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Installed Performance of Ceiling Insulation

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Note

This report is intended to be used by researchers interested in the performance difference between insulation installed between ceiling framing and insulation installed over the framing.

Installed Performance of Ceiling Insulation

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Abstract

This report presents a summary of a research project that compared the performance of ceiling insulation installed in the more traditional layout of friction fitting between ceiling framing with the performance of the same insulation installed over the top of framing (without insulation between the framing).

The project sought to determine the in-situ performance of insulation installed using these two methods and to verify the results using laboratory measurements. The project was based on in-situ measurements of thermal resistance in three ceilings using heat flux transducers.

The comparison was made by first insulating the ceilings with the insulation installed over the framing and determining the thermal resistance. Then the same insulation material was cut and friction-fitted between the framing before re-measuring the thermal resistance. As an additional comparison, the thermal resistance of the three test ceilings and existing insulation was measured before a sufficient area (approximately 4 m2) of the insulation was removed and replaced with the new insulation installed over the top of the framing. Additional measurements were also made with insulation installed both between and over the framing. Further laboratory based measurements were made using the BRANZ heat flow meter in conjunction with thermal modelling to confirm the thermal effect of insulation friction-fitted around framing.

One conclusion was that it is very difficult to avoid air exchange thermal bridging of insulation installed over the top of framing (without insulation between the framing). Another conclusion was that, when insulation is of a suitable thickness and is cut to a suitable width, it can be installed friction-fitted so that the top of the insulation expands over the top of the framing, adding insulation to the frame and thereby reducing the extent to which it thermally bridges the rest of the insulation.

Since insulation installed over the top of framing appeared to carry a significant risk that the thermal performance may be compromised by convective losses unless the insulation is installed with extreme care, the recommendation is that the method should not be viewed as achieving better overall performance than the same material fitted between framing. The level of care necessary when fitting insulation over the top of framing may limit its suitability to relatively simple framing profiles where additional bracing framing does not interfere with the ability to reliably butt insulation sections together. This need for care may also negate some of the assumed installation speed advantages of rolling out insulation over the top of framing.

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1. INTRODUCTION

The Building Research Levy has funded a project to compare two methods of installing ceiling insulation.

There has been a significant upsurge in retrofitting of existing housing stock, and the intention of this project is to allow the industry to make more informed choices as to which insulation product types to use, and where and how best to install them to take advantage of the unique properties each type has. Appropriate choice of product type and installation method will help to avoid lost efficiency from thermal bridging and convective leakage around the insulation layer. Installed performance will then be closer to the laboratory measured values for the products, making thermal design more effective.

This report begins with a brief overview of the technique for in-situ thermal resistance measurement followed by a summary of the measurements and results for the three ceilings and the results of the heat flow meter measurements and thermal modelling. Finally, there are concluding comments and some recommendations.

2. BACKGROUND

When ceiling insulation was first introduced into the New Zealand Building Code in the late 1970s, residential ceiling insulation was almost exclusively in the form of either precut glasswool pieces (batting) or loose-fill cellulose. Since then, ceiling insulation products made from both polyester and sheep's wool (and blends) have become available. While these were initially in the form of precut segments, they are now commonly also available in roll form, as are glasswool ceiling products. All three materials are sometimes installed by rolling them out over the top of ceiling framing. There are also the options of cutting the rolls into pieces and installing the pieces in the traditional way of friction-fittnig between the framing, or using a combination of rolling out a precut width between the framing with a further layer of roll material installed over the top of both the framing and the first layer of insulation.

Since the performance of two-layer installion method is well established in the literature, it was not a major as part of this study. However, although this method is not as susceptible to the risks of air-exchange heat loss or thermal bridging from framing as the other two methods, it still requires a good standard of installation – even though the bottom layer of insulation does not need to be friction-fitted, it must still be a good fit to minimise thermal bridging.

