GROUND SLAB INSULATION GUIDE

1. Introduction

In providing thermal comfort to its occupants, and minimising external energy inputs to do so, the sheltering envelope of homes in most climates across the world needs to have good resistance to unwanted inward and outward heat flow. Insulation of floors, external walls, windows, roofs and ceilings is obviously crucial in this regard. Over the past fifty years or so, homes across Australia have had their external walls, windows, roofs and ceilings insulated to progressively higher standards. And since 2006 these standards have been mandated by code. However, the uptake of floor insulation, most suited to homes in cooler climates, has been comparatively slow. This is particularly so for insulation of on-ground concrete slabs, due to its perceived cost and technical complexity.

On the Mullum Creek estate at Donvale VIC, earth temperatures (both under and beside on-ground slabs) will be well below the comfortable internal temperature range through the cooler months, when most of the energy consumed to maintain thermal comfort in the home will be directed to space heating. Conductive heat loss to the earth through an uninsulated on-ground floor slab will therefore account for a significant portion of the home's annual space heating load.

Whilst Section 3.12 of the NCC 2016 Building Code of Australia Volume 2 sets deemed-to-comply standards for floor insulation, its only requirement for an on-ground concrete slab is min. R1.0 (extruded polystyrene board or similar) insulation fitted around the vertical edge of the slab perimeter. And this only applies where an in-slab or in-screed heating or cooling system is installed. As an alternative to deemed-to-comply standards, whole-of-house energy modelling to a benchmark star rating under the National Home Energy Rating Scheme (NatHERS) has become the preferred approach for assessing the thermal performance of homes in Australia.

In achieving a 6.0 star energy rating for a Melbourne home, it is possible to offset significant winter heat loss to the earth from an uninsulated on-ground concrete floor slab, by applying high levels of insulation to all other elements of the building envelope (external walls, windows, roofs and ceilings).

A further rise to a 7.0 star benchmark energy rating under the BCA is now imminent. With this and its overarching environmental vision in mind, Mullum Creek has set a benchmark of 7.5 stars for homes built on the estate. Table 1 shows how in Donvale's climate zone, a 7.5 star energy rating sees a home consume around 75 MJ of energy per square metre floor area per year in active heating and cooling, to provide a set measure of thermal comfort as determined by the National Home Energy Rating Scheme (NatHERS). This equates to a 40% saving on the energy required to heat and cool a home with 6.0 star energy rating as currently mandated under the BCA (see Table 1 on page 2).

Star Rating	1	2	3	4	5	6	7	7.5	8	9	10
MJ/m^2/annum *	615	426	301	220	165	125	91	75	58	27	1

Table 1. Area-adjusted upper limits to energy consumption for space heating and cooling assigned to various energy star ratings (Donvale Victoria - Climate Zone 62)

* These energy requirements have been calculated using a standard set of occupant behaviours and so do not necessarily represent the usage pattern or lifestyle of the intended occupants. They are used solely for the purposes of rating the building, and do not infer actual energy consumption or running costs. Settings for occupant behaviours used in the simulation are shown in the detailed thermal performance report.

A home at Mullum Creek cannot achieve a 7.5 star energy rating without substantial floor insulation, unless all other elements of the building envelope (external walls, windows, roofs and ceilings) are insulated and sealed to a very high standard, AND MOST CRUCIALLY the architectural design is otherwise exemplary in its thermal performance.

Mullum Creek's Design Guidelines (Section 6.2) and its Design Review Committee (DRC) Step 1 Preliminary Design Review Checklist outline 12 principles which need to be fairly comprehensively satisfied in a dwelling design solution if it is to achieve a 7.5 star home energy rating, and certainly if substantial floor insulation is to be avoided. These principles are as follows:

1. *Orient your home and its layout to maximise northern exposure for living areas.*
2. *Use thermally efficient windows and external doors (frame and glass systems).*
3. *Be frugal with glass area (have it not exceed 20% of floor area where possible) and/or use thermally efficient doors and windows with particularly high thermal efficiency (Uw < 2.5 and SHGC > 0.5) as listed in the Window Energy Rating Scheme (WERS) database http://www.wers.net/werscontent/certified-products-residential.*
4. *Have a more generous expanse of glazing facing solar north (or within 15 degrees thereof) that has clear exposure to low winter sun, but only if the dwelling also has a good amount of internally accessible thermal mass.*
5. *Provide comprehensive and effective external sun shading of all glazing from summer sun.*
6. *Have a reasonably compact plan form, to reduce the building's external surface area to floor area ratio, and hence also reduce unwanted conductive summer heat gains and winter heat losses.*
7. *Incorporate doors, screens and flexible walls (such as large sliding panels) to separate air compartments within otherwise open living zones, thereby allowing more effective containment of mechanically heated and cooled air.*
8. *Ensure that location, size and detailing of door and window openings provide broad and easy pathways for cross (horizontal) and stack (vertical) ventilation through the dwelling interior.*
9. *Use materials with high thermal mass (heat storage capacity and surface conductance i.e. ability to absorb and release heat) and broad surface area in direct contact with interior air.*
10. *Provide substantial insulation for floors, walls, roofs and ceilings.*
11. *Avoid recessed light fittings that require substantial gaps or cut-outs in ceiling insulation.*
12. *Provide airlocks to the home's most regularly accessed entries and exits.*

Nine of these twelve principles (as noted in green text above) need to be satisfied at the early architectural design stage. However, the DRC is finding that they are not well addressed in most schematic designs submitted thus far for Step 1 Preliminary Design Review. This then leaves our nominated energy assessor Alex Rentsch the difficult task of raising the energy efficiency or star rating of a design from what is often a quite poor base towards 7.5 star performance. To do this without disturbing the architectural intent or construction approach, they need to focus on the three remaining principles (noted in blue text above), so those that relate solely to improving the thermal resistance (or insulation) of the building envelope. The energy assessors find themselves needing to specify windows of very high thermal efficiency (with specialised glazing and framing) and matching price tags. And commonly they also they also need to include substantial and potentially expensive insulation for on-ground concrete floor slabs.

2. Options for continuous insulation of on-ground concrete floor slabs

Many homes at Mullum Creek have approx. R2.0 (40-60 thick) extruded polystyrene (XPS) insulation board specified for on-ground concrete floor slabs. The intention, as assumed by the energy rating software AccuRate, is that it be laid continuously under the slab as well as around the base and all sides of edge and internal stiffening beams (see *Insulated Slab - NatHERS assumption - unbuildable solution* in Table 2 below). As such, AccuRate models continuous R2.0 under-slab insulation as improving the home's star rating by a substantial 0.3 and 0.8 stars. Conversely, removing this floor insulation from a 7.5 star home will increase total annual energy consumption in active heating and cooling by between maybe 9% and 26%.

