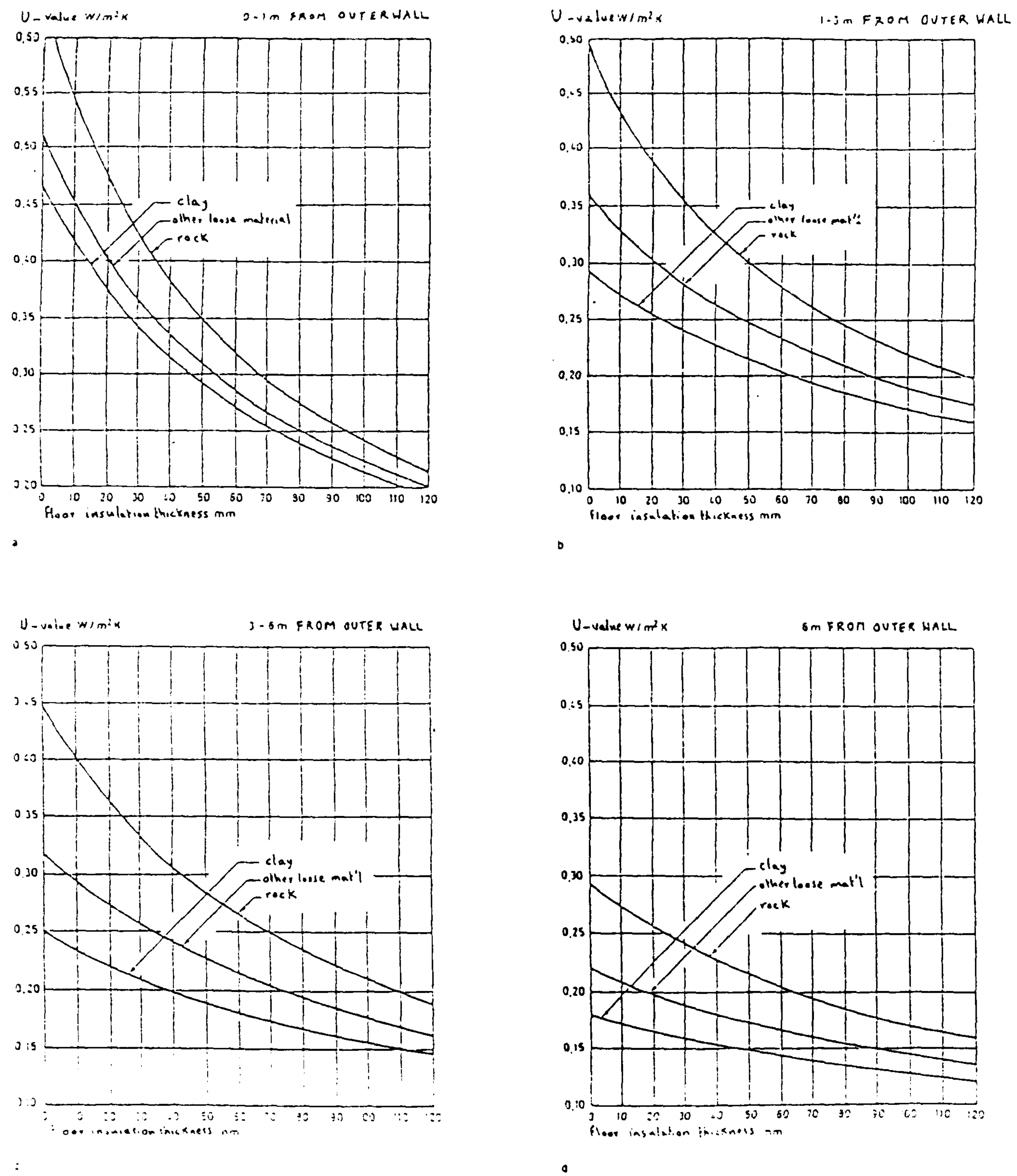


Fig. 58 a-d Floor insulation and U-value

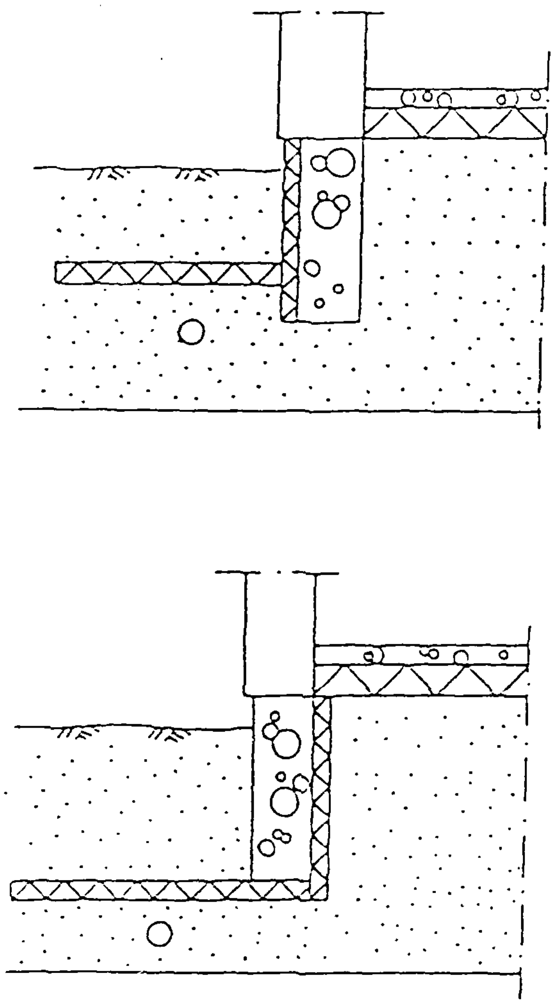
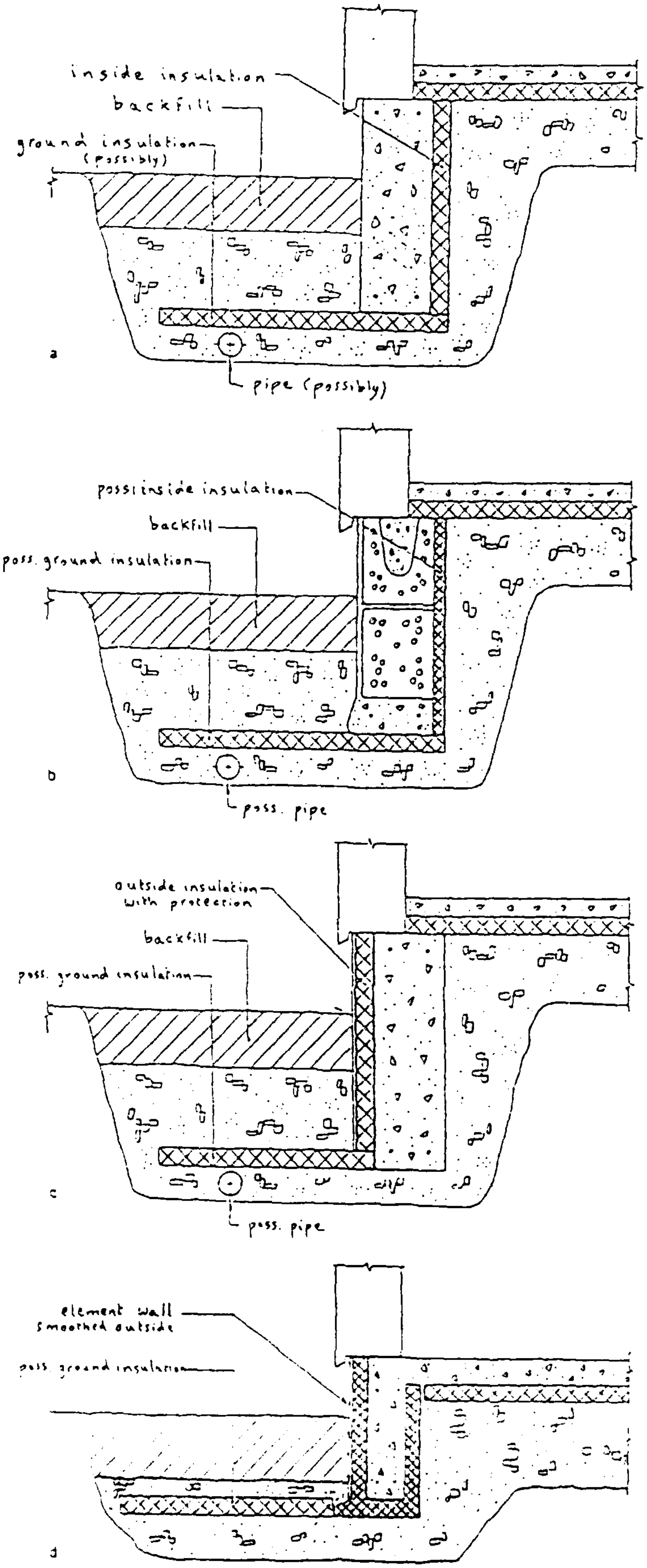


Fig. 59 Recommended location of insulation in association with a foundation wall.

(Finnish guidelines, 1987)



a East foundation wall with inside insulation.

b Built foundation wall with light aggregate blocks on cast concrete footing, possible with extra inside insulation.

c Cast foundation wall with outside insulation with protected surface.

d Cast foundation wall in elements of polystyrene with smoothed outside.

Fig. 60 Types of foundation wall

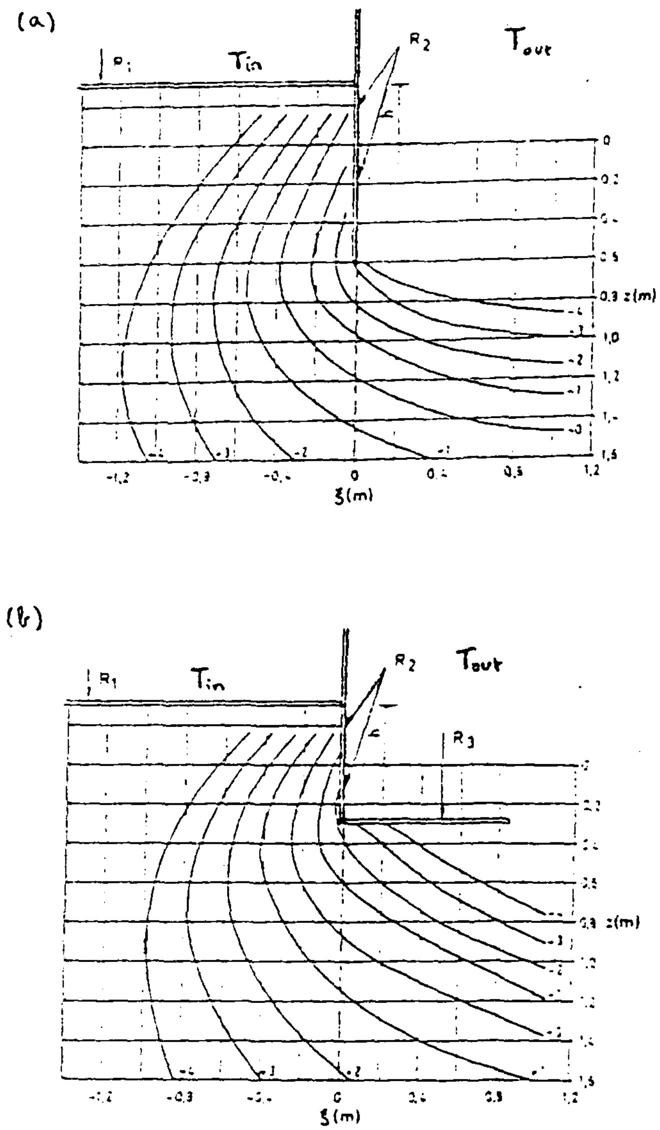


Fig. 61 Effect of ground insulation on isotherms

(a) No ground insulation

(b) Ground insulation: $R_3 = 1.08 m^2 K/W$.
Square building 10x10m. Section along diagonal.
$R_1 = 1.08 m^2 K/W = R_2$, Pedestal height = 0.3m.
Clay soil. Outside temperature = -11.0°C.

(DIAG. 117a and DIAG. 118a of Adamson et al, 1973)

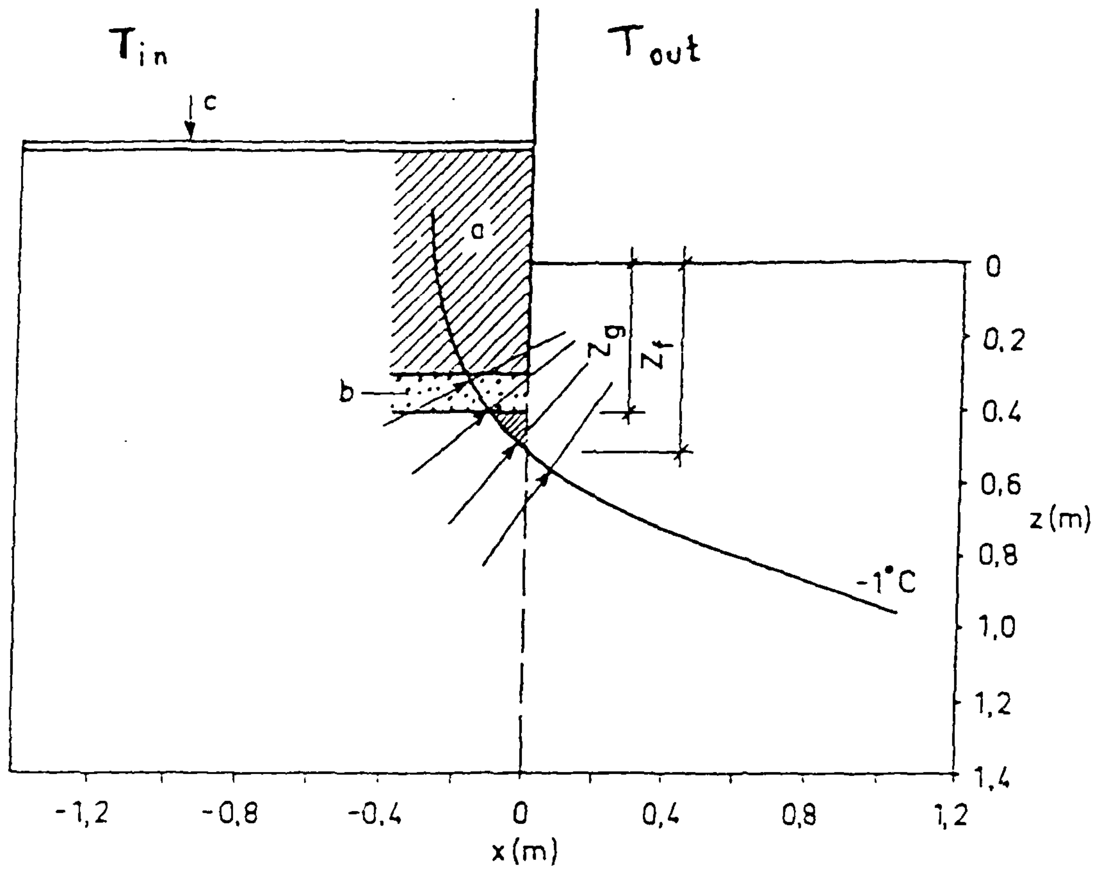


Fig. 62 Freezing zone's influence on ground construction.

(a) foundation wall or edge beam

(b) draining material that is non-frost-susceptible

(c) slab

(Fig. 17 of Adamson et al, 1973)

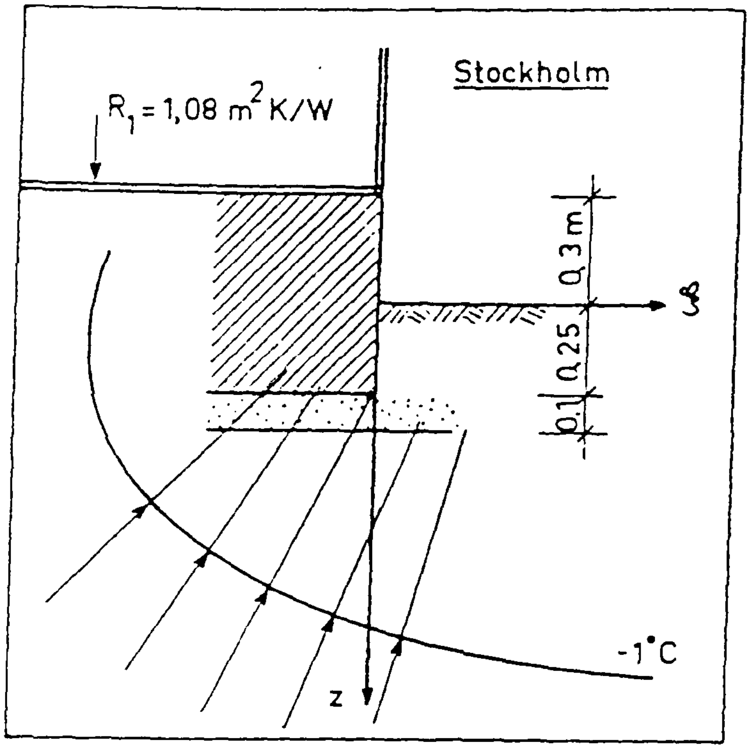


Fig. 63 -1°C isotherm at a corner of a square building 10x10m. Section along diagonal. Clay soil. No foundation wall insulation. Outside temperature = -9.9°C. Foundation depth = 0.35m.

(Fig. 20 of Adamson et al, 1973)

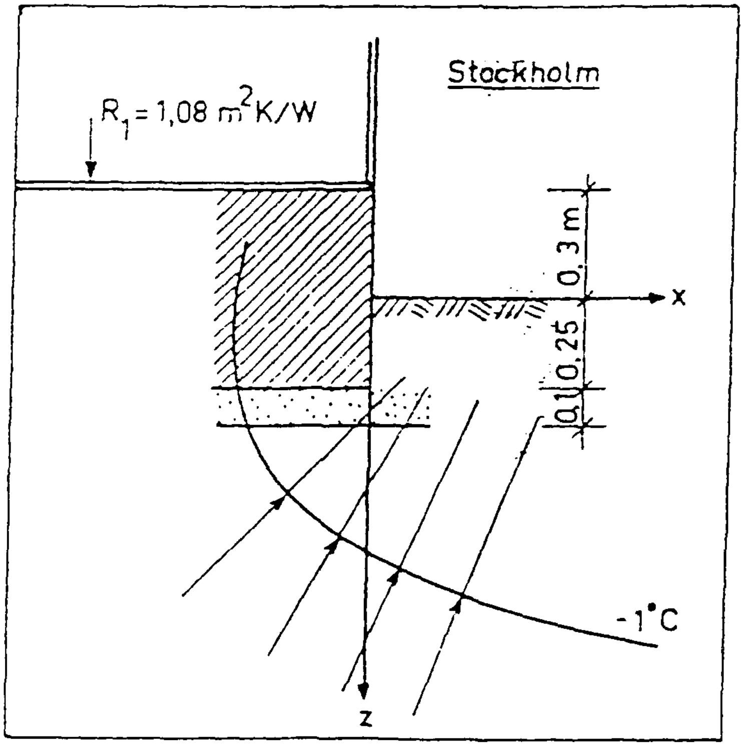


Fig. 64 -1°C isotherm at 0.8 m from corner. Otherwise same conditions as for Fig. 63

(Fig. 21 of Adamson et al, 1973)

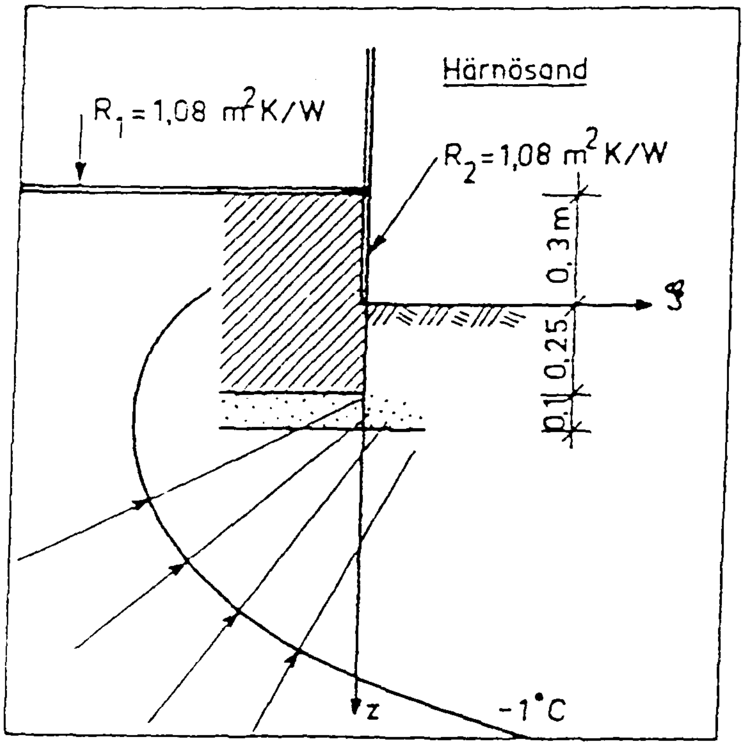


Fig. 65 $-1^{O}C$ isotherm at a corner of a square building 10x10m. Section along diagonal. Clay soil. Foundation wall insulation. Outside temperature = $-11.0^{O}C$. Foundation depth = 0.5m.

(Fig. 22 of Adamson et al, 1973)

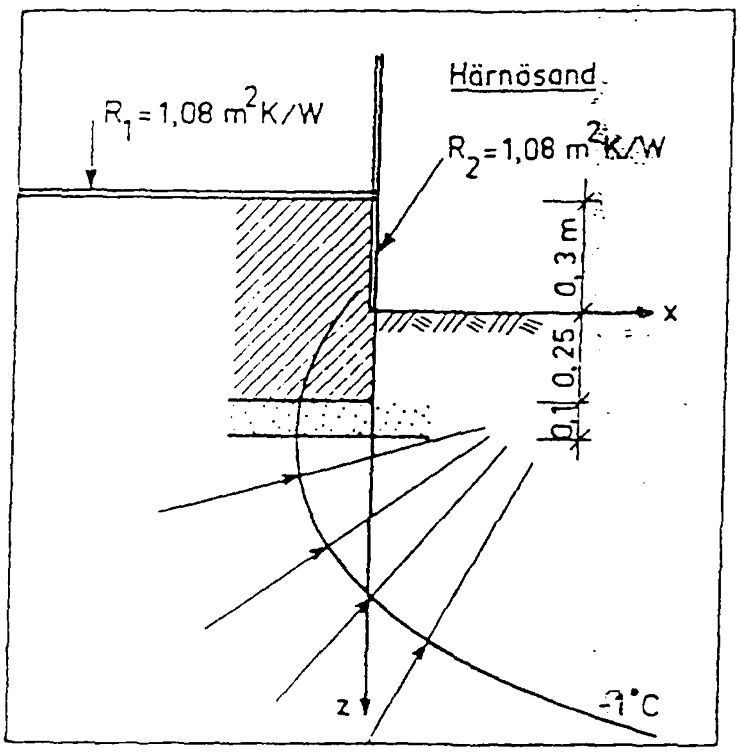
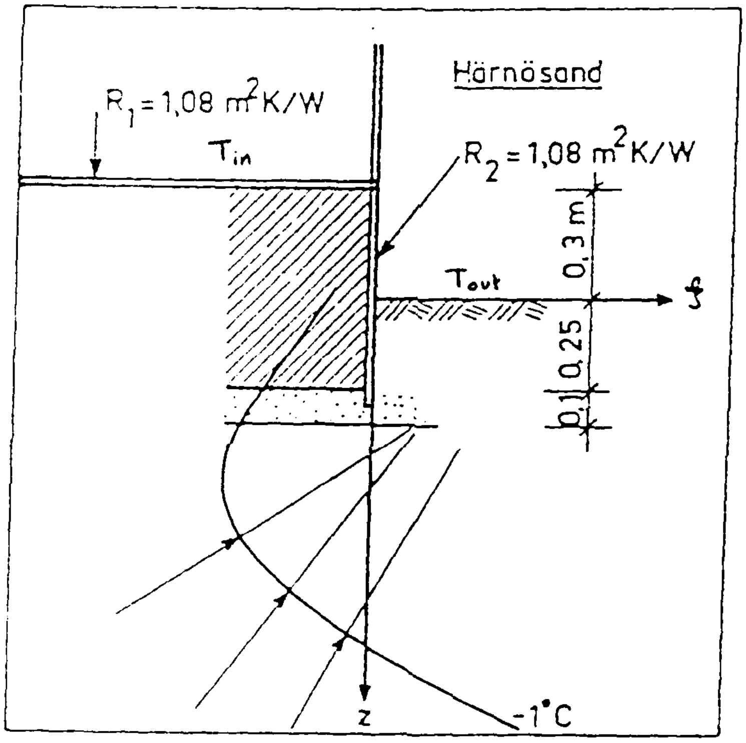


Fig. 66 $-1^{\circ}C$ isotherm at 0.8m from a corner. Otherwise same conditions as for Fig. 65

(Fig. 23 of Adamson et al, 1973)



Tout varies according to:
4.4 + 17.4 cos ωt

Isotherms apply to state 4 weeks after minimum Tout of −13°C
(Claesson, 1988)

cf. Fig. 69

Fig. 67 -1°C isotherm at a corner of a square building 10x10m. Section along diagonal. Clay soil. Foundation wall insulation. Outside temperature = -11.0°C. Foundation depth = 0.35m.

(Fig. 24 of Adamson et al, 1973)

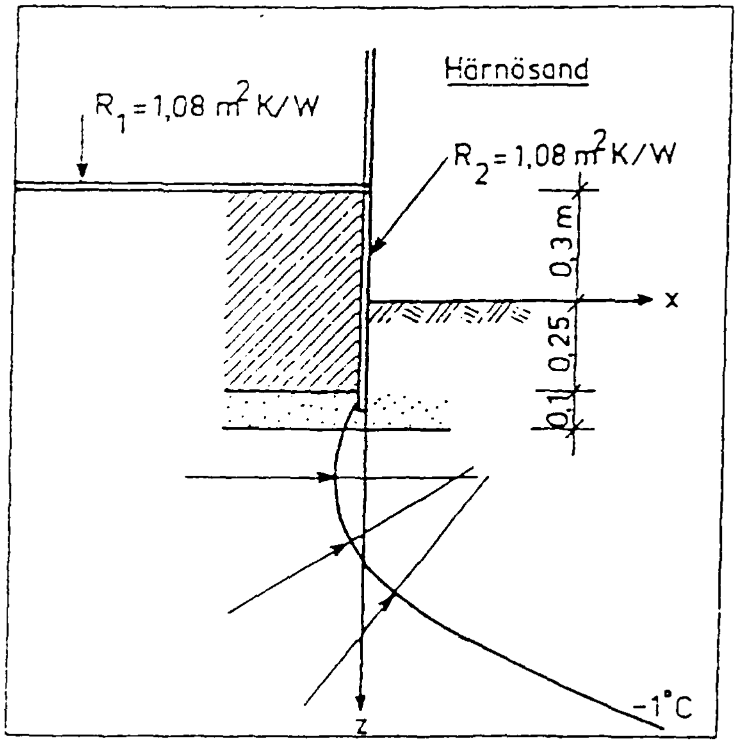
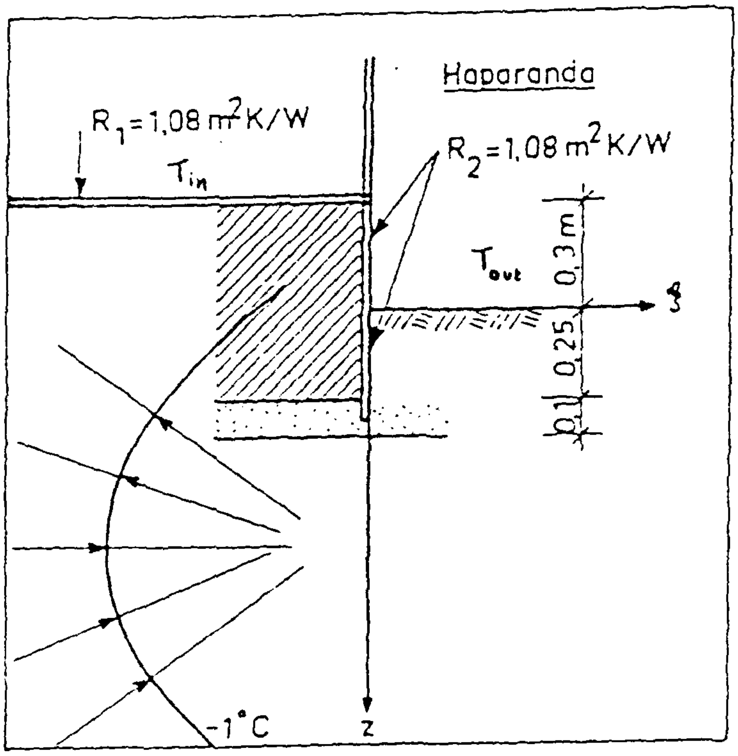


Fig. 68 $-1^{\circ}C$ isotherm at 0.8m from corner.

Otherwise same conditions as for Fig. 67

(Fig. 25 of Adamson et al, 1973)



T_{out} varies according to: $1.6 + 19.6 \cos \omega t$

Isotherms apply to state 7 weeks after minimum T_{out} of $-18°C$

(Claesson, 1988)

cf. Fig. 67

Fig. 69 $-1°C$ isotherm at a corner of a square building 10x10m. Section along diagonal. Clay soil. Foundation wall insulation. Outside temperature = -11.4°C. Foundation depth = 0.35m.

(Fig. 26 of Adamson et al, 1973)

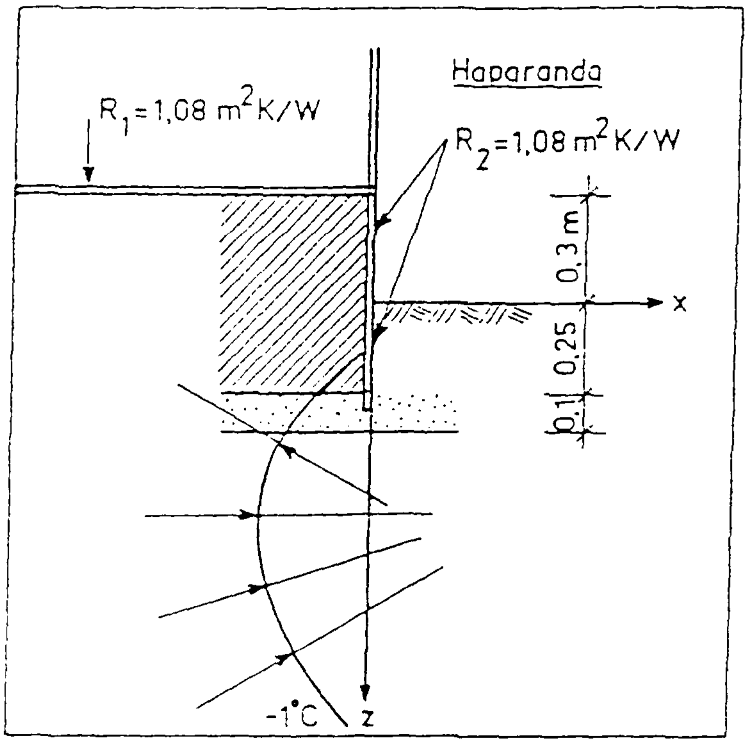


Fig. 70 $-1^{\circ}C$ isotherm at 0.8m from corner.
Otherwise same conditions as for Fig. 69 .

(Fig. 27 of Adamson et al, 1973)

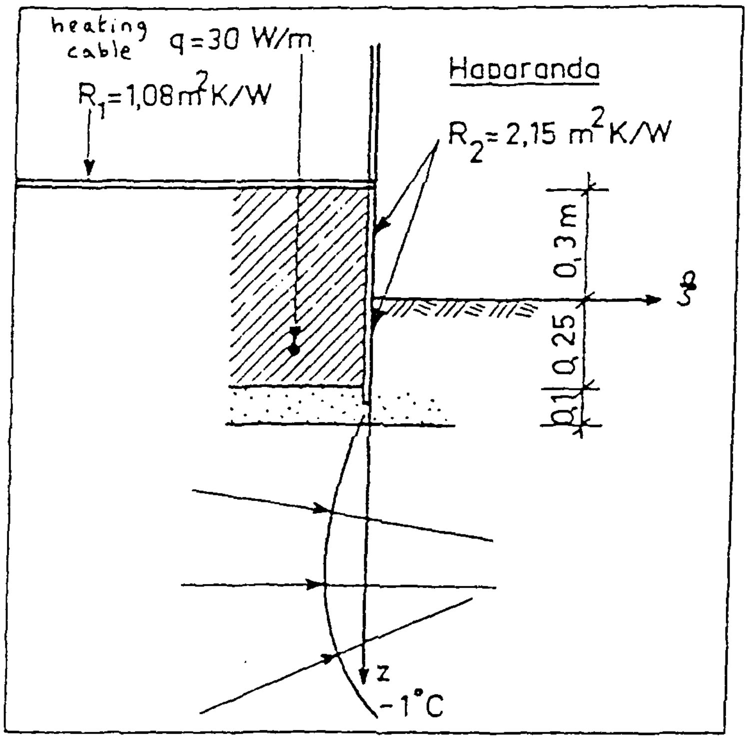


Fig. 71 -1°C isotherm at a corner of a square building 10x10m. Section along diagonal. Clay soil. Foundation wall insulation. Outside temperature = -15.8°C. Foundation depth = 0.35m.

