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Perimeter insulation of concrete slab foundations

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Preface

This report is part of BRANZ's ongoing research into improving the interior comfort and energy efficiency of heated concrete floor slabs in residential construction.

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Abstract

This research investigates the practicalities and effectiveness of adding exterior perimeter edge insulation to concrete floor slabs in residential construction in New Zealand. In particular, it attempts to demonstrate the benefits of perimeter insulation when used on new, reinforced floor slabs on compacted ground, as is currently the case with many new builds in Christchurch.

The work models the performance of perimeter insulation in various sizes, materials and configurations when used in combination with three common floor slab and wall construction techniques. It also investigates the performance of perimeter insulation when used with additional under-slab insulation.

As well as computer modelling, the performance of perimeter insulation was verified with experimental data and the results from a long-term study of an occupied residence in Christchurch.

Keywords

floor slab, concrete slab, insulation, energy efficiency

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1. Introduction

It is common practice to add perimeter insulation to heated floor slabs in Europe and North America, but the technique is not widely used in New Zealand.

There is a perception within the building industry that perimeter insulation is ineffective, costly and difficult to install. Many in the architectural community also consider it to be visually intrusive and that it reduces the aesthetic appeal of concrete floor slab construction.

This research attempts to debunk some of these misconceptions by investigating the practicalities and effectiveness of adding exterior perimeter edge insulation to concrete floor slabs in residential construction in New Zealand. In particular, it attempts to demonstrate the benefits of perimeter insulation when used on new, reinforced floor slabs on compacted ground, as is currently the case with many new builds in Christchurch.

The work models the performance of perimeter insulation in various sizes, materials and configurations when used in combination with three common floor slab and wall construction techniques. It also investigates the performance of perimeter insulation when used with additional under-slab insulation.

The floor systems were modelled using two-dimensional simplifications and the solution derived on the basis of steady-state heat transfer. The only exception was for the waffle pods where a two-dimensional simplification was derived for the pods based on a series of three-dimensional models. Two principal simplifications were that the pods had only half the width of the actual pods and the horizontal heat-flow in the pod air voids was the same as the vertical heat flow in the voids.

Other assumptions used for the modelling were that the heat flow through the floor was the winter condition of principally downward heat flow and that the interior floor surface thermal resistance was a constant 0.09 m^2.K/W, and the exterior surface resistance 0.03 m^2.K/W. The floors were modelled without any floor covering.

As well as computer modelling, the performance of perimeter insulation was verified with experimental data and the results from a long-term study of an occupied residence in Christchurch.

In reality, the heat flow through floor slabs is dynamic but the steady-state modelling is still a reasonable representation of the likely average performance and the relative impact of the various insulation options. The field measurements were able to confirm that the average performances were close to what is predicted by the steady-state models and was also able to confirm at least some of the basic design predictions such as the addition of perimeter insulation.

2. Method

Perimeter insulation consists of rigid foam insulation applied to the vertical face of the exterior edge of a floor slab. The foam insulation normally extends from just below the bottom edge of the exterior wall cladding to the bottom edge of the wall footing.

The exterior of the perimeter insulation is also often protected from impact damage and moisture accumulation with an additional layer of hardened plastic.

In order to investigate the thermal impact and the R-value of the floor slab when perimeter insulation is in place, four types of concrete floor slab and wall construction were considered:

1. simple slab foundation with a stud wall
2. waffle pod foundation with a stud wall
3. waffle pod foundation with brick veneer and stud wall
4. waffle pod foundation with brick veneer and stud wall, with the addition of under-slab insulation.

These representative configurations were chosen as they are widely used in New Zealand construction.

Figures 2.1–2.4 are indicative only to show the general construction configuration. Slab reinforcing, wall insulation, lining options and other details have been omitted for clarity.

2.1 Configuration A: Simple foundation with lightweight cladding

The first configuration models a simple concrete ground floor slab foundation supporting a 90 mm thick timber-framed stud wall and a lightweight cladding, as shown in Figure 2.1.

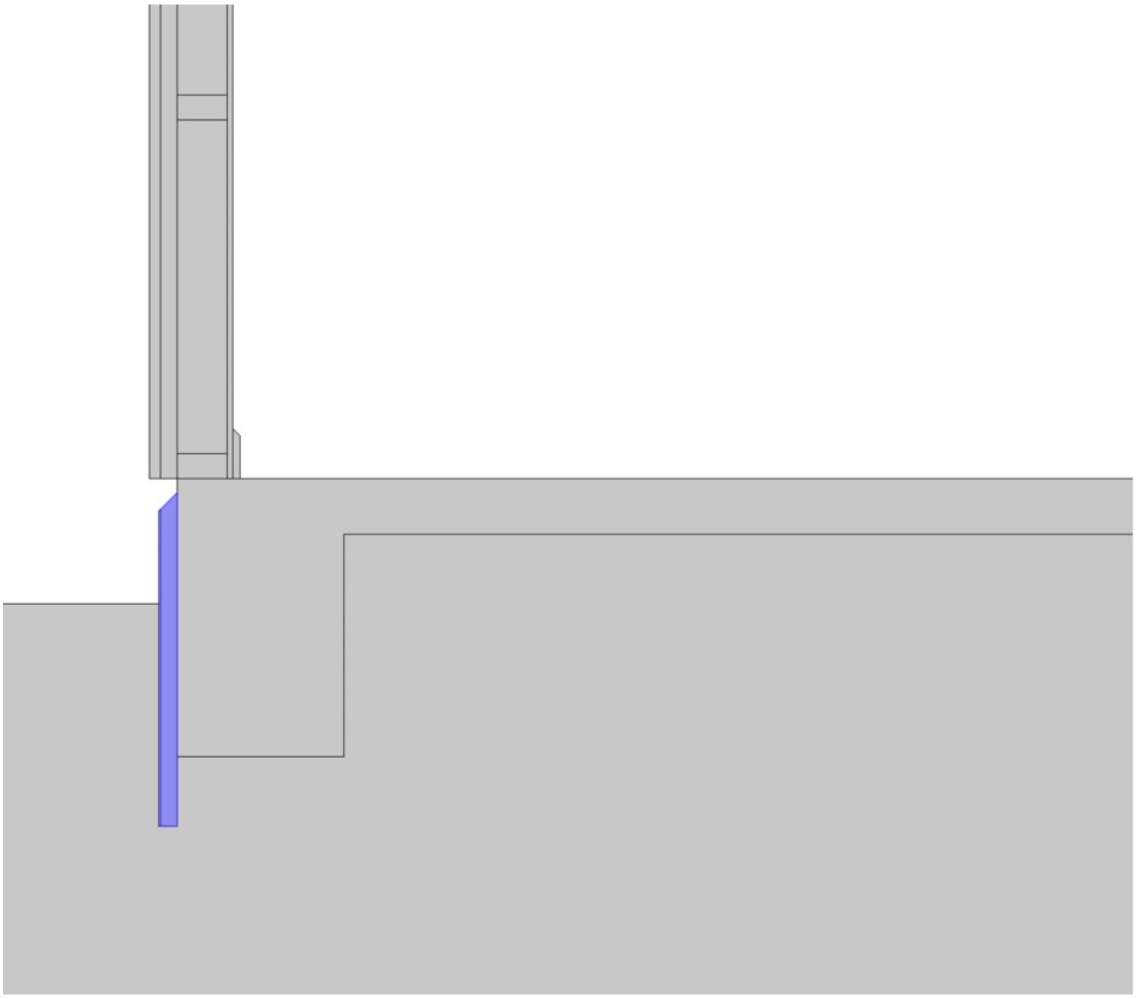

Figure 2.1. Configuration A: A simple concrete floor foundation and timber-framed wall, with perimeter insulation (shown in blue) added to the exterior side face of the slab.

Figure 2.1 shows a gap between the top edge of the perimeter insulation (shown with an outward-facing slope) and the lower face of the cladding overhang. This insulation top gap is necessary to maintain the cladding drip edge.

2.2 Configuration B: Waffle pod foundation with lightweight cladding

The second configuration models a waffle pod foundation supporting a 90 mm thick timber-framed stud wall and a lightweight cladding, as shown in Figure 2.2.

