The Environmental Measurement of Residential Buildings

Technical Guide Case Study 1:
Enclosed-perimeter Platform-floored Test Building

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The principal author of this document is Dr Mark Dewsbury. This case study draws extensively from Mark's personal experience from the design, construction, instrumentation, detailed measurement, detailed envelope simulation and data analysis tasks associated with the empirical validation of the house energy rating software AccuRate undertaken between 2005 and 2011. Mark's thesis "The empirical validation of house energy rating software for lightweight housing in cool temperate climates" (Dewsbury 2011), which goes into much greater detail is available from the University of Tasmania.

Extensive assistance in this field of research was provided by Dr Florence Soriano, Dr Detlev Geard, Dr Dong Chen (CSIRO) and Dr Angelo Delsante (CSIRO retired).

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Acronyms

BCA	Building Code of Australia
HER	House Energy Rating
HVAC	Heating ventilation and air-conditioning
NCC	National Construction Code
NatHERS	Nationwide House Energy Rating Scheme

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1 Introduction

This case study discusses and illustrates the method and processes that were undertaken by the School of Architecture, University of Tasmania, in a recent empirical validation project. This study also discusses the empirical validation of the AccuRate software by use of an enclosed-perimeter platform-floored test building, which formed part of an empirical validation study from 2006 to 2011 (Dewsbury 2011). The research included three key aspects, namely:

- The design and construction of a test building;
- The detailed thermal measurement of the test building;
- The use of co-located instruments to record the site climate;
- The detailed simulation of the test building using the AccuRate (V1.1.4.1) software; and
- The graphical and statistical analysis of the measured and simulated data sets.

The research was undertaken with the test building operated in an unoccupied and unconditioned mode.

2 The Test Building

The test building was to be located at the Newnham campus of the University of Tasmania. A careful assessment was completed of the university property exploring sites which had:

- No or minimal overshadowing from other site features
- Access to electricity for the monitoring equipment, building operation and building construction
- Ready access to data transport through LAN & WAN services for remote data acquisition
- Ready access to storm water services to meet council building regulations
- A location which met with University approval

After each proposed site was modelled with a three-dimensional computer-aided drafting software and digital seasonal sun studies were completed, a single site was selected, as shown in Figure 2.1.

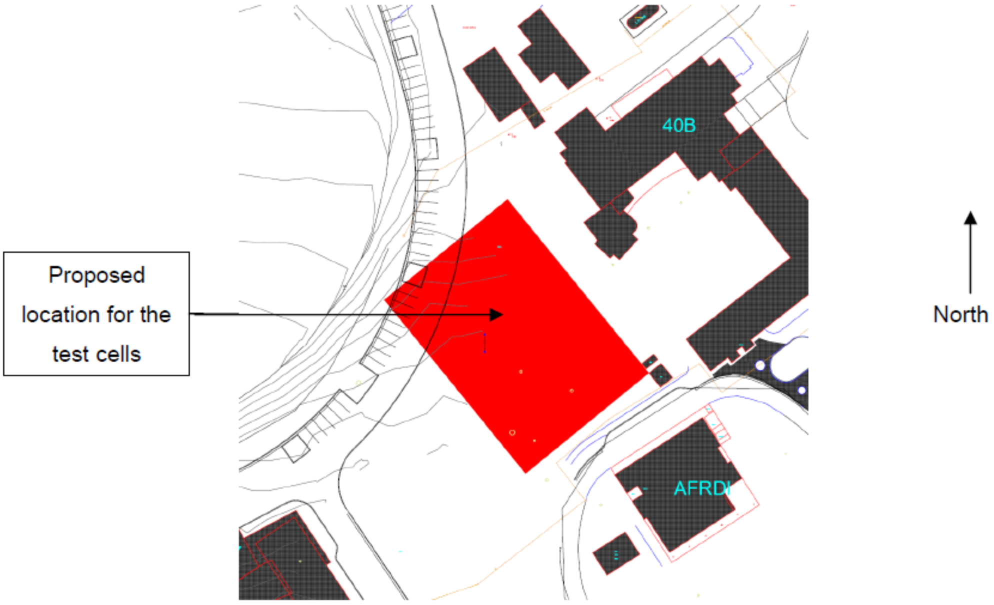


Figure 2.1 – Final Location for Launceston Test Cells

The site consisted of:

- Open grassland for approximately 20 metres to the north-east
- Single-storey buildings which provided a site boundary 23 metres to the north (Figure 2.2)
- Open grass for approximately forty metres before the two-storey AFRDI building to the south-east (Figure 2.3)
- A car park and sports oval along the western boundary (Figure 2.4)
- Some well-established trees to the south (Figure 2.3)

As there were to be three test buildings constructed, a further detailed analysis, both on site and with three dimension computer-aided drafting was undertaken to best evaluate shadow and weather shielding effects from nearby trees and buildings. This assessment deemed that some trees of minor significance on the northern part of the site should be removed.

Figure 2.2 – Northern aspect of site

Figure 2.3 – South & south-eastern aspect of site

Figure 2.4 – Western aspect of site

Three test buildings were to be constructed and this is discussed by Dewsbury (Dewsbury 2011). This case study focuses on the enclosed-perimeter platform-floored test building

2.1 Test Cell Size

After an analysis of other international and national test buildings (Dewsbury 2011) the size (width, depth & height) of the test cell was established, as detailed in Table 2.1.

Table 2.1: The Dimensions of the Launceston Thermal Performance Test Cells

Element	Size
Internal Length	5480mm
Internal Width	5480mm
Internal Height	2440mm
Internal Floor Area	30.03m^2
Internal Volume	73.3m^3
External Length & Width	Determined by building fabric
Orientation	Solar North

2.2 Construction Materials

The objective of this research was to empirically validate the AccuRate HER software. As such, the materials and structural systems for the test cell must be similar in nature to contemporary residential design and construction practices and yet, include flexibility for future research. The materials used to construct this test cell were further informed by the building type, (enclosed-perimeter platform-floored). To establish the appropriate systems and materials for this test cell, a simple examination of standard residential building systems was undertaken (Dewsbury, Nolan et al. 2007). The material selection was also influenced by industry sponsorship for the research, as many of the materials were provided by industry sponsors. Through this iterative process, a fabric matrix was finalized as shown in Table 2.2.

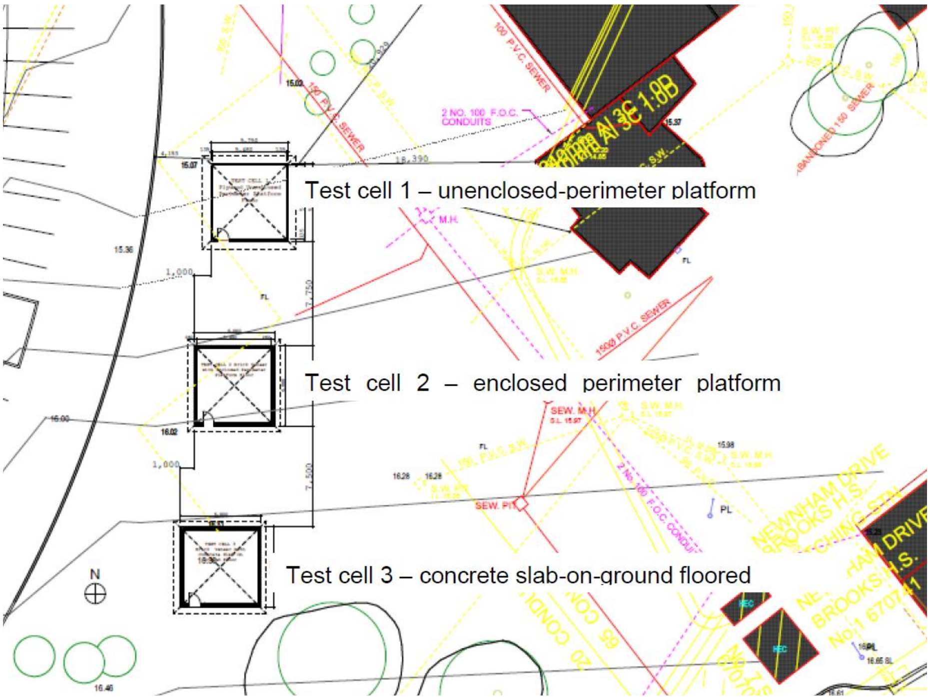
Table 2.2: Enclosed-perimeter Platform-floored Test Cell Fabric Matrix

Element	Materials used
Roof	Colorbond sheet metal roofing
Roof Sarking	CSR Bradford Enviroseal reflective foil sarking
Ceiling Insulation	R4.0 glass wool batt insulation
Ceiling Lining	10mm paper faced gypsum plasterboard, screw fixed to furring channel
Access Door	40mm solid core door
Structural Wall Framing	Prefabricated 90mm x 35mm pine frames
Wall Lining	10mm paper faced gypsum plasterboard, glue and screw fixed to wall framing
Wall Insulation	R2.5 rock wool wall batt (86mm)
Building Wrap	CSR Bradford Enviroseal reflective foil sarking
Wall Cavity Type	50mm reflective
Wall Cladding	110mm clay brick veneer
Floor	19mm particle board
Subfloor Structure	Hardwood joists, hardwood bearers, treated pine poles
Subfloor enclosure	110mm clay brick veneer

2.3 Test Cell Placement & Orientation

Once the size and volume of the test cell was established, its position and opportunities for overshadowing were analysed. The site was drawn in three-dimensional computer-aided drafting (CAD) software. All surrounding buildings and trees were included in the model, for the purpose of undertaking sun and shading studies. Sun study movies were generated for the summer solstice, winter solstice and equinox. Based on the information provided by the movies, the placement and orientation of the test cells were determined.

Within the possible building zone, nine test cell arrangements were explored, which included the location and distance required between test cells to eliminate overshadowing. After extensive studying of the most suitable options, a final site plan and arrangement was adopted, as shown in Figure 2.5. This was principally a solar north-south arrangement. As the site sloped gently down-hill in the northern direction, a distance between the test cells of 7500mm eliminated winter overshadowing.


Test cell 1 – unenclosed-perimeter platform

Test cell 2 – enclosed perimeter platform

Test cell 3 – concrete slab-on-ground floored

Figure 2.5 - Final Test Cell Site Plan

2.4 University & Council Approvals

As with any building project, approvals were required from the land owner (the University) and the building permit authority (local council). Once University approval was obtained for the project, the required planning and building applications for local council approval were completed. As the principal researcher for the project was an accredited building practitioner, all documentation for the University and council were generated by the researcher. A local building surveying firm provided certification and construction inspection services.

2.5 Test Cell Construction

The bulk of the test cell construction occurred in June and July 2006. Final finishing occurred in August 2006. The construction method for the test cell was as close as possible to the minimum allowable construction practice possible, as prescribed in the BCA (ABCB 2006). The only exceptions were the improvements in insulation and infiltration mentioned earlier. The principle researcher coordinated the construction of the test cells, to ensure the desired research outcome was achieved. This required regular meetings with: University staff, the builder, the builder's subcontractors (all trades) and environmental measurement consultants. The meetings ranged from general to detailed issues. Discussions often came back to BCA and Australian Standard requirements, as many contractors were not familiar with these documents.

During construction, the researcher was on site several times a day to assist and provide advice to the builder or sub-contractors. This established rewarding relationships between the researcher and key sub-contractors. The researcher became more aware of issues which affected the quality of construction practice and the sub-contractors were made aware of building thermal performance theory, the BCA and Australian Standard requirements.

In this research, industry sponsors and collaborators provided many of the building materials. Materials provided by industry sponsors were:

- reinforcing steel (for footings)

- Concrete (for footings)
- all timber materials (posts, bearers, joists, particle board floor, wall framing, and roof trusses)
- clay bricks (for the external brick veneer)
- paper faced gypsum plasterboard (internal wall and ceiling lining)
- wall and ceiling batt insulation
- truss and prefabricated wall assembly
- roof space reflective foil sarking
- sheet metal roofing

All other items and construction fixing materials were purchased by the project. The construction of the test cells was divided into four stages, namely: preliminary works, primary construction works, finishing and, the installation of environmental measuring equipment

2.5.1 Preliminary to Construction

A surveyor was engaged to define the location and orientation of the test cell buildings, such that they were placed in a similar manner to what had been defined in the CAD modelling. Once the site perimeter and co-ordinates were established, markers were put in place to identify True North. A survey line was established to the side of the proposed building area, as a permanent reference during and after the construction process Figure 2.6. The surveyor then placed markers for the corners of the test cell, as in Figure 2.7.

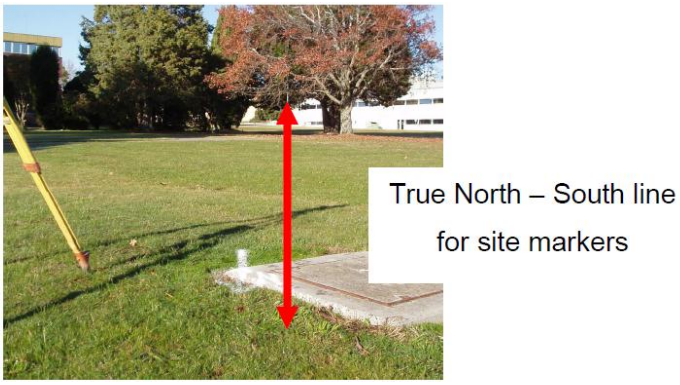

True North – South line for site markers

Figure 2.6 - Site markers for true north

Figure 2.7 - Test Cell corner marker

Meetings were organised and undertaken by the researcher between the builder and university staff to establish construction goals and requirements. One of the first roles of the builder was to provide a proposed project program. The project program enabled the researcher to:

- Ensure that the building process and site practices met university requirements
- Co-ordinate the supply of sponsored materials
- Co-ordinate the supply and staged installation of environmental measuring equipment
- Co-ordinate relevant university staff to ensure the connection to existing university services (data, electrical, storm water, sewer)

It was agreed during this stage that the builder and researcher would have a formal meeting once a week to discuss financial, human and physical resource issues and to revise the project plan. Furthermore, it was agreed that the researcher would meet with trades on site every day and would be available anytime, most days, to assist and guide the builder and subcontractors during the construction period.

2.5.2 Primary Construction of Test Cells

The builder commenced site works on June 5, 2006 and practical completion was achieved in early August. Like any outdoor project, construction days were lost as a result of inclement weather.

The following key milestones of the construction process are from Dewsbury's thesis (2011).

Figure 2.8 - Exclusion fence and commencement of site set out (June 5, 2006)

Figure 2.9 - Excavation for footings of test cell (June 7, 2006)

Figure 2.10 - Poles in place before concrete put in footings (June 13, 2006)

Figure 2.11 - The two-man process stage of erecting the prefabricated wall frames (June 20, 2006)

Figure 2.12 - Roof trusses erected on test cell (June 21, 2006)

Figure 2.13 - After the storm. Much of the building wrap and roof sarking was removed by strong winds and rain. (July 3, 2006)

Completion of wall wrap and sheet metal roofing (July 3, 2006)

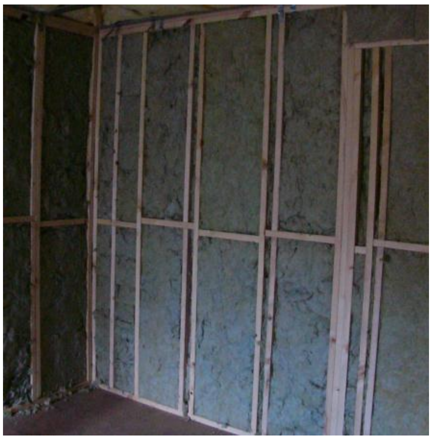


Figure 2.14 - Rockwool wall batt insulation (July 5, 2006)

Figure 2.15 - Another rainy day halts external works (July 5, 2006)

Figure 2.16 - Glasswool ceiling batt insulation installed (July 6, 2006)

Figure 2.17 - Application of paper-faced gypsum plasterboard to walls (July 6, 2006)

Figure 2.18 - Bricklaying well underway (July 6, 2006)

Figure 2.19 – Bricklaying completed with expansion joints in the wall for the knock-out panels (July 7, 2006)

Figure 2.20 – The plasterboard lining has received a plaster shim coat to cover joints and screw fixings (July 12, 2006)

Figure 2.21 – The thermal performance test cells after site cleaning and removal of safety fence (July 15, 2006)

2.5.3 Other Fabric Considerations

One of the objectives for investment to construct the test cell was to allow the opportunity for long-term thermal performance studies of residential construction systems, including the effect of glazing in various orientations. Care was required in the detailed design to ensure that construction provisions for the future research were accommodated. This resulted in some design and construction practices which were not common at the time the test cell was constructed. Some of the methods used were selected to further limit input variables that may affect the measurement and simulation of the test cell. These design and construction practices are discussed below. It is worth noting that these practices were closer to best practice methods as advised by many product manufacturers which, at the time of this research, were normally adopted by the house construction sector.

Sealing of Wall Cavity

A ventilation seal was installed between the cavity of the brick veneer wall and the subfloor zone, which was recommended for cooler climates (ABCB 2009). This action could be accounted for in the AccuRate HER software and reduced the chimney venting of the wall cavity. This promoted the possibility of a reflective still air cavity, which has a much greater insulation value than a reflective ventilated air space (Baker 2008). The diagram in Figure 2.22 details the design of the cavity seal in the external wall cavity for this test cell. A plastic dampproof course was installed at the line of the bottom plate between the brick veneer wall and the prefabricated wall frame of test cell 2 (Figure 2.23).

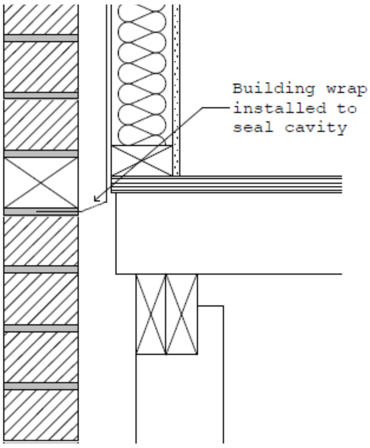


Figure 2.22 – Subfloor and wall cavity infiltration control

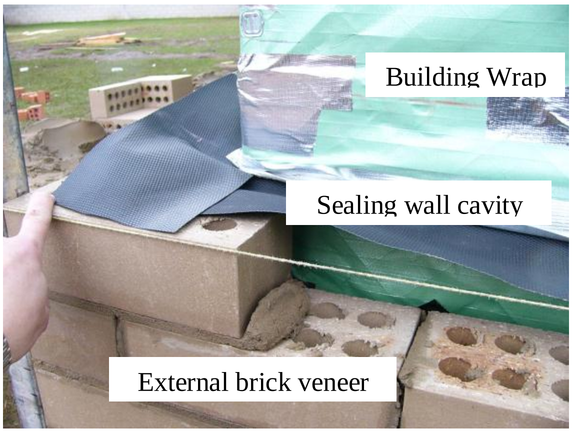


Figure 2.23 - Photograph of subfloor and wall cavity separation of test cell 2

Infiltration: Reducing External Wall Infiltration

For this research, the joints were taped as a means of reducing infiltration, as shown in Figure 2.24.

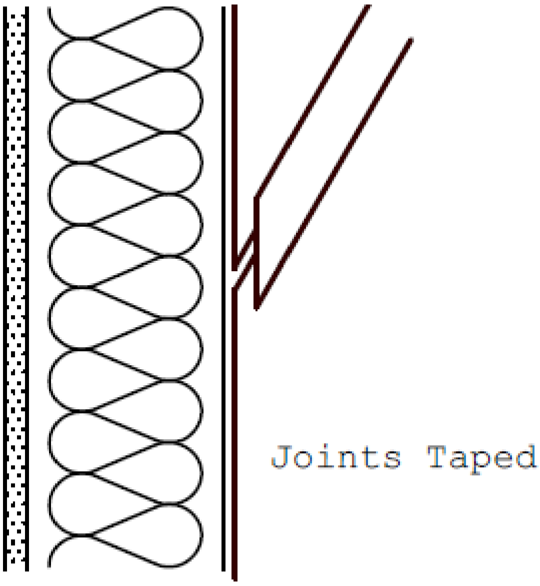


Figure 2.24 - Building wrap with joints taped together

For adequate building wrap installation, a constant quality of material with no discontinuity is required. This project observed conventional construction practises which resulted in damaged building wrap. The tradesmen involved with the project showed a lack of knowledge of the importance of this stage of construction and the function of building wrap. Consistent supervision was required to maintain the constructed integrity of the building wrapping. Upon being taught the importance of this stage of the construction, the contractors cooperated by using rolls of reflective foil tape to make repairs during construction. The problems that were experienced during the construction included:

- Tearing of building wrap resulting from the use of steel staples (Figure 2.25)
- Torn building wrap resulting from a lack of care by all trades (Figure 2.26 & Figure 2.27)
- Brick layer form-work puncturing and tearing building wrap
- The insulation was installed by pushing the material into the timber framed wall until it stopped. As the fixing of the building wrap is intermittent, often the wrap was torn off the steel staples, due to the forces exerted by the insulation installation.

Vigilance by the researcher and co-operation by site tradesmen ensured that repairs were made to the building wrap (Figure 2.28).

Figure 2.25 - Steel staples used to affix building wrap and roof sarking

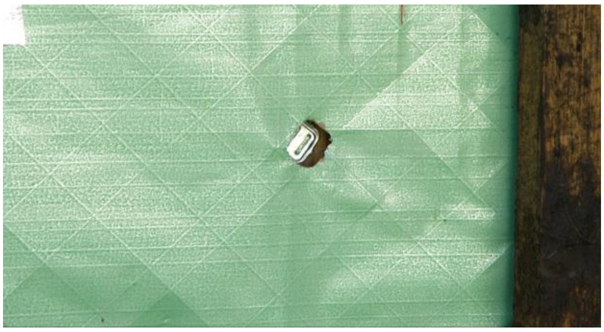


Figure 2.26 - Building wrap torn off staples during construction process

Figure 2.27 - Building wrap torn during construction process

Figure 2.28 - Reflective foil tape repairs to building wrap during construction

Infiltration: Door Gaps & Services Penetrations

To further reduce infiltration, further measures were adopted to make the test cell ‘tighter’. Gaps between the door jamb and wall frame ranged from 10mm to 30mm in width (Figure 2.29). This is a non-insulated zone and when examined, daylight was visible (Figure 2.30). This indicated that this zone would be a direct conduit for thermal bridging and infiltration. As a remedy, a closed cell foam rubber bar was installed and forced into the gap at both sides and at the top of the door jamb (Figure 2.31 & Figure 2.32).

Figure 2.29 - Gap between door jamb and wall frame is clearly visible

Figure 2.30 - Daylight is visible at the base of the gap between door jamb and wall frame

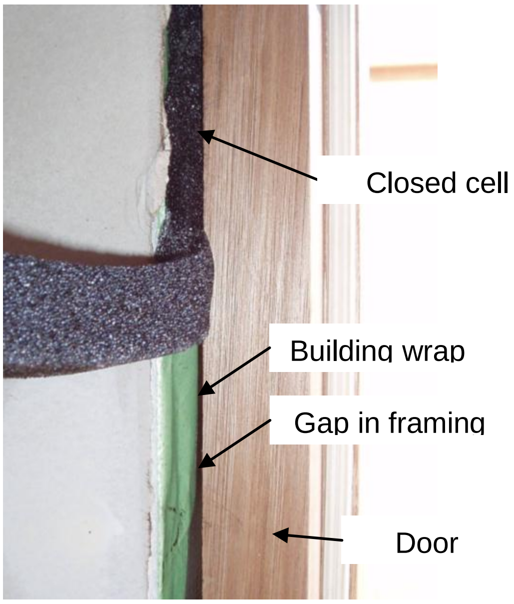


Figure 2.31 - The installation of closed cell foam rubber in gap between door jamb and wall frame

Figure 2.32 - Closed cell foam rubber is installed in gap between door jamb and wall frame

An important consideration for the installation of electrical and data services was to minimise impact on the building fabric. To achieve this, no penetrations were made by the electrical services into the floor, walls or ceiling. All conduits, outlets, circuit boards and lamps were surface mounted (Figure 2.33). The only penetration was a single hole through the floor of the test cell, to allow the conduit to bring the electrical and data services into the building. The gap between the conduit and particle board floor was sealed with silicone sealant, which was injected into the conduit to fill the gaps between the cables and the conduit, and into the small spaces between the conduit and the particleboard flooring.

Figure 2.33 - The surface mounting of electrical services

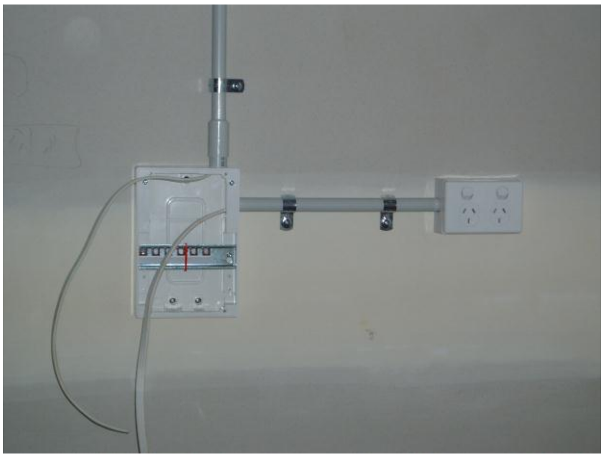


Figure 2.34 - Detail of surface mounted circuit board, conduits and general purpose outlet

Figure 2.35 - Detail of surface mounted lamp and lamp switch

Figure 2.36 - Surface mounted electrical services when finished

One concern was the electrical instability that may occur in a test cell. To reduce the risk of one test cell's electrical instability affecting another, each test cell had a separate power supply from the main switch board, located in an adjoining building. All power circuits were monitored to ascertain electricity consumption.

