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# Improving Thermal Efficiency in Lightweight Construction: Subfloor Insulation

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# **Improving Thermal Efficiency in Lightweight Construction: Subfloor Insulation**

Prepared for

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Products Australia**  
*Knowledge for a sustainable Australia*

## **Publication: Improving Thermal Efficiency in Lightweight Construction: subfloor insulation**

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# 1. Executive Summary

This research task was established to obtain new data to inform the challenges facing the construction of thermally efficient, light-weight, timber framed, small-scale buildings. This report focuses on the installation practices and measured thermal performance of reflective and bulk subfloor insulation systems for timber platform floored construction.

The subfloor insulation tasks included the installation, detailed measurement and detailed simulation of three platform floor subfloor insulation methods, namely:

- Reflective subfloor insulation installed to contemporary industry practice,
- Reflective subfloor insulation installed to the manufacturers specification, and
- Bulk subfloor insulation installed to contemporary industry practice.

In each case there were significant differences between measured and simulated results. The differences occurred between:

- Measured and simulated subfloor zone temperatures
- Measured and simulated room zone temperatures
- Measured and simulated roof space temperatures
- Measured and simulated energy use for heating operation

The measured thermal performance involved four operational methods, namely:

- Unconditioned and unoccupied,
- Continuously conditioned (heated),
- Intermittently heated, and
- Continuously conditioned (cooled).

These operational modes allowed for the comparison of both the envelope module and the heating and cooling energy modules within the house energy rating software. The differences between simulated and measured temperature data were often greatest at times of daily maximum or minimum temperatures. The significant differences that were found between simulated and measured heating and cooling energy use appears to be closely linked to the coefficient of performance of the heating and cooling equipment, but this requires further analysis. The assessment of cooling energy encountered a few challenges rendering some tasks unsuccessful but, as discussed in the report proper, the experience informed better methods that can be used in future research in this field.

The detailed measurement included an array of sensors in the subfloor zone, test building room zone, the roof space zone and a site weather station. The site weather station data were used in conjunction with other data from the Bureau of Meteorology to create a site-specific climate file for each experiment. The detailed simulation included modifications to conductivity values, infiltration rates and conditioned temperatures, to more correctly reflect the as-built nature of the buildings.

It must be noted that, even though there were significant differences between measured and simulated zone temperatures, the graphical analysis of the data-sets documented a similarity in profile, providing an assurance that the envelope modules of the software were working well and applied even small climatic inputs. The differences that have been documented between the measured and simulated temperatures may have a significant impact on energy use. At present, the software has a simplified energy calculation model. The opportunity to simulate different forms of heating and cooling equipment is required to better inform the

envelope and equipment design of new homes. This aspect of the software and NatHERS requires further development.

The critical findings from this research are many but key elements include:

- The quality of contemporary installation practice for reflective subfloor insulation was very inadequate and does not appear to follow manufacturers' specified methods. This is further complicated by the fact that the quality of installation documentation and education from manufacturers and suppliers for reflective subfloor insulation products is generally inadequate and often inconsistent, which significantly influences the poor quality of product installation. These incorrect installation practices provide an R-value of 0.72 instead of the marketed 3.0 and would significantly impact on the unwanted heat loss and/or heat gain in a home. This was characterised by the data in Table 3, which showed a 1.8 x greater flow of energy from a house with incorrectly installed reflective subfloor insulation when compared to correctly installed reflective subfloor insulation.
- The thermal performance for correctly installed reflective subfloor insulation was good and was well represented by the AccuRate building envelope simulation. However, the time taken to install the reflective subfloor insulation correctly was much longer than expected, due to current subfloor construction practices, and would impact on the cost of house construction.
- The reflective subfloor insulation research tasks identified a dire need for appropriate and consistent installation documentation to support marketed, (and often simulated), thermal resistance values. Furthermore, this information needs to be appropriately disseminated through an industry wide education and training program that highlights the impacts for house thermal performance that can result from both correct and incorrect installation practices.
- The contemporary installation practises for the bulk subfloor insulation was of a lesser quality than that shown in product installation literature. However, due to the nature of bulk insulation, this did not impact on the short-term thermal performance in this research task. Nevertheless, unless regular home-owner inspections are included as a part of the house maintenance program, concern is warranted for the long-term performance of the subfloor bulk insulation. In a similar nature, but to a lesser degree than the reflective subfloor insulation example mentioned above, the quality and consistency of bulk subfloor installation guidelines from manufacturers and suppliers was mixed.
- Both subfloor insulation tasks highlighted practises of product installation that did not follow market expectations. Contractors, construction supervisors and inspectors need to be educated and informed of the correct methods for subfloor insulation installation to ensure home owners receive the expected high quality, and thermally comfortable, lightweight timber home.
- In all the research tasks there was an unacceptable difference between the measured and simulated energy use for the reverse-cycle air-conditioner. This may not be caused by the AccuRate energy algorithms but by a significant difference between the Coefficient of Performance (COP) labelling and the actual installed energy efficiencies of the equipment. This requires further analysis and research to inform input variables for the National House Energy Rating Scheme.

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    - The three tasks all adopted the installation process. However, the reflective subfloor insulation tasks required two levels of industry involvement. In Task 1, industry collaborators organised a standard contractor who marketed their business as installers of the nominated reflective subfloor system. Due to the incorrect installation practises encountered in Task 1, for Task 2 the manufacturer of the reflective subfloor system nominated and trained a contractor. Aside from this difference, and to maintain an unbiased approach, the subfloor insulation system installation methodology followed the same steps, namely:..... 10
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## 2. Introduction

Resulting from the global awareness of climate change and its relationship to human activity, the Australian government has initiated a range of measures to reduce greenhouse gas emissions since 1992 (AGO, 1998; COAG, 2010). The measures include regulations to reduce the amount of energy that may be required to condition residential and commercial buildings (ABCB, 2003; Drogemuller, 1999; Tucker et al., 2002). The Nationwide House Energy Rating Scheme (NatHERS) was established and in co-operation with industry and state governments, established climate-based thermal comfort levels, internal load parameters and star-bands for Australian housing (Ballinger & Cassell, 1995). Based on the newly developed Star Rating based metric it was agreed that a minimum performance rating of 3.5 to 4 Stars would be adopted by all jurisdictions in 2003-2004 (ABCB, 2003). The minimum thermal performance requirement was upgraded to 5 Stars in 2006 (ABCB, 2005), and to 6 Stars in 2010 (ABCB, 2010). The change from no or minimal built envelope thermal performance regulations in 2002 to the 6 Star requirement of 2010 has had a significant impact on material choices and construction methods in the cooler and hotter climates. It is expected that by 2020 the regulations will include other aspects that effect building energy use, including domestic hot water services and lighting, and a further increase to the minimum Star Rating requirement (Pitt & Sherry, 2010).

These regulatory developments are inherently linked to the thermal performance of lightweight buildings, which rely greatly on the quality of envelope design and construction. A high quality lightweight timber framed envelope is achieved through the appropriate use of insulation within the subfloor, external walls, internal walls, ceiling and roofing built fabric systems, between unconditioned and conditioned spaces, and through the careful installation of building membranes to control infiltration (Dewsbury & Nolan, 2015; Hastings, 2007). The insulation will significantly reduce the unwanted outward or inward heat flow to occupied and often conditioned spaces. After matters affecting the design of a high quality envelope are achieved, and subject to climate and access or exclusion of solar radiation, thermal mass can then be used to moderate temperature fluctuations within each room (Slee & Hyde, 2015).

