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Date: April 2000

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EVALUATION METHOD

No. 2 (2000)

Insulation of Slab-on-Ground Floors

by

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The development of the method outlined here was funded by the Building Research Levy.

ISSN: 1175-1037

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Abstract

This paper proposes a method for estimating insulation effectiveness and heat losses from slab-on-ground floors in New Zealand. It also includes a method for estimating the seasonal swing in heat flow through slab-on-ground floors. The method has been developed from results of a four-year measurement study of two floors in the Wellington region as well as from other available measurements.

The measurements showed that the thermal performance of floors depends on the soil conductivity, the thickness of the external walls and the floor size. Floor thermal performance was shown to be particularly sensitive to soil conductivity and wall thickness, resulting in errors in forecasts of the experimental slab floor R-values of 25% to 60% if these two parameters were ignored.

Most engineering handbooks claim that soil conductivity is important in determining the floor heat losses but they fail to identify the soil conductivity appropriate to the tables they offer, or how to adjust for soil conductivity. Where soil conductivity data is provided, this has been found to be unreliable. The sensitivity of floor thermal properties to wall thickness is also ignored by existing handbook methods. This study has linked thinner walls with higher heat loss.

The best agreement with the measurements described here was found using a formula by Delsante of CSIRO in Australia, although forecasts using other formulae were improved if corrected for soil conductivity and the effect of wall thickness. The recommendation on when to use edge or whole-floor insulation depends on the severity of climatic conditions.

1. INTRODUCTION

Methods for estimation of the thermal performance of slab-on-ground floors have been available in design handbooks for over 50 years. These have been based on Macey's formula (CIBSE Handbook [1]) and the Latta & Boikau formula (ASHRAE Handbook of Fundamentals [2]). Both these formulae require values for the soil conductivity, and the thickness of the external wall. However, in the translation to handbook calculation methods the allowance for soil conductivity and wall thickness has been lost.

It was generally accepted up until about 1982 that the slab-on-ground component of space heating loss from houses was well enough described by handbooks such as ASHRAE [2] and CIBSE [1]. Then work in the UK by Spooner [3], suggested that the actual losses were as much as half the then-current handbook values. This report was quickly accepted in some quarters, although there was no satisfactory explanation for this result because the soil properties in particular had not been recorded. Later work by the UK Open University (Everett [4, 5]) measured nearly double the heat losses calculated using the CIBSE method, and accounted for both this and Spooner's results in terms of different soil properties. The resulting confusion led to slab-on-ground floor heat losses being uncertain within a range of 2:1.

This experimental study was initiated to provide a better understanding of heat flows through slab floors in New Zealand. The study also undertook to explore the effect of high ground moisture contents, which is common in New Zealand. Consequently a four-year study of two slab floors on wet ground was conducted by BRANZ over the period 1990 - 1996 [6, 7].

2. DESIGN METHOD

As a result of the data obtained with the BRANZ study [6,7], it is proposed that a slight change be made to the procedure for calculating heat losses from slab-on-ground floors. A major problem with this type of floor is that there are huge heat storage effects. These make it impracticable to apply standard steady state thermal design concepts, which was one of the difficulties encountered by Spooner. Instead of a one-step process with winter floor heat losses being estimated from the indoor and outdoor temperatures and the floor R-value, it is proposed that heat losses be estimated in two parts, as an **annual average** derived in a similar way to the previous one-step process, plus a **seasonal cyclic** part related to the time of year.