Roof Space Reflective Insulation

This project observed conventional practises, which resulted in damage to the roof sarking during installation. However, the correct installation of the sarking was an important factor in this research for controlling infiltration and maintaining the reflective insulation layer (CSR 2003).

In previous research, where a tracer gas was used to calculate the roof space infiltration rate, it was observed that the more unsealed the roof space, the more variant the infiltration rate, making the estimation of infiltration rate difficult. To reduce heat losses or gains due to infiltration, the same taping of joints approach that was used for the walls was adopted for the roof sarking. Additionally all tears in the sarking were repaired with tape.

Additionally, for the reflective foil sarking to effectively reflect heat and act as a vapour barrier, it requires an air space. The building simulation software has varying thermal resistance values for reflective sarking, dependent on the material’s reflectance and the type of bridged or unbridged air space between the sheet metal roofing and the sarking material (AccuRate 2007). It has been observed that sarking installed under the roofing battens, as in Figure 2.37, ensures that the air cavity is maintained. In this research, the method of installing the sarking was under the battens and over the rafters. This method of installation guaranteed a batten depth (35mm) air gap between the sheet metal roofing and the reflective foil sarking.

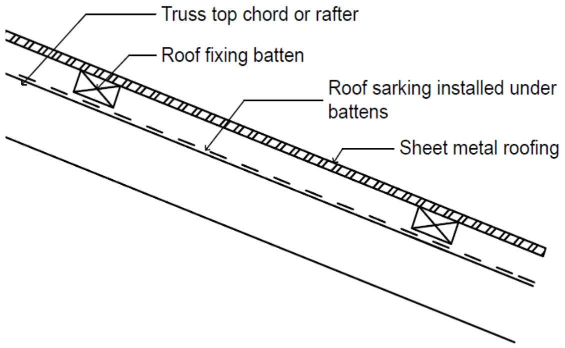


Figure 2.37 - Method for test cells – Sarking installed over rafters, under battens

Window Framing

The test cell was purposely designed and constructed to be initially without windows for this first stage of empirical validation. Future research involving assessment of solar gain and heat loss would necessitate the installation of windows. To install windows in the future with minimal structural impact, the prefabricated wall frames included a ‘knock-out’ panel in each wall. The panel size allowed for the installation of a standard 2100mm x 1800mm glazed sliding door unit. The panel included jamb studs and a lintel. This would allow for windows of varying sizes up to 2100mm x 1800mm to be installed in future thermal performance research. Figure 2.38 illustrates the concept for the prefabricated wall frame with the knock-out panel in place. In order to support the future addition of the window in the brick veneer cladding, control joints were place at the same point in the brickwork, as in Figure 2.39.

When a window is installed, infiltration and thermal bridging controls, (as discussed for the access door) would be installed between the wall and window frames.

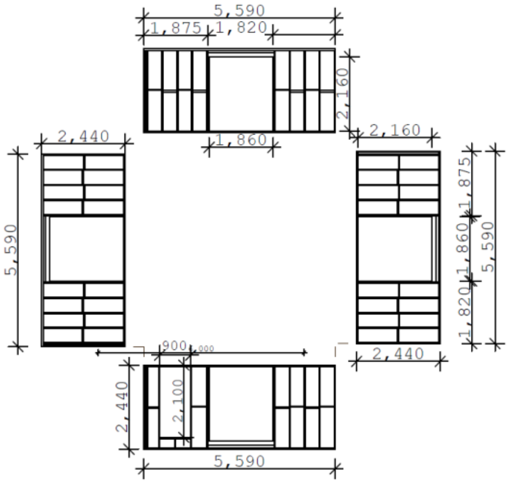


Figure 2.38 - Concept for prefabricated wall frame

Figure 2.39 - Control joints in brickwork for knock-out wall panel

Access Hatch to Roof Space

A standard access hatch made from formed plastic was screw-fixed to a sub-frame in the roof. Gaps of approximately 5mm existed on all four sides of the prefabricated insert. A square of plasterboard was cut to fit loosely within the frame. Both the gaps at the side of the insert and gaps around the plasterboard square provided ample opportunity for thermal bridging and infiltration losses. To counteract each of these issues the following actions were undertaken:

- High density foam rubber tape was applied as a backing rod, to the prefabricated plastic insert (Figure 2.40). The insert was then compressed against the ceiling plasterboard (Figure 2.41) and screw-fixed.

- To stop the hatch from lifting due to air pressure changes, high density foam rubber double sided tape was applied around the edges of the plasterboard sheet. Then two layers of 19mm particle board were affixed to the plasterboard (Figure 2.43). This gave the access hatch considerable weight, reducing the chance of air movement between the test cell room and roof spaces.

Figure 2.40 - Application of high density foam rubber tape to prefabricated insert

Figure 2.41 - Pushing prefabricated insert hard-up against the plasterboard ceiling

Figure 2.42 - Close up-view of high density foam rubber compressed between prefabricated insert and ceiling

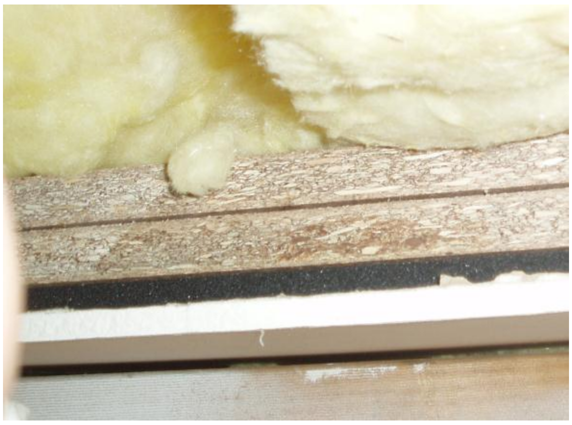


Figure 2.43 - High density foam rubber and particle board sheet affixed to top face of access hatch

Construction Joint in Brick Veneer Walls

The wall cavities of the brick veneered test cells were considered to be a relatively still-air space, with an accepted insulation value. The inclusion of the knock-out panel in each of the four external walls introduced a construction joint into the wall, providing egress for air into and out of the cavity. To maintain the still-air cavity, the construction joint had a polypropylene rod pushed into the gap (Figure 2.45 & Figure 2.46). The gap was then back-filled with an external flexible sealant (Figure 2.47).

Figure 2.44 - Sample of polypropylene rod

Figure 2.45 - Close up view of polypropylene rod inserted into construction joint

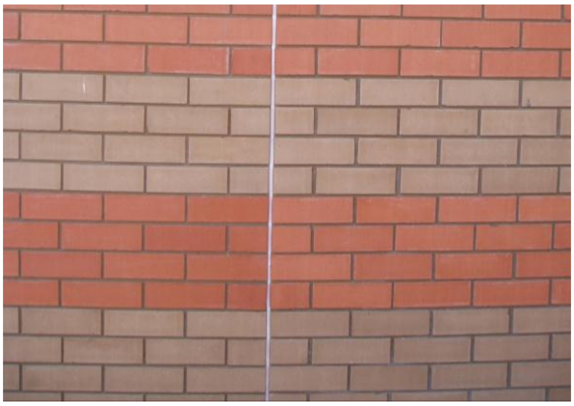


Figure 2.46 - Polypropylene rod inserted into construction joint

Figure 2.47 - External flexible sealant in construction joint

Test Cell Heating

The test cell design included the consideration of various modes of test cell operation which could include unconditioned and conditioned (heated) modes of operation. The purpose of providing these various modes of operation was to mimic internal loads and to further test the capacity of HER software to simulate the building envelope and calculate heating energy requirements (Lomas, Eppel et al. 1994; Strachan, Kokogiannakis et al. 2006). In the free-running mode, which is for empirical validation of the HER software envelope model, no heating or cooling is applied. The other modes of operation allow for the testing of the HER software HVAC model.

The installation of the heater required consideration of the heater type, heater placement and heater control. An investigation was undertaken into the common types of heaters in use in other test buildings. Discussions by the researcher with fellow researchers at the University of Newcastle cautioned against the use of the heat pump method, due to difficulties experienced by the University of Newcastle team in trying to quantify energy in and energy out equations. To ensure an adequate circulation of heated air, discussions with CSIRO researchers supported the selection of a fan-assisted resistor coil type of heater.

By using the HER software to simulating the test cell in various heating modes, a peak heating requirement of almost 2400 watts was established. This lead to the selection of a wall mounted 2400 watt heater. The heater was located in the middle of the western wall, low to the floor, so that it was close to the test cell circuit board and to maximise warm air distribution within the test cell. To ensure the wall fabric was not penetrated, plywood boxes were designed to suit the heater installation requirements and for surface mounting. The mounting boxes were cut on the computer controlled router at the School of Architecture. They were fabricated and installed onsite by the researcher and the School of Architecture technical assistant (Figure 2.48 and Figure 2.49).

Figure 2.48 - The School technical assistant screw-fixing the heater mounting box to test cell internal wall

Figure 2.49 - The heater mounting box fixed to test cell internal wall

Building Infiltration

Building infiltration control is an area rarely discussed in Australian residential construction practice. Much has been written on the amount of energy loss due to poor control of infiltration (Nolan and Dewsbury 2007). For the thermal performance test cells there were three areas that posed opportunities for infiltration control. Two of these were addressed during construction and discussed earlier, namely: i) the gaps between wall frame and the door jambs and ii) the roof space hatch.

The third area which provides an opportunity to reduce infiltration was the corner joint between the plasterboard walls and ceiling. The gap between plasterboard sheets was up to 50mm (Figure 2.50). The only elements that could reduce infiltration were the cornices and the bulk ceiling insulation (Figure 2.51). Depending on how the building wall wrap was applied to the outside face of the wall frame top plate, infiltration could also occur into the wall. Currently, the cornice is glued across this joint for presentation purposes, more than infiltration control. As these are lightweight buildings, the walls frames move over time; In addition an issue was the uncertainty of life expectancy of the cornice glue which apparently provides infiltration control.

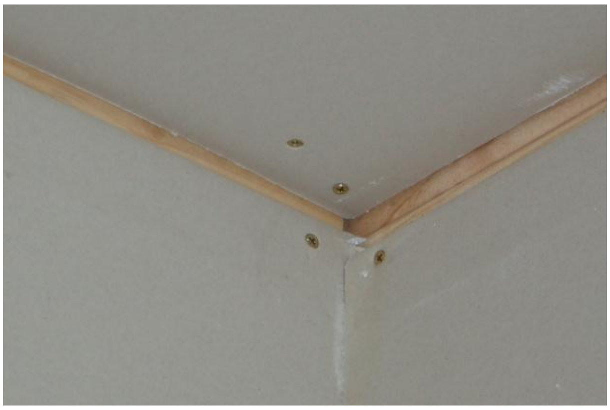


Figure 2.50 - Gap in ceiling corner between wall and ceiling plasterboard

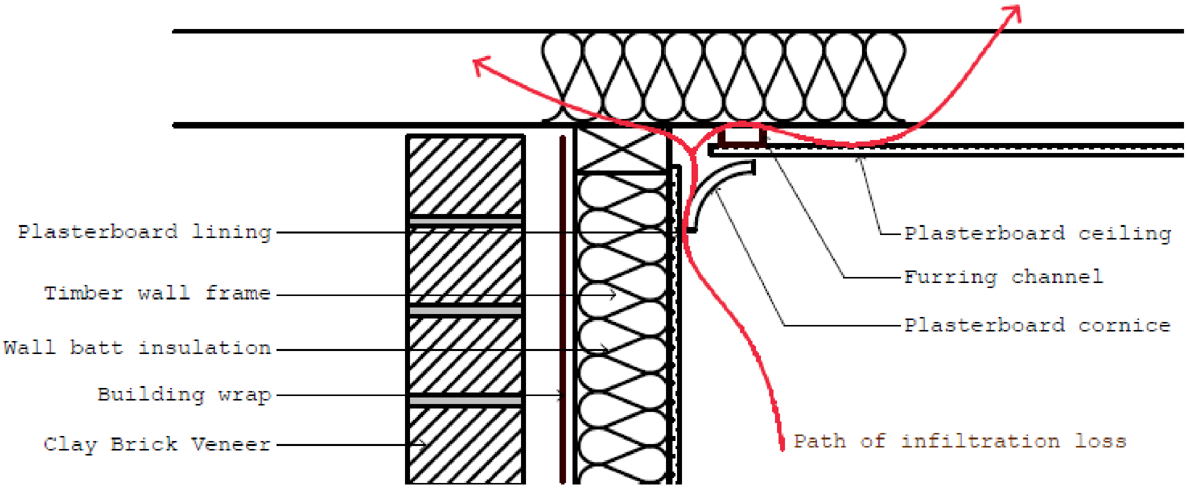


Figure 2.51 - Diagram showing potential unrestricted infiltration losses.

The Installation of Insulation

The installation of insulation into the wall frames and ceiling of the test cell raised three areas of critical concern in contemporary Tasmanian insulation installation practice. These were: the gaps in insulation, the method of installation and its impact on building wrap and air cavities, and framing practices which leave portions of external walls uninsulated.

In the construction of the test cell, the nominated contractors had a reputation for better than average installation of insulation. Even with this reputation, the contractor was unaware of the Australian Standard (Standards Australia 1992) which describes the installation of insulation. They were also not aware of the effect of gaps in insulation. The installation of the wall batt insulation took three attempts before it finally satisfied the requirements of the Australian Standard and manufacturers specifications (Figure 2.53). Due to persistent pressure for quality installation, in this project the ceiling batts were installed more carefully, with only minor gaps requiring filling.

Another major concern with regard to insulation installation was the method of pushing the batts into the wall frame until something stopped the batt (Figure 2.52). In the case of the test cell, a lot of the building wrap was torn from its staples as a result of this method. Only after the researcher showed the contractors the resultant damage to the building wrap, did they slow down and take more care.

The third aspect affecting insulation installation practice is caused by Australian residential framing practice and the use of double studs in external corners. The framing factor is discussed later but external corners are discussed here. Insulation contractors normally come to the building site after the building has had its wall wrap applied, and enclosing the external corners. There is no easy way of retrofitting the external corners of the timber frame and as such the corners remain uninsulated. In the case of the test cell insulation was retrofitted into the external corners.

Figure 2.52 - Billowing of building wrap as a result of insulation installation

Figure 2.53 - Insulation installation in test cell 1 – third attempt

Framing Factor

Establishing the framing factor for the floor, external walls and ceiling was required prior to this building being thermally simulated. The framing factor was determined from data supplied by the framing prefabricator and site photographs. Current wall framing practice includes: double top plates (Figure 2.55) and double, triple and quadruple jamb studs (Figure 2.54). The method of calculating the effect of the framing factor is discussed in Section 4.

Figure 2.54 - Triple jamb studs to support lintel in knock-out wall panel

Figure 2.55 - Double top plate

Figure 2.56 - Thermal performance test cells (30 August, 2006)

3 Generating the Empirical Data

Based on the assessment of the HER software being tested, its input and output files and a comparison with other international examples, a minimum data set of site-measured data was established. The items to be measured included the site and building elements. From these requirements and their respective values, methods could be explored to obtain the desired data. The key elements for obtaining the empirical data included:

- Data acquisition platform
- Measuring devices
- Data storage
- Data cleaning

A detailed examination of the experiences from past research activities further confirmed what to measure. This included a number of key international and Australian projects (Bowman and Lomas 1985; Torcellini, Pless et al. 2005; Loutzenhiser, Manz et al. 2007; Judkoff 2008; Strachan 2008). By combining the output data from AccuRate and the types of environmental measurements taken by previous projects, minimum data collection requirements were established, as in Table 3.1.

Table 3.1: Items Requiring Environmental Measurement

Site Measurements	Dry bulb (air) temperature(tenths of degree Celsius) Moisture content (tenths gram per kilogram) Atmospheric (air) pressure (tenths of kilopascal) Wind speed (tenths of metres per second) Wind direction Cloud cover in Octaves Global solar radiation (Wh/m^2) Diffuse solar radiation (Wh/m^2) Normal direct solar radiation (Wh/m^2)
Thermal Performance Test Cell Measurements	Test Cell Room temperature (tenths of degree Celsius) Test Cell Roof Space temperature (tenths of degree Celsius) Test Cell Subfloor Space temperature (tenths of degree Celsius)

Examination of past empirical validation research activities presented a vast difference in approaches to measuring environmental performance of buildings. The required exterior environment parameters were easily defined by the AccuRate inputs and other international publications (ASHRAE 2005).

As the primary purpose of the thermal performance test cell was the empirical validation of AccuRate, the research was not concerned with levels of comfort for human occupancy. However, the research was concerned with and needed to comprehend and measure the average zone temperature within the test cell. Consultation with CSIRO HER software developers and industry sponsors, led to agreement that the approach taken should be similar in nature to the PASLINK test buildings. An array of temperature sensors would be installed initially and selected sensors would be used to establish an average room temperature.

3.1 The Measurement Profile of the Thermal Performance Test Cells

The locations selected for environmental measurement allowed for a minimum group of essential sensors for the empirical validation exercise. Other sensors were installed to collect additional data, to support the minimum data set and to enable further study of the results. The environmental measurement included a horizontal and vertical profile of the test cell. The vertical profile established for the test cells is detailed in Table 3.2 and Figure 3.1. The horizontal profile established for test cell is detailed in Table 3.3 and Figure 3.2.

Table 3.2: Vertical Measurement Profile of the Launceston Thermal Performance Test Cells

Title	Description	Minimum data or supporting data
Outside sheet metal roof dry bulb surface temperature	To measure the external surface temperature of the sheet metal roofing	Supporting data
Inside sheet metal roof dry bulb surface temperature	To measure the internal surface temperature of the sheet metal roofing	Supporting data
Inside reflective sarking dry bulb surface temperature	To measure the internal surface temperature of the reflective foil sarking.	Supporting data
Mid-roof space dry bulb air temperature	To measure the air temperature of the middle of the roof space	Minimum data
Mid-roof space vertical air flow	To measure if there is any thermal chimney effect in the roof space	Supporting data
Mid-roof space relative humidity	To measure the relative humidity of the roof space	Supporting data

Title	Description	Minimum data or supporting data
Top of insulation dry bulb surface temperature	To measure the outside surface temperature of the ceiling batt insulation	Supporting data
Outside plasterboard ceiling dry bulb surface temperature	To measure the outside surface temperature of the plasterboard ceiling	Supporting data
Inside plasterboard ceiling dry bulb surface temperature	To measure the inside surface temperature of the plasterboard ceiling	Supporting data
Centre of room +1800mm dry bulb air temperature	To measure the air temperature at a height of 1800mm in the centre of the room	Minimum data
Perimeter of room +1800mm dry bulb air temperature	Eight poles around the internal perimeter of the test cell to measure the air temperature at a height of 1800mm	Supporting data
Centre of room +1200mm dry bulb air temperature	To measure the air temperature at a height of 1200mm in the centre of the room	Minimum data
Perimeter of room +1200mm dry bulb air temperature	Eight poles around the internal perimeter of the test cell to measure the air temperature at a height of 1200mm	Supporting data
Centre of room +1200mm relative humidity	To measure the relative humidity at a height of 1200mm in the centre of the room	Supporting data
Centre of room +1200mm mean radiant temperate	To measure the mean radiant temperature in the centre of the room at a height of 1200mm	Minimum data
Perimeter of room +1200mm mean radiant temperate	Eight poles around the internal perimeter of the test cell to measure the mean radiant temperature at a height of 1200mm	Supporting data
Centre of room +600mm dry bulb air temperature	To measure the air temperature at a height of 600mm in the centre of the room	Minimum data
Perimeter of room +600mm dry bulb air temperature	Eight poles around the internal perimeter of the test cell to measure the air temperature at a height of 600mm	Supporting data
Inside carpet dry bulb surface temperature	To measure the inside surface temperature of the carpet	Supporting data
Inside Particle-board floor dry bulb surface temperature	To measure the inside surface temperature of the particle board floor of the test cell	Supporting data
Outside Particle-board floor dry bulb surface temperature	To measure the outside surface temperature of the particle board floor of the test cell	Supporting data
Outside subfloor insulation dry bulb surface temperature	To measure the outside surface temperature of the subfloor insulation of the test cell	Supporting data
Mid-subfloor space dry bulb air temperature	To measure the air temperature in the centre of the subfloor space	Minimum data
Mid-subfloor air speed measurement (adjustable for vertical and horizontal air flows)	To measure subfloor horizontal air flow and whether or not there is any vertical chimney affect in the subfloor space	Supporting data
Mid-subfloor space relative humidity	To measure the relative humidity at the middle of the subfloor space	Supporting data`
Centre subfloor area ground air temperature	To measure the air temperature at ground level in the middle of the subfloor space	Supporting data
Centre of building -1000mm dry bulb surface temperature	To measure the ground temperature 1000mm below ground surface.	Supporting data

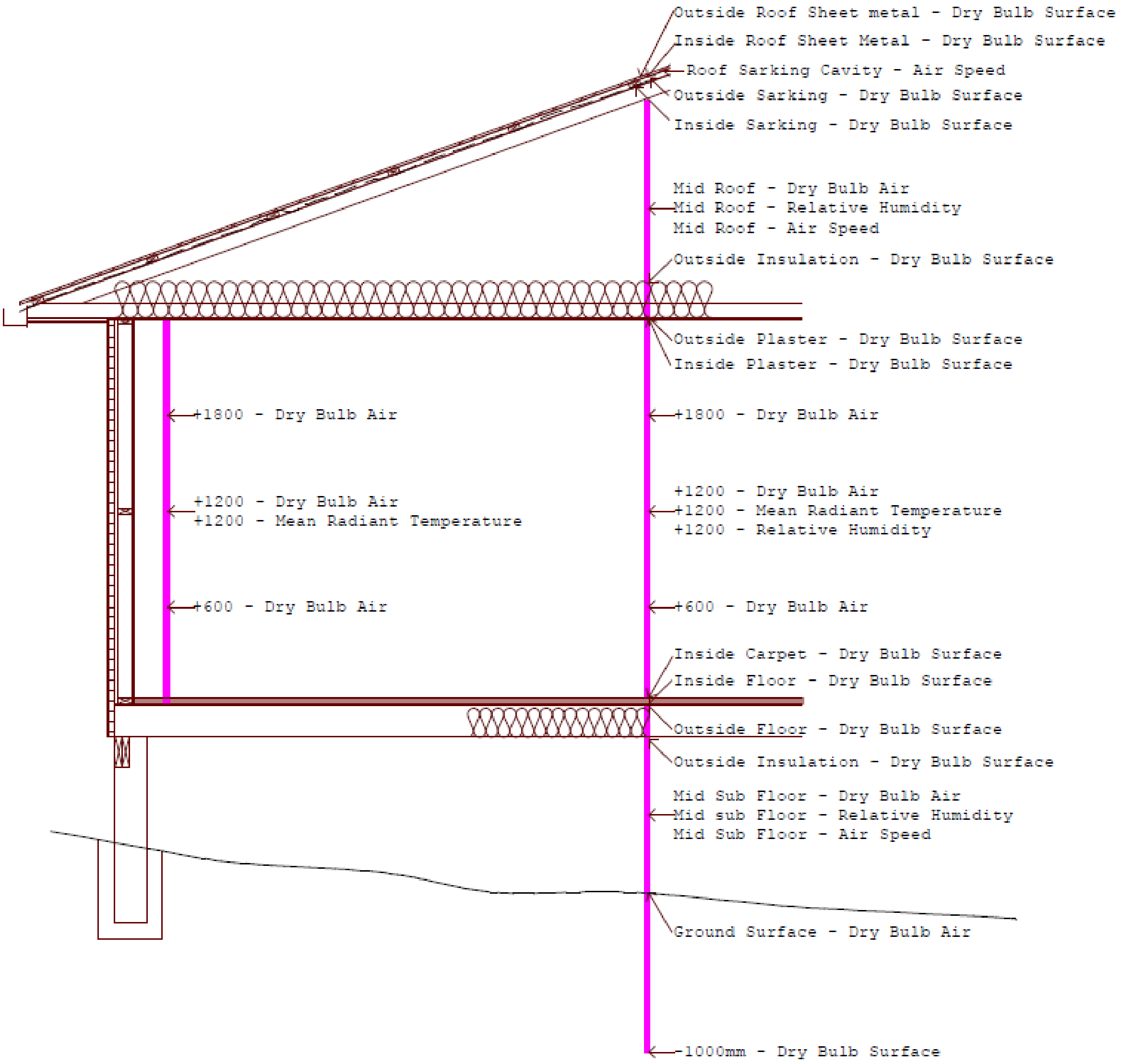


Figure 3.1 – Vertical measurement profile for the enclosed-perimeter platform-floored test cell

Table 3.3: Horizontal Measurement Profile, Providing Supporting Data, of the Launceston Thermal Performance Test Cells

Title	Description
Outside brick veneer or plywood cladding dry bulb surface temperature (North & South Walls)	To measure the external surface temperature of the Brick Veneer or Plywood cladding
Inside brick veneer or plywood cladding dry bulb surface temperature (North & South Walls)	To measure the internal surface temperature of the Brick Veneer or Plywood cladding
Outside reflective foil building wrap dry bulb surface Temperature (North & South Walls)	To measure the outside surface temperature of the reflective foil building wrap
Inside reflective foil building wrap dry bulb surface Temperature (North & South Walls)	To measure the inside surface temperature of the reflective foil building wrap
Wall frame relative humidity (North & South Walls)	To measure whether or not there are dangerously high relatively humidity levels within the wall-insulation batts in a cool temperate.
Outside plasterboard dry bulb surface temperature (North & South Walls)	To measure the outside surface temperature of the plasterboard wall lining
Inside plasterboard dry bulb surface temperature (North & South Walls)	To measure the inside surface temperature of the plasterboard wall lining
Outside plasterboard ceiling dry bulb surface temperature	To measure the outside surface temperature of the plasterboard ceiling
Solar Radiation (North, West, South & East Walls)	To measure the amount of solar radiation hitting all external walls of the test cells.