(Fig. 28 of Adamson et al, 1973)

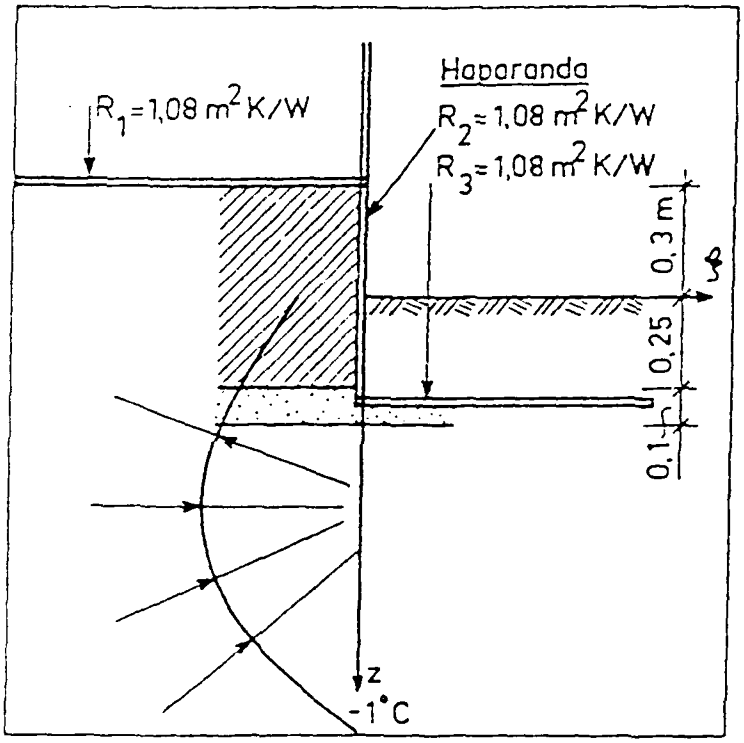


Fig. **72** $-1^{\circ}C$ isotherm at a corner of a square building 10x10m. Section along diagonal. Clay soil. Foundation wall and ground insulation. Outside temperature = $-13.1^{\circ}C$. Foundation depth = 0.35m.

(Fig. 29 of Adamson et al, 1973)

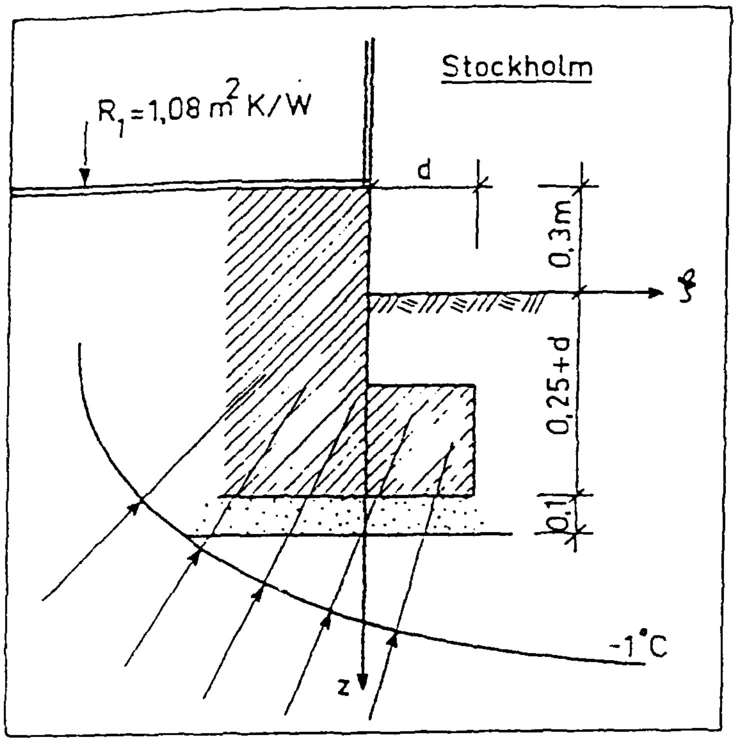


Fig. 73 -1°C isotherm at a corner of a square building 10x10m. Projecting construction with Foundation depth = (0.35+d)m. Otherwise same conditions as for Fig. 63

(Fig. 32 of Adamson et al, 1973)

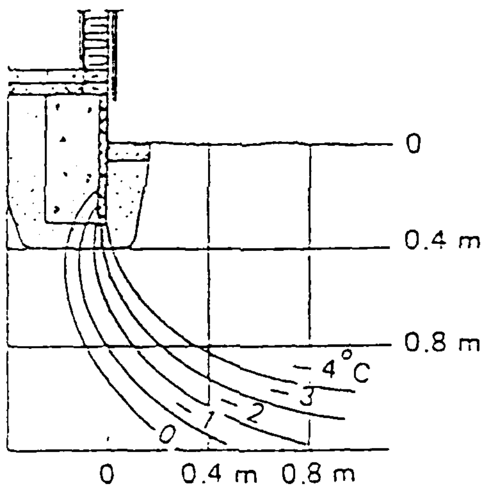
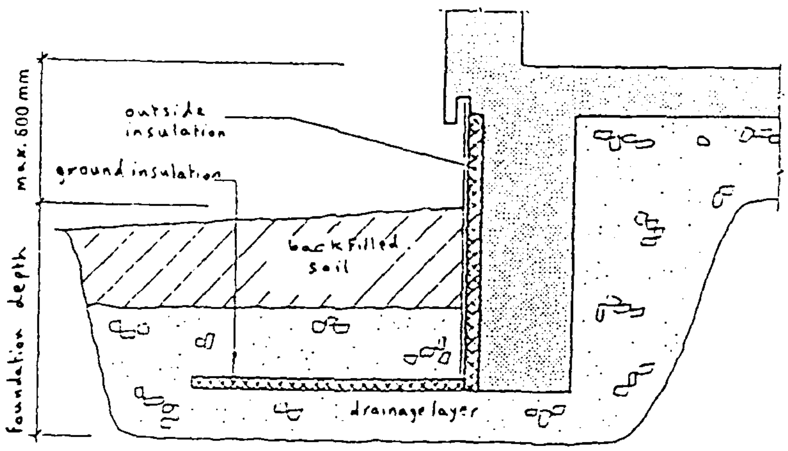
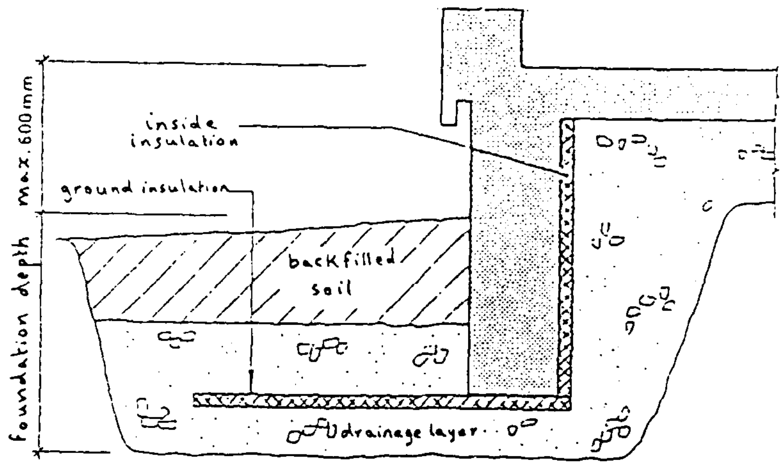


Fig. 74 Example of calculated temperature distribution at a foundation

(from Torgersen, 1976)



a



b

For foundation depth see Tables 6 and 7

Fig. 75 Placing of ground insulation
Frost-protection with horizontal
ground insulation outside foundation wall

a. Externally insulated foundation wall

b. Internally insulated foundation wall

(from 'Building Details', A 521.111)

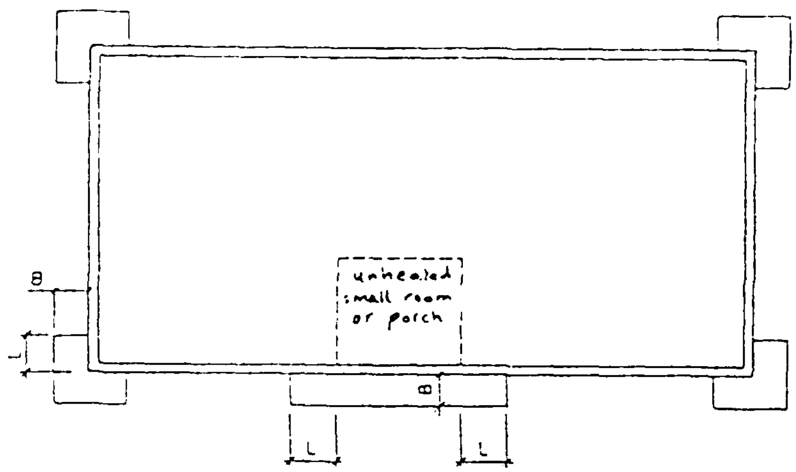


Fig. 76 Ground insulation at corners and an unheated small room

(from 'Building Details', A 521.111)

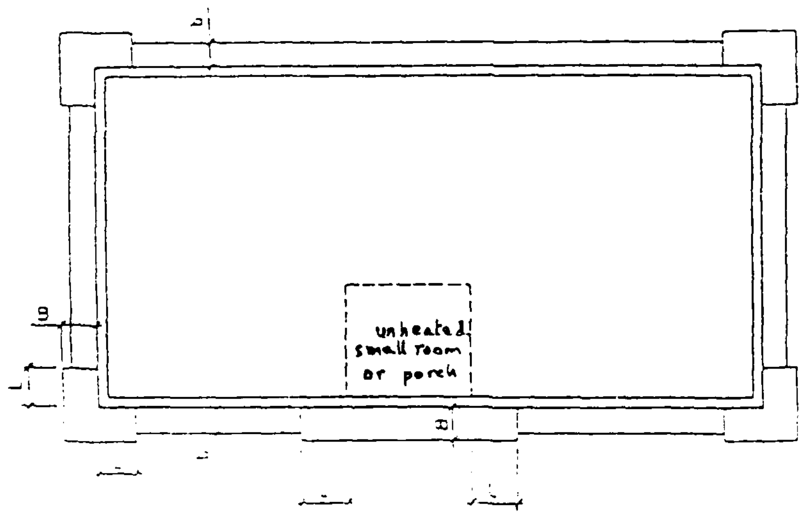


Fig. 77 Ground insulation along all walls, at corners and outside an unheated small room.

(from 'Building Details', A 521.111)

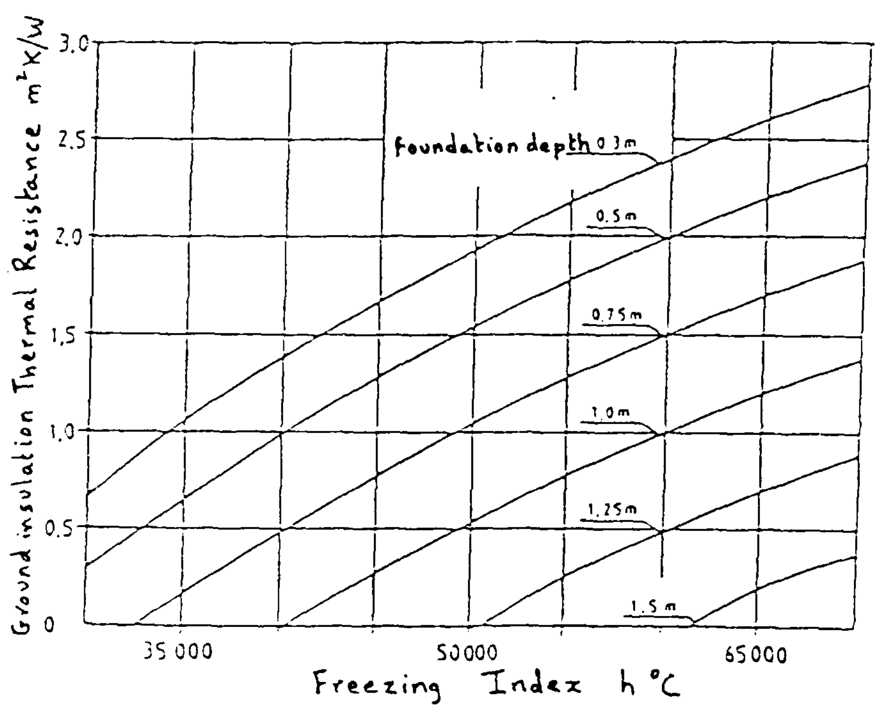


Fig. 78 Design of frost protection for heated structures. Slab-on-grade floor structure with thermal resistance = $2.6 m^2 K/W$.

(Finnish guidelines, 1987)

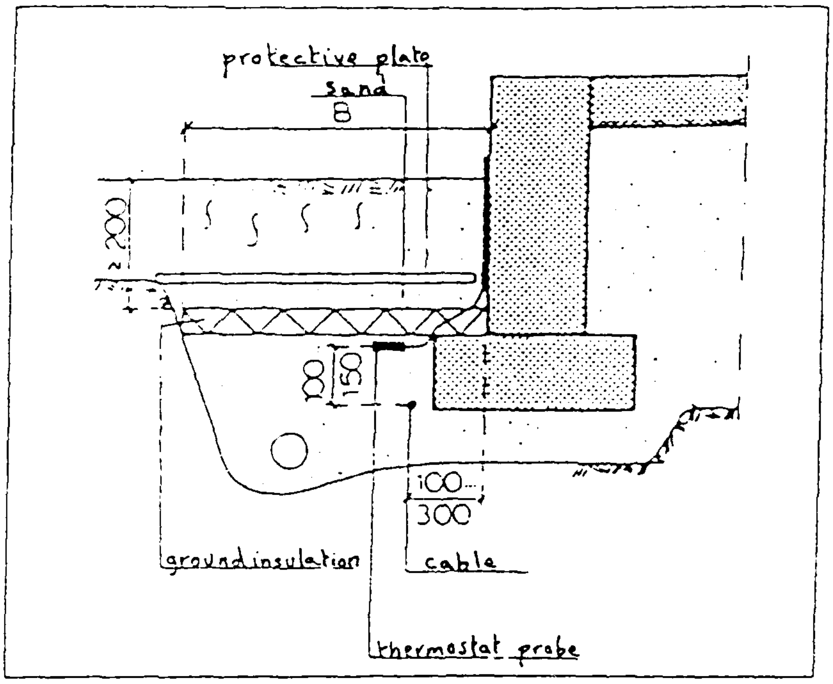


Fig. 79 Location of heating cable.

(Finnish guidelines, 1987)

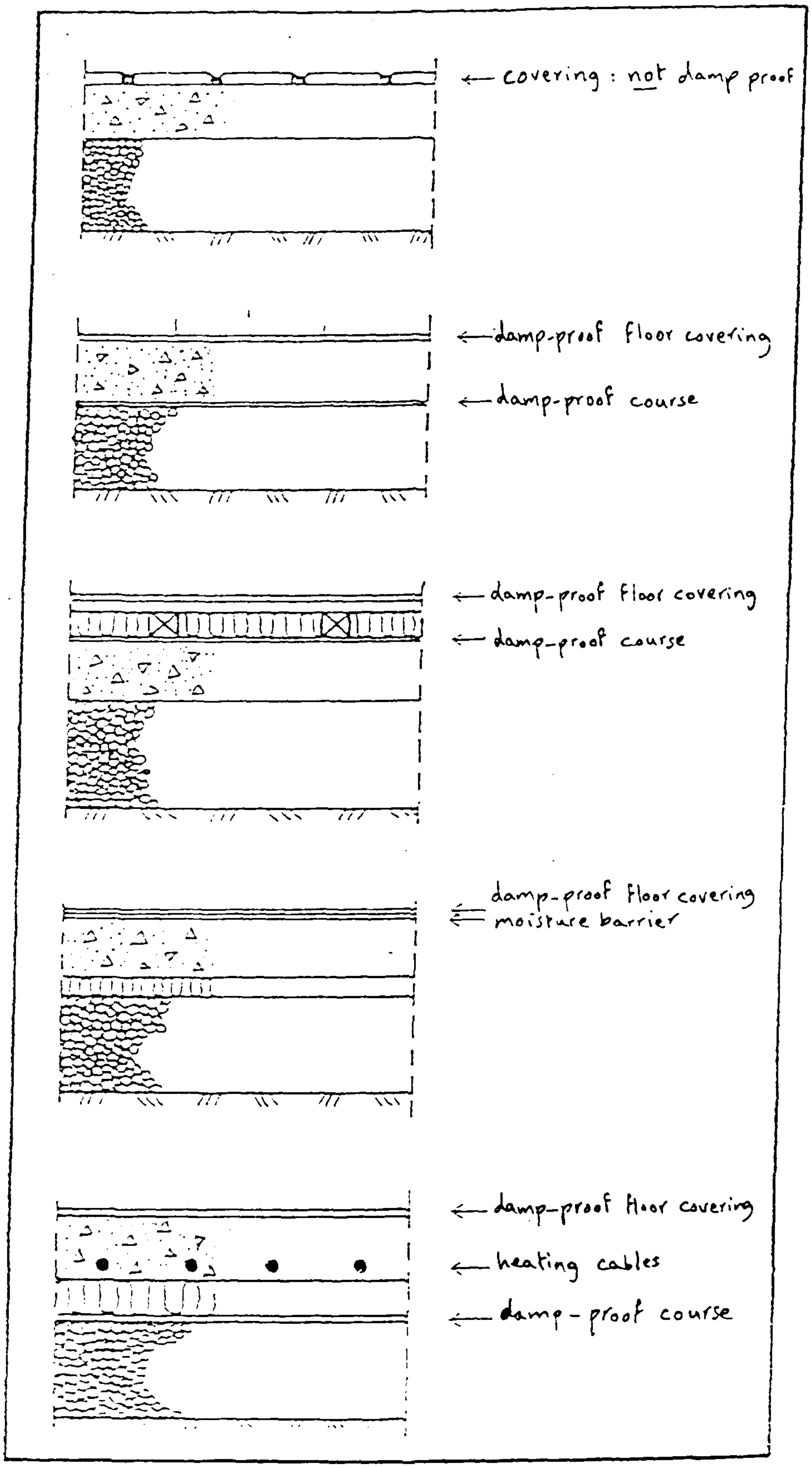


Fig. 80 Position of the damp-proof course for floors with damp-proof floor coverings. When the floor covering is not damp-proof, no damp-proof course is necessary.

(from Kldve and Thue, 1972)

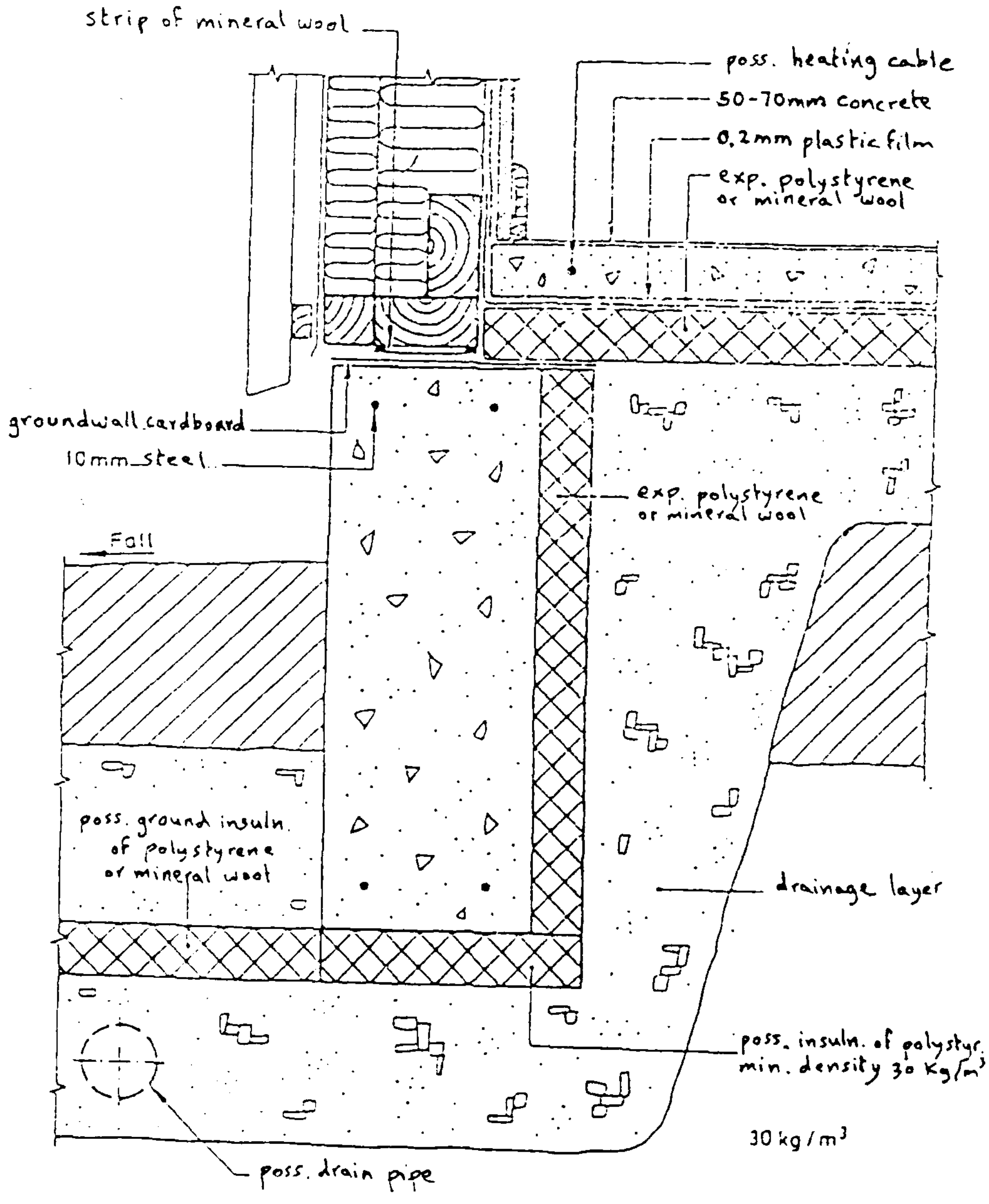


Fig. 81 Concrete slab with internally insulated concrete foundation wall

(from 'Building Details', A 521.111)

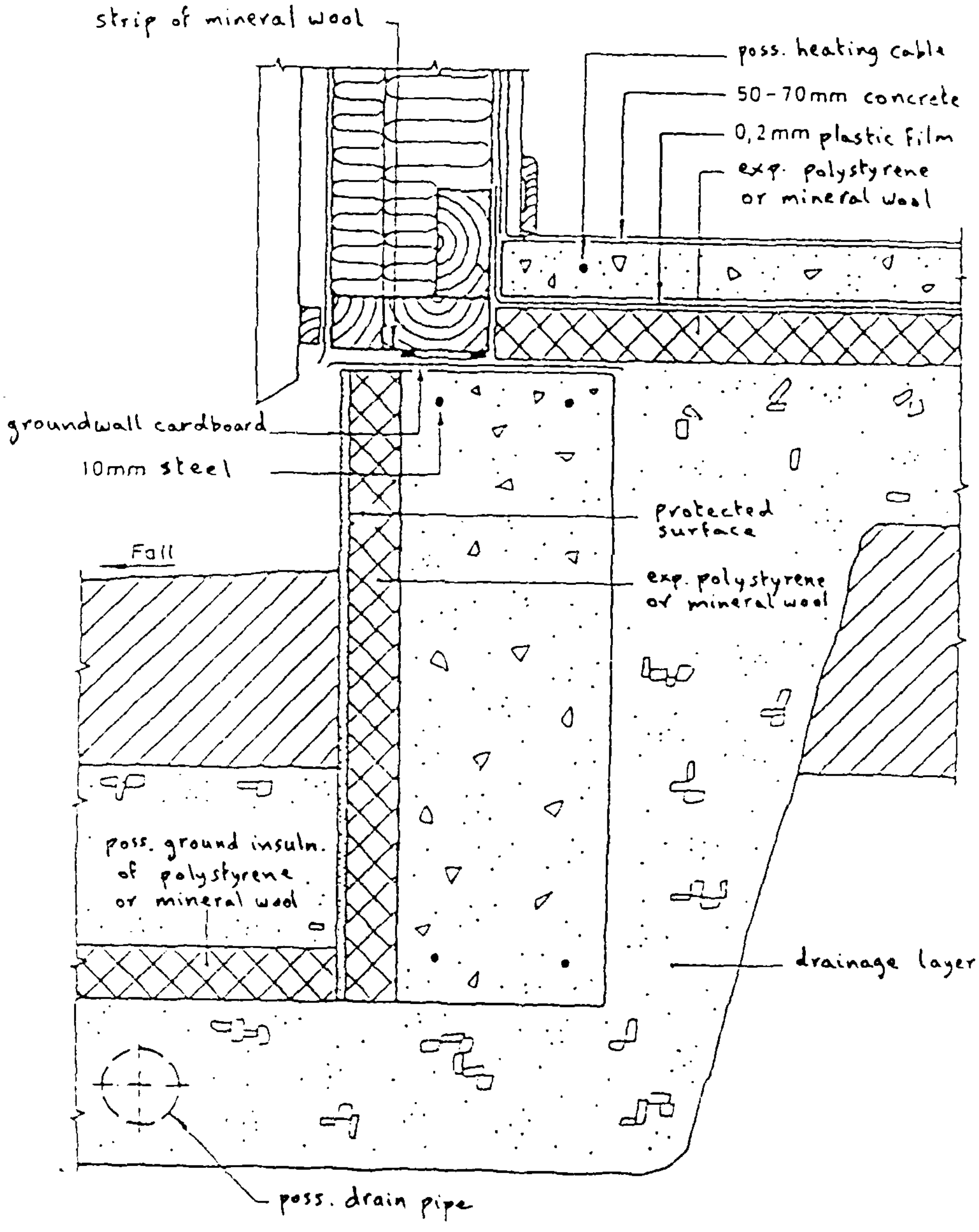


Fig. 82 Concrete slab with externally insulated concrete foundation wall.

(from 'Building Details' A 521.111)

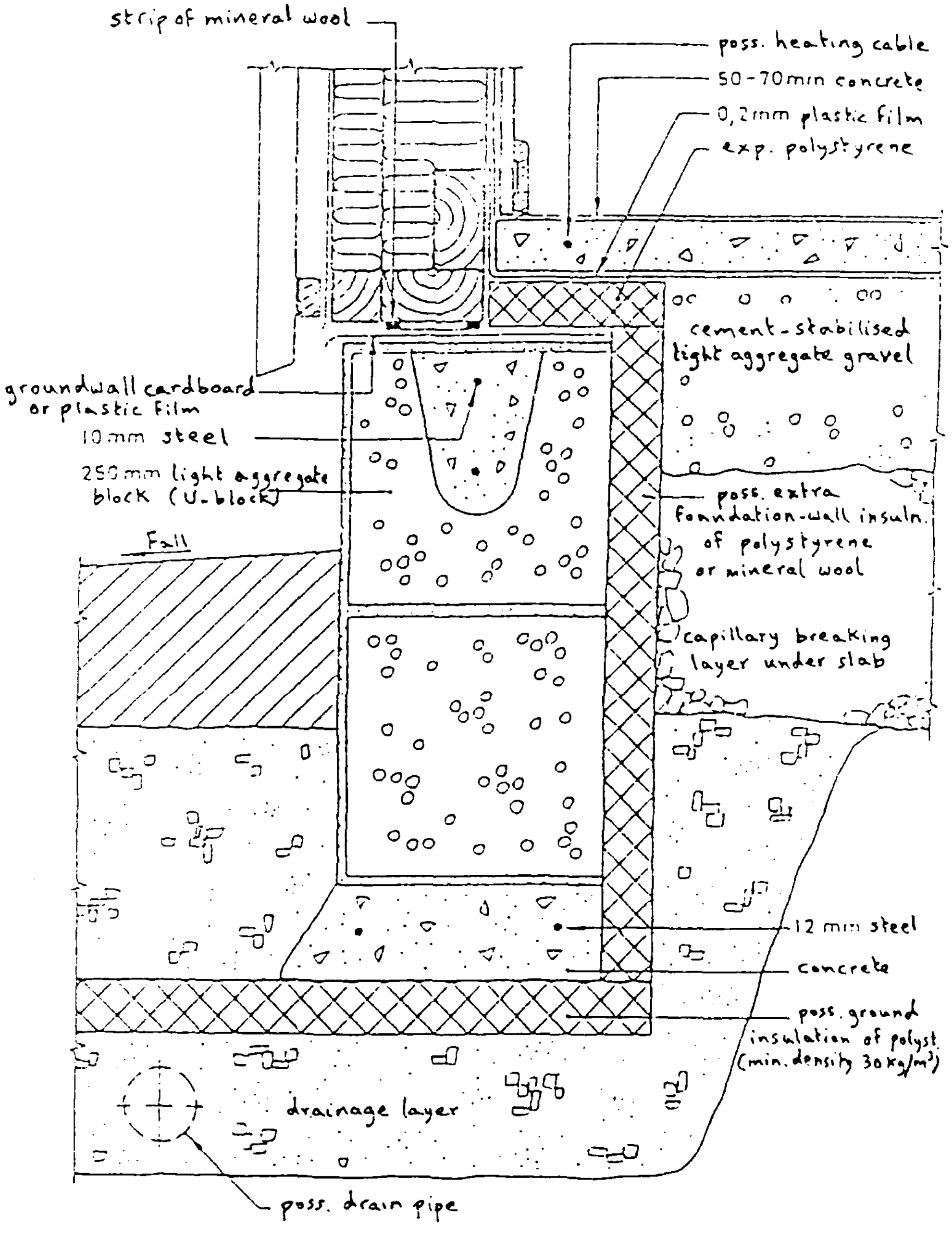


Fig. 83 Concrete slab with foundation wall of light aggregate concrete.

(from 'Building Details', A 521.111)

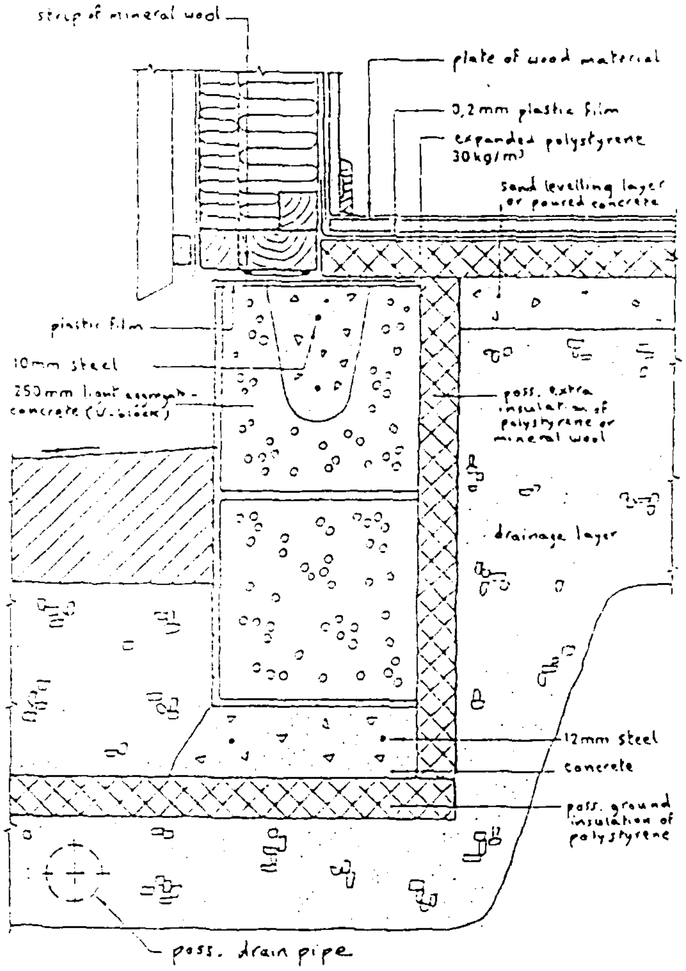


Fig. 84 A light floor with foundation wall of light aggregate concrete.