2.1 Floor R-value - Annual Average Conditions

In the BRANZ study the most reliable forecasting tool for slab-on-ground floor R-values was found to be a formula developed by Delsante of CSIRO, Australia [8] and improved by Davies, UK [9]. This formula is given as Equation (1), and illustrated in Figure 1.

$$R = \frac{\pi.A}{k.P} / \ln\{(1 + x)(1 + 1/x)^{x}\} \quad \mathrm{m^2\,°C/W} \qquad (1)$$

where: $$x = \frac{l.d}{t(l+d)} = \frac{2.A}{t.P}$$

d = half-width of floor m   A = floor area m^2
l = half-length of floor m   P = floor perimeter m
t = external wall thickness m   k = soil conductivity W/m.°C

R = floor + ground thermal resistance m^2 °C/W (uninsulated and excluding carpets)

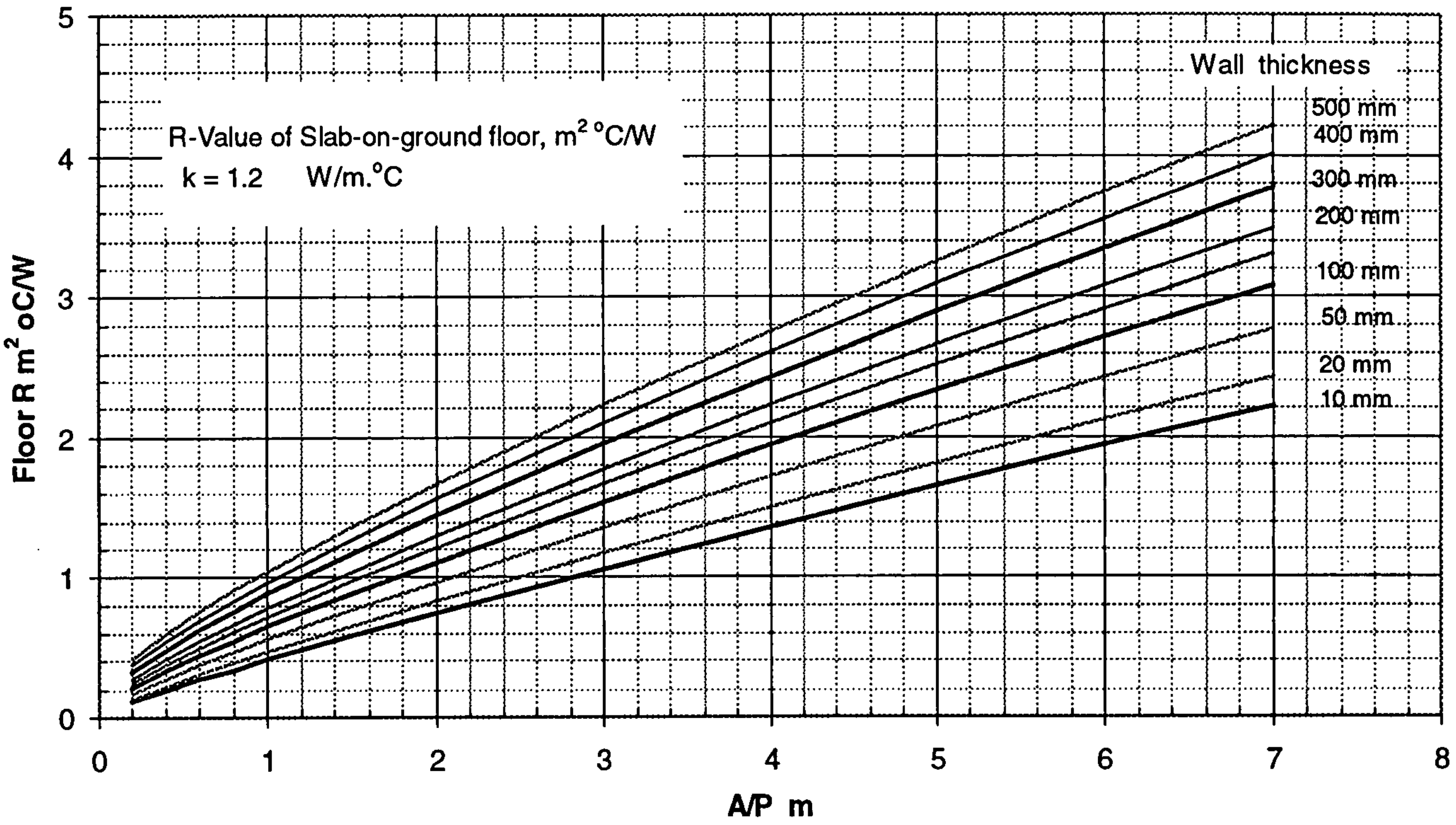

Figure 1. Thermal resistance of the ground, by the Delsante/Davies formula

Figure 1 shows that the thickness of the external wall will have a very significant influence on the floor thermal resistance.