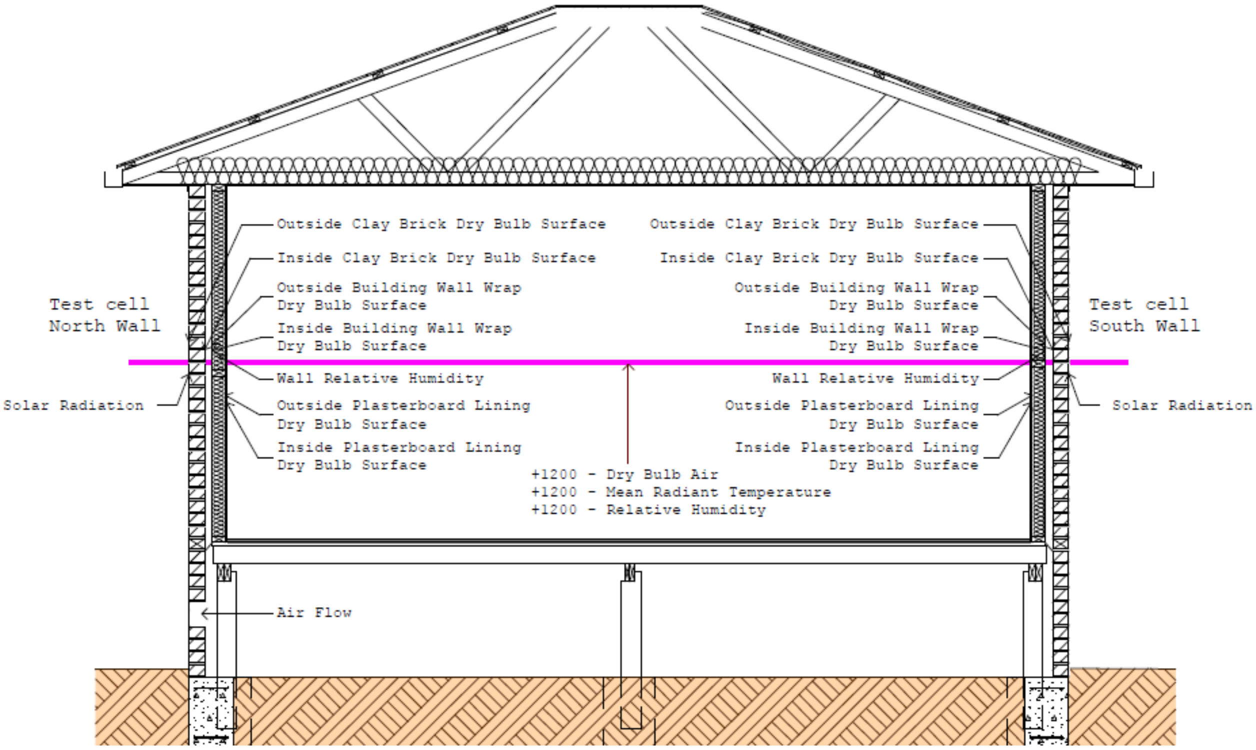


Figure 3.2 – Horizontal measurement profile for the enclosed-perimeter platform floored test cell

Once the location and purpose of environmental measuring equipment had been defined, the type and accuracy of the environmental sensor types and the equipment required to support the sensors was investigated.

3.1.1 Platforms for Environmental Measurement

The test cell was to provide a long term research platform and the equipment installed must meet this need. This brief required the following key elements:

- A flexibility of approach which allowed for relocation of equipment to other building environmental measurement projects
- A flexibility of approach which allowed a relatively simple process for adding and removing sensors
- A system which could be owned by the research centre
- A system which allowed technical management within the technical capabilities of the researchers.

It was acknowledged during the initial stages of the research that many sensors would still be in transit. The system adopted would have to be flexible enough to support the gradual addition of sensors to the logging system over time. In addition, new research questions might arise and sensors might need to be removed or added depending on the research question.

An investigation of data logging and acquisition methods revealed three principle approaches: Building Management Systems, Digital Systems and Analogue Devices. Each of these approaches was investigated for their suitability for this research program. Factors affecting data acquisition were considered, including:

- the types of probes or sensors that could be connected to equipment
- ease of operation and programming
- power supply requirements
- Portability
- affordability

Only the analogue data acquisition platform supported all of these requirements. Based on technical support services and cost, the DataTaker DT500 was chosen. Later a DT80 was to separate the weather station data and to add a LAN interface.

Figure 3.3 - Analogue data acquisition equipment at the University of Newcastle (Photograph from site visit 2005)

Figure 3.4 - Analogue data-logger as installed in the test cell (July 2006)

3.1.2 Building Environmental Measurement

The choice of the analogue data acquisition platform and DT500 equipment enabled the selection and purchase of individual sensors to commence. Due to the innovative nature of the research and the limited technical support, sensors that came with some form of pre-calibration were preferred. However, each sensor was checked for calibration during installation. After the review of capabilities, the resultant sensors that formed the basis of the environmental measurement were the items listed in Table 3.4. Their installation method is discussed below.

Table 3.4: Probes and Sensors for the Test Cell

Purpose	Description
Dry bulb air temperature (^{0}C)	AD592CN
Mean radiant temperature (^{0}C)	AD592CN suspended within a 150mm copper ball
Relative humidity	Vaisal HMW40U
Air movement	TSI 8455 hot wire air velocity transducer
Solar radiation	SolData 80SPC pyranometer
Electricity consumption	Solid core CS-450 current transducer

Manufacturers' technical specifications are not included here but are readily available from each manufacturer. The assessment and location of each device included: a review of manufacturer specifications, published research, and advice from CSIRO and industry researchers.

Dry Bulb Temperature

The temperature sensor chosen was required to measure temperature to the same magnitude as the simulated zone temperature from the AccuRate software, to one decimal place or 0.1^{0}C (ABCB 2006; AccuRate 2007). A review of suitable devices and experience from other researchers, led this research to choose the AD592CN analogue device temperature sensor.

- AD592CN: Produces measurements to 0.1^{0}C. At 25^{0}C the calibration error was typically 0.3^{0}C (Figure 3.5).

Once supplied, and during the installation process, each probe was checked for accuracy, in a range of temperatures, in both the workshop and test cell, as shown in Table 3.5. After each sensor was tested, bell wire was soldered to the terminals (Figure 3.6) and the calibration occurred again. The length of the bell wire was relative to the proposed location and purpose of the AD592CN. The length of bell wire ranged from 300mm to several metres. Each AD592CN was then installed in place to perform its function and a final calibration check occurred.

Table 3.5: Calibration of AD592CN Measuring Equipment

Workshop Based Testing when Supplied	Workshop Based Testing After Bell Wire Soldered	Test Cell Based Testing (After Connection to Data Cable and Data-logger
Comparison to pre-calibrated AD592CN	Comparison to pre-calibrated AD592CN	Comparison to pre-calibrated AD592C
Comparison to calibrated Thermo-couple	Comparison to calibrated Thermo-couple	

Figure 3.5 –AD592CN as supplied

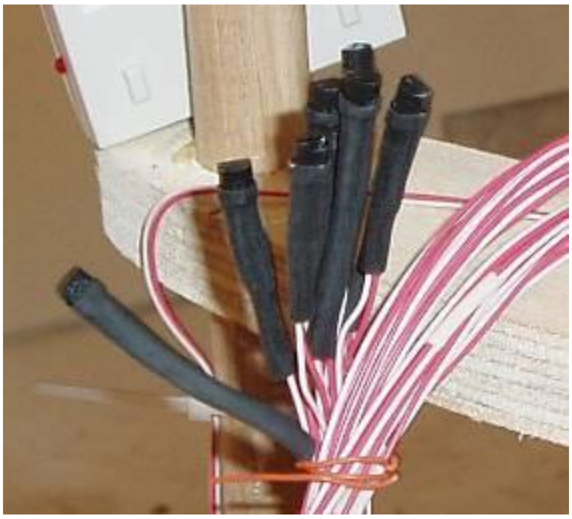


Figure 3.6 – AD592CN Temperature probes after leading bell wires were attached with solder

The principal uses of the AD59CN were:

- Air temperature: The probe was placed in the centre of a 25mm PVC conduit, which was placed at the specified height and location (Figure 3.14). The PVC tube was used to reduce the possibility of measuring mean radiant temperature and to eliminate the effect of occasional air flow washing against the probe and affecting spot readings (Sugo 2005-2009).

- Surface Temperature: Using a very thin glue medium, the probe was affixed to the surface being measured. Reflective tape was then used to cover the probe, to reduce the air temperature’s effect on measurements (Figure 3.10).

- In-Ground Temperature: Due to AD592CN failure, this method was revised a few times. The final method required the placement of the AD592CN probe within the centre of a PVC tube and then filling the tube by injecting silicone (Figure 3.11). Once installed below ground, it was found that the probe stabilised quite quickly and remained moisture resistant.

Figure 3.7 – Test cell wall profile showing inside brick surface temperature, outside wrap surface temperature, inside building wrap air temperature and inside plasterboard surface temperature

Figure 3.8 – Mid-subfloor air temperature for the subfloor of the test cell

Figure 3.9 – Outside particleboard surface temperature of platform floor

Figure 3.10 – Surface temperature measurement: AD592CN probe affixed to floor and covered with reflective tape

Figure 3.11 – The final type of in-ground temperature probe within a silicone-filled tube

Figure 3.12 – Mid-roof space air temperature and relative humidity

Figure 3.13 – Mid-roof space air temperature and inside sarking surface temperature

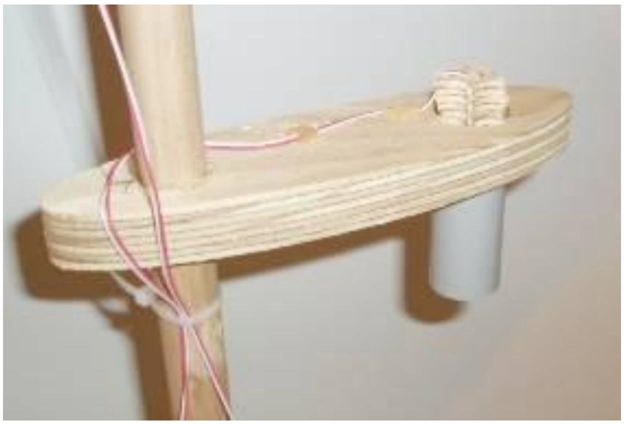


Figure 3.14 – AD592CN temperature probe installed within 25mm PVC tube

Figure 3.15 – Adjustable poles within test cell showing air temperature measurement at 600mm, 1200mm, 1800mm air temperature and relative humidity at 1200mm

Mean Radiant Temperature

There has been an extensive discussion on the methods and use of mean radiant temperature to establish the temperature within a room. Copper globe temperature measuring globes were designed and manufactured by the researcher in 2007. The copper globe method was selected after the examination of a range of methods from painted ping-pong balls to formed ellipsoid balls. Spun copper half spheres were ordered from a copper spinner. In June 2007, the researcher made the globe thermometers using the spun copper spheres and AD592CH probes (Figure 3.16 and Figure 3.17).

Figure 3.16 – Joined copper globes drying

Figure 3.17 – After painting, completed copper globe sensor in place

Relative Humidity

The Vaisala HMW40U relative humidity transmitter was selected to measure relative humidity. The transmitter required a low voltage power supply, provided by the DT500 data logger and returned a signal ranging from 4 to 20 milliamps, dependent on measured relative humidity. The data-logger programming included a span to convert the milliamp value into a relative humidity value.

Figure 3.18 – HMW40U relative humidity transmitter installed within a test cell roof space

Figure 3.19 – HMW40U relative humidity transmitter installed within a test cell wall cavity

Table 3.6: Calibration of Vaisala HMW40U Measuring Equipment

Workshop Based Testing when Supplied	Test Cell Based Testing (After Connection to Data Cable and Data-logger
Comparison to pre-calibrated HMW40U	Comparison to other HMW40U sensor
Comparison to other relative humidity sensor	

Air Movement

The measurement included air flows in the subfloor and roof space. Interest by one of the industry sponsors added the cavity between roof sarking and the roof sheeting. Further discussions with the CSIRO added measurement at a subfloor air vent. The measurement of vertical and horizontal airflows was required for the subfloor and roof space. The measurement of laminar air flow was required for the roof sarking cavity and the subfloor air vents. After a preliminary investigation it was expected that the probes should measure between 0.001m/s and 10m/s. Other researchers were unable to provide expected air flow rates for the subfloor space, roof space or roof sarking cavity. Through an iterative investigation and discussion process it was established that:

- Wind speed minimum: 0 m/s
- The weather file required wind speed measurements in tenths of a metre per second (0.X m/s).
- The current subfloor model of the unenclosed-perimeter, platform-floored test cell presumed that the subfloor air speed was the same as the weather station wind speed, with a reduction factor based on topography.
- Subfloor air vent speed could vary from 0.0 to 10.0 m/s

The anemometer was required to measure air flow in a constantly fluctuating environment. An examination of the literature was undertaken and the various forms of anemometers were explored and included:

- Paddle type: Problematic due to the size and free-floating nature of the paddles
- In-line impeller type: Problematic due the size of impeller enclosure and most had a minimum measurable air speed of 0.5 m/s, which was unsuitable for this research

- Hot wire type: The hot wire type included single directional, bi-directional and multi-directional with a small probe that could be placed within small spaces and was able to measure air speeds from 0.00 to 10.00 m/s.

After analysing hot wire anemometer types, levels of accuracy and cost, the TSI 8455 hot wire air velocity transducer was selected. The unit consisted of a control box (Figure 3.20) and hot wire probe (Figure 3.21). An independent 12 Volt DC power supply was provided, as this was beyond the capability of the data-logger. The units were provided pre-calibrated however, limited calibration was still performed on site (Table 3.7).

Figure 3.20 - The TSI 8455 hot wire air velocity transducer

Figure 3.21 - Detail of TSI 8455 hot wire air velocity transducer probe

Table 3.7: Calibration of TSI8455 Hot Wire Transducer

Workshop Based Testing when Supplied	Test Cell Based Testing (After Connection to Data Cable and Data-logger
Comparison to pre-calibrated TSI8455 hot wire transducer	Comparison to other TSI8455 hot wire transducer when installed

Having the same 4 to 20 milliamp output, data logger programming for the hot wire transducers followed the same method as the relative humidity sensors.

Figure 3.22 – Roof space vertical airflow measurement

Figure 3.23 - Airflow measurement through the subfloor air vent of the test cell

Figure 3.24 - Airflow measurement (close view) through subfloor air vent of the test cell

Power Consumption

To establish the amount of heat generated artificially within the test cell, power consumption was measured. The data-loggers and the DC power supply for the air speed transducers consumed electricity and emitted heat. The amount of energy consumed was required to allow for appropriate amendment to the default internal heat loads for the test cell room. The measurement of all electrical circuits included:

- Total Power: Total value for power used within the test cell which should match the sum of individual circuits.

- Lighting: Light fitting energy use which allowed for a checking mechanism on data readings. The measurement of light usage was also useful to help define times when the test cell data was not suitable for validation purposes, as it normally indicated that someone was inside the test cell.

- General Purpose Outlets: All data logging equipment and sensor power supply was taken from the general purpose outlet. As with the lighting measurement, spikes in the measurements taken could indicate that the test cells were undergoing some form of maintenance and data collected at that time was not useful for validation purposes.

- Heater: The heater was installed so that the amount of energy required to heat the test cell was known. Being a cool temperate climate, the heater was often turned on during test cell maintenance. This became another indicator that particular data was unsuitable for validation purposes.

The SC-551-1 current sensors were selected to measure electricity consumption. The 5 volt power supply required for the SC-551-1 current sensors was provided by the data-logger. The output signal was set to suit the amount of current being measured (0 to 10 volts, 0 to 10 amps, 0 to 20 amps). The programming for the data-logger included span tables to provide the conversion from the recorded amp input to energy consumed. When initially installed, the SC-551-1 current sensors recorded a 10 minute spot reading. As the research progressed this was modified to take continuous readings and record a 10 minute average, as it was found that the spot reading did not capture intermittent changes or spikes in energy consumption.

Figure 3.25 – Circuit board enclosure with four SC-551-1 current sensors and heater control relay

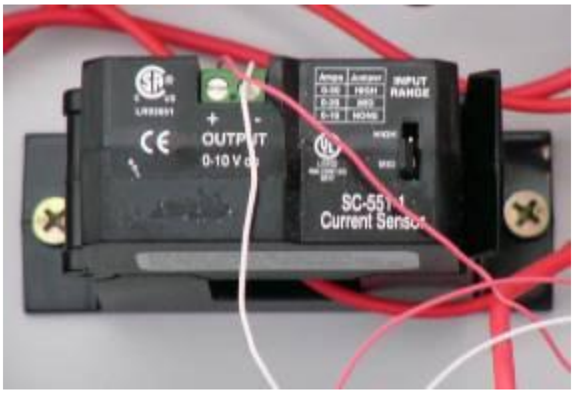


Figure 3.26 – SC-551-1 Current sensor with the electrical cable passing through the sensor and the red and white bell wires connected for the output signal

Adjustable Poles for Environmental Measurement

A flexible form of support was required to attach sensors to in the subfloor space, test cell room and roof spaces of the test cell. Flexibility was required to allow for the adjustment in height and location of sensors. The temperature sensors were positioned at mid roof space, mid subfloor space and 600mm, 1200mm and 1800mm in the test cell room. An adjustable pole system was designed to support the environmental sensors, which allowed flexibility to amend the height of the space in which the pole was located and the height of the sensor. The system comprised:

- A square base plate (Figure 3.27),
- A 20mm timber pole,
- A 25mm electrical conduit
- An ovoid sensor holder, and
- A square top plate.

The pole was placed inside the conduit. The pole and conduit were then pushed apart until the desired length was achieved and screw-fixed in place. Ovoid-shaped pieces were designed (Figure 3.27), which slid over the pole or conduit and could move freely up or down the pole; these were fixed in place by hot glue (Figure 3.28).

Figure 3.27 – CNC router-cut bottom or top plate and ovoid environmental sensor support

Figure 3.28 – Ovoid piece, hot glued in place

Figure 3.29 – Adjustable pole in centre of test cell room with AD592CN temperature sensors at 600mm, 1200mm and 1800mm

Figure 3.30 – Adjustable pole along western wall of test cell room with AD592CN temperature sensors at 600mm, 1200mm and 1800mm

Infiltration

The measurement of infiltration for the subfloor, test cell room and roof spaces was required to enable amendments the default infiltration input values within the AccuRate software. The measurement of infiltration losses required expert technical capabilities and associated equipment, which were beyond the capabilities of the research team. The Mobile Architecture & Built Environment Laboratory (MABEL) from Deakin University was engaged to undertake the measurement of infiltration. In consultation with the researchers from MABEL, it was established that the most suitable method to measure infiltration was by the tracer gas method. The methods used by MABEL adhered to the requirements of AS1668.2-2002 (Standards Australia 2002) and ASHRAE Standard 129-1997. As MABEL had only performed studies on single or double zone spaces, this research forced a careful consideration of how to measure three co-joined zones at the same time. Dosing gas pipes were attached to electric fans which distributed different gases to each of the three zones (Figure 3.31, Figure 3.32 and Figure 3.33). A second pipe from each zone, which took samples of the zones atmosphere, measured the rate of decay for the gas (Figure 3.34.

Figure 3.31 – SF6 and CO2 cylinders with Tracer gas equipment, which controlled gas dosing and measured gas decay in the test cell zones

Figure 3.32 – Tracer gas pipes: a dosing gas and a return sampling gas pipe for each zone

Figure 3.33 – The dosing gas was dispersed with an electric fan

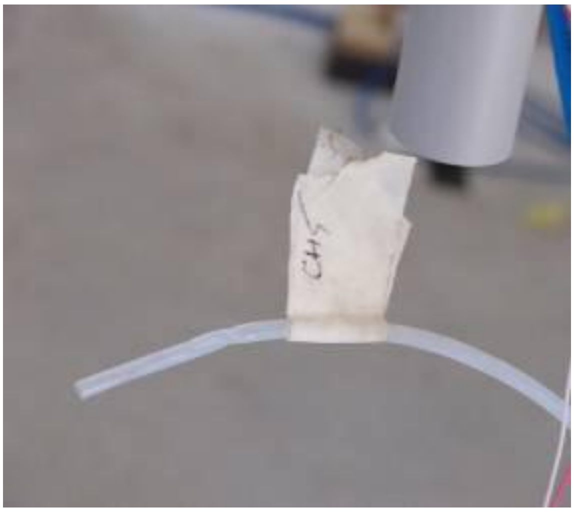


Figure 3.34 – A return sampling gas line was placed in the centre of each zone to measure gas presence within the zone

Infra-Red Camera Imagery

During this research, infra-red images were taken of the exterior and interior of the test cells. In the early stages of the research, this service was provided by the MABEL research team. After the research centre obtained its own infrared camera, infra-red images were taken at various stages. This tool was used to inform and clarify the effects of construction practices on the test cell thermal performance (Dewsbury 2009; Dewsbury, Soriano et al. 2009). A sample of some infra-red images can be seen in Figure 3.35 and Figure 3.36.

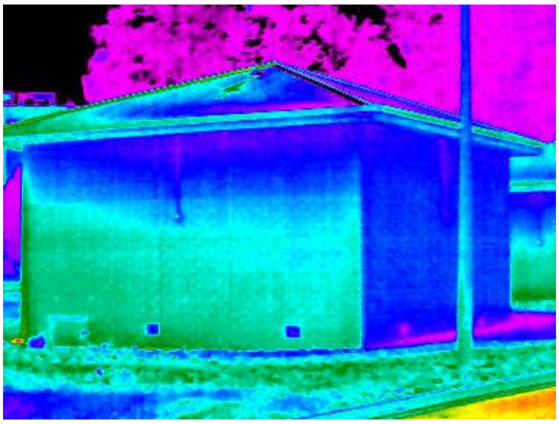


Figure 3.35 – External infra-red image of the test cell

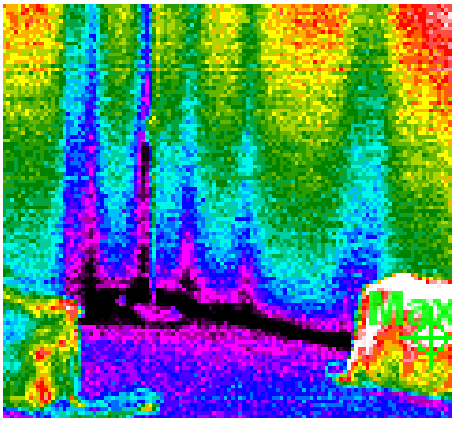


Figure 3.36 – Internal infra-red image showing the variation in surface temperatures associated with wall framing

3.1.3 Site Climate Data

The external environmental measurements of the test cell included the establishment of a site weather station and the measurement of solar radiation on each of the external walls of the test cell. The site weather station was affixed to the roof of the test cell with a modified roof antennae mounting system (Figure 3.37). The site weather station measured: dry bulb air temperature, relative humidity, wind speed, wind direction and solar radiation. A range of ‘off-the-shelf’ weather station products were examined for accuracy, durability, cost and connectivity to the analogue data-logger platform. Most systems were analysed into the sub-groups of temperature and relative humidity, wind speed and wind direction, and solar radiation. The selected sensors are listed in Table 3.8.

Table 3.8: Probes and Sensors for Site Weather Station

Purpose	Description
Solar radiation	SolData 80SPC pyranometer
Site weather station air temperature and relative humidity	Vaisala HUMICAP HMP45A/D
Site weather station wind speed and wind direction	Pacific data Systems, PDS-WD/WS-10

As research progressed, short breaks in power supply occurred and the current required for the combined temperature and humidity probe drained the DT500 battery too quickly, which resulted in the loss of data. Memory cards were acquired to eliminate data losses from the DT500 data-loggers but the power drain for the weather station was still a problem. A DT80 data logger was acquired for LAN connectivity. It was decided to migrate the weather station sensors to the DT80 to limit the effect of power disruptions. At a later stage an Uninterrupted Power Supply (UPS) was installed.