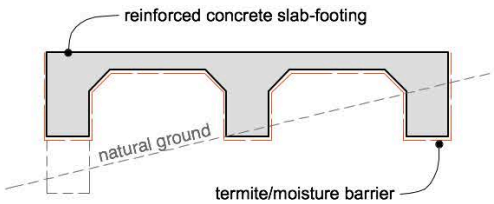
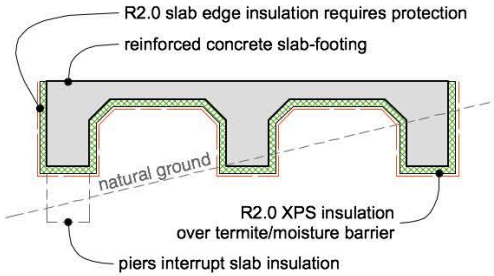
Description	Sketch	slab perimeter/area ratio	overall R-value of slab as constructed	approximate cost of slab insulation #	Comments
UNINSULATED SLAB Structural integral slab-footing.		0.25	1.8 - 2.2	nil	
		0.40	1.2 - 1.5	nil	
		0.55	1.0 - 1.2	nil	
INSULATED SLAB **- NatHERS assumption** **- Unbuildable solution** Structural integral slab-footing With continuous XPS insulation board to underside and perimeter.		0.25	3.9 - 4.4 *	$85/m2	**Advantages:** All the concrete is internal to the insulating skin, so contributes fully to the thermal inertia of the building. **Disadvantages:** Unreasonable difficulty in slab preparation, so very expensive to build. Requires special edge detailing to protect and conceal perimeter insulation. Compressible XPS insulation will probably need to be removed where slab-footing bears on bored or backhoe piers as required (your structural engineer can advise on this). Piers will then act as uninsulated thermal bridges between slab and earth below, compromising the thermal resistance of the floor slab. Piers are inevitable on sites with slope and/or fill as common at Mullum Creek.
		0.40	2.9 - 3.3 *	$95/m2	
		0.55	2.5 - 2.9 *	$105/m2	

Table 2. Unbuildable solution assumed by NatHERS for continuous insulation of on-ground concrete floor slabs.

* These overall R-values of slabs as constructed do not allow for thermal bridging caused by discontinuities in compressible extruded polystyrene (XPS) insulation, as may be necessary where the slab underside bears on concrete piers required to provide load transfer down to stable and consistent foundations. Unfortunately, current energy rating software under NatHERS (including AccuRate) is unable to simulate this significant thermal bridging effect.

Approximate cost (excluding builder's margin and GST) for supply and installation of XPS insulation per square metre slab floor area, allowing also for protection and concealment of perimeter insulation where applicable.

However, a decision to install continuous insulation in this way adds an extremely difficult and expensive dimension to the task of on-ground slab preparation, and as such it is very rarely seen in Australian residential building practice. How can an on-ground concrete floor slab be designed for a comparable insulation outcome but at a more affordable cost in construction?

Five alternative options follow which we offer to you for proofing and development.

Since this Guide was first published, Alternative 1 has been fully engineered and constructed for two homes at Mullum Creek. The first structural consulting firm to do so was Fenton Partners Pty Ltd (contact Rob Fenton on 03 9898 2200 or rob.fenton@fentonpartners.com.au). Several other dwelling designs for Mullum Creek have now also adopted Alternatives 1, 2 and 3. Early feedback from participating builders has been very positive (see photos on page 7). If your preliminary thermal performance report indicates that on-ground concrete floor slabs to your home will need to be insulated, please discuss these alternatives with your architect and engineer for consideration early in the design process.

A few homes at Mullum Creek have had their integral slab-footings insulated continuously with R2.0 XPS insulation, so as per the Default Solution shown on page 3 of this Guide. The builders installed this XPS board with extraordinary care and patience. Whilst fully effective in providing thermal resistance to the slab, under commercial sub-contract it proved extremely time consuming and prohibitively expensive. Also, despite being well taped in place, the XPS board was difficult to hold in place during the concrete pour.

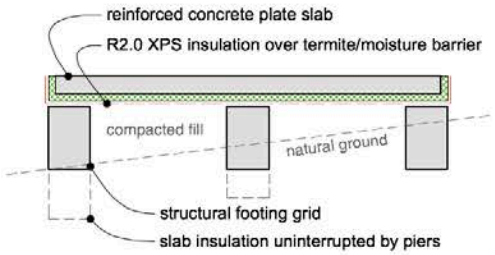
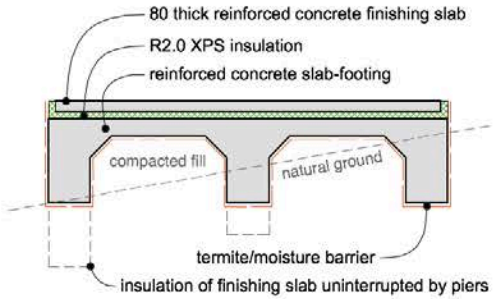
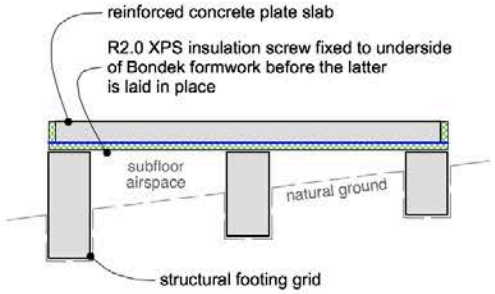
Description	Sketch	slab perimeter/area ratio	overall R-value of slab as constructed	approximate cost of slab insulation #	Comments
ALTERNATIVE 1 Structural flat plate slab Over continuous XPS insulation board Over structural footing grid with compacted fill between		0.25	4.0 - 4.5	$40/m2	**Advantages:** Relatively easy to construct. Footing grid is external to the insulating skin, so piers as required will not compromise thermal performance. Concealed concrete to footing grid can include 100% SCM. **Disadvantages:** Insulating skin may need to be interrupted by insertions of other thermal break material with high compressive strength where major linear or point loads bear on plate slab. Your structural engineer can advise on this.
		0.40	3.9 - 4.4	$43/m2	
		0.55	3.8 - 4.3	$46/m2	
ALTERNATIVE 2 Reinforced finishing slab (with or without hydronic heating/cooling installed) Over continuous XPS insulation board Over structural integral slab-footing		0.25	4.0 - 4.5	$40/m2	**Advantages:** Relatively easy to construct. Structural slab is below and external to the insulating skin, so piers as required will not compromise thermal performance. Concrete to structural slab can include 100% SCM. **Disadvantages:** Whilst common for floor slabs to industrial cold storage buildings, and for residential slabs-on-ground in cold European climates, this requires a lot of extra concrete. Structural slab is below and external to the insulating skin, so only the finishing slab will contribute to the thermal inertia of the building. Insulating skin may need to be interrupted by insertions of other thermal break material with high compressive strength where major linear or point loads bear on plate slab. Your structural engineer can advise on this.
		0.40	3.9 - 4.4	$43/m2	
		0.55	3.8 - 4.3	$46/m2	
ALTERNATIVE 3 Structural plate slab on Bondek steel tray formwork Over continuous XPS insulation board Bondek spans across structural footing grid		0.25	4.0 - 4.5	$45/m2	**Advantages:** Relatively easy to construct. Footing grid is external to the insulating skin, so piers as may be required will not compromise thermal performance. Concealed concrete to footing grid can include 100% SCM. **Disadvantages:** Insulating skin may need to be interrupted by insertions of other thermal break material with high compressive strength where major linear or point loads bear on plate slab. Your structural engineer can advise on this.
		0.40	3.9 - 4.4	$48/m2	
		0.55	3.8 - 4.3	$51/m2	

Table 3a. Alternative solutions 1, 2 and 3 for continuous insulation of on-ground concrete floor slabs.

