LEP

The Low-Energy House Project
The Danish Ministry of Energy

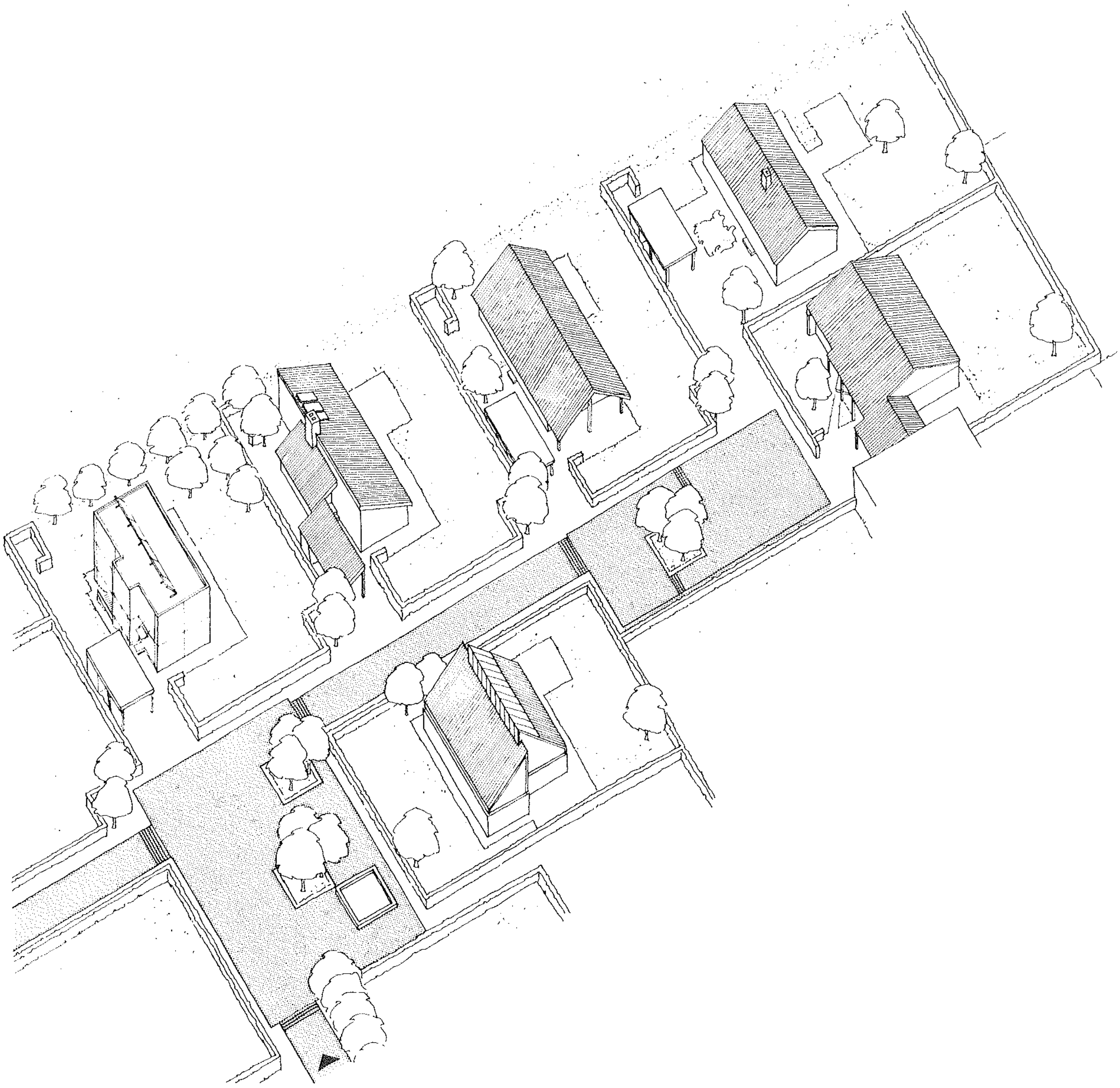
FOUNDATIONS FOR ENERGY CONSERVATION HOUSES

130

Thermal Insulation Laboratory
Technical University of Denmark
November 1982

DEN POLYTEKNISKE LÆREANSTALT KØBENHAVN 1829

The Low-Energy House Project, The Danish Ministry of Energy



FOUNDATIONS FOR ENERGY CONSERVATION HOUSES - a thermal analysis based on examples from five low-energy houses at Hjortekær, DK

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The Low-Energy House Project

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PREFACE

The main part of the results in this report was presented at the ENERGEX'82 SESCI Energy Conference at Regina, Saskatchewan, Canada, August 23-29 1982. The material has been reedited and a number of new examples and illustrations has been added.

The Low-Energy Project is carried out by the Thermal Insulation Laboratory at the Technical University of Denmark. The project is part of the National Energy Research Programme and is funded by the Danish Ministry of Energy.

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ABSTRACT

In 1978-79 six prototype low-energy houses were built at Hjortekær, Denmark. In this report the foundation construction of four slab-on-ground houses and a basement wall are described. The temperature distribution and thus the heat flow through each construction are analysed by means of an orthogonal network computer model for two-dimensional heat flow. In such calculations the thermal conductivity and the actual temperature of the earth are usually uncertain parameters. At Hjortekær several temperature sensors were placed in the earth and around the houses as part of the monitoring project, a few for continuous monitoring and the rest for occasional registration. Thus it has been possible to adjust the input data to bring the calculation model into agreement with the actual conditions.

In the analyses the actual constructions are compared to a corresponding traditional solution. Also, the results from the two-dimensional calculation model are compared to the results from the simplified one-dimensional Danish standard calculation model with respect to heat losses and minimum internal surface temperatures.

The introduction of floor heating systems in slab-on-ground houses, especially in energy conservation houses has given the impulse to the second series of analyses where the combination of slab-on-ground constructions and floor heating is analysed as to the varying dimensions of floor insulation and to the introduction of insulated composite foundations.

NOMENCLATURES

Q-DS	Heat flow by Danish standard calculation
Q-1	One-dimensional heat flow through floor
Q-2	Two-dimensional heat flow through floor and foundation
$\Delta Q(2)$	Difference between Q-2 and Q-1
r.f.l.	Relative floor level (above ground level 0)
t_{ext}	External air temperature
t_{int}	Internal air temperature
t_{ear}	Constant earth temperature (deep earth)
t_{min}	Minimum internal surface temperature
t_{flo}	Floor temperature (at embedded tubes)

INTRODUCTION

During the recent ten to twenty years most single-family houses in Denmark have been built as one-storey houses without basement, and the main part has been built slab-on-ground. The foundation is traditionally a weak point, thermally speaking, especially in connection with slab-on-ground constructions. The joining of the walls and the substructure often results in severe thermal bridges. It is a common winter observation that the snow close to a house melts away very quickly even at the north wall.

Cold bridges in the foundation construction increase the transmission heat loss and should be minimized or avoided in energy conservation houses if only for that reason. They also lower the surface temperature at the base of the wall and the adjacent floor and thus cause discomfort as well as condensation risk. Condensation to a small extent may only bring about maintenance problems, but in severe cases the result may be mould or (in timber structures) dry rot.

Another problem may often occur in energy conservation houses. To increase the efficiency of heat pumps or active solar systems a low-temperature heating system is preferred, mostly floor heating. The combination of a floor heating system and a slab-on-ground construction introduces new demands to the floor insulation as well as to the foundation construction.

In 1978-79 six detached single-family energy conservation houses were built at Hjortekær, north of Copenhagen, as part of the Danish Energy Research and Development Programme, [1]. The six prototypes are all different as to architectural design, choice of building materials, heating systems etc, and they offer a diversity of technical solutions to the problems of thermal bridges, [2]. All six houses have a living area of about 120 m^2, five of them in one storey and the sixth in two storeys (and a basement). One of the one-storey houses has a crawl space and is not included in this investigation, and the remaining four are slab-on-ground houses. One of the slab-on-ground houses (E) has a basement under the central section of the house, Figure 1.

House	A	B	C	D	E	F
Number of storeys	1	1	1	1	1	2
Slab-on-ground	X		X	X	X	
Basement					X	X
Crawl space		X				

Figure 1. The six low-energy houses at Hjortekær - Type description.

DESCRIPTION

Figure 2 (left) shows a vertical section of the floor and foundation of house A. The floor construction consists of single flooring on chocks, 50 mm of mineral wool, vapour barrier (polyethylene), concrete slab cast on site, 50 mm of mineral wool and 200 mm of expanded clay clinkers. The foundation itself is extremely well insulated, its 225 mm of mineral wool (reaching about 1 m below the ground level) being adjacent to the 200 mm of mineral wool in the wall - without any thermal bridge.