(from 'Building Details', A 521.111)

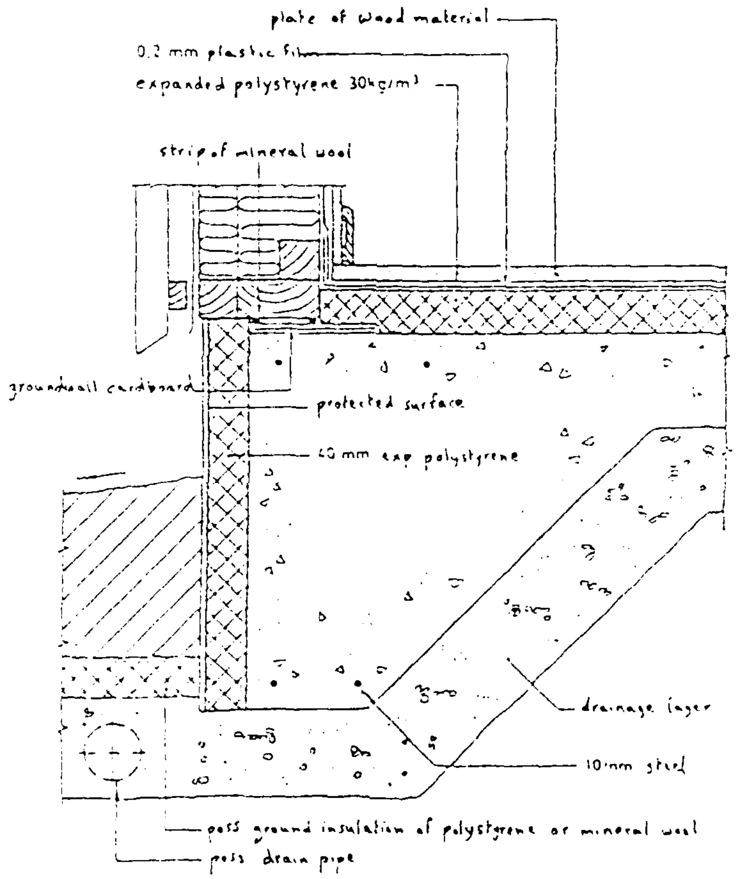


Fig. 85 A light floor and a concrete slab with expanded edge
(from 'Building Details', A 521.111)

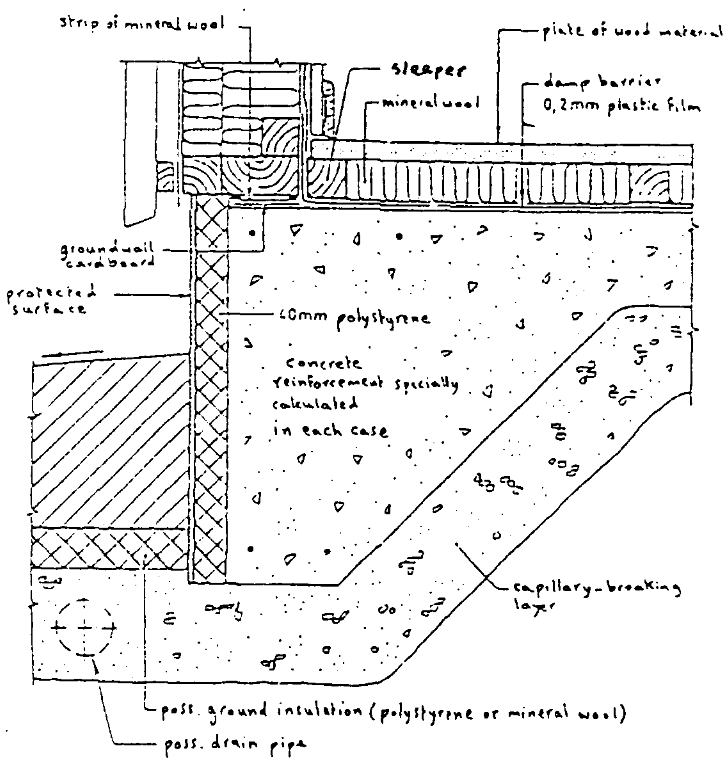


Fig. 86 Wood surfaced floor with edge-expanded concrete slab

(from 'Building Details', A 521.111)

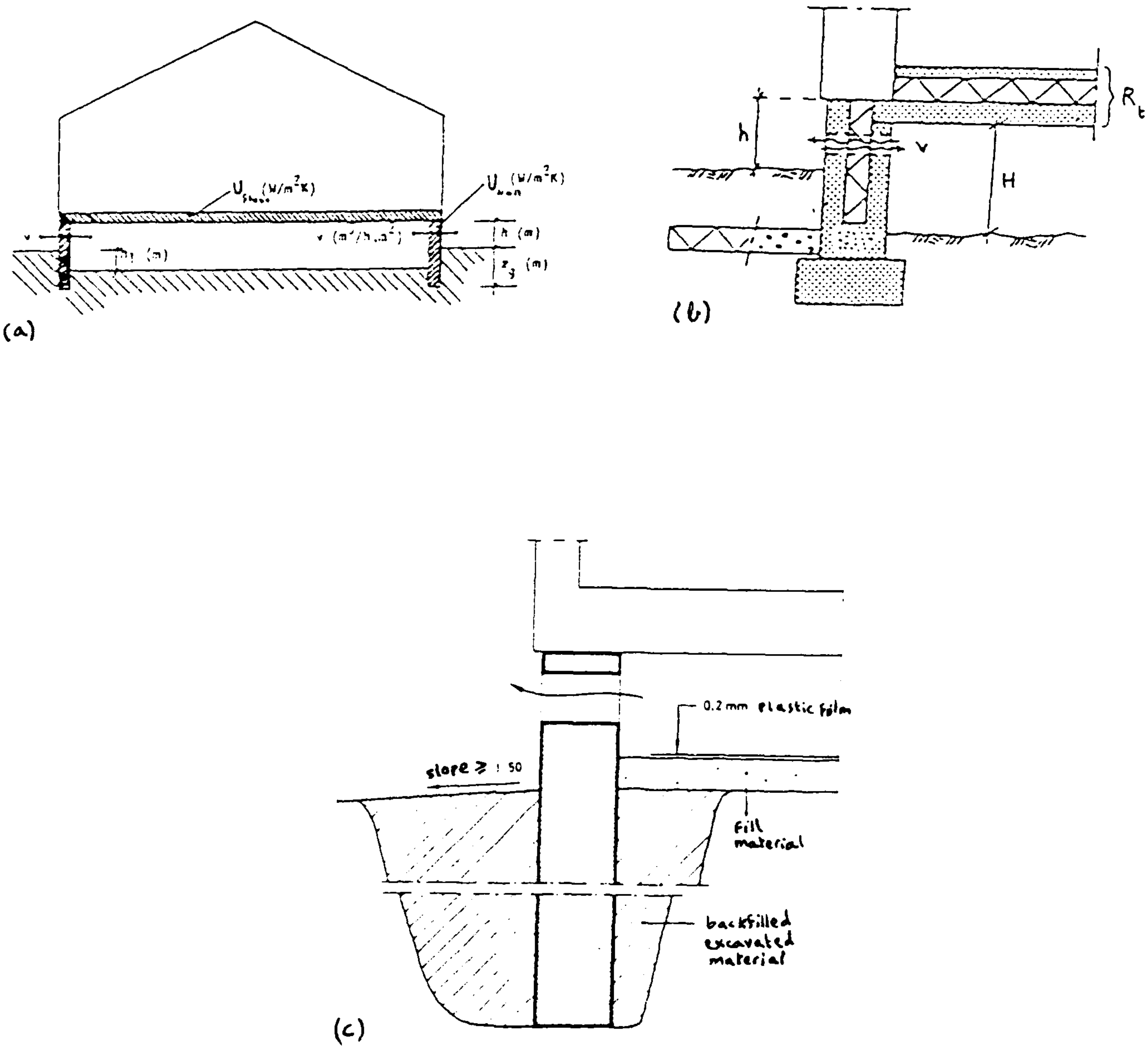


Fig. 87 Foundation with crawl space
(a) Parameters (Adamson, 1972).
(b) Finnish design (Finnish guidelines, 1987)
(c) Norwegian 'Building Details', A 521.203.

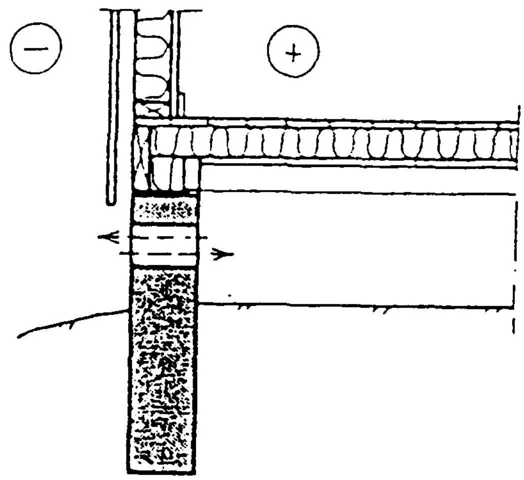


Fig. 88 A 'cold' crawl space ventilated with outside air, usually through openings in the foundation wall.

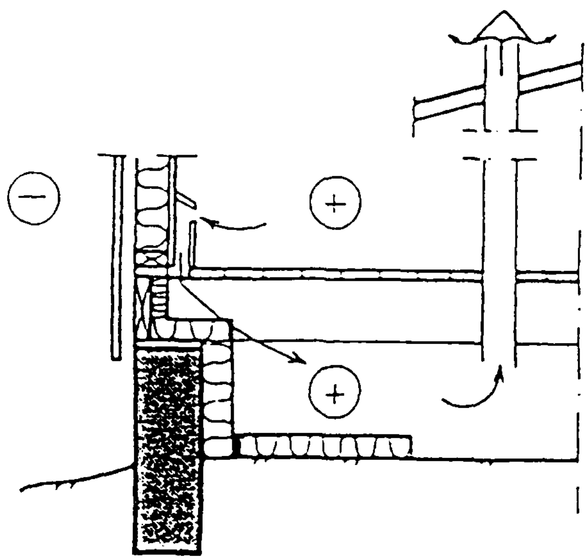


Fig. 89 A 'warm' crawl space ventilated with heated inside air.

(from Algaard, 1976)

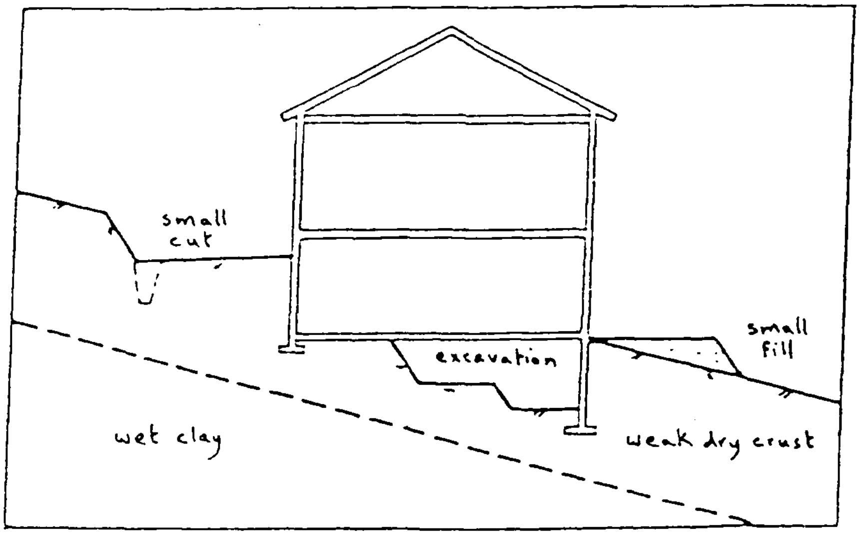


Fig. 90 Combination of crawl space with basement and 'slab-on-grade' in steep terrain.

(from Algaard, 1976)

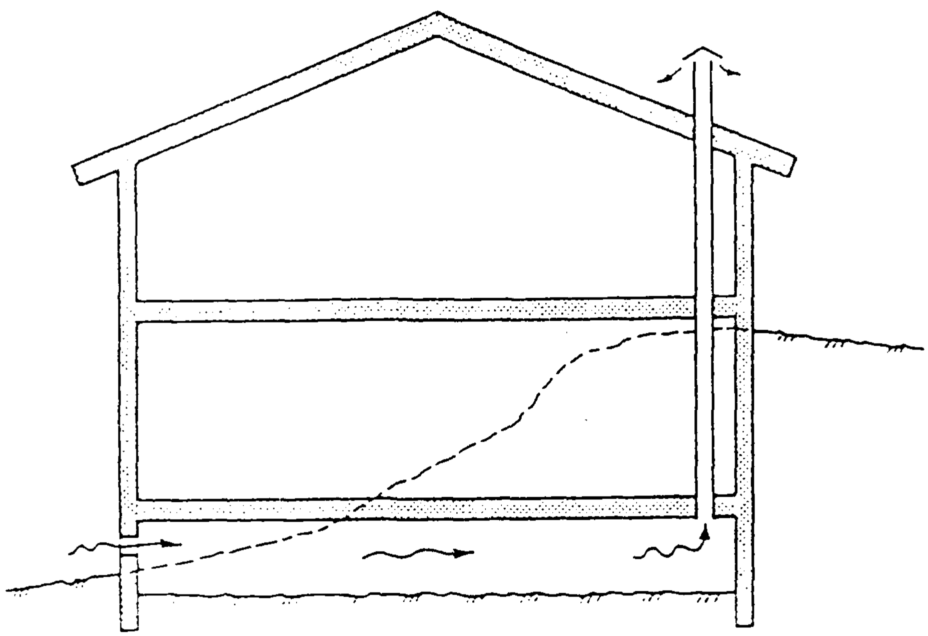


Fig. 91 Ventilation of a crawl space through the ceiling.

(from Algaard, 1976)

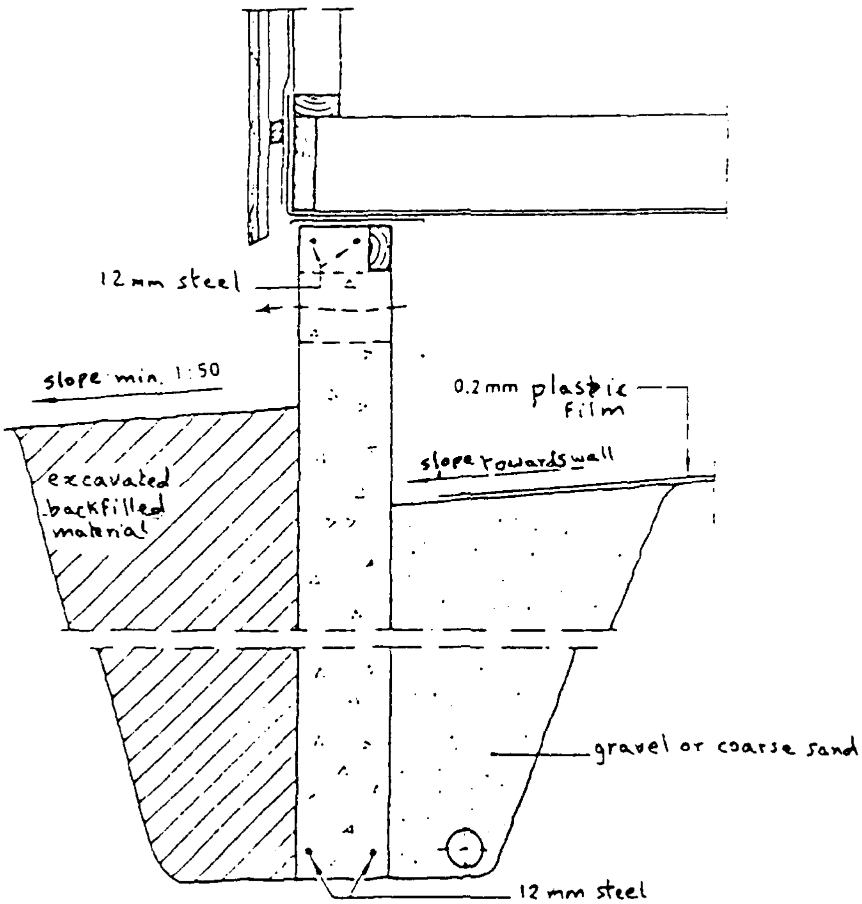


Fig. 92 Foundation wall cast in concrete

(from 'Building Details', A 521.203)

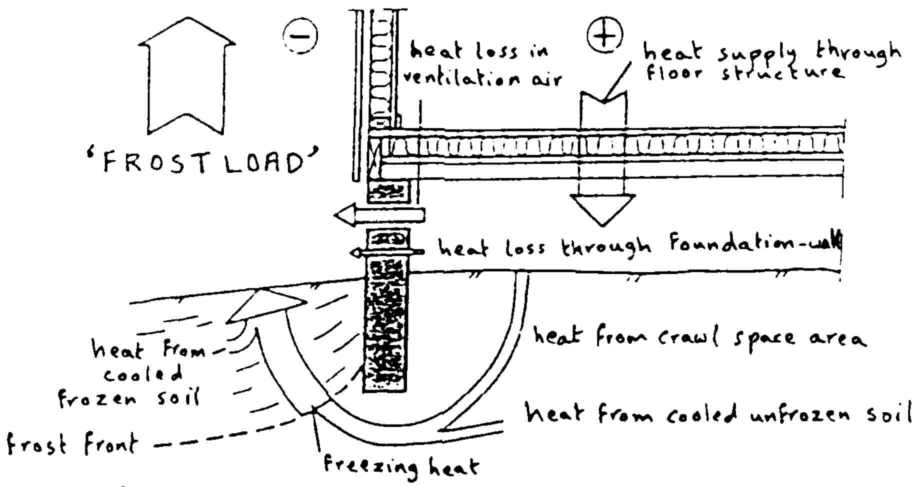


Fig. 93 Schematic representation of heat flow with a 'cold'crawl space under a heated building.

(from Algaard, 1976)

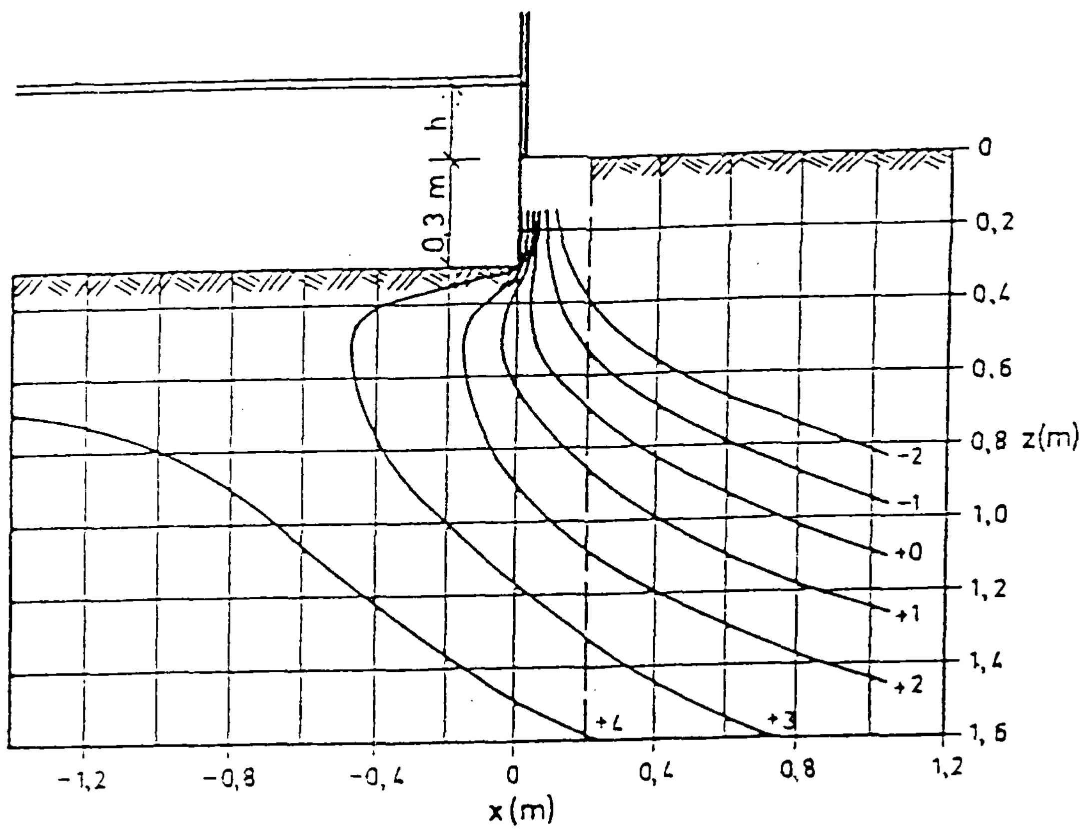


Fig. 94 Isotherms at a long building, width 10m, Clay soil, Outdoor temperature = $-9.9^{\circ}C$ (Stockholm conditions)

U value of floor slab = 0.582 W/m^2K

Heat flow through foundation wall = 1.19W/mK

Crawl space: ventilation = $1m^3/m^2$, temp. = $3.2^{\circ}C$

(from Adamson et al, 1971 and Adamson, 1972)

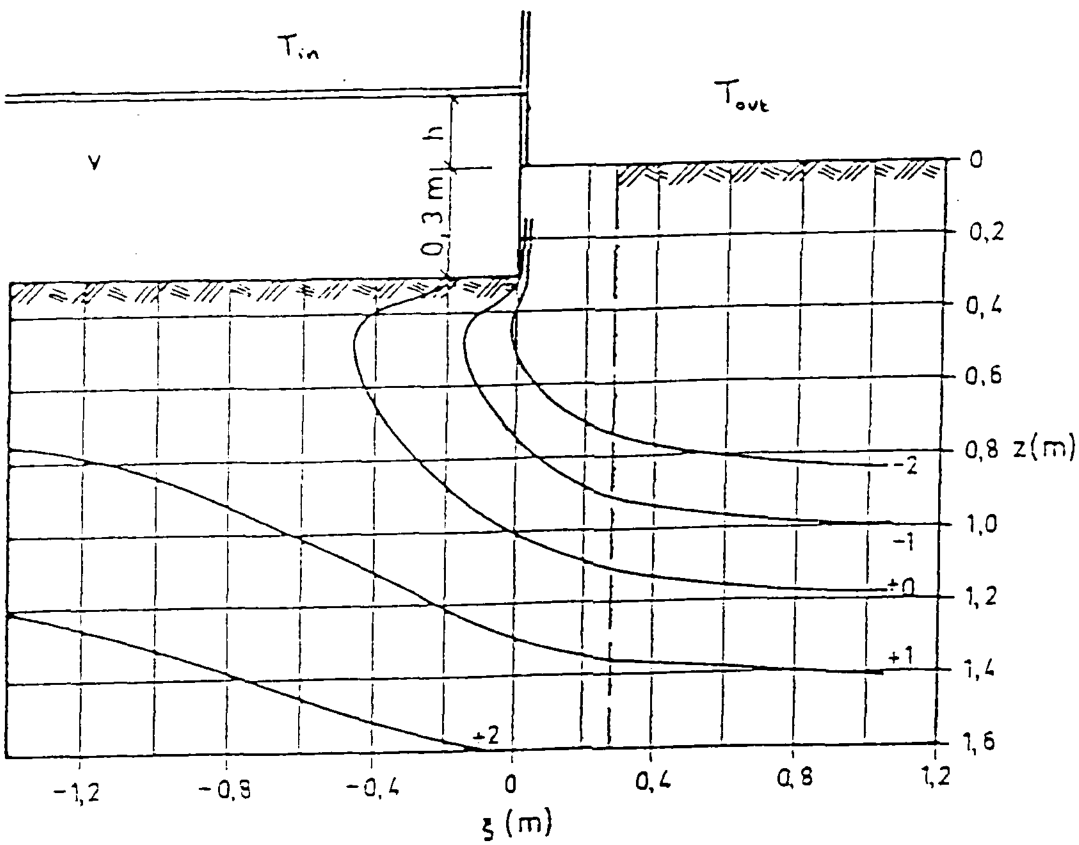


Fig. 95 Isotherms at a square building 10x10m.

Clay soil, Outdoor temp. = -9.0 °C (Stockholm conditions)

U-value of floor slab = 0.582 W/m^2K

Heat flow through foundation wall = 1.19 W/mK

Crawl space: ventilation = $1m^3/m^2$, temp. = 0.3 °C

(from Adamson et al, 1971 and Adamson, 1972)

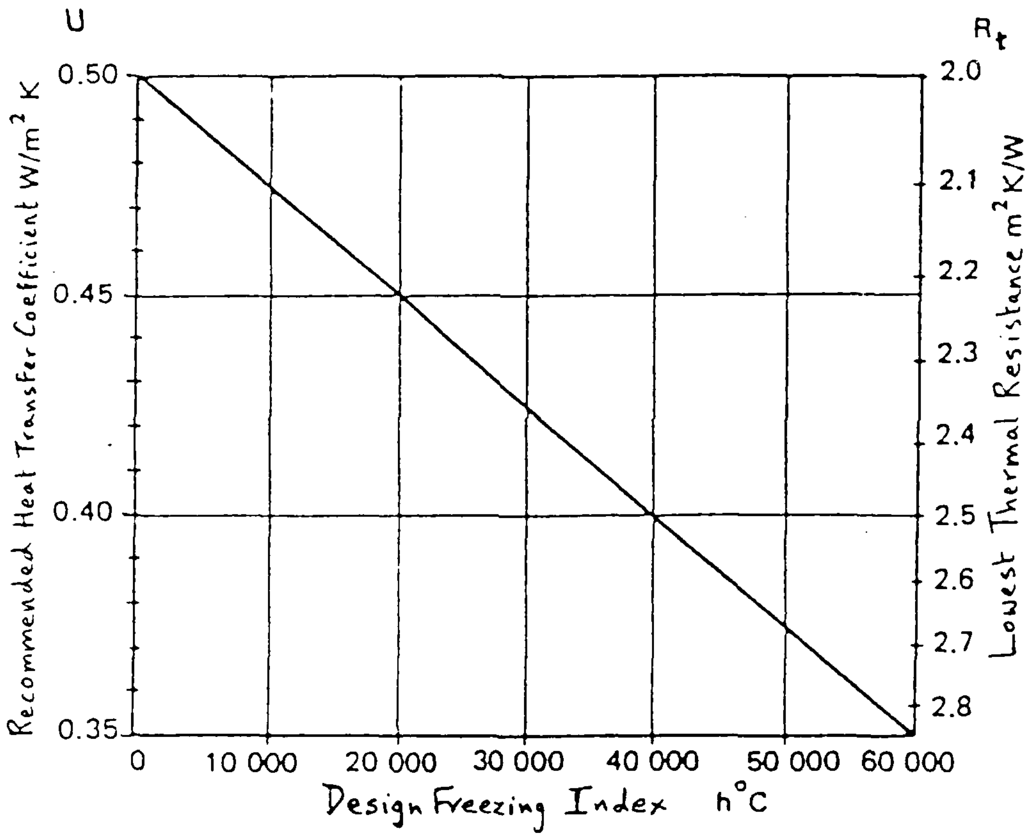


Fig. 96 Recommended thermal insulation of a floor structure over a 'cold' crawl space to obtain at least + 17.5 °C on the floor surface with an inside temperature of + 21 °C, as a function of the Design Freezing Index. Crawl space ventilation = 1 - 3m³/m²h.

(from Algaard, 1976)

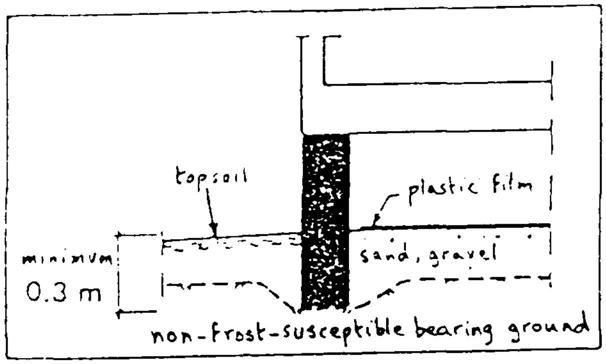


Fig. 97 Crawl space foundation on non-frost-susceptible ground. Wet and weak material is removed from under the foundation and humus-containing soil is replaced with clean and draining material.

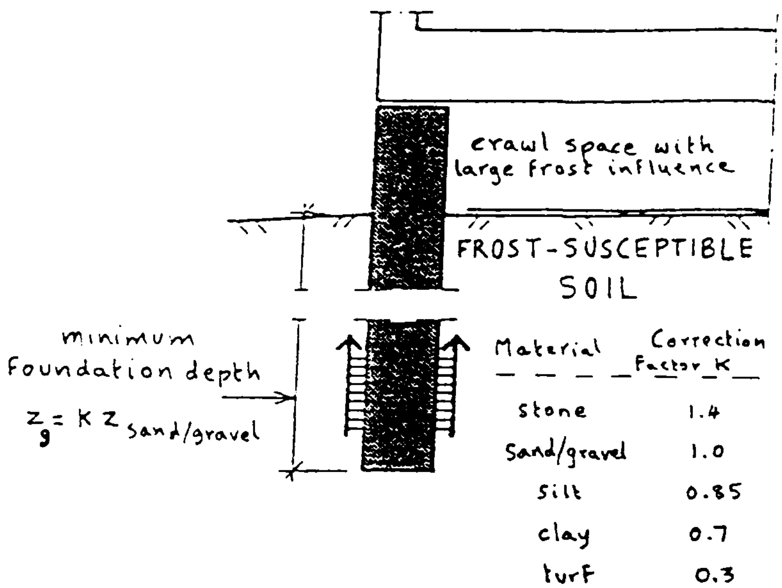


Fig. 98 If the reduced foundation depth cannot be applied, the foundation must be placed at the 'frost-free' depth depending on the locality and the actual soil type.

(from Algaard, 1976)

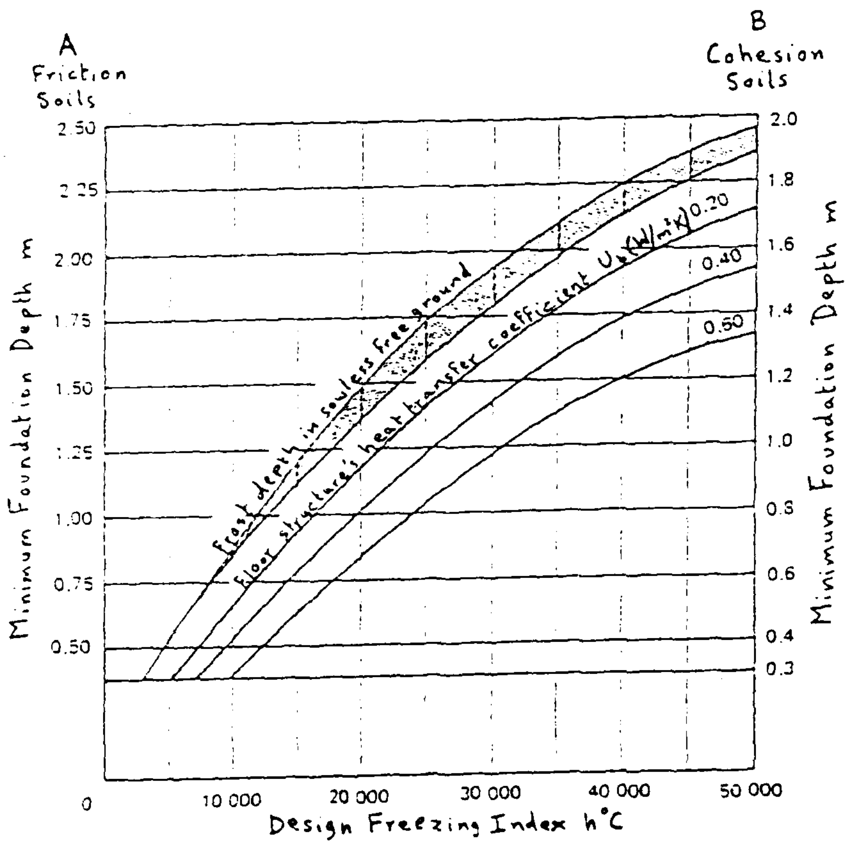


Fig. 99 Minimum foundation depth for crawl space foundation-wall under a continuously heated building on frost-susceptible soil. Ventilation value = 1 - 3 m^3/m^2h

(from Algaard, 1976)

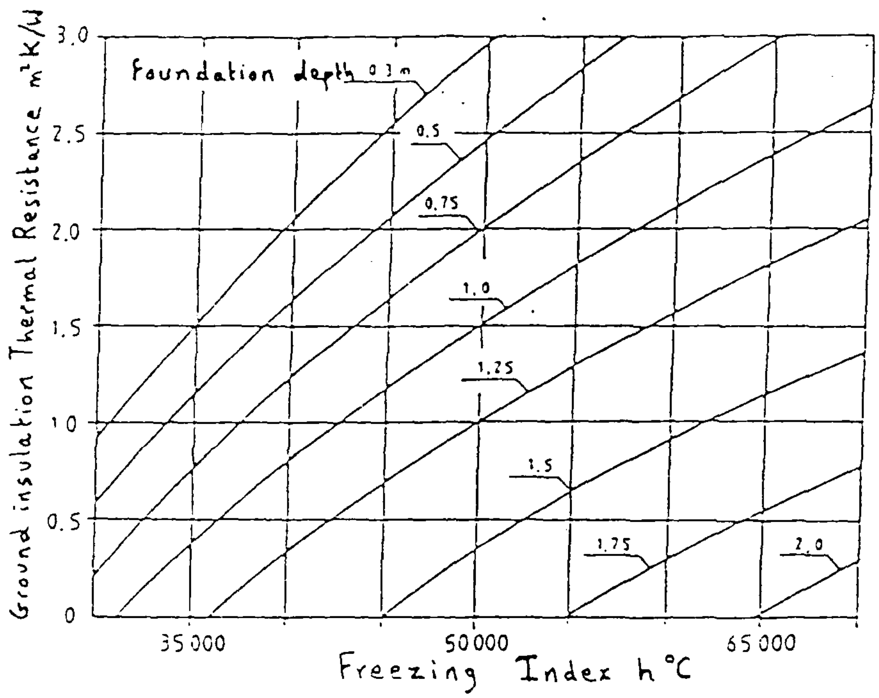


Fig. 100 Design of frost protection for heated structures. Floor structure with crawl space (thermal resistance = $4.5 m^2K/W$, ventilation rate = $0.6\ l/s.m^2$).

(Finnish guidelines, 1987)

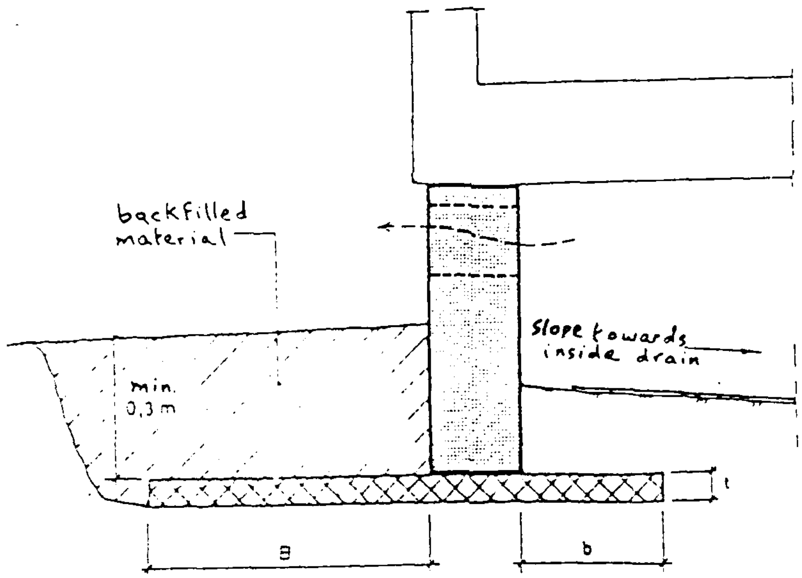


Fig. 101 Placing of insulation with reduced foundation depth.