Temperature and Humidity

By this stage in the design of the measurement equipment, several of the selected products were provided by a single supplier in Queensland. The first elements analysed for the site weather station were the air temperature and relative humidity measurement. The air temperature was to be measured to tenths of a degree Celsius and relative humidity was to be measured to tenths of a percentage. The Vaisala HUMICAP HMP45A/D temperature and humidity probe was chosen (Figure 3.38 and Figure 3.39).

The Vaisala HUMICAP HMP45A/D probe required a 7 to 35 volt direct current input power supply, which was provided by the DT500 data-logger. The output signal from both probes was zero to one volt, resulting in readings of -40.0 to +60.0 degrees Celsius for dry bulb temperature and 0.8 to 100% for relative humidity.

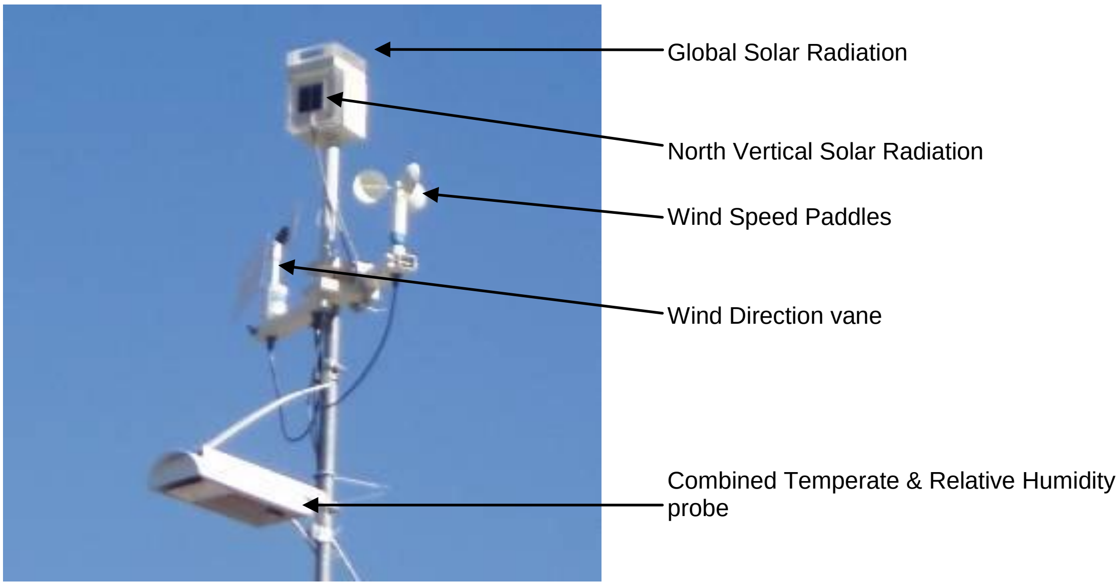


Figure 3.37 - Site Weather Station

Figure 3.38 – The Vaisala HUMICAP HMP45A/D combined temperature and humidity probe viewed from below, affixed to modified roof aerial mounting system

Figure 3.39 – The radiation and rain shield of the Vaisala HUMICAP HMP45A/D combined temperature and humidity probe viewed from above

Wind Speed and Wind Direction

The experience gained from the selection of the indoor air-flow measurement was used in the selection of the wind speed devices. Available equipment ranged from combined devices to systems with a separate wind vane and paddles or impellers. The impeller type offered a more accurate spot reading: however, initially the research only required a ten minute spot reading. There was also a distinct difference in cost between the impeller and paddle type of devices. Based on cost and the type of measurement required, the impeller type could not be justified and a paddle type was chosen. The principal specification was the measurement of wind speed to tenths of a metre per second. This parameter limited the choice of paddle devices to the Pacific Data Systems PDS-WD/WS-10 with a paddle type wind speed measurement and separate wind vane.

The PDS-WD/WS-10 wind speed and wind direction probes were two separate devices, as shown in Figure 3.40. The wind speed probe was an electrical generator producing 0 to 1 volts, representing a wind speed of 0 to 27.78 metres per second. The programming of the data-logger applied an appropriate span to calculate the varying wind speed.

The wind direction probe required a 5 volt DC power supply, which for the early stages of the research was provided by the DT500 data-logger. In later stages, the power and data acquisition was provided by the DT80 data-logger, as discussed earlier. The wind vane required a 360^0 clear space for rotation. A piece of square hollow section steel was fabricated with a fixing point on one end for the wind speed probe, a hole in the centre for affixing to the roof bracket and a fixing point on the opposing end for the wind vane device (Figure 3.40). The wind vane output ranged from 0 to 1 volt, which represented 0^0 to 360^0. An appropriate span was applied to the data-logger programming to calculate the wind direction, based on the fraction of voltage supplied.

The values recorded for wind speed were modified prior to being included in the site climate file, as the device was on top of the test cell roof and not the standard 10m off the ground. CSIRO researchers provided advice on the method of converting the recorded data.

Figure 3.40 – PDS-WD/WS-10 wind speed and wind direction probes affixed to rectangular hollow section steel tube and roof bracket

Solar Radiation

Originally, only global solar radiation was to be observed. As an awareness grew of the limited empirical solar radiation data that was available for research, the types of solar radiation to be observed increased, to include north vertical, diffuse and each of the four external walls on each test cell. The site weather station included pyranometers for the measurement of global solar radiation and direct north vertical solar radiation (Figure 3.37 and Figure 3.44). At a later stage a shadow ring device was fabricated to measure diffuse solar radiation (Figure 3.44).

After a review of suitable devices, products from Pacific Data Systems were examined for capability, durability and cost. The SolData 80SPC pyranometer, which at the time was relatively new to the market, was selected for the measurement of solar radiation in all instances. The final configuration of pyranometers comprised:

- External mid-wall height on all four external walls (north, west, south and east) of the test cell (Figure 3.41). This was to provide additional data for checking incidental radiation on the external walls of the buildings.
- The measurement of global and north vertical solar radiation as part of the site weather station (Figure 3.37 and Figure 3.42)
- The measurement of diffuse solar radiation by means of a shadow ring device (Figure 3.43 and Figure 3.44).

The SolData 80SPC pyranometers converted solar radiation into electricity. The voltage supplied by the pyranometer was converted to watts/m^2 based on the individual calibration values for each sensor. Each pyranometer arrived with a calibration certificate and a sticker attached, which specified the span for the device (Figure 3.43). The span for each pyranometer was different requiring an appropriate span in the data logger programming. The calibration for each pyranometer was completed as shown in Table 3.9.

Figure 3.41 - The SolData 80SPC pyranometer affixed to brick veneer wall

Figure 3.42 – SolData 80SPC pyranometers measuring global and north vertical solar radiation

Figure 3.43 – SolData 80SPC pyranometer serial number 563 with a span value of 155mV = 1.0KW/m^2

Figure 3.44 – SolData 80SPC pyranometer as part of shadow ring device for measuring diffuse solar radiation

Table 3.9: Calibration of SolData 80SPC Pyranometers

Workshop Based Testing when Supplied	Test Cell Based Testing (After Connection to Data Cable and Data-logger
Comparison to pre-calibrated SolData 80SPC Pyranometer	Comparison to pre-calibrated SolData 80SPC Pyranometer

3.2 Environmental Measurement: Installation Process

Primary sensors were installed progressively, from mid July 2006 to December 2006 (Dewsbury, Nolan et al. 2007). During this process, minor systemic or sensor problems were identified and rectified, namely:

- The earth cabling between the data-logger and channel expansion module
- The care of cable connections or terminations
- Programming errors
- Span errors, and
- The general testing and calibrating of equipment.

The rectification of these errors often led to improvements in the programming and cabling systems, which were adopted during the monitoring period of this research. The test cell had two data-loggers, comprising:

- Data-logger A: Primarily recorded the air temperatures of the pole sensors, electricity consumption and other temperature sensors in the subfloor and roof space
- Data-logger B: Recorded data from the remaining temperature sensors, air movement, relative humidity and solar radiation

3.2.1 The Fabrication, Installation and Calibration of Environmental Measuring Equipment

The manufacture, installation and calibration of the environmental measuring equipment took more than a year to complete. As the principles of the environmental measuring system were known, a range of tests were carried out on each item of equipment as it arrived, (prior to installation) to reduce the number of system or device faults that occurred. Many essential elements were installed within the test cell prior to August 29, 2006, but a general debugging of equipment continued to occur until January 2007. The installation of new equipment continued until February 2008.

The selection of a system that was suitable for LAN and WAN connectivity was a key requisite for the long term vision of the research. The concept, as shown in Figure 3.45, consisted of:

- DataTaker DT500 data loggers and channel expansion modules for primary data acquisition
- Wiring from data logger terminals to RJ45 terminal blocks
- Eight wire data cable from RJ45 terminal blocks to Krone connector near to the location of the particular measuring device
- Two wires from Krone connector providing power to and return signal from each individual measuring device

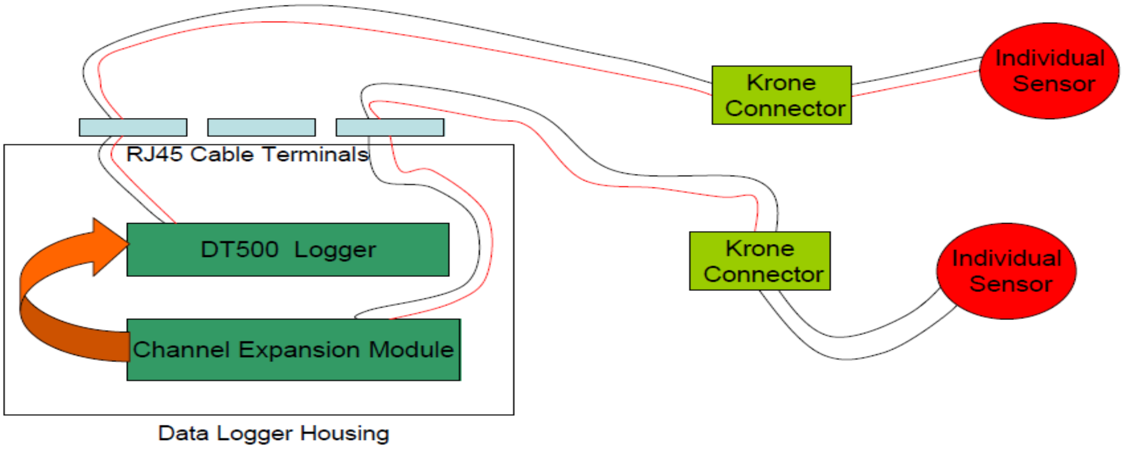
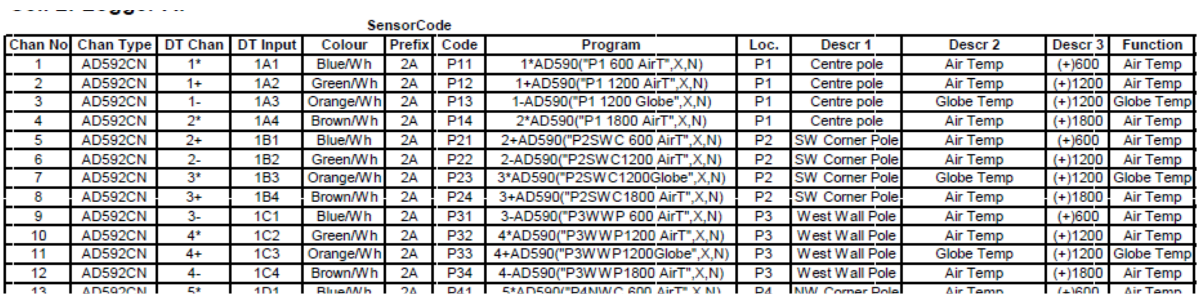


Figure 3.45 – Wiring diagram for environmental measuring equipment

Most of the sensors required a two-wire connection. The adoption of an eight-wire data cable methodology enabled each data cable to carry the signal of four individual sensors. To maximise the benefits of this approach, extensive planning and design of the sensors and their configuration was undertaken. Figure 3.46 shows a sample of a channel allocation schedule for the test cell. This method enabled the careful consideration of sensor type and requirements from an early planning stage.



SensorCode

Chan No	Chan Type	DT Chan	DT Input	Colour	Prefix	Code	Program	Loc.	Descr 1	Descr 2	Descr 3	Function
1	AD592CN	1*	1A1	Blue/Wh	2A	P11	1*AD590("P1 600 AirT",X,N)	P1	Centre pole	Air Temp	(+)600	Air Temp
2	AD592CN	1+	1A2	Green/Wh	2A	P12	1+AD590("P1 1200 AirT",X,N)	P1	Centre pole	Air Temp	(+)1200	Air Temp
3	AD592CN	1-	1A3	Orange/Wh	2A	P13	1-AD590("P1 1200 Globe",X,N)	P1	Centre pole	Globe Temp	(+)1200	Globe Temp
4	AD592CN	2*	1A4	Brown/Wh	2A	P14	2*AD590("P1 1800 AirT",X,N)	P1	Centre pole	Air Temp	(+)1800	Air Temp
5	AD592CN	2+	1B1	Blue/Wh	2A	P21	2+AD590("P2SWC 600 AirT",X,N)	P2	SW Corner Pole	Air Temp	(+)600	Air Temp
6	AD592CN	2-	1B2	Green/Wh	2A	P22	2-AD590("P2SWC1200 AirT",X,N)	P2	SW Corner Pole	Air Temp	(+)1200	Air Temp
7	AD592CN	3*	1B3	Orange/Wh	2A	P23	3*AD590("P2SWC1200Globe",X,N)	P2	SW Corner Pole	Globe Temp	(+)1200	Globe Temp
8	AD592CN	3+	1B4	Brown/Wh	2A	P24	3+AD590("P2SWC1800 AirT",X,N)	P2	SW Corner Pole	Air Temp	(+)1800	Air Temp
9	AD592CN	3-	1C1	Blue/Wh	2A	P31	3-AD590("P3WWP 600 AirT",X,N)	P3	West Wall Pole	Air Temp	(+)600	Air Temp
10	AD592CN	4*	1C2	Green/Wh	2A	P32	4*AD590("P3WWP1200 AirT",X,N)	P3	West Wall Pole	Air Temp	(+)1200	Air Temp
11	AD592CN	4+	1C3	Orange/Wh	2A	P33	4+AD590("P3WWP1200Globe",X,N)	P3	West Wall Pole	Globe Temp	(+)1200	Globe Temp
12	AD592CN	4-	1C4	Brown/Wh	2A	P34	4-AD590("P3WWP1800 AirT",X,N)	P3	West Wall Pole	Air Temp	(+)1800	Air Temp
13	AD592CN	5*	1D1	Blue/Wh	2A	P41	5*AD590("P4NWC 600 AirT",X,N)	P4	NW Corner Pole	Air Temp	(+)600	Air Temp

Figure 3.46 – Sample of DT500 channel allocation spreadsheet.

The test cell initially required two data loggers. A simple naming convention of test cell number and data logger A, B or C was adopted. The columns of the channel allocation schedule provided elements of functionality, namely:

- Channel Number: Each data logger and channel expansion module (CEM) could accommodate 30 analogue two wire sensors (DT500 30 + CEM 30 = 60).
- Channel Type: This specified the sensor type (i.e., AD592CN, Voltage, 4-20mA).
- DT Channel: Data logger channel allocation where 01 referred to the channel number on the data-logger and from 31 onwards referred to the channel on the CEM.
- DT Input: Naming convention for linkage to 8 wire data cable and RJ45 cable socket. Each data cable wall plate could accommodate four RJ45 outlets. 1A3 referred to Wall Plate 1, RJ45 socket A and the third pair of wires (orange/white).
- Colour: this detailed the colour of the pair of data cable wires which were allocated to the sensor (Blue, Green, Orange or Brown).
- Prefix: Test cell and data logger identification.
- Code: Each type of sensor was allocated an alphabetical prefix. Each type of sensor received a tally (P42 = AD992CN number 42).
- Program: This was the specific wording that was used for the data logger programming.
- Location: Location of sensor within test cell (P1 = Pole 1).

- Description 1-3: This described the location of the sensor within the test cell building and its purpose, (i.e., centre of test cell room, air temperature, 600mm).

The channel allocation schedule was an integral document for the planning and implementation of the environmental measurement of the test cell.

DT500 DataTaker Data Loggers

The DT500 data loggers were the primary tools for data acquisition. Even with the manufacturer's calibration certification, the data loggers were tested before any further work progressed. The tests included: checking of the data logger system, battery, power supply, integrated circuit integrity and earthing. The CEM was tested in the same manner.

The appropriate wiring between the data logger, channel expansion module and the RJ45 terminals was installed offsite by an appropriately skilled contractor (Figure 3.47 to Figure 3.50). After the wiring to the RJ45 terminal was installed, each channel was checked again to make sure the data logger was still calibrated. The data logger and connected channel expansion module were then installed into a secure metal box and delivered to the University.

Figure 3.47 – New DT500 data loggers and channel expansion modules

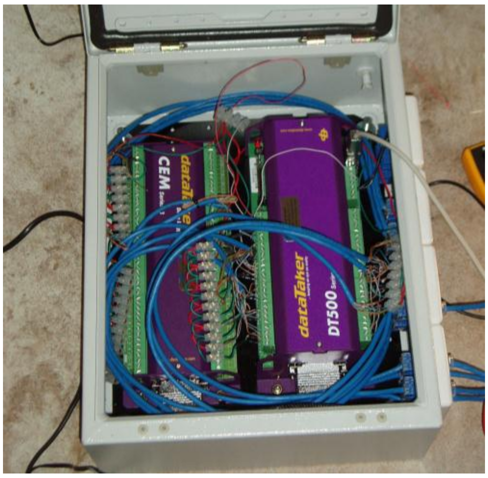


Figure 3.48 - DT500 and channel expansion module in metal case after wiring was installed to RJ45 terminals

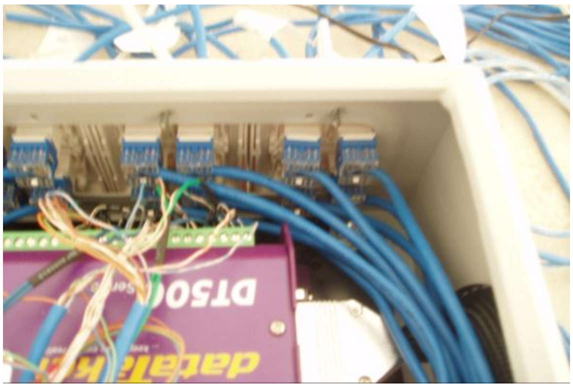


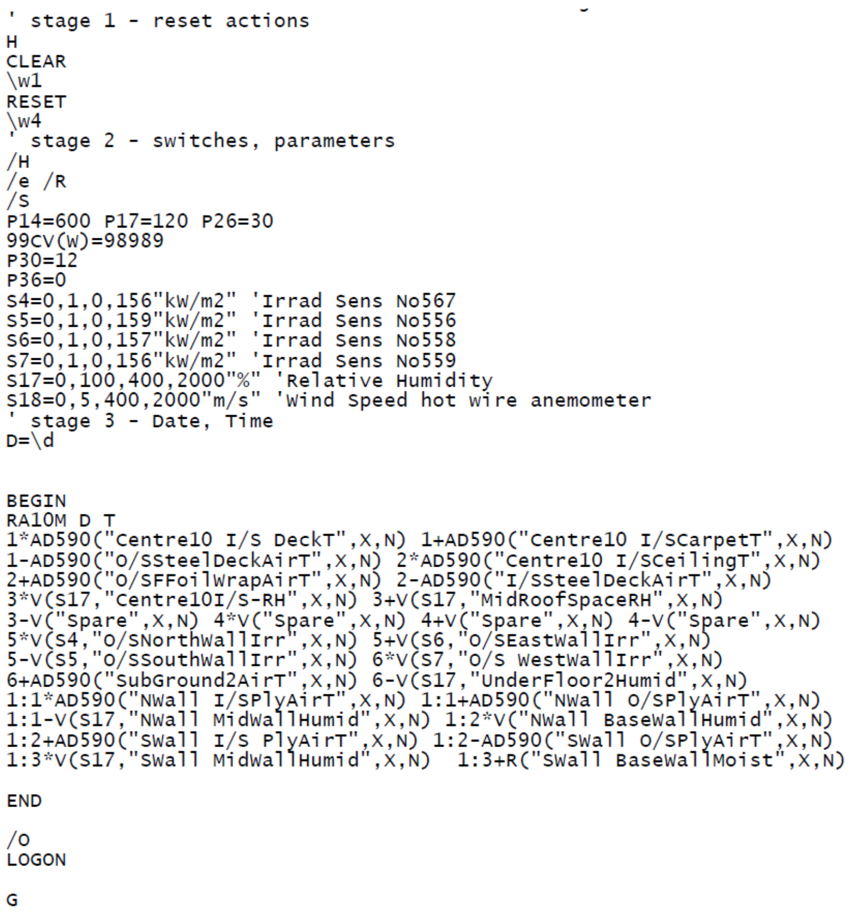
Figure 3.49 – Interior view of metal box and RJ45 terminals

Figure 3.50 - Exterior view of metal box and RJ45 sockets

From August 2006 to August 2009, five generations of wiring within the data logger metal box occurred. This was due to a balanced combination of maintenance and ease of accessibility for the methods used to connect wires. With each generation of wiring, the data logger appeared cleaner and more professional in approach.

Data Logger Programming

Each data logger was programmed to suit the sensors it was reading. A sample of one of the data logger programs is shown in Figure 3.51. During the course of this research, minor modifications to data logger programming were made. As the research progressed, particular measurements were changed from a ten minute spot reading to an average reading for the ten minute period. This method was adopted for the measurement of electricity usage, as it allowed for a more thorough understanding of when particular electrical services were in use and the energy use within the test cell.



```
' stage 1 - reset actions
H
CLEAR
\w1
RESET
\w4
' stage 2 - switches, parameters
/H
/e /R
/S
P14=600 P17=120 P26=30
99CV(W)=98989
P30=12
P36=0
S4=0,1,0,156"kW/m2" 'Irrad Sens No567
S5=0,1,0,159"kW/m2" 'Irrad Sens No556
S6=0,1,0,157"kW/m2" 'Irrad Sens No558
S7=0,1,0,156"kW/m2" 'Irrad Sens No559
S17=0,100,400,2000"%" 'Relative Humidity
S18=0,5,400,2000"m/s" 'Wind Speed hot wire anemometer
' stage 3 - Date, Time
D=\d


BEGIN
RA10M D T
1*AD590("Centre10 I/S DeckT",X,N) 1+AD590("Centre10 I/SCarpetT",X,N)
1-AD590("O/SSteelDeckAirT",X,N) 2*AD590("Centre10 I/SCeilingT",X,N)
2+AD590("O/SFFoilWrapAirT",X,N) 2-AD590("I/SSteelDeckAirT",X,N)
3*V(S17,"Centre10I/S-RH",X,N) 3+V(S17,"MidRoofSpaceRH",X,N)
3-V("Spare",X,N) 4*V("Spare",X,N) 4+V("Spare",X,N) 4-V("Spare",X,N)
5*V(S4,"O/SNorthWallIrr",X,N) 5+V(S6,"O/SEastWallIrr",X,N)
5-V(S5,"O/SSouthWallIrr",X,N) 6*V(S7,"O/S WestWallIrr",X,N)
6+AD590("SubGround2AirT",X,N) 6-V(S17,"UnderFloor2Humid",X,N)
1:1*AD590("NWall I/SPlyAirT",X,N) 1:1+AD590("NWall O/SPlyAirT",X,N)
1:1-V(S17,"NWall MidWallHumid",X,N) 1:2*V("NWall BaseWallHumid",X,N)
1:2+AD590("SWall I/S PlyAirT",X,N) 1:2-AD590("SWall O/SPlyAirT",X,N)
1:3*V(S17,"SWall MidWallHumid",X,N)  1:3+R("SWall BaseWallMoist",X,N)

END

/O
LOGON

G
```

)
)
) Establishing data
) logger parameters
)
)

)
)
) Defining Spans
)
)

) setting Date & Time

)
)
) General
) programming for all
) environmental
) measuring devices
)
)

) Informing the data
) logger to commence
) recording data

Figure 3.51 – Sample of data logger programming

Connecting the Sensors to the Data Loggers

The system cabling method, as shown in Figure 3.45, utilised high quality eight wire data cable between the data logger RJ45 outlets and Krone terminals (Figure 3.52). A range of tests was undertaken before installing the cables in the test cell. This included testing the data cable and bell to assess signal interference or loss over varying distances, indoors and outdoors, over other active data cables and electrical services. Generally, no effect or distortion of measurements was observed in cable distances less than ten metres. Distortions that could potentially affect the sensor signal did occur, when that data cable ran alongside or crossed over electrical services. It was observed that if the cable was shielded where it crossed over electrical services, the distortion to the sensor signal was alleviated.