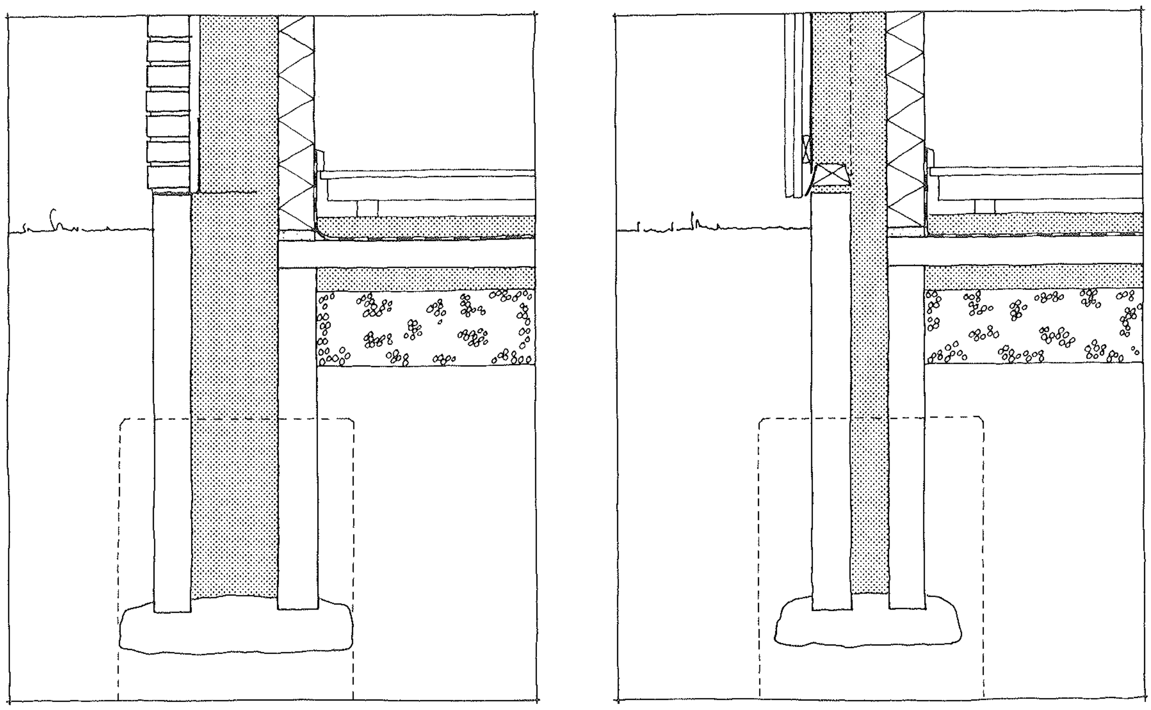


Figure 2. Foundations of house A.

The inner and outer prefabricated concrete elements rest on 10 annular concreted footings, 0.60 m in diameter, as shown in Figure 3 (and by the dashed line in Figure 2). The working operation is as follows: The reinforced foundation beams are placed on the footings, the bottom is concreted to stabilize the two leaves, a few loose expanded clay clinkers

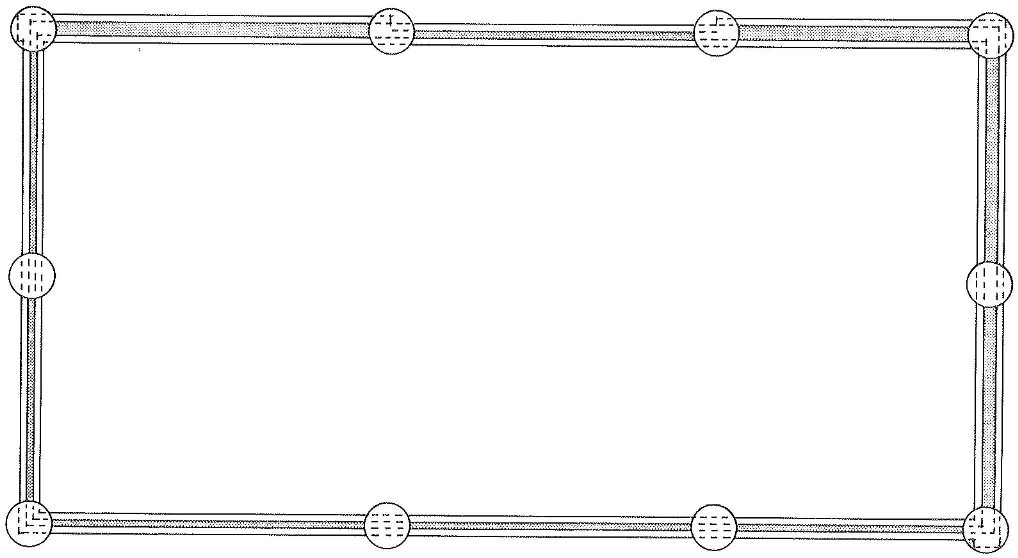


Figure 3. House A. Annular concreted footings.

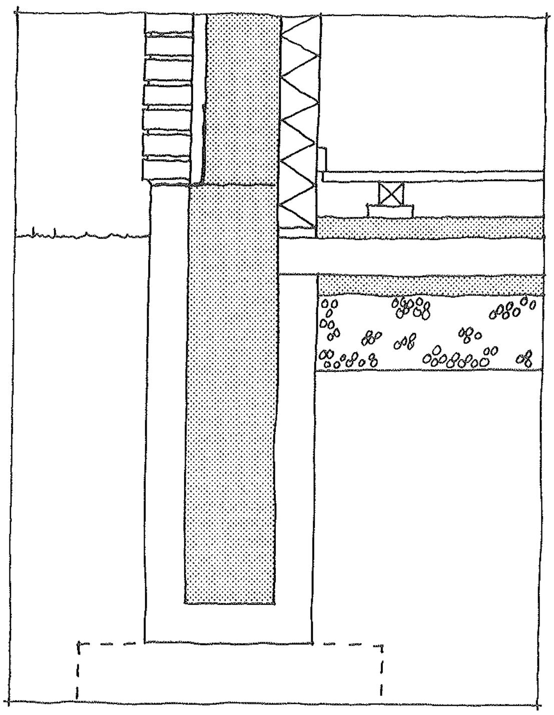


Figure 4. Commercially developed version of house A foundation.

are put in to level the bottom, and the cavity is insulated with slabs of mineral wool. Only a part of the house has a brick facing - the west and south aspect have a facing of mahogany wainscoting and a more slender foundation insulated with 100 mm of mineral wool as indicated in Figure 2 (right) and in Figure 3.

This type of foundation construction was put to practical use for the first time in house A at Hjortekær. The construction has since been further developed into a U-shaped precast and pre-insulated unit as shown in Figure 4.

Figure 5 shows a vertical section of the floor and foundation of house C. The house has a concrete floor covered with wall-to-wall coir carpets or tiles. Beneath the concrete slab (100 mm cast on site) there are a vapour barrier, 50 mm of mineral wool, 50 mm of concrete (also cast on site) and 250 mm of expanded clay clinkers. The 50 mm mineral wool is continued vertically as 0.45 m internal foundation insulation. The foundation itself has a concrete base cast on site in an earth trench. On top of this is placed a block of expanded clay concrete, and then another, more slender. The cavity between the expanded clay concrete and the concrete is insulated with 75 mm of mineral wool. It should be noticed that the house has a floor heating system with concreted plastic tubes.

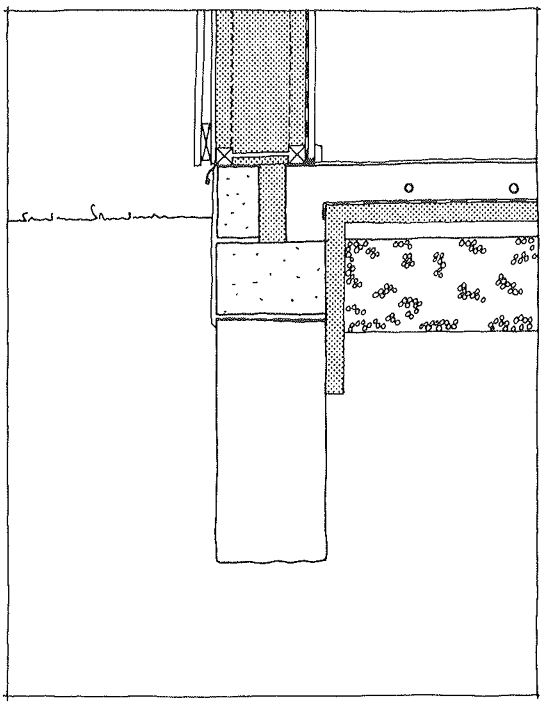


Figure 5.
Foundation of house C.

House D has a sandwich foundation built on site, shown in Figure 6. The flooring is parquet or chip boards laid directly on 100 mm rigid mineral wool. From the mineral wool downwards the floor is composed of a vapour barrier, a smoothing (levelling) layer of concrete (approx 40 mm), about 90 mm concrete cast on site and 200 mm of expanded clay clinkers. In the scullery there is a tile flooring. The foundation base is concreted in an earth trench and the foundation built on top of it from blocks of aerated concrete. A bituminous millboard separates the lightweight concrete from the concrete. The cavity (width 130 mm, depth 600 mm) is insulated with polyurethane (PUR) foam, sprayed in situ. It should be noticed that the aerated concrete below ground level is surfaced (a protective rendering and a special coating).

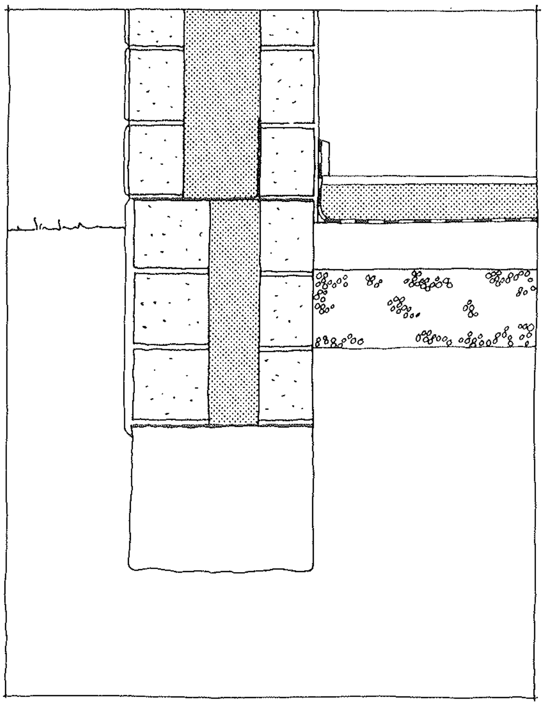


Figure 6.
Foundation of house D.