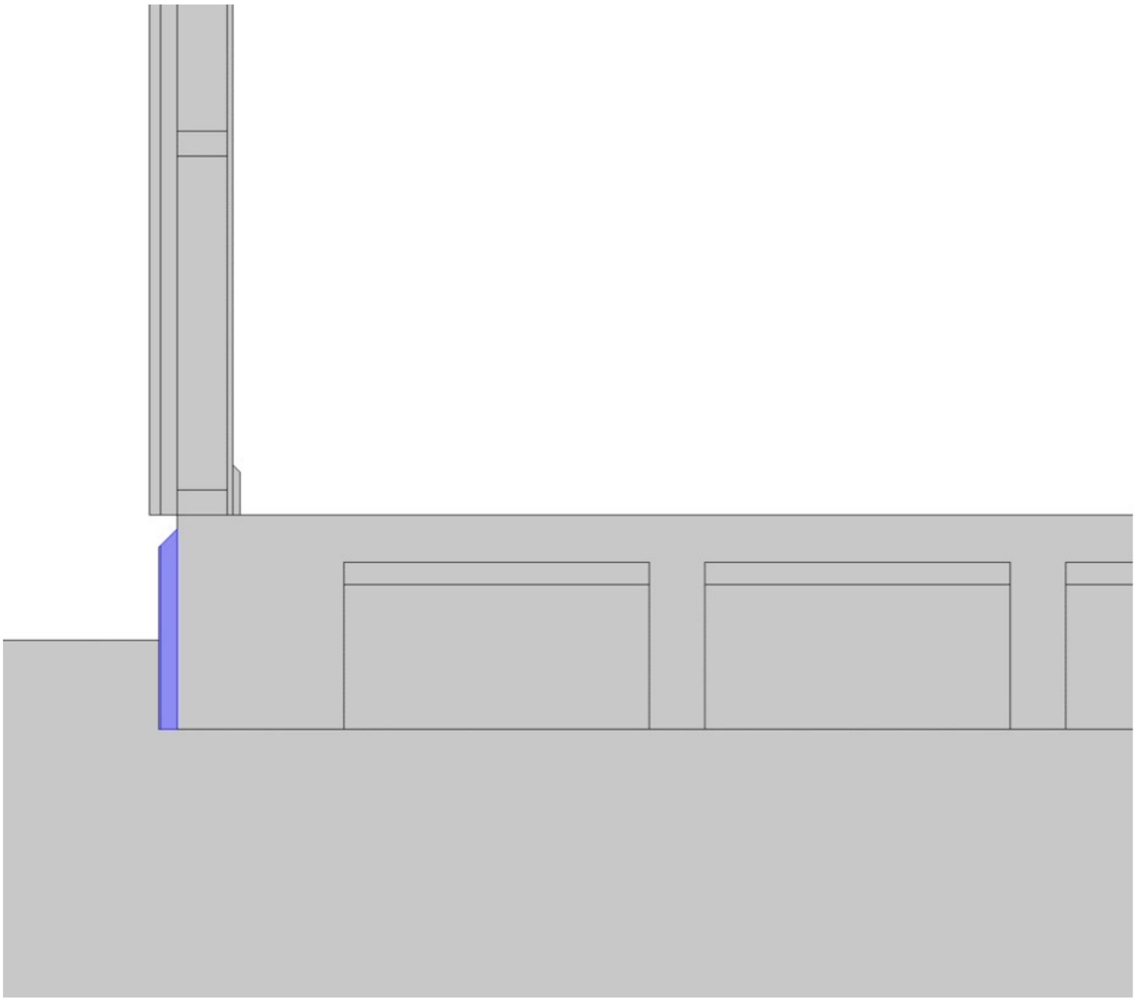

Figure 2.2 Configuration B: A waffle pod foundation and timber-framed wall, with perimeter insulation added to the exterior side face of the slab.

Two pod heights were considered – 220 mm and 300 mm. In both cases, the pods were modelled using solid 50 mm expanded polystyrene (EPS) insulation on the top face (in contact with the underside of the slab) and hollow cores beneath.

Ground compaction often makes it difficult to install perimeter insulation below the bottom edge of the footing, so the height of the perimeter insulation in this configuration was limited to 305 mm for the smaller pod height and 385 mm for the larger pod height.

While it is possible to add whole-of-system insulation to this configuration, typically below both the ribs and pods, doing so is outside the scope of standard waffle pod foundation design and was therefore omitted from the model.

This configuration also requires a perimeter insulation top gap to maintain the cladding drip edge.

2.3 Configuration C: Waffle pod foundation with heavy cladding

The third configuration models a waffle pod foundation supporting a 90 mm thick timber-framed stud wall and brick veneer cladding, as shown in Figure 2.3.

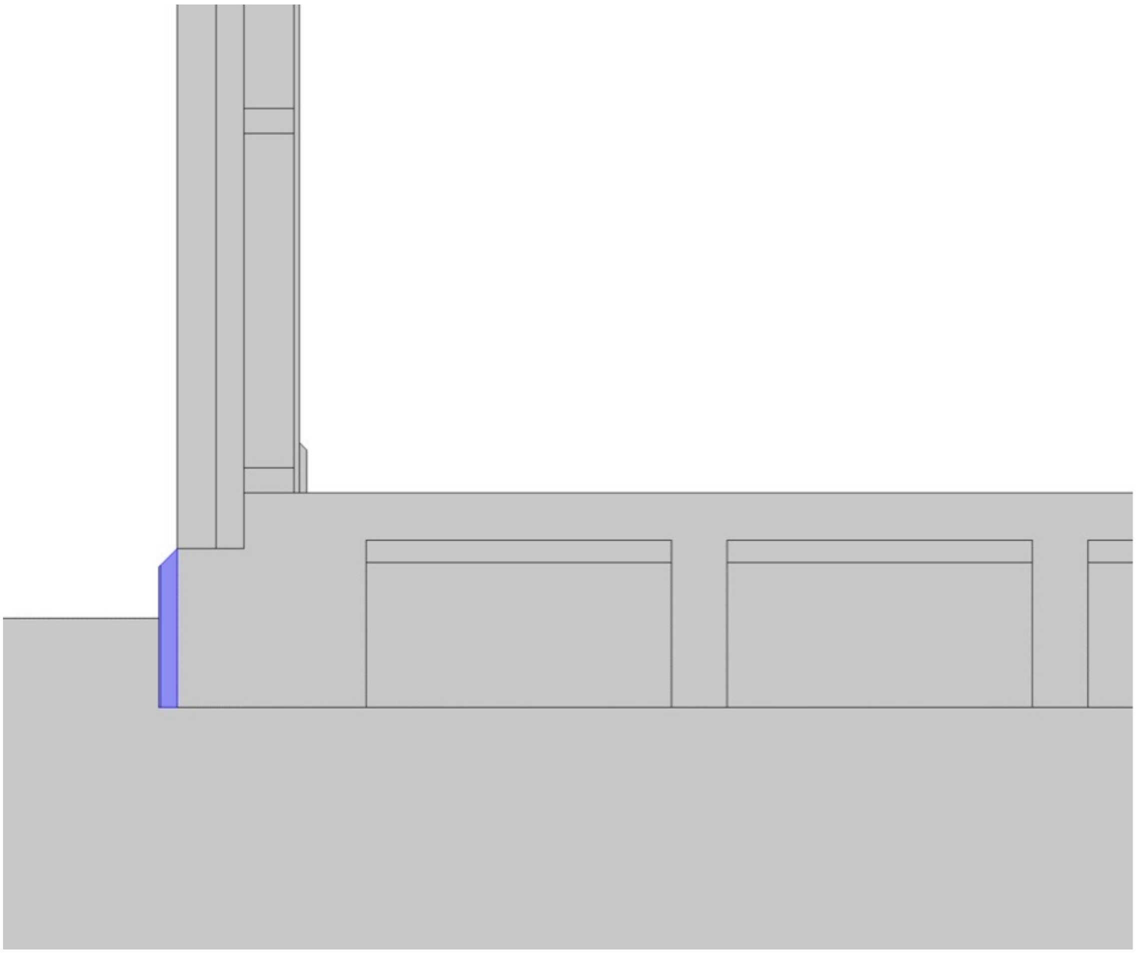

Figure 2.3 Configuration C: A waffle pod foundation, timber-framed wall and brick veneer cladding, with perimeter insulation added to the exterior side face of the slab.

Pod heights of 220 mm and 300 mm were again considered and the pods were again modelled with solid 50 mm EPS insulation on the top face and hollow cores beneath.

While this configuration can employ a 50 mm or 100 mm step-down for the brick veneer cladding, the thermal performance difference between the two is negligible. A 100 mm step-down is more commonly used in New Zealand and was therefore selected for the model.

The step-down also reduces the height of the exterior side face of the slab, so the height of the perimeter insulation in this configuration was limited to 205 mm for the smaller pod height and 285 mm for the larger pod height.

The outer face of a brick veneer cladding is also typically flush with the lower, exterior side face of the slab, so no perimeter insulation top gap was required.

Configuration C was also modelled with the addition of an under-slab insulation system, as shown in Figure 2.4.

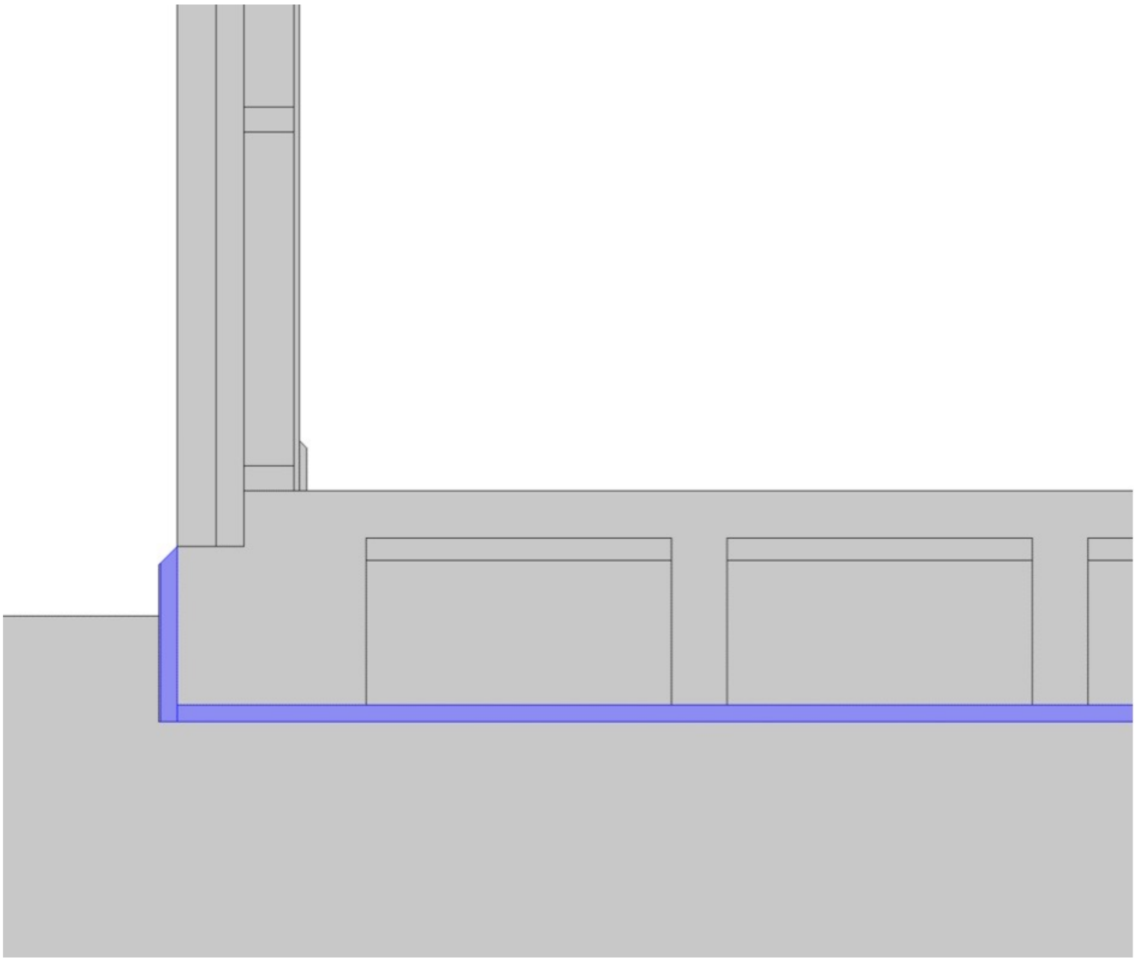

Figure 2.4 Configuration C: The addition of under-slab insulation.