2.1 BRANZ heat flux measurements

BRANZ staff have been using heat flux transducers (HFTs) for field measurements of heat flow since the 1970s. Scientist Harry Trethowen originally developed large panel transducers that were used to investigate the thermal performance of slab-on-grade floors and for a survey of the thermal performance of houses in the 1980s that involved measuring the R-value of walls, floors and ceilings (*A survey of house insulation*, Isaacs, NP and Trethowen HA, Research report R46 BRANZ 1985).

These field measurements generally need to be conducted during winter to ensure there is sufficient temperature difference across the building components to generate enough heat flow to enable reliable heat flux measurement. The best overall measurement accuracy for the HFT system is estimated to be 10%, with the actual

performance being somewhat dependent on the system R-value and the actual on-site temperature conditions during the period of measurement.

2.2 Data acquisition

The use of HFTs requires a data acquisition system to record data at 1 or 2 minute intervals for periods of a week or more. Advances in micro-electronics have enabled the relatively large mains-powered data aquistion units used to conduct the earlier field measurements to be replaced by tiny battery-powered data loggers, and advances in computer software have streamlined and simplified the process of analysing the data. BRANZ staff have developed a series of custom battery data loggers to perform particular measurement tasks, including a BRANZ microvolt logger (µV-logger) that was designed for measuring the microvolt level signal from both thermocouples and the BRANZ HFTs. The BRANZ microvolt logger has four input channels – three for thermocouples and one for an HFT – and includes a built-in reference junction temperature sensor.

3. PROJECT OUTLINE

The main components of the project were:

1) in-situ measurement of thermal resistance in two ceilings with insulation installed over the top of framing
2) in-situ measurement of thermal resistance in two ceilings with insulation friction-fitted between framing
3) in-situ measurement of thermal resistance in two ceilings with insulation installed both between and over the top of the framing
4) laboratory measurement of the impact of friction-fitted insulation, using the BRANZ heat flow meter
5) thermal modelling of friction fitted insulation.

4. EQUIPMENT

The measurement system consists of three parts:

1) BRANZ developed logger
2) thermocouples for measuring temperature difference between the underside of the ceiling and the air above the insulation in the ceiling space
3) BRANZ developed heat flux transducers (HFTs) plus stand to hold it against the underside of the ceiling.

4.1 Heat flux transducers (HFTs)

The behaviour, use and performance of the BRANZ HFTs have been described previously in *Engineering application of heat flux sensors in buildings – the sensor and its behaviour* (BRANZ RP046) and *Measurement errors with surface-mounted heat flux sensors* (BRANZ RP051). Previously, the HFTs were not used in conjunction with a heat box to modify the local interior air temperature.

The BRANZ HFTs are constructed from two 600 x 450 mm sheets of 2.5 mm thick aluminium separated by a 4 mm airspace created using a rim of 4 mm thick balsa wood

and small blocks of the balsa in the centre. The low emittance airspace created between the inside faces of the aluminium sheets provides a thermal resistance of approximately 0.1 m^2K/W. Ten pairs of type-T thermocouples are attached to the inside faces of the aluminium sheets and connected in series to give a single output of approximately 10 x 40 = 400 µV/K. A separate single thermocouple is also attached to the inside face of one of the aluminium sheets. The aluminium sheet with the separate thermocouple attached then becomes the face of the HFT that is held against the building component being measured so that the thermocouple is measuring the surface temperature of the building component under test (for this project, the underside of the ceiling).

4.2 Using HFTs to determine thermal resistance

R-value is determined from the accumulative sum of temperature difference and accumulative sum of heat flow:

$$\text{R-value} = \frac{\sum \Delta T}{\sum Q}$$

An alternative is to use the sum of squares method:

$$\text{R-value} = \frac{\sum \Delta T^2}{\sum Q.\Delta T}$$

The alternative method is only needed when the heat flow through the component under test occurs in both directions, making both the sum of temperature and sum of heat flow smaller and therefore making the determination of R-value less accurate.