(from 'Building Details', A 521.203)

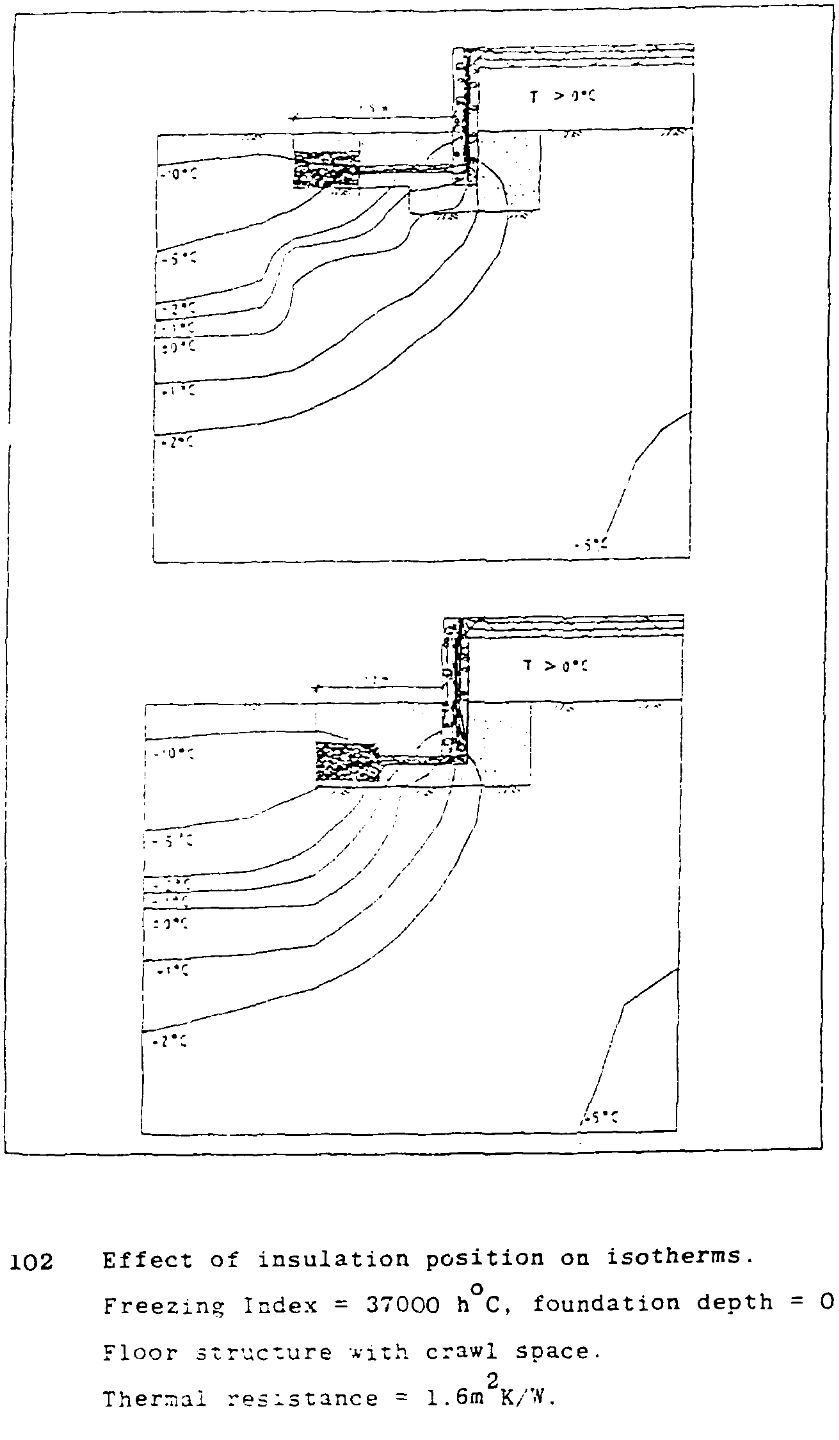


Fig. 102 Effect of insulation position on isotherms.
Freezing Index = 37000 h^{o}C, foundation depth = 0.5m
Floor structure with crawl space.
Thermal resistance = 1.6m^{2}K/W.

(Finnish guidelines, 1987)

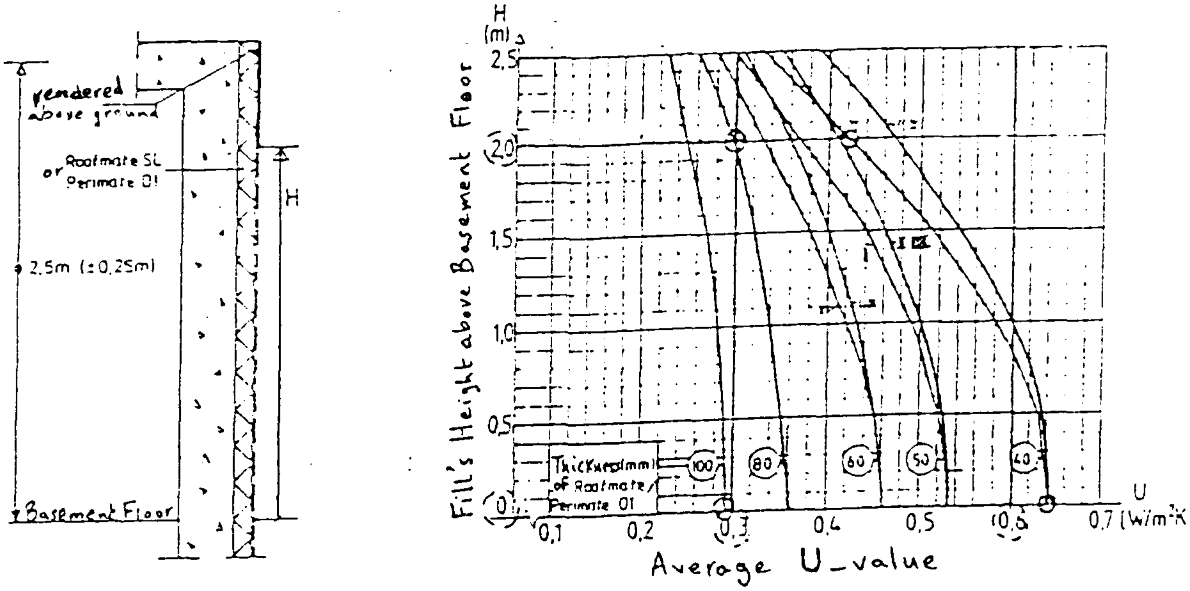


Fig. 103 2.5 m high concrete basement wall with the same thickness of Roofmate SL/Perimate DI styrofoam above and below ground.

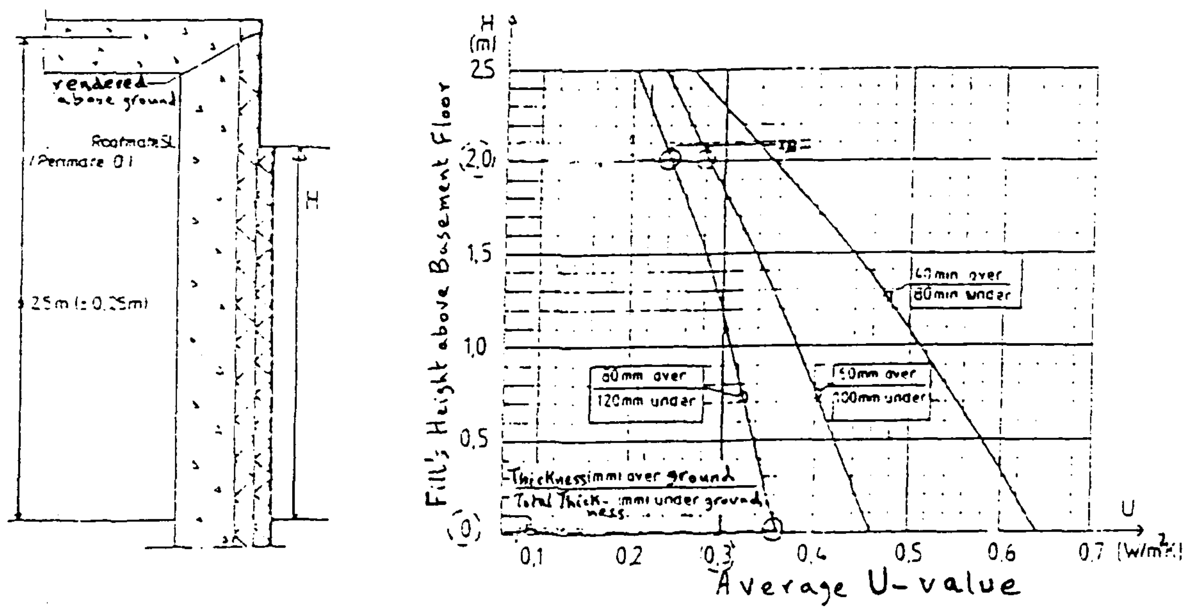


Fig. 104 2.5 m high concrete basement wall with extra insulation thickness under the ground.

(from Dow Chemical, 1987)

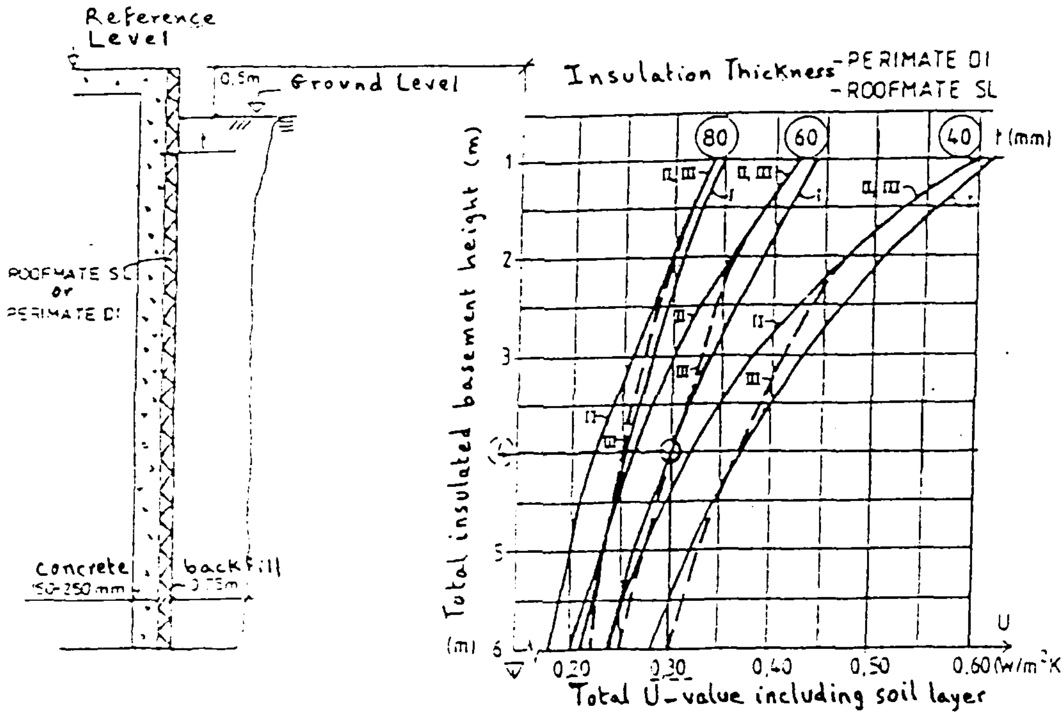


Fig. 105 Insulated concrete basement wall with height up to 6 m and fixed top height over ground (0.5 m)

(from Dow Chemical, 1987)

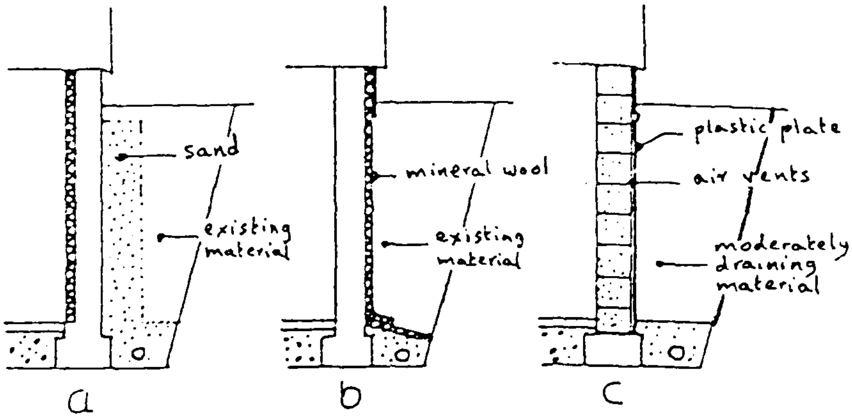


Fig. 106 Alternate designs of basement wall drainage.

a. Traditional method

b. Stiff mineral wool plate that combines thermal insulation, drainage and filtering

c. Plastic plate with projections as shaped air openings.

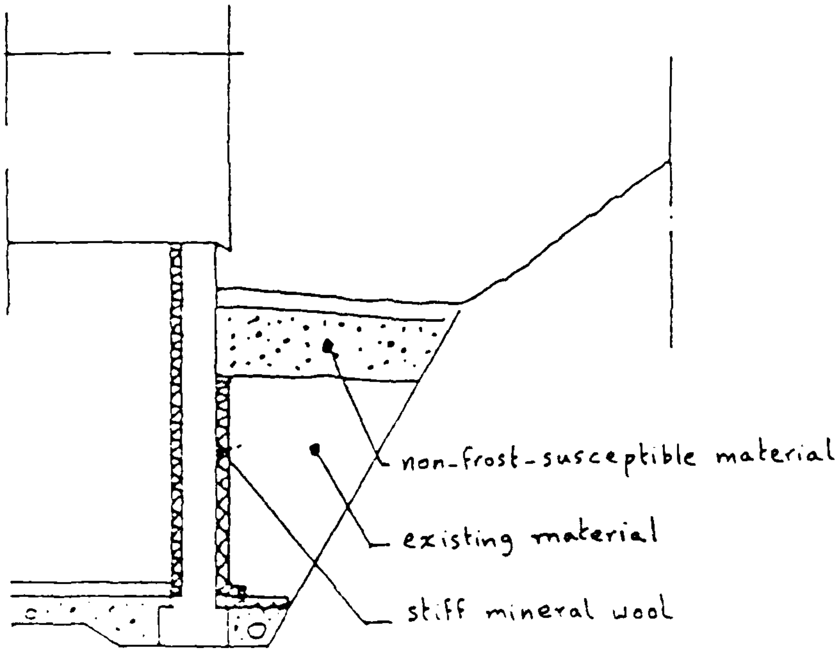


Fig. 107 Replacement of steeply inclined frost-susceptible material by coarse draining material.

(from Nordgård, 1972).

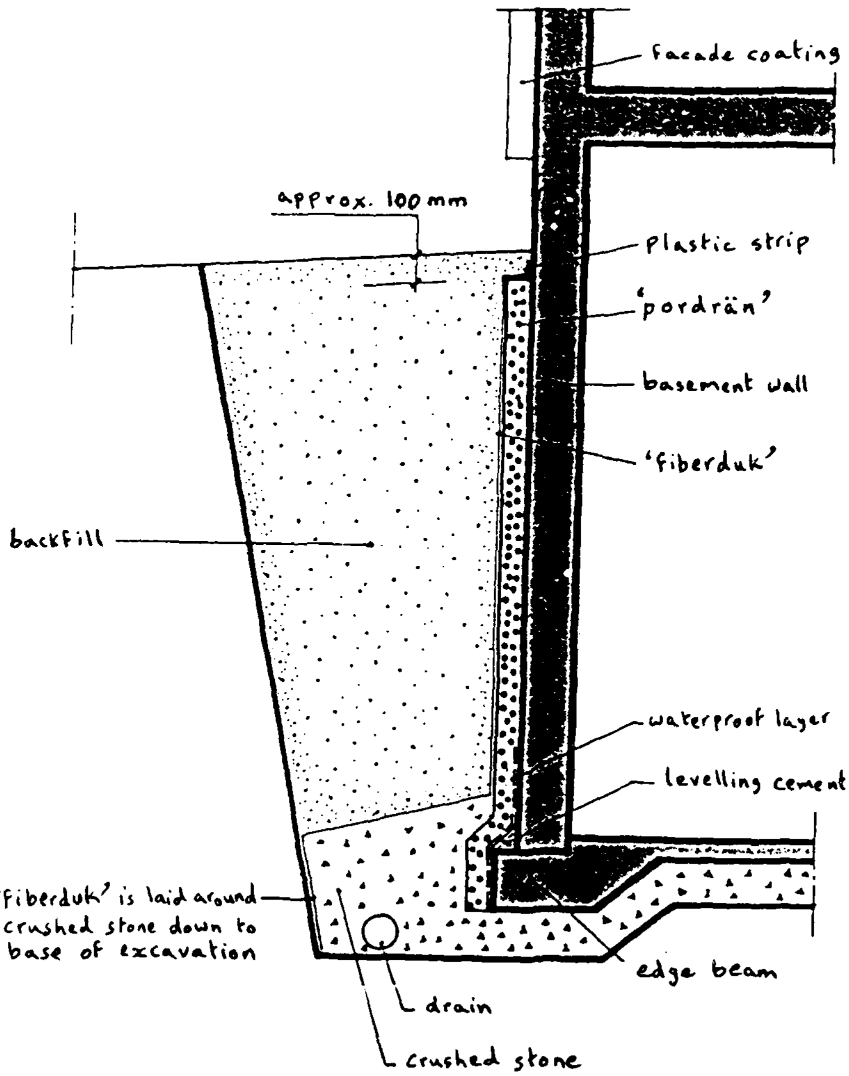


Fig. 108 Protection and drainage of a basement wall.

(WIAB. No date)

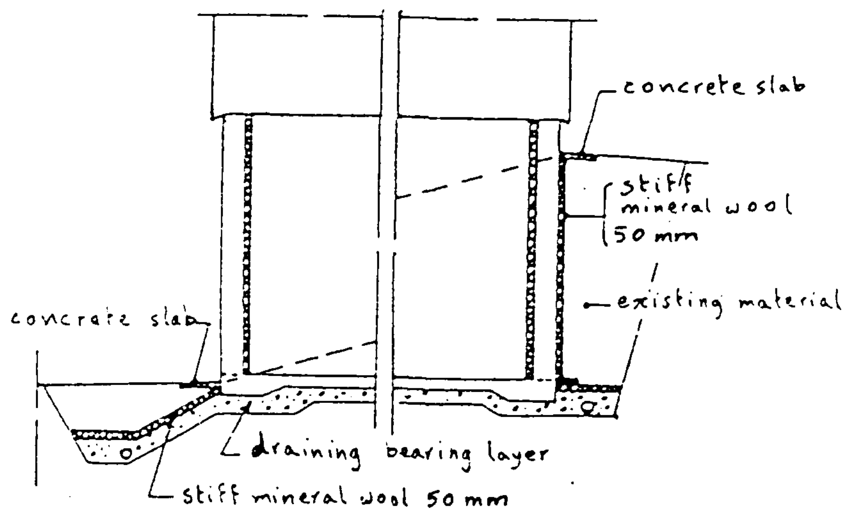


Fig. 109 Recommended design of a basement foundation where one basement wall is exposed to outside air.

(from Nordgård, 1972).

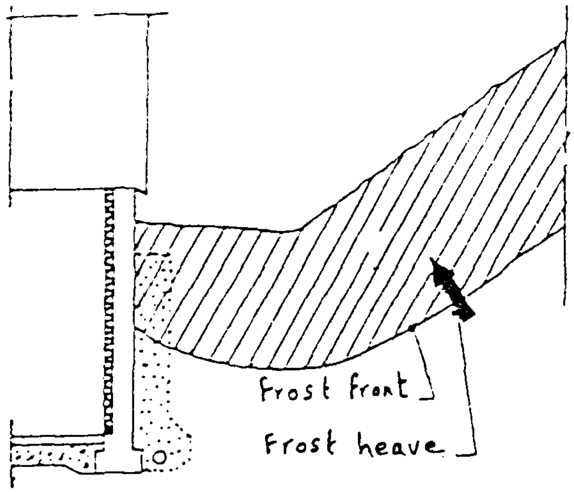


Fig. 110 With an inclined soil surface, the frost heave can have a horizontal component towards basement wall

(from Nordgård, 1972)

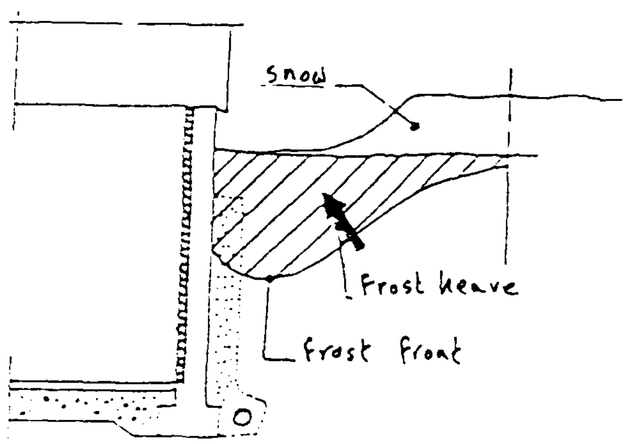


Fig. 111 With a snow-free zone along the wall, the frost heave can be inclined towards the wall

(from Nordgård, 1972)

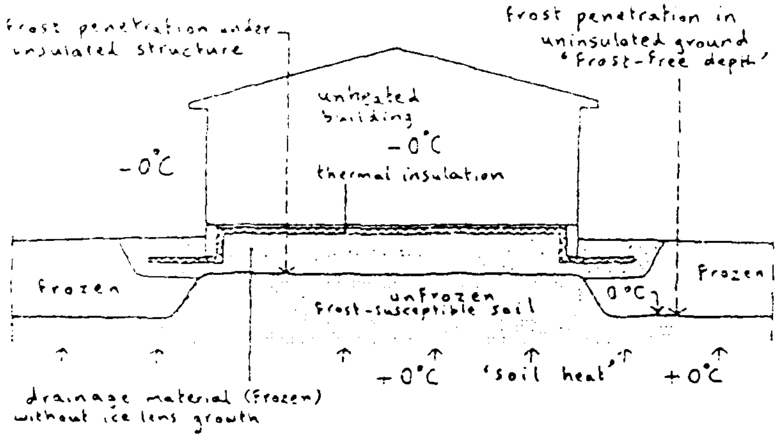


Fig. 112 Thermal insulation limits frost penetration such that frost-susceptible soil under the structure does not freeze.

(from 'Building Details', A521.811)

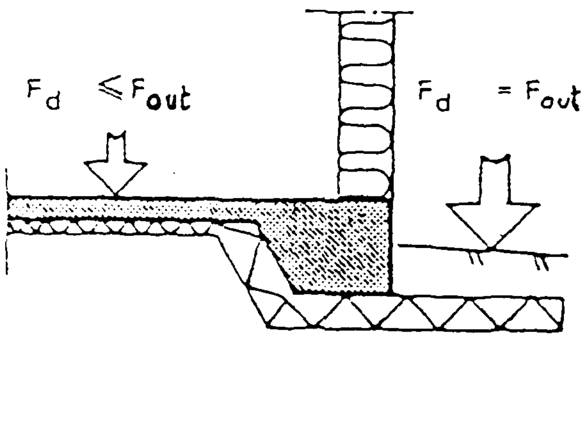


Fig. 113 The foundation wall and outer foundation are exposed to the outer climate, regardless of the frost load indoors on the floor.

(from Algaard, 1976)

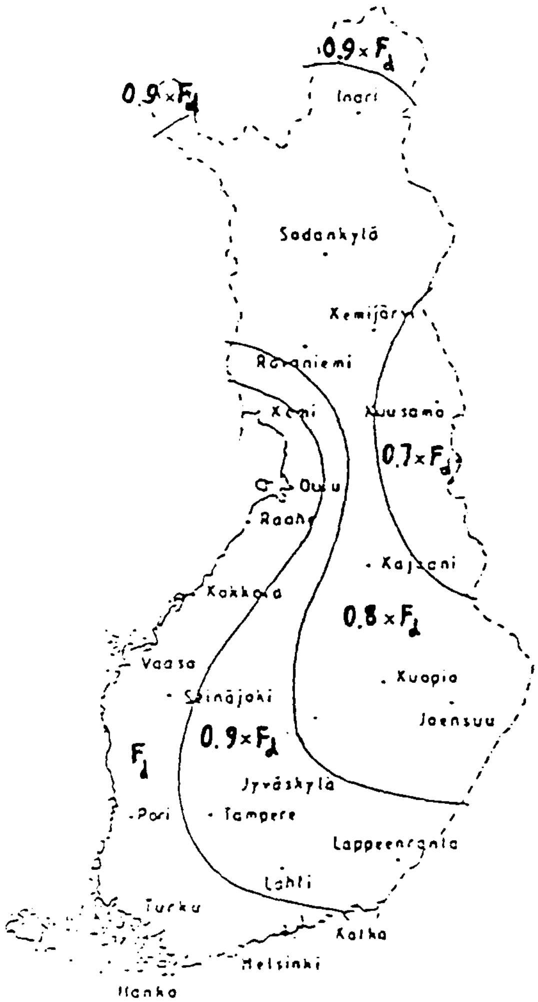


Fig. 114 Reduction factors for Freezing Index.

(Finnish guidelines, 1987)

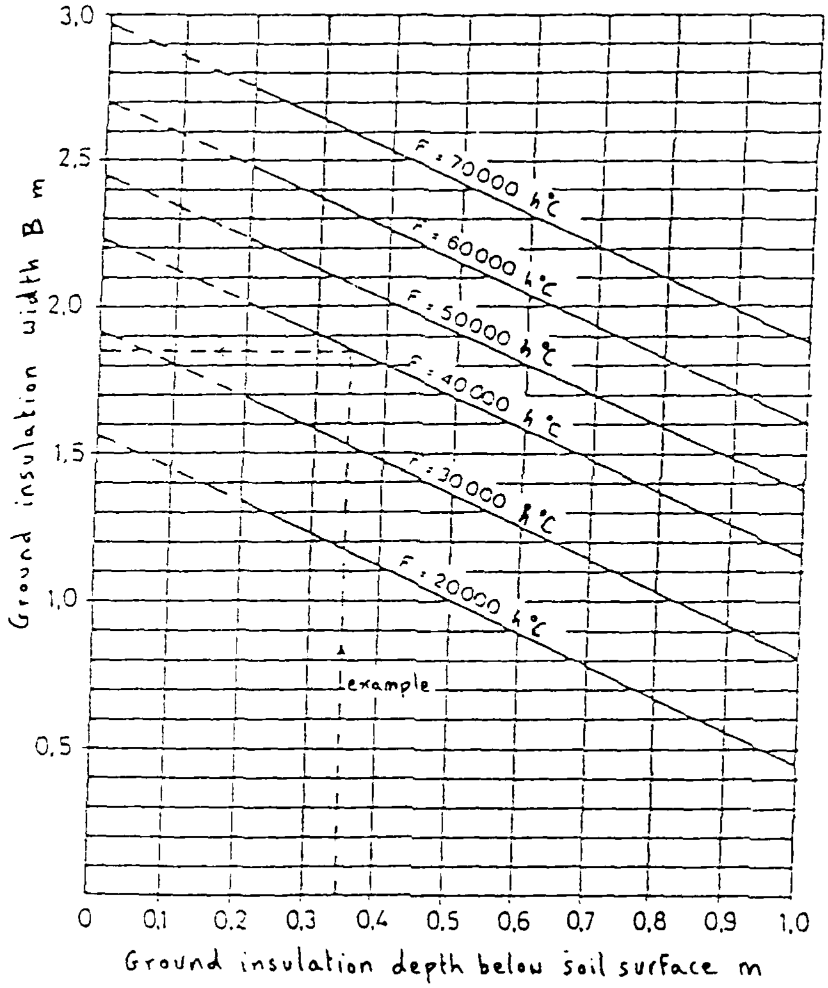


Fig. 115 Width of ground insulation for cold structures.

(Finnish guidelines, 1987)

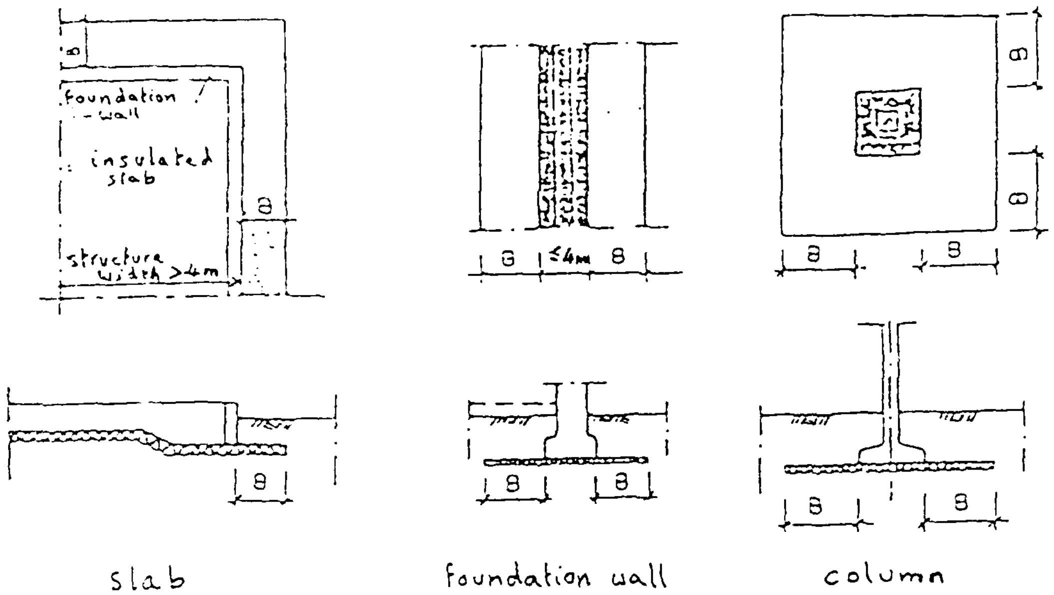
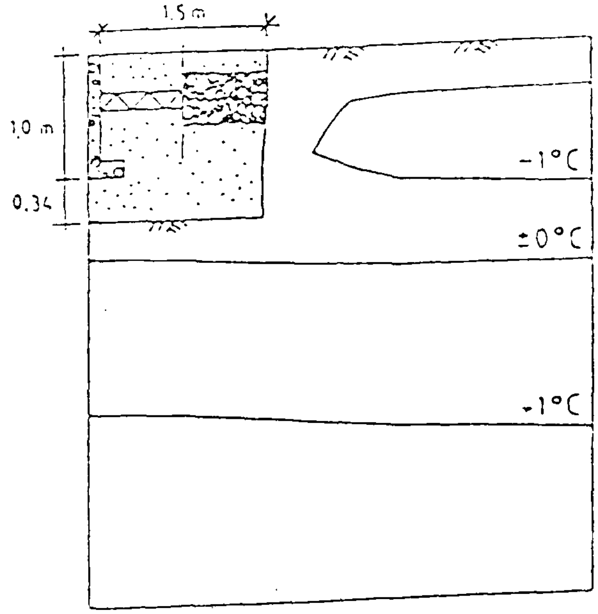


Fig. 116 Width of ground insulation for protection of cold foundations.

(Finnish guidelines, 1987)



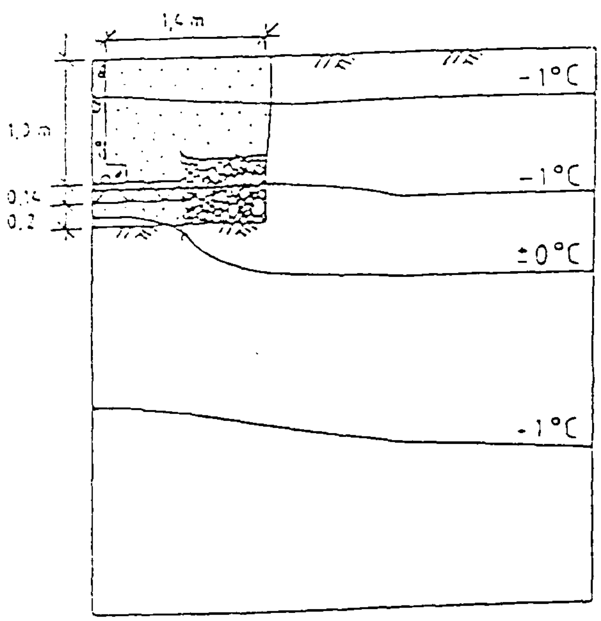


Fig. 117 Effect of ground insulation position on isotherms for a cold structure.
Freezing Index = 42000 h°C,
foundation depth = 1.0m
Thermal resistance of ground insulation = 2.8 m^2K/W

(Finnish guidelines, 1987)

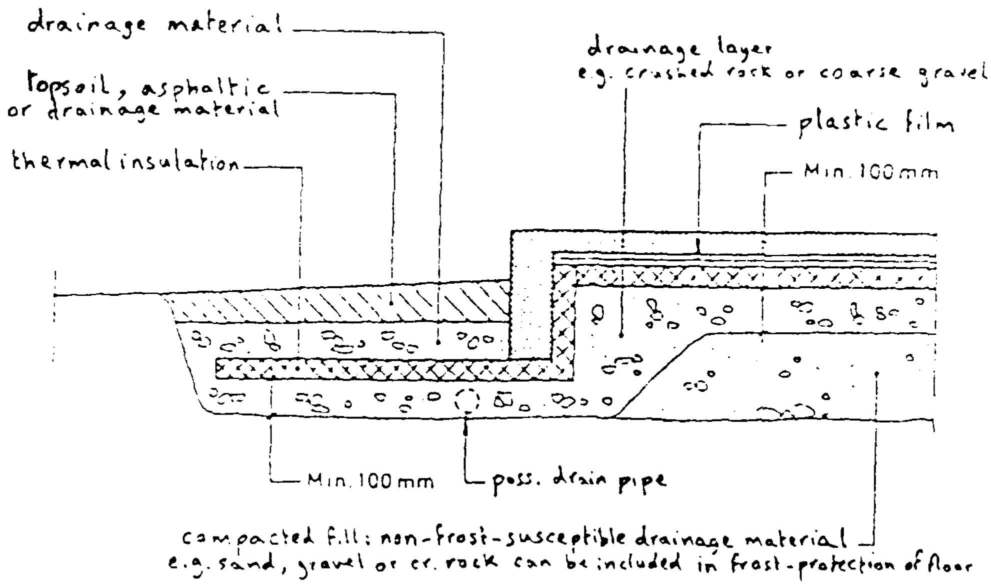


Fig. 118 Drainage layer under floor and foundation wall. If the drain pipe is laid say 100 mm below the foundation wall, its distance from the foundation wall should be at least doubled, i.e. 200 mm.

(from 'Building Details', A 521.811)

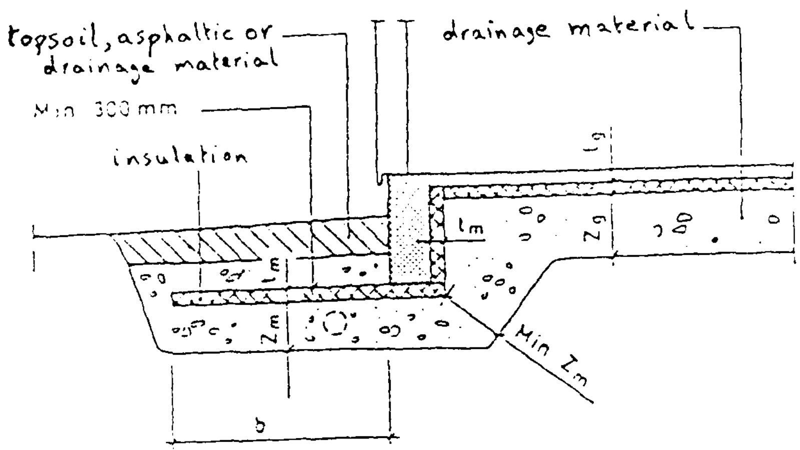


Fig. 119 Frost protection : Foundation wall and slab.