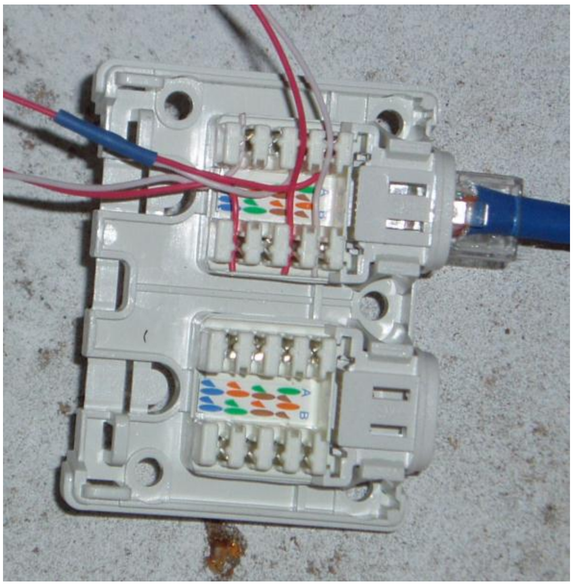


Figure 3.52 – Krone terminal: with RJ45 plug inserted on the right and red/white bell wire leads to an individual sensor connected to the Krone terminal

To maintain a calibration regime during the installation of the equipment within the test cell, a procedure was developed to enable efficient and reliable installation. The process was broken into two distinct stages, involving either the data logger wiring or the wiring to an individual sensor. The process for the installation of wiring within the data logger metal box was as follows:

- Step 1: Empty data logger. Data logger tests were run and checked to ensure that all channels read zero.
- Step 2: The data logging program was installed into the data logger and all channels were checked to ensure that a zero reading was still being recorded. The zero value depended on the type of signal provided by the sensor to be installed on a particular channel.
- Step 3: Resistors and other wiring was installed to individual channels of the data logger. The data logger was tested to ensure a zero value was still being recorded.
- Step 4: Earth and reference wires were installed. The data logger was tested to ensure a zero value was still being recorded.
- Step 5: The data cables were attached to the RJ45 terminal blocks and the data logger was tested to ensure a zero value was still being recorded.

This method of installing wiring from the data logger channel to the RJ45 terminal block allowed the removal or repair of any item which might not be giving a true or clean signal. During the data collection period, occasional testing of the data loggers was completed, in which all cables leaving the RJ45 terminals were removed and all wires were tested, to ensure all data logger channels were still reading a zero value.

The second stage for the installation of individual sensors was as follows:

- Step 1: A new piece of data cable, which was cut to the desired length, had an RJ45 plug placed on one end. The RJ45 plug was plugged into the RJ45 terminal block on the data logger metal box. The data logger was tested to ensure a zero value was still being recorded.
- Step 2: An RJ45 plug was attached to the other end of the data cable and the data logger was tested to ensure a zero value was still being recorded.
- Step 3: The new RJ45 plug was placed into the Krone terminal block and the data logger was tested to ensure a zero value was still being recorded.
- Step 4: Depending on sensor type, two methods occurred at this stage: For sensors which had the bell wire soldered to output terminals, the two bell wires from the individual sensor were attached to the Krone block and a signal was then received from the individual environmental sensor. However, for sensors which had screw type terminals, the bell wires were attached to the Krone terminal block and the data logger was tested to ensure a zero value was still being recorded. The wires were then connected to the sensor and a signal was then received at the data logger.
- Step 5: Output readings were then compared between data from the newly cabled sensor and data from another directly wired sensor in the same location. This was to check for any variation in data readings. If there was a variation, the process started again, this may have required replacement of cable, wires or sensor.

This method of installing individual environmental sensors allowed for a simple process of error recognition.

Local Area Network (LAN) Connection and Logger Automation

The configuration of the data loggers was to support LAN connectivity, to allow for remote management and data acquisition. This required a data logger which could communicate with the DT500 data loggers and had the capability to communicate with an external server. The DataTaker DT80 provided this function (Figure 3.53). It was programmed to collect data from the DT500 data loggers and to act as a server, to send and receive data from computers and servers located within the research centre offices.

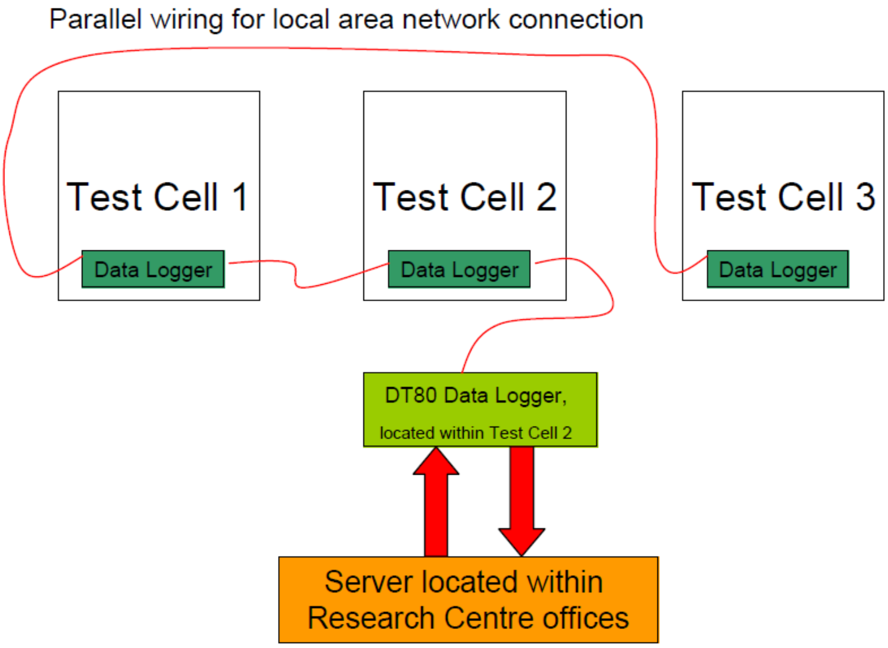


Figure 3.53 – Connection diagram for Local Area Network connectivity of the thermal performance test cells.

3.3 Calibration of Measuring Equipment

Calibration and the ongoing checking of sensors occurred during the research period. As described above for each type of sensor, calibration initially occurred when equipment was received, and subsequently in the workshop when wiring was attached and in the test cell during the installation process.

The data-loggers were tested at regular intervals as subtle effects in measurements were observed by the University of Newcastle (Sugo 2005-2009) and also during the workshop bench testing in this research. The data loggers were installed within a metal security box to eliminate any effect from the air movement across the data-logger (Figure 3.54). The data-loggers in-built testing program was used at regular intervals during the research and especially after power disruptions occurred. The data-loggers were configured to operate from their battery power, which limited the Effect of power fluctuations in the test cell power supply (Figure 3.55). However, after some power surges, the integrated circuits within a data-logger were damaged, requiring their replacement. In one case, some of the resistors within the data-logger were damaged. These events led to the installation of the UPS power supply.

Figure 3.54 - Data–logger within a steel security box to eliminate effects from air movement

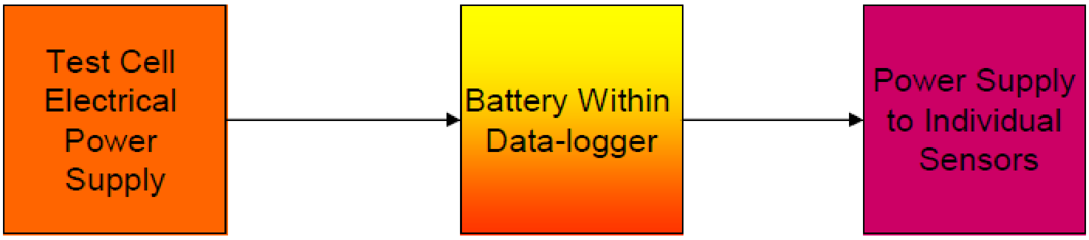


Figure 3.55 – Diagram of power supply from test cell to individual sensors

3.4 Operational Control of the Test Cell

The operational control included a detailed log of activity within the test cell and modes of operation. The test cell included a fan assisted electric resistance heater capable of heating the test cell room. This allowed for future research to examine the HVAC module within HER software. The test cell had the capability to operate in three modes, namely:

- Unoccupied and unconditioned
- Unoccupied and permanently heated
- Unoccupied and variably heated

However, the empirical validation research only examined data from extended periods of the unoccupied and unconditioned mode of operation.

The test cell was equipped with an electric heater (Figure 3.57). During the first few months of operation several trials were attempted to control the test cell room temperature using the inbuilt thermostat of the heater (Dewsbury, Nolan et al. 2007). It was found that there was little similarity between dial position and the temperature set point of the heater and that the cut in and cut out activity of the inbuilt thermostatic controls of the heater was unreliable. To overcome these problems, and for more precise heating control, an electrical relay was installed (Figure 3.56), which required:

- The installation of a relay switch within the box enclosing current transducer sensors (Figure 3.58).
- The rerouting of heater power supply via the relay switch.
- The programming of an alarm in the data logger based on the temperature being measured by the dry bulb air temperature sensor located in the middle of the test cell room.
- The programming of the reading of data from the sensor was modified from a ten minute spot reading to a constant reading.
- When the air temperature dropped 0.1^0C below the programmed value, the alarm would send a signal to a relay to close a circuit, providing electricity supply to the heater.

- When the air temperature increased to 0.1^0C above the programmed value, the alarm would send a signal to a relay to open a circuit, stopping the provision of electricity supply to the heater.
- The internal thermostat controls of the heaters were modified, such that they would not impede heater operation.

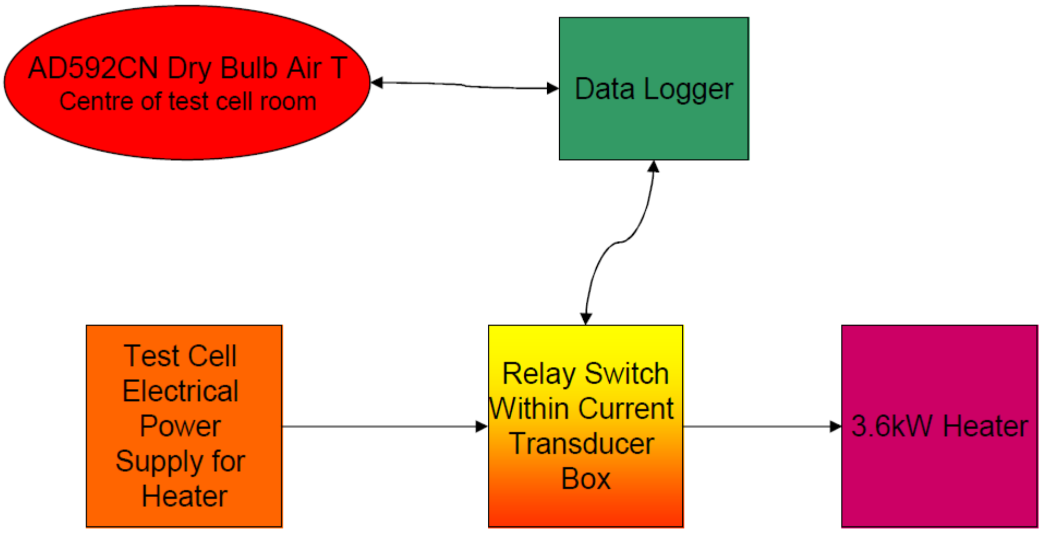


Figure 3.56 – Wiring diagram for relay control of thermal performance test cell room heater

Figure 3.57 – Wall heater being installed during test cell construction

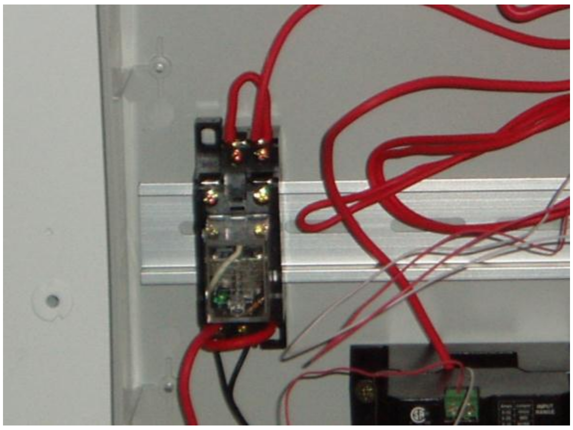


Figure 3.58 – Relay control for heater installed within box enclosing current transducers

3.5 Thermal Performance Test Cell Data

The data acquisition process required several steps and included the development and implementation of systems for:

- Data loggers
- Download methods
- Data storage
- Data cleaning and averaging

3.5.1 Data Logger Data Acquisition

The DT500 data logger had an on-board memory capacity, which could store between two and three weeks of data. Initially, the test cell room was accessed at fortnightly intervals to download the data from the data logger. The data was saved in two formats (logger native format and CSV) which reduced the risk of data being accidently amended during the research process. This method helped to ensure data integrity. During the data cleaning process the reference file was always the data logger native format file.

After a series of data losses due to unannounced or unexpected electricity supply disruptions, static memory cards were added to the data loggers. This method of data storage involved the data logger saving recorded measured information directly to the static memory card. If there was an extended power outage, the data on the static memory card was retained. The static memory card was able to store nearly six weeks of logging data. The memory capacity of the card reduced the need to access the test cell room to download data, while it also increased the time for faults with sensors to become visible.

As the research progressed, the DT80 data logger was acquired and installed. The installation of the DT80 data logger established a new paradigm for data collection and storage (Figure 3.53). Initially the programming of the DT80 data logger allowed for the data from all three thermal performance test cells to be collated on a single data logger. Once the LAN infrastructure was established between the thermal performance test cells and the Newnham campus and the WAN connectivity was established between the Newnham and Inveresk campuses, automated downloading of data was established. The data storage process, as discussed below, required the acquisition of a suitable server, which was installed with appropriate software and programming to enable it to communicate directly with the DT80 data logger at the test cells. Once this link was established, data from the test cells was automatically downloaded to the offsite server every ten minutes.

Table 3.10: Data Storage Methods

Data Storage Method	Collection Period	Data Storage Capacity
Data Logger 'on board' memory	Maximum of every ten minutes	2-3 weeks data
Data Logger with Static memory card	Maximum of every ten minutes	Up to 6 weeks data
DT80 Data Logger: Stage 1	Copied from DT500 data loggers every ten minutes	Up to 8 weeks data
DT80 Data Logger: Stage 2	Copied from DT500 data loggers every ten minutes Transmitted to Research Centre Server every ten minutes	Unlimited (server dependent) Back up of up to 6 weeks of data still stored on static memory card

3.5.2 Data Storage

During the first stages of the research prior to the DT80 data logger being installed, all data was downloaded and a simple naming convention was placed on all files which consisted of date and building descriptors, for example:

- 2006-08-23TC2B:
  date of data download as August 23, 2006, and the data came from data logger B from test cell 2.

Towards the end of 2007, all the individual fortnightly downloaded comma separated files were combined into annual single spreadsheet files. When the DT80 data logger and server connectivity was completed, a self-appending table was developed within the server. There was a separate table for each data logger and the data within the table was configured to a new table per calendar year.

The server required two primary forms of software, namely:

- DT80 WAN Interface, to enable the automated downloading of data from the DT80 data logger located with the thermal performance test cells and was provided by the manufacturer of the DT80 data logger.
- A suitable MYSQL form of database was acquired. Templates for tables within the database were created, where each table was for a separate data logger and tables reflected the data logger programming.

3.5.3 Data Cleaning

In consultation with CSIRO scientists, a data cleaning procedure was developed for the test cell data. Table 3.11 below details the step-by-step process undertaken to clean the test cell and site weather station data. At the completion of each step a new version of the database file was created. This enabled a history of the data cleaning process to be kept for future reference. To avoid personal biases, the researcher performed none of the data checking. However, the researcher did analyse all errors raised by the data-checking staff and in co-operation with a co-researcher, made amendments to data when required. For most measurement locations, the data checking involved the cross-comparison of data from a nearby similar device and/or data from the site weather station. The key data points which were extracted to form the final empirical validation data set were:

- Centre of roof space dry bulb air temperature
- 1800mm, 1200mm, 600mm centre of test cell room dry bulb air temperature
- 1200mm centre of test cell room mean radiant temperature
- Mid subfloor dry bulb air temperature (unenclosed and enclosed-perimeter platform-floored test cells)
- Site weather station environmental measurements

Table 3.11: Data Cleaning Method

Stage	Title	Description
1	10 Minute Data Range Check	Each environmental measuring device was allocated an expected range of measurement. All data for each device was checked to ensure it was within the expected range.
2	10 Minute Data Null Value Check	All data was analysed to ascertain periods with missing data or corrupted data. All values for these periods were converted to a null value.
3	10 Minute Data Step Value Check	Each environmental measuring device was allocated a step value, which was an estimate of the expected change in measurement between each ten minute reading. All data for each device was checked, to ensure that the data did not have steps in value greater than those defined.
4	Modification of Test Cell Data Based on Test Cell Log Book Entries	The log books of the thermal performance test cells were analysed and an additional notes column was added to the test cell database tables. If there was activity within a thermal performance test cell, which would affect the free-running nature of the data, the data was modified to a null value.
5	10 Minute Data Graphical Analysis	A final checking process for the ten minute data was the use of graphing software, which converted the data into graphical form. This analysis allowed for the researchers to notice any phase shift or other anomalies in the pattern of the data.
5	Averaging 10 Minute Data into Average Hourly format	The data from the 40 minute, 50 minute, 0 minute, 10 minute, 20 minute and 30 minute readings were averaged to establish a new average hourly value. The only exception to this method was the wind direction which used a mix of mode, mean and wind speed to establish an average hourly wind direction value.
6	Average Hourly Data Range Check	Each environmental measuring device was allocated with an expected range of measurement. All data for each device was checked to ensure it was within the expected range.
7	Average Hourly Data Step Value Check	Each environmental measuring device was allocated with a step value, which was an estimate of the expected change in measurement between each average hourly data value. All data for each device was checked to ensure that the data did not have steps in value greater than those defined.
8	Average Hourly Graphical Analysis	A final checking process for the average hourly data was the use of graphing software which converted the data into graphical form. This analysis allowed for the researchers to notice any phase shift or other anomalies in the pattern of the data.
9	Test Cell Notes Cross Check	A final cross check of the thermal performance test cell log book entries was undertaken, to ensure that no data which would be affected by test cell access had a value within the final data set.

4 Generating the Simulation data

The observed temperatures from the three zones of the test cell provided the empirical data for the validation process. The AccuRate software was used for the building thermal simulation to create a data set for the empirical validation. The standard method of producing a house energy rating using the AccuRate software was not suitable for empirical validation purposes. To produce a suitable data set, a more detailed thermal simulation was required (Dewsbury 2009; Dewsbury, Soriano et al. 2009; Dewsbury 2011). The initial simulation was completed in December 2008 and was a co-operative effort between the researcher and the CSIRO AccuRate software developers. From this initial simulation model several improvements were made throughout 2009 and 2010 to the input variables. During this process the thermal modelling of the test cell was revised and improved.

The AccuRate software included many default values to make standard house energy ratings simple and quick to undertake. However, a number of these default parameters required amendment for this research (Dewsbury 2011). This established a second tier of simulation requirements, namely:

- Determine ‘as-built’ values for roof, ceiling, wall and floor assemblages to modify fabric thermal properties
- Determine ‘as-built’ values for shading elements that would affect fabric thermal performance
- Obtain observed data for site shading elements
- Use of appliance-generated heat loads that occurred within the test cell
- Use of measured infiltration values for each zone of the test cell
- Modify thermostat settings within the software to recognise the unoccupied and unconditioned operating mode of the test cell
- The use of synchronised site-measured climate data for use in the AccuRate simulation

Only when these values were established and simulation inputs modified, could there be confidence in the output simulation temperature data from the AccuRate software (Dewsbury 2011). Through this process, four distinctly different detailed thermal simulations, as shown in Figure 4.1, were completed for the test cell, which are best illustrated by Figure 4.2.

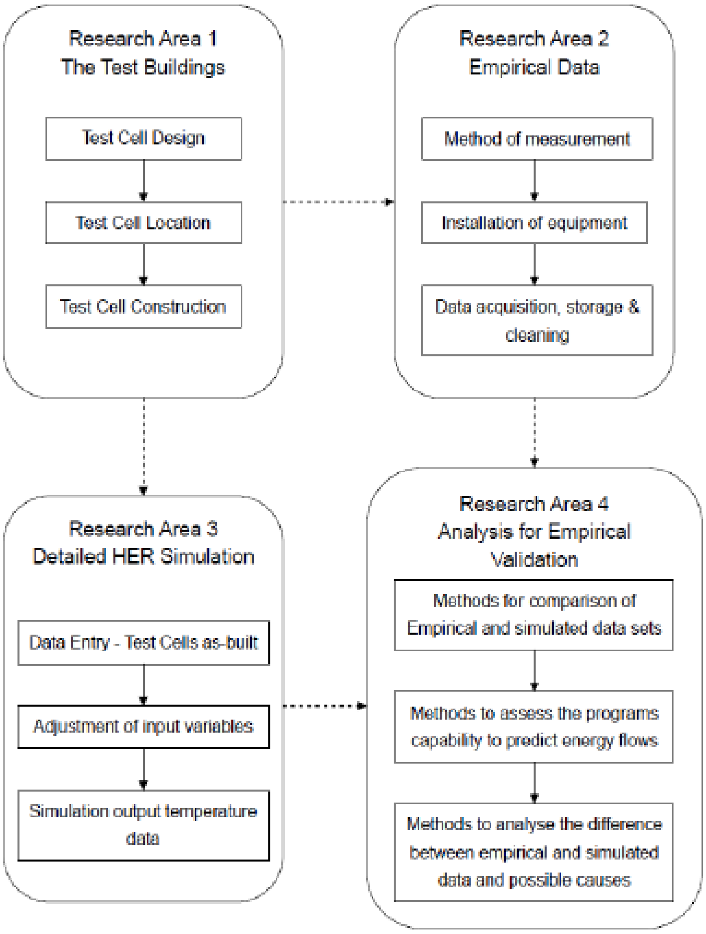
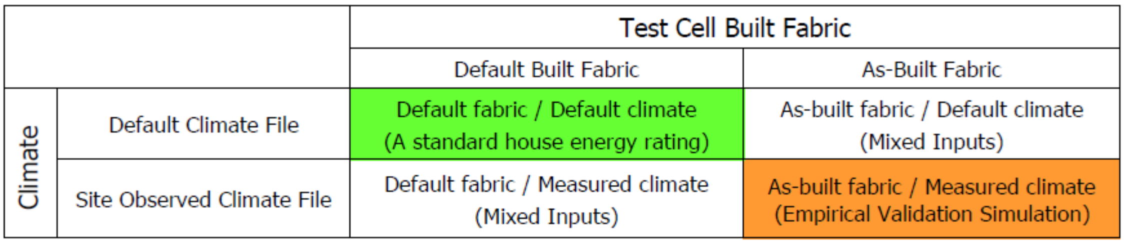


Figure 4.1 – Validation Methodology (Dewsbury 2011)



		Test Cell Built Fabric	
		Default Built Fabric	As-Built Fabric
Climate	Default Climate File	🟩 Default fabric / Default climate (A standard house energy rating)	As-built fabric / Default climate (Mixed Inputs)
	Site Observed Climate File	Default fabric / Measured climate (Mixed Inputs)	🟧 As-built fabric / Measured climate (Empirical Validation Simulation)

Figure 4.2 –Detailed Simulation Matrix (Dewsbury 2011)

Each simulation type required different levels of improved data inputs. The final version, (As-built/Measured Climate) was used for the empirical validation process (Dewsbury 2009; Dewsbury 2011). The As-built/Measured Climate simulation required an intricate assessment of the 'as-built' materials and systems, by which modifications to the default values within the software were made. The site-measured climate data were used to create a site climate file. This was the only method suitable for providing the resultant AccuRate simulation data set for comparison to the measured building thermal performance for empirical validation. The data inputs that were required for the test cell are listed in Table 4.1.

Standard user interface and other non-standard inputs were completed to make the input data suitable for the detailed simulation for empirical validation purposes (Dewsbury 2011). In this research the non-standard modified inputs were:

- The modification of fabric assemblages to account for framing factors
- The modification of sensible internal heat gains to account for free-running operation
- The modification of latent internal heat gains to account for free-running operation
- The modification of heating thermostat controls to account for free-running operation
- The modification of cooling thermostat controls to account for free-running operation
- The modification of infiltration values from default to observed values
- The development and use of a site-observed climate file.

Once all the appropriate standard and non-standard input values were suitably modified, the AccuRate thermal simulation was completed. The output files included the resultant energy use and temperature by zone. The energy use by zone report provided a final checking mechanism to ensure that the simulation inputs were appropriately configured for the unoccupied and unconditioned mode of operation.