However, as the Australian design and construction sector has continued to adopt the required level of thermal performance specified by the Building Code of Australia, there has been a significant reduction in the use of lightweight timber platform floored construction systems. This has generally resulted from industry-based recommendations to use more massive systems instead of lightweight timber, from general marketing literature and the energy rating industry, where a common recommendation is to replace lightweight construction systems with more massive systems such as a concrete slab-on-ground floor (Floyd Energy, 2014; Iskra, 2004; Sustainable Energy Authority, 2004; Tony Isaacs Consulting Pty Ltd, 2006). This general adoption appears to be caused by perceptions that any thermal mass is good, regardless of quantity or solar access, and that it is too costly or the construction process is too difficult to construct well insulated and thermally efficient lightweight buildings. This Australian pattern appears to be at odds with international design and construction trends where there are an assortment of methods to provide high quality insulation and thermal mass within lightweight buildings (Nolan & Dewsbury, 2007). Within this context, there is a significant need for appropriate and specific building science knowledge and education in the Australian design, construction and thermal performance industries (M. Dewsbury, 2011; Dewsbury, Wallis, Fay, & Nolan, 2009; Energy Partners, 2007; Henderson, 2005; HIA, 2004; Iskra, 2004; Marceau, 1999; Murphy et al., 2005; Productivity Commission, 2004; Slee, Parkinson, & Hyde, 2013; Tucker et al., 2002; Wallis & Dewsbury, 2009; Williamson, Plaves, & Hart, 2007). Similarly, for timber products and lightweight construction to be

thought of in a complementary nature and to be intrinsically linked to high thermal performance buildings, is paramount for the ongoing sustainability of a readily available Australian timber resource.

Past empirical validation research within the Launceston test buildings has already verified construction practices and their impact on thermal performance (Dewsbury, 2015a; Dewsbury, Fay, & Nolan, 2008; Dewsbury, Nolan, & Fay, 2007). However, industry and home owner concerns became the springboard for this research task has focused on the measured thermal performance and effectiveness of subfloor insulation for platform floors.

This report covers an introduction to the research task reasoning, the Nation-wide House Energy Rating Scheme system, the general methodology and a vast quantity of research data. The research results follow this section. Due to the complexity and quantity of data, task-specific appendices are included with this report, namely:

- Appendix 1: Industry installed reflective subfloor insulation
- Appendix 2: Manufacturer installed reflective subfloor insulation
- Appendix 3: Industry installed bulk subfloor insulation

The final sections to this report are Conclusions, Recommendations (which includes future research needs), Acknowledgements and Bibliography.

## **Subfloor insulation**

In response to the increased insulation requirements for timber platform flooring systems the manufacturing and construction industries have reconfigured and created new subfloor insulation products. These have included batt or bulk products with varying support systems, rigid polystyrene systems (some with reflective foil) and a range of reflective foil and foil sandwich systems. Many of these products have borrowed from, or redesigned, internationally accepted systems to suit Australian construction practices. However, industry representative bodies and government agencies have raised concerns with regard to industry knowledge of, and the specific installation requirements for, reflective subfloor insulation products as a component of platform floored systems (M. Dewsbury, 2012; M Dewsbury, 2012a, 2012b; Dewsbury, 2013; Dewsbury, Geard, & Fay, 2013).

The lack of adequate historical material use and installation practice knowledge has led to misunderstandings about what correct installation is, and its relative impact on thermal performance. This has led to a quandary for building designers, builders and building inspectors, all of whom have contacted members of the project steering committee and the University of Tasmania research team, seeking clarification and advice. Does incorrectly installed reflective subfloor insulation require removal and reinstalling, or does the whole house thermal performance rating get downgraded? Similarly, problems that are often raised about bulk subfloor include installation practice, the product's long-term durability - through it either falling from or through subfloor support systems, and product deterioration.

Within this context, the enclosed-perimeter platform-floored test building, at the Launceston Campus University of Tasmania, was used as a testing and empirical validation platform to explore contemporary reflective and bulk subfloor installation practices and any thermal performance effect that may occur. After exploring concerns about the most common subfloor insulation products within the market place, there was a desire to quantify the thermal performance effect of insulation types and installation practice. Within this framework the project steering committee established three platform-floored, subfloor insulation tasks, namely:



- Task 1 - Industry installed reflective subfloor insulation,
- Task 2 - Manufacturer installed reflective subfloor insulation, and
- Task 3 - Industry installed bulk subfloor insulation.

These three distinctly different research tasks are described in greater detail below in the Methodology section. Additionally, in all three cases, detailed measurements were taken and a detailed building thermal performance simulation was completed, allowing for a comparison of simulated and measured data.

## **Nation-wide house energy rating scheme (NatHERS) & empirical validation**

A significant by-product of this research is the acquisition of high quality data sets which can be used to inform the ongoing improvement and calibration of the CSIRO developed CHENATH building simulation software, which is the principle tool behind the AccuRate, BERS and FirstRate house energy rating tools. The true benefits provided by tight well-insulated buildings could only become obvious when the energy required to maintain acceptable levels of thermal comfort is reduced. In Australia the NatHERS protocol has established nationally agreed, climatically based, thermal comfort bands for most populated parts of Australia, and occupancy patterns for different rooms within a house (ABCB, 2006; Ballinger & Cassell, 1995; A Delsante, 2005; Lee, 2005; Marker, 2005). Previous research has established that the occupancy and conditioning patterns within NatHERS do resemble modern households (Ambrose, James, Law, Osman, & White, 2013). Additionally, recent empirical validation research has documented that the software does consider built fabric and climatic variables quite well, but differences between measured and simulated results indicated the need to improve algorithms within the CHENATH and AccuRate simulation tools with regard to lightweight buildings, thermal mass and heating/cooling energy use (Delsante, 2006; M. Dewsbury, 2011; Dewsbury & Fay, 2013; Dewsbury, Soriano, & Fay, 2011; M. Dewsbury, F. Soriano, G. Nolan, & R. Fay, 2009; Geard, 2011). Similarly, others have identified differences in energy use and have explored the further calibration of energy algorithms (Williamson et al., 2007). This historical research framework has made software developers and building researchers aware of the program's capabilities and allowed for this research to further explore the capacity of the CHENATH software to accurately simulate the thermal conditions provided by reflective subfloor insulation and bulk subfloor insulation.

When insulation systems are used, the impact on energy use to condition the room can be reduced significantly. The first aim of many building designs is to use passive principles to obtain satisfactory levels of human thermal comfort. However, the internal room temperatures achieved through an unconditioned passive building operation may often be hotter or cooler than the occupant's expectation for human comfort. When this occurs, the approach from NatHERS is to engage natural ventilation strategies, followed by mechanical heating and cooling systems, to provide a more thermally comfortable internal environment (NatHERS, 2007). The NatHERS system applies these principles to housing, where thermal comfort temperature bandwidths have been established for 69 climate typologies within Australia. A NatHERS simulation, for energy rating purposes, calculates the amount of energy in megajoules that may be required to maintain human thermal comfort within each room of a house.

To validate empirically the thermal impact of the built fabric, the output data from detailed non-standard simulations using software tools like CHENATH, and detailed measurements from carefully constructed and instrumented buildings, are collected and compared. This is discussed below in the Methodology section. To date there has been no empirical validation research, which has compared the energy use of a thermally controlled and conditioned test building to the energy calculation from a detailed simulation from the AccuRate Nationwide

House Energy Rating Scheme approved software. The inclusion of a heating and cooling component allows for software developers to be made aware of differences between simulated and measured data sets for the ongoing improvement and calibration of the CSIRO developed building simulation tools.

### **3. Methodology**

To test the real life, (and not laboratory), thermal performance of built fabric systems requires the use of appropriately designed and constructed test building facilities (Judkoff, 1983; Kalyanova, 2009; Loutzenhiser, 2007; Moinard, 1999) . The measured thermal performance data can be compared to simulated thermal performance to ascertain software capabilities. The comparison of measured and simulated thermal performance provides empirical information to validate the built envelope and the heating and cooling energy calculation modules within house energy rating simulation tools. To provide appropriate information and guidance to industry and government, this research task required the detailed measurement, the detailed thermal simulation and the analysis of the measured and simulated data sets of the three subfloor insulation systems described below. Many parts of the methodology were the same for each task, however there were some task specific modifications. The common elements of the methodology are discussed within this section. Task specific elements are discussed within the Appendix for each task.

#### **Built fabric methodology**

To adequately validate thermal performance improvements requires the collection of measured and simulated data sets . Within this project each built fabric research task required precise definitions to enable rigour and accuracy. The detailed measurements from the test building provided the elemental data on thermal performance relative to measured site conditions and simulated thermal performance data sets. To acquire simulated thermal performance data sets, non-standard, detailed built envelope thermal simulations were completed using the AccuRate front end user interface and the CHENATH simulation program. The built fabric, data acquisition and simulation methodologies are discussed below.