Approximate cost (excluding builder's margin and GST) for supply and installation of XPS insulation per square metre slab floor area.

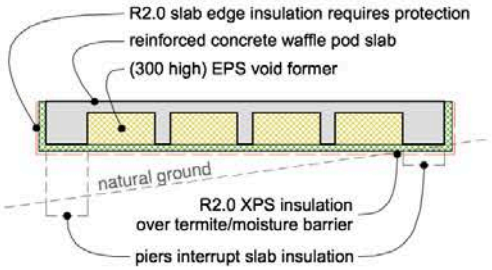
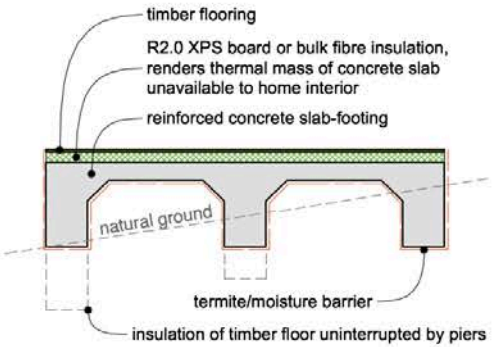
Description	Sketch	slab perimeter/area ratio	overall R-value of slab as constructed	approximate cost of slab insulation #	Comments
ALTERNATIVE 4 Structural waffle pod slab Over polystyrene void formers With continuous XPS insulation board to underside and perimeter of slab		0.25	4.4 - 4.8 *	$60/m2	**Advantages:** Easy to construct on flat sites. Requires the least concrete and reinforcement. Void formers provide extra insulation. All the concrete is internal to the insulating skin, so contributes fully to the thermal inertia of the building. **Disadvantages:** Structural engineers often prefer to avoid waffle pod slabs on sites with slope, fill and/or reactive soils. Requires special edge detailing to protect and conceal perimeter insulation. Compressible XPS insulation will probably need to be removed where waffle pod slab bears on bored or backhoe piers (your structural engineer can advise on this). Piers will then act as uninsulated thermal bridges between slab and earth below, compromising the thermal resistance of the floor slab. Piers are inevitable on sites with slope and/or fill.
		0.40	3.5 - 3.8 *	$70/m2	
		0.55	3.1 - 3.4 *	$80/m2	
ALTERNATIVE 5 Timber flooring Over batten cavity with XPS board or bulk fibre insulation Over structural integral slab-footing		0.25	4.0 - 4.5	$40/m2	**Advantages:** Easy to construct. Structural slab is below and external to the insulating skin, so piers as required will not compromise thermal performance. Concrete to structural slab can include 100% SCM. **Disadvantages:** Structural slab is below and external to the insulating skin. So this option offers virtually no thermal inertia (mass) to the building.
		0.40	3.1 - 3.5	$43/m2	
		0.55	2.8 - 3.2	$46/m2	

Table 3b. Alternative solutions 4 and 5 for continuous insulation of on-ground concrete floor slabs.

* These overall R-values do not account for the heat sinking effect of concrete piers where they are included to support a slab-footing from below. Submitted in 2016 for DRC Step 3 Construction Documentation Review was an engineer's drawing of a waffle pod slab with a 0.35 perimeter/area ratio. Were this slab to have its underside continuously insulated with extruded polystyrene (XPS) board, that compressible insulation would probably need to be discontinued where bored and backhoe piers are required to provide point load transfer to stable and consistent foundations, amounting to approximately 15% of the slab's underside area. This area of insulation discontinuity, which then also thermally couples pier and slab concrete, would dramatically reduce the overall R-value of the waffle pod slab to well below the values listed here. Land slope and soil geology on this lot with waffle pod slab proposed are typical for Mullum Creek, so concrete pier sub-structures to on-ground slabs will be commonplace across the estate. Unfortunately, current energy rating software under NatHERS (including AccuRate) is unable to simulate the significant thermal bridging or heat sink effect of piers. If some other moisture resistant board of higher compressive strength and still respectable thermal resistance (say > R1.0) can take the place of compressible XPS board at the head of piers, this thermal bridging could be substantially overcome. One such product is *CSR Hebel* 150 thick aerated autoclaved concrete (AAC) panel with an R-value of 1.09 and compressive strength of 3.0MPa. Beware of other specialist structural thermal breaking products that cost a lot more yet have a poorer thermal resistance and compressive strength (e.g. *Schöck Novomur* 113 thick *Thermal-Block* – R0.43 (vertical heatflow), 1.8MPa).

Approximate cost (excluding builder's margin and GST) for supply and installation of XPS insulation per square metre of slab floor area, allowing also for protection and concealment of perimeter insulation where applicable.

Photos of slabs under construction at Mullum Creek with continuous XPS insulation installed as per Alternative 1 (p.5) and to detail shown in Appendix B (p.11):

Compacting sand bed to finish flush with top of strip footing grid.

R2.0 XPS insulation board is laid over moisture barrier, over strip footing grid.

Structural flat plate slab is laid over R2.0 XPS insulation board, over moisture barrier, over concrete block subwalls, over below-ground strip footing grid.

3. Options for partial insulation of on-ground concrete floor slabs

Continuous under-slab insulation may prove too difficult or costly for your build. If so, options for partial slab insulation may be suitable.

Partial ground slab insulation comes with precedence in contemporary Australian building culture, particularly Alternative 6 (waffle pod slab) as shown in Table 4 below. However, it affords considerably less improvement to thermal resistance and energy rating than does continuous ground slab insulation. Vertical perimeter or slab edge insulation offers better incremental improvement to the overall thermal resistance of an on-ground slab than does partial under-slab insulation alone. However architectural detailing required to protect and conceal slab edge insulation can be challenging and expensive. Alternatives 1, 2, 3 and 5 avoid this expense and complexity.

If you choose partial slab insulation, you may need to achieve higher thermal resistance in other architectural elements (external walls, windows, roofs and ceilings) to make up the shortfall in slab performance.