For the purposes of the model, under-slab insulation was placed uniformly below the footing, ribs and pods. In most situations, there is negligible difference in thermal performance if only footing and ribs are insulated, so this approach was considered a reasonable representation of current practice.

2.4 Modelled variables

The thermal performance of Configurations A–C was then modelled using the following performance variables:

- height of the floor surface above ground level

- thermal conductivity of the under-slab soil
- thickness of the wall (excluding overhang)
- under-slab insulation R-value
- size of the foundation (the ratio of the floor area to the perimeter length)
- perimeter insulation R-value
- perimeter insulation height
- perimeter insulation top gap.

Three representative floor slab sizes were selected and investigated for each configuration. These slabs are square and have areas of 50 m^2, 100 m^2 and 200 m^2.

Each configuration was also modelled with no perimeter insulation present in order to establish a baseline for the thermal performance of perimeter insulation. The results were then compared to give the relative difference in thermal performance.

2.5 Case study

As well as using models to predict performance, the project monitored heat loss from three floor slabs at BRANZ and a residential floor slab in Christchurch.

Measurements were carried out over the 2015 winter months, including March and October, but the months with significant heat loss from the perimeter of the slab were from April through to and including September.

Expanded polystyrene (XPS) was chosen for the field measurements because it enables a thinner and therefore less visible insulation system. For the same reason, 3 mm grey uPVC sheet was used to protect the insulation.

Another reason for selecting XPS rather than EPS or alternative foams such as polyurethane, polyisocyanurate or phenolic was that it has a history of successful use in this type of application.

The floor slab monitored in Christchurch was a waffle pod style incorporating 220 mm EPS pods. This provided results for a heated slab in a climate with a significant difference in temperature between the interior floor surface and the outside air and ground temperature.

Because the insulation needed to be retrofitted, only a short section of the Christchurch floor slab perimeter was insulated and monitored. A nearby section of uninsulated slab perimeter was also monitored.

3. Results

In terms of construction design, the most interesting results were related to the characteristics of the perimeter insulation, in particular the insulation R-value, height and top gap, and the relationship between these variables and the geometry of the floor slab.

3.1 Configuration A: Simple foundation with lightweight cladding

The following sections present the findings for the design variables in Configuration A.

3.1.1 Perimeter insulation R-value

The effect that the perimeter insulation R-value has on the overall thermal performance of the concrete floor slab in Configuration A is shown in Table 3.1.

For simplicity, the results were derived by modelling the system with a representative perimeter insulation that is 600 mm high and with and without under-slab insulation that has an R-value of 1.2. A common under-slab insulation technique uses 50 mm EPS with an R-value of 1.2, so the latter figure is deemed reasonable.

Table 3.1 Slab R-values for various perimeter insulation R-values in Configuration A.

Perimeter insulation R-value	Slab R-value					
	Perimeter insulation 600 mm high			Perimeter insulation 600 mm high and R1.2 insulation under-slab		
	50 m² slab	100 m² slab	200 m² slab	50 m² slab	100 m² slab	200 m² slab
0.0	0.75	1.01	1.37	0.94	1.26	1.68
0.2	1.02	1.36	1.82	1.27	1.67	2.20
0.4	1.13	1.49	1.99	1.40	1.84	2.41
0.6	1.19	1.57	2.09	1.48	1.93	2.52
0.8	1.24	1.62	2.16	1.53	1.99	2.60
1.0	1.27	1.66	2.20	1.56	2.03	2.65
1.2	1.29	1.69	2.24	1.59	2.07	2.69
1.4	1.31	1.71	2.26	1.61	2.09	2.72
1.6	1.32	1.73	2.29	1.63	2.11	2.75
1.8	1.33	1.74	2.30	1.64	2.13	2.77
2.0	1.34	1.76	2.32	1.65	2.14	2.79

The effect that the perimeter insulation R-value has on the relative improvement in thermal performance of the floor slab in Configuration A is shown in Figure 3.1 and Figure 3.2.

The first graph, Figure 3.1, shows the performance improvement of the configuration with 600 mm of perimeter insulation when compared with an uninsulated slab (no perimeter or under-slab insulation). Similarly, Figure 3.2 shows the performance improvement of the configuration with 600 mm of perimeter insulation combined with an R-value of 1.2 of under-slab insulation compared with an uninsulated slab (no perimeter or under-slab insulation).

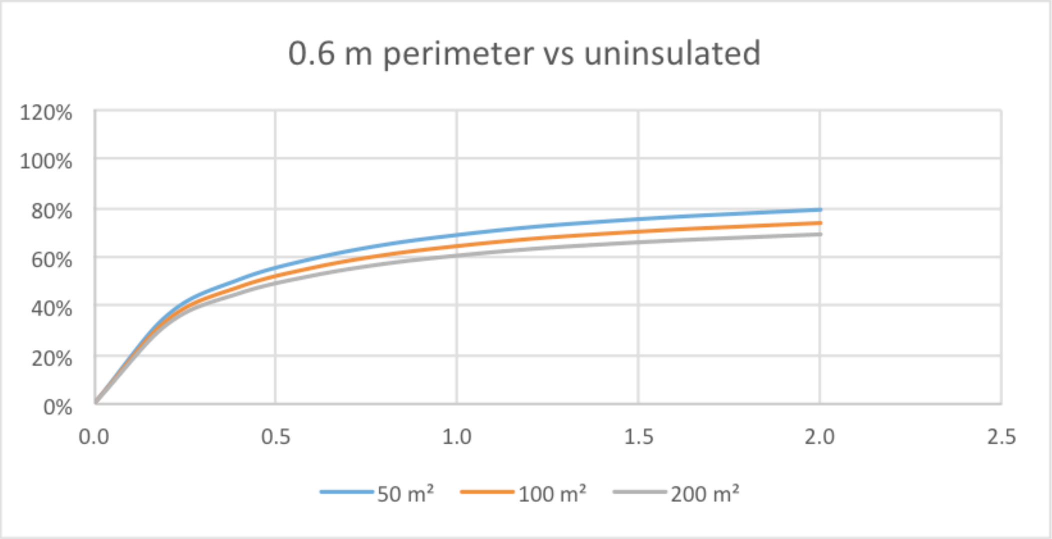

Figure 3.1 Relative effect of perimeter insulation R-value on the thermal performance of a floor slab compared with an uninsulated slab.

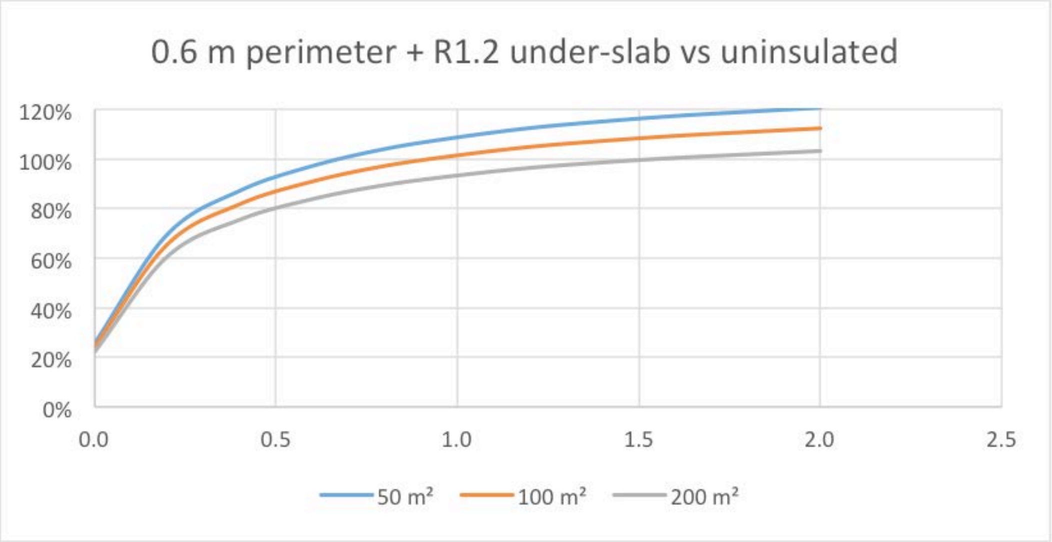

Figure 3.2 Relative effect of perimeter insulation R-value on the thermal performance of an under-slab insulated floor slab compared with an uninsulated slab.