Provided there is sufficient temperature difference across the component, the R-value determined using this method usually converges adequately in about 72 hours, and the final R-value is calculated over a total time interval that is a multiple of 24 hours (i.e. 72, 96, 120 hours and so on).

Principal features for the practical use of HFTs:

- 5 days is a practical minimum measurement period, but the results should still be examined after 5 days to decide if the measurement needs to proceed for a longer period.
- The mean temperature difference between indoor and outdoor needs to be above 4°C to avoid large measurement uncertainty.
- Temperature reversals and associated inward heat flows can result in unreliable measurements if they form a significant fraction of the total test period.
- Accuracies of about 10% are achievable if there is sufficient temperature difference.
- It is important to maintain good contact between the HFT and the component being measured.

5. ASSUMPTIONS

The inference from simple isothermal plane calculations of the thermal performance of ceiling insulation is that, when insulation is installed over the top of ceiling framing, it should perform significantly better than the same material installed friction-fitted between the framing.

These calculations require two significant assumptions to be made:

1) In the case of insulation installed over the framing, the airspace created underneath the insulation is a still airspace without significant convective or ventilation air exchange (and heat loss) to the rest of the ceiling space.
2) When insulation is friction-fitted between the framing, it does not expand over the top of the framing and insulate the frame from the roof space above.

If the first assumption is incorrect then the performance of insulation installed over the top of framing will be thermally bridged by the air exchange and the overall performance will be lower than the calculation would suggest. If the second assumption were incorrect then because of the additional area of insulation above the framing, the thermal bridging caused by the framing will be less and the overall performance will be better than the calculated value for insulation friction fitted between framing.

6. TEST SITES

The test sites consisted of an approximately 4 m^2 area of insulated ceiling in three houses in the greater Wellington area.

The first ceiling (Ceiling A) was in a late 1980s house and had been insulated at the time of construction with loose-fill glasswool. The insulation was approximately 50–70 mm thick. Two HFTs were installed – one directly under an area containing just a batten (Figure 1) and the other under an area containing both a batten and a joist (Figure 2).

The thermocouple to measure the air temperature above the insulation was passed through the light fitting to avoid drilling holes through the ceiling (Figure 3). (The same technique was used at the other two test sites.) The panels were attached with clips rather being held in place with stands, and the loggers were wired to the panels but are not visible in the picture. For the measurements with insulation only over the top of the framing, the area near the outer edge of the ceiling was insulated with an extra piece of insulation added between the framing to eliminate ventilation through that area.

Figure 1: Ceiling A – area 1, batten only.

Figure 2: Ceiling A – area 2, batten and joist.

Figure 3: Ceiling A – heat flux transducers in position.

The second ceiling (Ceiling B) was in an early 1970s house that had been retrofitted in the 1980s with glasswool insulation segments. The insulation segments were approximately 70 mm thick and poorly installed, with the widespread presence of tucking and folding (Figure 4). The single HFT was installed directly under an area containing a joist but no dwangs, and the panel was held in place with a purpose-designed stand (Figure 5). The logger was placed on the stand just underneath the HFT panel.

Figure 4: Ceiling B – original insulation poorly installed.

Figure 5: Ceiling B – heat flux transducer in position.

The third ceiling (Ceiling C) was in an early 1990s house insulated at the time of construction with nominal R 2.4 glasswool insulation segments – the plastic bags from the insulation had been left in the ceiling (Figure 6). While the installation was better than that of Ceiling B, there was some tucking present. The segments were approximately 90 mm thick. Only one HFT was installed, was placed directly under an area containing both a batten and a joist (Figure 7).

Figure 6: Ceiling C – plastic bags from the original insulation had been left in the ceiling.

Figure 7: Ceiling C – heat flux transducer in position.

7. IN-SITU MEASUREMENTS

Each measurement of R-value required approximately 7 days of data. The measurements were conducted simultaneously at the three test sites over a period of 6 weeks during the winter of 2008.

