

Perimeter insulation design for frost protection of footings of buildings with insulation under slabs-on-grade.

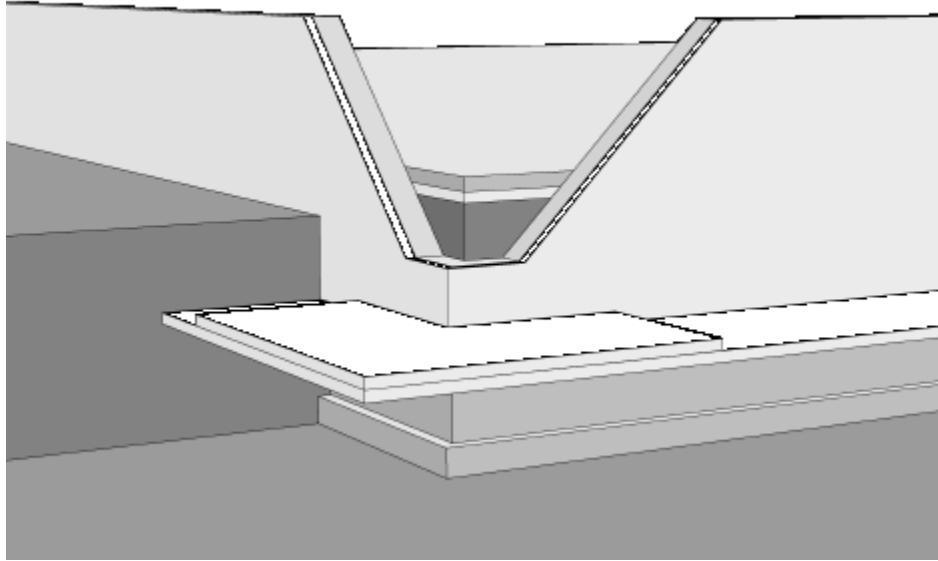


Illustration: Insulated foundation with wall cut away to show floor slab and sub-floor insulation, and with ground cut away to show exterior perimeter insulation below grade, doubled in thickness at corner.

Introduction

Insulation under a slab-on-grade reduces heat loss to the ground, particularly where in-slab hydronic heating is used. However, with insulation, heat lost through the slab is no longer available to protect foundations from freezing and frost heave. Adding appropriate perimeter insulation can compensate, however, protecting the foundation while further reducing heat loss to the environment. Because winter is transient, and because heat is still lost through an insulated slab, although at a lower rate, insulating the foundation walls, and also the ground around the perimeter can ensure that the annual minimum temperature experienced at footing depth is no lower than it would have been if there were no insulation.

At depth, the ground temperature is essentially constant, and equal to the annual air temperature. Closer to the surface, the temperature at a given depth varies in an annual cycle whose amplitude at the surface is about the same as that of the annual cycle of air temperature, and decreases with depth. The thermal capacity of the ground, and the heat lost when water freezes and required to thaw it again, are dampers that reduce temperature variation with depth. They also cause a time lag, so that the annual minimum and maximum temperatures at depth occur later in the year than at the surface, or at shallower depths. The depths we usually think of as "below frost", deep for isolated footings, and shallow for footings adjacent to a heated building, ensure that both types experience approximately the same annual minimum temperature.

The whole point of adding insulation to a slab-on-grade is to reduce heat lost to the ground. Some compensating change is needed to maintain the annual minimum footing temperature. This could be increased footing depth, or additional insulation around the perimeter of the building. Table 2 gives the dimensions of insulation required to accomplish this, for the configuration shown in the illustration, derived from a series of finite element transient heat-flow models. Table 1 gives the input parameters used in the models.

Table 1: Input parameters

Parameters	Medicine Hat	Calgary	Red Deer	Edmonton	Ft. McMurray
Footing depth for heated buildings, m	1.5	1.5	1.7	1.9	2.5
Annual mean air temperature, deg C	5.5	3.9	2.3	2.1	0.2
Annual air temperature cycle amplitude, deg C	13.2	13.3	13.1	12.4	12.2
Thermal conductivity of soil, W/mK	2.0	1.4	1.4	1.4	2.0
Thermal capacity of soil, MJ/m ³ * K	2.0	2.35	2.35	2.35	2.0
Width of horizontal subgrade insulation, mm	600	1200	1200	1200	1800
Thermal conductivity of concrete, W/mK	1.5				
Thermal capacity of concrete, MJ/m ³ * K	2.0				
Thermal conductivity of insulation, W/mK	0.036				
Thermal capacity of insulation, MJ/m ³ * K	0.0435				
Interior temperature, deg C	20				
Building width, m	10				

The values in Table 2 are based on the premise that an insulated foundation will be just as safe from freezing and frost heave as a foundation with no insulation, if models of both report the same annual minimum temperature at the footing. In comparing two models, the depth of footing below grade, the soil, and the climate are all identical. However, insulated configurations with various elevations of floor above grade are compared with an uninsulated configuration with floor 400 mm above grade.