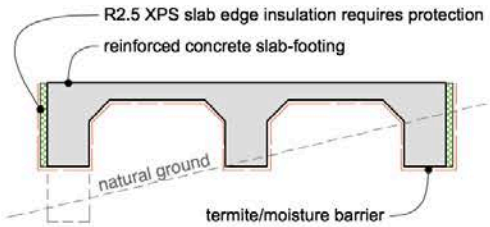
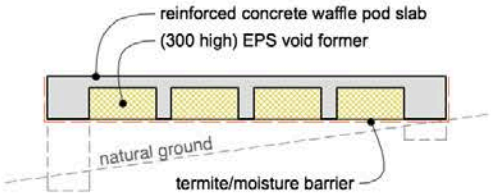
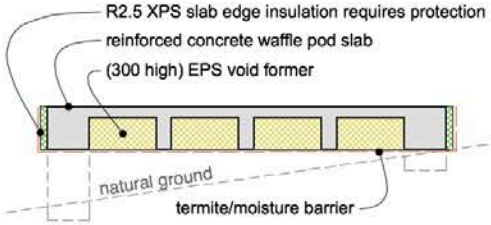
Description	Sketch	slab perimeter/area ratio	overall R-value of slab as constructed	approximate cost of slab insulation #	Comments
ALTERNATIVE 6 Structural integral slab-footing With XPS insulation board laid vertically to perimeter only		0.25	2.7 - 2.9	$25/m2	**Notes:** Whilst not as effective as continuous insulation, this alternative goes a good way to insulating against wintertime heat loss through slab. Is of greatest benefit for homes with high slab perimeter/area ratios. Requires special edge detailing to protect and conceal perimeter insulation. Current NatHERS software is quite poor at simulating the benefit of slab edge insulation. A software revision planned for release in 2019 will improve this simulation. A proprietary 75 thick R2.5 XPS slab edge insulation board with champfered top edge will soon be available in AUS. This will be suited to rendering where exposed above ground.
		0.40	1.9 - 2.1	$40/m2	
		0.55	1.5 - 1.7	$55/m2	
ALTERNATIVE 7 Structural waffle pod slab Over polystyrene void formers Without perimeter insulation		0.25	2.1 - 2.6	nil	**Notes:** Structural engineers often prefer to avoid waffle pod slabs on sites with slope, fill and/or reactive soils. Typically, where a waffle pod slab requires a sub-structure of piers for load transfer to stable foundations, some 20-30% of its concrete underside remains exposed and uninsulated. Current NatHERS software does not adequately account for this thermal weakness.
		0.40	1.5 - 1.9	nil	
		0.55	1.2 - 1.6	nil	
ALTERNATIVE 8 Structural waffle pod slab Over polystyrene void formers With XPS insulation board laid vertically to perimeter		0.25	2.9 - 3.3	$20/m2	**Notes:** Structural engineers often prefer to avoid waffle pod slabs on sites with slope, fill and/or reactive soils. Requires special edge detailing to protect and conceal perimeter insulation. Typically, where a waffle pod slab requires a sub-structure of piers for load transfer to stable foundations, some 20-30% of its concrete underside remains exposed and uninsulated. NatHERS software may not adequately account for this thermal weakness.
		0.40	2.1 - 2.4	$35/m2	
		0.55	1.8 - 2.1	$50/m2	

Table 4. Options for partial insulation of on-ground concrete floor slabs.

Approximate cost (excluding builder's margin and GST) for supply and installation of XPS insulation per square metre of slab floor area, allowing also for protection and concealment of perimeter insulation where applicable.

The R-values (overall thermal resistance as constructed) of insulated on-ground concrete slabs, as listed in Tables 2, 3a, 3b and 4, apply to the winter (downward heat flow) mode. They are informed by:
- preset values applied to NatHERS modelling.
- research articles published by BRANZ (New Zealand) building physicist Ian Cox-Smith (attached as Appendices to this Guide).
- A.B. Coldicutt's timeless reference 'Thermal Properties of Construction', University of Melbourne 1977.

R-values are listed in range only because they are dependent on soil conductivity, external wall thickness, thermal bridging attributable to slab edge detailing and quality of workmanship with installation of XPS board. Also the greater the ratio of the slab's perimeter over its floor surface area (for conditioned/habitable space), the lower the overall R-value of the slab as constructed.

4. CONCLUSION

If you are at an early stage in the process of designing your Mullum Creek home and would like to avoid having to install continuous under-slab insulation with its attendant costs and complexities, the DRC very strongly recommends you adhere to the 9 key principles of architectural design outlined in Section 1 of this Guide. However, you may have already progressed a long way towards gaining Mullum Creek and Council approvals, or are otherwise reluctant to make architectural changes to your design. And meanwhile your min. 7.5 star energy rating (as established by Floyd Energy) may rely heavily on the ***Default Solution*** of continuous under-slab insulation; the preliminary thermal performance report issued with your step-by-step design approval will clarify this under *Upgrades and Considerations*. In this case, consider ***Alternatives 1-5*** (as introduced in Section 2 of this Guide) with your architect and engineer.

Improvement to energy ratings afforded by continuous under-slab insulation has shown to be considerable (at between 0.3 and 1.8 stars) for dwelling designs submitted thus far to the Mullum Creek DRC for preliminary energy assessment. From AccuRate modelling of Mullum Creek homes, the improvement appears to be greatest for single storey homes on ground slabs with high perimeter-to-floor ratios. As further thermal simulation outputs and certificate energy ratings are received and collated in due course, we will be able to confirm trends in how background design factors impact on improvements to star rating resulting from slab insulation, and will include incorporate our learnings in revisions to this Guide. This should help to inform your early design process.

Or it may be that your home's design is not overly reliant on continuous under-slab insulation for its 7.5 star energy rating. In this case you may look to exchanging continuous ground slab insulation for a partial ground slab insulation (as per ***Alternatives 6-8*** outlined in Section 3 of this Guide), but then also further upgrading window and/or other envelope specifications, to offset reduced slab performance, thereby possibly reducing construction costs whilst maintaining your 7.5 star energy rating.

The responsibility for proving structural suitability of your site-specific on-ground concrete floor slabs (with or without insulation) however remains with your project architect and engineer. Engineering for your insulated ground slab may require more than simply referencing deemed-to-comply standards so ensure that fee agreements with your consultants acknowledge this potential extra computation and drawing workload.

The benchmark 7.5 star energy rating for Mullum Creek is presenting home owners, architects and engineers challenges that can be met in elegant and affordable ways, based on terrific design rather than expensive tech-fixes. Let's share the detail of what we learn and achieve here for the benefit of everyone engaged at Mullum Creek as well as for other future housing developments. An excellent way to do this in the first instance is through contact with the DRC via email info@mullumcreek.com.au or the website www.mullumcreek.com.au.

APPENDIX A: PROBLEMS WITH PARTIAL UNDERSLAB INSULATION

Prior to its July 2018 amendment, Mullum Creek's Ground Slab Insulation Guide flagged the option of installing XPS insulation board to the underside of ground slabs between, but not also over, integral footings (edge and internal stiffening beams). This option has been applied on occasions in building construction for cool climate zones of Australia. Where it's been applied in construction of a few of the first homes at Mullum Creek, the results have been very disappointing.

It's common and somewhat unavoidable that excavations for edge and internal stiffening beams are executed somewhat wider and rougher than what design drawings show. And where the upper edges of these beams engage with the underside of an integrally cast floor slab, sand bedding is by necessity battered back. Because XPS insulation board can only bear on the flat top of a sand bed, the proportion of the top surface area of an integral slab-footings that is insulated from below as built is invariably much less than (commonly down to around half of) what the energy assessor's area measurements off plans would suggest. As such the thermal benefit of this partial insulation as built ends up minimal and not worth the effort and cost.