The three lines shown in Figure 3.1 and Figure 3.2 represent the results for the three slab sizes that were considered in the model. Results may be interpolated for to find the R-value for floor slabs with areas between these representative figures. However, a more useful parameter may be the area-perimeter ratio. Results should not be extrapolated for slabs with an area greater than 200 m^2.

3.1.2 Perimeter insulation height

The effect of the perimeter insulation height on the overall thermal performance of the floor slab in Configuration A is shown in Table 3.2.

The R-value of the perimeter insulation was kept constant at 1.0, which is a reasonable assumption with 50 mm of EPS insulation products. Generally, an R-value of 1.0 can be achieved using 30 mm of good-quality XPS. A larger thickness (35–45 mm) will be required if EPS is used.

Perimeter insulation heights up to 1.0 m were modelled and are shown here, but in practice, the height is limited by the height of the slab and the ease of installing insulation at depth.

Table 3.2 Slab R-values for various perimeter insulation heights in Configuration A.

Perimeter insulation height (m)	Slab R-value					
	Only perimeter insulation			Perimeter insulation and R1.2 insulation under-slab		
	50 m^2 slab	100 m^2 slab	200 m^2 slab	50 m^2 slab	100 m^2 slab	200 m^2 slab
0	0.75	1.01	1.37	0.94	1.26	1.68
0.3	1.09	1.45	1.93	1.37	1.79	2.35
0.4	1.16	1.53	2.04	1.45	1.89	2.48
0.6	1.27	1.66	2.20	1.56	2.03	2.65
0.8	1.33	1.74	2.30	1.63	2.12	2.76
1.0	1.37	1.79	2.36	1.67	2.17	2.82

The effect that the perimeter insulation height has on the relative improvement in thermal performance of the floor slab in Configuration A is shown in Figure 3.3 and Figure 3.4. The first graph, Figure 3.3, shows the performance improvement of the configuration with perimeter insulation when compared with an uninsulated slab (no perimeter or under-slab insulation). Similarly, Figure 3.4 shows the performance improvement of the configuration with perimeter insulation combined with R1.2 under-slab insulation compared with an uninsulated slab (no perimeter or under-slab insulation).

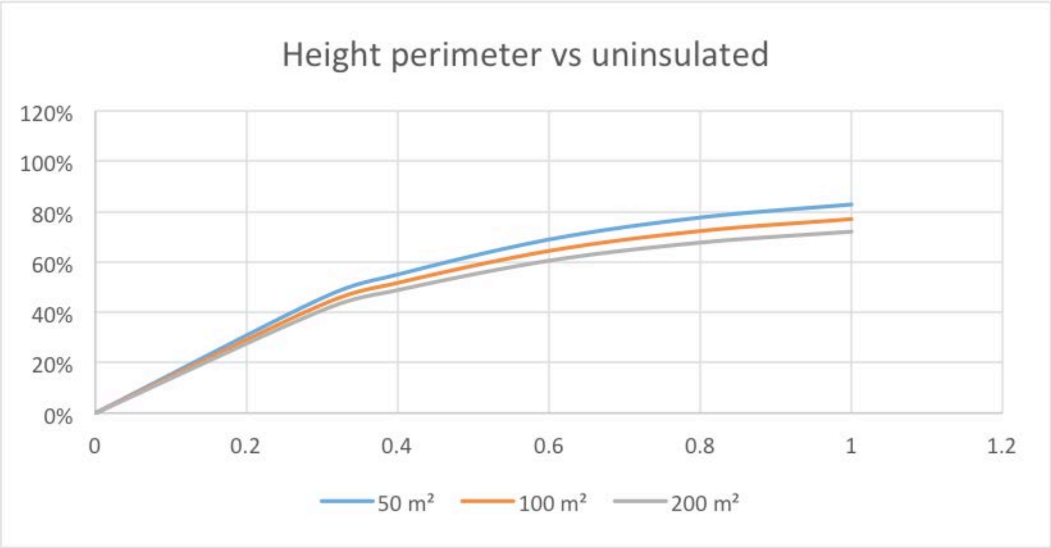

Figure 3.3 Relative effect of perimeter insulation height on the thermal performance of a floor slab compared with an uninsulated slab in Configuration A.

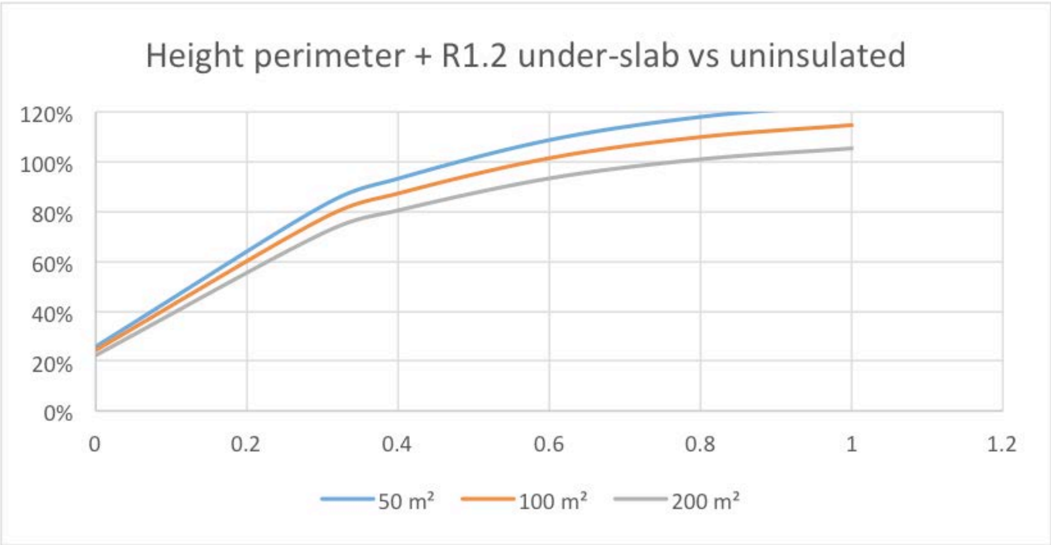

Figure 3.4 Relative effect of perimeter insulation height on the thermal performance of an under-slab insulated floor slab compared with an uninsulated slab in Configuration A.

3.1.3 Perimeter insulation top gap

The effect of the perimeter insulation top gap size on the overall thermal performance of the floor slab in Configuration A is shown in Table 3.3. Again, the R-value of the perimeter insulation was kept constant at 1.0.

Table 3.3 Slab R-values for various perimeter insulation top gap sizes in Configuration A.

Perimeter insulation top gap (m)	Slab R-value					
	Only perimeter insulation			Perimeter insulation and R1.2 insulation under-slab		
	50 m^2 slab	100 m^2 slab	200 m^2 slab	50 m^2 slab	100 m^2 slab	200 m^2 slab
0	1.27	1.66	2.20	1.56	2.03	2.65
0.02	1.15	1.52	2.03	1.41	1.86	2.44
0.04	1.08	1.43	1.92	1.32	1.75	2.30
0.06	1.03	1.37	1.84	1.26	1.67	2.19
0.08	0.99	1.31	1.77	1.21	1.60	2.11
0.1	0.96	1.27	1.71	1.16	1.54	2.04

The effect that the size of the perimeter insulation top gap has on the relative improvement in thermal performance of the floor slab in Configuration A is shown in Figure 3.5.

This graph shows the net reduction in the performance improvement. For example, from Figure 3.1, the thermal performance of a 50 m^2 floor slab in Configuration A improves by approximately 70% when 600 mm high insulation with an R-value of 1.0 is added to the perimeter. Figure 3.5 shows that a 100 mm perimeter insulation top gap will reduce that gain by 25%, giving a net performance improvement of 45%.

Figure 3.5 also shows the change in performance improvement when perimeter insulation is combined with under-slab insulation with an R-value of 1.2. However, modelling shows that under-slab insulation has negligible effect on the performance improvement provided by the perimeter insulation top gap.

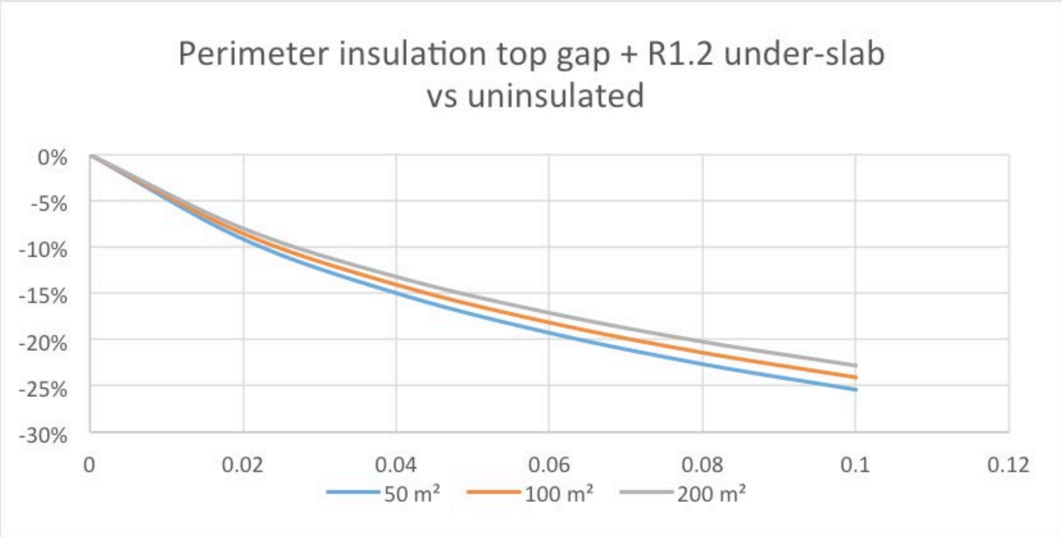

Figure 3.5 Relative effect of the size of the perimeter insulation top gap on the performance of an under-slab insulated floor slab compared with an uninsulated slab in Configuration A.