While the spacing between ceiling framing for the three test ceilings was larger than many houses where retrofit insulation is installed, the HFTs used for these measurements were placed directly under joists so that the 45 mm joist width represented 10% of the 450 mm width of the HFT. Not many ceilings have frame spacings less than 450 mm so the measurement probably represents a worst case in terms of thermal bridging from framing.

7.1 Ceiling A

After first measuring the thermal resistance of the ceiling at two locations with the existing loose-fill insulation, the insulation was removed from the test area and replaced with 120 mm thick R 3.2 glasswool insulation product (roll form) installed over the top of the framing (Figure 8). The thermal resistance was then remeasured.

Next, the same pieces of insulation were cut down in size and friction-fitted between the framing. Care was taken to cut the insulation width to ensure that the insulation was able to bulge over the top of the framing and conceal (insulate) it (Figure 9).

Figure 8: Ceiling A – 120 mm thick R 3.2 glasswool insulation product (roll form) installed over the top of the framing.

Figure 9: Ceiling A – pieces of insulation friction-fitted between the framing.

A fourth set of measurements was made with more of the same insulation material installed over the top of the framing in addition ot the material already friction-fitted between the framing (Figure 10).

Figure 10: Ceiling A – layer of insulation over framing and second layer between framing

7.2 Ceiling B

After first measuring the thermal resistance of the ceiling with the existing retrofitted insulation segments, the thermal resistance was remeasured with 120 mm thick R 3.2 glasswool insulation product (roll form) installed over the top of the framing and existing insulation (Figure 11).

Figure 11: Ceiling B – 120 mm thick R 3.2 glasswool insulation product (roll form) installed over the top of the framing and existing insulation.

Because of the limited height in the ceiling space, it was difficult to access the test area, and this made it impractical to precision friction-fit the insulation either between the framing or over it.

7.3 Ceiling C

After first measuring the thermal resistance of the ceiling with the existing nominal R 2.4 insulation segments, the insulation was removed from the test area and replaced with 120 mm thick R 3.2 glasswool insulation product (roll form) installed over the top of the framing (Figure 12). The thermal resistance was then remeasured. As with Ceiling A, the area near the outer edge of the ceiling contained additional insulation between the framing to prevent ventilation.

Figure 12: Ceiling C – 120 mm thick R 3.2 glasswool insulation product (roll form) installed over the top of the framing.

After the measurements with the insulation installed over the framing were completed, the same insulation material was cut down in size and friction-fitted between the framing. The thermal resistance was then remeasured.

8. RESULTS OF INSITU MEASUREMENTS

Table 1 summarises the results for the 13 sets of thermal resistance measurements.

Table 1: Summary of results

Thermal resistance (m^2K/W) – estimated measurement uncertainty 10%	**Ceiling A batten only**	**Ceiling A batten and joist**	**Ceiling B joist only no dwang**	**Ceiling C batten and joist**
Original insulation	1.5	1.3	1.7	2.2
Single layer of Insulation over the top of framing	Initial 1.5 Final 3.5	Initial 2.9 Final 3.4		1.5
Calculated	3.6	3.6		
Single layer of insulation friction-fitted between framing	3.5	3.6		3.7
Calculated	3.6	3.3		
Layer of insulation over framing and second layer between framing	>5	>5	4.8	
Calculated	6.5	6.3	5.2	

For Ceiling A and the situation with insulation only over the the top of the framing, the intial R-value result was surprisingly low, despite taking considerable care with installation. A revisit to the test site revealed that small gaps (5 mm) had opened up at some of the joins between the sections of insulation. The insulation was carefully moved so as to close these gaps, and the R-value was then remeasured and found to be close to what would be expected if there were no ventilation losses occuring.

For Ceiling C, the thermal resistance was also very low for the case of insulation installed over the top of the framing, but because of nature of the framing, it was not possible to apply a better fit to the insulation.