House E has a sandwich foundation as well, but of a quite different construction, Figure 7. The floor consists of single flooring, a vapour barrier, 195 mm of reinforced concrete cast on site and 300 mm of mineral wool (the top 80 mm being a very rigid quality) on shingle. The foundation base and inner leaf were cast on site in form, and the outer leaf was built from blocks of expanded clay concrete. The cavity has a depth of 600 mm and is insulated with 125 mm of mineral wool.

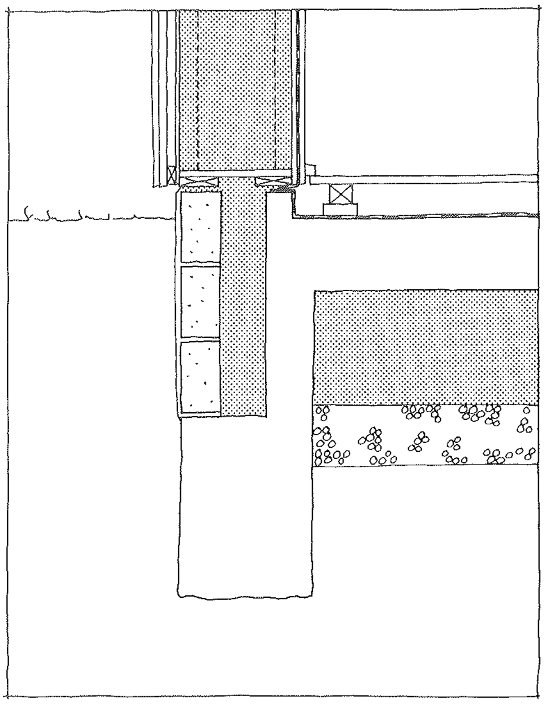


Figure 7.
Foundation of house E.

Figure 8 shows a vertical section of the basement floor and the lower part of the basement wall of house F. The ground is sloping, and the surface of the basement floor is 1.2-2.4 m below ground level (the depth 2.4 m being prevalent). The concrete floor is cast on site on top of 200 mm of mineral wool (on shingle). The basement wall is made of large prefabricated concrete building units - as is the rest of the house. The composite wall elements in the basement are insulated with 170 mm of mineral wool; the corresponding wall elements above ground level are insulated with 200 mm of mineral wool. Such well insulated concrete building units were used for the first time in house F at Hjortekær. In these new elements the insulation thickness is not reduced at the edges, and the outer and inner leaf are mechanically connected with stainless reinforcement steel only (approx 350 mm^2/m^2). Part of the basement has floor heating installed as shown in Figure 8, but normally the basement is not heated.

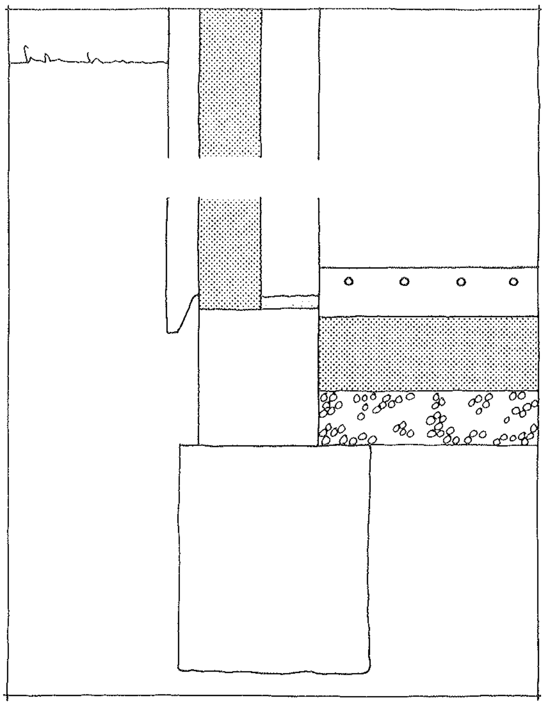


Figure 8.
Foundation of house F.

CALCULATION OF TWO-DIMENSIONAL HEAT FLOW

The applied model utilizes the analogy between thermal and electric resistance, [3], and the computer program is an adapted version of an electric resistance program developed at another institute at the Technical University, [4]. Figure 9 shows the principle of calculation of the heat flows appearing in the following Figures. The arrows indicate the heat flow through each mesh of the model network (along the chosen surface). The hatched areas indicate the difference between the two-dimensional and the one-dimensional heat flow. The sum of the differences forms the additional heat loss, $\Delta Q(2)$. The illustration suggests that a condition of one-dimensional heat flow through the floor does exist - very often (narrow houses, moderately insulated floors and foundations) it does not. The situation is then as sketched for the wall section.

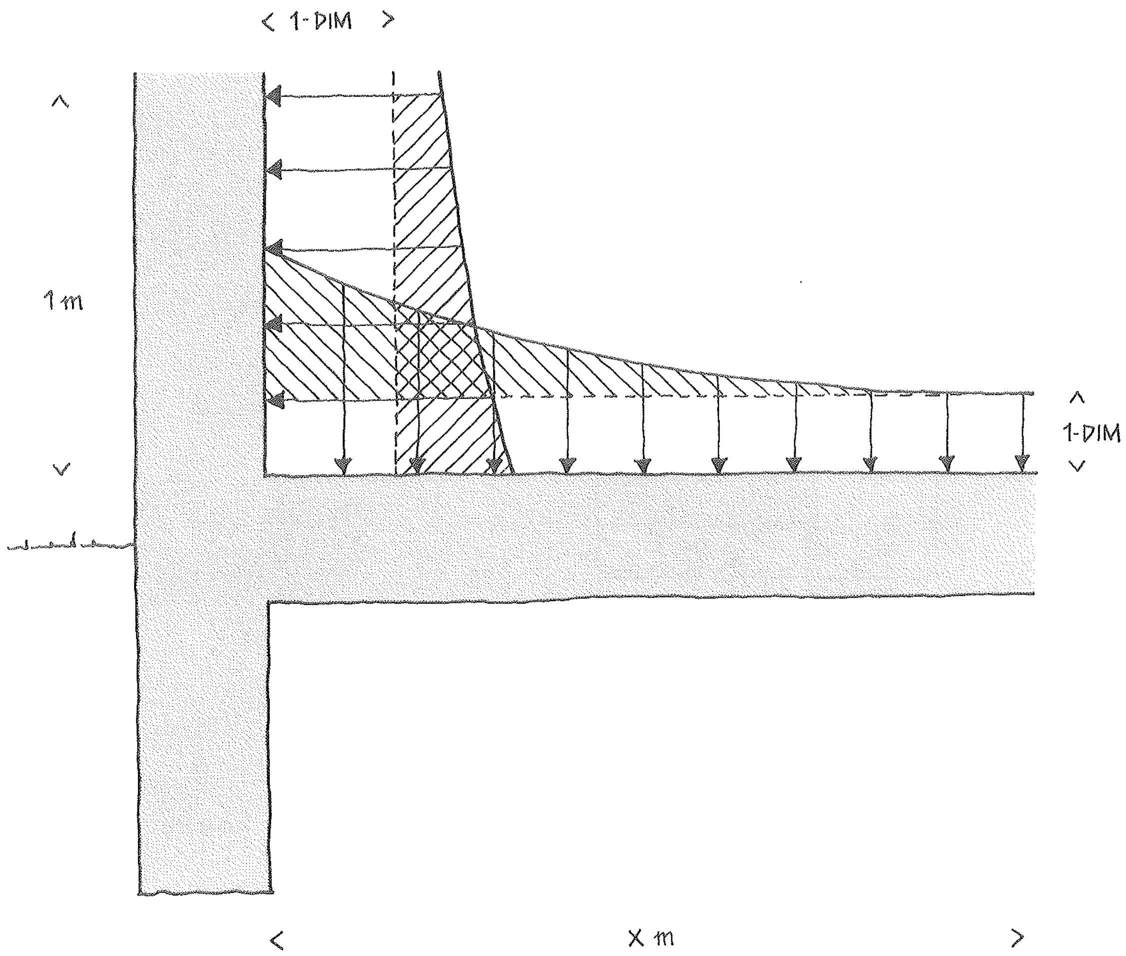


Figure 9. Illustration of heat flows.

The total (two-dimensional) heat flow through the floor and the foundation, Q-2, is usually given as the one-dimensional flow through the floor, Q-1 [W/m^2], and the above-mentioned addition, ΔQ(2) [W per running meter foundation, along the internal perimeter of the house]. However, ΔQ(2) in this report is given in W/m^2 to facilitate the comparison of the different houses. Multiplication by the X-value from Figure 10 will yield the additional heat flow in W/m. We have chosen to include 1.0 m of the wall in all calculations. The distance X depends on the design of the house, the maximum being half the width of the house - if the house is not rectangular X will be smaller. The values used in the analyses are listed in Figure 10.

House	A	C	D	E	F
X [m]	3.65	2.10	2.70	2.11	2.40

Figure 10. Distance X in the calculation network.

Internal and external temperatures of 21 deg C and 0 deg C respectively have been used for all calculations as has the - almost - constant deep earth temperature 8 deg C. In case of floor heating a uniform floor temperature of 32 deg C at the level of the embedded tubes has been applied. Denmark has approx 70,000 heating degree hours (17 deg C base) in a year, and the average external temperature during the heating season is 3.0 deg C. As conservation houses make better use of the free heat and thus have shorter heating seasons the average outdoor temperature 0 deg C has been found appropriate.