3.1.4 Area-perimeter ratio

The effect that the geometry of the slab (area-perimeter ratio) has on the overall thermal performance of the floor slab in Configuration A is shown in Table 3.4 and Figure 3.6. Slab R-values are given for four insulation scenarios.

Table 3.4 Slab R-values for various slab area-perimeter ratios and insulation scenarios in Configuration A.

Floor slab construction	**Area-perimeter ratio**					
	1.5	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
	Slab R-value					
No insulation	0.65	0.83	1.01	1.19	1.36	1.53
R1.0 perimeter insulation	1.09	1.37	1.63	1.89	2.15	2.40
R1.2 under-slab insulation	0.82	1.04	1.26	1.46	1.66	1.86
R1.0 perimeter and R1.2 under-slab insulation	1.35	1.69	2.00	2.30	2.59	2.87

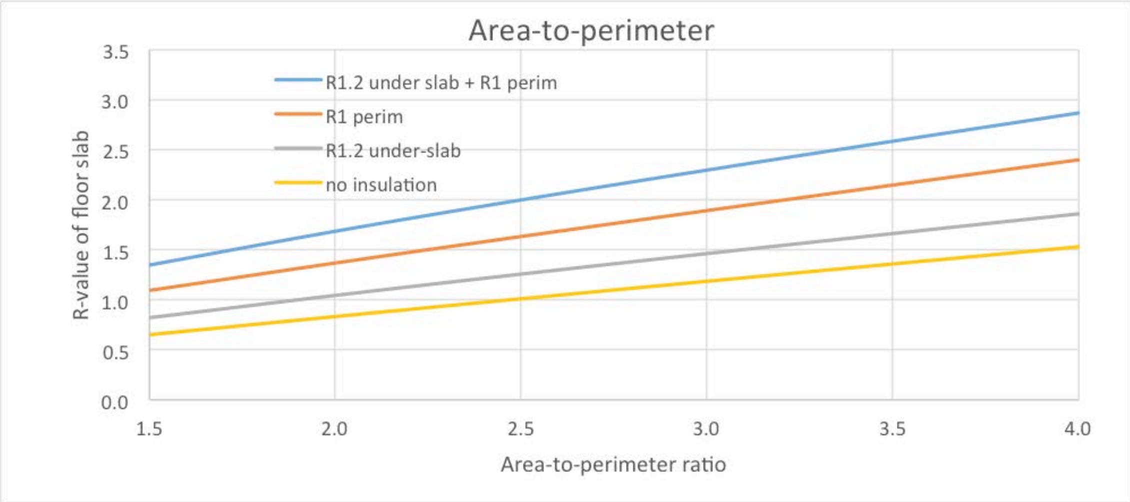

Figure 3.6 Relationship between area-perimeter ratio and slab R-value for different floor slab insulation types in Configuration A.

The usefulness of area-perimeter tables and figures may be familiar to readers of the BRANZ *House Insulation Guide*.

3.2 Configuration B: Waffle pod foundation with lightweight cladding

The following sections present the findings for the design variables in Configuration A.

3.2.1 Perimeter insulation R-value

The effect that the perimeter insulation R-value has on the overall thermal performance of the waffle pod foundation in Configuration B is shown in Table 3.5.

For simplicity, the results were derived by modelling the system with 220 mm waffle pods and perimeter insulation 205 mm high, and 300 mm waffle pods with perimeter insulation 285 mm high. No perimeter insulation top gap was present in both cases.

Table 3.5 Slab R-values for various perimeter insulation R-values in Configuration B.

Perimeter insulation R-value	Slab R-value					
	220 mm pods and 305 mm perimeter insulation			300 mm pods and 385 mm perimeter insulation		
	50 m^2 slab	100 m^2 slab	200 m^2 slab	50 m^2 slab	100 m^2 slab	200 m^2 slab
0.0	0.91	1.22	1.63	0.92	1.23	1.65
0.2	1.17	1.54	2.04	1.21	1.59	2.10
0.4	1.25	1.64	2.16	1.31	1.71	2.24
0.6	1.29	1.69	2.22	1.36	1.78	2.32
0.8	1.32	1.73	2.26	1.39	1.82	2.37
1.0	1.34	1.75	2.29	1.42	1.84	2.41
1.2	1.35	1.77	2.31	1.43	1.87	2.43
1.4	1.37	1.78	2.33	1.45	1.88	2.45
1.6	1.37	1.79	2.34	1.46	1.90	2.47
1.8	1.38	1.80	2.35	1.47	1.91	2.48
2.0	1.39	1.81	2.37	1.48	1.92	2.50

The effect that the perimeter insulation R-value has on the relative improvement in thermal performance of the floor slab in Configuration B is shown in Figure 3.7.

The graph shows the performance improvement of Configuration B with 300 mm waffle pods and perimeter insulation 385 mm high when compared to an uninsulated floor slab.

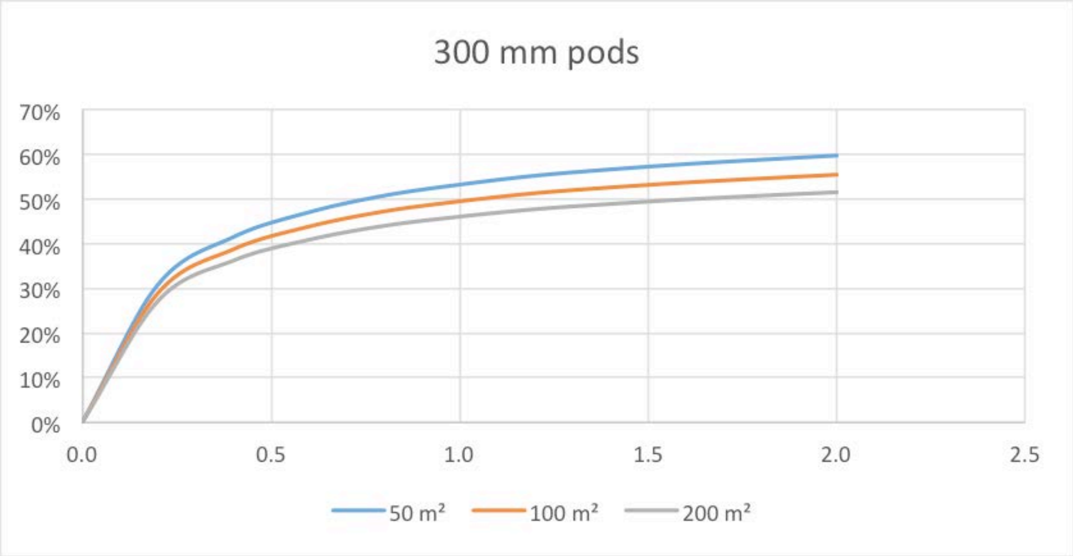

Figure 3.7 Relative effect of perimeter insulation R-value on the thermal performance of a waffle pod floor slab compared with an uninsulated slab.

The three lines represent the results for the three slab sizes that were considered in the model. Results may be interpolated for to find the R-value for waffle pod slabs with areas between these representative figures. However, a more useful parameter may be the area-perimeter ratio. Results should not be extrapolated for slabs with an area greater than 200 m^2.

3.3 Perimeter insulation height

The effect of the perimeter insulation height on the overall thermal performance of the floor slab in Configuration B is shown in Table 3.6.

As with Configuration A, the R-value of the perimeter insulation was kept constant at 1.0, which is a reasonable assumption with EPS insulation products. Perimeter insulation heights up to 1.0 m were modelled and are shown here. However, waffle pod slabs typically have shallower embedment depths and shorter floor heights, but greater soil compaction, which all limit the maximum height that perimeter insulation may be easily installed.

Table 3.6 Slab R-values for various perimeter insulation heights in Configuration B.

Perimeter insulation height (m)	Slab R-value					
	220 mm pods			300 mm pods		
	50 m² slab	100 m² slab	200 m slab	50 m² slab	100 m² slab	200 m² slab
0.0	0.91	1.22	1.63	0.92	1.23	1.65
0.305	1.34	1.75	2.29	1.34	1.75	2.30
0.385	1.41	1.83	2.39	1.42	1.84	2.41
0.6	1.51	1.96	2.54	1.53	1.98	2.57
0.8	1.56	2.02	2.62	1.58	2.05	2.65
1.0	1.60	2.06	2.67	1.62	2.09	2.71

Figure 3.8 shows the effect that perimeter insulation height has on the relative improvement in thermal performance of the waffle pod floor slab in Configuration B.

The graph shows the performance improvement of the configuration with 300 mm waffle pods and perimeter insulation with an R-value of 1.0 when compared with an uninsulated slab of the same type (no perimeter or under-slab insulation). Three floor slab sizes are shown.