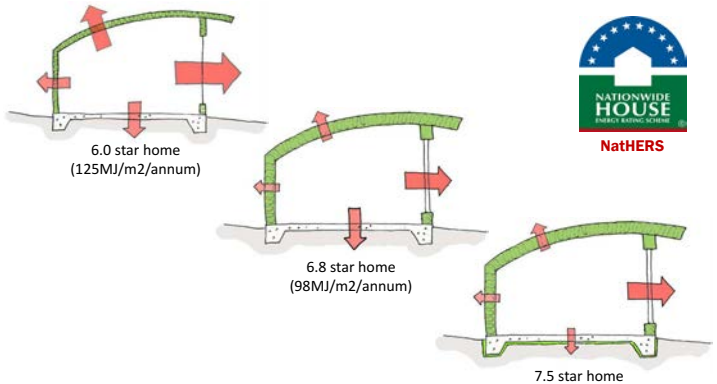
Consequently, the thermal benefit of partial underslab insulation of on-ground concrete floor slabs, to details other than those flagged by Alternatives 6-8 (being those which NatHERS software can readily simulate), will not be accounted for in future energy ratings targeting minimum 7.5 stars as prescribed for homes at Mullum Creek.

Preparation for this integral slab-footing at Mullum Creek was very carefully and competently executed. But note the only approx. 30% cover of insulation to underside of slab as built. Edge and internal stiffening beams remain uninsulated.

Even more problematic is when partial underslab insulation is detailed to cover also the side faces of edge and internal stiffening beams, but not also their bottom faces. Such detailing leaves the bottom edge of vertically laid XPS board unrestrained to then invariably dislocate prior to or during the slab pour. This is extremely difficult to rectify once reinforcing mesh is laid. However, if not rectified, the insulative benefit of this vertically laid XPS is all but lost. And the structural integrity of a slab can be seriously compromised by XPS board that is improperly located or becomes dislodged during the slab pour.

Attempts to insulate the vertical side faces of internal stiffening beams to this integral slab-footing at Mullum Creek were fraught by poor design detailing. Again, note also the excessive distance between 'insulated pads'.

APPENDIX B: EXTRACT FROM PRESENTATION TO ECOCITY WORLD SUMMIT



NatHERS

WINTER HEAT LOSS in cool temperate climate

Achieving an independent and conservative 7.5 star thermal performance under NatHERS is not easy. We've found that homes with anything other than a compact architectural form and modest, well-oriented glazing, will really struggle to achieve 7.5 stars in our cool temperate climate, without all the following design features in place:

- high levels of insulation in external walls and roof/ceilings.
- double-glazed windows with high thermal resistance and solar heat gain co-efficient.

… and interestingly also …

- substantial and continuous insulation to lower floors.

EXTRACT FROM
PRESENTATION TO THE ECOCITY WORLD SUMMIT

Melbourne Australia 12 July 2017

A personal reflection on Mullum Creek by Paul Haar Architect

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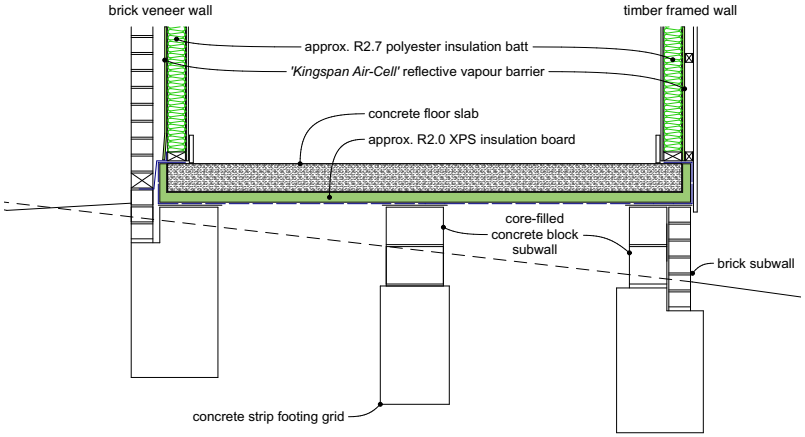

If lower floor insulation is removed from a typical 7.5 star Mullum Creek home, it'll commonly lose between 0.3 and 1.8 stars. Constructing an on-ground concrete floor with continuous under-slab insulation (to provide both good uninterrupted thermal resistance and internally accessible thermal mass) is challenging, potentially expensive and a practice generally unfamiliar to the Australian home building industry.

We acknowledge that home design and construction can voluntarily follow Passivhaus thermal performance standards and we have a few such homes proposed at Mullum Creek. They address air-tightness with much more rigour than homes assessed by the mandated NatHERS system. But neither Passivhaus or HatHERS address adequately wintertime thermal bridging between on-ground concrete floor slabs and blinding or piers, required on sites with slope and/or reactive soils.

If regulatory bodies wish to raise the thermal performance of new homes beyond the currently mandated 6 stars, they first need to advance to industry new solutions in design and construction detailing that'll tackle the weak links this raising of the bar will expose. Mullum Creek has advanced some solutions to this problem through its Ground Slab Insulation Guide.

APPENDIX C: REPORTS BY IAN COX-SMITH (BRANZ BUILDING PHYSICIST)

By Ian Cox-Smith, BRANZ Building Physicist

Perimeter insulation

To help improve our homes, the recently released BRANZ *House Insulation Guide* now includes thermal performance values for more insulated slab-on-ground flooring options and waffle pod systems.

Perimeter insulation was built into the floor slab.

THERMAL RESISTANCE (or R-value) is used to measure the effectiveness of insulation - the higher the figure, the better the resistance to heat flow.

Perimeter insulation advantages

Perimeter insulation is defined in the BRANZ *House Insulation Guide* as a rigid foam insulation (typically expanded polystyrene (EPS) or extruded polystyrene (XPS)) placed vertically against the outside face (the perimeter) of a concrete floor slab or foundation wall. Although not currently standard practice, perimeter insulation is sometimes the only practical way to significantly increase the R-value of a floor slab.

Perimeter insulation will also increase the R-value of a slab-on-ground floor that has insulation under the slab. It can be retrofitted, but ideally it should be incorporated into the detailing of the wall cladding and foundation or the floor system.

BRANZ thermal modelling has shown R1.0 perimeter insulation to be optimal - higher levels have minimal benefits as edge losses have been largely eliminated and most of the heat loss is then from under the slab.

Two big areas for heat loss

Since most heat loss is at the perimeter of a slab, the primary influence on the overall R-value is the length of the slab perimeter compared to its area - the area-to-perimeter ratio. A small slab will have a smaller area-to-perimeter ratio and consequently a lower R-value. A large slab will have a higher area-to-perimeter ratio and therefore a higher R-value.

A secondary influence on the R-value is the depth of the building walls above the slab. In buildings with deeper walls, the heat escaping through the perimeter of the slab has a greater distance to travel, and hence the edge of the floor slab has a higher R-value.

Waffle pod systems

The *House Insulation Guide* defines waffle pod systems as any concrete flooring system that uses 200-250 mm thick expanded polystyrene blocks in a grid pattern with 100 mm gaps between. Concrete fills both the gaps and a 300 mm wide perimeter band to give the floor system structural strength.

Unfortunately, the concrete thermally bridges the expanded polystyrene. The result of BRANZ thermal modelling has shown that there is a minimal overall increase in R-value for these systems above a plain slab-on-ground floor.

Looking at some examples

As an example, Table 1 summarises R-values for a variety of flooring systems from the 5th edition of the *House Insulation Guide*.