Previous studies have estimated the uncertainty in determining thermal resistance using the HFTs as 10%, including calibration errors and uncertainties associated with installation and in-use conditions. The estimation of the uncertainty was based on an assumption that the average temperature difference is at least 10℃. If the temperature difference is less than 10℃, the method becomes less reliable, and repeat measurements are needed to provide confidence in the results.

For Ceiling A with two layers of the R 3.2 insulation, it was only possible to determine that the thermal resistance was significantly above R 5. This happened because the temperature difference was insufficient to produce a significant heat flow through the heat flux transducer.

For Ceiling B, it was possible to make a reliable measurement because the temperature difference was larger and so the output from the HFT was sufficient to be able to measure it reliably. It also helps that the overall thermal resistance was lower (because the lower layer of insulation was the original material and not the replacement R 3.2 material).

The measured R-values for the ceilings insulated with their original insulation materials are what would be expected given the material types and thicknesses. For the examples with insulation friction-fitted between the framing, the results are well within measurement error of the values calculated on the basis that the edges of the

insulation effectively spread over the top of the frame and insulate it from the air space above. In this way, the insulation is effectively behaving as if it is two layers.

9. LABORATORY HEAT FLOW METER MEASUREMENTS & MODELLING

To help verify and extend the insitu measurements, laboratory measurements were carried out using a heat flow meter appratus on samples sections containing insulation fitted against a small piece of framing timber. The pupose of the measurements was to obtain more precise data on the impact of the insulation being fitted so that it extends over the top of the framing. At the same time the sections were modelled using both 2 & 3-dimension finite element modelling software. Figure 13 shows a typical result from the 2-D model. Note that because of the natural symetry of the heat flows involved, only half of the frame is modelled.

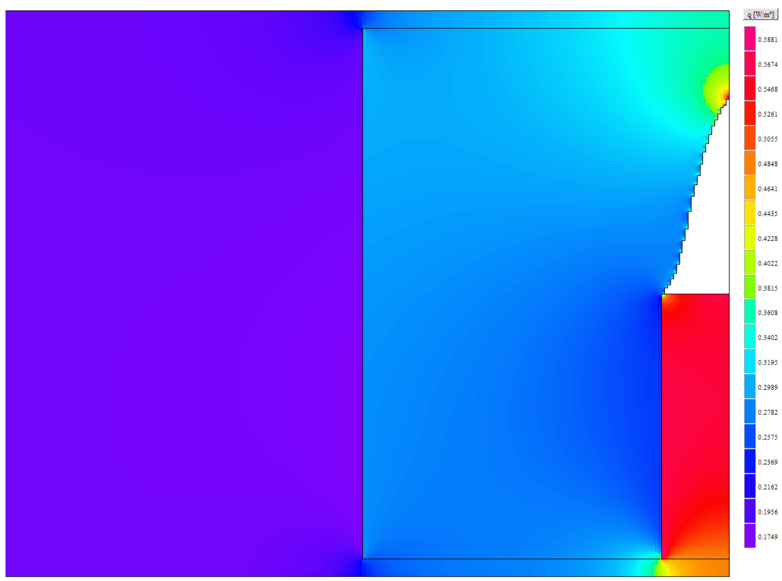

Figure 13: 2-D thermal model result (temperature) for frame with well fitted insulation

Table 2 contains the results of the heat flow meter measurements with various combinations of insulation, frame, and fit method.

Table 2: Laboratory heat flow meter (HFM) measurements

Thermal resistance (m^2K/W) – estimated measurement uncertainty 5%	**Measured**	**2-D thermal model**
Insulation material	3.31	
Insulation as two pieces (perfect fill above frame)	3.00	3.05
Insulation friction-fitted as in Figure 17	2.93	2.90
Insulation only fitted against framing as in Figure 15	2.41	2.43
Calculated for layer of insulation over framing and assuming no convective losses thru insulation layer		3.6
Layer of insulation over framing and second layer between framing	>5	
Calculated		6.5

In Table 2 it can be seen that when insulation is fitted between the framing so that it also insulates over the top of frame, the system R-value can be significantly better than

what is is achieved when the framing is left exposed. The results also demonstates very good agreement between measurement and models.