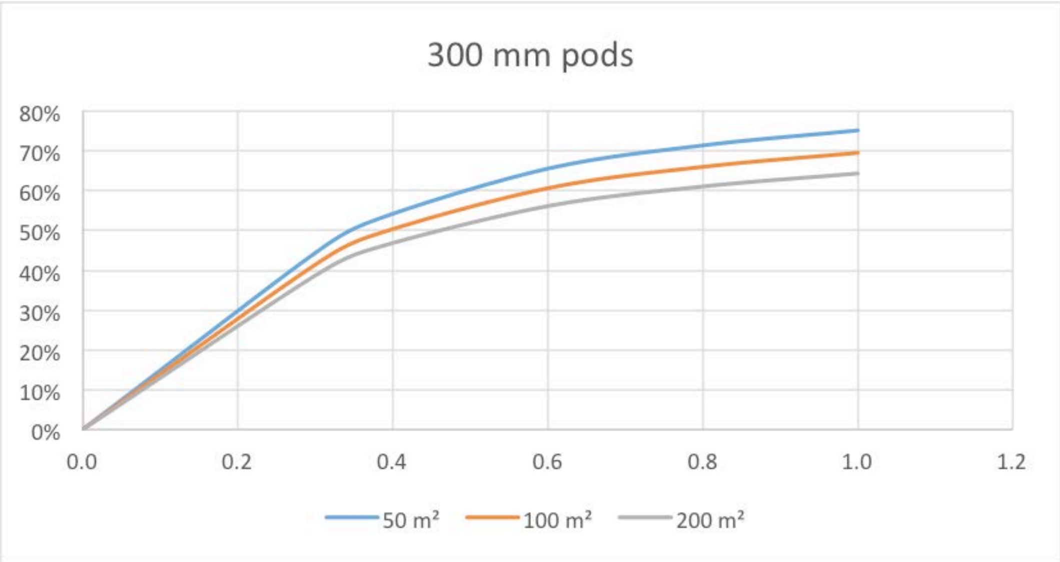

Figure 3.8 Relative effect of perimeter insulation height on the thermal performance of a waffle pod floor slab when compared with an uninsulated slab.

3.3.1 Perimeter insulation top gap

The effect of the perimeter insulation top gap size on the overall thermal performance of the floor slab in Configuration B is shown in Table 3.7. Again, the R-value of the perimeter insulation was maintained at a constant 1.0.

Table 3.7 Slab R-values for various perimeter insulation top gap sizes in Configuration B.

Perimeter insulation top gap (m)	Slab R-value					
	220 mm pods			300 mm pods		
	50 m^2 slab	100 m^2 slab	200 m^2 slab	50 m^2 slab	100 m^2 slab	200 m^2 slab
0	1.34	1.75	2.29	1.42	1.84	2.41
0.02	1.25	1.64	2.15	1.30	1.71	2.24
0.04	1.18	1.56	2.06	1.23	1.62	2.13
0.06	1.14	1.50	1.98	1.17	1.55	2.05
0.08	1.10	1.45	1.93	1.13	1.50	1.98
0.1	1.06	1.41	1.87	1.09	1.45	1.92

Figure 3.9 shows the effect that the size of the perimeter insulation top gap has on the relative improvement in thermal performance of the waffle pod floor slab in Configuration B.

The graph shows the performance improvement of the configuration with 300 mm waffle pods and perimeter insulation with an R-value of 1.0 when compared to an uninsulated floor slab (no perimeter or under-slab insulation). Three floor slab sizes are shown.

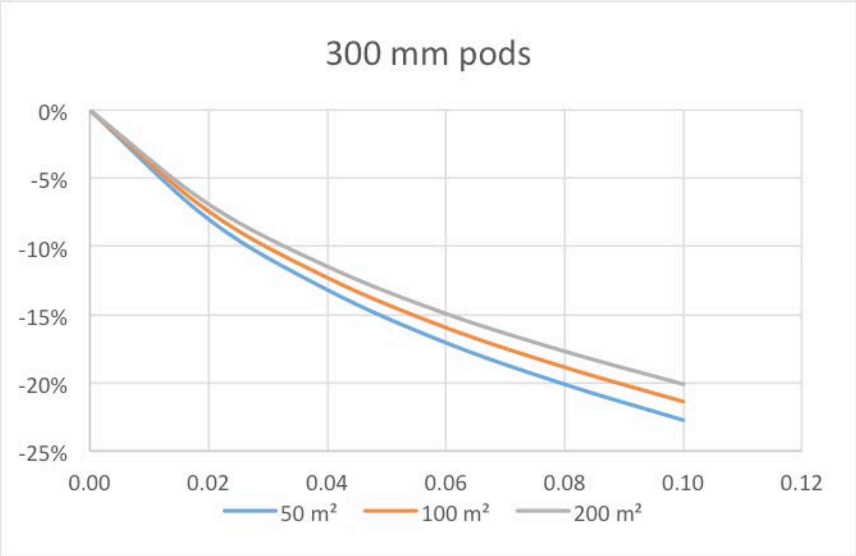

Figure 3.9 Relative effect of the size of the perimeter insulation top gap on the performance of a waffle pod floor slab compared with an uninsulated slab in Configuration B.

As per the results for Configuration A, this graph shows the net reduction in the performance improvement and should be interpreted in the same way.

3.3.2 Area-perimeter ratio

The effect that the geometry of the slab (area-perimeter ratio) has on the overall thermal performance of the waffle pod floor slab in Configuration B is shown in Table 3.8 and Figure 3.10.

Slab R-values are given for four slab and perimeter insulation scenarios.

Table 3.8 Slab R-values for various slab area-perimeter ratios and insulation scenarios in Configuration B.

Floor slab construction	**Area-perimeter ratio**					
	1.5	**2.0**	**2.5**	**3.0**	**3.5**	**4.0**
	Slab R-value					
220 mm pods, no perimeter insulation	0.80	1.02	1.22	1.41	1.61	1.81
220 mm pods, R1.0 perimeter insulation 305 mm high	1.23	1.49	1.75	2.01	2.27	2.53
300 mm pods, no perimeter insulation	0.81	1.04	1.23	1.43	1.63	1.84
300 mm pods, R1.0 perimeter insulation 385 mm high	1.30	1.58	1.84	2.11	2.39	2.67

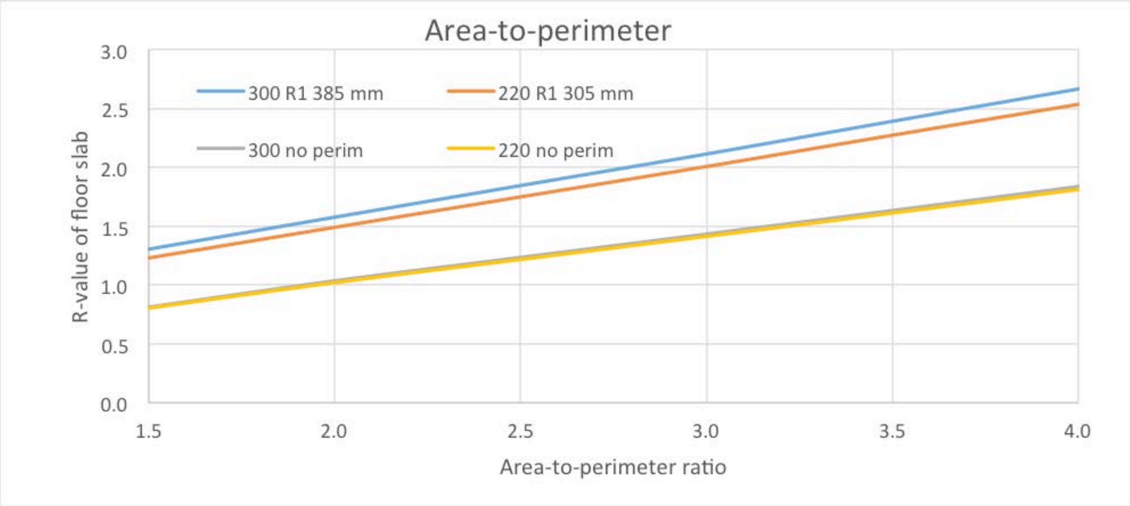

Figure 3.10 Relationship between area-perimeter ratio and slab R-value for different waffle pod sizes and perimeter insulation heights in Configuration B.

3.4 Configuration C: Waffle pod foundation with heavy cladding

The following sections present the findings for the design variables in Configuration C.

3.4.1 Perimeter insulation R-value

The effect that the perimeter insulation R-value has on the overall thermal performance of the waffle pod and brick veneer combination in Configuration C is shown in Table 3.9.

For simplicity, the results were derived by modelling the system with 220 mm waffle pods and perimeter insulation 205 mm high, and 300 mm waffle pods with perimeter insulation 285 mm high. No perimeter insulation top gap or under-slab insulation was present in both cases.

Table 3.9 Slab R-values for various perimeter insulation R-values in Configuration C.

Perimeter insulation R-value	Slab R-value					
	220 mm pods			300 mm pods		
	50 m^2 slab	100 m^2 slab	200 m^2 slab	50 m^2 slab	100 m^2 slab	200 m^2 slab
0.0	1.08	1.44	1.92	1.09	1.46	1.95
0.2	1.17	1.56	2.07	1.20	1.60	2.13
0.4	1.19	1.58	2.10	1.22	1.63	2.17
0.6	1.19	1.59	2.12	1.24	1.65	2.19
0.8	1.20	1.60	2.13	1.24	1.66	2.20
1.0	1.21	1.60	2.13	1.25	1.66	2.21
1.2	1.21	1.61	2.14	1.25	1.67	2.22
1.4	1.21	1.61	2.15	1.26	1.67	2.22
1.6	1.21	1.62	2.15	1.26	1.68	2.23
1.8	1.22	1.62	2.15	1.26	1.68	2.23
2.0	1.22	1.62	2.16	1.26	1.68	2.24

Figure 3.11 and Figure 3.12 show the effect that the perimeter insulation R-value has on the relative improvement in thermal performance of the floor slab in Configuration C.

The first graph, Figure 3.11, shows the performance improvement of the configuration with 300 mm waffle pods and perimeter insulation 285 mm high when compared to an uninsulated floor slab (no perimeter or under-slab insulation). The second graph, Figure 3.12, shows the same configuration with the addition of under-slab insulation with an R-value of 1.0 when compared to an uninsulated floor slab (no perimeter or under-slab insulation).