#### **Installation of subfloor insulation system**

The three tasks all adopted the installation process. However, the reflective subfloor insulation tasks required two levels of industry involvement. In Task 1, industry collaborators organised a standard contractor who marketed their business as installers of the nominated reflective subfloor system. Due to the incorrect installation practises encountered in Task 1, for Task 2 the manufacturer of the reflective subfloor system nominated and trained a contractor. Aside from this difference, and to maintain an unbiased approach, the subfloor insulation system installation methodology followed the same steps, namely:

1. Industry members of the project steering group identified the most commonly installed reflective and bulk subfloor insulation systems in Tasmania.
2. Industry members of the project steering committee organised for an insulation installation business, which has been in business for some time and has a good industry reputation, to install the product.
3. A university staff member met the contractor on site and ensured that the contractor had the required product literature, was well informed about the task at hand, and had installed the product previously.
4. Following normal industry practices, the contractor was then left to install the reflective subfloor insulation product unhindered and unsupervised.

5. After installation was completed a detailed analysis of the installation quality was completed and documented (as discussed in the Appendices 1, 2 & 3).

Figures 4, 5 and 6 below show the installation of the subfloor insulation system for each of the three tasks.



*Figure 1: Industry installed reflective subfloor insulation*



*Figure 2: Manufacturer installed reflective subfloor insulation*



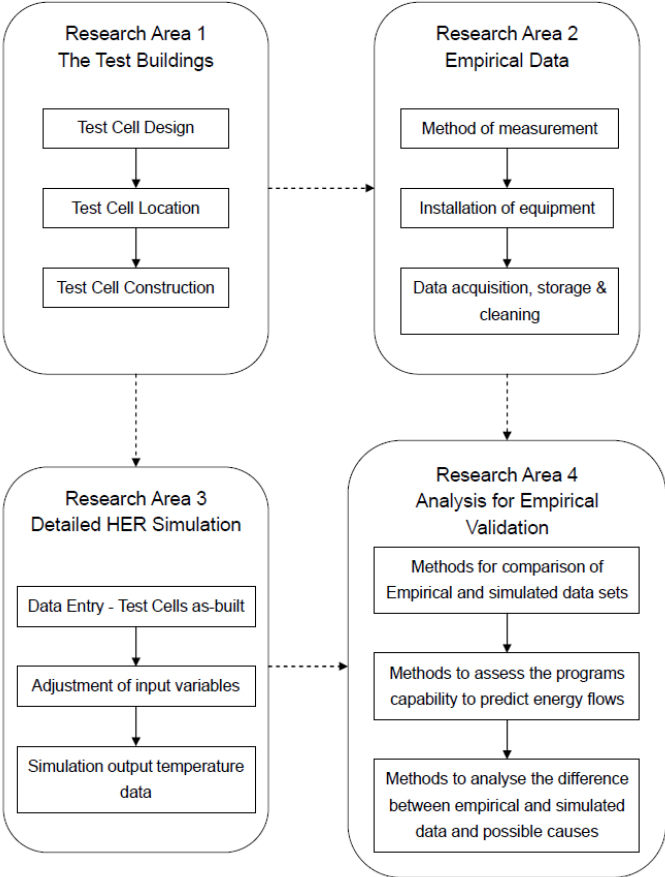
*Figure 3: Industry installed bulk subfloor insulation*

### **Thermal performance data acquisition methodology**

For appropriate measurement to occur, the three built systems required installation within a test-building and empirical validation framework. This type of framework would enable a suitable measurement and data acquisition process to support the detailed thermal performance simulation and the comparison of measured and simulated data sets. A framework of this nature was documented and used by Dewsbury (M. Dewsbury, 2011; M Dewsbury, 2011; Dewsbury & Nolan, 2015) and included a process diagram, as shown in Figure 4.

The three test buildings, located on the Launceston Campus University of Tasmania, were purpose-built for material thermal performance analysis and empirical validation research tasks for industry and government collaborators (M. Dewsbury, 2011; Dewsbury & Fay, 2013; Dewsbury, Fay, Nolan, & Vale, 2007; Dewsbury, Nolan, et al., 2007; Dewsbury et al., 2011; M. Dewsbury, F. Soriano, et al., 2009; M Dewsbury, F Soriano, G Nolan, & R Fay, 2009). The three test buildings comprise an unenclosed-perimeter platform-floored,

enclosed-perimeter platform-floored and concrete slab-on-ground floored construction systems. For this research, Test Building 2, the enclosed-perimeter platform-floored building, as shown in Figure 5 was used.



**Figure 4: Empirical validation task framework**



*Figure 5: Enclosed-perimeter platform-floored test building*

The generic thermal measurement profile within the test building, is shown in Table 1. This method meets the established minimum measurement profile, for empirical validation purposes, that is supported by the Australian Government (M Dewsbury, 2011).The

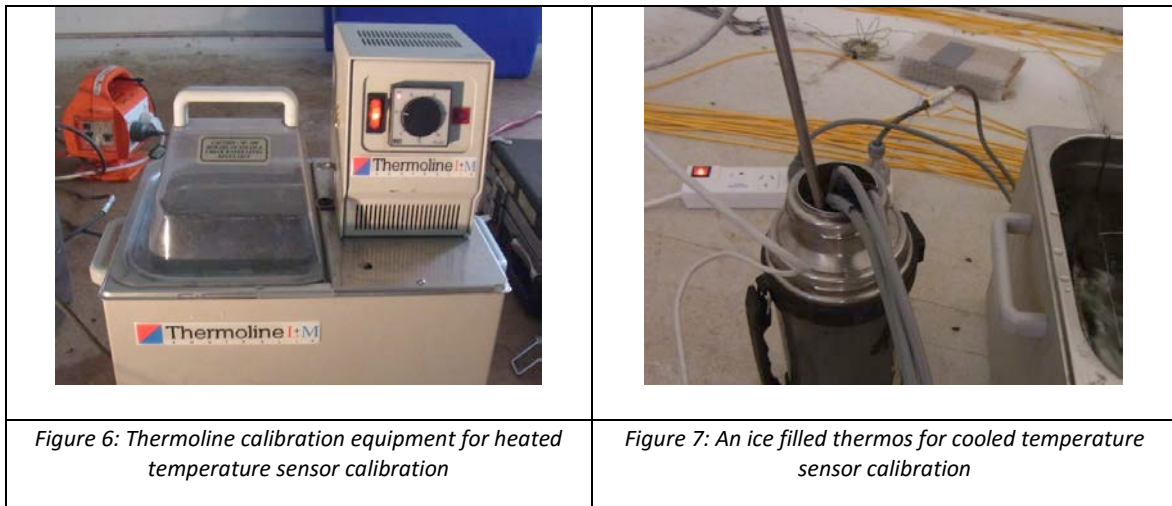
measurements taken from the 600mm, 1200mm, 1200mm globe and 1800mm were averaged to provide an average room temperature.

**Table 1: Test building thermal measurement profile**

<b>Description</b>	<b>Function</b>
1000mm below ground level temperature	Background & supporting data
Ground surface temperature	Background & supporting data
Mid-subfloor zone temperature	Thermal performance and validation data
Outside subfloor insulation surface temperature	Background & supporting data
Inside subfloor insulation surface temperature	Background & supporting data
Outside platform-floor surface temperature	Background & supporting data
Inside platform-floor surface temperature	Background & supporting data
600mm test building room temperature x 3	Thermal performance and validation data
1200mm test building room temperature x 3	Thermal performance and validation data
1200mm globe temperature x 3	Thermal performance and validation data
1800mm test building room temperature 3	Thermal performance and validation data
Inside ceiling surface temperature	Background & supporting data
Outside ceiling surface temperature	Background & supporting data
Outside ceiling insulation temperature	Background & supporting data
Mid-roof space air temperature	Thermal performance and validation data
Inside sarking surface temperature	Background & supporting data
Outside sarking surface temperature	Background & supporting data
Inside sheet-metal roof surface temperature	Background & supporting data
Outside sheet-metal roof surface temperature	Background & supporting data

Additionally, a site weather station collected data for air temperature, relative humidity, wind speed, wind direction and global solar irradiation, which were used in conjunction with other data from the Bureau of Meteorology to create experiment-specific climate input files. Additionally, high quality energy use metering was collected by one of the research collaborators, Aurora Energy, for comparison to simulated energy use.