Figure 11 shows two examples of heat flow calculations at different internal temperatures and at the design internal/external temperatures 20 deg C/-12 deg C. The Figure illustrates how the results in this report within reasonable limits can be used at different thermal conditions. Q-2 can be considered directly proportional to the internal to external temperature difference when only the indoor temperature is varied. With less accuracy $\Delta Q(2)$ can be considered in direct ratio to the same temperature difference when only the outdoor temperature is varied. The examples indicate that this estimate will be fairly accurate for well insulated foundations and conservative for moderately insulated foundations at external temperatures below 0 deg C.

Example	t_{int} [C]	t_{ext} [C]	Q-1 [W/m²]	ΔQ(2) [W/m²]	Q-2 [W/m²]
I	19	0	0.9	1.0	1.9
	21	0	1.0	1.1	2.1
	23	0	1.2	1.2	2.4
	25	0	1.3	1.3	2.6
	20	-12	0.9	1.8	2.7
II	21	0	1.7	3.0	4.7
	20	-12	1.6	4.0	5.6

Figure 11. Examples of heat flow calculation (I: well insulated foundation, II: moderately insulated foundation) at different internal and external temperatures - floor not heated.

The detached houses are built on adjacent sites of about 700-900 m^2. The earth consists mainly of diluvial sand and some silt, and samples from test drilling have shown some variation as to the depth of the different strata. However, all samples were rather dry, having a water content of less than 12%. The thermal conductivity of the earth according to [5] varies between 1.0 and 1.8 W/mC. Therefore it was not attempted to make a single thermal model fit the five houses. Five different models were made based on temperature readings at different times of the year. As shown in Figure 12 the total heat resistance of the earth layers hardly varies in the five two-dimensional models, and thus the results from the different houses may be compared directly. The standard heat resistance values according to the Danish Rules [6] are included in Figure 12. The thermal earth model for house C has been used for all floor heating analyses.

House	A	C*)	D	E	F
M(2-dim. model)	4.0	4.0	4.0	4.0	4.1
M(Danish Rules)	1.5	1.5	1.5	1.5	2.5
*) used for all floor heating analyses					

Figure 12. Heat resistance of earth layers, M [m^2C/W].

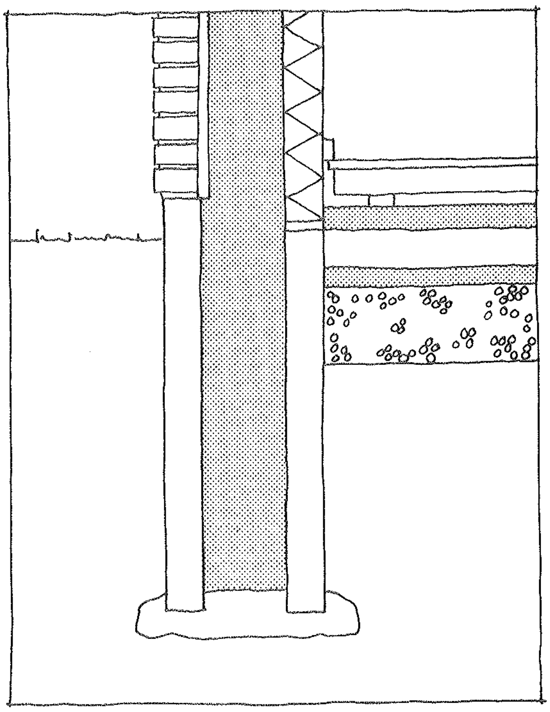
DANISH STANDARD CALCULATION (ONE-DIMENSIONAL)

According to the Danish Rules [6] two different temperature differences are used for the calculation of the heat flow through slab-on-ground floors: the internal to external temperature difference (in our case 21 deg C) is used for a 1.0 m wide perimeter strip, and the internal to deep earth temperature difference (in our case 13 deg C) is used for the remaining floor area. Similarly, different standard heat resistance values are used as indicated in Figure 12. Vertical foundation insulation may be wholly or partially considered as horizontal insulation of the perimeter strip depending on whether the vertical insulation reaches 1.0 m or less below the floor surface. It is obvious that although this method may yield satisfactory design heat losses it is unsuitable for the calculation of minimum surface temperatures. However, it may often be the only method available to the consultant engineer so the results have been included in this report for comparison with the truer results from the two-dimensional calculations.

HEAT FLOWS AND MINIMUM SURFACE TEMPERATURES
(EXISTING FLOORS, UNHEATED)

The traditional type of foundation for Danish slab-on-ground houses is a solid concrete structure cast on site, normally in an earth trench. In many houses the horizontal concrete slab and the foundation adjoin, but during the later years they are often separated by a thin strip of insulation, mostly 20 mm as shown to the right in Figure 13. The floor indicated on the illustration is exactly like the floor of house A described earlier and shown to the left in Figure 13. The thermal earth model for house A has been used for the traditional foundation calculations. The results are listed in Figure 14.

The calculations for the commercially developed version of the house A foundation shown in Figure 4 yield exactly the same results as for the prototype listed in Figure 14 (A, 225 mm insulation). The main thermal advantage of the U-beam is the undiminished insulating efficiency at the footings.



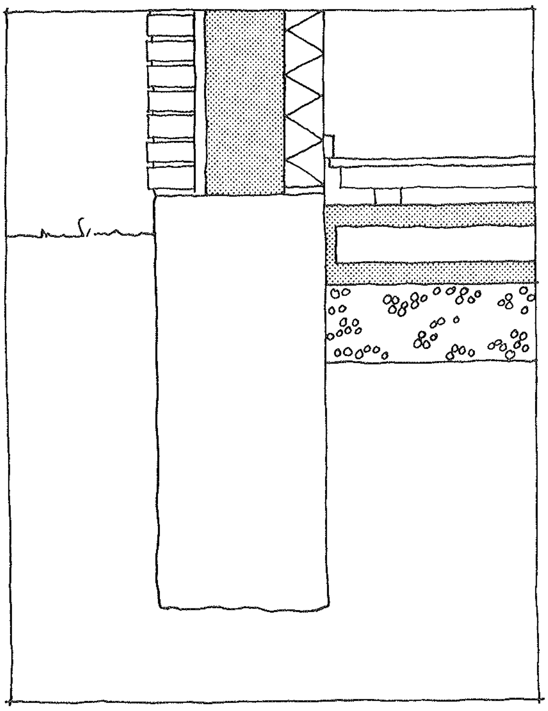
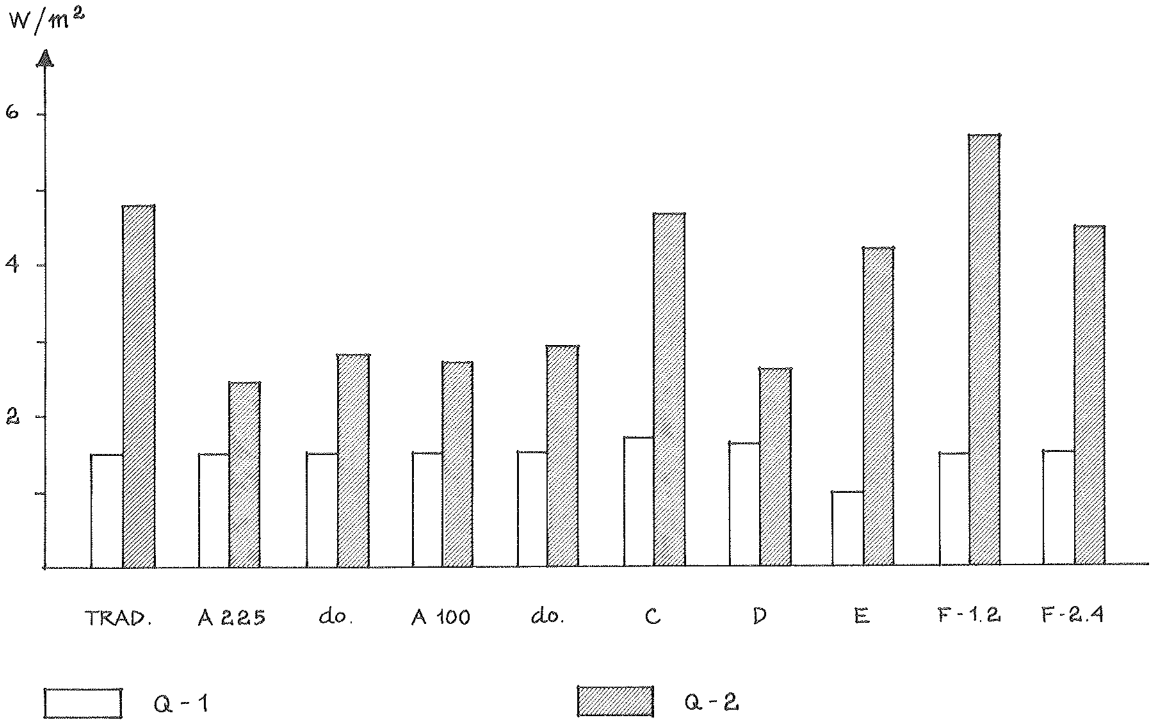


Figure 13. Conservation house foundation (left) and traditional foundation (right).



	Danish Rules		Two-dimensional model			
	Q-DS [W/m²]	t_{min} [deg C]	Q-1 [W/m²]	ΔQ(2) [W/m²]	Q-2 [W/m²]	t_{min} [deg C]
Traditional foundation	2.7	20.5	1.5	3.3	4.8	18.5
House A (225 mm insulation)	2.1	20.5	1.5	0.9	2.4	20.2
Do, at footing	2.3	20.5	1.5	1.3	2.8	20.1
House A (100 mm insulation)	2.3	20.5	1.5	1.2	2.7	20.2
Do, at footing	2.5	20.5	1.5	1.4	2.9	20.2
House C	3.5	20.3	1.7	3.0	4.7	18.5
House D	2.5	20.6	1.6	1.0	2.6	19.6
House E	1.6	20.7	1.0	3.2	4.2	20.1
House F (r.f.l. -1.2 m)	2.6	20.4	1.5	4.2	5.7	18.2
House F (r.f.l. -2.4 m) *)	1.9	20.4	1.5	3.0	4.5	18.5

t_{int} = 21.0 C t_{ext} = 0.0 C t_{ear} = 8.0 C

*) prevailing

Figure 14. Results of heat flow calculations.