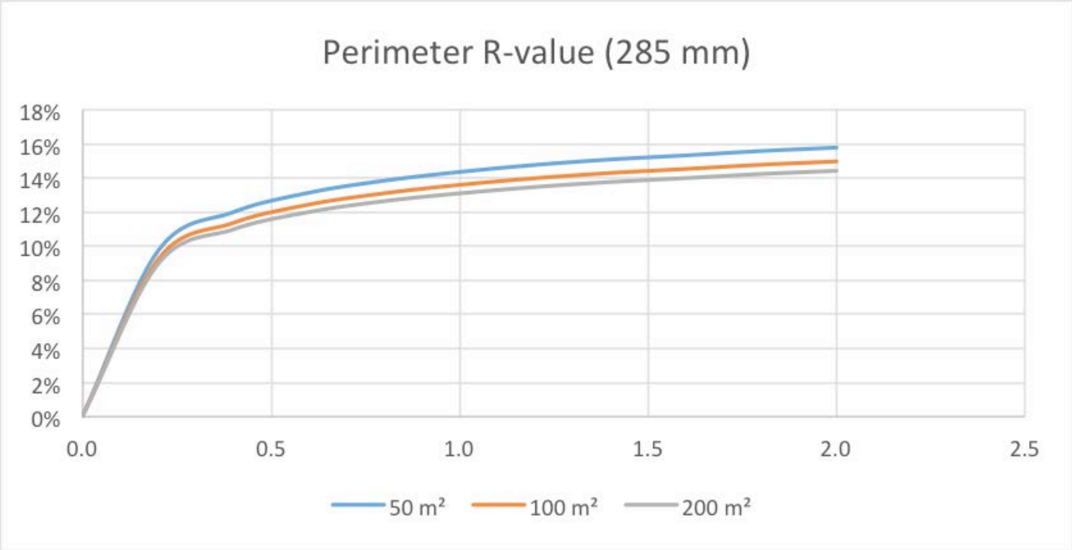

Figure 3.11 Relative effect of perimeter insulation R-value on the thermal performance of a waffle pod slab and brick veneer cladding compared with an uninsulated slab.

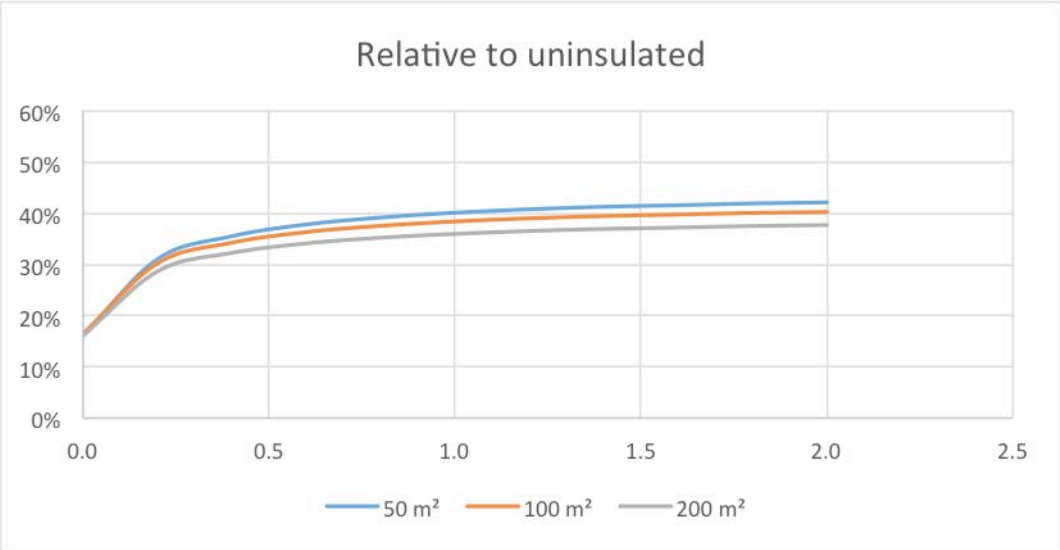

Figure 3.12 Relative effect of perimeter insulation R-value on the thermal performance of a waffle pod slab with under-slab insulation and brick veneer cladding compared with an uninsulated slab.

3.4.2 Perimeter insulation height

The effect of the perimeter insulation height on the overall thermal performance of the floor slab in Configuration C is shown in Table 3.10.

As with Configurations A and B, the perimeter insulation R-value was kept constant at 1.0. Perimeter insulation heights up to 1.0 m were modelled and are shown here. However, a waffle pod slab and brick veneer cladding are likely to limit the maximum height at which perimeter insulation may be easily installed.

Table 3.10 Slab R-values for various perimeter insulation heights in Configuration C.

Perimeter insulation height (m)	Slab R-value					
	220 mm pods			300 mm pods		
	50 m² slab	100 m² slab	200 m² slab	50 m² slab	100 m² slab	200 m² slab
0.0	1.08	1.44	1.92	1.09	1.46	1.95
0.205	1.21	1.60	2.13	1.22	1.63	2.16
0.285	1.23	1.64	2.17	1.25	1.66	2.21
0.4	1.26	1.67	2.21	1.28	1.70	2.25
0.6	1.28	1.70	2.26	1.31	1.74	2.30
0.8	1.30	1.73	2.29	1.33	1.76	2.33
1.0	1.32	1.75	2.32	1.34	1.78	2.36

Figure 3.13 shows the effect that perimeter insulation height has on the relative improvement in thermal performance of the waffle pod floor slab in Configuration C.

The graph shows the performance improvement of the configuration with 300 mm waffle pods and perimeter insulation with an R-value of 1.0 when compared with an uninsulated slab of the same type (no perimeter or under-slab insulation). Three floor slab areas are shown.

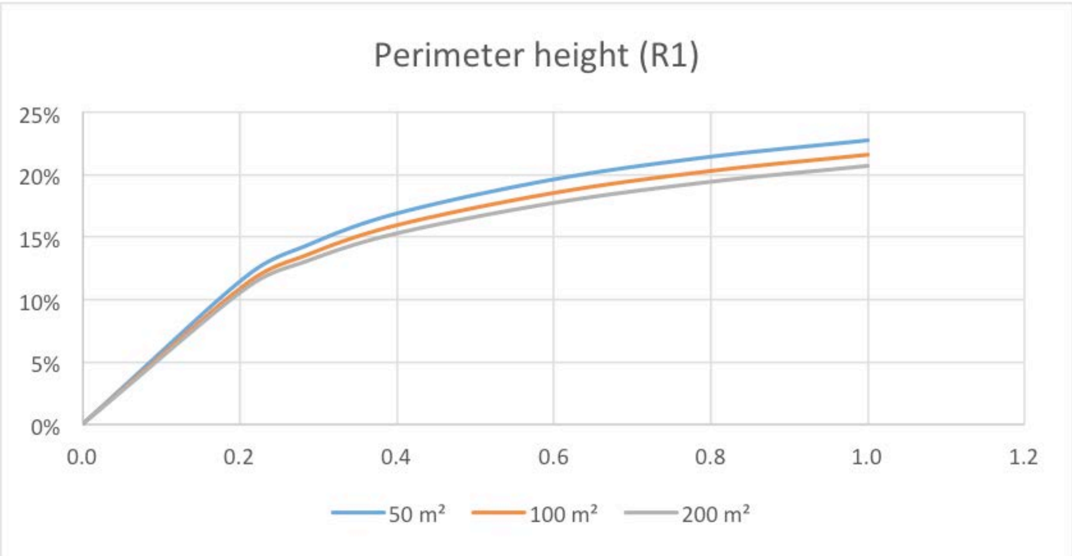

Figure 3.13 Relative effect of perimeter insulation height on the thermal performance of a waffle pod floor slab and brick veneer cladding when compared with an uninsulated slab.

Due to the step-down of the brick veneer cladding, Configuration C does not require a perimeter insulation top gap.

3.4.3 Area-perimeter ratio

The effect that the geometry of the slab (area-perimeter ratio) has on the overall thermal performance of the waffle pod floor slab in Configuration C is shown in Table 3.11 and Figure 3.14.

Slab R-values are given for four slab and perimeter insulation scenarios.

Table 3.11 Slab R-values for various slab area-perimeter ratios and insulation scenarios in Configuration C.

Floor slab construction	Area-perimeter ratio					
	1.5	2.0	2.5	3.0	3.5	4.0
	Slab R-value					
220 mm pods, no perimeter insulation	0.97	1.21	1.44	1.67	1.91	2.14
220 mm pods, R1.0 perimeter insulation 205 mm high	1.10	1.35	1.60	1.86	2.12	2.37
300 mm pods, no perimeter insulation	0.99	1.23	1.46	1.70	1.94	2.17
300 mm pods, R1.0 perimeter insulation 285 mm high	1.14	1.40	1.66	1.92	2.20	2.45

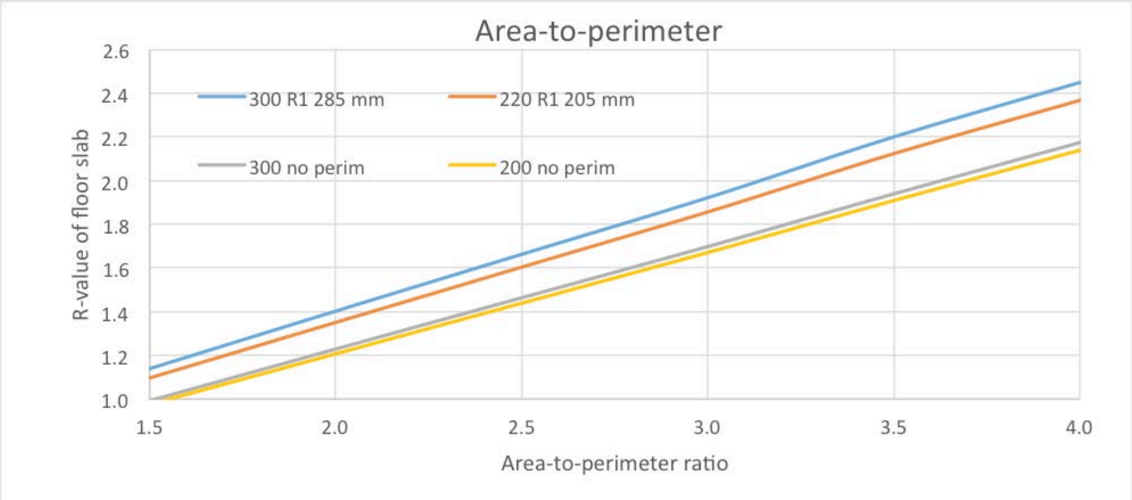

Figure 3.14 Relationship between area-perimeter ratio and slab R-value for different waffle pod sizes and perimeter insulation heights in Configuration C.