The installation of all sensors required an initial calibration followed by intermediate calibration during the completion of the three research tasks. All temperature sensors were individually checked for calibration at zero degrees Celsius, room temperature and a temperature close to boiling point (as shown in Figure 6 and Figure 7). Any temperature sensor that did not provide a result within 0.3°C was removed. However most temperature sensors were within 0.1°C of the calibration temperature. The solar radiation, relative humidity and wind speed sensors were compared to output data from similar, pre-calibrated, sensors. The wind direction sensor output was compared to synchronous compass bearings taken beside the wind vane.



With the exception of the energy use data, which was collected cumulatively every fifteen minutes, all other data was collected at ten minute intervals (A. Delsante, 2005). All data, once cleaned, was averaged to hourly data for comparative analysis with the simulated output temperature files (K Lomas, 1991). Other data that was collected, but is not included in this report, included a range of heat flow (flux) measurements, direct vertical north solar irradiation and diffuse solar irradiation. This data requires significant analysis and will be presented in future publications.

To gain adequate information on thermal performance and relative energy use, the test building operation for each built fabric task included four operational modes, namely:

- unoccupied and unconditioned (commonly known as ‘free running’ or ‘free floating’)
- unoccupied and continually heated (to a pre-set temperature)
- unoccupied and intermittently heated (to mimic a NatHERS room operation)
- unoccupied and continually cooled (to a pre-set and agreed temperature).

The temperatures measured, and the energy consumption used, to maintain pre-set temperatures could then be compared to the outputs from the AccuRate house energy rating software. A detailed discussion of the data acquired can be found in the task-specific appendices (Appendix 1 to Appendix 3).

### **Detailed thermal performance simulation methodology**

To enable a more correct analysis of simulated and measured thermal performance data requires the completion of non-standard house energy rating simulations. A standard thermal simulation and energy calculation for house energy rating includes a range of accepted default values for built fabric, infiltration, internal heat loads, thermostat set points and climate input data. All of these can vary significantly from the as constructed built fabric and the climatic conditions during the research task (Clarke, Strachan, & Pernot, 1994; Girault, 1994; K. Lomas, Eppel, Martin, & Bloomfield, 1994; Strachan, 2000). To enable a rigorous comparison of the measured and simulated data set results, changes were made to some front-end input and back-end scratch file inputs for each simulation, as shown in Table 2. Temperature thermostat set points for simulating the heated and cooled modes of operation could only be established once the test building room data had been acquired and cleaned.

The initial research proposal only included the use of a modified conductivity value for the floor, walls and ceiling to account for the reduction in insulation caused by the framing factor (M. Dewsbury, L. Wallis, et al., 2009; Kosny, Yarbrough, Childs, & Mohiuddin, 2007; Syed & Kosny, 2006). However, during the early stages of the research some collaborators

requested that two simulation types be completed. The first simulation type was to include the modified conductivity values as described above. The second was to model each floor, wall and ceiling element as components, which allowed for the built fabric (timber framing) to be accounted for as thermal mass and insulation. For example, a wall might be modelled as:

- 10 m<sup>2</sup> plasterboard, insulation, cavity, cladding, and
- 1 m<sup>2</sup> plasterboard, 90mm softwood, cavity, cladding.

This action did provide different results, but also more than doubled the research task workloads. This established eight simulation types for each built fabric type, namely:

- unconditioned with modified U-value (no-mass)
- unconditioned with modified built fabric thermal mass (with-mass)
- continuously heated with modified U-value (no-mass)
- continuously heated with modified built fabric thermal mass (with-mass)
- intermittently heated with modified U-value (no-mass)
- intermittently heated with modified built fabric thermal mass (with-mass)
- continuously cooled with modified U-value (no-mass)
- continuously cooled with modified built fabric thermal mass (with-mass)

The completion of the detailed simulation tasks provided simulation data sets, which could then be compared to the measured data sets for comparison and validation. The data sets included simulated hourly temperatures and energy for the subfloor zone, test building room and the roof space zone. A detailed discussion on this analysis is shown in the task-specific appendices.

**Table 2: Modified inputs for detailed simulation**

<b>Description</b>	<b>Reason</b>	<b>Experiment Type</b>
Modified floor, wall and ceiling U-values	To account for the reduction in insulation resulting from timber framing	All simulations
Modified infiltration values	To use measured infiltration values rather than the default values	All simulations
Modified internal load values	To use measured internal energy load values rather than the default values	All simulations
Modified heating set points	To reflect the thermal condition of the experiment	Zero for free running and cooled modes of operation. Measured value for heated modes of operation.
Modified cooling set points	To reflect the thermal condition of the experiment	Zero for free running and heated modes of operation. Measured value for cooled modes of operation.
Natural ventilation	To account for non-ventilated operation	Hours of operation and thermostat set points set to zero.

## **Methodology summary**

The discussion above provides a detailed summary of the steps taken to establish built fabrics, acquire measured thermal performance data and the detailed simulation process to enable a comparison of measured and simulated data-sets. The next section presents task-specific experiences and findings from the research tasks.

## 4. Results and Discussion

The results and discussion for this research come from twelve different experiments. Each experiment ran for a minimum of twenty days. Each experiment acquired seven data sets which included measured temperatures, measured energy use, site weather data, BOM weather data, simulated temperatures and simulated energy use. The total research task has acquired 84 data sets. The data from each experiment was combined in a spread sheet format (in the Excel software), to allow for graphical and analytical comparisons. The task-specific appendices include the graphical analysis of measured and simulated data for each experiment, within each task. The following section will summarise some of the key findings.

### General and task non-specific results

This research has found several matters that are common across most of the experiments within each of the three tasks.

#### Built envelope results

- A sample of the measured and simulated temperatures for the enclosed perimeter subfloor is shown below in Figure 8. Due to the very limited thermal mass effect in this zone, there is very little difference between the with-mass and no-mass simulation results. This figure, like most, shows there were often significant differences between the measured and simulated temperatures for the enclosed-perimeter platform-floored subfloor zone. Sometimes the simulated maximum temperatures are warmer, whilst at other times they are cooler. However, a more consistent pattern of under calculation is evident when comparing the simulated and measured minimum temperatures. Within the software the enclosed subfloor area is modelled as a separate zone. The zone is thermally connected to the ground, the external conditions (via the subfloor perimeter wall) and the test building room (via the flooring system). Subject to the differences that may be occurring, and the relative energy within the test building room and the level of subfloor insulation, additional energy may be flowing into or out-of the building.

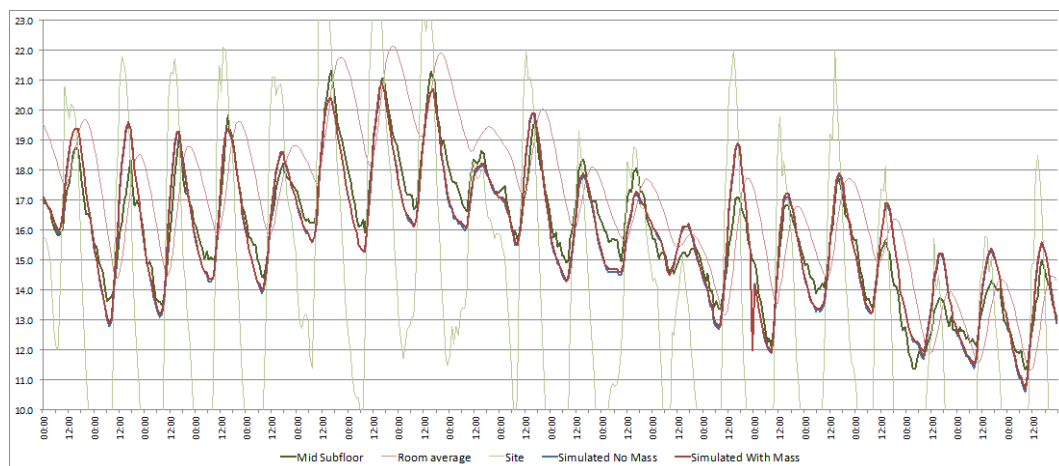


Figure 8: Unconditioned and unoccupied subfloor measured and simulated temperatures for industry installed reflective subfloor insulation

- A sample of the measured and simulated temperatures for the roof space zone is shown below in Figure 9. This figure, like most, shows there were often significant



differences between the measured and simulated temperatures for the roof space zone. In most cases the calculated minimum temperature is lower than the measured temperature, whilst the calculated maximum temperature is higher than the measured mid roof space temperature. The analysis of the data across the various experiments may indicate that these differences are due to radiant heat flow calculations. Subject to the differences that may be occurring, and the relative energy within the test building room and the level of ceiling insulation, additional energy may be flowing into the building.