Table 4.1: Built elements data input requirements for the enclosed-perimeter platform-floored test cell

Subfloor	External Wall	Applicable
	External Wall Fixed Shading	Applicable
	External Wing Walls	Not Applicable
	External Screens	Applicable - Nearby buildings and trees
	Internal Wall	Not Applicable
	Floor	Applicable - Ground
	Ceiling	Applicable – Test cell floor
	Doors in Walls	Applicable – Access door in northern wall
	Windows in Walls	Not Applicable
	Roof	Not Applicable
Test Cell Room	External Walls	Applicable
	External Wall Fixed Shading	Applicable - Eaves
	External Wing Walls	Not Applicable
	External Screens	Applicable – Nearby buildings and trees
	Internal Wall	Not Applicable
	Floor	Applicable
	Ceiling	Applicable
	Doors in Walls	Applicable – Access door in southern wall
	Windows in Walls	Not Applicable
	Roof	Not Applicable
Roof Space	External Walls	Not Applicable
	External Wall Fixed Shading	Not Applicable
	External Wing Walls	Not Applicable
	External Screens	Not Applicable
	Internal Wall	Not Applicable
	Floor	Applicable – Test cell ceiling
	Ceiling	Not Applicable
	Doors in Walls	Not Applicable
	Windows in Walls	Not Applicable
	Roof	Applicable

4.1 *AccuRate - Standard Inputs*

To validate empirically and to enable calibration of the AccuRate software required the elimination of input variable simplifications, which affect the underlying physics of the building thermal simulation (Dewsbury 2011). This required a detailed analysis of the built fabric, which enabled informed data entry modifications.

Prior to data entry, a critical analysis of the built fabric and nearby elements was completed for the test cell. The required inputs for the empirical validation process were standard and improved front end user interface data entry and modifications to the software's 'Scratch' file. The software generated a 'scratch' file when the front end user interface data entry was completed. The scratch file was used by the simulation engine to calculate house energy use, for heating and cooling. The front end user interface input modifications were performed in the same order as a standard HER process occurs. The modifications which required direct data entry within the AccuRate Scratch file were completed after the scratch file was created.

Table 4.2: Default Fabric / Default Climate and As-Built Fabric / Measured Climate Data Entry Iterations

Iteration	AccuRate Front End Data Entry	Scratch File Modifications	Default or Actual Climate Data
Default Fabric / Default Climate	Standard data entry based on plans	Thermostat, heating, cooling and internal energy loads	Default climate file
As-Built / Measured Climate	Modified conductivity values based on as-built analysis	Thermostat, heating, cooling, internal energy loads and infiltration parameters	Observed climate data

The order of the data entry followed the standard order within the AccuRate software and included: project data, constructions, zones, shading, elements and ventilation.

4.1.1 Project Data: Postcode & Exposure

Table 4.3: Project Data

Name	Post Code	Climate Zone	Exposure	Ground Reflectance
Test cell 2	7250	23	Open	0.2

Table 4.4: Project Data – Iteration variations

Iteration	Default fabric / default climate	As-built fabric / Measured climate
Post Code	7250	7250
Climate Zone	23 (Default file)	23 (Observed climate data)
Exposure	Open	Open
Ground Reflectance	0.2	0.2

4.1.2 Construction Information

Table 4.5: Construction Data – Iteration Variations

Iteration	Default Built Fabric	As Built Fabric
External Walls	Application of AccuRate pre-determined values	Modified values based on analysis of test cell as-built
Windows	nil	Nil
Doors	Application of AccuRate pre-determined values	Modified values based on analysis of test cell as-built
Floor	Application of AccuRate pre-determined values	Modified values based on analysis of test cell as-built
Ceiling	Application of AccuRate pre-determined values	Modified values based on analysis of test cell as-built
Internal Wall	nil	nil
Roof	Application of AccuRate pre-determined values	Modified values based on analysis of test cell as-built
Skylight & Roof Window	nil	nil

4.1.3 Zone Types

Table 4.6: Zone Types

Zone	Zone Type
Roof Space	Roof Space
Test Cell Room	Other (daytime usage)
Subfloor	Subfloor (enclosed)

4.1.4 Shading Features

Table 4.7: Eave Width Calculations

Element	Calculation
Wall System	Brick Veneer Wall: - 110mm clay brick - Air gap vertical 50mm - 90 Frame - Plasterboard 10mm
Wall Width	260mm
Eave Elements	Eave, Barge Board & Gutter
Eave Width	580mm

4.1.5 Built Elements

Table 4.8: Built Elements' Data Input Requirements

Zone	Applicable Data Input Requirements
Subfloor	External Wall External Wall Fixed Shading (eaves) External Screens (nearby buildings & trees) Floor (ground) Ceiling (test cell floor) Doors in Walls (access door in northern wall)
Test Cell Room	External Walls External Wall Fixed Shading (eaves) External Screens (nearby buildings & tress) Floor Ceiling Doors in Walls (access door)
Roof Space	Floor (test cell ceiling) Roof

4.1.6 Ventilation

As the test cells were square in shape and facing true north, this tab required little consideration of input values.

4.1.7 Default Fabric Input Summary

The default fabric inputs are best summarised by Table 4.9, below.

Table 4.9: Default Fabric Inputs

Project Information		
Postcode	7250	Empirical climate file in use
Exposure	Open	Normal countryside with some trees and scattered buildings
Constructions		
External Walls	Subfloor wall 110mm Generic extruded clay brick	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: medium; Solar Absorptance: 50%
External Walls	Brick Veneer Wall: 110mm Generic extruded clay brick, Air gap vertical 31-65mm (40 nominal) unventilated reflective (0.4/0.9; E = 0.38), Rockwool batt R2.5, Plasterboard 10mm	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: Paint light cream; Solar Absorptance: 30%
Windows	NIL	
Door - Room	Timber Mountain Ash 40mm	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: medium; Solar Absorptance: 50%
Door – Subfloor	12mm Plywood	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: medium; Solar Absorptance: 50%
Ceiling	Plasterboard ceiling: Glass Fibre Batt R4.0,Plasterboard 10mm	
	Top Surface	Colour: medium; Solar Absorptance: 50%
	Bottom Surface	Colour: Paint light cream; Solar Absorptance: 30%
Floor	Timber with no carpet: 19mm Particle Board	
	Top Surface	Colour: medium; Solar Absorptance: 50%
	Bottom Surface	Colour: medium; Solar Absorptance: 50%
Ground	Bare Ground	
	Top Surface	Colour: medium; Solar Absorptance: 50%
	Bottom Surface	Colour: Dark; Solar Absorptance: 85%
Internal Wall	NIL	
Roof	Metal Deck: Steel 1mm, Air gap 22.5^0 31-65mm (40mm nominal) ventilated reflective (0.4/0.9; E = 0.38)	
	External Surface	Colour: medium; Emissivity: 0.9; Solar Absorptance: 50%
	Internal Surface	Colour: Light; Solar Absorptance: 30%
Skylight	Nil	
Roof Window	Nil	
Zones	Test Cell	Usage: Daytime other (Free running) Volume: 5.48 x 5.48 x 2.44 = 73.27m^3 Floor Height: 0.60 Maximum Ceiling Height: 2440mm Infiltration: Nil Ceiling Fans: Nil
	Roof Space	Usage: Roof Space

		Volume: (6.88 x 6.88)/3 x 1.25 = 19.7m^3 Reflective: Yes Sarking: Sarked Roof Surface: Continuous metal deck Openness: Standard			
	Subfloor	Usage: Subfloor Volume: (5.78 x 5.78) x 0.6 = 20.05m^3 Floor Height: 0.00 Maximum Ceiling Height: 0.60mm Infiltration: Openness – Enclosed Wall Cavity Air Flow: No Area of Subfloor Ventilation: 6000mm^2/m Ceiling Fans: Nil			
Shading	Type 1: All walls	580mm: Offset 0mm (at ceiling height)			
	Type 2: Subfloor	580mm: Offset 2400mm			
Elements					
Subfloor	External walls	Wall 1: 110 Clay Brick	Wall 2: 110 Clay Brick	Wall 3: 110 Clay Brick	Wall 4: 110 Clay Brick
	Length	5.78m	5.78m	5.78m	5.78m
	Height	0.6	0.6m	0.6m	0.6m
	Azimuth	0^0	90^0	180^0	270^0
	Fixed Shading	Subfloor eave	Subfloor eave	Subfloor eave	Subfloor eave
	Opening	Nil	Nil	Nil	Nil
	Insect Screens	Nil	Nil	Nil	Nil
	Wing Walls	Nil	Nil	Nil	Nil
	Windows in wall	Nil	Nil	Nil	Nil
	Doors in wall	Nil	Nil	Plywood Door 0.37m^2	Nil
Subfloor	External Screens				
	- Screen 1	Old Art	Old Art dist	Trees SW	Nil
	Height	7.0m	3.6m	6.0m	
	Width	44.0m	37.0m	9.0m	
	Distance	35.5m	66.0m	17.0m	
	H.Offset	55.6m	3.5m	13.5m	
	V. Offset	-1.0m	0.0m	0.0m	
	Blocking Factor	100% all	100% all	95% all	
	- Screen 2	Test Cell 1	Old Art Close	Tree SE	Nil
	Height	4.2m	3.6m	11.0m	
	Width	5.75m	12.0m	21.0m	
	Distance	7.5m	50.0m	19.0m	
	H.Offset	1.0m	15.0m	-6.0m	
	V. Offset	-0.4m	0.0m	2.0m	
	Blocking Factor	100% all	100% all	95, 95, 70, 50, 30, 20, 15, 15, 20, 50, 70, 95	

	- Screen 3	Nil	Workshop	Test Cell 3	Nil
	Height	Nil	7.0m	3.6m	
	Width	Nil	26.0m	7.0m	
	Distance	nil	25.0m	7.5m	
	H.Offset	nil	-22.5m	-1.0m	
	V. Offset	nil	0.0m	0.3m	
	Blocking Factor	nil	100% all	100% all	
Subfloor	Internal Walls	Nil			
Subfloor	Floor	Type: Bare Ground Area: 33.41m2 Under Floor: Not Applicable Edge Insulation: Nil			
Subfloor	Ceiling	Type: Particle board 19mm Area: 30.03m2 Above Ceiling: Test Cell			
Subfloor	Roof	Nil			
Test Cell	External walls	Wall 1: Brick Veneer	Wall 2: Brick Veneer	Wall 3: Brick Veneer	Wall 4: Brick Veneer
	Length	5.48m	5.48m	5.48m	5.48m
	Height	2.44m	2.44m	2.44m	2.44m
	Azimuth	0^0	90^0	180^0	270^0
	Fixed Shading	Eave All	Eave All	Eave All	Eave All
	Opening	Nil	Nil	Nil	Nil
	Insect Screens	Nil	Nil	Nil	Nil
	Wing Walls	Nil	Nil	Nil	Nil
	Windows in wall	Nil	Nil	Nil	Nil
	Doors in wall	Nil	Nil	Door 1.72m^2	Nil
Test Cell	External Screens				
	- Screen 1	Old Art	Old Art dist	Trees SW	Nil
	Height	7.0m	3.6m	6.0m	
	Width	44.0m	37.0m	9.0m	
	Distance	35.5m	66.0m	17.0m	
	H.Offset	55.6m	3.5m	13.5m	
	V. Offset	-1.6m	-0.6m	-0.6m	
	Blocking Factor	100% all	100% all	95% all	
	- Screen 2	Test Cell 1	Old Art Close	Tree SE	Nil
	Height	4.2m	3.6m	11.0m	
	Width	5.75m	12.0m	21.0m	
	Distance	7.5m	50.0m	19.0m	
	H.Offset	1.0m	15.0m	-6.0m	
	V. Offset	-1.0m	-0.6m	1.40m	
	Blocking Factor	100% all	100% all	95, 95, 70, 50, 30, 20, 15, 15, 20, 50, 70, 95	
	- Screen 3	Nil	Workshop	Test Cell 3	Nil

	Height	Nil	7.0m	3.6m	
	Width	Nil	26.0m	7.0m	
	Distance	Nil	25.0m	7.5m	
	H.Offset	Nil	-22.5m	-1.0m	
	V. Offset	Nil	-0.6m	-0.3m	
	Blocking Factor	Nil	100% all	100% all	
Test Cell	Internal Walls	Nil			
Test Cell	Floor	Type: Particle board 19mm Area: 30.03m2 Under Floor: Subfloor Edge Insulation: Nil			
Test Cell	Ceiling	Type: Plasterboard with R4.0 Insulation Area: 30.03m2 Above Ceiling: Roof Space			
Test Cell	Roof	Nil			
Roof Space	External Walls	Nil			
Roof Space	Internal Walls	Nil			
Roof Space	Floor	Type: Plasterboard with R4.0 Insulation Area: 30.03m2 Under Floor: Test Cell			
Roof Space	Ceiling	Nil			
Roof Space	Roof	Roof 1	Roof 2	Roof 3	Roof 4
	Type	Metal Deck	Metal Deck	Metal Deck	Metal Deck
	Area	$12.73m^2$	$12.73m^2$	$12.73m^2$	$12.73m^2$
	Azimuth	0^0	90^0	180^0	270^0
	Pitch	23^0	23^0	23^0	23^0
	Exposure	Normal	Normal	Normal	Normal
Ventilation	Azimuth of front façade: 0^0				
	Building Footprint: 5.5m x 5.5m				

4.2 AccuRate – Non-Standard Inputs

To simulate the test cell in a suitable manner for empirical validation, a range of non-standard inputs were required (Dewsbury 2011). The required modifications were: climate file assignment, heating and cooling parameters, energy loads, infiltration, and built fabric conductivity values (Table 4.2). These modifications were either performed by amending values via the software front end user interface, or within the output scratch file, prior to the simulation being undertaken.

4.2.1 Modified Thermostat and Internal Heat Gains

As there was no heating or cooling of the test cell, all thermostat settings which would invoke heating or cooling processes were removed from the test cell as-built specific scratch file prior to simulation (Table 4.10). A check of the output energy file was completed to ensure that no heating or cooling rules had been invoked by the software. Similarly, the sensible and latent heat loads were amended within the test cell scratch file. The value was amended to a constant value of thirty (30) watts to account for power use by the data logging equipment (Table 4.10). The amendment of the thermostat and internal heat gain values within the AccuRate scratch files was applied to all four simulation types.

Table 4.10: As-built Scratch File Modifications

Zone	Line	Scratch File Modification	Value
Test Cell	3-1401	Sensible Internal Heat gains (Hours 1-12)	Modified to 30 watts
Test Cell	3-1402	Sensible Internal Heat gains (Hours 13-24)	Modified to 30 watts
Test Cell	3-1403	Latent internal heat gain (watts), [hours 1-12]	Modified to 0 watts
Test Cell	3-1404	Latent internal heat gain (watts), [hours 13-24]	Modified to 0 watts
Test Cell	3-1501	Heating thermostat settings [hours 1-12]	Modified to 0.0 deg.
Test Cell	3-1502	Heating thermostat settings [hours 13-24]	Modified to 0.0 deg.
Test Cell	3-1503	Cooling thermostat settings [hours 1-12]	Modified to 0.0 deg.
Test Cell	3-1504	Cooling thermostat settings [hours 13-24]	Modified to 0.0 deg.

4.2.2 Climate File Assignment

The climate files within AccuRate were developed from ten or more years of postcode specific BOM measured data. The data in many cases had portions missing and mathematical methods were utilised to fill gaps in the data sets. For validation purposes much of the default climate data file was unsuitable, as variations of up to 7.0^{o}C were observed between hourly values in the AccuRate climate file and site-measured data. As the Accurate built-in default climate file was unsuitable, a project specific climate file was established.

The external environment was monitored by a site weather station mounted on the roof of one of the test cells. This location ensured that security and an obstruction-free environment were provided for the equipment. The weather station took measurements every ten minutes for air temperature, relative humidity, wind speed, wind direction and global solar radiation. This data was combined with some BOM data to complete a site specific climate file of one year's duration. A typical AccuRate climate file consisted of sixty columns of data. Each column provided a space for required data or flag values. The first step was to identify what input values would be unchanged, or could use BOM data or required site observed data (Table 4.11). This stage was completed with inputs from the software developers from the CSIRO.

Table 4.11: Climate File Input Sources

Col. No.	Description	Method
5-6	Month Number	On site data acquisition
7-8	Day Number	On site data acquisition
9-10	Hour Number	On site data acquisition
11-14	Dry Bulb Temperature	On site data acquisition
15-17	Moisture Content	On site data acquisition
18-21	Atmospheric (air) Pressure	Bureau of Meteorology
22-24	Wind Speed	On site data acquisition
25-26	Wind direction	On site data acquisition
27	Cloud cover	Not measured
34-37	Global Solar Radiation	On site data acquisition
38-40	Diffuse Solar Radiation	Not Measured – Calculated from observed Global Solar Radiation
41-44	Normal Direct Solar Radiation	Not Measured – Calculated from observed Global Solar Radiation
45-46	Solar Altitude	Data adopted from existing Launceston Climate file
47-49	Solar Azimuth	Data adopted from existing Launceston Climate file

The BOM collected data from Launceston airport at half hourly intervals. However, Launceston airport weather station was eighteen kilometres from the test cell site and at a different altitude. The Launceston airport weather station collected half hourly air pressure values and calculated mean sea level air pressure. The mean sea level pressure was amended to account for the test cell site which was fifteen metres above sea level. The revised value was then averaged to an hourly value, to suit the climate file.

The cloud cover was not measured on site. From discussions with BOM satellite imagery software developers, it was intended that calculated values would be used. Due to constraints of time and financial resources the BOM had not established this service at the time of this research. Discussions with CSIRO AccuRate software developers established that the cloud cover value was only used for night sky loss calculations for the roof space of a building. A series of simulations was undertaken by CSIRO software developers, with varying values for cloud cover. It was found that there was a minimal effect on test cell room temperature during these iterations. Based on these tests, a cloud cover figure of four (4) was adopted, inferring a cloud cover of 50% at night.

The site weather station included a probe measuring global solar radiation. The data from this device was used to calculate values for Diffuse and Normal Direct Beam solar radiation. After a review of mathematical methods, this task was performed with CSIRO software developers, using the Moriarty and Bolland & Ridley methods for establishing diffuse radiation and Spencer's method for establishing direct beam radiation. It was found that the calculated low sun angle diffuse solar radiation values were not suitable. Therefore, values for low sun angle times were manually modified to suitable values.

All the climate data for the AccuRate climate file were combined into a single table within the research database. A program was written to read the data from the database table and provide an output file in the correct format. Once the file was produced, it was checked against other climate files and against the observed values, to ensure the formatting and scripting was correct. This process was repeated a few times, as faults in the scripting and data order were gradually removed before the final site-measured climate file was obtained.

The observed climate file was given the same name as the default climate file within the AccuRate software, as the software has a limited library of climate files it is able to read. The default and observed climate files were copied into the climate files folder to suit the simulation type that was undertaken.

4.2.3 Infiltration parameters

The AccuRate software included zone-dependant default values for infiltration. The Mobile Architecture and Built Environment Laboratory (MABEL) from Deakin University was engaged to measure infiltration within the test cells. This study was conducted over a two day period, under varying wind speeds and day and night conditions. Zones measured included the roof space and the room and the subfloor space. Researchers from MABEL and within the School of Engineering, (University of Tasmania), calculated values for the constant and wind speed multiplier values. The scratch files for the simulations which considered the as-built parameters were manually modified to account for the calculated values.

4.2.4 Framing Factor

As the AccuRate software did not consider this parameter, to establish the correct as-built conductivity values for the floor, walls and ceiling of the test cell, the framing factor was accounted for. Figure 4.3 and Figure 4.4 illustrate the timber framing within two external walls of the test cell. The framing factor in these figures consisted of: bottom plates, studs, noggins, lintels, jamb studs and top plates. An analysis of the framing factor was completed for each floor, wall and ceiling of the test cell, as shown in Table 4.12.

Figure 4.3 - Test cell southern wall

Figure 4.4 - Test cell northern wall

Table 4.12: Wall Framing Area Calculation

Wall Structure							
Member	Qty	Depth	Length	Width	Area m^2		Wall Area m^2
Nth Wall Studs	11	0.090	2.325	0.035	0.895	0.035	
Nth Wall 2100	8	0.090	2.030	0.035	0.568	0.025	
Nth Wall TP	2	0.090	5.480	0.035	0.384	0.006	
Nth Wall BP	1	0.090	5.480	0.045	0.247	0.004	
Nth Wall Noggins	1	0.090	4.905	0.035	0.172	0.003	
Nth Wall Window Head	1	0.090	2.000	0.035	0.070	0.003	
Nth Wall Lintel	1	0.063	2.000	0.200	0.400	0.013	2.735
Sth Wall Studs	10	0.090	2.325	0.035	0.814	0.032	
Sth Wall 2100	10	0.090	2.030	0.035	0.711	0.032	
Sth Wall TP	2	0.090	5.480	0.035	0.384	0.006	
Sth Wall BP	1	0.090	5.480	0.045	0.247	0.004	
Sth Wall Noggins	1	0.090	3.970	0.035	0.139	0.003	
Sth Wall Window Head	1	0.090	2.000	0.035	0.070	0.003	
Sth Wall Lintel	1	0.063	2.000	0.200	0.400	0.013	
Sth Wall Door Head Hor	1	0.090	0.900	0.035	0.032	0.003	
Sth Wall Door Head Vertical	1	0.035	0.900	0.090	0.081	0.003	2.876
East Wall Studs	11	0.090	2.325	0.035	0.895	0.035	
East Wall 2100	8	0.090	2.030	0.035	0.568	0.025	
East Wall TP	2	0.090	5.480	0.035	0.384	0.006	
East Wall BP	1	0.090	5.480	0.045	0.247	0.004	
East Wall Noggins	1	0.090	4.905	0.035	0.172	0.003	
East Wall Window Head	1	0.090	2.000	0.035	0.070	0.003	
East Wall Lintel	1	0.063	2.000	0.200	0.400	0.013	2.735
West Wall Studs	11	0.090	2.325	0.035	0.895	0.035	
West Wall 2100	8	0.090	2.030	0.035	0.568	0.025	
West Wall TP	2	0.090	5.480	0.035	0.384	0.006	
West Wall BP	1	0.090	5.480	0.045	0.247	0.004	
West Wall Noggins	1	0.090	4.905	0.035	0.172	0.003	
West Wall Window Head	1	0.090	2.000	0.035	0.070	0.003	
West Wall Lintel	1	0.063	2.000	0.200	0.400	0.013	2.735

The test cell included a mix of standard building materials for walls, ceiling and roof, as shown in Figure 4.5 and Figure 4.6. Each of the materials shown in the diagrams had a different value for conductivity and resistance.

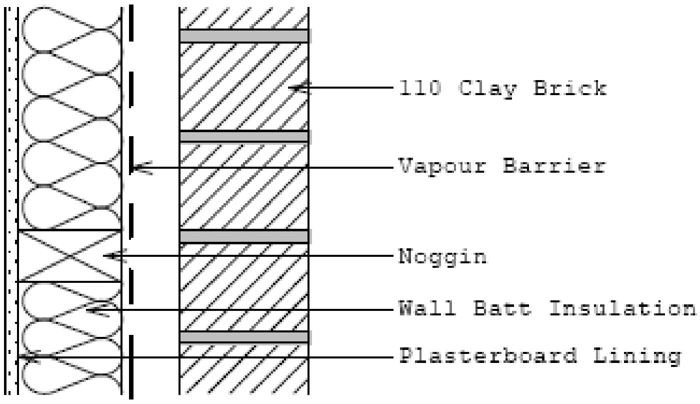


Figure 4.5 - Brick Veneer Wall Detail

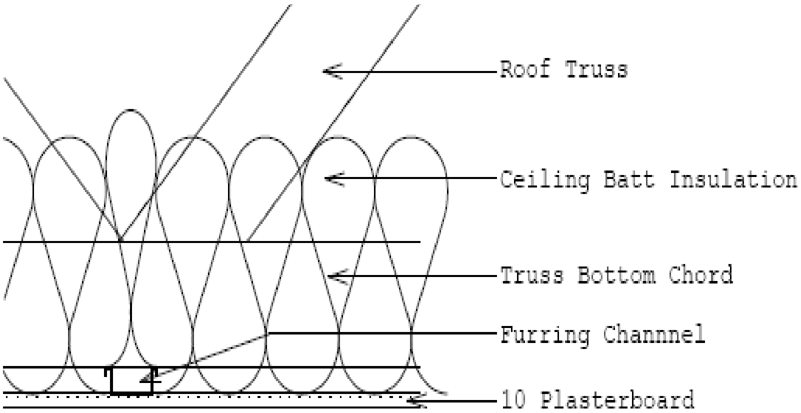


Figure 4.6 - Ceiling Detail

Each of the materials used to construct the test cell, had a different conductivity value. An analysis of methods to calculate the framing factor was undertaken in consultation with the CSIRO software developers. The isotherm planes method was selected to establish the revised conductivity values for the floor, walls and ceiling of the test cells. An example of this calculation is shown in Equation 4.1.

Once the revised average resistance value was obtained for the floor, ceiling and each wall, a new version of each AccuRate building model was saved. To amend the resistance values of the platform floors, the resistance value of the particle board floor was established. To increase the insulation of the platform floor, the thickness of the particle-board floor was increased (Equation 4.2). The revised particleboard floor thickness was used for all simulations requiring as-built inputs.