The measured R-values can also be compared with the results of computer calculated 3-dimensional finite element models of the measured ceiling structures. An example of one of the models is shown in Figure 13. The colour represents temperature, with red being warmer than purple. Since the computer models are not able to simulate the ventilation that may be occuring, the models assume that the air space under the insulation is an unventilated space.

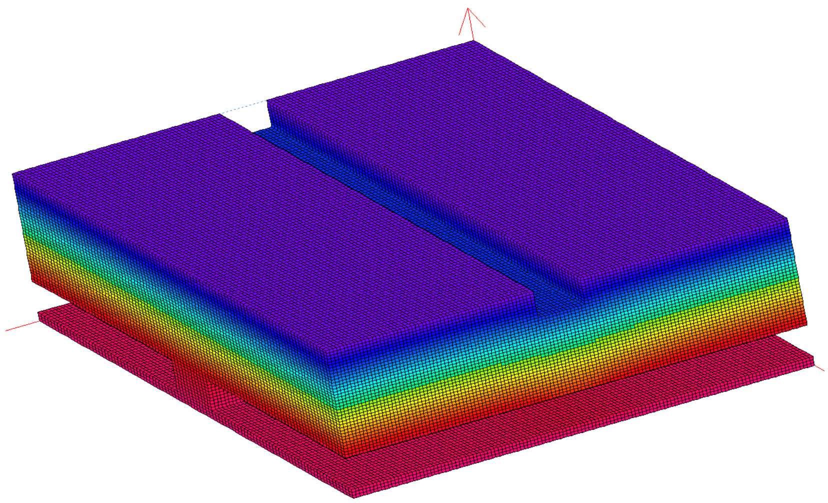

Figure 14: Thermal modelling result for insulation fitted against framing

10. DISCUSSION

Since the insitu measurements were limited to the use of glasswool insulation aditional laboratory based investigations were carried out that looked at friction fitting of polyester insulation around framing.

Figure 15 shows a representation of polyester insulation fitted between framing in the way that the R-value has traditionally been calculated using 1-dimensional calculation methods such as NZS 4214. It assumes incorrectly that insulation is cut exactly to the width of the spaces between framing. The assumption therefore is that there is no insulation over the top of the framing, and increasing the thickness of the insulation will not reduce the thermal bridging from the framing.

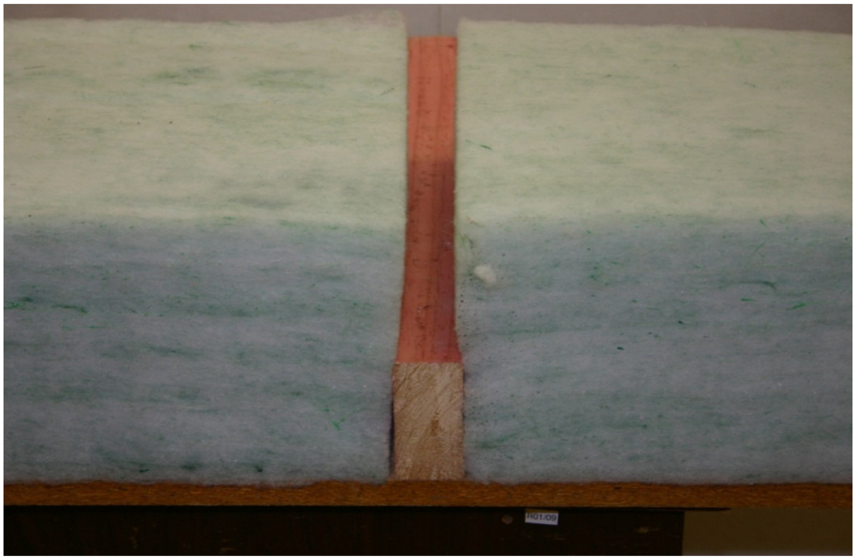

Figure 15: Polyester insulation fitted against framing in the way the R-value has traditionally been calculated using 1-dimensional calculation methods such as NZS 4214.