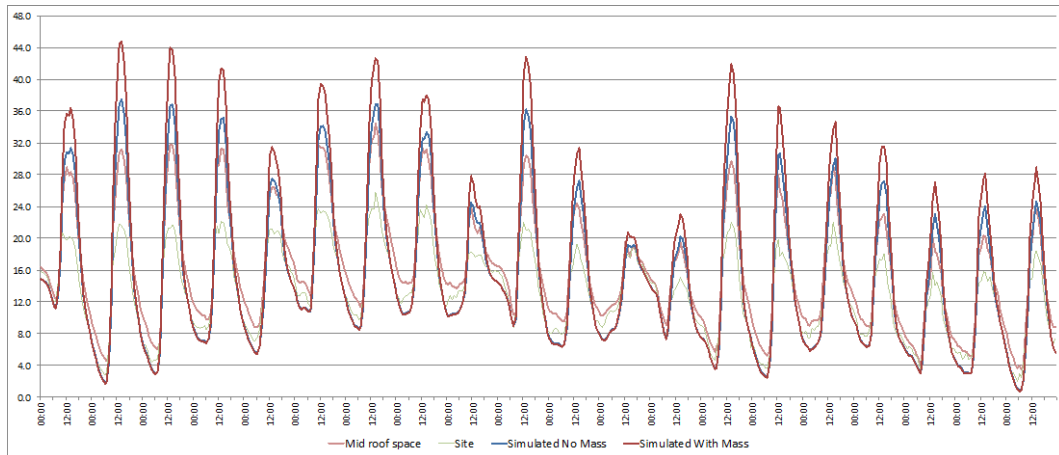


Figure 9: Unconditioned and unoccupied roof space measured and simulated temperatures for industry installed reflective subfloor insulation

- Generally, as much as there were differences observed between the measured and simulated temperatures, the software was responsive to hourly changes in environmental inputs.

### Heating and cooling energy use results

- A sample of the measured and simulated energy data for the test cell room, during the continuously heated task is shown below in Figure 10. The detailed simulations established a ‘raw’ heating and cooling energy calculation to condition the test building room. A reverse-cycle air-conditioner was used to condition the room during heated and cooled modes of operation. However, the software uses a simplified energy calculation with a coefficient of performance of 1. This resulted in significant difference between the simulated and measured energy use. This over-calculation of simulated energy should be expected due to the different forms of energy efficiency in the heating and cooling algorithms. But this issue highlights the need for more contemporary options within the simulation engine.

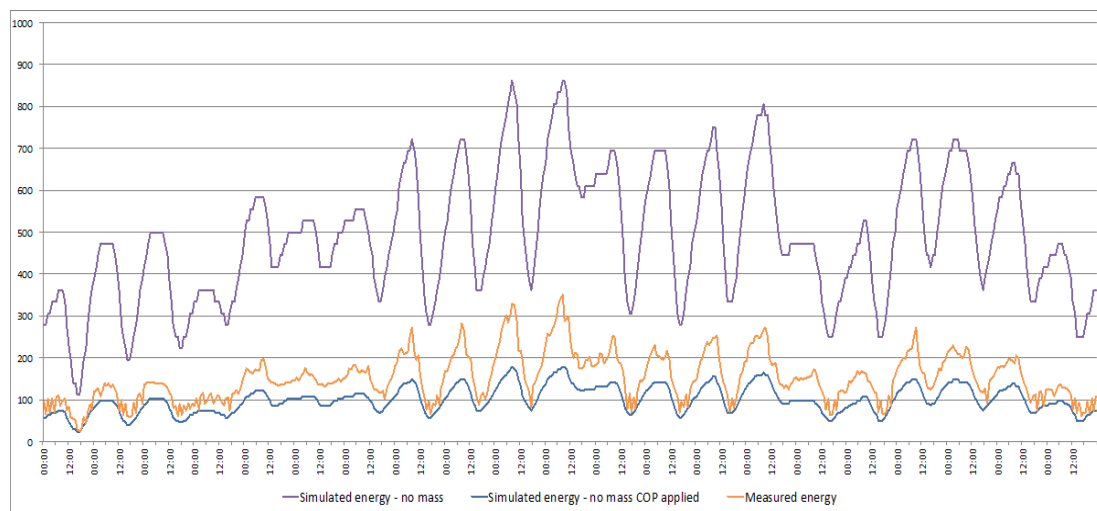


Figure 10: Continuously heated and unoccupied measured and simulated energy use from industry installed reflective subfloor insulation

- Figure 10 above, also shows the COP applied data from the continuously heated task. COP applied energy use data sets were established by dividing the simulated energy use by the accepted heating and cooling COP values of the installed reverse-cycle air-conditioner. However this created a situation where the simulated COP applied energy data values were significantly less than the measured energy. This requires further investigation as the operational efficiency of the air-conditioner, the thermal resistance of the built fabric, or the thermal capacitance of the built fabric may cause the significant differences.
- One of the key aspects of the implementation of thermal performance regulations is the capacity to reduce peak energy demands. Figure 10 above shows significant differences between type of heating simulation and the measured peak energy needs. The different tasks, with their different built fabric insulation systems and the types of heating energy simulation, all show significant differences in the peak energy demand. This demonstrates that well insulated built fabric and energy efficient appliances can significantly reduce peak energy demand.
- The reverse-cycle air-conditioner was selected based on its efficiency and its capacity to provide cool air, to allow a comparison of measured and simulated energy use for cooling. However during this research it was established that the on-board computer that forms a part of the equipment's efficiency would not allow the room to be cooled to less than 18°C. Attempts were made to over-ride this control mechanism but they were unsuccessful. This meant that some continuously cooled tasks worked, whilst others did not. Future research must consider the timing of experiments relative to site climate, to enable the completion of an effective and productive experiment.

To provide a better and more detailed report on the results from each task, they are listed below in dot point form. In all cases there is further information within the appendix for each task.

### Industry installed reflective subfloor insulation results

This was the first task completed within this research project, and it made the research team and the project collaborators aware of some interesting challenges facing lightweight

construction. After the reflective subfloor insulation was installed, the building was then operated unoccupied, and in unconditioned, continuously heated, intermittently heated and continuously cooled modes of operation. During operational modes an array of temperatures was recorded on site and within the building, and energy use was measured. The building was then modelled in a non standard, detailed manner to allow for the comparison of measured and simulated data for empirical validation of its as-built thermal performance properties. The results discussed below refer to the analysis of measured and simulated data within Appendix 1, which compared the thermal performance and relative energy use to condition the test building room in its four modes of operation.

In this research task the reflective subfloor insulation was installed incorrectly, as shown in Figure 1, and it was considered that this would significantly compromise its thermal resistance properties. Initially, it was planned that a comparison of the simulated correctly and incorrectly installed reflective subfloor insulation would occur within this task. However the challenges and experiences of this task had a significant impact on the whole research program. Within this context the analysis in this report has focussed on the act of insulation and the detailed thermal modelling of the as-built scenario. The as-built subfloor system has a calculated R-value of 0.44, which is significantly different to the marketed R3.0 and would have a significant impact on the thermal comfort and performance of the building. The task did plan to assess cooling energy, but due to pre-set restrictions within the air-conditioner controller, as mentioned above, the cooling operation within this task failed.