(from 'Building Details', A 521.811)

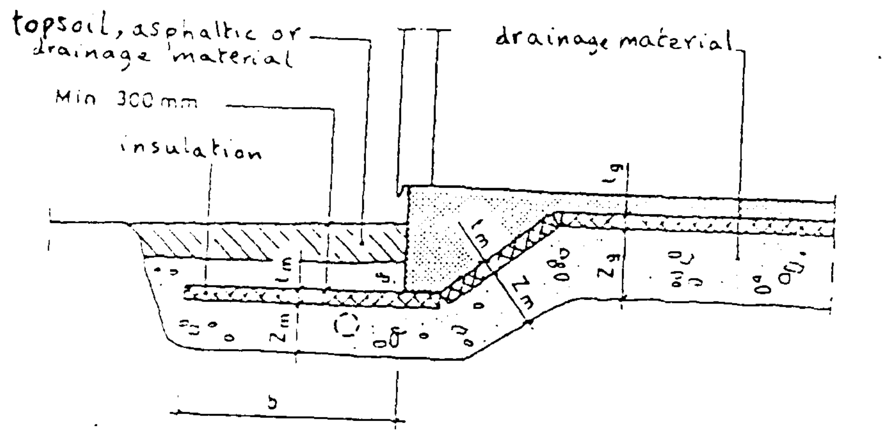


Fig. 120 Frost protection : Foundation and slab cast as one unit.

(from 'Building Details', A 521.811)

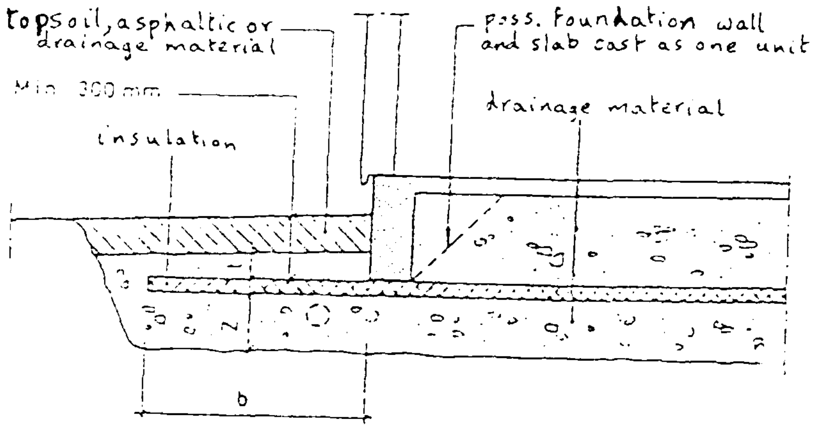


Fig. 121 Frost protection : Small building like a garage, free-standing shack or similar.

(from 'Building Details', A 521.811)

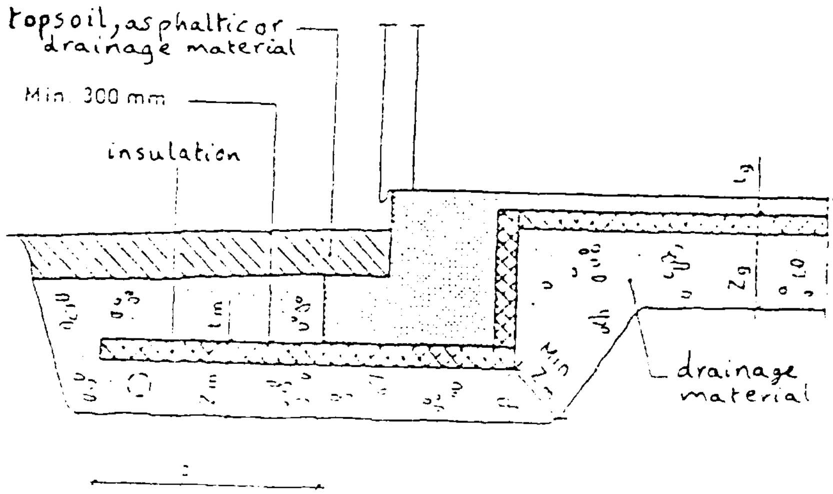


Fig. 122 Frost protection : Foundation for large loading. Inside formwork.

(from 'Building Details', A 521.811)

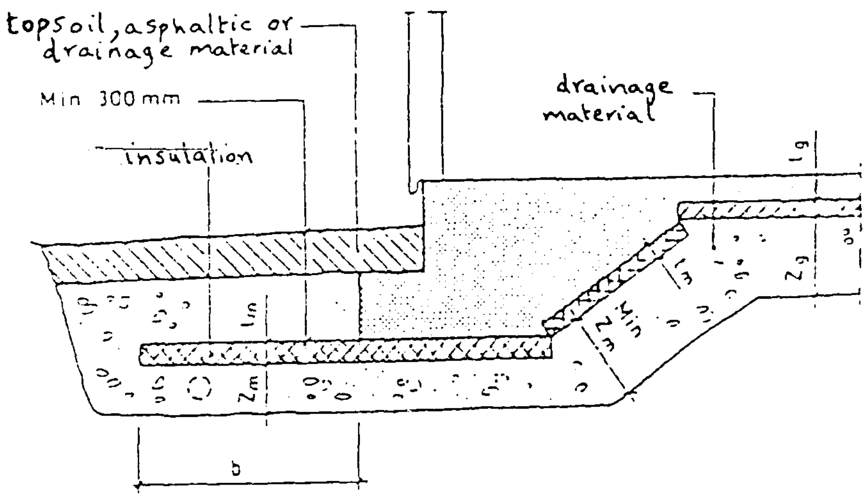


Fig. 123 Frost protection : Foundation for large loading. Without inner formwork.

(from 'Building Details', A 521.811)

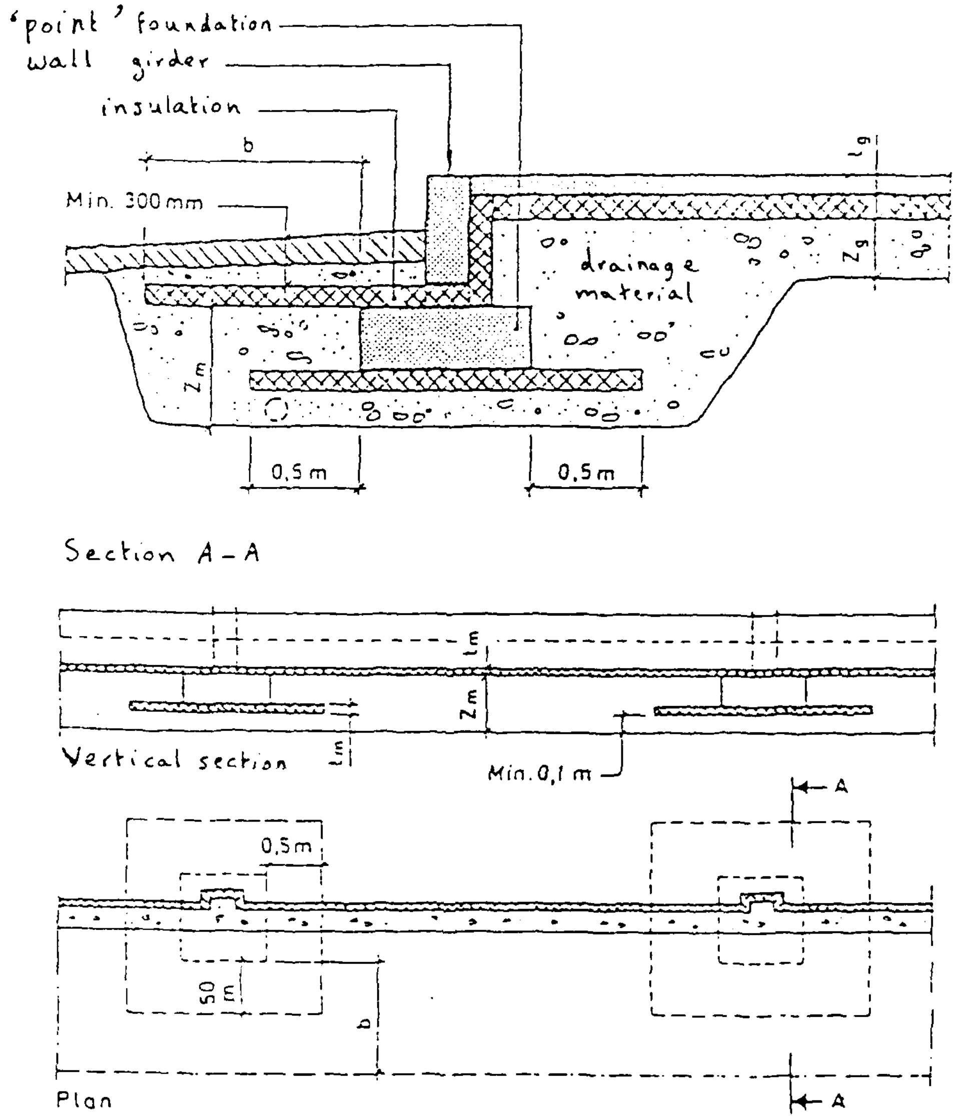


Fig. 124 Frost protection : Column foundation with wall girder. Frost protection of column foundations is only necessary when these are shallower than the usual frost-free depth in undisturbed ground.

(from 'Building Details', A 521.811)

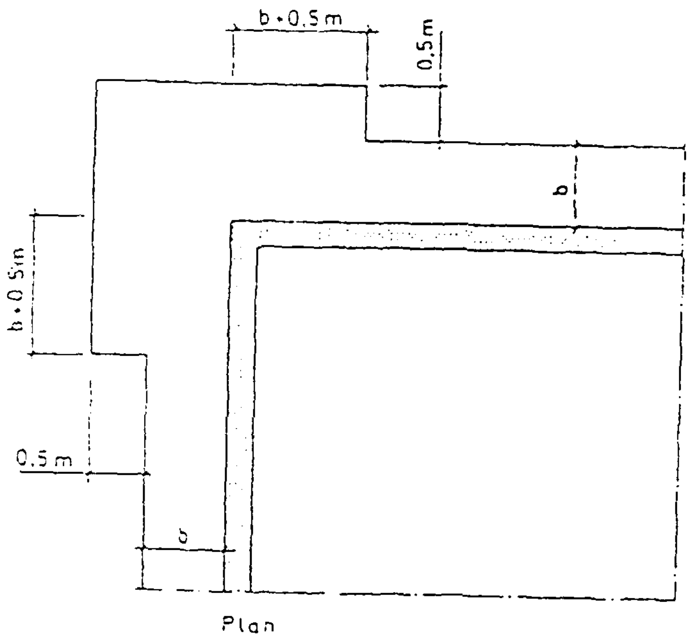


Fig. 125 Extra frost protection at a corner.
(from 'Building Details', A 521.811)

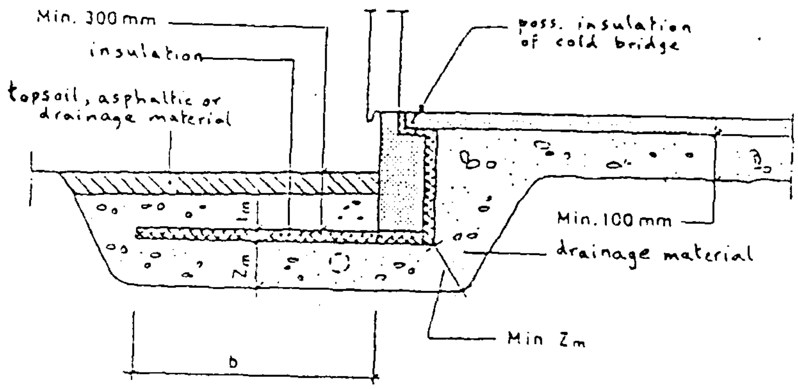


Fig. 126 Frost protection of the floor can be omitted if the inside temperature stays above 0°C. It would be necessary to break the cold bridge between the foundation wall and the foundation.

(from 'Building Details', A 521.811)

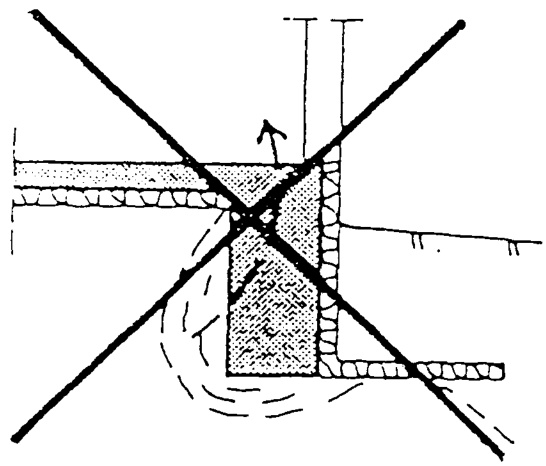


Fig. 127 Dangerous design with a foundation wall.
Frost can penetrate underand inside the wall.

(Algaard, 1976).

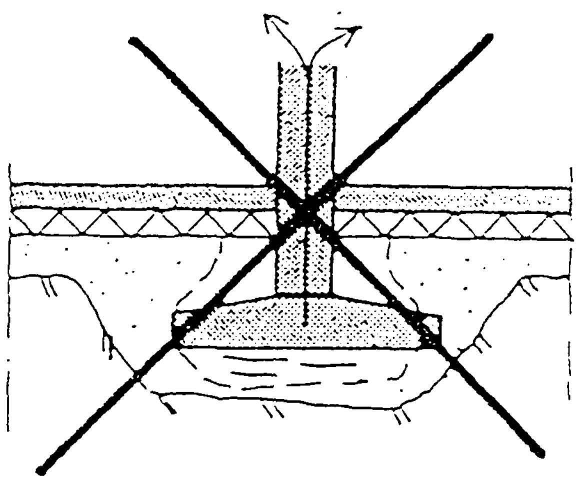


Fig. 128 Dangerous design with a column foundation.
The column gives a cold bridge
with frost penetration under the floor and footing.

(Algaard, 1976)

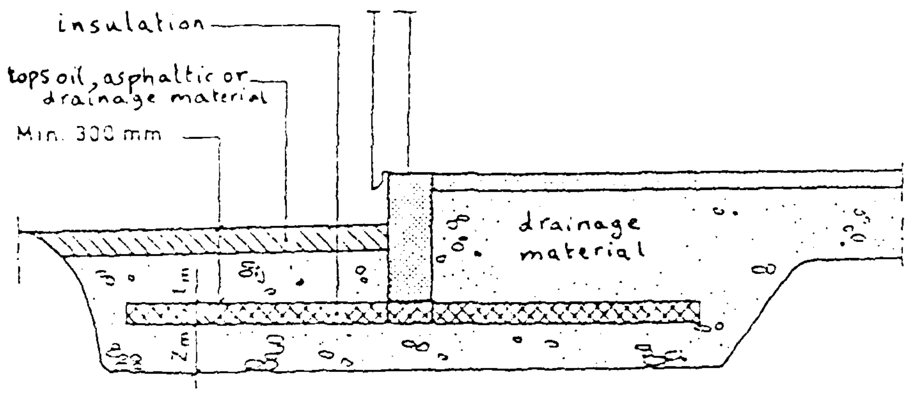


Fig. 129 Building where only the foundation wall is frost-protected.

Frost heave of the slab beyond the insulation must then be accepted.

(from 'Building Details', A 521.811)

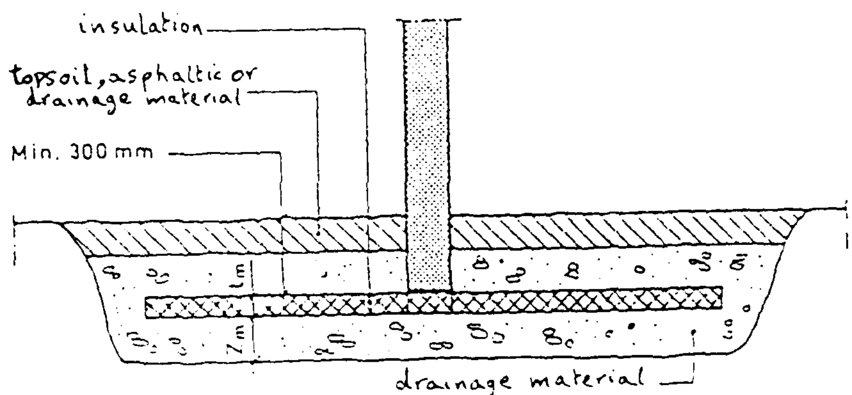


Fig. 130 Frost protection of foundation for 'levegger', atrium wall, foundation strip, etc.

(from 'Building Details', A 521.811)

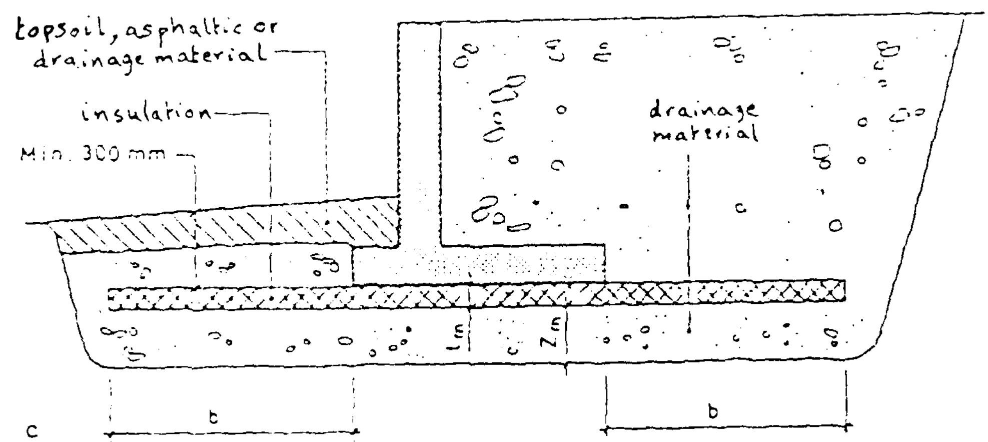


Fig. 131 Frost protection of cantilever wall.
(*from* 'Building Details', A 521.811)

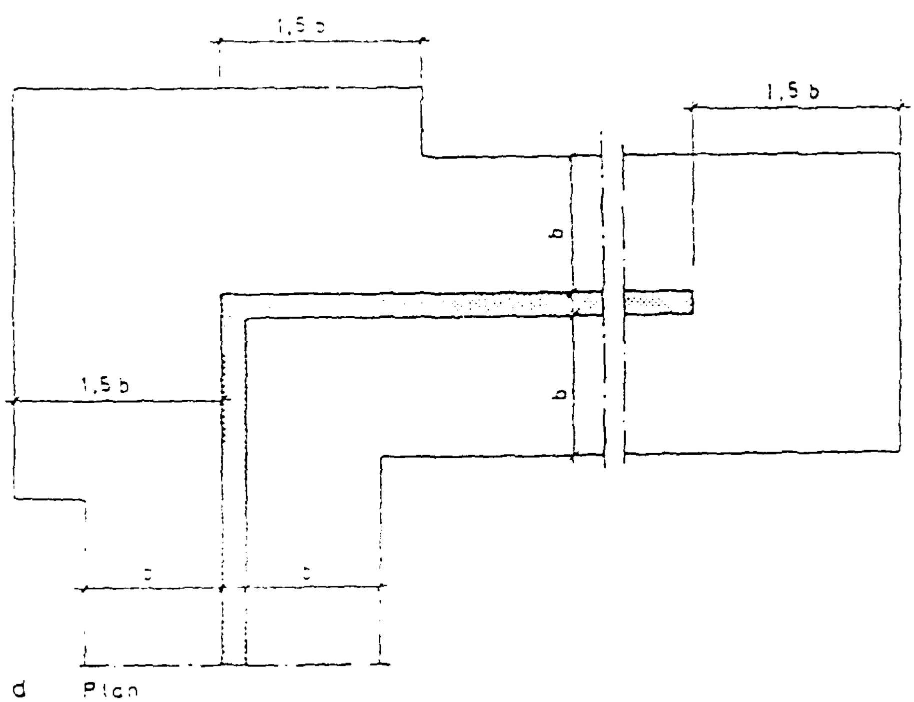


Fig. 132 Frost protection at corner and at end of foundation.

(*from* 'Building Details', A 521.811)

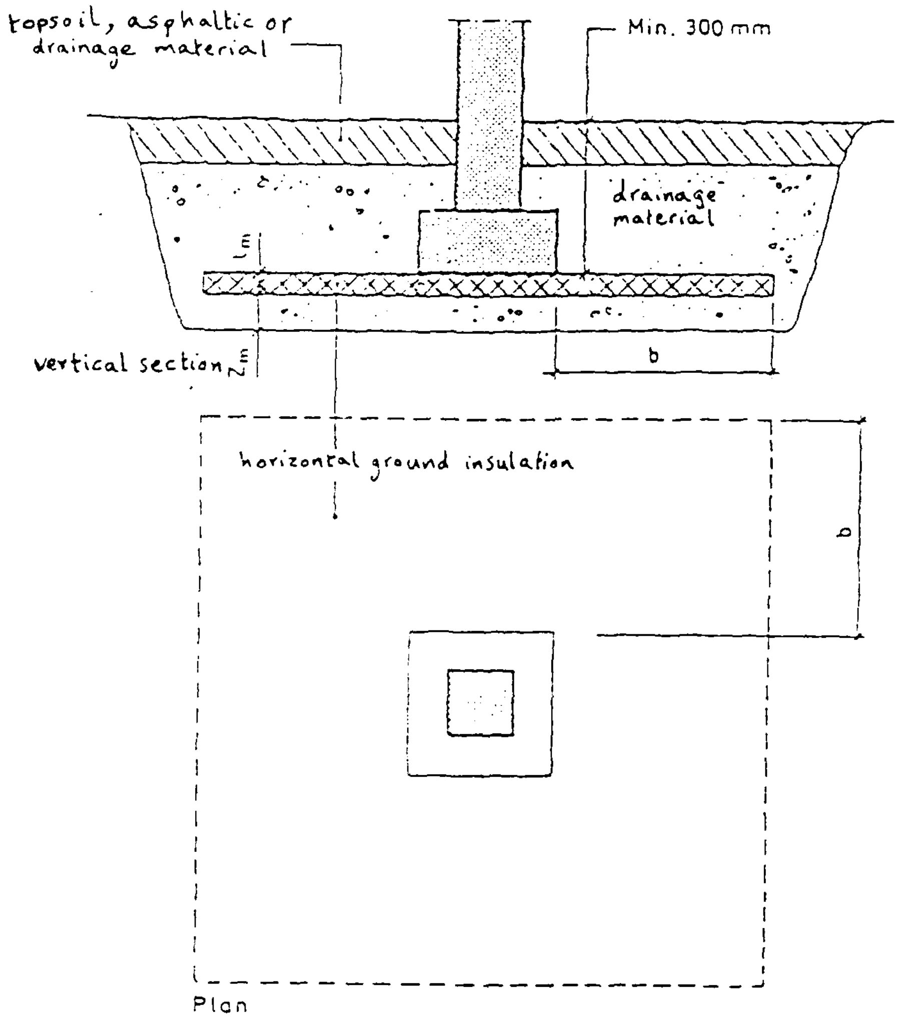
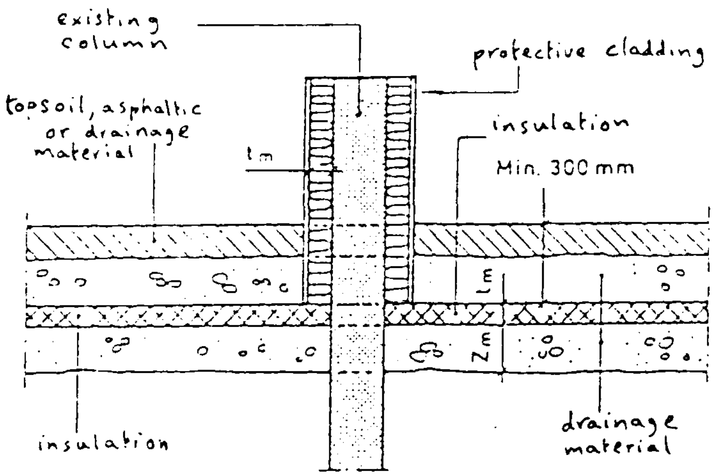
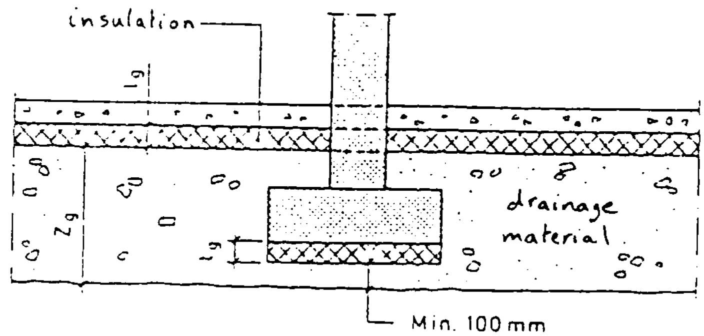


Fig. 134 Frost protection of column and column foundation

(from 'Building Details', A 521.811)



(a) Frost protection of existing column that is exposed to frost heave.



(b) A column foundation under frost-protected slab construction.

Fig. 135 Frost-protection of column and column foundation

(from 'Building Details', A 521.811)

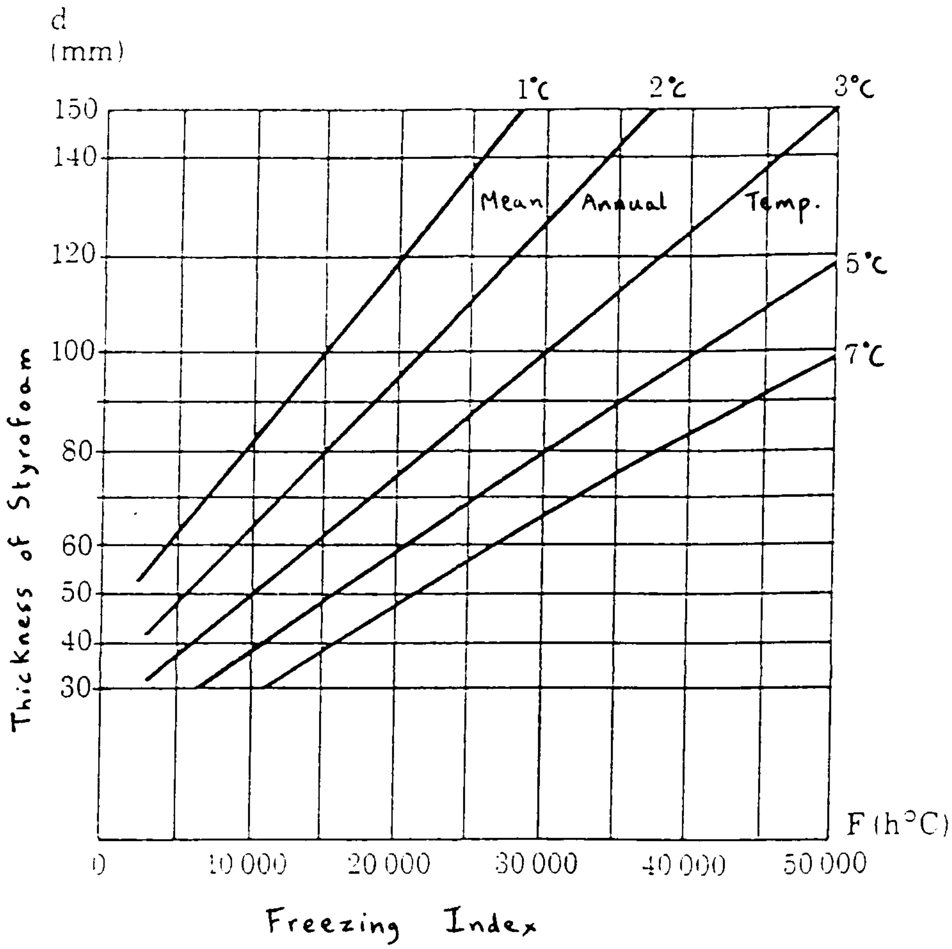


Fig. 136 Necessary thickness of 'styrofoam' as function of Design Freezing Index in air (F_2, F_{10}, F_{100}) and Mean Annual Temperature.

(Dow Chemical, 1987)

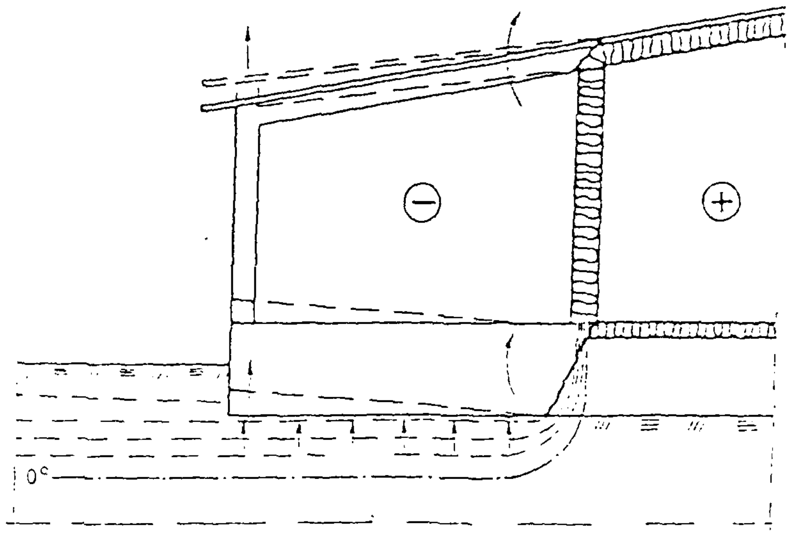


Fig. 137 Differential movement between 'cold' and 'heated' parts of a building.

(Dow Chemical, 1987).

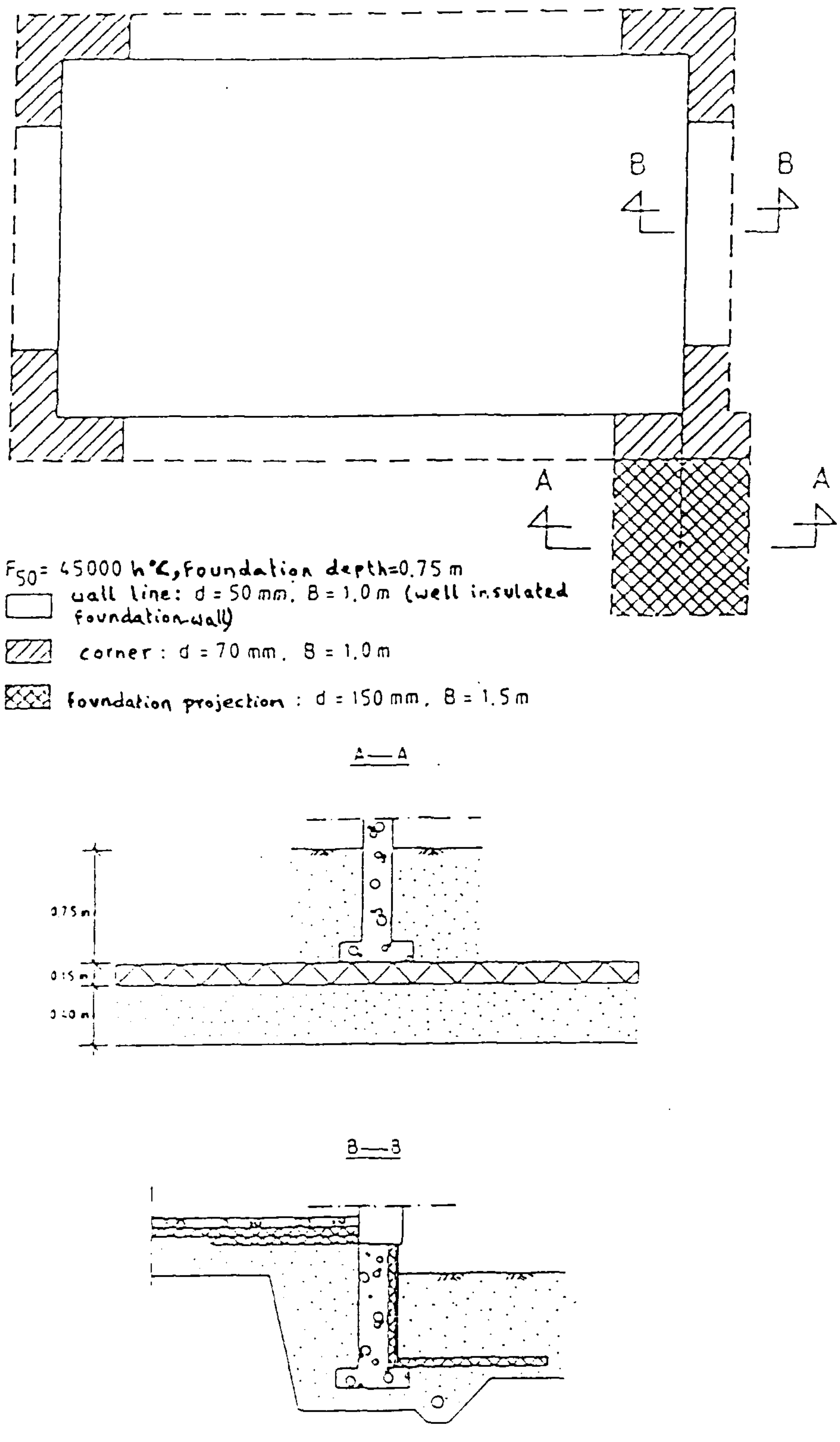


Fig. 138 Examples of frost protection of heated buildings and their cold parts.