HEAT FLOWS (HEATED/UNHEATED FLOORS)

The analyses of heated slab-on-ground floors were inspired by the floor construction of house C, Figure 15, left. The floor insulation (50 mm mineral wool and 250 mm expanded clay clinkers) must be considered insufficient in connection with a heated floor, at least for conservation houses. To the right in Figure 15 30 mm external foundation insulation have been added to the construction as a possible retrofitting operation. Alternatively the effect of separating the floor slab from the foundation (as in Figure 13, right) and replacing the concrete foundation top by expanded clay concrete is examined.

The floor construction recommended by several floor heating firms is shown in Figure 16 (left). The floor is insulated with 75 mm of expanded polystyrene, and blocks of expanded clay concrete are used for the upper part of the foundation - the floor slab is separated from the foundation. Calculations have been made for the recommended insulation thickness as well as for an insulation thickness of 200 mm (Figure 16, right). In a slightly changed version of the recommended construction the separation has been omitted.

A construction that has been used in Denmark for some years for ordinary houses is shown to the left in Figure 17. The foundation is built from solid blocks of expanded clay concrete and is separated from the floor slab. In some countries with cold climates (eg Canada and Finland) an external horizontal perimeter insulation is applied. Though it has not been practiced in Denmark we have included the construction in the investigation in combination with the solid expanded clay concrete foundation, Figure 17 (right). As the perimeter insulation cannot be accepted as surface material - for aesthetic as well as for mechanical reasons - the strip of polystyrene (100 mm thick and 1 or 2 m wide) is placed 50 mm below the ground surface.

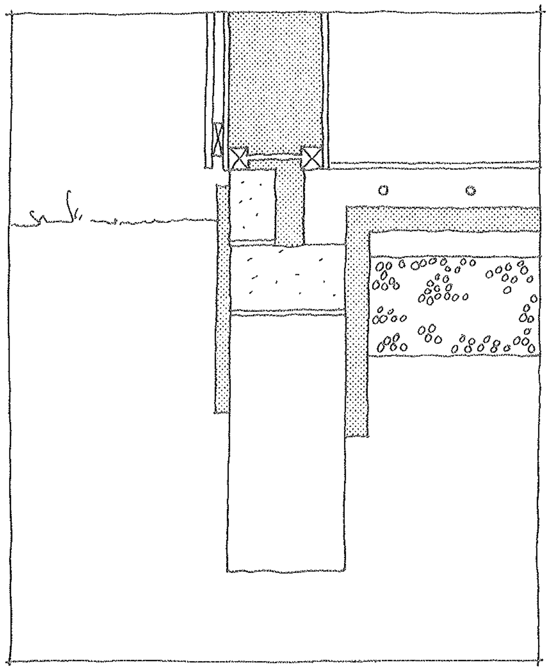


Figure 15. House C foundation with/without external insulation.

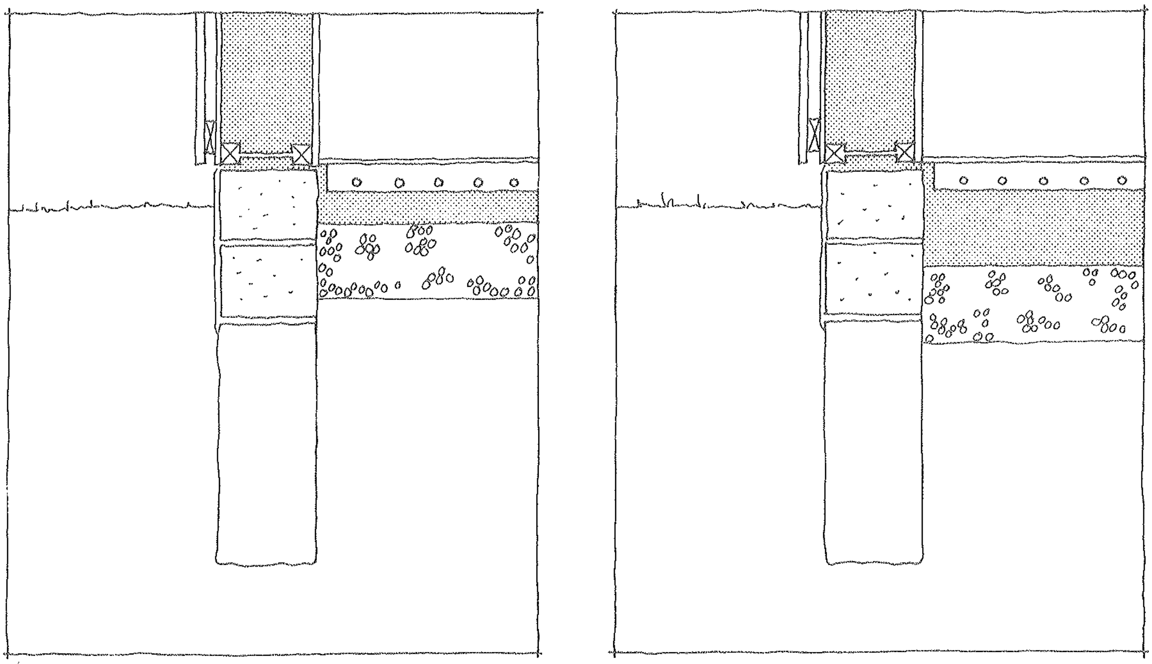


Figure 16. Foundation recommended by manufacturers of floor heating systems (left) and a version with improved floor insulation (right).

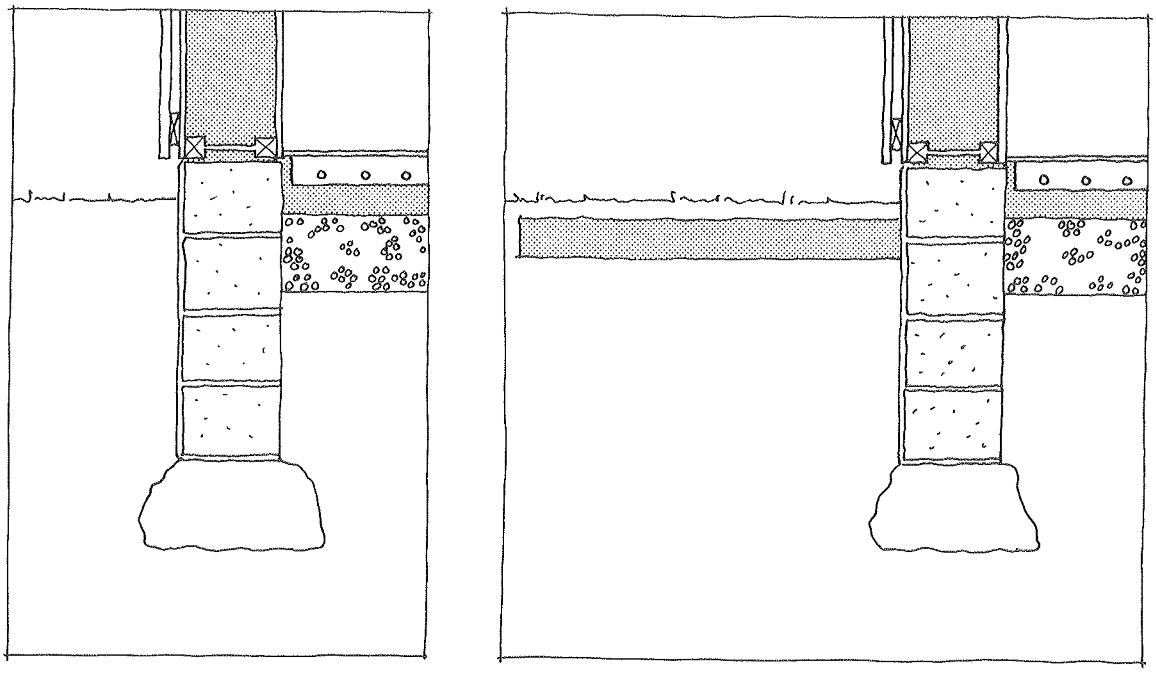


Figure 17. Solid expanded clay concrete foundation (left) and the same foundation with external horizontal perimeter insulation (right).

The insulated composite foundations at Hjortekær have given the inspiration to the final designs. Figure 18 shows a construction similar to the one in house D (Figure 6) with 100 mm mineral wool in the floor. Calculations have been made for three different depths of the composite foundations (y=0.60/0.70/1.50 m) with and without separation of the floor slab.

Figure 19 (left) shows a sandwich foundation similar to the well insulated type in house A (Figure 2), but having additional internal foundation insulation (50 mm mineral wool) and separation of the floor slab. Calculations have been made for slightly different versions of this foundation (with and without separation and/or the additional internal insulation). For the version without internal insulation the floor insulation has been increased to 200 mm (Figure 19, right). Finally insulation thicknesses of the composite foundation of 100 mm and 325 mm have been examined (no internal insulation and no separation).