Initial analysis has revealed several findings, namely:

- Most significantly, this task identified the shortcomings in manufacturer-based education, product installation literature and training in reflective insulation installation resulting in a R0.44, rather than a marketed R3.0, insulated platform-floor system.
- The task also identified a gap in product knowledge for builders, building surveyors, building designers, engineers and architects (Dewsbury, 2015b; Dewsbury et al., 2013). This indicates that if reflective subfloor insulation is to be accepted for broad use, extensive training and documentation must be provided; otherwise there may be significant comparative complaints from owners of new platform-floored buildings that are not providing the expected reduced heat flow through the floor system.
- In all cases there were distinct and significant differences between the measured and simulated no-mass and with-mass temperatures for the subfloor zone and roof space zone. The impact that these differences may have on the test building room temperature requires further investigation.
- The inclusion of the built fabric elements, (thermal mass), did not appear to have much impact on the simulated temperatures for subfloor zone.
- The inclusion of the built fabric elements did have an impact on the simulated temperatures for the roof space zone.
- The inclusion of the built fabric mass did have a generally positive impact on the test building room simulations by providing lower residual values than the no-mass simulation data-sets. Figure 11 below best shows this pattern, which is a sample of the measured and simulated temperatures for the test building room. This pattern of the generally closer fit of the as-built with-mass simulated and measured data sets was observable in most tasks.

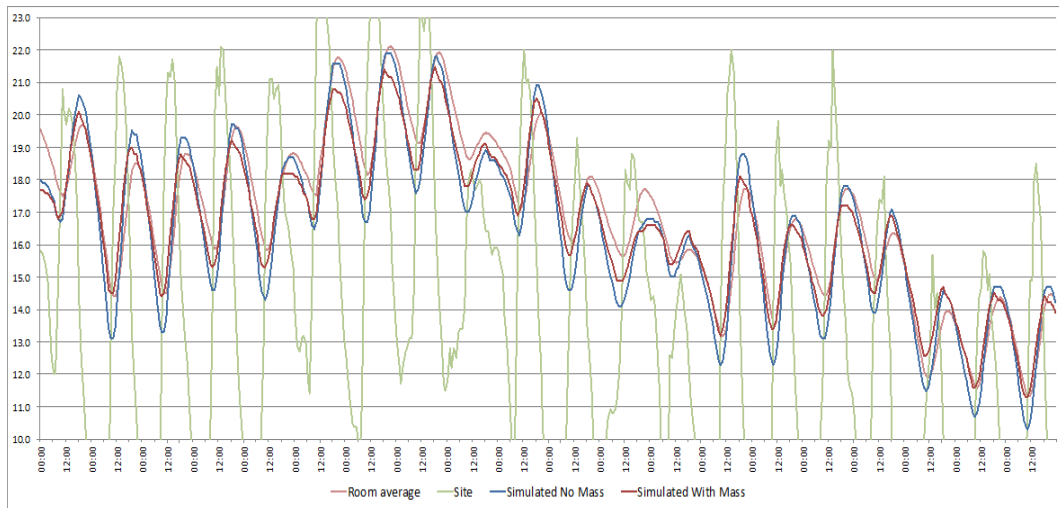


Figure 11: Unconditioned and unoccupied measured and simulated test building room temperatures from industry installed reflective subfloor insulation

- The analysis, as shown in Appendix 1, showed a reasonable correlation between simulated and measured temperatures, which included a significant devaluing of the R-value for the reflective subfloor insulation. Further analysis needs to be completed to establish the relative impact or devaluing that may be required for incorrectly installed reflective subfloor insulation.
- As mentioned in the general section above, the simulated raw energy use data was significantly different from the measured air-conditioner energy use during heated modes of operation.
- As mentioned in the general section above, the COP applied simulation data did have a much closer fit to the measured reverse-cycle air-conditioner energy use during the heated modes of operation, which was best shown in the very low residual values during the intermittently heated mode of operation
- The pattern in the time series analysis energy graphs was very similar for the measured and raw data sets, indicating the heating energy algorithm is working well but may require subtle calibration.

Furthermore, the de-rating of the thermal performance for a new home with incorrectly installed reflective subfloor insulation requires further analysis. To provide an example of how incorrectly installed subfloor insulation may impact on house thermal performance a house plan, that was developed by the University for previous research, is shown in **Error! Reference source not found.** This is a house of 167m<sup>2</sup>, which is smaller than the average Australian home. Table 3 shows the calculation of heat loss for this house with correctly and incorrectly installed reflective subfloor insulation. The R-values for walls, windows and roof are typical for houses within Australian temperate climates.

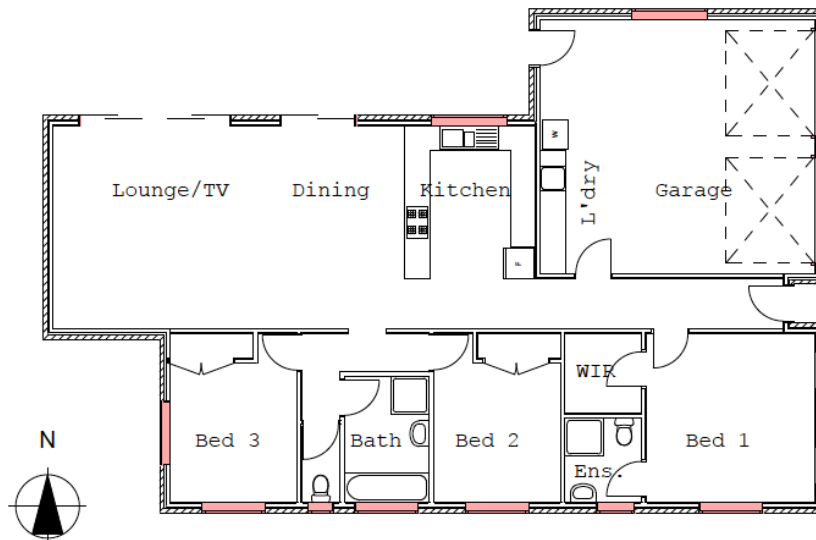


Figure 12: Sample house plan developed by UTAS for research purposes

**Table 3: Calculation for relative heat loss for reflective subfloor insulation**

Element	Area m <sup>2</sup>	Thermal Resistance R-value (M <sup>2</sup> K)	Conductivity U-value W/m <sup>2</sup> K	Rate of heat loss (W/K)	
				Correctly installed	Incorrectly installed
Floor (Presumed)	167	3.00	0.33	55.7	
Floor (Actual)	167	0.72	1.39		231.9
Walls	150	2.8	0.36	53.6	53.6
Windows	22.7	0.4	2.5	56.8	56.8
Doors	3.78	0.3	3.33	12.6	12.6
Roof	167	4.6	0.22	36.3	36.3
				214.9	391.2
Difference in rate of heat loss per degree					176.3
Percentage difference in rate of heat loss					+182%

The calculation shows that the house with incorrectly installed reflective subfloor insulation has 1.82 times greater unwanted heat loss or heat gain, than the house with correctly installed subfloor insulation. This simple calculation shows the very significant impact on house thermal performance, occupant comfort and possible heating and/or cooling energy needs that may occur when reflective subfloor insulation is installed incorrectly.

Additionally, this task has generated a significant amount of data that still requires further analysis, which will result in further publications and recommendations to government and industry. For further background information refer to Appendix 1.

### **Manufacturer installed reflective subfloor insulation results**

In this research task, the reflective subfloor insulation was installed as per the manufacturers specification within the subfloor zone of the enclosed-perimeter platform-floored test building, as shown in Figure 2, which allowed for an appropriate validation of the as-built thermal performance properties. The building was then operated unoccupied, and in unconditioned, continuously heated, intermittently heated and continuously cooled modes of operation. During operational modes an array of temperatures were recorded on site and within the building, and energy use was measured. The building was then modelled in a non-standard, detailed manner to allow for the comparison of measured and simulated data for

empirical validation of its as-built thermal performance properties. The results discussed below refer to the analysis of measured and simulated data within Appendix 2, which compared the thermal performance and relative energy use to condition the test building room in its four modes of operation.