In comparison with the previously commonly used CIBSE formula [1], the Delsante formula gives similar R-values for medium and large floors (A/P values over say 2), and lower R-values for small or narrow floors.

Note that Equation 1 and Figure 1 provide the average thermal resistance or R-value. The R-value is a steady state property, and therefore applies fully only to the long-term average condition. In the case of normal walls and roofs, 'long-term' means over a few hours, and the R-value is therefore applicable without much reconsideration. But slab-on-ground floors are so slow responding that 'long-term' really means 'year-average'. This means that one can estimate reliably the year average heat flow through the floor, but not necessarily the peak winter heat flow.

2.2 Cyclic Adjustment - Seasonal Variations

The heat flow downward throughout slab-on-ground floors varies in a cyclic manner with the season; increasing as the winter progresses and decreasing in summer. In the BRANZ study [7] it was found that the annual cyclic swing in heat flux was roughly half the annual average value. For theoretical reasons this is expected to apply to other cases so that the seasonal variation of floor heat flows can be approximated as follows:

a. Calculate the mean value as outlined above, from the annual mean indoor and outdoor temperatures and the floor R-value.

b. Superimpose on this an annual cyclic swing of ~ 50 % of this mean value, and delayed by one to two months.

Example 1:

Take a 100 m^2 floor of R-value 1.8 m^2 °C /W in Canterbury; with annual mean indoor temperature of 18 °C and annual mean outdoor temperature of 10 °C.

The annual mean heat flux qm = (18 - 10)/1.8 = 4.4 W/m^2 (444 W total).

The annual cyclic heat flux qc ~ 0.5 * 4.4 = ± 2.2 W/m^2 (± 222 W total).

Thus the floor heat flux ranges from 2.2 to 6.6 W/m^2 (222 to 666 W total)
and would peak in about August, with the minimum about February.

2.3 Short-Term Variations

If desired, it is possible to estimate the cyclic adjustment resulting from shorter term fluctuations, by superimposing further heat flow variations on top of the mean and seasonal variations. As the duration of a disturbance becomes shorter, the cyclic heat flow becomes larger, and progressively more dependent on surface heat transfer processes and less on the floor R-value. For short term disturbances in room temperature lasting a week or less, theory indicates that the floor heat flow can be estimated by assuming the concrete floor remains at constant temperature, acting through the surface coefficient and floor covering thermal resistances – i.e., about 0.2 to 0.5 m^2 °C/W. The BRANZ measurements agreed with this view.

Example 2:

A floor with cork tiles of R-value 0.2 m^2 °C /W, is in a room heated normally to 20 °C in winter. The heating is turned off for three days, with the result that the room temperature drops by 5 °C over that time. What happens to the floor heat flow?

The total floor surface resistance is (surface + tiles) ~ 0.2 + 0.2 = 0.4 m^2 °C/W.
The room temperature, previously 20 °C, drops to 15 °C.
The concrete surface temperature, previously about 18 °C, remains about that temperature.

Thus the heat flow into the surface, previously about 6.6 W/m^2 downwards, now becomes about (15-18)/0.4 = -7.5 W/m^2, i.e. 7.5 W/m^2 upwards.