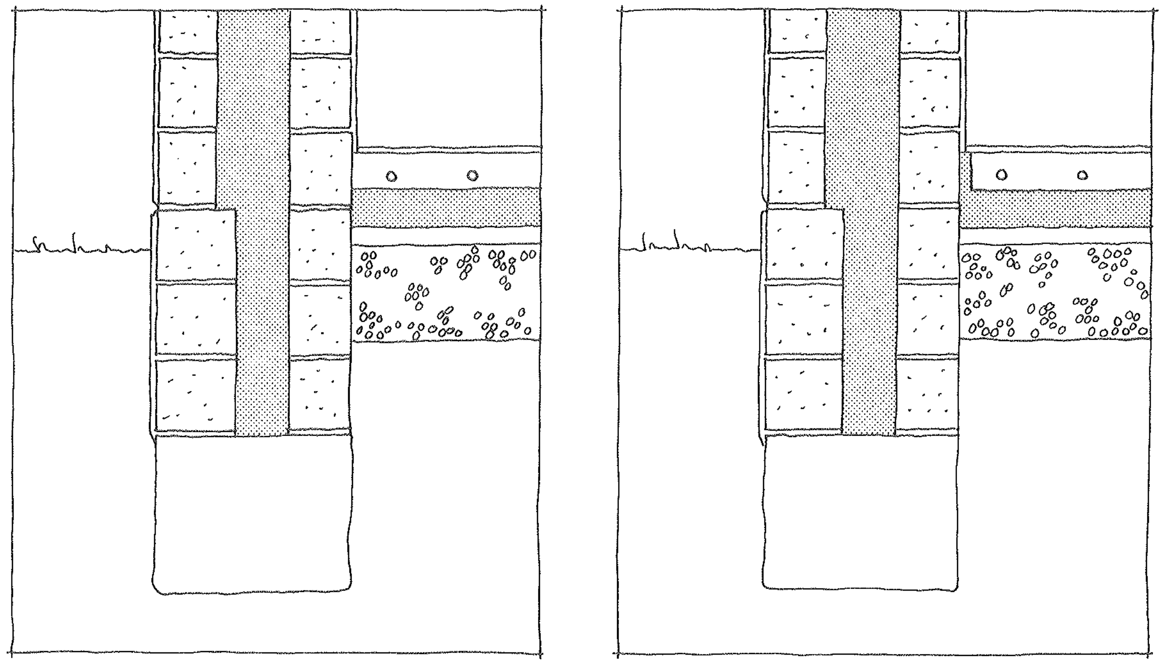


Figure 18. Block built sandwich foundation with/without separation of floor slab.

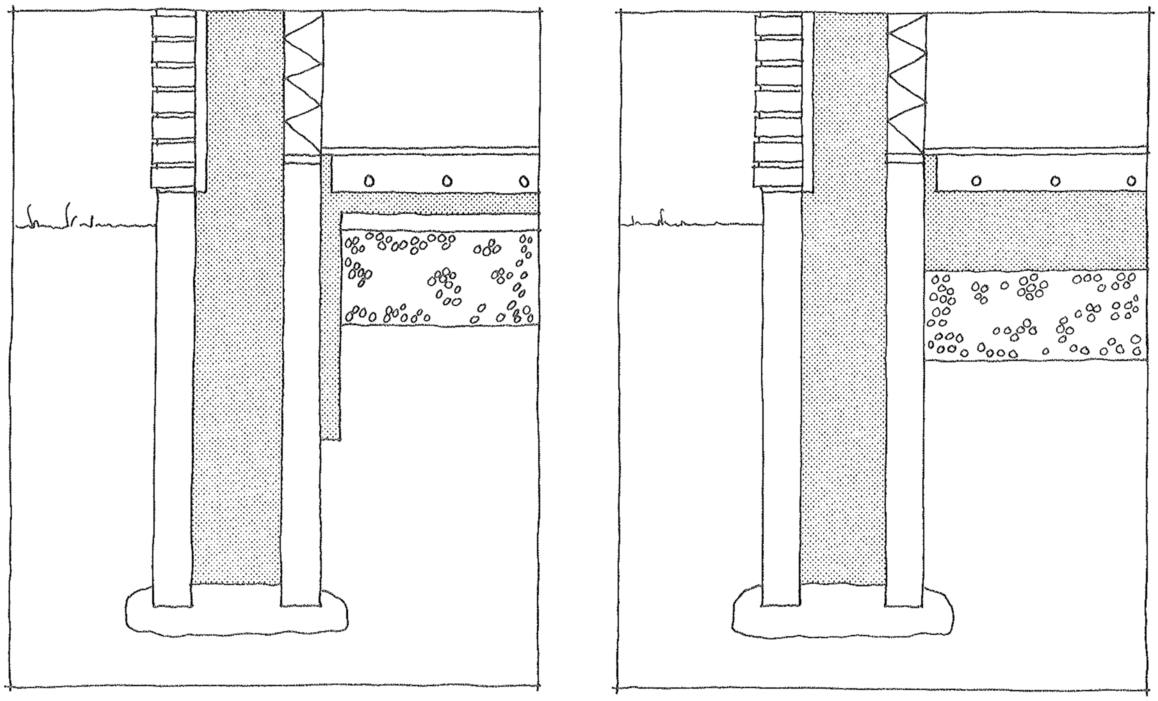


Figure 19. Precast sandwich foundation with/without internal insulation and improved floor insulation.

The different versions of the foundations included in the investigation are outlined in Figure 20, and the results are listed in Figure 21.

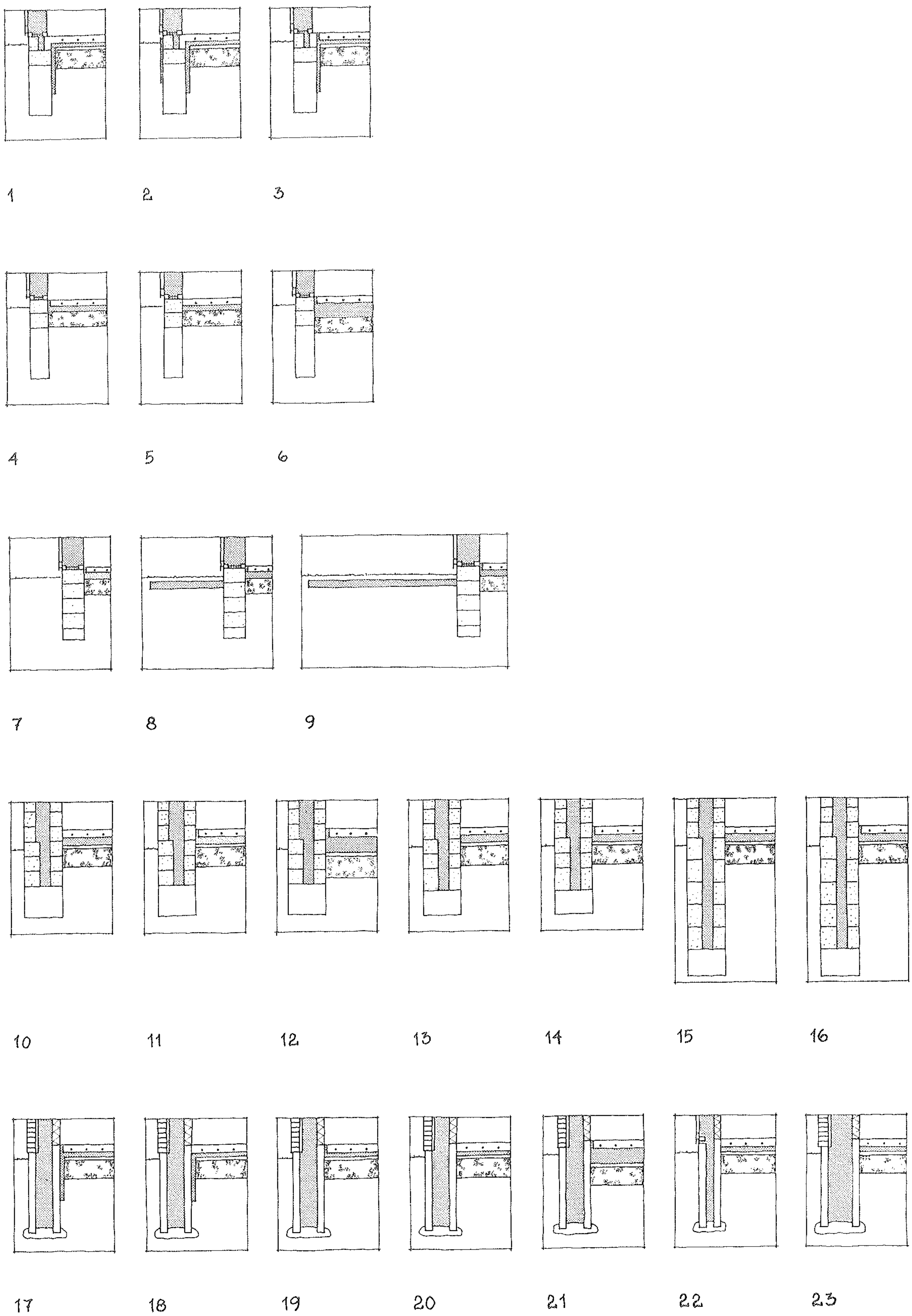
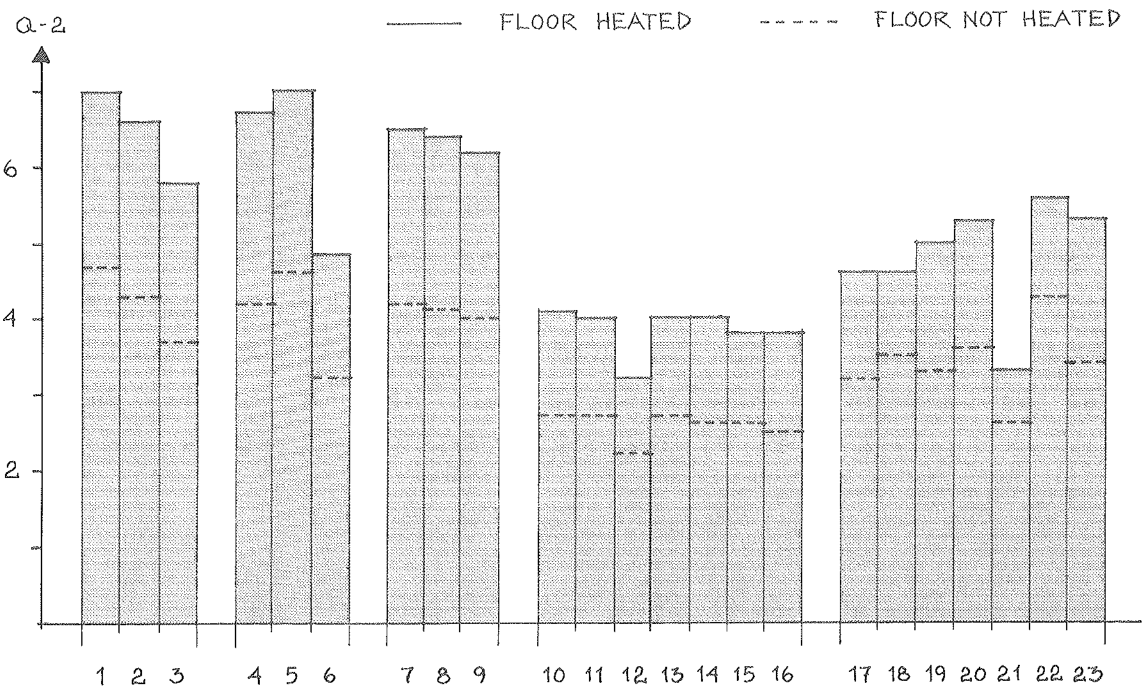