Initial analysis has revealed several findings, namely:

- Most significantly, this task identified the short comings in manufacturer-based education, product installation literature and training in reflective insulation installation (Dewsbury, 2015b; Dewsbury et al., 2013) .
- The task identified a gap in product knowledge for builders and product installers. The final installer spent considerable time clarifying installation needs with national representatives of the product manufacturer. A very lengthy installation process then ensued. This indicates that if reflective subfloor insulation is to be correctly installed to obtain the calculated thermal resistance value of R2.39, extensive training and documentation must be provided (Dewsbury, Geard, & Dunlop, 2014).
- As mentioned in the general section above, there were regular, and at times significant, differences between the subfloor measured and simulated temperatures. The inclusion of the built fabric thermal mass did not appear to affect the subfloor simulation data. The impact that these differences may have on the test building room temperature requires further investigation.
- As mentioned in the general section above, there were regular, and very significant, differences between the roof space zone’s measured and simulated temperatures. This was often most apparent for daily maximum temperatures. The inclusion of the built fabric thermal mass did significantly affect the roof space maximum temperatures. However the minimum simulated no-mass and with-mass temperatures were often very similar to the minimum roof space measured temperatures.
- There were regular, and at times, significant differences between the test building room measured and simulated temperatures. An example of this is shown in Figure 13 below. Often the average difference was quite small, but differences between the simulated and measured maximum and minimum temperatures were up to 3.3°C, which may have a significant impact on cooling and heating energy calculations.

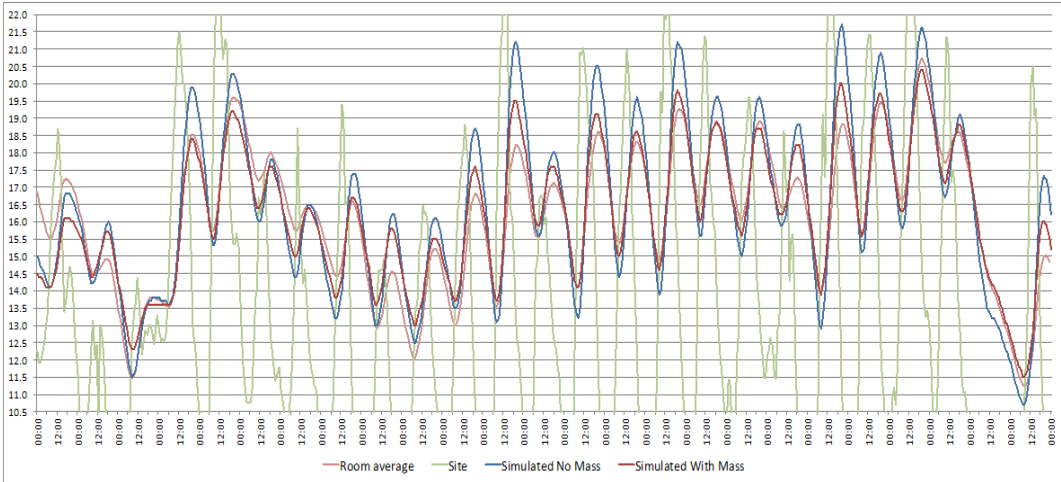


Figure 13: Unconditioned and unoccupied measured and simulated test building room temperatures from manufacturer installed reflective subfloor insulation

- The inclusion of the built fabric mass, as shown above in Figure 13, did have a generally positive impact on the test building room simulations by providing lower

residual values than the no-mass simulation data sets. This is pattern is continuously shown in the time series graphical analysis, in Appendix 2, by the generally closer fit of the as-built with-mass simulated and measured data sets.

- The analysis presented in Appendix 2 shows a reasonable correlation between simulated and measured temperatures, which confirms the thermal performance characteristics of reflective subfloor insulation, if installed correctly in a very similar manner to that occurring in this research task.
- As mentioned in the general section above, the simulated raw energy use data was significantly different from the measured reverse-cycle air-conditioner energy use during heated modes of operation.
- As mentioned in the general section above, the pattern in the time series energy graphs was very similar for the measured and raw data sets, indicating the heating energy algorithm is working well but may require subtle calibration.
- As mentioned in the general section above, the COP applied simulation data did have a much closer fit to the measured reverse-cycle air-conditioner energy use during the heated and cooled modes of operation, which was best shown in the very low residual values.
- As mentioned in the general section above, the application of the accepted COP value for the reverse-cycle air-conditioner often created significant positive residual values. This requires further investigation as the difference in energy use could be due to energy calculation algorithms in the software, a greater flow of energy through the built fabric or the air-conditioner as-installed may have a lower COP.

Additionally, this task has generated a significant amount of data that still requires further analysis, which will result in further publications and recommendations to government and industry. For further background information refer to Appendix 2.

### **Industry installed bulk subfloor insulation results**

In this research task, a standard insulation installation contractor was engaged to install bulk subfloor insulation within the subfloor zone of the enclosed-perimeter platform-floored test building. After the insulation was installed, the building was then operated unoccupied, and in unconditioned, continuously heated, intermittently heated and continuously cooled modes of operation. During operational modes an array of temperatures was recorded on site and within the building, and energy use was measured. The building was then modelled in a non-standard, detailed manner to allow for the comparison of measured and simulated data for empirical validation of its as-built thermal performance properties. The results discussed below refer to the analysis of measured and simulated data within Appendix 3, which compared the thermal performance and relative energy use to condition the test building room in its four modes of operation.

Initial analysis has revealed several findings, namely:

- In stark contrast to the reflective subfloor insulation tasks, discussed above and in Appendix 1 and Appendix 2, the first attempt to install the bulk subfloor batt system, as shown in Figure 3, was completed adequately. This method would achieve the marketed R-value for this system.
- The installation guidelines did specify the use of metal straps to assist in keeping the glass-wool batts in place. These were supplied by the manufacturer but were not used in this installation. This method of installation relies on the glass-wool batts being held in place for many years purely by friction. It is unknown if, and over what time period, the batts may drop from the subfloor system. It should be noted that members of the research team have seen batts on the ground under other existing buildings.

- During the six months of this task some very limited delamination of glass-wool batts became evident, as shown in Figure 14. More research needs to occur to quantify this issue over a longer period of time, as houses are built to last many years. Alternatively, a maintenance schedule needs to be developed by manufacturers and provided to home-owners, builders and building certifiers.



*Figure 14: Delamination of glass-wool subfloor insulation batt*

- The installation was effective but it was not completed to the manufacturer's specification. More research needs to be completed which can record the quality of as-built installations for bulk subfloor insulation.
- As much as this task was able to be completed as-installed, it would be prudent that training should be provided to building designers (architects, engineers, building designers), builders, product installers and building certifiers in the correct methods of installation and the common pitfalls that exist from the use of unsuitable batts or support systems.
- As mentioned in the general section above, there were regular, and at times, significant differences between the subfloor measured and simulated maximum and minimum temperatures. The inclusion of the built fabric thermal mass did not appear to affect the subfloor simulation data. The impact that these differences may have on the test building room temperature requires further investigation.
- As mentioned in the general section above, there were regular, and very significant, differences between the roof space zone's measured and simulated temperatures. This was often most apparent for daily maximum temperatures. The inclusion of the built fabric thermal mass did significantly affect the roof space maximum temperatures. However the minimum simulated no-mass and with-mass temperatures were often very similar to the minimum roof space measured temperatures. The impact that these significant maximum differences may have on the test building room temperature requires further investigation.
- There were regular, and at times significant, differences between the test building room measured and simulated temperatures. Often the average difference was quite small, but differences between the simulated and measured maximum and minimum temperatures were up to 3.6°C, as shown in Figure 15 below, which may have a significant impact on cooling and heating energy calculations.