Equation 4.1 – Isotherm Planes Method: Test Cell Wall

<table>
<tr><td>1</td><td colspan="2">Select differing assemblages on parallel planes of the building, where the elements will have varying resistance values and number them.</td><td>R1: Insulated wall</td><td>R2: Framed Wall</td></tr>
<tr><td>2</td><td colspan="2">For each differing assemblage establish the percentage fraction of total planar area that this assemblage encompasses.</td><td>76%</td><td>24%</td></tr>
<tr><td>3</td><td colspan="2">Calculate the differing resistance value for each assemblage</td><td>R2.5 Wall Insulation – R2.5</td><td>90mm Timber – R0.90</td></tr>
<tr><td>4</td><td colspan="2">Calculate the revised resistance value for the assemblage
$1/R_b = f_1/R_1 + f_2/R_2 + f_3/R_3 + \ldots$</td><td colspan="2">$1/R_b = 0.76/2.5 + 0.24/0.90$,
$1/R_b = 0.304 + 0.216$
$1/R_b = 0.52$</td></tr>
<tr><td>5</td><td colspan="2">Then $R_b = 1/(1/R_b)$</td><td colspan="2">$R_b = 1/(0.52)$
$R_b = 1.92$</td></tr>
<tr><td rowspan="2">6</td><td colspan="2">Then $R_T = R_{si} + R_1 + R_2 + \ldots. + R_n + R_{se}$</td><td colspan="2" rowspan="2">OS Surface 0.03
12 Ply 0.09
Non Ref. Cavity 0.18
Bridged plane 1.92
10 Plasterboard 0.06
IS Surface 0.12
R_T 2.40</td></tr>
<tr><td>Where:</td><td>R_T : is the total resistance
R_{si} : is the internal surface resistance
$R_1 + R_2 + .. + R_n$: are the thermal resistances of each layer, including the bridged layers
R_{se} : is the external surface resistance</td></tr>
</table>

Equation 4.2 – Establishing Particleboard Thickness to Suit Revised Resistance Value of Floor

Particle-Board Resistance value (19mm)	R0.16
Desired Resistance value based on framing factor	R0.18
To obtain revised particle-board thickness	= (R0.18/R0.16) x 19mm = 21mm

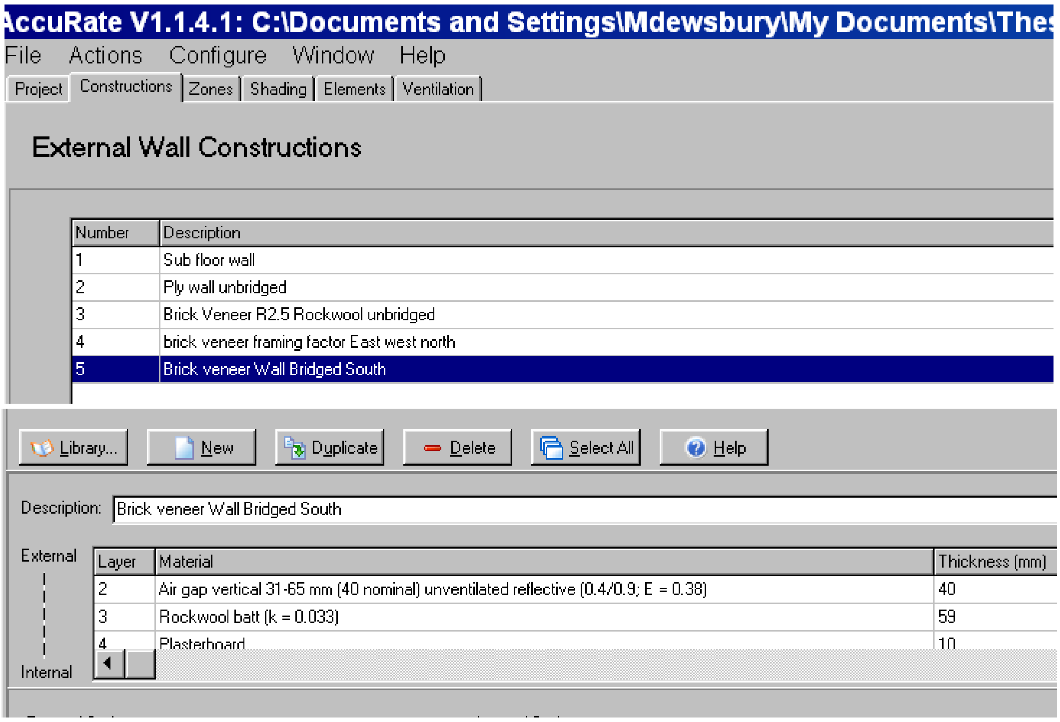
Use of the isotherm planes method established the average resistance value for the stud/insulation or joist/insulation portions of the walls and ceiling planes respectively. For each wall and ceiling a new construction was established. For the walls, the north, east and west walls of the test cell were identical, while the south wall with the access door, had a different framing factor. This required the input of two external wall types. To modify the resistance value, rather than selecting a preset resistance value for the insulation material, the conductivity of that material was selected. Then a revised thickness for the insulation material was obtained (Equation 4.3).

Equation 4.3 – Establishing Insulation Thickness to Suit Revised Resistance Value of Wall

Insulation Resistance value (83mm)	R2.5
Desired Resistance value based on framing factor	R1.795
To obtain revised particle-board thickness Rockwool insulation (k=0.033)	R = Thickness / k R x k = Thickness R1.795 x 0.033 = 59mm

Once the revised thickness of the materials was established, they were modified within the constructions tab of the standard front-end user interface. In the example of the revised thickness of the rockwool insulation illustrated above, the rockwool thickness was defined in the material data entry process. Through this process, two scratch files were established for each test cell (Default and As-built).

The method of modifying the construction resistance values for the 'as-built fabric' simulations, (based on the calculation of the framing factor), is shown in Figure 4.7.



External Wall Constructions

Number	Description
1	Sub floor wall
2	Ply wall unbridged
3	Brick Veneer R2.5 Rockwool unbridged
4	brick veneer framing factor East west north
5	Brick veneer Wall Bridged South

Description: Brick veneer Wall Bridged South

Layer	Material	Thickness (mm)
2	Air gap vertical 31-65 mm (40 nominal) unventilated reflective (0.4/0.9; E = 0.38)	40
3	Rockwool batt (k = 0.033)	59
4	Plasterboard	10

Figure 4.7 – Amendment to resistance value of the southern wall

4.2.5 *Default As-built Fabric Input Summary*

The as-built fabric inputs are best summarised by Table 4.13, below.

Table 4.13: As-built Fabric Inputs

Project Information		
Postcode	7250	Empirical climate file in use
Exposure	Open	Normal countryside with some trees and scattered buildings
Constructions		
External Walls	Subfloor wall 110mm Generic extruded clay brick	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: medium; Solar Absorptance: 50%
External Walls	Brick Veneer Wall – East, West, North: 110mm Generic extruded clay brick, Air gap vertical 31-65mm (40 nominal) unventilated reflective (0.4/0.9; E = 0.38), Rockwool batt 61mm (K-0.033), Plasterboard 10mm	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: Paint light cream; Solar Absorptance: 30%
	Brick Veneer Wall – South: 110mm Generic extruded clay brick, Air gap vertical 31-65mm (40 nominal) unventilated reflective (0.4/0.9; E = 0.38), Rock wool batt 59mm (K-0.033), Plasterboard 10mm	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: Paint light cream; Solar Absorptance: 30%
Windows	NIL	
Door	Timber Mountain Ash 40mm	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: medium; Solar Absorptance: 50%
Door – Subfloor	12mm Plywood	
	External Surface	Colour: medium; Solar Absorptance: 50%
	Internal Surface	Colour: medium; Solar Absorptance: 50%
Ceiling	Plasterboard ceiling: Glass Fibre Batt 158mm (K= 0.044), Plasterboard 10mm	
	Top Surface	Colour: medium; Solar Absorptance: 50%
	Bottom Surface	Colour: Paint light cream; Solar Absorptance: 30%
Floor	Timber with no carpet: Particle Board 21mm (K=0.120)	
	Top Surface	Colour: medium; Solar Absorptance: 50%
	Bottom Surface	Colour: medium; Solar Absorptance: 50%
Ground	Bare Ground	
	Top Surface	Colour: medium; Solar Absorptance: 50%
	Bottom Surface	Colour: Dark; Solar Absorptance: 85%
Internal Wall	NIL	
Roof	Metal Deck: Steel 1mm, Air gap 22.5^{0} 31-65mm (40mm nominal) ventilated reflective (0.4/0.9; E = 0.38)	
	External Surface	Colour: medium; Emissivity: 0.9; Solar Absorptance: 50%
	Internal Surface	Colour: Paint light cream; Solar Absorptance: 30%
Skylight	Nil	
Roof Window	Nil	

Zones	Test Cell	Usage: Daytime other (Free-running) Volume: 5.48 x 5.48 x 2.44 = $73.27m^3$ Floor Height: 0 Maximum Ceiling Height: 2440mm Infiltration: Nil Ceiling Fans: Nil			
	Roof Space	Usage: Roof Space Volume: (6.88 x 6.88)/3 x 1.25 = $19.7m^3$ Reflective: Yes Sarking: Sarked Roof Surface: Continuous metal deck Openness: Standard			
	Subfloor	Usage: Subfloor Volume: (5.78 x 5.78) x 0.6 = $20.05m^3$ Floor Height: 0.00 Maximum Ceiling Height: 0.60mm Infiltration: Openness – Enclosed Wall Cavity Air Flow: No Area of Subfloor Ventilation: $6000mm^2/m$ Ceiling Fans: Nil			
Shading	Type 1: All walls	580mm: Offset 0mm (at ceiling height)			
	Type 2: Subfloor	580mm: Offset 2400mm			
Elements					
Subfloor	External walls	Wall 1: 110 Clay Brick	Wall 2: 110 Clay Brick	Wall 3: 110 Clay Brick	Wall 4: 110 Clay Brick
	Length	5.78m	5.78m	5.78m	5.78m
	Height	0.6	0.6m	0.6m	0.6m
	Azimuth	0^0	90^0	180^0	270^0
	Fixed Shading	Subfloor eave	Subfloor eave	Subfloor eave	Subfloor eave
	Opening	Nil	Nil	Nil	Nil
	Insect Screens	Nil	Nil	Nil	Nil
	Wing Walls	Nil	Nil	Nil	Nil
	Windows in wall	Nil	Nil	Nil	Nil
	Doors in wall	Nil	Nil	Plywood Door $0.37m^2$	Nil
Subfloor	External Screens				
	- Screen 1	Old Art	Old Art dist	Trees SW	Nil
	Height	7.0m	3.6m	6.0m	
	Width	44.0m	37.0m	9.0m	
	Distance	35.5m	66.0m	17.0m	
	H.Offset	55.6m	3.5m	13.5m	
	V. Offset	-1.0m	0.0m	0.0m	
	Blocking Factor	100% all	100% all	95% all	
	- Screen 2	Test Cell 1	Old Art Close	Tree SE	Nil
	Height	4.2m	3.6m	11.0m	
	Width	5.75m	12.0m	21.0m	
	Distance	7.5m	50.0m	19.0m	

	H.Offset	1.0m	15.0m	-6.0m	
	V. Offset	-0.4m	0.0m	2.0m	
	Blocking Factor	100% all	100% all	95, 95, 70, 50, 30, 20, 15, 15, 20, 50, 70, 95	
	- Screen 3	Nil	Workshop	Test Cell 3	Nil
	Height	Nil	7.0m	3.6m	
	Width	Nil	26.0m	7.0m	
	Distance	nil	25.0m	7.5m	
	H.Offset	nil	-22.5m	-1.0m	
	V. Offset	nil	0.0m	0.3m	
	Blocking Factor	nil	100% all	100% all	
Subfloor	Internal Walls	Nil			
Subfloor	Floor	Type: Bare Ground Area: 33.41m2 Under Floor: Not Applicable Edge Insulation: Nil			
Subfloor	Ceiling	Type: Timber with no carpet Area: 30.03m2 Above Ceiling: Test Cell			
Subfloor	Roof	Nil			
Test Cell	External walls	Wall 1: Brick Veneer	Wall 2: Brick Veneer	Wall 3: Brick Veneer	Wall 4: Brick Veneer
	Length	5.48m	5.48m	5.48m	5.48m
	Height	2.44m	2.44m	2.44m	2.44m
	Azimuth	0^0	90^0	180^0	270^0
	Fixed Shading	Eave All	Eave All	Eave All	Eave All
	Opening	Nil	Nil	Nil	Nil
	Insect Screens	Nil	Nil	Nil	Nil
	Wing Walls	Nil	Nil	Nil	Nil
	Windows in wall	Nil	Nil	Nil	Nil
	Doors in wall	Nil	Nil	Door 1.72m^2	Nil
Test Cell	External Screens				
	- Screen 1	Old Art	Old Art dist	Trees SW	Nil
	Height	7.0m	3.6m	6.0m	
	Width	44.0m	37.0m	9.0m	
	Distance	35.5m	66.0m	17.0m	
	H.Offset	55.6m	3.5m	13.5m	
	V. Offset	-1.6m	-0.6m	-0.6m	
	Blocking Factor	100% all	100% all	95% all	
	- Screen 2	Test Cell 1	Old Art Close	Tree SE	Nil
	Height	4.2m	3.6m	11.0m	
	Width	5.75m	12.0m	21.0m	
	Distance	7.5m	50.0m	19.0m	
	H.Offset	1.0m	15.0m	-6.0m	

	V. Offset	-1.0m	-0.6m	1.40m	
	Blocking Factor	100% all	100% all	95, 95, 70, 50, 30, 20, 15, 15, 20, 50, 70, 95	
	- Screen 3	Nil	Workshop	Test Cell 3	Nil
	Height	Nil	7.0m	3.6m	
	Width	Nil	26.0m	7.0m	
	Distance	Nil	25.0m	7.5m	
	H.Offset	Nil	-22.5m	-1.0m	
	V. Offset	Nil	-0.6m	-0.3m	
	Blocking Factor	Nil	100% all	100% all	
Test Cell	Internal Walls	Nil			
Test Cell	Floor	Type: 21mm Particle Board Area: 30.03m2 Under Floor: Subfloor Edge Insulation: Nil			
Test Cell	Ceiling	Type: Plasterboard with 158mm Glass Wool Insulation Area: 30.03m2 Above Ceiling: Roof Space			
Test Cell	Roof	Nil			
Roof Space	External Walls	Nil			
Roof Space	Internal Walls	Nil			
Roof Space	Floor	Type: Plasterboard with 158mm Glass Wool Insulation Area: 30.03m2 Under Floor: Test Cell			
Roof Space	Ceiling	Nil			
Roof Space	Roof	Roof 1	Roof 2	Roof 3	Roof 4
	Type	Metal Deck	Metal Deck	Metal Deck	Metal Deck
	Area	$12.73m^2$	$12.73m^2$	$12.73m^2$	$12.73m^2$
	Azimuth	0^0	90^0	180^0	270^0
	Pitch	23^0	23^0	23^0	23^0
	Exposure	Normal	Normal	Normal	Normal
Ventilation	Azimuth of front façade: 0^0				
	Building Footprint: 5.5m x 5.5m				

Table 4.14: As-built fabric scratch file modifications

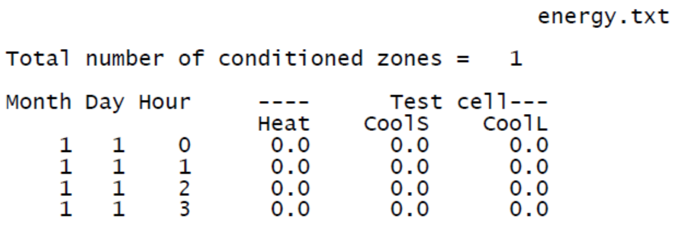
Infiltration Rates			
	A	B	
Test Cell Subfloor	3.292	1.910	The infiltration rate, in air changes per hour, is specified as A + B*v, where v is the wind speed in m/s.
Test Cell Room	0.000	0.021	
Test Cell Roof	0.400	0.258	
Sensible Internal Heat Gains			
Test Cell Room	30 Watts for hours 0 to 23		Normally occupancy heat gains. In this instance it is the heat from measuring equipment.
Thermostat Settings			
Test Cell Room	0.0 deg C for hours 0 to 23		Thermostat settings for invoking cooling & heating operation

4.3 The AccuRate Simulations

Once the site measured climate file and the scratch files for each test cell were established, they were checked several times before the simulations were undertaken. Once the checking was completed, the thermal simulations using AccuRate commenced. The first simulation completed was the Default Fabric / Default Climate simulation. This was used as the check simulation and the output data was examined for logical patterns. The second simulation type was the Default Fabric / Measured Climate simulation, which allowed for an analysis of the effect on test cell zone temperatures resulting from using the site measured climate file. The third simulation was the As-Built fabric / Default Climate, which allowed for an exploration of the effects of the as-built inputs. The final simulation was the As-Built Fabric / Measured Climate configuration. This was compared to the three previous simulations.

When each AccuRate simulation was completed, four output reports were provided: ‘energy’, ‘output’, ‘star rating’ and ‘temperature’ files. Each of these reports was analysed as part of the verification of simulation correctness.

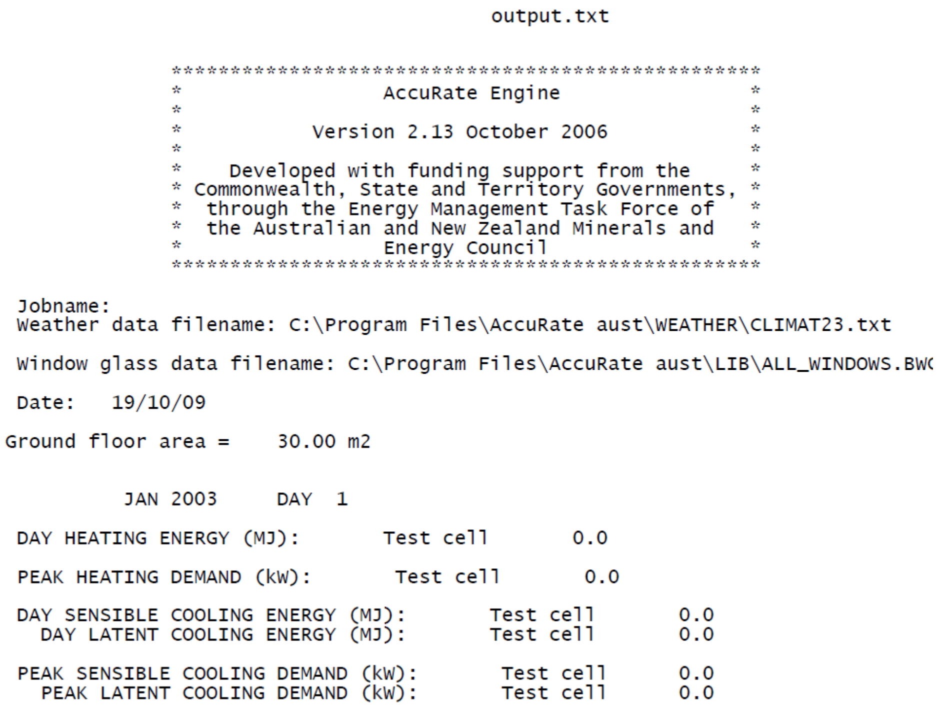
The energy report provided the calculated energy required to maintain a particular temperature bandwidth, within conditioned zones of the simulated building. For the empirical validation of AccuRate the test cells were unconditioned. After each simulation, the file was checked to ensure that all energy values for heating or cooling were zero (Figure 4.8).



```
                                          energy.txt
Total number of conditioned zones =   1

Month Day Hour      ----      Test cell---
                    Heat     CoolS     CoolL
    1   1    0       0.0       0.0       0.0
    1   1    1       0.0       0.0       0.0
    1   1    2       0.0       0.0       0.0
    1   1    3       0.0       0.0       0.0
```

Figure 4.8 – Energy.txt AccuRate Output file

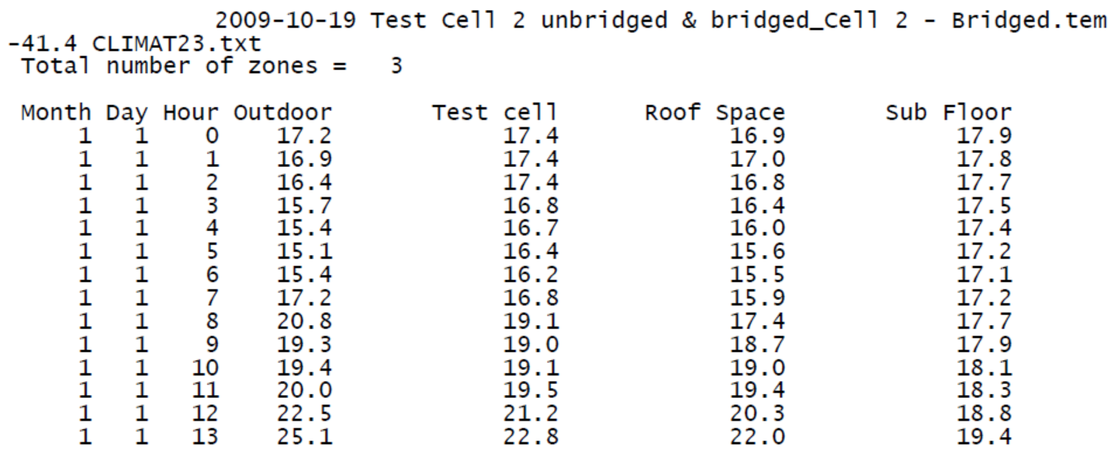
Like the energy.txt report, the output.txt report summarises the energy projections for the conditioned zones of the modelled test cell (Figure 4.9). For the empirical validation, this report was checked to ensure that all values were zero, as an indication that all thermostat settings had been removed.



```
                             output.txt

    **************************************************
    *                 AccuRate Engine                *
    *                                                *
    *           Version 2.13 October 2006            *
    *                                                *
    *    Developed with funding support from the     *
    * Commonwealth, State and Territory Governments, *
    *  through the Energy Management Task Force of   *
    *  the Australian and New Zealand Minerals and   *
    *                 Energy Council                 *
    **************************************************

 Jobname:
 Weather data filename: C:\Program Files\AccuRate aust\WEATHER\CLIMAT23.txt

 Window glass data filename: C:\Program Files\AccuRate aust\LIB\ALL_WINDOWS.BW

 Date:   19/10/09

Ground floor area =    30.00 m2

          JAN 2003     DAY  1

 DAY HEATING ENERGY (MJ):       Test cell       0.0

 PEAK HEATING DEMAND (kW):       Test cell       0.0

 DAY SENSIBLE COOLING ENERGY (MJ):       Test cell       0.0
   DAY LATENT COOLING ENERGY (MJ):       Test cell       0.0

 PEAK SENSIBLE COOLING DEMAND (kW):       Test cell      0.0
   PEAK LATENT COOLING DEMAND (kW):       Test cell      0.0
```

Figure 4.9 – Output.txt AccuRate Output file

The AccuRate software calculated the temperature of each zone of the simulated building. For the empirical validation project, this was the most important file. This report listed the calculated temperature for each hour, and each zone of the simulated test cell (Figure 4.10). This report provided the data for comparison to observed data for the empirical validation analysis.



```
               2009-10-19 Test Cell 2 unbridged & bridged_Cell 2 - Bridged.tem
-41.4 CLIMAT23.txt
 Total number of zones =   3

 Month Day Hour Outdoor       Test cell      Roof Space        Sub Floor
     1   1    0    17.2            17.4            16.9             17.9
     1   1    1    16.9            17.4            17.0             17.8
     1   1    2    16.4            17.4            16.8             17.7
     1   1    3    15.7            16.8            16.4             17.5
     1   1    4    15.4            16.7            16.0             17.4
     1   1    5    15.1            16.4            15.6             17.2
     1   1    6    15.4            16.2            15.5             17.1
     1   1    7    17.2            16.8            15.9             17.2
     1   1    8    20.8            19.1            17.4             17.7
     1   1    9    19.3            19.0            18.7             17.9
     1   1   10    19.4            19.1            19.0             18.1
     1   1   11    20.0            19.5            19.4             18.3
     1   1   12    22.5            21.2            20.3             18.8
     1   1   13    25.1            22.8            22.0             19.4
```

Figure 4.10 – AccuRate Temperature.tem Report

5 Comparing Simulated and Measured Data

The comparison and analysis of the measured and simulated data sets for this research was, as follows:

- The AccuRate default climate file is compared with data from the site weather station.
- The various AccuRate simulation types are compared to demonstrate the appropriateness of using the As-built Fabric / Measured Climate simulation type for empirical validation.
- Temperature measurements from each test cell zone are compared with the AccuRate simulated temperature data.
- Statistical analysis of simulated and measured values.

The quantity of data collected and analysed was large. All data sets were of a consistent format to allow for comparison.

5.1 Climate Data

This analysis compared the TMY climate data with the site-measured air temperature, global solar radiation and calculated diffuse solar radiation. The graphical time series method was used for this analysis, as shown in Figure 5.1, Figure 5.2 and Figure 5.3.