Figure 16 represents the reality of insulation cut to friction-fit the frame spacing. The width of the insulation is then the width of the space between the framing plus the width of the framing (usually 45 mm). This results in the insulation partially covering over the framing and produces a reduction in thermal bridging from the framing. The thermal bridging from the framing would be expected to be reduce if the insulation thickness is increased, but since there is still a gap in the insulation above the framing, there will still be some convective heat transfer into the ceiling space above the insulation.

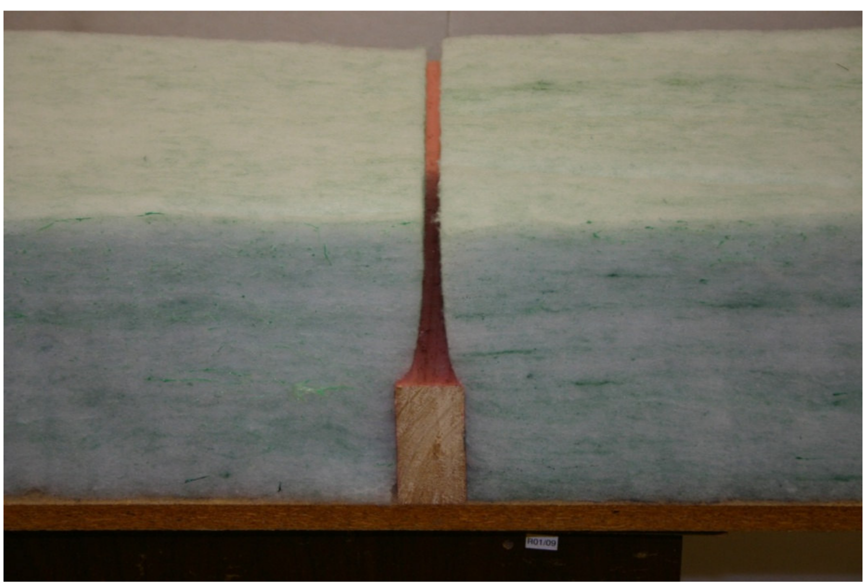

Figure 16: Insulation cut to friction-fit the frame spacing.

Cutting the insulation slightly wider enables the insulation to close up over the top of the framing, minimising the conventive heat transfer. Figure 17 shows insulation cut to the width of the space between framing plus twice the width of the frame (2 x 45 mm)

and installed with the segments end on to the framing. Figure 18 shows insulation cut to the same width but installed with the segments side on to the framing.

In both cases, the insulation closes up very effectively over the top of the framing, and the thermal resistance would be expected to be very close to what would be achieved if the insulation was installed as two layers. For this particular insulation product, these two examples are indistinguishable but because some fibrous insulation products, particular polyester ones, can have a significant polarity in fibre rigidity, this may not always be the case. In one direction, the material may not close over the top of the framing as well as it does when oriented the other way.