4. Analysis

In Configuration A, it can be seen from Figure 3.1 that most of the thermal performance improvement can be achieved with a perimeter insulation R-value of less than 1.0. Even an R-value of 0.8, which is achievable with only 25 mm of XPS, still provides a reasonable thermal performance improvement. Increasing the R-value above 1.0 yields only relatively minor improvements.

Likewise, increasing the height of the perimeter insulation above 600 mm yields smaller performance benefits, as seen from Figure 3.3.

The improvement becomes even more significant when perimeter insulation is combined with under-slab insulation. Figure 3.2 shows that with an under-slab insulation with an R-value of 1.2, increasing the R-value of the perimeter insulation as high as 2.0 takes the performance increases to over 100% – that means the overall R-value of the slab more than doubles.

The smaller thermal performance improvement in Figure 3.7 shows that Configuration B has lower thermal conductivity along the perimeter. There is marginally less heat flow to the perimeter because of the air gap in a waffle slab foundation, but comparing the perimeter conductivity with the soil conductivity shows that the overall thermal performance is similar to a plain floor slab such as in Configuration A.

The step-down in Configuration C, which is necessary to accommodate the brick veneer, reduces the available perimeter height for insulation and therefore reduces the thermal performance improvement. Figure 3.11 shows that even adding perimeter insulation with an R-value of 2.0 only yields a 15% performance increase, a fraction of the increases seen with Configuration A and B. This is because the brick veneer system, which consists of an air gap and the bricks themselves, also provides little insulation to the slab perimeter behind the step-down.

However, Figure 3.12 also shows that a significant additional performance improvement can be achieved with Configuration C by combining perimeter insulation with under-slab insulation. While the results modelled a sheet of under-slab insulation with an R-value of around 1.2, insulating the ribs and external beams of the waffle pod system would yield similar improvements.

While these thermal performance gains may seem relatively small, the heat loss caused by the lack of perimeter insulation occurs 24/7 for several months of the year. They must also be integrated over the entire perimeter of the slab, which may be 70 m or more for a typical floor slab.

In the Christchurch case study, the average heat losses equated to approximately 5.7 W/m for the uninsulated sections of the slab perimeter. This figure dropped to 2.2 W/m where the slab had perimeter insulation installed. Integrating the difference of 3.5 W/m over the 70 m perimeter length gives an estimated heat loss of 245 W. When integrated over the 3,660 hours of the data, this gives an accumulated difference in heat loss of approximately 900 kWh for the 5-month winter period.

5. Conclusions

Overall, the research demonstrated that perimeter insulation can provide significant gains in energy efficiency, depending on the type of construction and configuration of the floor slab. For artificially-heated slabs, energy savings of 15% or more were achievable in most cases. These thermal performance improvements can be factored by a further 100% or more with the addition of under-slab insulation for the construction configurations considered in this report.

The option to add exterior perimeter edge insulation to floor slabs is particularly pertinent for the rebuild of Christchurch. These floor slabs may contain more concrete and steel, and the ground underneath the slabs is compacted to a higher density, which increases potential heat loss from the slab.

Appendix A: Insulating floor slabs in North America

A.1 Insulation protection

InsulGuard protection sheet for insulation. Made from GRP and in roll form. Either 300, 400 or 600 mm wide. Peel and stick with optional textured coating.
http://www.weatherblocsystems.com/resources/Product-Information-Sheets/WB-InsulGuard-Lit-b.pdf

Foundation Shield. Similar to InsulGuard.
http://www.creativepanelsolutions.com/Pages/FRPPanels.aspx

Nudo GroundBreaker. Similar to InsulGuard. US$5/m for 300 mm. US$10/m for 600 mm.
http://www.nudo.com/p_groundbreaker.php

A.2 Insulated panels

Stucco finished XPS panels. Styro Industries FP Ultra Lite. Available 25, 50 or 75 mm thick and 300 or 600 wide. 25 mm x 300 mm, US$6.25/m. 600 mm, US$12.50/m. Fasteners or glue. Designed as DIY retrofit.
http://styro.net/FoundationInsulationPanel.htm

Strongwell building panels. Durashield, 25 mm thick x 300 mm or 75 mm x 600 mm. Lengths up to 8 m. US$49/m for 25 mm. Approximately R0.7.
http://www.strongwell.com/products/structural-building-panels/

Scudotherm insulation. Strips of rigid foam (EPS, XPS and PUR) laminated to an elastoplastomeric bituminous membrane with glass fibre or non-woven polyester reinforcement. Roll form. Insulation 30, 40, or 50 mm. 330 mm wide. Not specifically for floor slabs but slab is listed as one of its possible applications.
http://www.italianamembrane.com/prodotti/isolanti_termici/scudotherm/

A.3 Insulated formwork

Formsulate Project. Insulated formwork system.
http://www.osti.gov/scitech/servlets/purl/973557

Insulated formwork system consisting of PVC boxing and R1.8 insulation. 200 mm high x 3 m. US$55. Can also be retrofitted.
http://www.eeform.com/

Appendix B: Insulating floor slabs in Australia

Updated AS 3999:2015 *Bulk thermal insulation – Installation* contains a diagram showing a slab floor with brick veneer, with insulation behind the bottom two courses of bricks and wrapped fully around the footing and extending under the slab. A water barrier membrane is between the insulation and the concrete of the slab and a vapour barrier membrane is between the ground and the insulation. The top of the insulation in front of the footing is just below ground level and the vertical sheet of insulation is shown to have a ‘protective layer’ but material is not specified. The vapour barrier extends up between the protection layer and the insulation. A second brick veneer example has the insulation behind the bricks and in front of the footing. The insulation does not extend under and behind the footing as in the first example. But as per that example, a vapour barrier is shown between the soil and the concrete and between the protection layer and the vertical sheet of perimeter insulation. There is no water barrier in this case.

For the waffle raft with brick veneer example the extra insulation layer is continuous under the waffle pods and the concrete ribs between them, and extends around the footing. The footing is extended down below the bottom of the waffle pods. There is a note that a vapour barrier may be needed between the insulation and the soil. There is no protection layer shown for the vertical perimeter section of the insulation.

For the lightweight-clad, timber-framed construction examples only slab edge insulation is shown. This is in combination with a protective layer for the insulation and a vapour barrier between both the insulation and the protective layer and between the concrete and soil.

The insulation is required to be water resistant rigid board insulation of sufficient compressive strength. Maintaining durability and performance of any externally-applied insulation should be resolved in the design.

Where it can be shown that the thermal performance of the bulk insulation is virtually unaffected by water, the water barrier may be omitted and the vapour barrier installed above the insulation rather than below it.

Appendix C: EPS vs XPS insulation

Based on a Canadian study that looked at the long-term performance of EPS in ground contact, the manufacturers of EPS in North America and Canada started claiming that it was just as suitable for ground use as XPS. Later industry-sponsored research went further and, based on evidence of in-service failures with roof decks, claimed that XPS did not perform in practice the same as it did in laboratory tests and therefore EPS was in fact superior. The XPS industry has countered that with research of their own. It is interesting to note that the emphasis from the XPS industry has shifted from low moisture uptake, as happens with the laboratory immersion and moist air testing regimes, to the moisture vapour diffusion properties of XPS.

The examples of XPS failure appear to be mostly related to complicated roof deck situations and use in conjunction with less than perfect waterproof membranes. The weight of evidence is in favour of XPS being significantly more resistant to moisture uptake in ground contact when there is no deliberate provision for drainage around and under the insulation.

The traditional method of installing EPS perimeter insulation was in conjunction with drainage material backfill, polyethylene to protect the foam and a drain below the insulation. With XPS, only the polyethylene membrane is used.

Both EPS and XPS have evolved with time. Blowing agents have changed and in the case of EPS the blowing agents are in the process of changing again. XPS in North America and Canada is now made without ozone-depleting blowing agents but this is not the case elsewhere. Some of the XPS products being imported into New Zealand appear to be made from slicing down of bulk stock rather than extruding at thickness with skins. The skins on XPS sheets slow down the ageing and are a major contributor to moisture properties. BRANZ has tested an XPS product with a thermal conductivity of 0.036 W/mK. In contrast, the carbon-infused EPS can have a conductivity significantly lower than that value. Much of the EPS manufactured in New Zealand includes recycled content and the texture can sometimes be more porous.

It is important to allow moisture to diffuse out of the foam, so is not a good idea to try to fully encapsulate it in a waterproof protection. It is better to allow moisture diffusion out into the soil. During winter any moisture in the wall footing will be driven outward into the perimeter insulation so is best to use a vapour-permeable protection for the outside of the insulation. If that is not possible then the foam should extend below ground, only leaving the above-ground component with the moisture-impermeable protection layer. In general, the footing should not have a very high moisture content so the main risk is in the retrofit situation if water is transported up between the insulation and the concrete by capillary. A capillary break such as a butyl strip may be need at the bottom edge of the insulation.