Table 1

R-VALUES FOR A VARIETY OF FLOORING SYSTEMS FROM BRANZ MODELLING

		AREA-TO-PERIMETER RATIO						
		1.3	1.9	2.2	2.5	2.8	3.1	4.0
		TOTAL CONSTRUCTION R-VALUE						
WITHOUT PERIMETER INSULATION								
SLAB ON GROUND	90 mm deep wall frame	0.8	1.0	1.1	1.2	1.4	1.5	1.8
	140 mm wall frame or 150 mm masonry	0.8	1.1	1.2	1.3	1.5	1.6	1.9
	200 mm masonry	0.9	1.2	1.3	1.4	1.5	1.7	2.1
	250 mm masonry	1.0	1.2	1.4	1.5	1.5	1.8	2.2
WAFFLE POD	90 mm deep wall frame	1.0	1.2	1.3	1.5	1.6	1.7	2.1
	140 mm wall frame or 150 mm masonry	1.0	1.3	1.4	1.5	1.7	1.8	2.2
	200 mm masonry	1.1	1.4	1.6	1.7	1.9	2.0	2.4
	250 mm masonry	1.3	1.6	1.8	1.9	2.1	2.2	2.6
R1.0 PERIMETER INSULATION								
SLAB ON GROUND	90 mm deep wall frame	1.2	1.5	1.7	1.9	2.0	2.2	2.7
	140 mm wall frame or 150 mm masonry	1.3	1.6	1.8	1.9	2.1	2.3	2.8
	200 mm masonry	1.3	1.6	1.8	2.0	2.1	2.3	2.8
	250 mm masonry	1.3	1.7	1.9	2.0	2.2	2.4	2.9
WAFFLE POD	90 mm deep wall frame	1.4	1.8	1.9	2.1	2.3	2.4	2.9
	140 mm wall frame or 150 mm masonry	1.5	1.8	2.0	2.1	2.3	2.5	3.0
	200 mm masonry	1.6	1.9	2.1	2.3	2.5	2.6	3.1
	250 mm masonry	1.7	2.1	2.2	2.4	2.6	2.8	3.3
R1.0 PERIMETER AND R1.2 UNDER-SLAB INSULATION								
SLAB ON GROUND	90 mm deep wall frame	1.7	2.1	2.3	2.5	2.7	2.9	3.5
	140 mm wall frame or 150 mm masonry	1.8	2.2	2.4	2.7	2.9	3.1	3.7
	200 mm masonry	1.9	2.4	2.6	2.8	3.0	3.2	3.8
	250 mm masonry	2.0	2.5	2.7	2.9	3.2	3.4	4.0

The green shaded areas are systems that meet the R1.9 minimum requirement for embedded heated flooring specified in H1/AS1 Replacement Table 2.

Small increase for waffle pod

The increase in overall R-value for a waffle pod system relative to a plain slab without EPS under the slab is only R0.2 (for a building with 90 mm deep wall frames) and up to R0.4 (for 250 mm thick masonry walls).

Perimeter insulation impact clear

The impact of adding R1.0 perimeter insulation is equally effective for both plain concrete slabs and the waffle pod type, with an increase in R-value of 30-50% (see Table 1).

Without perimeter insulation, only the large slabs (greater than 150 m²) will have R-values more than the R1.9 required for embedded heating flooring. However, by adding perimeter insulation, all but the smallest waffle pod floors will be thermally sufficient.

Under-slab insulation increase R-value

Plain concrete floor slabs with perimeter insulation also have the option of including R1.2 under-slab insulation to increase the R-value further and enable the smaller slabs (30 m²) to achieve R1.9 overall. Those plain slabs with area-to-perimeter ratios above 2.5 (minimum of a 100 m² square slab) will also meet the R1.9 minimum.

The combined effect of perimeter and under-slab insulation is an almost doubling of the R-value, which equates to halving of the heat loss.

Widely used overseas

Perimeter insulation of floor slabs is common practice internationally where products are commercially available. In New Zealand, however, perimeter insulation has been much more ad hoc, with strips of rigid foam insulation material (usually EPS) cut and assembled on site, then covered with a protection material.

One product available in North America is made from a glass-reinforced plastic protection layer bonded to high-density expanded polystyrene. Using a higher-performance but more expensive foam means the overall thickness, and therefore the visual impact, can be reduced.

Products on the horizon

There is at least one perimeter insulation product currently being developed locally. This is designed to be incorporated into the boxing when a waffle pod floor is being poured. The EPS foam has a protective plaster coating preapplied, and the product is installed so it sits flush with the cladding rather than protruding out.

There is also at least one New Zealand-based fully enclosed basin-style fully insulated system. This uses high-density EPS to have a continuous (unbroken) insulation layer between the concrete and the perimeter as well as the underside of the concrete.

A current Building Research Levy-funded project is helping industry to develop perimeter insulation products. The initial results of the research will be available at the end of this winter.

INSULATION OF SLAB-ON-GROUND FLOORS

Understanding how to maximise the insulation of a slab-on-ground floor is an important step to designing an energy-efficient building. So, where is the main heat loss, and how is a slab best insulated?

By Ian Cox-Smith, BRANZ Building Physicist

A recent caller to the BRANZ helpline asked why the BRANZ *House insulation guide* does not include examples of a slab-on-ground floor insulated using either polystyrene under the entire floor slab or a much thicker layer of insulation.

The answer is simply that the thermal performance achieved is essentially the same as only adding insulation under the floor slab for the first 1.2 m from the edges. That example is included in the *House insulation guide*.

Thermal resistance does not improve significantly by extending insulation from a perimeter of 1.2 m to the full depth, or by increasing its thickness, The reason being that, with no insulation on the perimeter foundations, most of the heat is conducted along the slab and out through the exterior face of the footing (see Figures 1–3).

Insulate exterior of footing or add thermal break

For buildability, it is usual to cover the underside of the entire slab with 50 mm thick polystyrene. To make the best use of insulation under the full depth, there needs to be either:

- a thermal break where the outer edge of the slab joins the perimeter footing (see Figure 4). Details of this were given in *Build* 100 June/July 2007, pages 32–33 and 103–105
- additional insulation applied, and protected, to the exterior face of the footing (see Figure 5).

The same also applies when increasing the thickness of the insulation (see Figure 6). There needs to be either exterior insulation (see Figure 7) or a thermal break to get the best out of the extra insulation material. In practice, floors are never constructed as in Figures 6 and 7, but the example illustrates the relatively small impact that this substantial increase in thickness of insulation (R6) has on the thermal performance.

Thermal models

Figures 1–7 show the results of thermal modelling a simple 10 m by 10 m square floor slab, with an area (A) to perimeter length (P) of 100/40 = 2.5. Because the ground under a slab provides insulation, the primary heat flow path is through the perimeter of the slab. The higher the A/P value, the greater the thermal resistance. This means that larger slabs perform thermally better than smaller slabs.

The coloured areas in the figures represent heat flow – red is higher heat flow and blue is lower heat flow. The total heat loss depends on both the intensity (represented by the colour) and the area (shown by the size of the coloured area) of heat flow. The areas of lowest heat flow are not coloured.