Figure 20. Outlines of foundations included in the investigation.



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					
[ND]	[mm]	[mm]	[mm]	[mm]	[mm]	[ND]	[W/m^2]	[W/m^2]
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} = 21.0 C t_{ext} = 0.0 C t_{flo} = 32.0 C t_{ear} = 8.0 C

H = Height *) = Mineral wool or cellular plastics

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

Figure 21. Results of floor heating analyses.

The external horizontal perimeter insulation mentioned earlier is a possible retrofitting measure for older slab-on-ground houses. Figure 22 shows a retrofitted construction with an original solid concrete foundation like in Figure 13, but in this case with 75 mm floor insulation. For the sake of argument floor heating is indicated. Fortunately, in Denmark the combination is rare. The suggested retrofit may or may not include a 50 mm thick external vertical insulation of the exposed part of the foundation (as shown to the right in Figure 22). The calculated heat flows are listed in Figure 23.

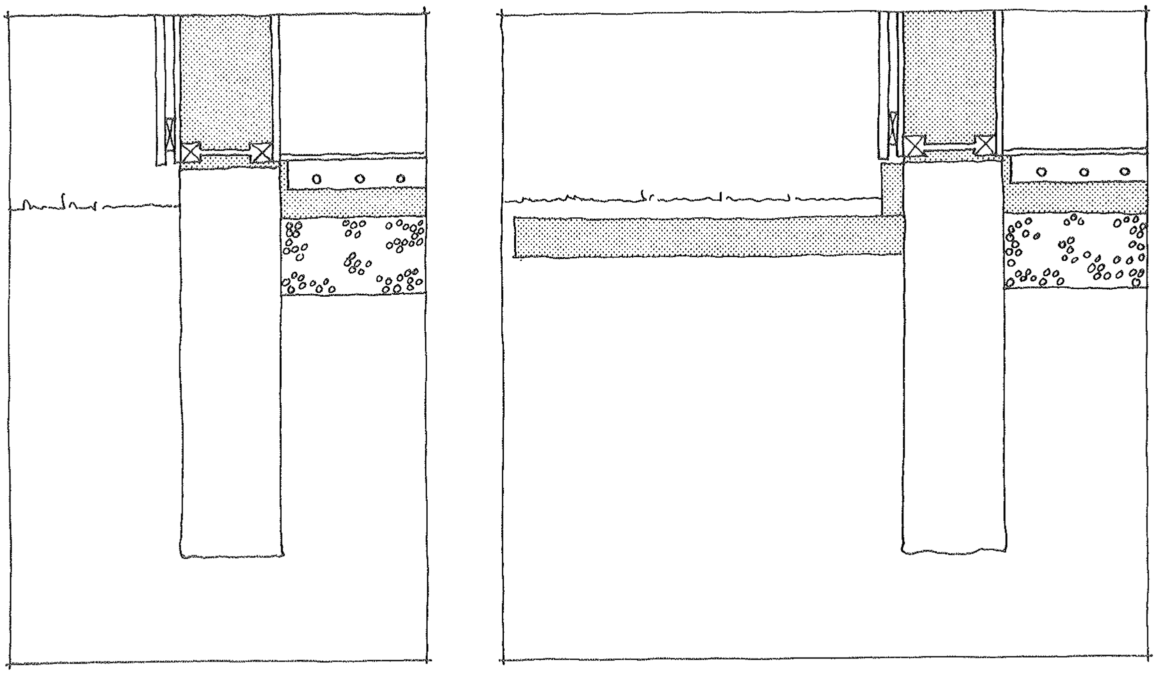


Figure 22. Two ways of retrofitting a solid concrete foundation (shown to the left) by applying external horizontal perimeter insulation with or without the external vertical insulation shown to the right.

Version	Q-2 (Floor heated) [W/m²]	Q-2 (Floor not heated) [W/m²]
Original foundation	8.8	6.3
Perimeter insulation 1.0 m wide	8.5	6.1
Do, with vertical insulation	7.8	5.4
Perimeter insulation 2.0 m wide	8.4	5.8

Figure 23. Retrofit of concrete foundation, cf Figure 22.

DISCUSSION

The comparison between the one-dimensional Danish standard calculations and the two-dimensional calculations (Q-DS and Q-2 of Figure 14) shows that the simplified calculation model underestimates the heat flow even though the heat resistance of the earth layers in the two models is 1.5/2.5 and 4.0 m^2C/W respectively. The heat flow may be almost three times the values indicated by the Danish Rules.

All houses but E have approx the same one-dimensional heat flow (Q-1) through the floor - in house E it is smaller (about two thirds of the average value). The resulting total heat flows (Q-2) show the extreme importance of an effective vertical perimeter insulation.

The composite foundations of house A and D are seen to be effective, the total heat flow being about half the reference heat flow for the traditional foundation. It should be noticed that the efficiency of the foundation of house A is only slightly reduced at the footings (insulation depth approx 0.50 m vs 1.0 m) and similarly that the reduction of heat flow by a reduction of insulation thickness from 225 mm to 100 mm is small.

The internal vertical perimeter insulation of house C is seen to be inefficient as the resulting heat flow equals that of the traditional foundation.

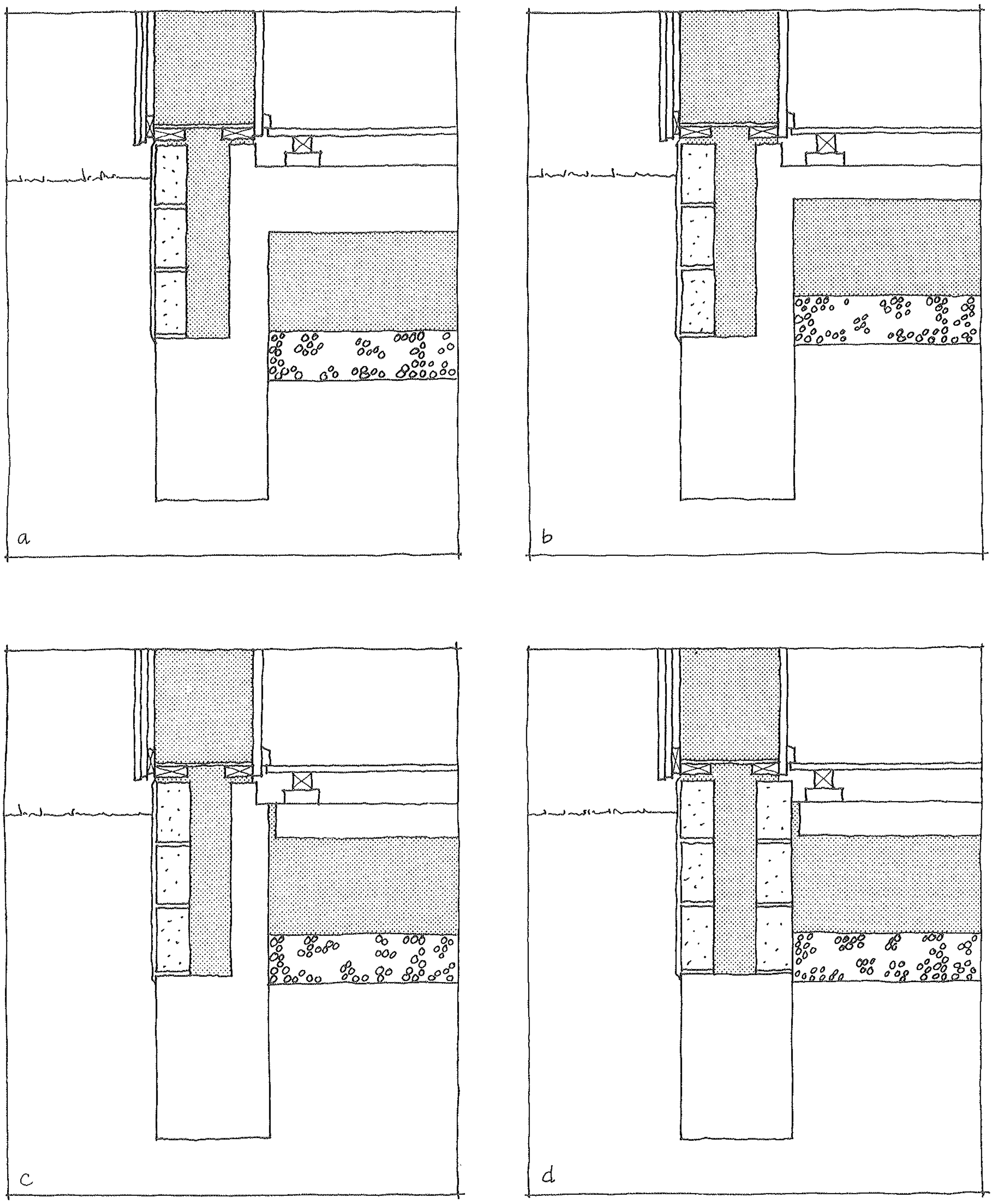


Figure 24. House E. Foundation, actual version and three (successively) improved versions.