Many configurations are possible, other than those shown. Preliminary models indicated that:

- extending exterior insulation down the wall further, with the horizontal extension lowered and reduced in width, results in more or less the same heat loss, but a lower annual minimum footing temperature.
- making the building wider than 10 m makes little difference to footing temperature - but making it smaller makes a lot. Table 2 configurations should not be used for buildings smaller than 10 x 10 m.
- extending the horizontal insulation further, keeping thickness and depth the same, increases minimum footing temperature without much effect on heat loss.
- if the perimeter is uninsulated or modestly insulated, increasing the elevation of the floor above grade substantially increases heat loss, and also lowers the annual minimum footing temperature. Floor elevation has little effect if the wall and the ground around the building are well insulated.
- at outside corners, horizontal perimeter insulation should be increased. (3-d models show that corners get significantly colder). The illustration shows one way of doing this.

Design Selection (from Table 2)

Starting with thickness of insulation under the slab, a city, and the maximum elevation of floor above grade, scan down the G column for that city, to determine how much wall insulation is required. If you know the thickness of wall insulation you want to use, then the G column for the city shows how far the floor can be above grade. The q column shows the net annual heat flow through the interior floor surface, from the centre of a 10 m wide building to the interior face of the wall, per metre of building length. These values are approximate (they don't account for latent heat, hydronic heating of the slab, or increased heat lost at corners, and would differ for wider buildings), but they do show roughly how much heat flow is reduced by various insulation configurations. The q value given is the maximum for that configuration of insulation, for the range of floor-to-grade distance in the same row of the table. When all insulation is the same thickness, this loss increases with distance from floor to grade. When wall insulation is thick, the loss is more or less the same, or may actually decrease somewhat as the floor to grade distance increases.

Table 2: Maximum grade-to-floor distance (G), mm, and Maximum net annual heat flow through floor (q), kWh/m for various configurations of insulation

Insulation, mm			Medicine Hat		Calgary		Red Deer		Edmonton		Ft. McMurray	
Slab	Fin	Wall	G	q	G	q	G	q	G	q	G	q
0	0	0	400	367	400	327	400	359	400	364	400	500
25	25	25	600	208	800	192	800	211	600	210	600	280
		50	1000	191	1200	173	1200	190	1000	191	800	256
		75	1200	184	1200*	160	1200*	176	1200	178	1000	245
		100	1200	180	1200*	156	1200*	171	1200*	173	1200	240
50	50	50	600	160	1200*	149	1200*	164	800	164	600	213
		75	800	154	1200*	139	1200*	153	1000	154	800	203
		100	1200	151	1200*	134	1200*	147	1200	149	1000	199
75	75	75	600	134	1200*	124	1200*	136	800	137	400	177
		100	1000	131	1200*	119	1200*	131	1200	132	600	173
100	100	100	600	117	1200*	108	1200*	119	1000	120	400	154

*Greater distances from grade to floor might work for these configurations. However, no models with grade to floor dimensions of more than 1200 mm were run in developing this table.

Slab insulation: the thickness of insulation under the interior slab-on-grade

Fin insulation: the thickness of horizontal sub-grade insulation around the exterior perimeter

Wall insulation: the thickness of vertical insulation on the outside of the exterior wall, above and below grade to 600 mm depth.

At exterior corners, double the thickness of the sub-grade horizontal insulation at the corner and back along the wall from the corner, as shown in the illustration, 600 mm for Medicine Hat, 1800 mm for Ft. McMurray, and 1200 mm for Calgary, Red Deer, and Edmonton.

Background

Table 2 was compiled from a series of more than 300 two-dimensional, transient (as opposed to steady-state), finite element heat-flow models. The models were evaluated using Blocon Heat2 version 4; software that allows boundary temperature to vary as a function of time, and that reports temperature at any point as a function of time, taking thermal capacities and conductivities of the materials into account. Each model was run until differences between succeeding years became insignificant. The software did not account for freezing and thawing of moist materials, for diffusion of vapour or liquid, or for transient modifications of heat flow at the ground surface caused by solar heating, radiation, vegetation, and snow. As a result, the annual minimum temperatures the models reported are lower than would actually occur. No granular base was included under the slab. Had these effects been included, reported temperatures would have been different, but results of comparisons would have been the same.

All the models represented buildings 10 m in width, with concrete foundations, slab-on-grade, and concrete exterior walls. The footing depth, always the same for a given city, was equal to the established depth for footings adjacent to heated buildings. The amount of insulation under the slab-on-grade was varied in 25 mm increments, from 0 to 100 mm. Insulation on the exterior wall was varied in 25 mm increments, from 0 to 100 mm, extending to 600 mm below grade. The elevation of floor above grade was varied in 100 mm increments, from 200 to 1200 mm. Horizontal subgrade perimeter insulation, placed at 600 mm below grade, was varied in 25 mm increments of thickness from 0 to 100 mm, in tandem with the thickness of sub-slab insulation. Preliminary models for each city were used to determine what width of horizontal perimeter insulation should be used, varying the width in 600 mm increments. Table 1 shows the parameters used for input. In the models, computational cell densities were increased in regions of high

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heat flow, and in materials of low thermal conductivity, and were similar in all models. Indoor temperature was always 20 deg C. Three-dimensional steady state models were used to decide how insulation at corners should be configured. The configuration suggested is a compromise between effectiveness and extent of excavation. See [add link to previous report].

The input parameters and criteria for deciding when an insulated configuration is as safe from freezing and frost heave as the same foundation when uninsulated were suggested by Charles Kwok, PEng of Jacques Whitford. Modelling was done by Jim Posey of Posey Construction Specifications, and input files were checked for consistency by Andrew Little, Architect.

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