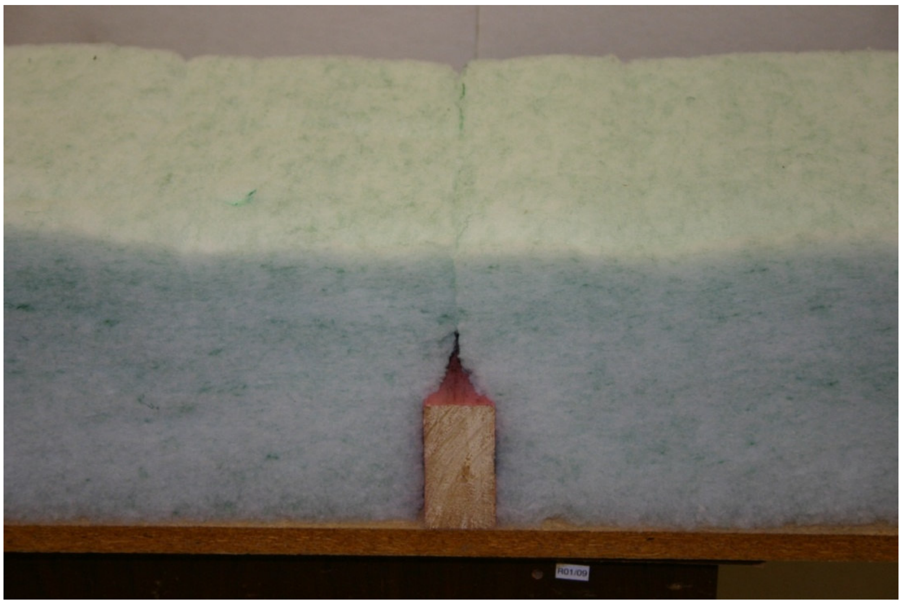

Figure 17: Insulation cut to the width of the space between framing plus twice the width of the frame (2 x 45 mm) and installed with the segments end on to the framing.

Figure 18: Insulation cut to the width of the space between framing plus twice the width of the frame (2 x 45 mm) and installed with the segments side on to the framing.

11. CONCLUSIONS AND RECOMMENDATIONS

Ceiling insulation installed over the top of framing in principle creates a still air space between the ceiling lining and the underside of the insulation and can therefore in theory provide additional insulation performance. The reality in the case of these particular in-situ measurements was that it was very difficult to fit the insulation with tight enough joins between sections to prevent severe convective heat losses through the insulation layer. Where the insulation was cut to a suitable width and fitted between the framing it was possible to achieve a fit quality where the insulation was a visibly continuous layer without framing visible. In that situation the thermal performance was measured as being significantly better than is normally calculated for the common situation of visible framing. In addition the thermal performance was found to be close to what would have been achieved if the same insulation was installed over the top of the framing and assuming at the same time that there are no convective losses.

Thermal modelling has demonstrated that it would be possible to adjust NZS 4214 type calculations to account for the better thermal performance achieved when insulation is fitted in a way that covers over the framing. In contract it would be very difficult to model the situation of convective bridging through insulation fitted over the top of framing. Since insulation installed over the top of framing would appear to carry a significant risk that the thermal performance may be compromised by convective losses unless the insulation is installed with extreme care, the recommendation is that the method should not be viewed as achieving better overall performance than the same material fitted between framing. The level of care necessary when fitting insulation over the top of framing may limit its suitability to relatively simple framing profiles where additional bracing framing does not interfere with the ability to reliably butt insulation sections together. This need for care may also negate some of the assumed installation speed advantages of rolling out insulation over the top of framing.

There is the possibility that for some other fibrous insulation materials other than the glasswool used in this case it may be possible to install it over the top of framing and avoid convective losses but for insulation fitted between framing the potential to be able to fit the material so that it insulates the framing is expected to be universal. Whilst it is difficult to visually assess that insulation installed over framing has been fitted with sufficient quality to minimise convective bridging, it is relatively easy to see if insulation fitted between framing is insulating the framing since the framing will not be visible if it has been done correctly.

The R 3.2 glasswool material used for this project probably represents the minimum R-value of insulation that will effectively cover over standard 90 mm high framing when cut to fit between the framing. Since the thermal conductivities of polyester and sheep wool insulation products are higher than those of glasswool products, the products are thicker for the same R-value and the same effect (framing insulation) will be achieved for lower R-value products made from them than the value of R 3.2 for glasswool. Obviously the ability to insulation the framing will improve as the installed insulation product R-value is increased. The insulation products will need to be manufactured to a slightly larger width than they typically are now. Using two layers of insulation is another way to ensure that the framing is insulated but it may be that a well fitted single layer takes the same or less time as it would to install two.