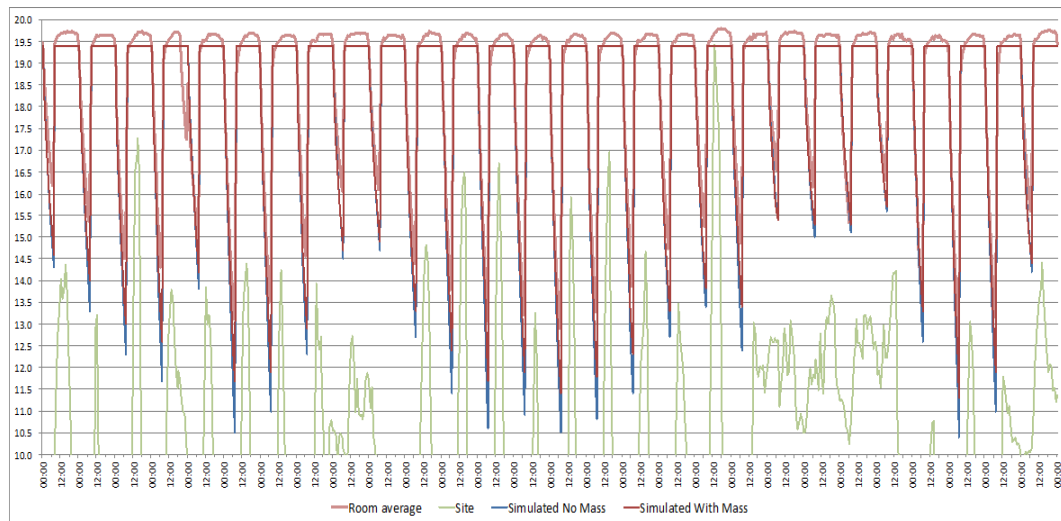


Figure 15: Intermittently conditioned and unoccupied measured and simulated test building room temperatures from industry installed bulk subfloor insulation

- The inclusion of the built fabric mass did have a generally positive impact on the test building room simulations, as shown in Figure 15 above, by providing lower residual values than the no-mass simulation data sets. This is shown in the time series graphical analysis, within Appendix 3, by the generally closer fit of the as-built with-mass simulated and measured data sets.
- The analysis presented in Appendix 3 shows a reasonable correlation between simulated and measured temperatures, which confirms the thermal performance characteristics of the stiffened glass-wool bulk subfloor insulation, if installed correctly in a very similar manner to that occurring in this research task.
- Further analysis needs to be completed to establish the relative impact or devaluing that may need to be applied to new housing when unsuitable batt products and/or support systems have been installed ineffectively within platform floored housing.
- As mentioned in the general section above, the simulated raw energy use data was significantly different from the measured reverse-cycle air-conditioner energy use during heated modes of operation.
- As mentioned in the general section above, the pattern in the time series energy graphs (within Appendix 3) was very similar for the measured and raw data sets, indicating the heating energy algorithm is working well but may require subtle calibration.
- As mentioned in the general section above, the COP applied simulation data did have a much closer fit to the measured air-conditioner energy use during the heated and cooled modes of operation, but most often produced a simulated energy use that was significantly less than measured energy use. This is not an adequate situation and requires further investigation, as the difference between simulated and measured energy use could be due to energy calculation algorithms in the software, a greater flow of energy through the built fabric or the air-conditioner as-installed may have a lower COP.

Additionally, this task has generated a significant amount of data that still requires further analysis, which will result in further publications and recommendations to government and industry. For further background information refer to Appendix 3.

## 5. Conclusion & Recommendations

This research undertook a thermal assessment of three built fabric subfloor insulation systems in conditioned and unconditioned modes of operation. Each of the built fabric systems was modelled in as-built, experiment specific, detailed thermal performance simulations. From the data shown in the three project appendices (as attached), and as discussed above in the results, there are many findings.

Firstly, the general patterns of the measured and simulated data sets for the subfloor, room and roof space zones were similar, which indicates that the CHENATH software is considering many built fabric and climatic inputs but requires calibration.

In all three of the unconditioned tasks there were significant differences between the measured and simulated data sets of the subfloor, room and roof-space zones. The differences often occur at minimum and maximum temperatures, which would also correspond with times when heating or cooling operation would be called upon to maintain thermal comfort. If the roof space was consistently warmer, then more energy would be flowing into the room, similarly if the subfloor was warmer, but cooler than the room, there would be a lesser flow of energy to the subfloor. Furthermore, the heating and cooling energy calculations may be significantly affected if the test building room is storing more energy or has a slower loss of energy. All these instances would impact on the energy within the test building room and corresponding heating and cooling energy to maintain human comfort. However the differences appear to be linked to some climatic variables, (i.e., solar radiation on the sheet metal roofing), and this requires further investigation.

This research developed two simulation types, no-mass modified U-value and with-mass built fabric thermal mass. This research did show that this variation in the simulation input often produced significantly different results for the test building room and roof space, with a much less apparent effect on the subfloor temperatures. However, the two simulation types provided varying qualities of better fit between the simulated and measured data sets. This requires further analysis to establish probable benefits from, or problems with, the inclusion of the built fabric thermal mass, and to allow for algorithmic improvement

The analysis of the measured and simulated energy use raised more questions than answers. As a reverse-cycle air-conditioner was used to provide heating and cooling it was expected that there would be significant differences between the measured and simulated data sets. However it was expected that when a COP multiplier was used the differences between the measured and simulated data sets would reduce. However, the application of the COP multiplier allowed the measured energy use to be greater than the simulated energy use. This is a complex issue and requires further investigation, as the built fabric or the true efficiency of the reverse-cycle air-conditioner could cause the differences. One of the challenges that may face the deeper analysis of the reverse-cycle air-conditioner may be a significant difference between ISO testing results and results from a standard installation within a real building. There are unpublished discussions which revalue some equipment from a Cop greater than 4 to a Cop of around 2. This does require further investigation. Furthermore, one of the key aspects of thermal performance legislation is to reduce both general and peak energy demands. The use of reverse-cycle air-conditioners in this task showed a significantly lower measured peak energy demand when compared to the raw simulated energy needs, indicating that high efficiency appliances need to be included within the regulatory mix for heating and cooling of buildings.

The first task, industry installed reflective subfloor insulation, raised critical issues encompassing the manufacturers' literature, installation practices and the current levels of reflective insulation system knowledge by the design and construction professions. One of the initiators of this task was new home-owners, who were complaining about the cold floor in their new platform-floored home. The standard, and contemporary, method of installation had an R-value of 0.44, instead of the marketed 3.0. This has a critical impact on the market place's willingness to accept timber platform floors as a component of lightweight and well-insulated buildings. Product literature must be improved and the design, construction and inspection industries must be made aware of the consequences of poor design detailing and incorrect product installation.

The second task, manufacturer installed reflective subfloor insulation, took an inappropriate amount of time to organise, and several hours were required to install the product as per the manufacturers guidance. Both these scenarios would be very costly within the design and construction industry. Greater guidance needs to be provided to designers when this type of product is used to ensure appropriate detailing is considered and included within the building documentation.

The bulk subfloor insulation task still raised some installation issues, as no support mechanism was installed with the batts. This method relies on the batt remaining stiff to ensure the friction connection between the batt and subfloor structure remains intact, otherwise the batts will not stay in place. During the six months of this research task some batt delamination was identified. This needs further and ongoing research to ensure that the batts perform their task, with minimal maintenance, for some years. Furthermore, if the manufacturer believes that the batts should be checked at regular intervals, this needs to be specified and included in building 'hand-over' packages.

This research task has raised many questions but some key areas of future research have been identified, namely:

#### **Subfloor insulation**

- This research identified critical and unguided installation practices that are significantly less than market expectations, from both manufacturers and the construction industry. Research must occur at regular intervals to ensure that the manufacturers' literature is suitable and that installations are occurring correctly.

#### **CHENATH & AccuRate calibration**

- A newer version of AccuRate with algorithmic improvements within the CHENATH program has recently been released. The simulations described above should be completed a second time to establish if the CHENATH improvements have reduced the differences between measured and simulated data sets.
- The tasks completed within this research need to be continued, so as to test other built fabric systems and the accuracy with which Australian thermal performance tools simulate temperatures and energy used to maintain human comfort.

#### **Heating and Cooling Energy**

- The reverse-cycle air-conditioner measured and test building room calculated raw and COP applied energy data are significantly different. This requires further investigation to ascertain if it is a built fabric or an appliance-based issue.

- The test buildings have fan heaters installed. Now that the data acquisition process and test building room control has been demonstrated, it would be beneficial to collect a comparison energy use data set from less efficient heating sources.
- Similarly, other forms of heating and cooling could be tested.

Finally, this research task collected a large amount of data that needs further analysis and publishing within research and industry based publications to ensure the continuing increase in building science knowledge in Australia and internationally. This data and its analysis are needed by software developers to ensure thermal simulation algorithms and concepts are continuously improved.

## 6. Appendices

Supporting documents to this research report are included as appendices. Each appendix focuses on a particular research task, namely:

- Appendix 1: Industry installed reflective subfloor insulation
- Appendix 2: Manufacturer installed reflective subfloor insulation
- Appendix 3: Industry installed bulk subfloor insulation

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