(Finnish guidelines, 1987)

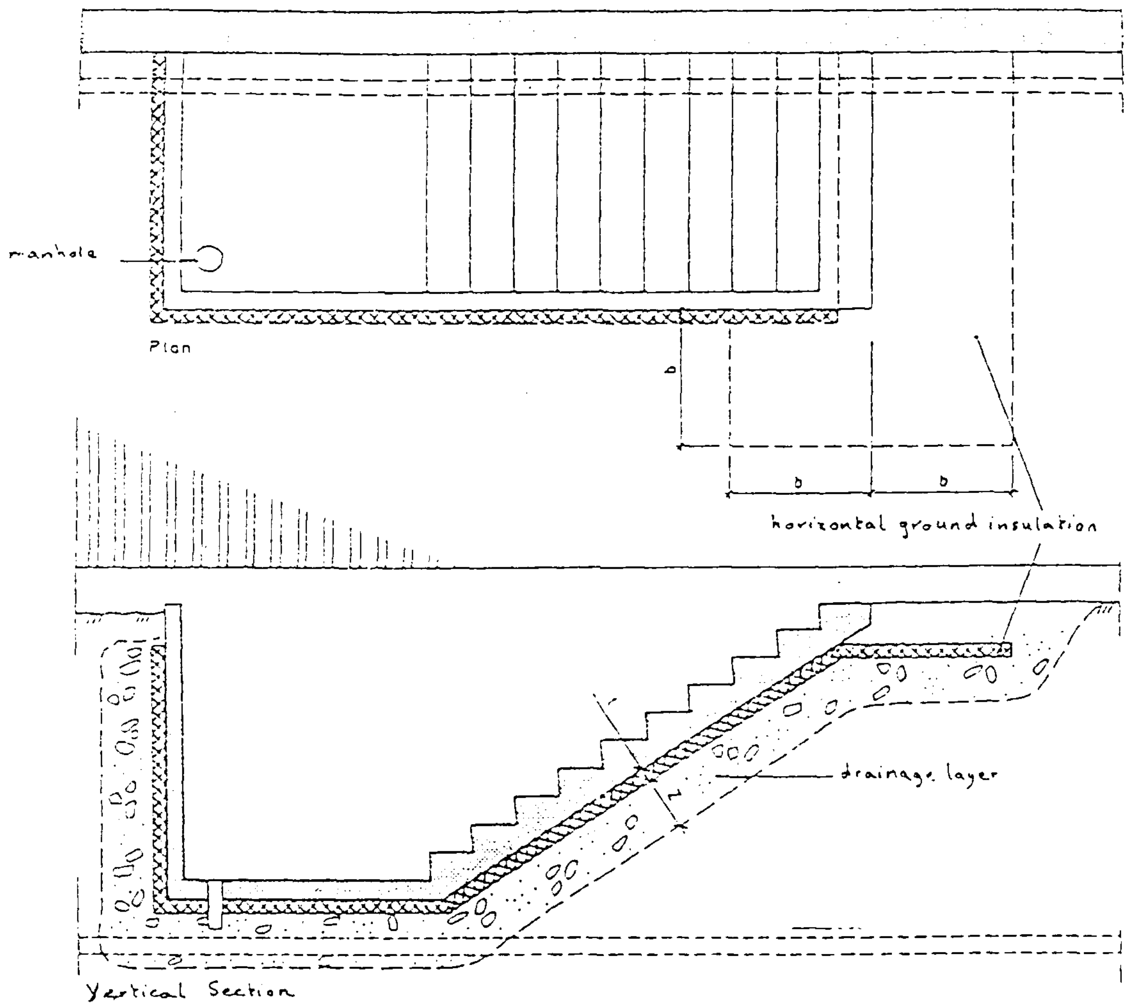


Fig. 139 Frost protection of an exterior cellar staircase.

(from 'Building Details', A 521.811)

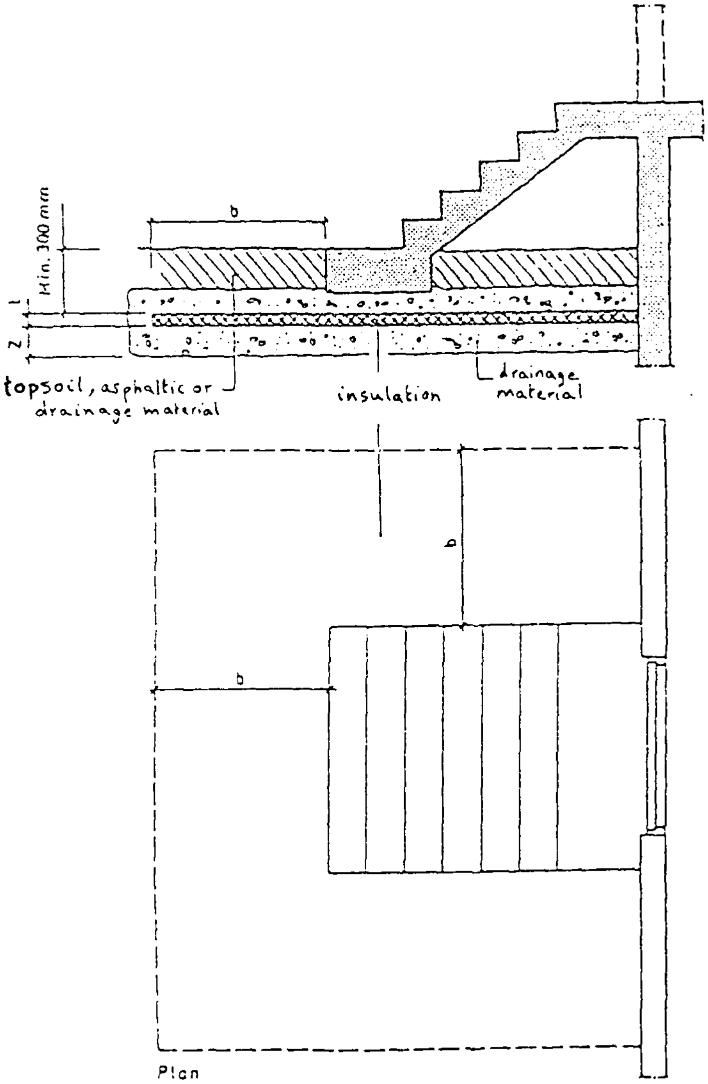


Fig. 140 Frost protection of foundation for an entrance staircase.

(from 'Building Details,', A 521.811)

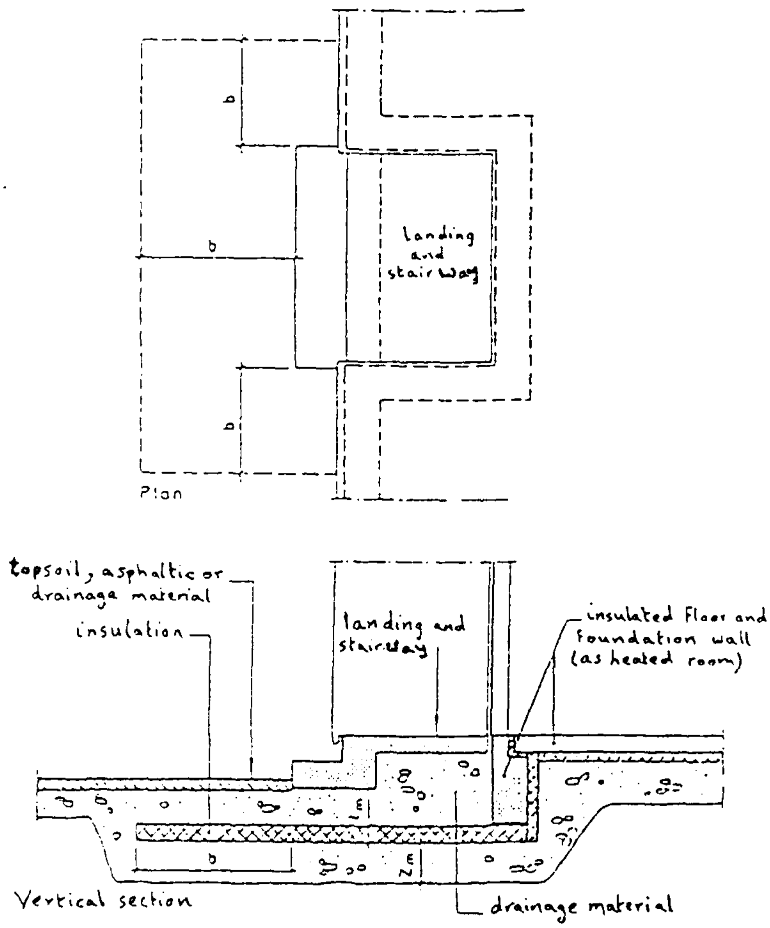
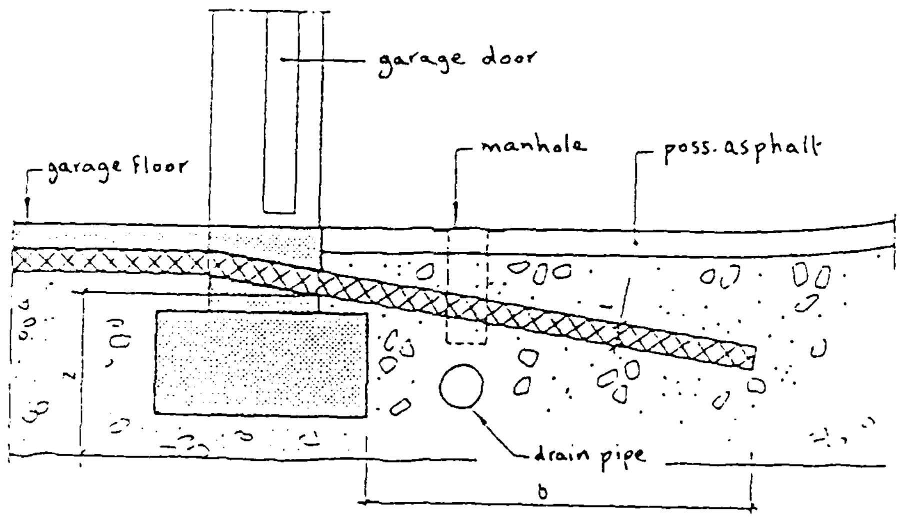
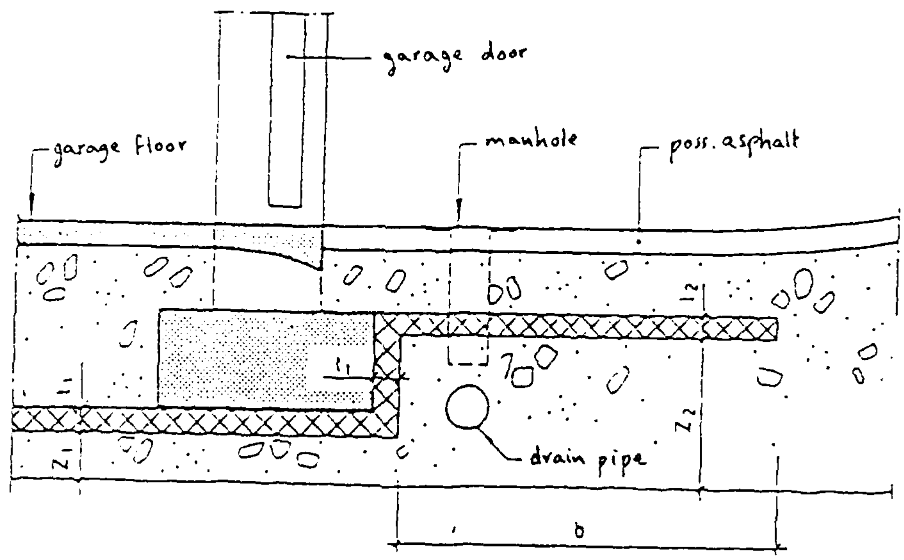


Fig. 141 Frost protection of a landing and stairway with a closed-in entrance.

(from 'Building Details', A 521.811)





Figs. 142 and 143 Frost-protection of garage entrance drive

(from 'Building Details' A 521.811)

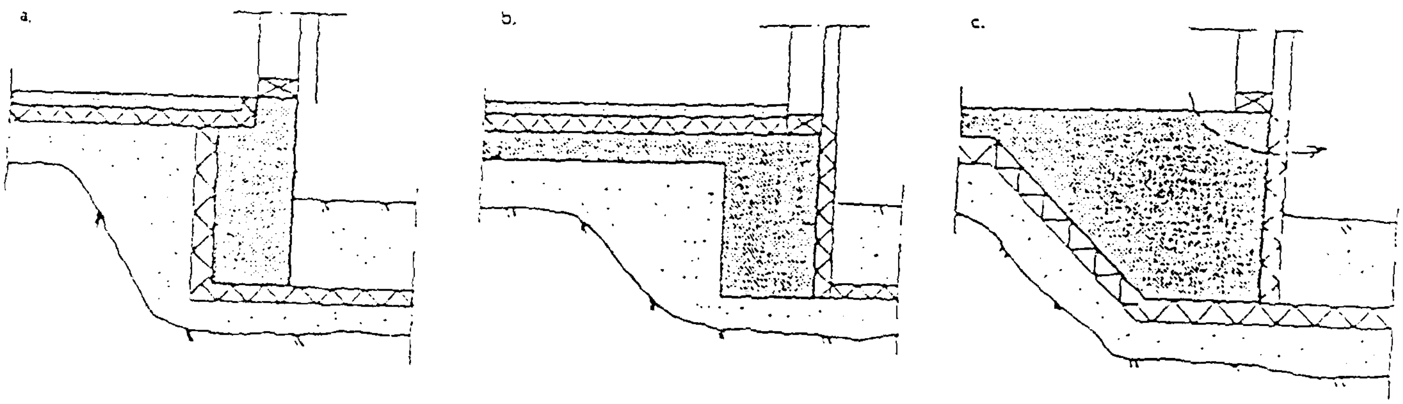


Fig. 144 These designs for heated or cold buildings are satisfactory with regard to frost penetration requirement but design c. is unsuitable for heated buildings without vertical insulation of the foundation wall.

(from Algaard, 1976)

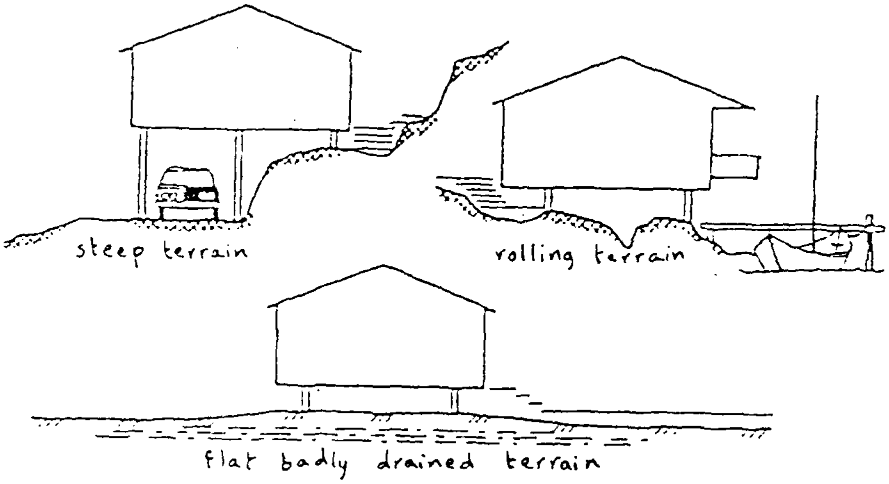
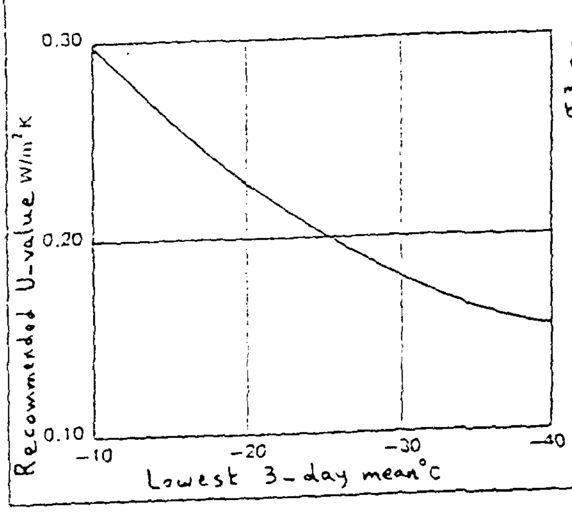


Fig. 145 A house on piers is specially suited to places with steep or rolling terrain or on ground with bad drainage conditions.

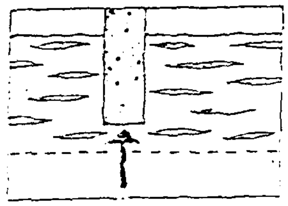
(from 'Building Detials', A 521.304)



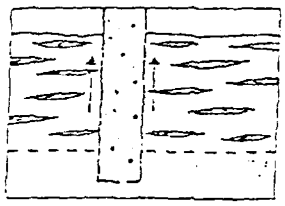
Wood floor structure, mineral wool thickness mm	U-value W/m²K
125	0.33
150	0.28
175	0.24
200	0.22

Fig. 146   Recommended *U*-value for floor structure

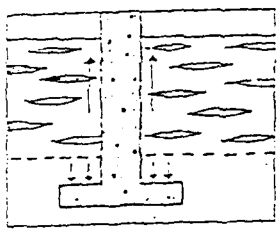
(from Torgersen, 1976)



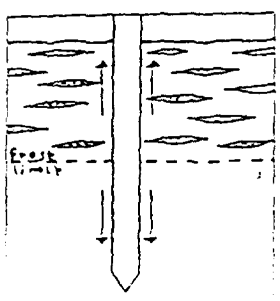
Frost under the foundation gives frost heave



Soil that freezes firmly to the
foundation gives a lifting force with sidegrip



Anchoring with expanded footing
under the frost zone.



Anchoring by friction between
the foundation and the soil under the
frost zone.

Fig. 147 Frost heave and sidegrip

(from Torgersen, 1976)

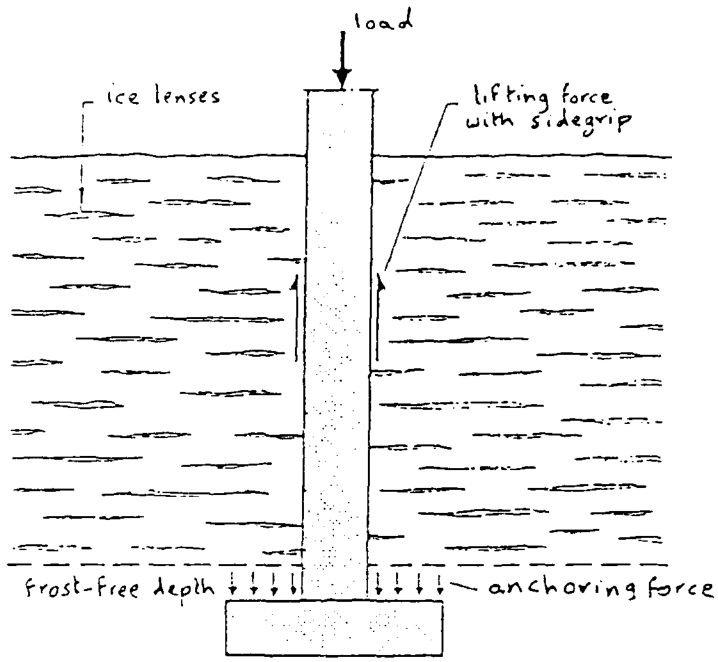
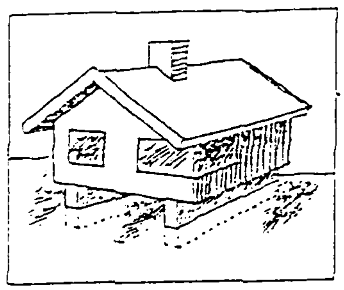
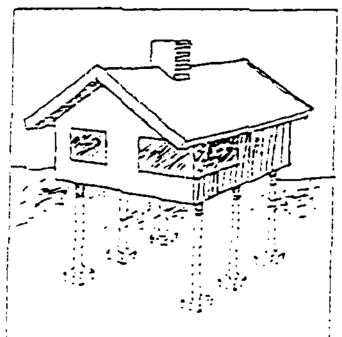


Fig. 148 pier taken down to frost-free depth and anchored against the lifting force from ice sidegrip.

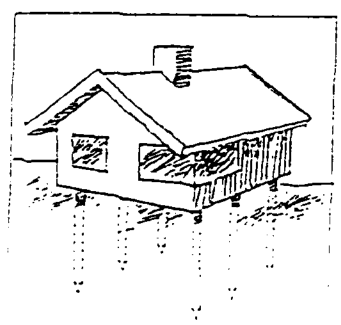
(from 'Building Details' A 521.304)



Foundation with groundwall strips



Foundation with piers



Foundation with piles

Fig. 149 Types of open foundations

(from Torgersen, 1976)

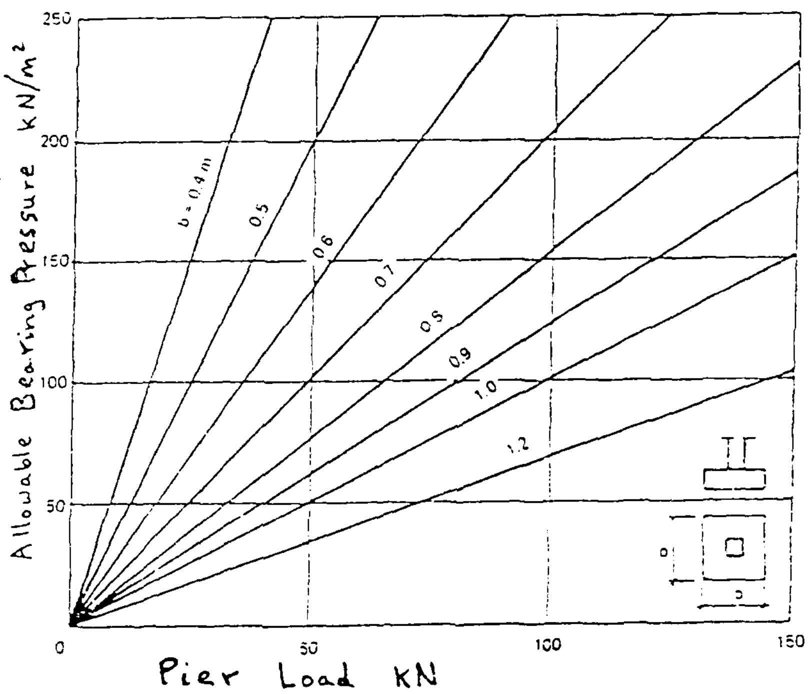


Fig. 150 Necessary footing size for carrying load.

(from Torgersen, 1976)

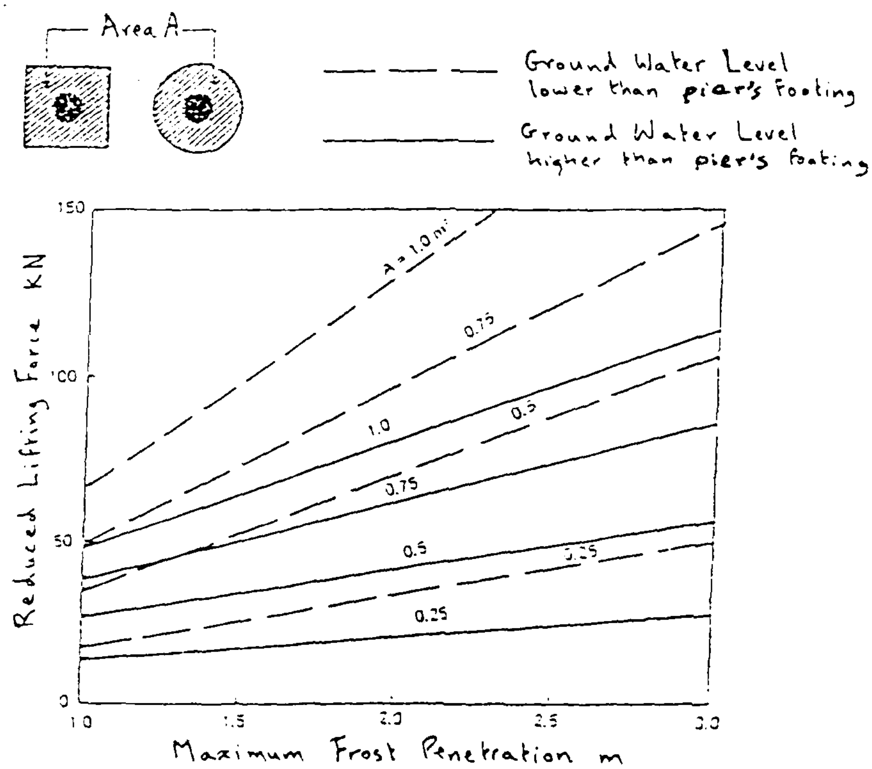


Fig. 151 Necessary footing area for anchoring against sidegrip

(from Torgersen, 1976)

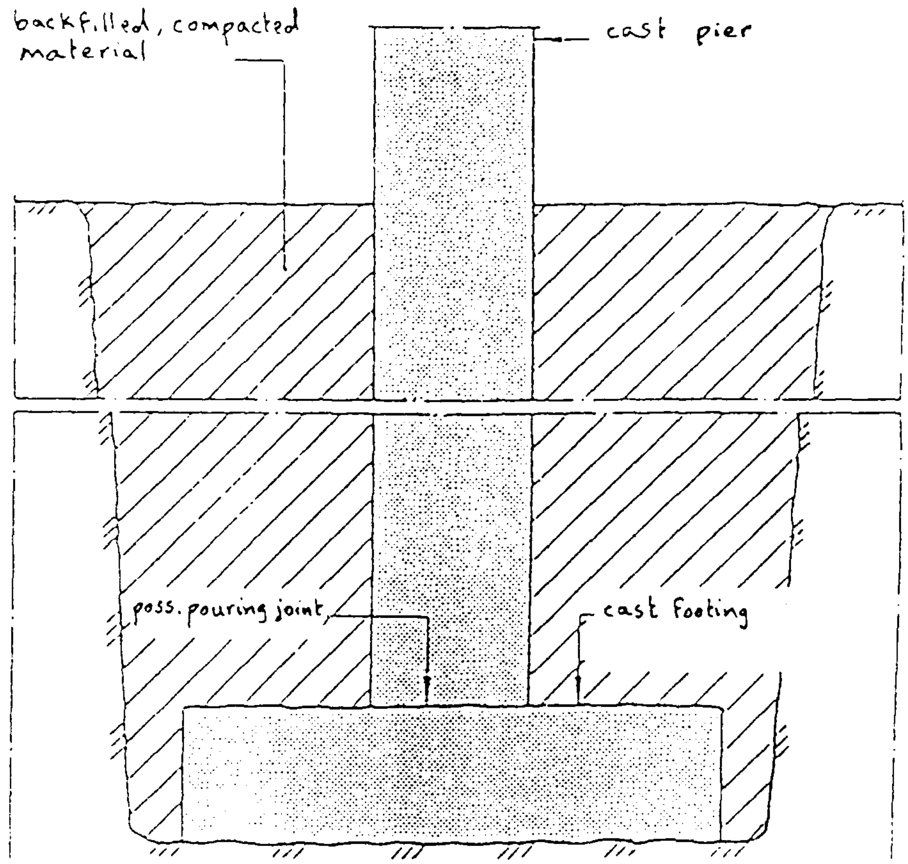


Fig. 152 Section of **pier** with footing.

The footing can possibly be cast direct into a trench without formwork.

(from 'Building Details' A 521.304)

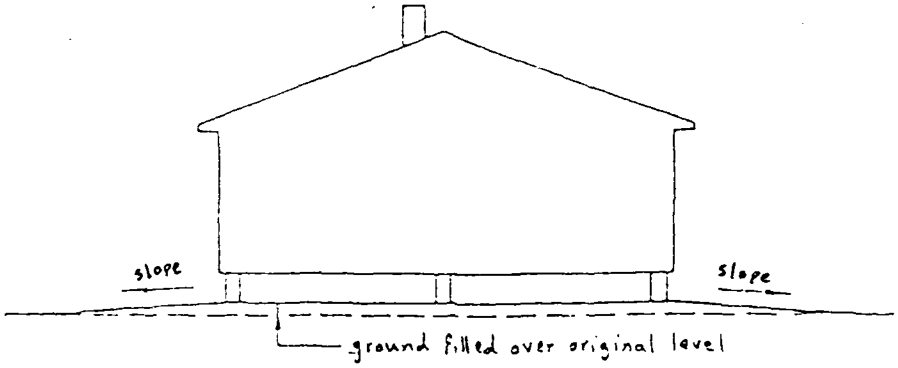


Fig. 153 With wet conditions the ground under the house should be raised up to keep it dry. The ground should be graded outside with a slope to lead surface water away.

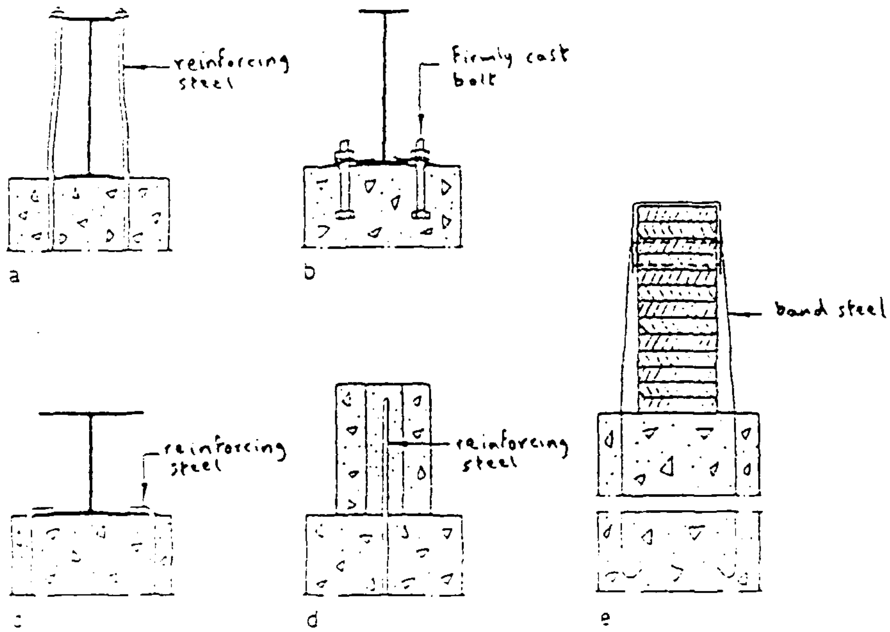


Fig 154 Anchoring of beam to column
(from 'Building Details', A 521.304)

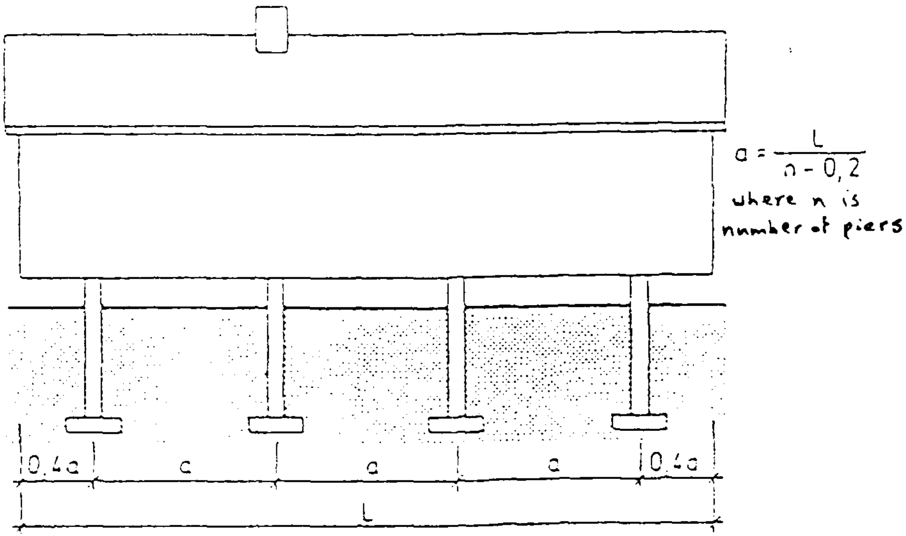


Fig. 155 pier positions to give approximately the same load on each pier under a bearing wall.

(from 'Building Details', A 521.304)

AD-A194 140 FOUNDATION DESIGN AGAINST FROST ACTION IN EUROPE(U) 4/4
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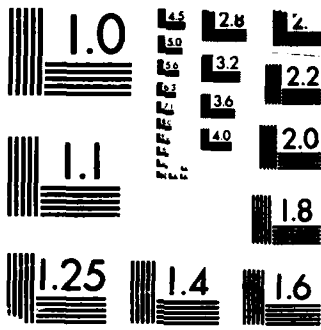


MICROCOPY RESOLUTION TEST CHART

BUREAU OF STANDARDS-1963-A

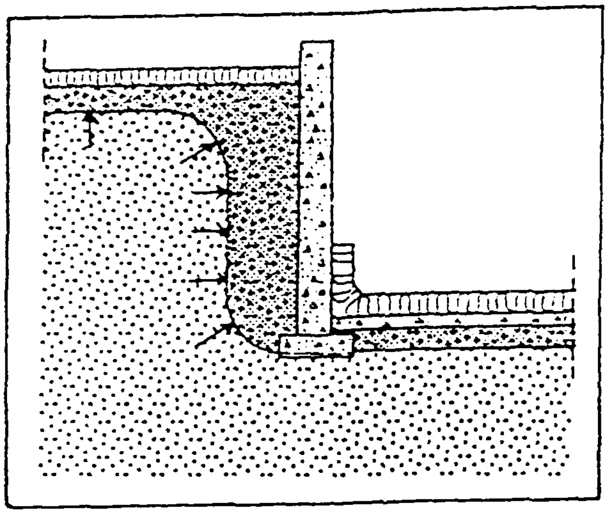


Fig. 156 Horizontal heave forces on a vertical structure

(from Thue, 1972)

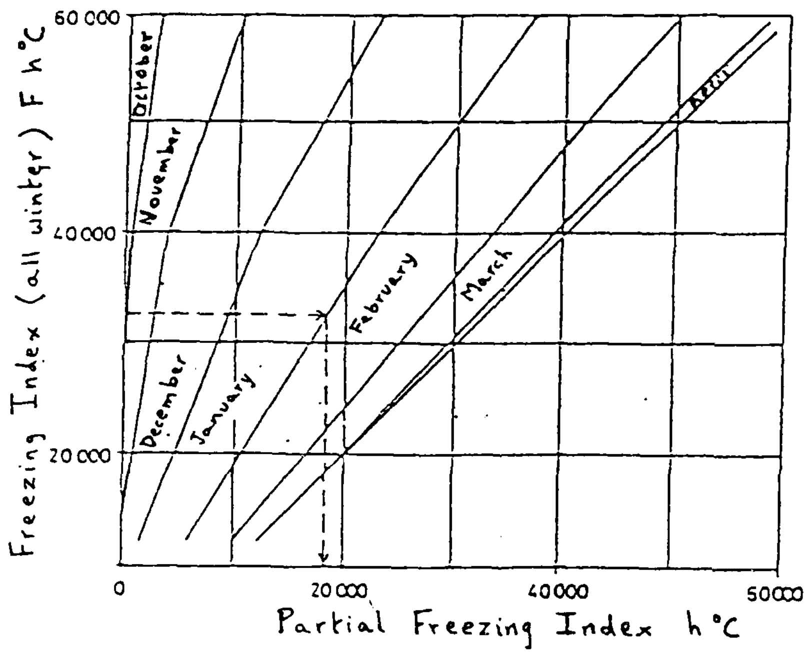


Fig. 157 Estimation of partial Freezing Index.