3. SOIL CONDITIONS

3.1 Soil Conductivity

Typical soil conductivities are given in the ASHRAE Handbook of Fundamentals [2]. The values in the 1989 edition were found to roughly fit formula (2):

1989 $k \sim k_0.(1 + 7m).(\rho_0/1600)^{2.1}$ (2)

where k = conductivity W/m. °C

m = moisture content by fraction of weight (0 to 1)

ρ = bulk density kg/m^3

suffix $_0$ indicates value for dry soil

($k_0 = 0.5$ clay, $k_0 = 0.6$ loam, $k_0 = 0.9$ sand, $k_0 = 1.2$ quartz)

Values in the 1993 edition approximate to formula (3):

1993 $k \sim 0.7 + 0.05*m$ for fine grained soils (3)

$\sim 0.7 + 0.1*m$ for poorly graded soils

$\sim 0.7 + 0.2*m$ for well graded soils

Neither of these rules was reliable for forecasting the soil conductivities in the BRANZ study. The 1989 ASHRAE Handbook data leads to expected soil conductivities values of about 0.4 and 1.8 respectively for the two houses in this study, whilst the 1993 Handbook gives values of > 2 and 1.3. There are equally large differences between these Handbook conductivities and those measured on the two building sites of 0.7 (House P) and 1.1 (House W).

Farouki [10] provides a much more comprehensive source of data for soil conductivities. From Farouki it might be expected that the soil conductivity for the wet peat soil at the first house (P) would be below 1.0 W/m. °C, and possibly even below 0.5 depending on unknown factors (degree of peat formation and type of minerals). The wet clay at the latter site (W) might be expected to have conductivity anywhere between 0.5 and 1.5 W/m. °C.

In view of the wide range of these forecasts, the difficulty in assigning realistic soil conductivities to subfloor soils at the building design stage is readily apparent. Further attention to this issue is clearly necessary.

In view of the measured soil conductivities for two damp soil sites in the BRANZ study, it is suggested that a **soil conductivity value of about 1.2 W/m. °C** be used until more comprehensive and accurate data is available. This is a little lower than the value of 1.4 W/m. °C commonly adopted in the handbooks.

3.2 Ground Water

On both BRANZ sites, the water table depth was permanently rather shallow, at about 0.4 m to 1 m. As far as was possible to determine, the groundwater affected the floor heat loss primarily by altering the apparent conductivity of the soil. In one of the floors there was a lateral ground-water flow of a few metres/year, and the floor heat loss was displaced in the direction of this ground-water flow. The floor heat loss rate appeared to be reliably predicted by the Delsante formula, so long as the measured ground conductivity (obtained using the transient probe method) was used in the calculation.

4. ESTIMATION FOR CODE AND CONTRACT PURPOSES

Whole floor R-values calculated for Code compliance purposes should include the effects of (a) actual soil conductivity and (b) external wall thickness. Further investigation of the soil conductivities at the proposed building site may be necessary, but for the present, default values are given in (a) below. The R-values for whole floors should calculated from the Delsante formula, or read from Figure 1 and adjusted in proportion for the actual conductivity if different from 1.2 W/m °C. It should then be further adjusted if edge or full under-floor insulation is added, as in (b). Where seasonal variations are of interest, these can be estimated as in (c). A step-by-step procedure is listed in Appendix 1.

(a) Where feasible, especially for major developments, the soil conductivity should be measured. This is not a difficult process. It is desirable that the conductivity of soils be measured **in situ** in a variety of urban or regional centres to provide more extensive design data for New Zealand.

On the basis of measurements in only two wet soil locations, it is conceivable that the conductivity of soils in urban areas in New Zealand may be lower than the traditional value of 1.4 W/m °C. In the interim, a value of k = 1.2 W/m °C is suggested. The validity of this suggestion would need to be tested by a more extensive survey.

(b) The floor R-values can be estimated from Equation 1 or Figure 1, using the ratio of the floor area to floor perimeter length (A/P), and allowing for the thickness of external walls.

If additional insulation is to be added around the perimeter of the floor or under the slab, the "uninsulated R-value" obtained above can be increased as follows:

for; Ri = thermal resistance of the whole-floor insulation
Rf = thermal resistance of floor + ground

Table 1:

Condition	Width of 50 mm thick edge insulation		
	0 m	0.5 m	1.0 m
	R-value Multiplier		
Vertical Edge Insulation	1.0	1.09	1.18
Horizontal Edge Insulation	1.0	1.18	1.33
Whole Floor insulation	add Ri to Rf		

(c) Seasonal floor heat losses can be estimated as in Example 1.