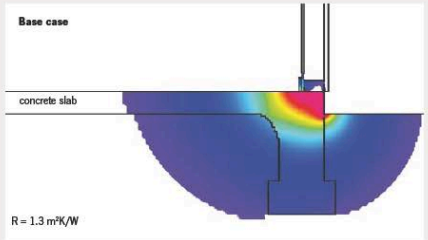

Figure 1: Plain slab (A/P ratio = 2.5, e.g. 10 m x 10 m).

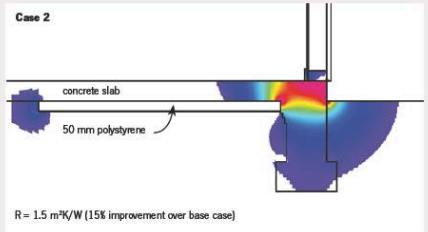

Figure 2: 50 mm polystyrene for the first 1.2 m width under edge of slab.

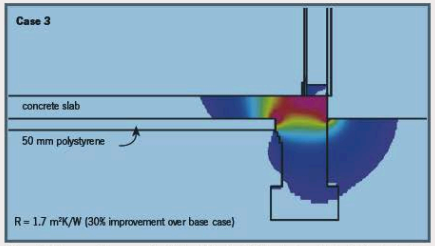

Figure 3: 50 mm polystyrene under full depth (5 m) of slab (but not under foundation footing).

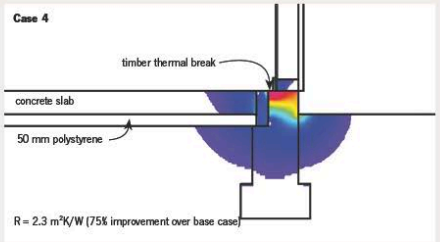

Figure 4: 50 mm polystyrene plus 45 mm wide timber thermal break at the inner edge of the slab.

Not all changes improve performance

Examination of the modelling results highlights the impact of changes in design.

BASE CASE

This represents the most common construction. Without insulation, this has a large area of high heat flow (red) at the exterior edge of the slab and the largest area of heat flow (colour).

SMALL IMPROVEMENTS

Case 2 represents a 15% improvement in the thermal resistance, but the addition of 50 mm of polystyrene with R1.2 has only added R0.2 overall. The area of highest heat flow is similar, but the total coloured area is less.

Case 3 is similar to case 2 except for the absence of heat flow around the inner end of the insulation. Doubling the area of insulation has resulted in a further 15% improvement but only another R0.2 in absolute terms.

BIG IMPROVEMENT WITH THERMAL BREAK

Case 4 shows that, with the further addition of a thermal break, the overall improvement of R1.0 is approaching the R-value of the insulation layer that has been added (R1.2). If the thermal break was made from polystyrene, rather than timber, the overall improvement would be equivalent to the R-value of the 50 mm polystyrene material.

Case 5 is an alternative to case 4 and results in the same overall improvement (R1.0). Again, if the R-value of the insulation added to the outside of the footing was similar to that of the 50 mm polystyrene material, then the effect would be an overall improvement of R1.2. The restriction is the visual impact where the insulation is above ground level, hence the use of extruded polystyrene to limit the thickness of insulation needed.

THICKER INSULATION

Case 6 demonstrates how, without a thermal break or thermal protection to the slab edge, the use of 250 mm of insulation (R6) achieves only slightly more (R0.1) than the result for the 50 mm thick insulation layer (R1.2) in case 2. Note this is not how the floor would be constructed in practice.

Case 7 represents a significant improvement in the R-value and almost the same result as for cases 4 and 5. Again, this is not how the floor would be constructed in practice.

CODE COMPLIANCE

Only cases 4, 5 and 7 would provide sufficient thermal resistance to meet the Building Code requirements for heated floor slabs.

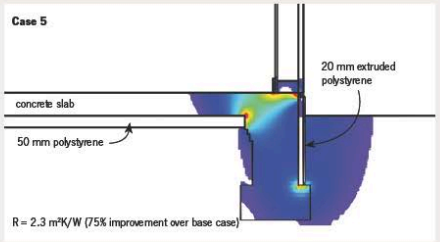

Figure 5: 50 mm polystyrene plus 20 mm extruded polystyrene to exterior face of footing.

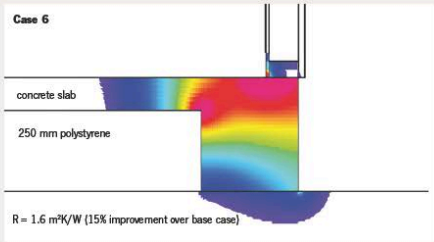

Figure 6: 250 mm thick polystyrene.

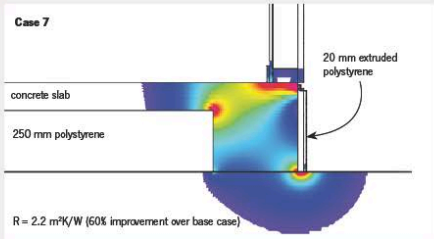

Figure 7: 250 mm thick polystyrene with 20 mm extruded polystyrene to exterior edge of slab.

By **Ian Cox-Smith**, *BRANZ Building Physicist*

Edge insulation of concrete slabs

Heating costs could be cut if we do as Americans and Europeans do and add perimeter edge insulation to heated concrete floor slabs.

A BRANZ BUILDING RESEARCH LEVY-funded project has been investigating the practicalities and effectiveness of adding exterior perimeter edge insulation to concrete floor slabs. This is common practice in North America, Canada and Europe but less so here. Reasons include that it can be difficult to install and make durable and that it can be visually intrusive.

Particularly useful for rebuild in Christchurch

The BRANZ project aimed to counter negative perceptions by demonstrating how it can be done and the performance that can be achieved.

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.

Perimeter insulation is most effective with heated floor slabs, including ones that capture solar energy.

Research involved modelling and monitoring floor slabs

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

Exterior 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. It is protected from impact damage and moisture accumulation.

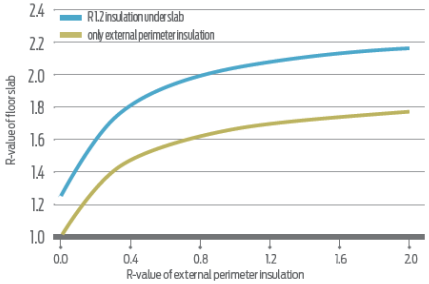

Figure 1: 100 m² floor slab with 0.6 m high perimeter insulation.

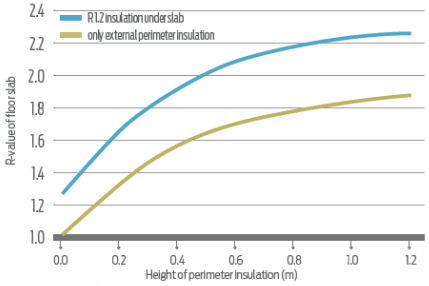

Figure 2: 100 m² floor slab with R1.0 perimeter insulation.

Modelling results

Figures 1 and 2 show the modelling results for a square 100 m² floor slab with a 40 m perimeter.

Figure 1 shows the impact of changing the thermal resistance of the perimeter insulation while keeping the vertical height fixed at 600 mm. Including insulation underneath the floor slab provided a significant additional improvement in thermal resistance.