(Finnish guidelines, 1987)

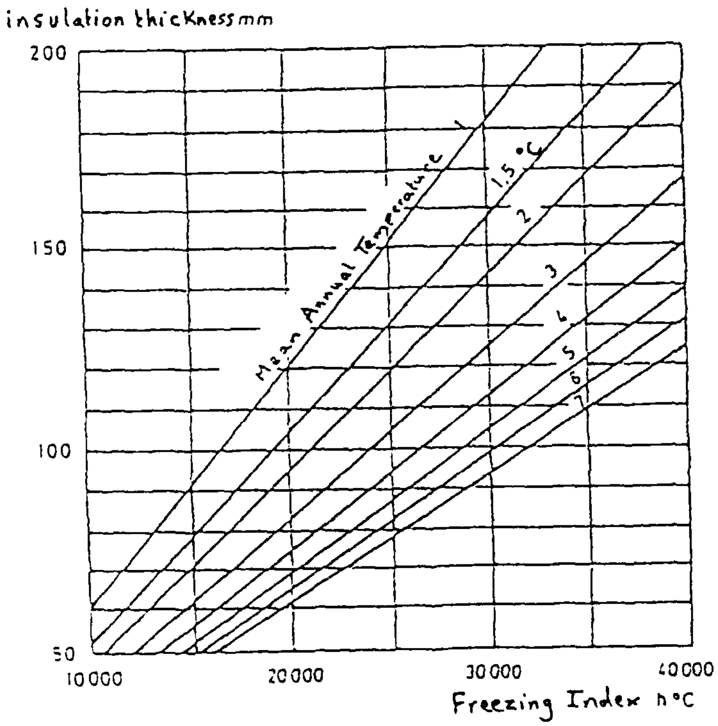


Fig. 158 Necessary insulation thickness for frost protection with insulation of expanded polystyrene (30 kg/m^3)

(from 'Building Details' A 521.111)

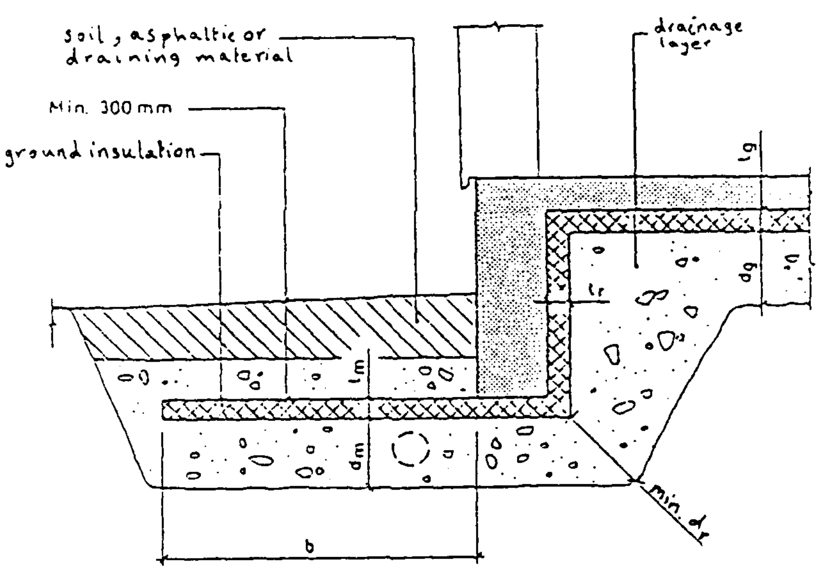


Fig. 159 Inter-related thicknesses of thermal insulation and drainage material that give frost protection, together with the necessary width b of the ground insulation outside the foundation wall.

(from 'Building Details', A 521.111)

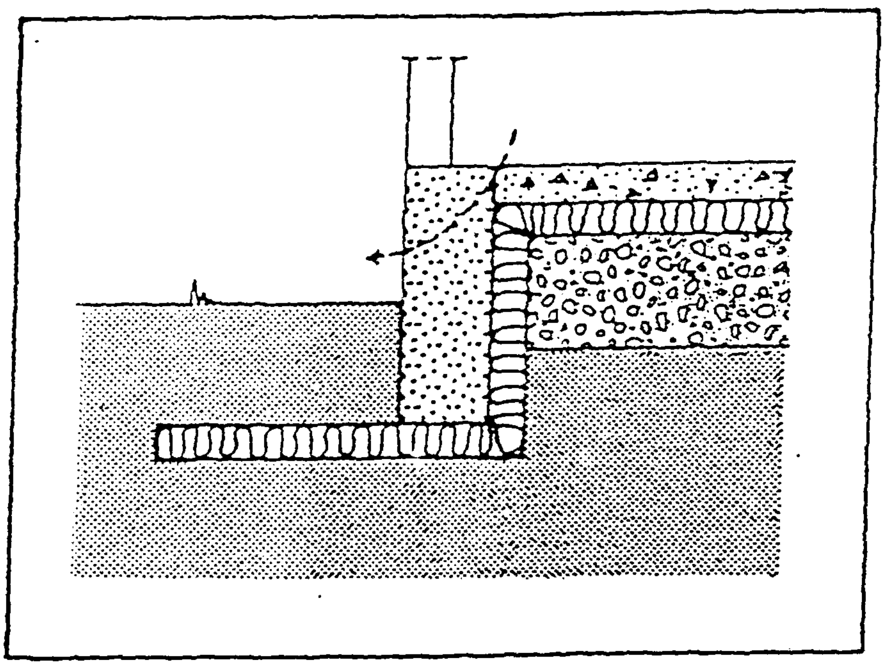


Fig. 160 Foundation placed on ground insulation (from Thue, 1972)

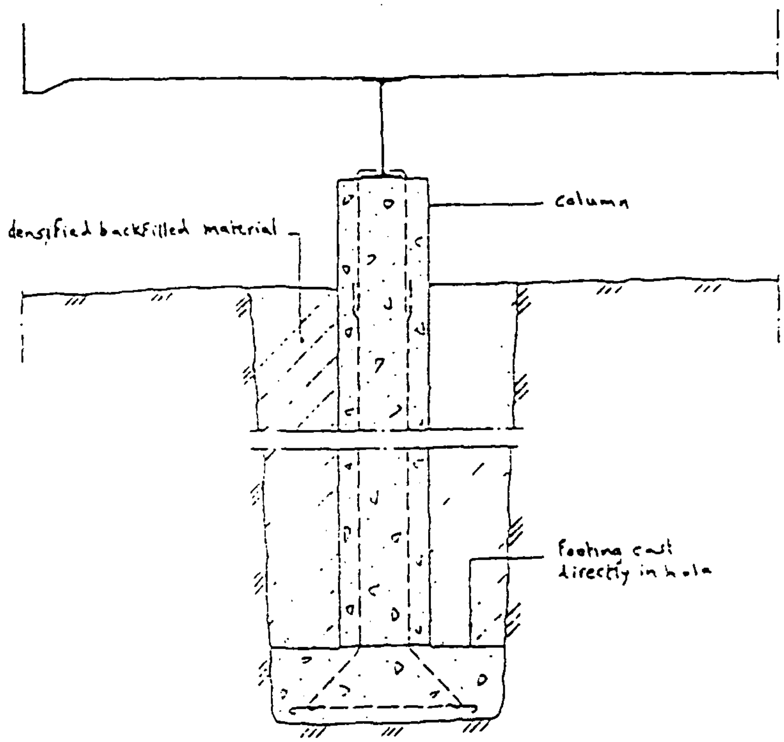


Fig. 161 Example of cast-in-place pier

(from 'Building Details', A 521.011)

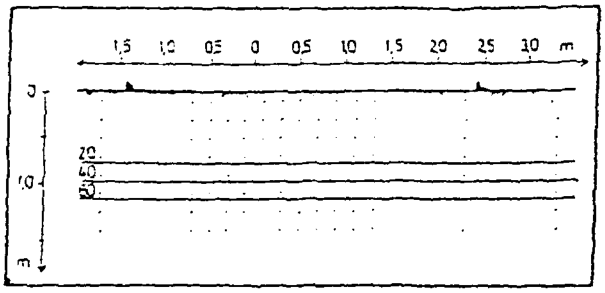


Fig. 162 Frost penetration in undisturbed ground.
No insulation.

Curve 20 : 0°C isotherm at January 20 1966
Curve 40 : " " " February 9 1966
Curve 60 : " " " March 1 1966

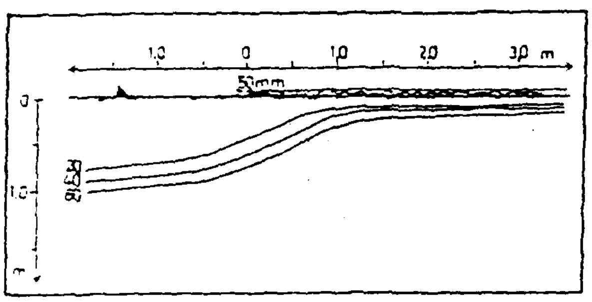


Fig. 163 Frost penetration with 50mm thick insulation, 9.20m wide (from 0 to the right)
Isotherms do not penetrate as deep as in Fig. 162

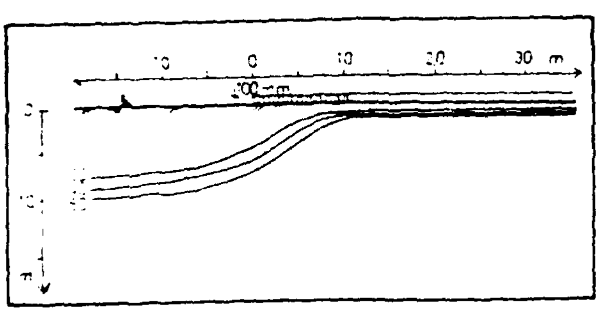


Fig. 164 Frost penetration with 100mm thick insulation, 9.20m wide.

Thermal conductivity of insulation = 0.046 W/mK

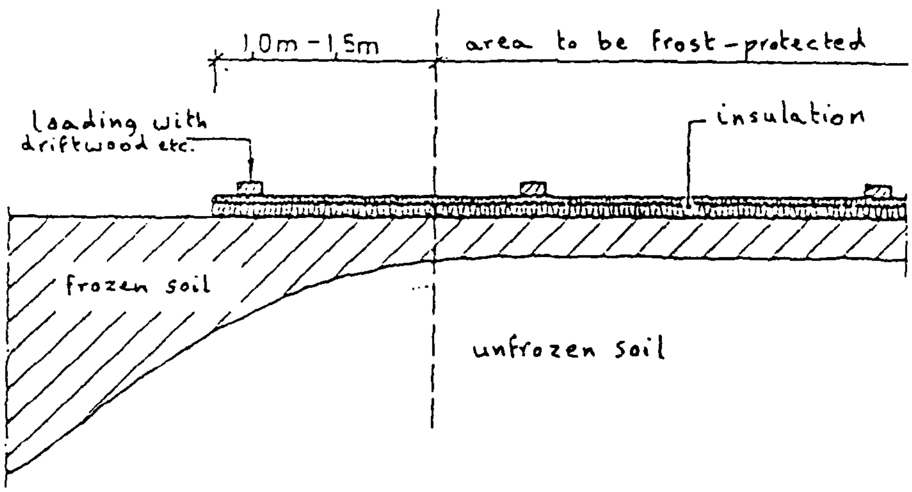


Fig. 165 Insulation is extended 1.0m - 1.5m outside the _rea which should be frost-protected.

(from 'Building Details', A 513.121)

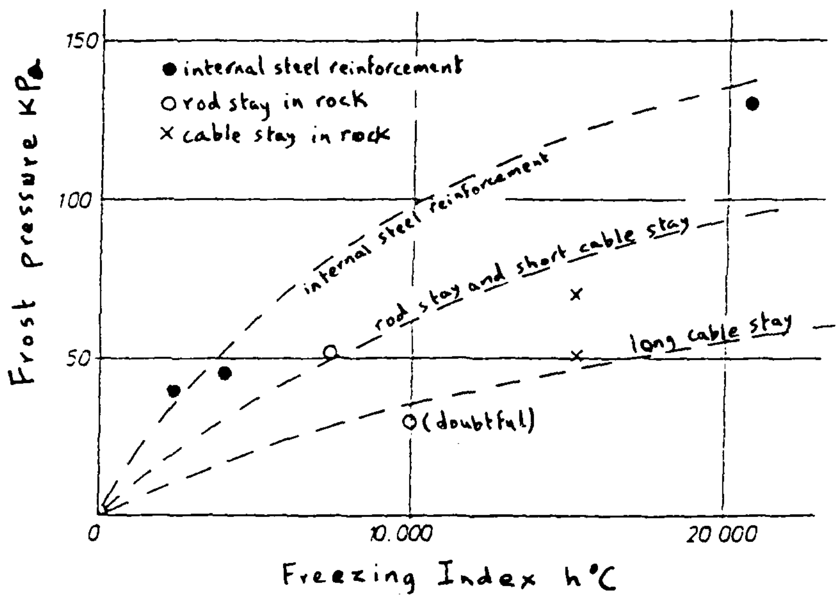


Fig. 166 Proposal for design of frost pressure based on observations.

(Eggestad, 1982)

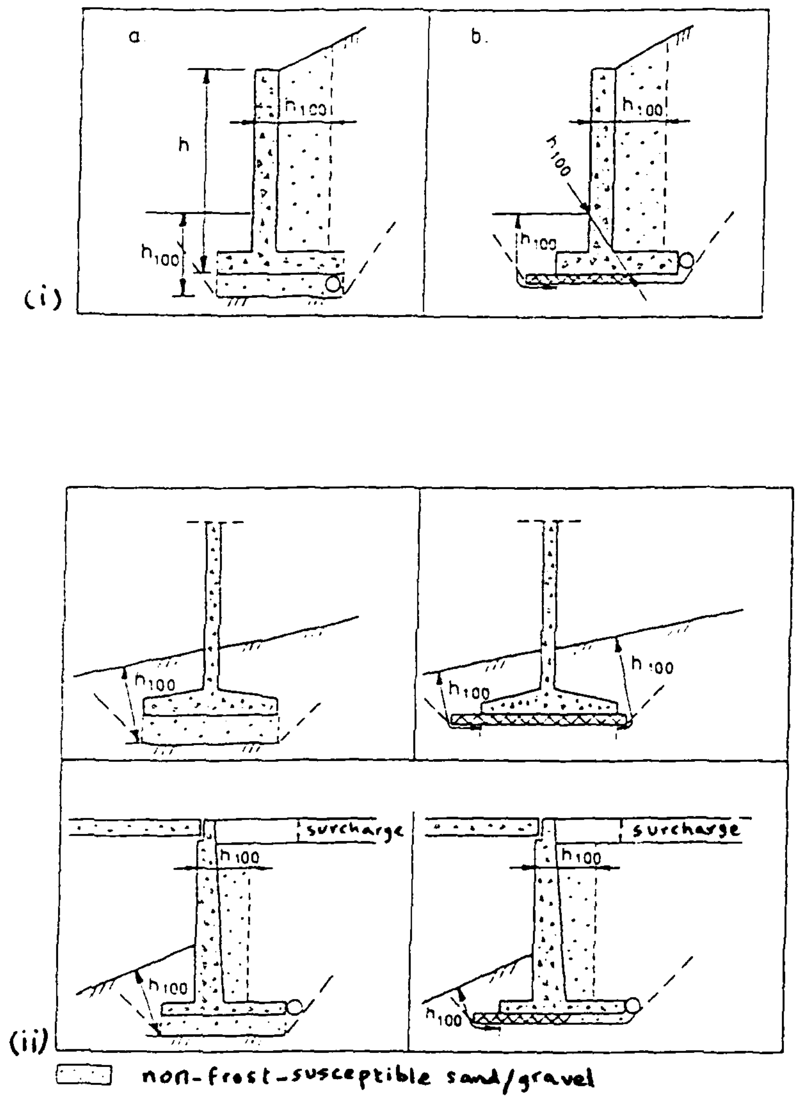


Fig. 167 Examples of frost protection of
(i) Retaining wall
(ii) Bridge foundation.

(Statens Vegvesen, 1980)

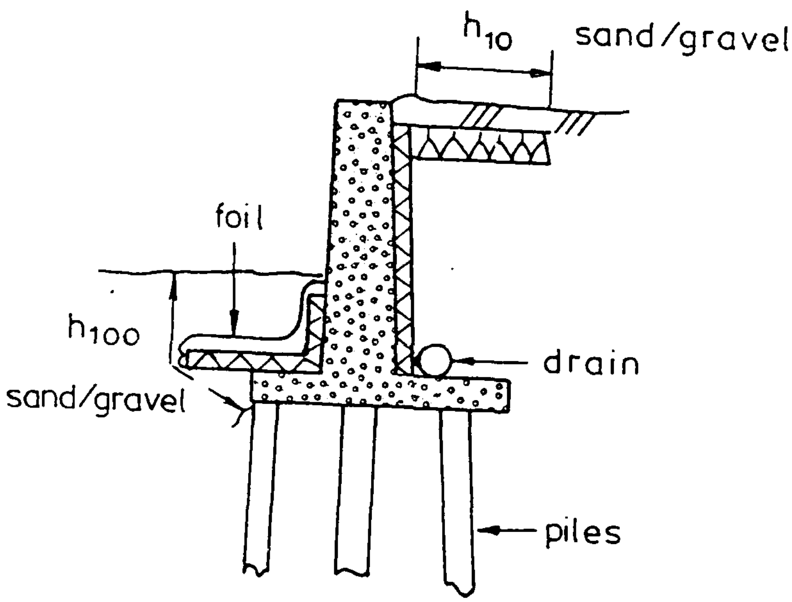


Fig. 168 Insulation with a pile foundation for a retaining wall.

(Pedersen, 1976).

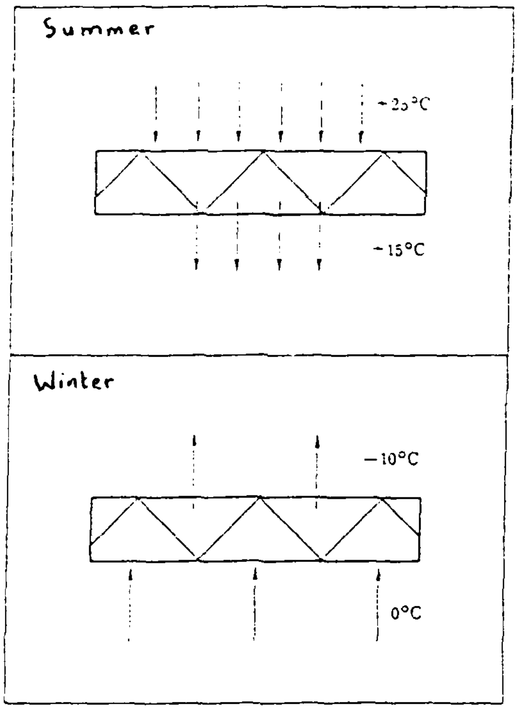


Fig. 169 Temperature difference caused by insulation.

(Dow Chemical, 1987).

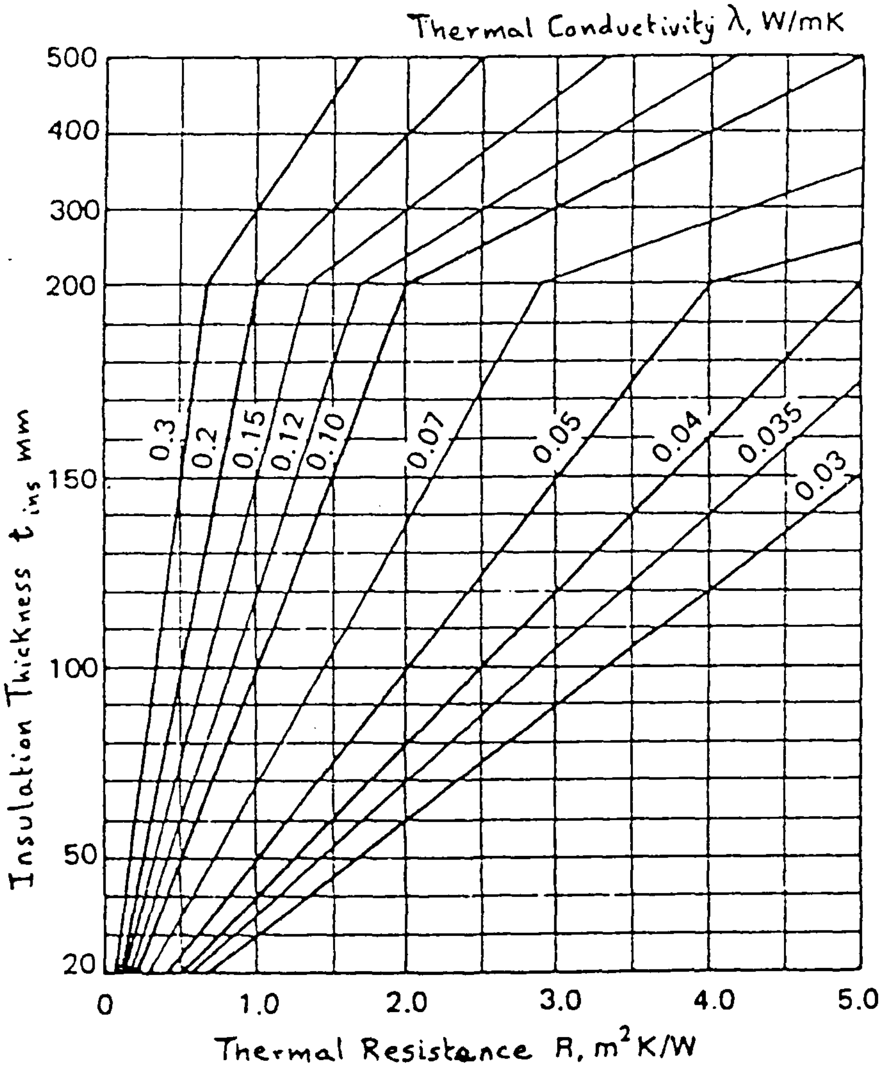
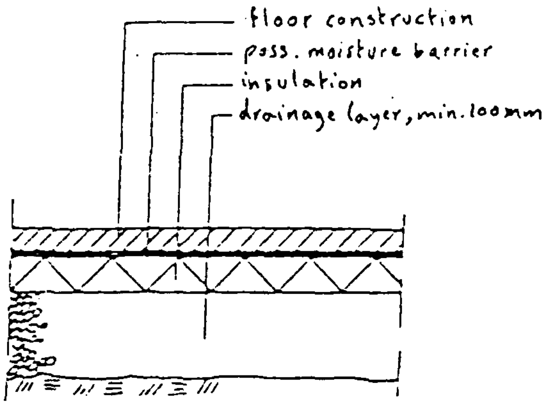
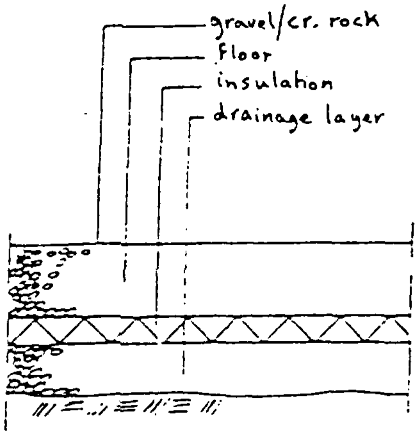


Fig. 170 Diagram for determination of the necessary insulation thickness if the required thermal resistance and the insulation's thermal conductivity are determined. (The lines are based on $t_{ins} = R\lambda$).

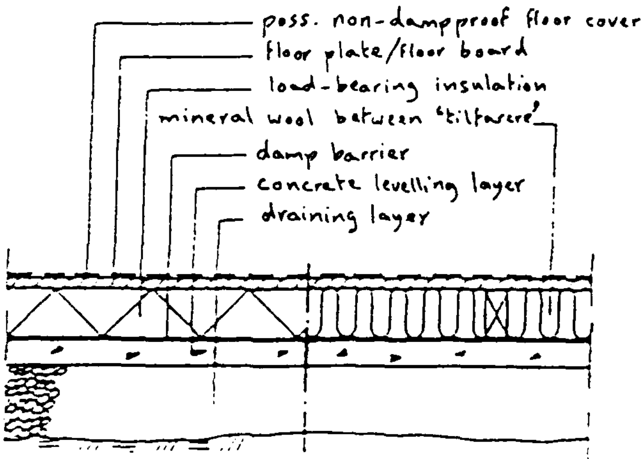
(from Algaard, 1976)



(a) With a strong insulation or a load-distributing concrete slab, the insulation can be laid directly under the slab. If a moisture barrier is necessary, it should be laid between the insulation and the overlying slab. A drainage layer should always be laid on frost-susceptible ground.



(b) To reduce the stress influence from a point load, the insulation could be laid lower down. If the surface of the construction is not damp-proof and protected against precipitation, a separate moisture barrier can be omitted in many cases.



(c) In permanently, or sporadically cold buildings with a small floor load, the floor shown can be used on 'tilfarere' or on load-bearing insulation (in dry conditions). A high-grade moisture barrier must then be placed <u>under</u> moisture-sensitive material and under the floor insulation and one should be careful with use of damp-proof floor cover.

Note: 'tilfarere' = wood surfaced floor

Fig. 171 Floor construction. Arrangement of insulation and possible damp barrier.

(from Algaard, 1976)

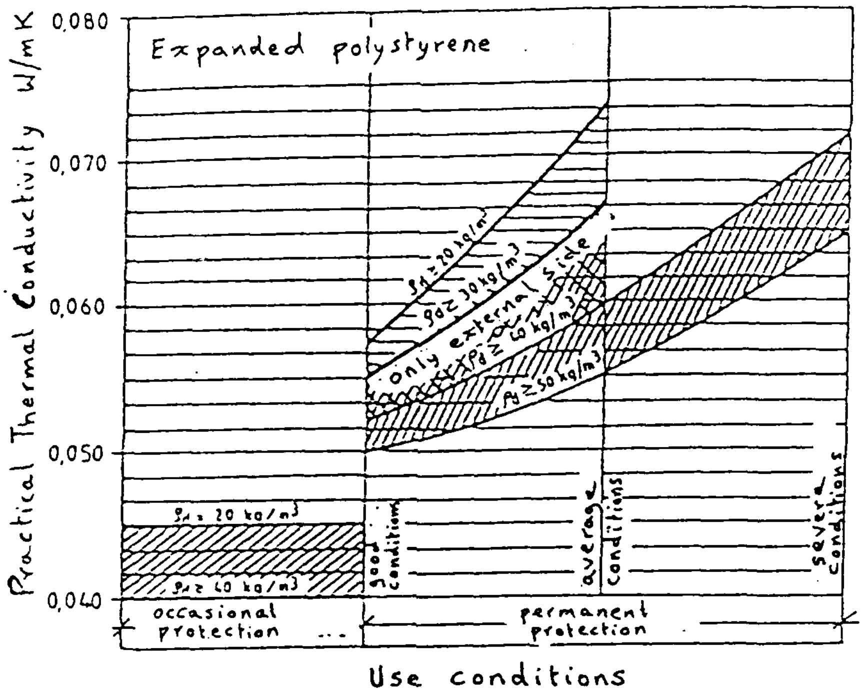


Fig. 172 Design thermal conductivity of expanded polystyrene for frost protection under different use conditions.

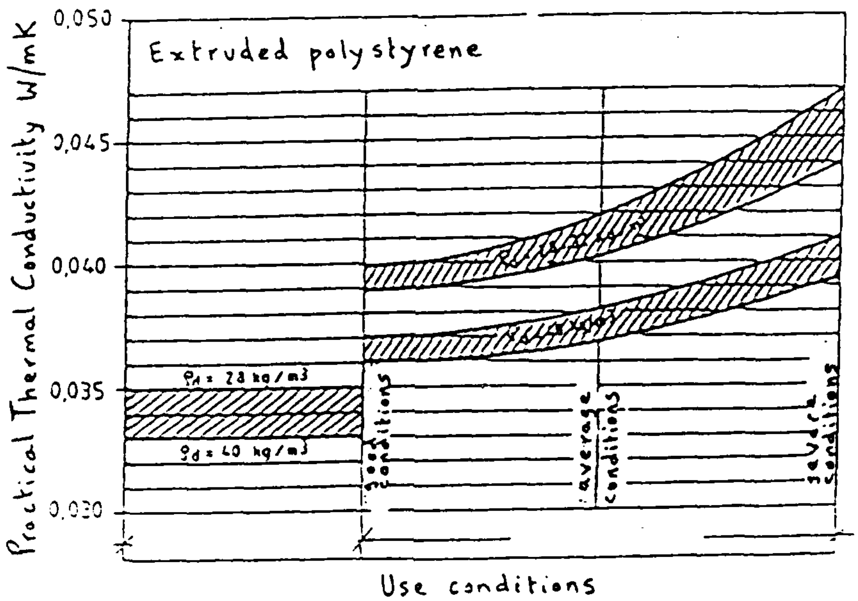


Fig. 173 Design thermal conductivity of extruded polystyrene for frost protection under different use conditions.

(Finnish guidelines, 1987)

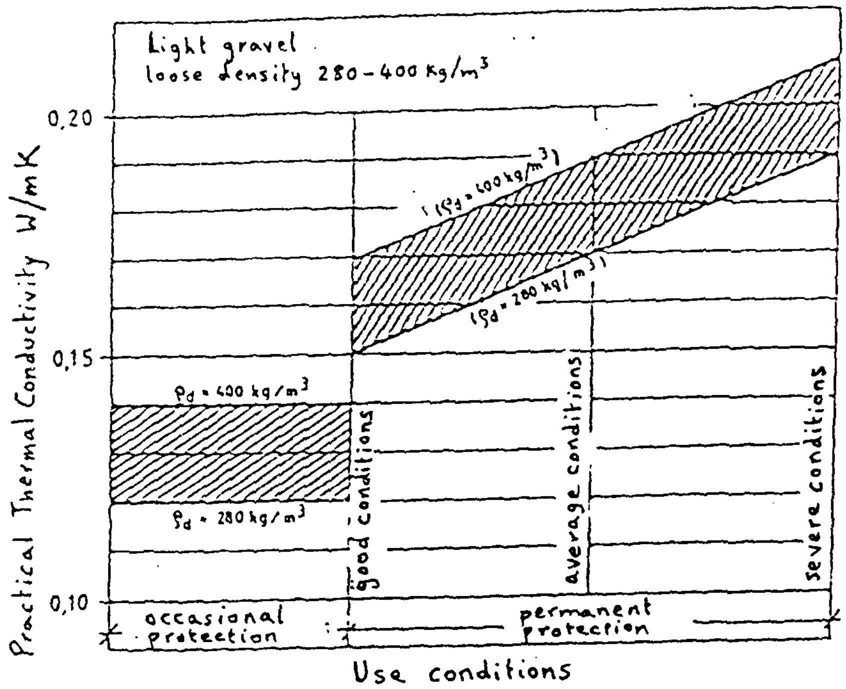


Fig. 174 Design thermal conductivity of light aggregate for frost protection under different use conditions.

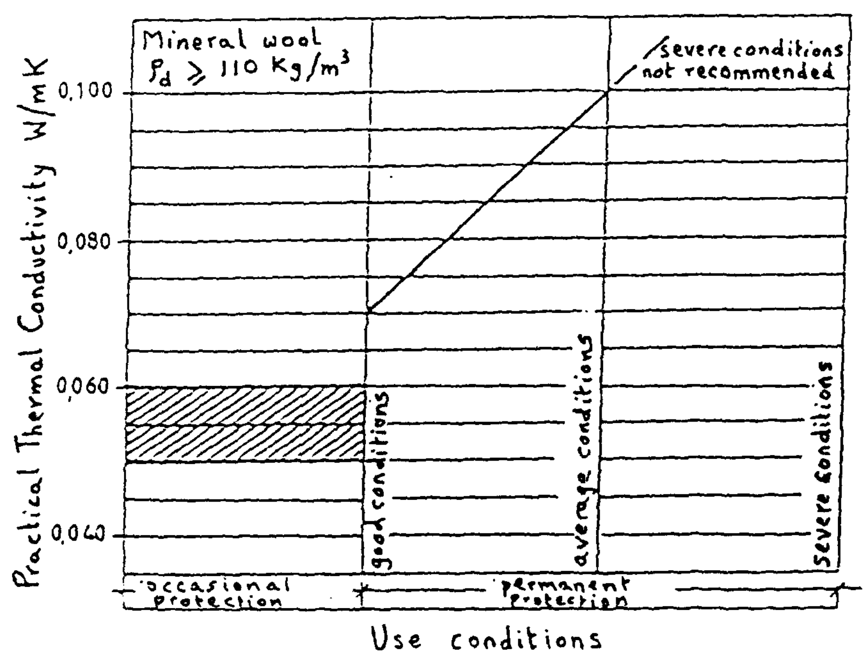


Fig. 175 Design thermal conductivity of mineral wool for frost protection under different use conditions.