Attention is called to the foundation construction of house E which serves as a warning example to house designers. It is a composite foundation insulated to the same depth as house D and the floor is extremely well insulated, but due to the thick concreted floor slab being concreted to a concrete inner leaf the efforts are wasted - the heat flow is about as high as in a traditional foundation. The foundation and three suggested (successively introduced) improvements are illustrated in Figure 24.

Foundation	Illustrated	Q-1 [W/m²]	ΔQ(2) [W/m²]	Q-2 [W/m²]
Traditional	Figure 13	1.5	3.3	4.8
E	Figure 24 a	1.0	3.2	4.2
E, improved	Figure 24 b	1.0	2.9	3.9
E, improved	Figure 24 c	1.0	2.7	3.7
E, improved	Figure 24 d	1.0	1.4	2.4

Figure 25. House E. Effect of thermal bridge at inner leaf of foundation (Comparison to traditional foundation and some suggested improvements).

Firstly, the unusually thick concrete slab is replaced by an ordinary 100 mm slab - secondly, the floor slab is separated from the inner leaf of the foundation - and finally, the concreted inner leaf is replaced by blocks of expanded clay concrete. The corresponding heat flows are shown in Figure 25. The only truly efficient improvement is the replacement of the concreted inner leaf.

Exactly the same words of warning may be said about the basement foundation of house F. Figure 26 shows the actual construction and a modified version with a) separated floor slab and b) only a slender block of concrete adjacent to the inner leaf of the wall and a block of expanded polystyrene adjacent to the wall insulation and outer leaf. The calculated heat flows are listed in Figure 27. The modification causes about a 40% reduction of the heat flows.

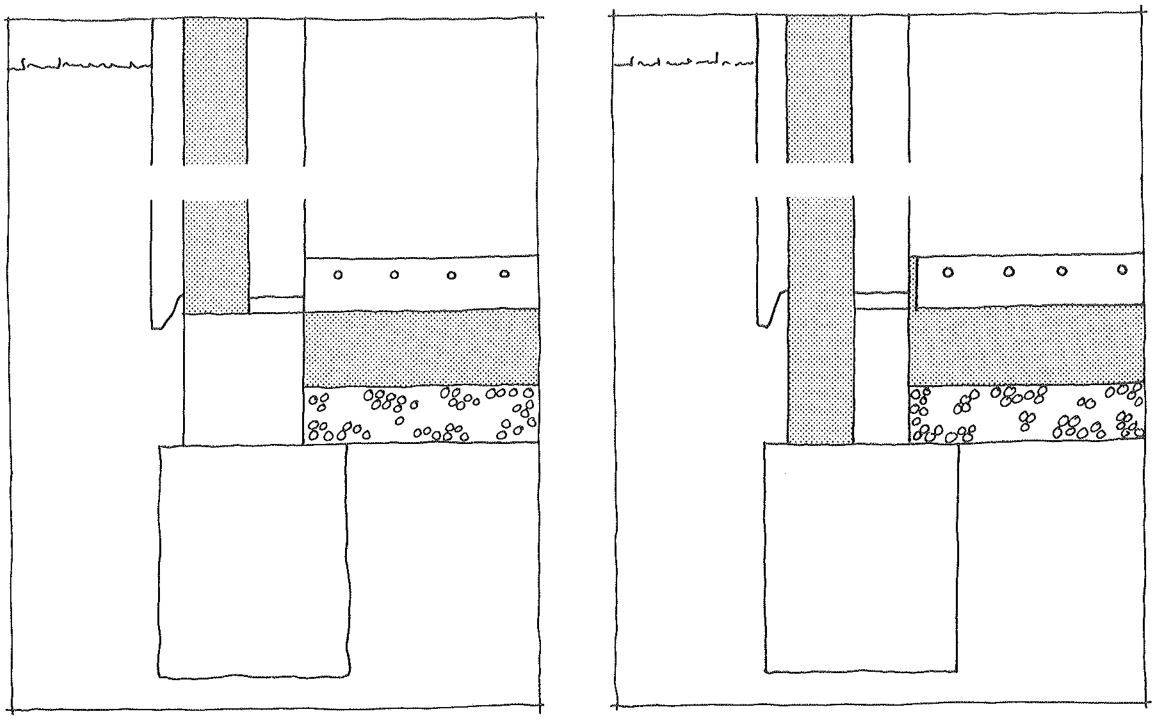


Figure 26. House F. Basement wall (foundation base), actual and improved version.

Basement foundation		Q-1 [W/m²]	Q-2 [W/m²]
r.f.l. -1.2 m	F, actual	1.5	5.7
	F, improved	1.5	3.6
r.f.l. -2.4 m	F, actual	1.5	4.5
	F, improved	1.5	2.8

Figure 27. House F. Effect of thermal bridge at foundation base.

The results from Figure 14 are further supported by the results from Figure 21 (unheated floors). For unheated floors separation of the floor slab gives a heat flow reduction of 7-12%.

The minimum internal surface temperatures reflect just about the same pattern. The D value is lower than the E value due to better wall insulation in house E. None of the temperatures listed gives rise to alarm - the corresponding minimum temperature at a window with double glazing is approx 13 deg C.

A few general observations of the floor heating analyses are listed below:

- floor slab separation (20 mm) has almost no influence on the heat flows for heated floors.

- internal foundation insulation has very little effect on unheated floors, but may reduce the heat flow of heated floors by approx 10%.

- external horizontal perimeter insulation is inefficient for heated as well as for unheated floors.

- the analyses show that the heat flows through the floor constructions are 27-57% higher when the floors are heated, averaging 50%. The 27% apply to a floor construction with 200 mm horizontal insulation and a sandwich foundation with 225 mm insulation.

- for heated as well as for unheated floors the earlier remarks about the effects of well insulated composite foundations and the insulation thickness and depth apply. Almost nothing is gained by increasing the insulation thickness from 225 to 325 mm or the depth from 600 to 1500 mm.

- similarly, in a solid foundation the effect of having four blocks of expanded clay concrete instead of only the top two is hardly noticeable.

- it must be remembered that the marginal effect of adding insulation decreases with increased initial degree of insulation. This fact is emphasized by Figure 28 (as well as by Figure 21). The heat loss through an unheated floor insulated with 50 mm of mineral wool/cellular plastics is equal to the loss through a heated floor with 225 mm of insulation, but the heat loss through an unheated floor with 100 mm of insulation is equal to the loss through a heated floor with 325 mm of insulation.

Floor insulation [mm]	Q-2 (Floor heated) [W/m^2]	Q-2 (Floor not heated) [W/m^2]
50	4.8	3.1
100	4.0	2.7
150	3.6	2.5
200	3.2	2.2
250	3.0	2.1
300	2.8	2.0

Figure 28. Block built sandwich foundation. Calculated heat flows at different floor insulation thicknesses (mineral wool on top of 200 mm expanded clay clinkers).

CONCLUSIONS

For slab-on-ground houses as well as for heated basements the application of insulated composite foundations must be recommended for heated as well as for unheated floors. The avoidance of thermal bridges, eg concreting, is extremely important. If the foundations have no cold bridges a simplified one-dimensional heat flow calculation model like the method prescribed in [6] may give acceptable results.

A slab-on-ground floor in a conservation house should not be heated, even as a low-temperature system, but if so, the designer should increase the floor insulation to a minimum of 200 mm (mineral wool or cellular plastics) only to keep the heat loss at the same level as in a normal unheated floor construction, and the well insulated floor should be combined with a composite foundation insulated with approx 100 mm mineral wool or cellular plastics to a depth of approx 600 mm, Figure 29.

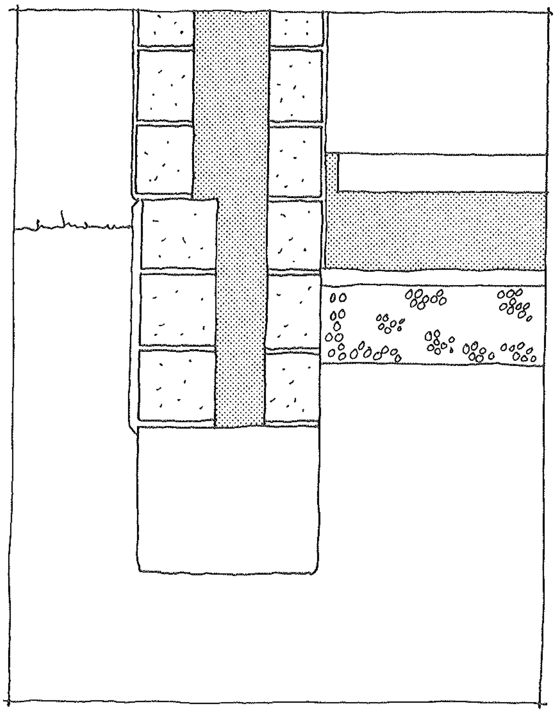


Figure 29.
Foundation recommended by authors for energy conservation houses.

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