Figure 2 shows the impact of changing the height of the perimeter insulation while keeping the thermal resistance at R1.0. A thermal resistance of R1.0 can be achieved using 30 mm of good-quality extruded polystyrene foam (XPS). A greater thickness (35-45 mm) will be required if expanded polystyrene (EPS) is used.

Key modelling findings

Increasing the thermal resistance of the perimeter insulation above R1.0 is relatively ineffective, and even using only R0.8 (25 mm of XPS) should still provide a reasonable improvement (see Figure 1).

Likewise, increasing the height of the perimeter insulation above 0.6 m becomes increasingly less effective (see Figure 2).

In practice, it is often difficult to extend the insulation much below the bottom edge of the footing. The results of modelling for larger slabs lead to the same conclusions about the optimum perimeter insulation R-value and height.

Field trial in Christchurch

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 (see Figures 3 and 4) 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.

The floor slab system was a waffle-pod style incorporating 220 mm high EPS pods.

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.

Heat loses revealed

Measurements were carried out over the 2015 winter months (see Figure 4). Measurements included March and October, but the months with significant heat loss from the perimeter of the slab were from April through to and including September. The data points are averages over successive 24-hour periods.

Typical floor slabs, including this one, often have a total slab perimeter length of 70 m or more. While the heat losses shown in Figure 1 may seem relatively small, the heat loss is occurring 24/7

Figure 3: Insulation and monitoring system retrofitted to sections of the Christchurch floor slab.

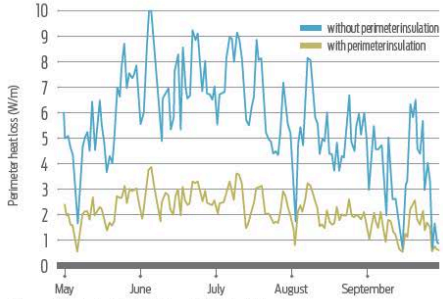

Figure 4: Heated residential floor slab in Christchurch.

for 5 months and needs to be integrated over the 70 m perimeter length. The average heat losses over 5 months are 2.2 W/m for the slab perimeter with perimeter insulation included. This compares with 5.7 W/m for the section without the perimeter insulation.

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.

Savings recover cost relatively quickly

The estimated cost for the perimeter insulation, including fitting to a new floor slab and the uPVC sheet for protection, is around $20/m.

For a slab with a 70 m perimeter, that would be an additional $1,400 for the cost of the floor slab. Heat-loss reductions in the order of 900 kWh per annum would recover that investment relatively quickly. At a standard rate of 20 cents per unit of electricity, that heat loss equates to a saving of $180.

The only downside is that the plants near the edge of the slab will lose their indirect frost protection!

For more A BRANZ study report containing full results of this research will be freely available shortly from www.branz.co.nz/shop.

By **Ian Cox-Smith**, *BRANZ Building Physicist*

Edge insulation of slabs

Modelling of concrete floor slabs at BRANZ has provided insights into how to optimise the effectiveness of exterior perimeter edge insulation.

SIMPLE BUILDING FOOTPRINTS often have thermally efficient concrete slabs (see page 34, *Simply efficient concrete slabs*), but for more complex designs, it is sometimes beneficial to add perimeter edge insulation.

In *Build* 151, *Edge insulation of concrete slabs* presented results of field trials conducted on a Christchurch residential floor slab and computer modelling of the performance of slab edge insulation. This discussed the R-value and height of the insulation material applied to the edge of a slab. These are the most critical features affecting the overall heat loss from the perimeter edge. However, there are other factors that also need to be considered.

Optimum R-value and height found

Modelling of floor slabs has shown that the optimum:

- thermal resistance of the edge insulation is around R1.0
- height is around 600 mm.

Decreasing the R-value or height has a significant impact on the slab R-value, whereas increasing both of those parameters any further has increasingly less benefit.

Modelling other parameters

Using the two optimum results, the next most important parameters have been investigated by computer modelling. Those parameters are:

- dimension from ground level to floor height
- distance between the top of the insulation and the floor surface
- thickness of the exterior walls of the house
- soil conductivity.

Soil conductivity is dependent on the specific location and is usually unknown. It can possibly even change with time because of changes in the wetness of the soil.

A further consideration for the modelling was the effect of combining perimeter insulation with insulation underneath the slab. An R-value of 1.2 was assumed for the underslab insulation since this is typically used.

Impact of other features varies

The modelling results for a 100 m² square floor slab with 0.6 m high R1.0 edge insulation and an area:perimeter ratio of 2.5 are shown in Figures 1-4.

The overall R-value of the floor slab is clearly less sensitive to the four additional parameters than to edge insulation R-value and height.

The two features with most impact are the:

- size of any gap between the top of the edge insulation and the floor surface (see Figure 2)
- soil conductivity when edge insulation is included (see Figure 3).

Interestingly, an uninsulated floor slab or one with just insulation underneath would receive much less benefit from having soil that is lower in conductivity.

Similarly, a floor slab with just insulation underneath receives a more noticeable benefit from thicker house walls (see Figure 4).

R1.0 edge insulation combined with R1.2 underslab insulation typically doubles the overall slab R-value. Underslab insulation alone provides 20-40% improvement on no insulation.

Variety of slabs modelled

Study Report 352 includes results for other slab sizes, waffle pod style slabs and for the floor slabs of houses with brick veneer walls.

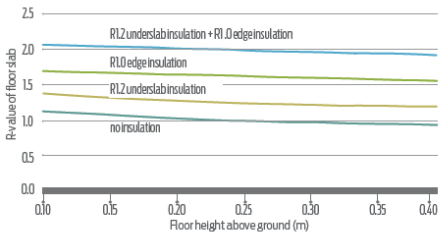

Figure 1: Impact of floor height above 100 m² floor slab.

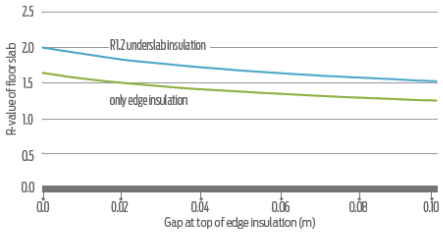

Figure 2: Impact of gap between top of the edge insulation and floor surface.

For more SR352 *Perimeter insulation of concrete slab foundations* contains design advice and is free from www.branz.co.nz/study_reports.

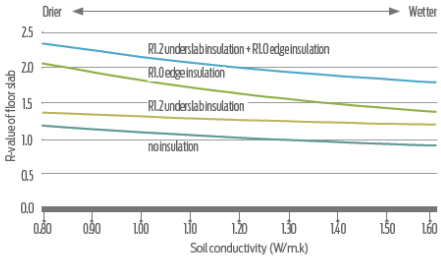

Figure 3: Impact of soil conductivity.

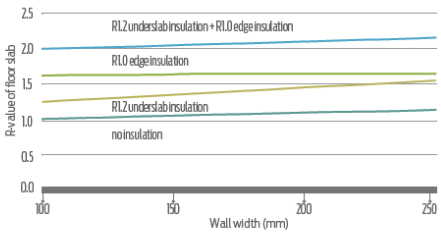

Figure 4: Impact of wall width.