Short-term responses for thermal disturbances can be obtained by applying a further weighting factor to the one-year cyclic response, as below:

Table 2:

Duration of disturbance	**Weighting factor**
3 months	x 1.4
1 month	x 2.4

For disturbances of less than a week or two, behaviour is different and the method in Example 2 may be used. For disturbances between a fortnight and a month, the results are intermediate. (E.g. for Example 2 above, if the indoor temperature were increased by 4 °C to 24 °C for one day, the floor heat loss for that day would increase to (24-18)/0.4 = 15 W/m^2. The heat loss through the 100 m^2 floor would be 1.5 kW.

5. CONCLUSION

The current reference information on the heat loss from slab-on-ground floors has been reconsidered in the light of a recently completed four-year study of heat flows through floor slabs on damp soils. The conclusions reached are that:

- The best forecasting tool for the R-value of these floors is given by the Delsante/Davies formula, rather than the Macey formula previously used by CIBSE and others. The Delsante formula gives similar R-values for medium-sized floors and a lower rating for small floors than previously.

- The method of estimating floor heat losses should be changed to a two-stage process in which the annual average heat loss is calculated, and a seasonal cyclic swing superimposed on that value. The seasonal cyclic swing can be calculated approximately and simply from the floor R-value using a soil conductivity value of 1.2 W/m °C.

- A simplified method for adding the effects of subfloor and perimeter insulation to the R-value of the floor and soil has been derived from the literature and presented here as a series of correction factors.

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APPENDIX 1

Results of the BRANZ Four-Year Site Survey

The BRANZ site survey [7] and various calculations are shown in Table 3, to illustrate variations between the methods, and the sensitivity to several factors.

The survey was conducted in two houses on wet soils in the Wellington region, by covering both floors completely with Heat Flux Transducers (HFT's) and surface thermocouples, and then monitoring both continuously for ~ four years. Both houses were occupied normally throughout the observation period. Measurements were made at a rate of 8/hour and converted to one-hour averages. Soil conditions were measured once daily whenever possible, and fortnightly when sensor failure prevented this. On completion, this data was presented as averages of R-values and soil conductivity.

Table 3 shows R-values calculated with and without corrections for conductivity and external wall thickness.

	Calculation Source				
	CIBSE [1]	ASHRAE [2]	Anderson [11]	Delsante/Davies [8,12]	Measured [7]
Paraparaumu					**2.35**
"normal"	1.6	1.7	1.5	1.4	
adjusted to soil k = 0.7	3.2	3.4	3.1	2.8	
adjusted for wall t 0.27m				2.7	
Whitby					**0.98**
"normal"	1.3	1.4	1.35	1.25	
adjusted to soil k = 1.1	1.6	1.8	1.7	1.6	
adjusted for wall t 0.10m				1.2	

Table 3. Summary of calculated and measured R-values for both floors.

(these values are from indoor concrete surface to outdoor ground surface)
(the "normal" values are for soil k = 1.4, and are calculated from the A/P value)

STEP-BY-STEP PROCEDURE FOR ESTIMATING SEASONAL FLOOR HEAT LOSS:

1. Estimate the floor area/perimeter ratio, "A/P".
2. Choose an appropriate soil conductivity "k" (use 1.2 W/m °C if better data not available).
3. Find the exterior wall thickness "t".
4. Calculate the floor R-value, from Equation 1 or Figure 1. If "k" is not 1.2, then multiply the Figure 1 R-value by 1.2/k.
5. Adjust this value for edge insulation or whole floor insulation, if used, from Table 1.
6. Add the R-value of any floor covering in the same way as for whole-floor insulation.
7. Calculate annual average and seasonal cyclic heat flows as in Example 1.

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ISSN: 0111-8161