(Finnish guidelines, 1987)

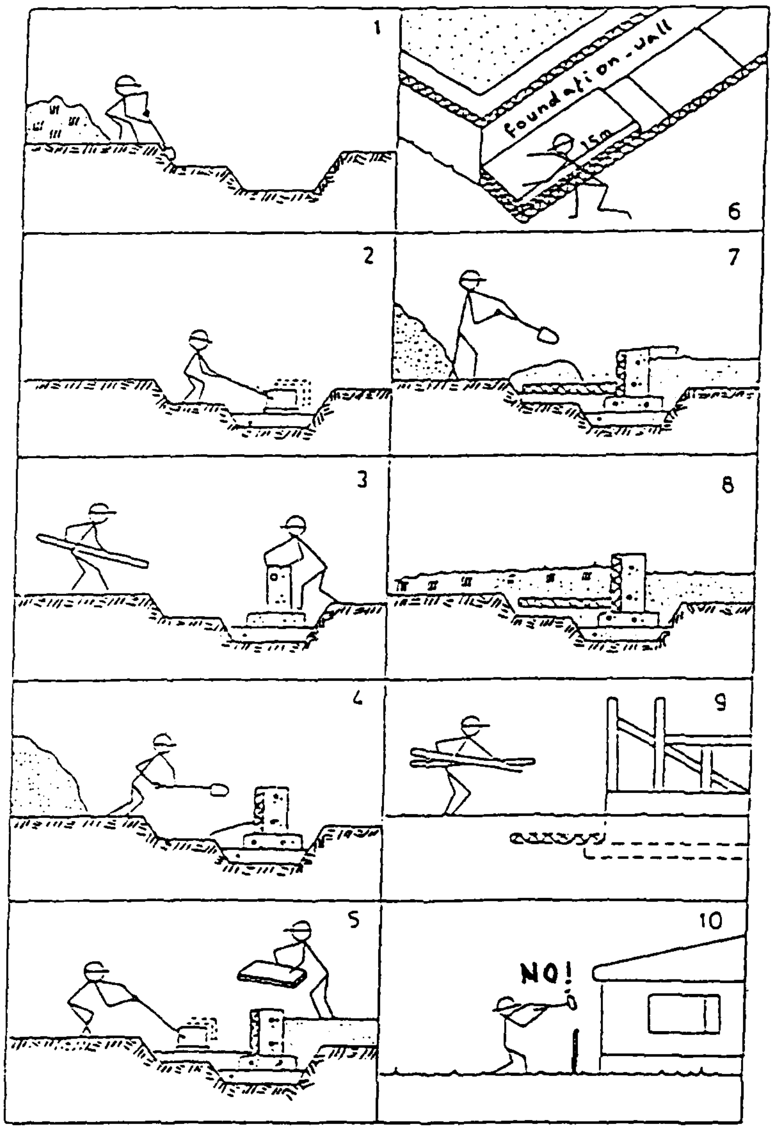


Fig. 176 Method of placing insulation for frost protection as a foundation is being constructed. Similar principles apply if the insulation is placed after construction.

(Finnish guidelines, 1987)

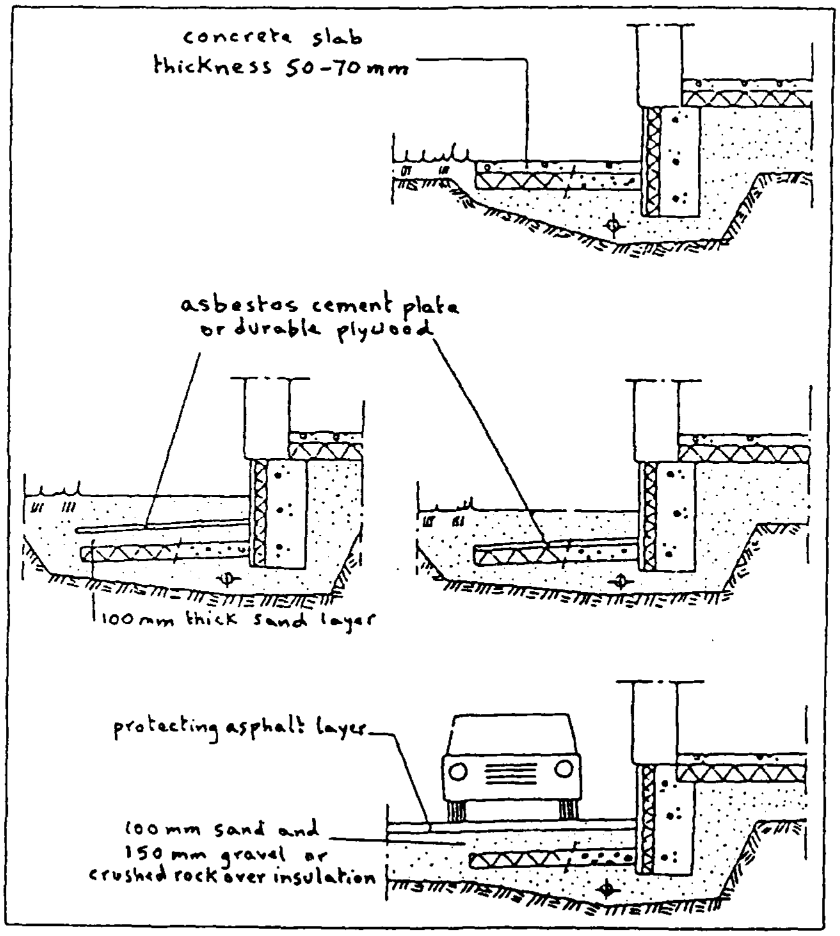


Fig. 177 Examples of protection of ground insulation.

(Finnish guidelines, 1987)

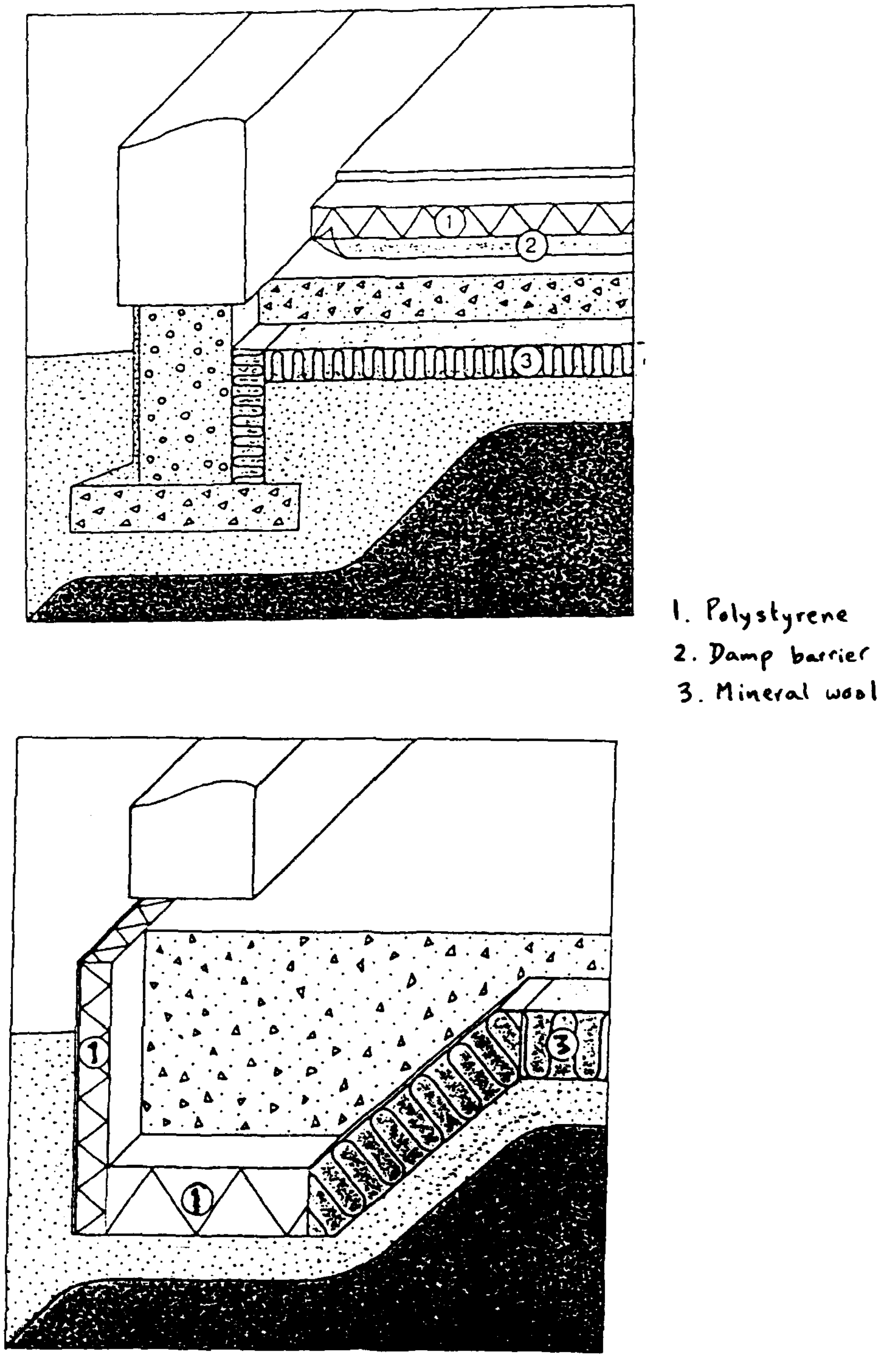


Fig. 178 Types of slab-on-grade construction showing insulation

(Gullfiber, 1985)

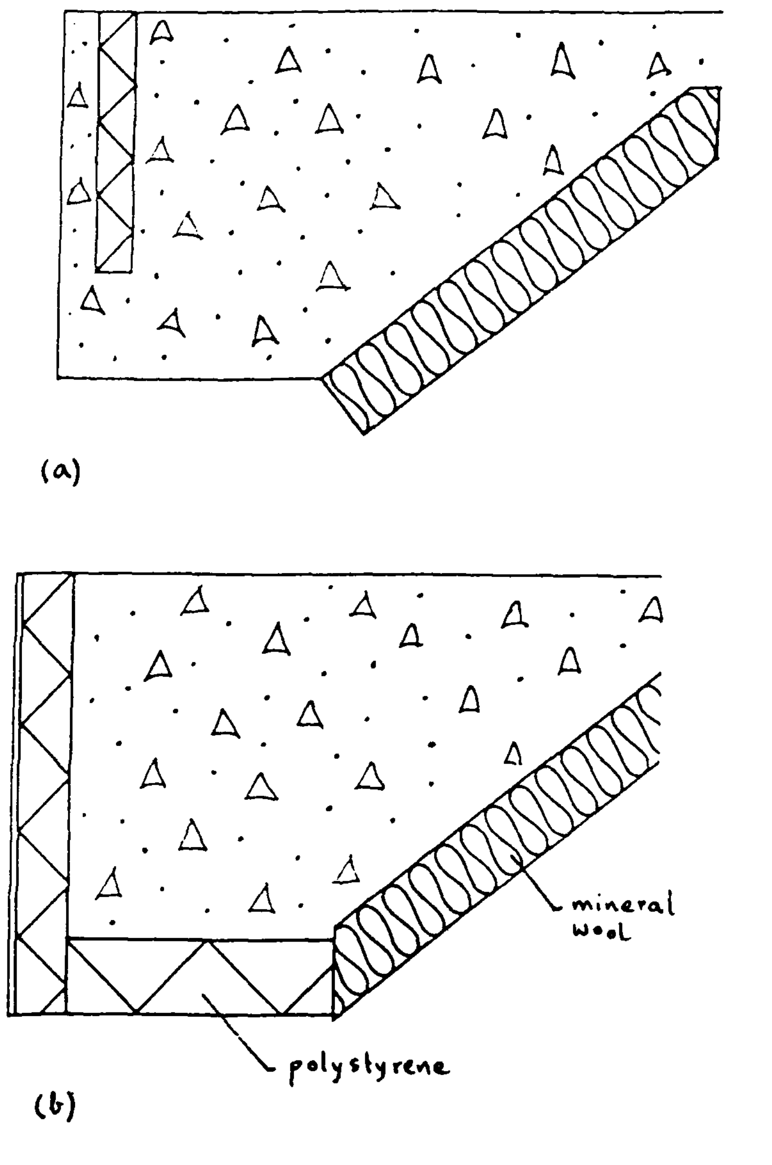


Fig. 179 Comparison of
(a) conventional slab insulation
and (b) continuous insulation.

(Gullfiber, 1986).

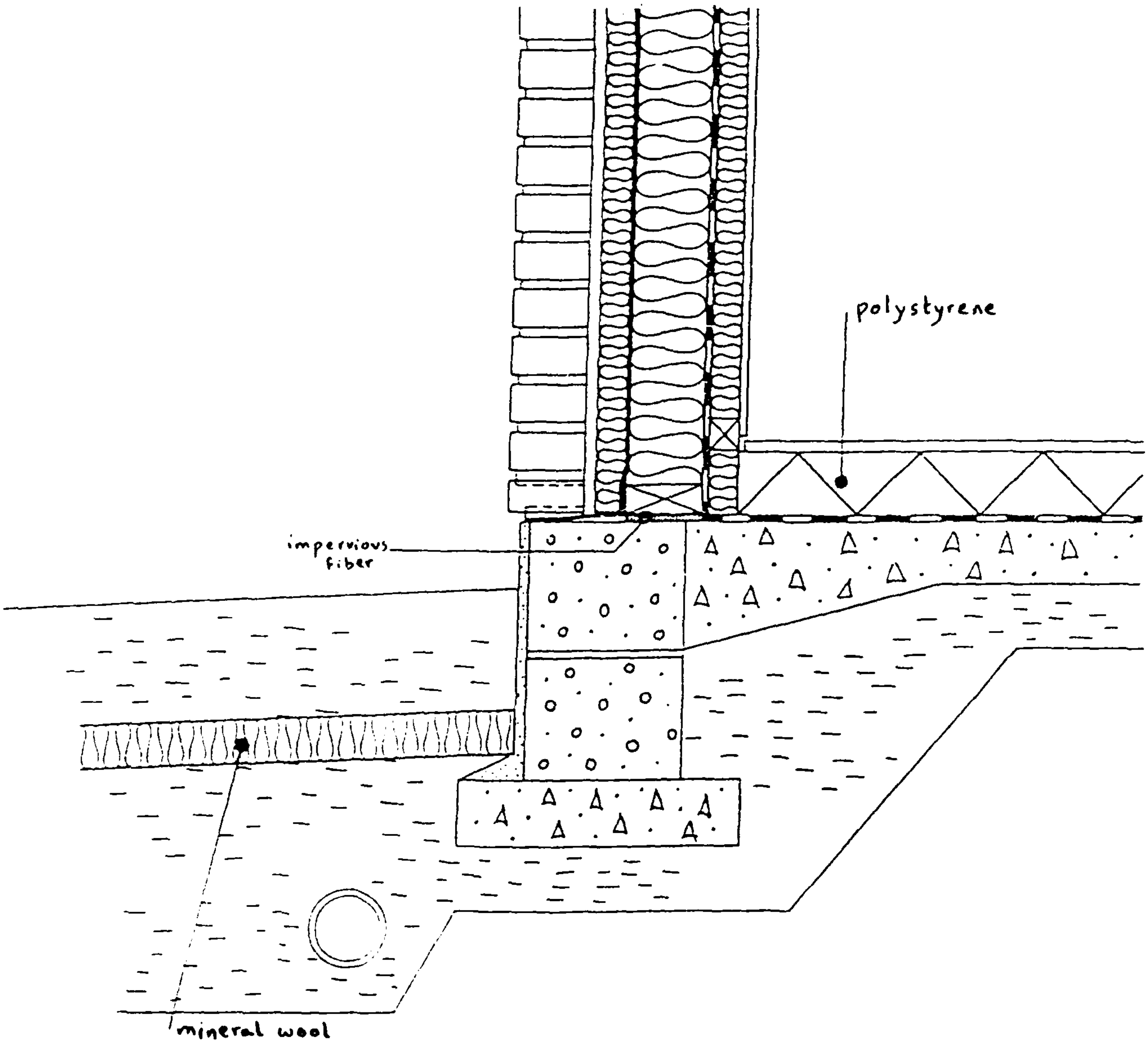


Fig. 180 Leca foundation wall and ground insulation.
Gullfiber floor system 1.

(Gullfiber. 1986).

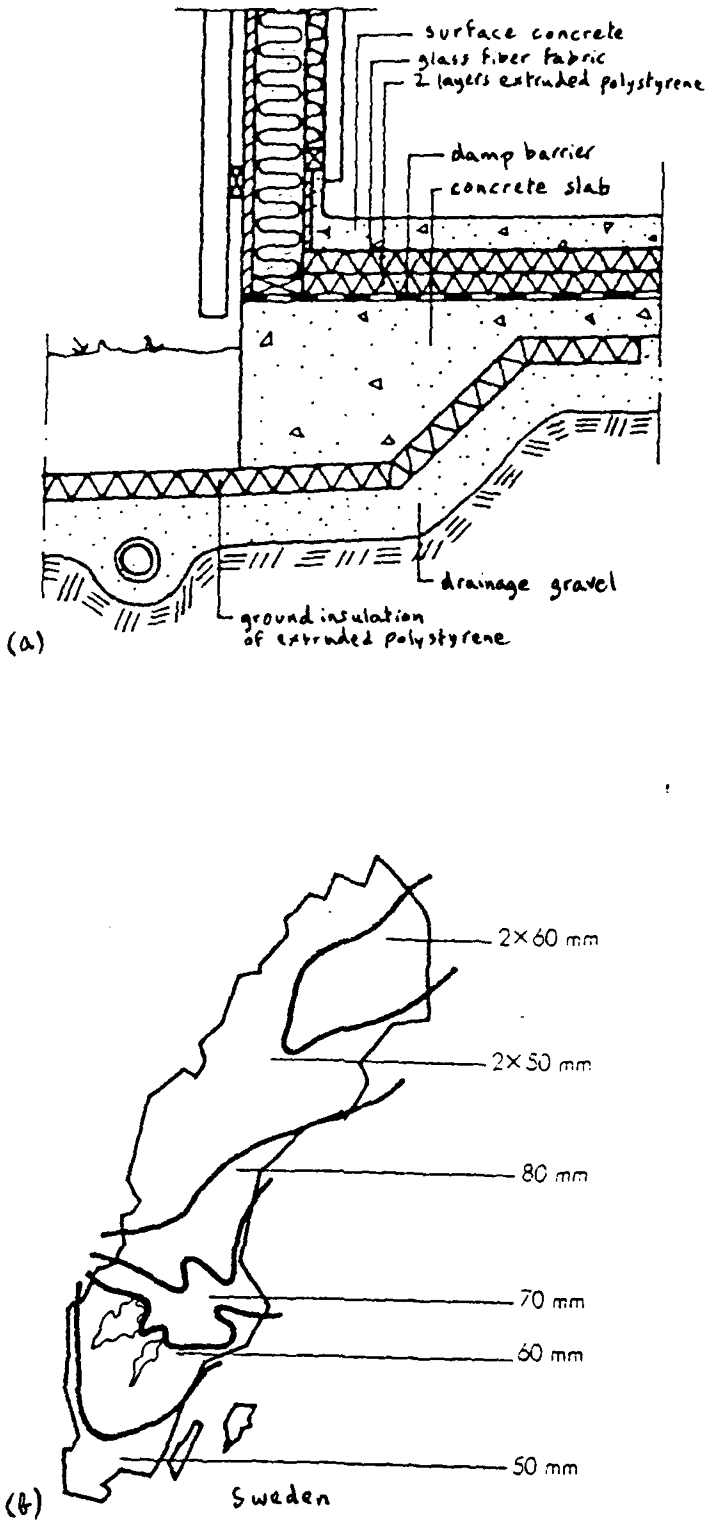


Fig. 181 Recommended thickness of polystyrene ground insulation

(Rockwool. 1984)

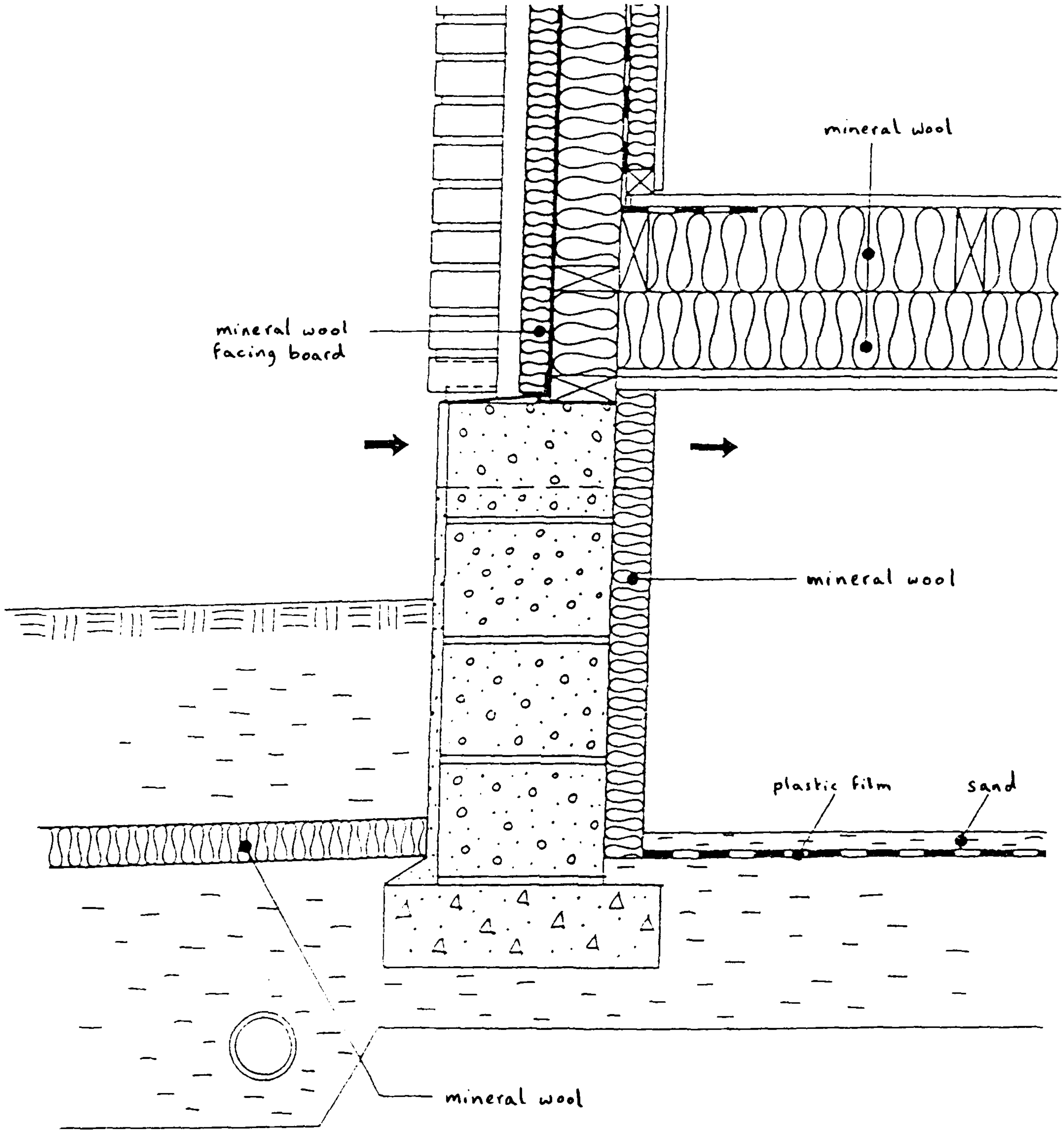


Fig. 182 Foundation with crawl space and leca foundation wall.
Gullfiber floor system 3.

(Gullfiber, 1986)

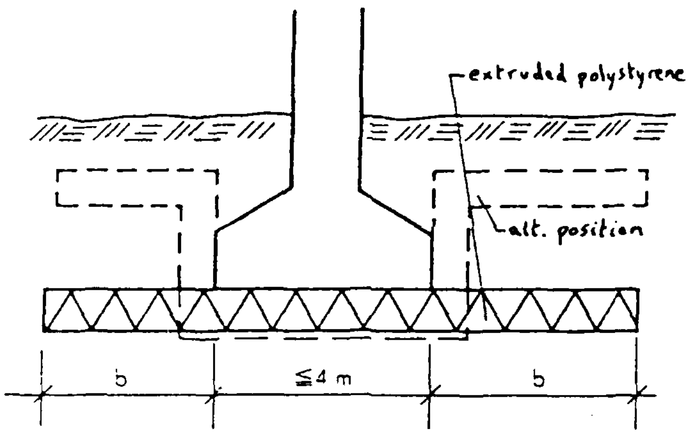
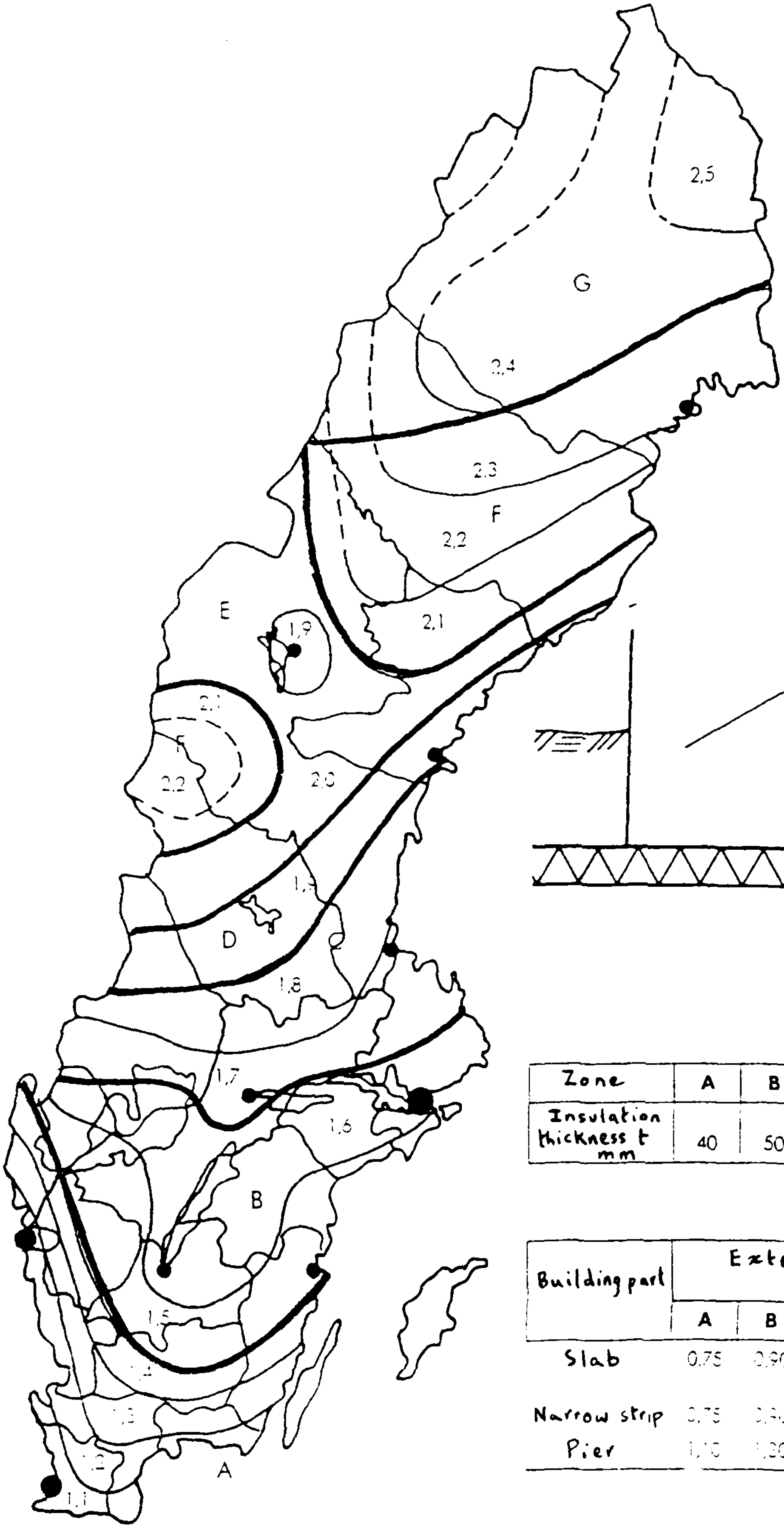
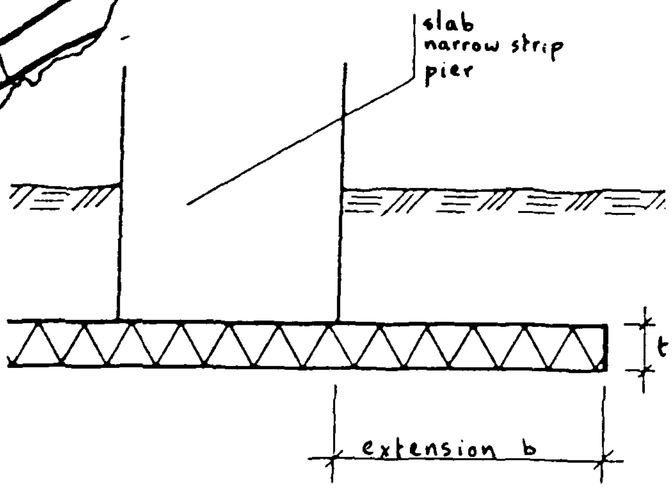


Fig. 183 Alternative placing of insulation for a narrow strip foundation.

(Rockwool, 1984).

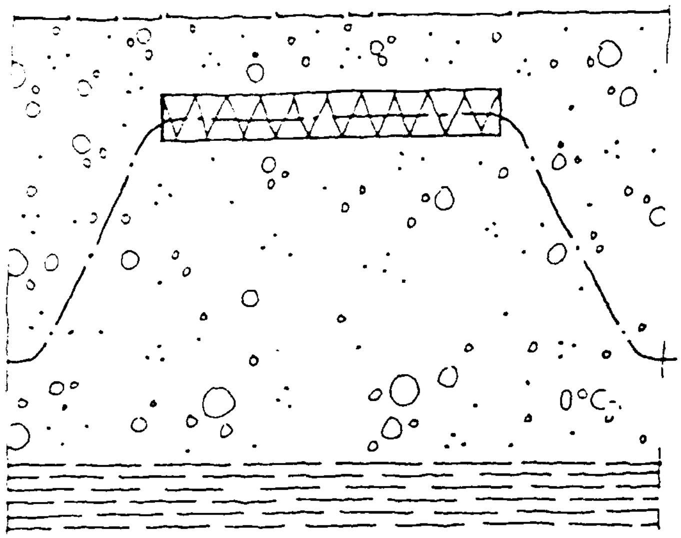




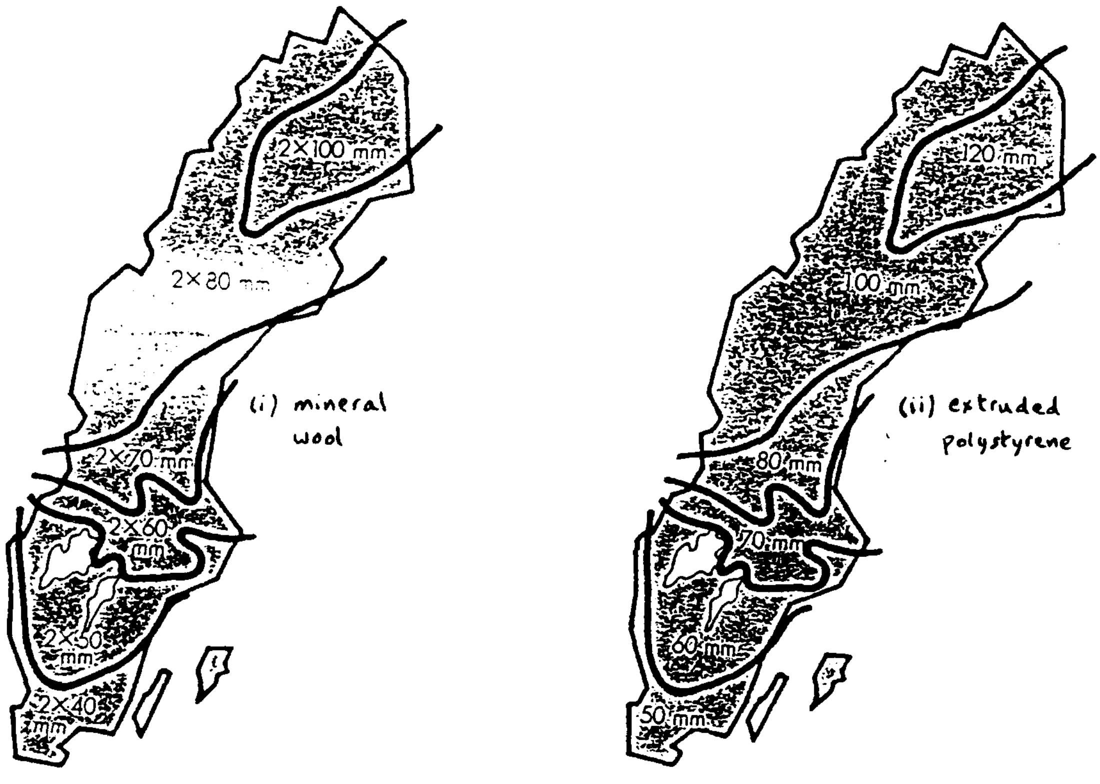
Zone	A	B	C	D	E	F
Insulation thickness t mm	40	50	70	80	120	180

Building part	Extension b metres Zone					
	A	B	C	D	E	F
Slab	0.75	0.90	1.00	1.10	1.25	1.50
Narrow strip	0,75	0,90	1.00	1.25	1.50	2.00
Pier	1,10	1,30	1.50	1.40	2.25	3.00

Fig. 184 Dimensions of insulation
for foundations of 'cold' structures.



(a)



(b)

Fig. 185 (a) Effect of ground insulation on 0°C isotherm.

(b) Recommended thicknesses of ground insulation
for (i) mineral wool
(ii) extruded polystyrene

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