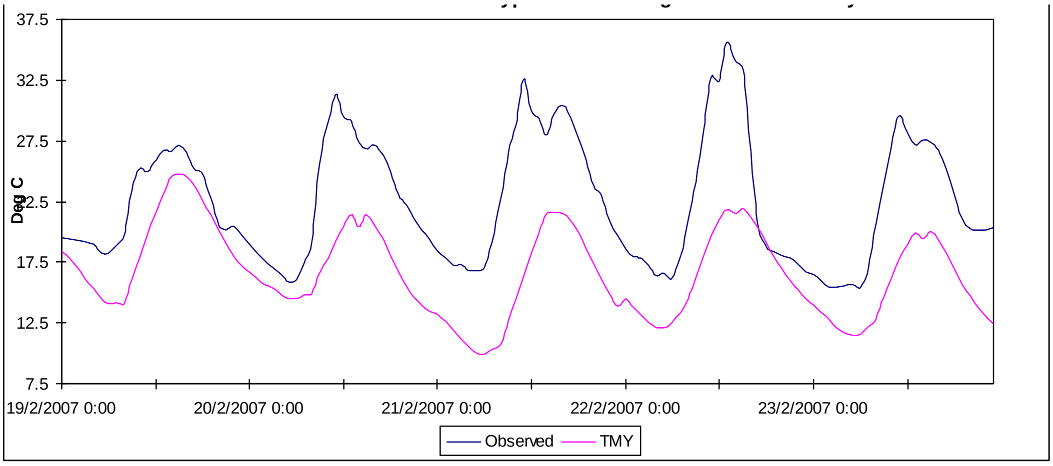


Figure 5.1 – Graph of Measured & TMY Air Temperature Values

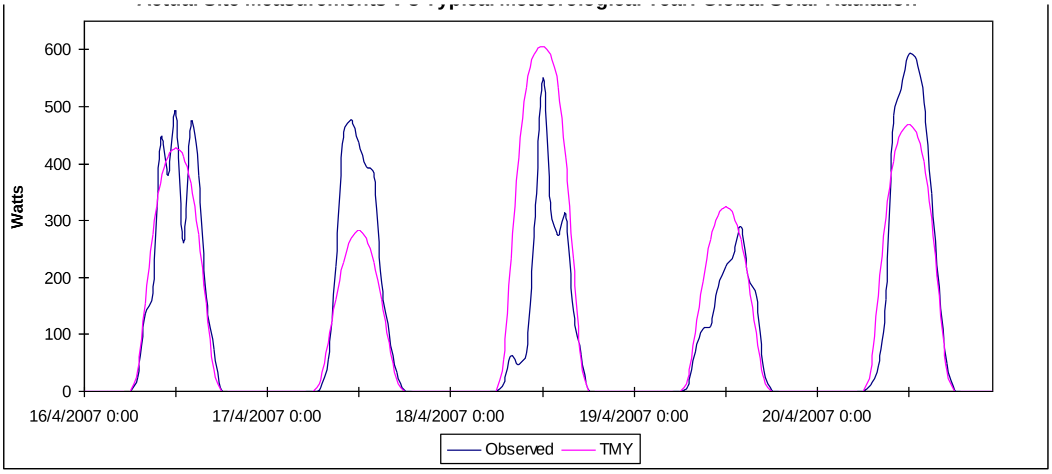


Figure 5.2 – Graph of Measured & TMY Global Solar Radiation Values

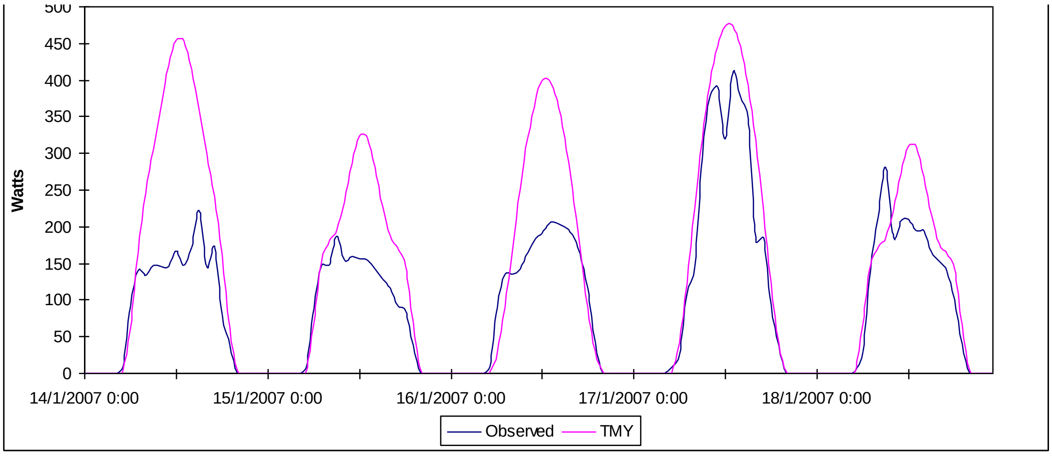


Figure 5.3 – Graph of Measured & TMY Diffuse Solar Radiation Values

5.2 Variation between Simulation Types

To better understand the effect of the different input variables for the four simulation types, a graphical time series analysis was used to compare the resultant zone temperatures as shown in Figure 5.4. This allowed for a sensitivity analysis of the input variables.

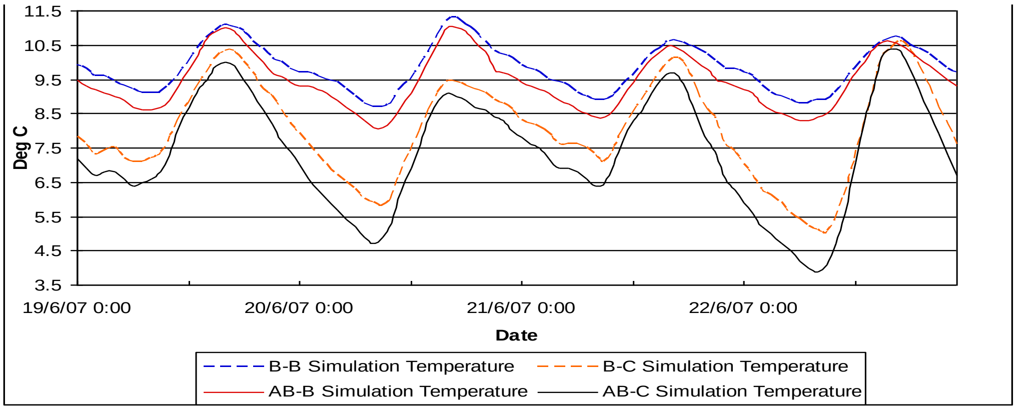


Figure 5.4 – Test Cell Subfloor: B-B, B-C, AB-B, AB-C Results

5.3 Empirical Validation Graphs

This analysis compared the measured temperatures from the three zones of the test cell with the As-built/Measured-Climate simulation data. For this preliminary analysis the graphical time series method was used, as shown in Figure 5.5. The purpose of the empirical validation graphs was to examine whether the AccuRate software was considering environmental and built fabric energy flows and whether there were similarities between measured and simulated values. The visual analysis of the graphs allowed for this analysis to occur.

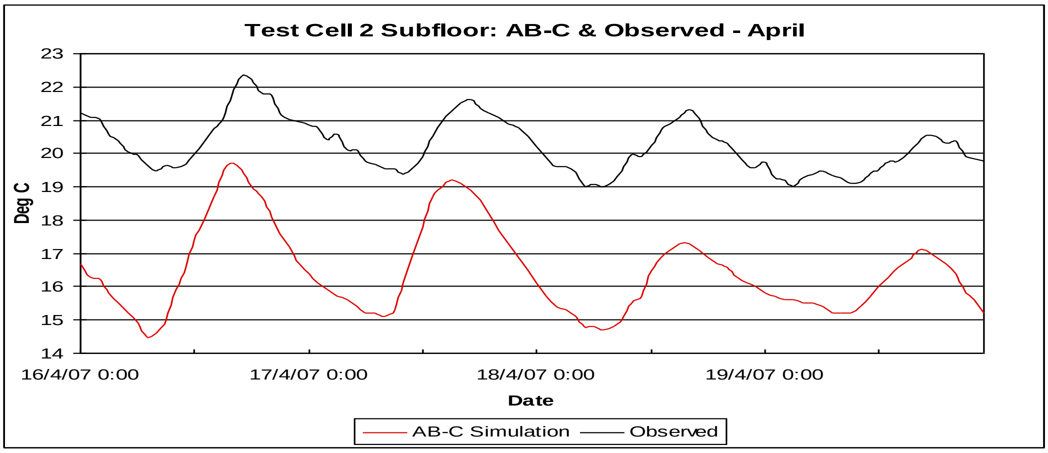


Figure 5.5 – Test Cell Subfloor: AB-C & Measured Results

5.4 Statistical Analyses

The graphical analysis provided a basis for an initial assessment of the responsiveness of the AccuRate software to environmental influences and its capacity to predict zone temperatures. However, it was very limiting in its use as an analysis tool. For more detailed analyses of the differences between measured and simulated data statistical analyses were used. The statistical analyses included comparison of measured residual (Measured – Simulated) values for each zone of the test cell. The purpose of these forms of analysis was to investigate any relationships between values. The analyses conducted were:

- Correlations between the measured and simulated temperatures for each zone;
- Histogram and time series analyses of the residual values for each zone;
- Correlations of the residual values of adjoining zones; and
- Correlations between residual values for each zone and measured climatic conditions.

These forms of analysis were conducted using data from the entire validation period, and monthly data.

5.4.1 Scatter Plot of Measured and Simulated Temperatures

These analyses compared the measured and simulated temperatures for each zone within the test cell. Scatter plots and determining the line of best fit were used to determine how or whether or not two variables were related, and to indicate the strength of that relationship. A second key factor for this type of analysis was the consideration that AccuRate was principally an energy balance program. The software calculates energy flows within a building until balance is achieved. The results from this form of analysis are shown in Figure 5.6 and Figure 5.7, where one axis represents the simulated temperature and the other axis represents the measured zone temperatures.

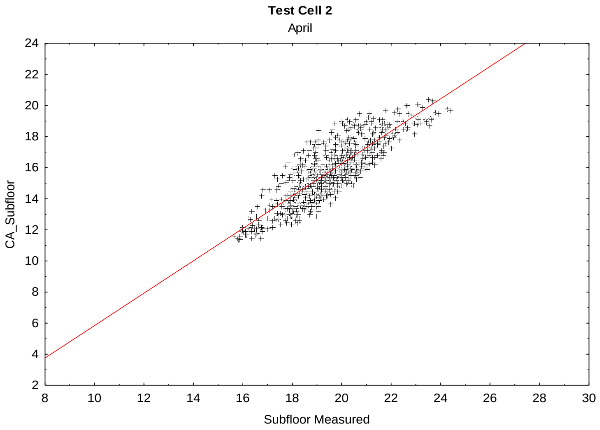


Figure 5.6 –Subfloor Measured v Simulated

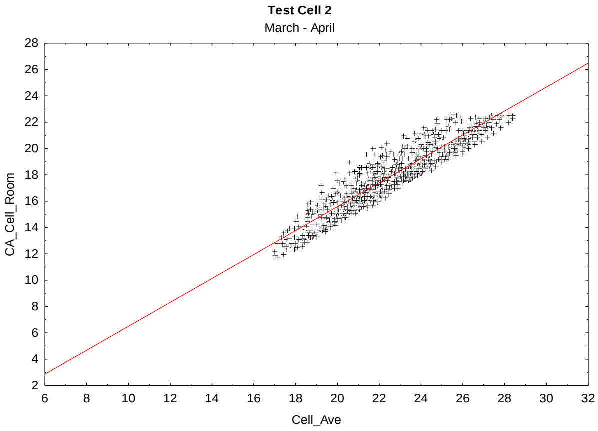


Figure 5.7 –Room Measured v Simulated

5.4.2 Residual Histograms

This analysis was completed to enable a quick visualisation of the difference, (the residual value), between the measured temperature and simulated temperature. In all cases, the residual value has been obtained by subtracting the simulated temperature from the measured temperature (Measured Temperature – Simulated Temperature = Residual Value). Figure 5.8 and Figure 5.9 illustrate the histogram form of analysis.

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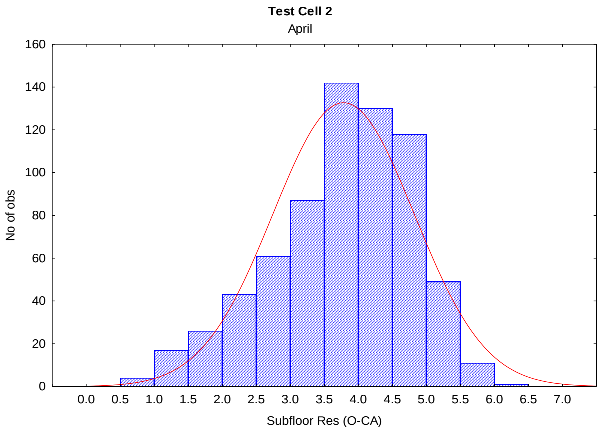

Figure 5.8 –Subfloor Residual Values

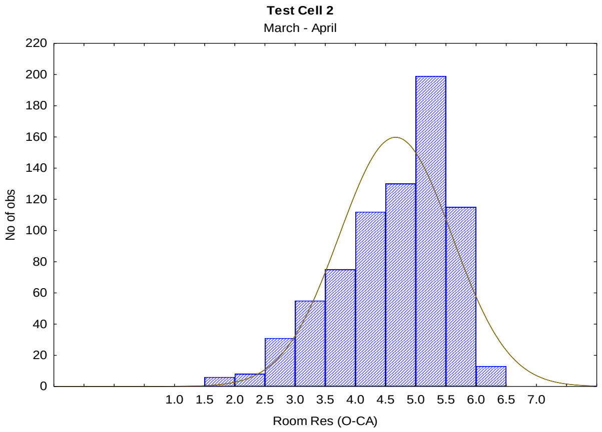

Figure 5.9 – Room Residual Values

5.4.3 Residual Value Time Series Plots

This analysis was completed to enable a quick visualisation of any long term trends, short term cyclical movements, seasonal patterns, and unexplained fluctuations. Figure 5.10 illustrates the residual value time series form of analysis.

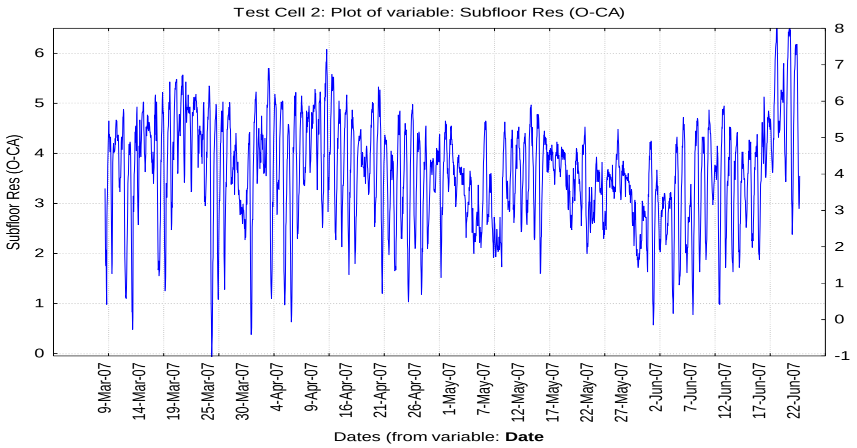

Figure 5.10 – Subfloor Residual Time Series Plot

5.4.4 *Correlation of Adjoining Zone Residual Values*

The purpose of this correlation analysis was to ascertain if there was any relationship between the residual values of adjoining test cell zones. The AccuRate software calculates temperature based on an energy balance within a building. In the context of the test cell, this energy balance equation considers: the zone temperature, fabric conductivity and emittance values, infiltration, thermal capacitance and climatic inputs. If the software has not appropriately considered an energy input, the zone model will in reality store, receive or give more energy to adjoining zones than the software has predicted. As the residual values for the test cell zones were predominantly positive in nature, this implies that the zone or zones receive or store more energy than the software predicts. Conversely, when the residual is negative, the zone receives or stores less energy than the software has predicted. The additional energy being received or lost may be transferred in or out of an adjoining zone. The use of correlation analysis in this context could indicate that the residual value, or simulation error, in one zone may be impacting on the residual value, or simulation error, of an adjoining zone. Figure 5.11 and Figure 5.12 illustrate the residual correlation analysis of adjoining zones.

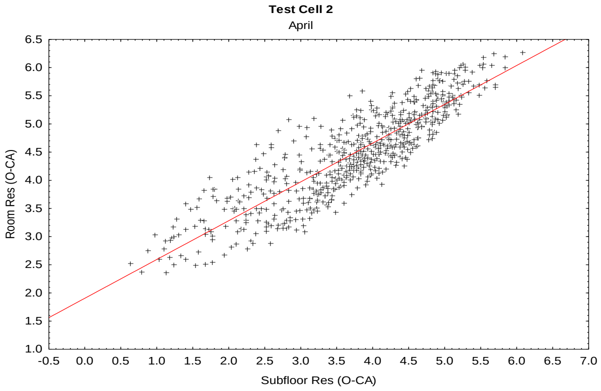

Figure 5.11 – Room & Subfloor Residual Correlation

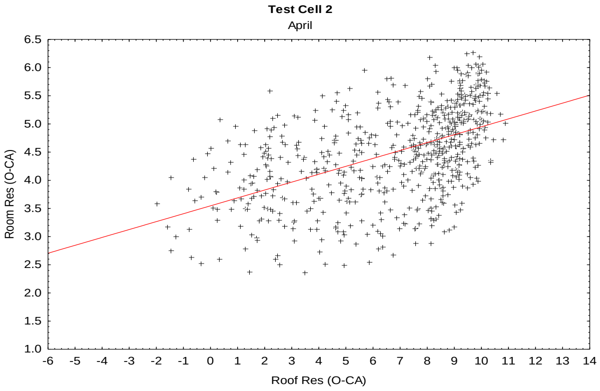

Figure 5.12 – Room & Roof Space Residual Correlation

5.4.5 Correlation of External Air Temperature and Zone Residuals

The two principle energy inputs to the test cell were air temperature and solar radiation. This analysis was intended to examine the correlation between the site-measured air temperature and the calculated residual values for each zone of the test cells. Figure 5.13 and Figure 5.14 illustrate the correlation analysis of zone residual value and site air temperature.

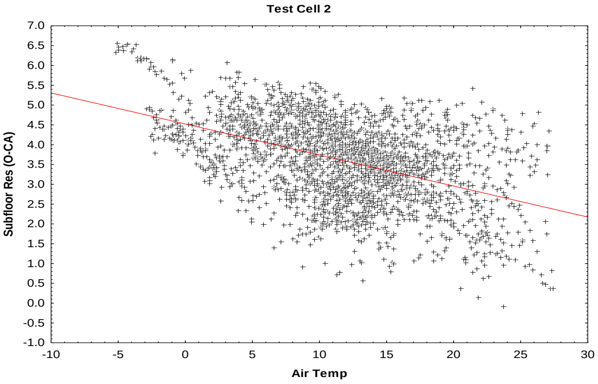

Figure 5.13 – Subfloor Residual & Air Temperature Correlation

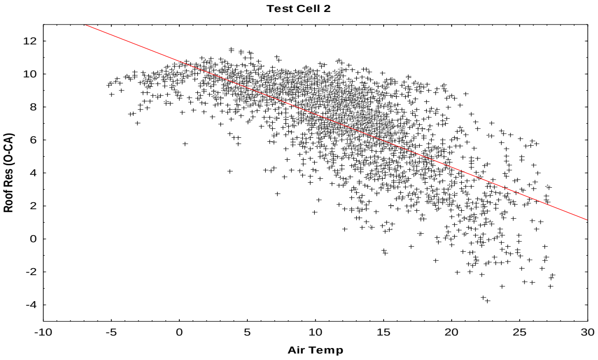

Figure 5.14 – Roof Space Residual & Air Temperature Correlation

5.4.6 Correlation of Wind Speed and Test Cell Residuals

This analysis was completed to examine any correlation that may exist between the site wind speed and the calculated residual values from each zone of the test cells. Figure 5.15 and Figure 5.16 illustrate the correlation analysis of zone residual value and site wind speed.

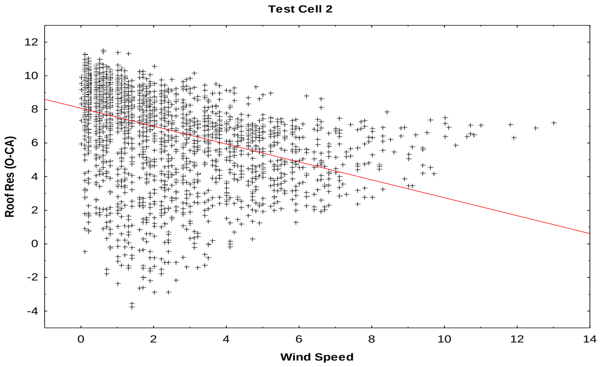

Figure 5.15 – Roof Space Residual & Wind Speed Correlation

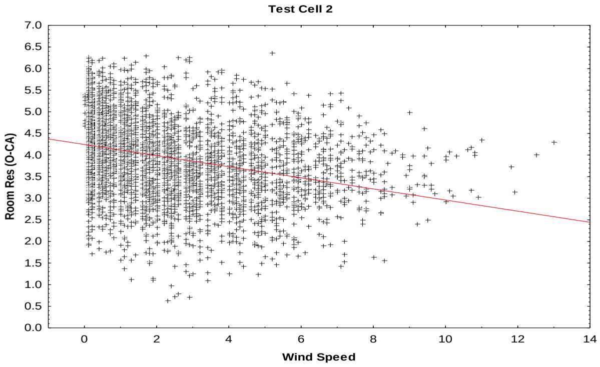

Figure 5.16 – Room Residual & Wind Speed Correlation

5.4.7 Correlation of Wind Direction and Test Cell Residuals

This analysis aimed to examine any correlation that may exist between the measured site wind direction and the residuals from each zone of the test cell. Figure 5.17 and Figure 5.18 illustrate the correlation analysis of zone residual value and site wind direction.

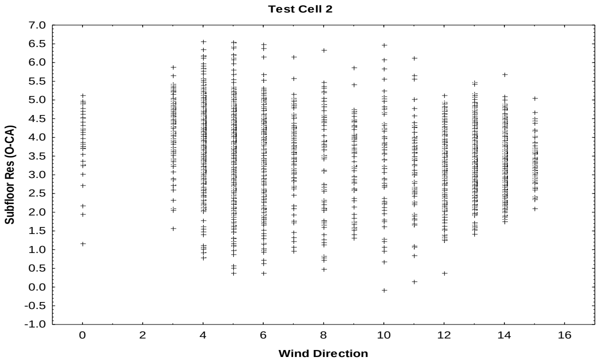

Figure 5.17 – Subfloor Residual & Wind Direction Correlation

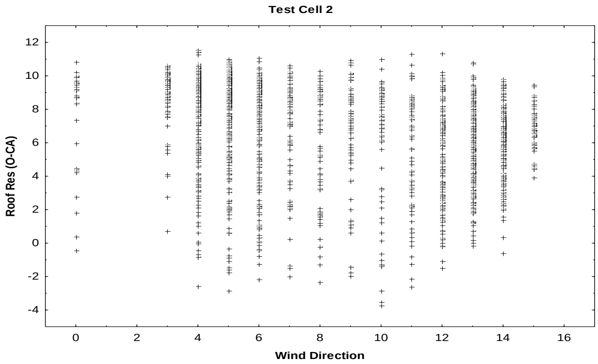

Figure 5.18 – Roof Space Residual & Wind Direction Correlation

5.4.8 *Correlation of Global Solar Radiation and Test Cell Residuals*

This analysis examined any correlation that may exist between the site-measured global solar radiation and the residual values for each zone of the test cells. Figure 5.19 and Figure 5.20 illustrate the correlation analysis of zone residual value and site global solar radiation.

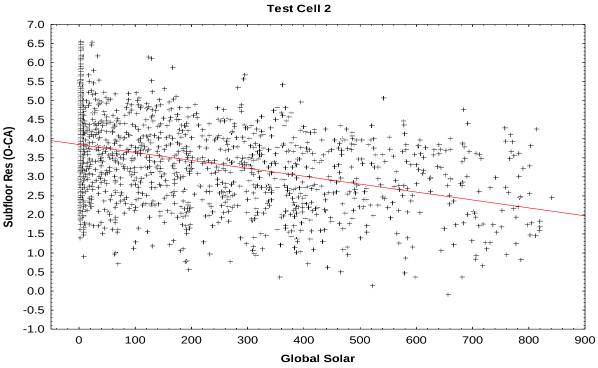

Figure 5.19 –Subfloor Residual & Global Solar Radiation Correlation

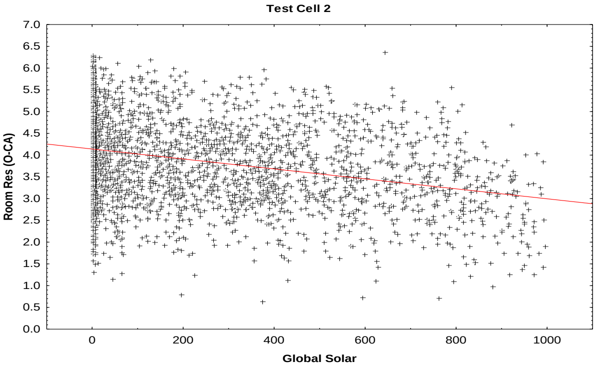

Figure 5.20 – Room Residual & Global Solar Radiation Correlation

5.4.9 *Correlation of Diffuse Radiation and Test Cell Residuals*

This analysis examined any correlation between the calculated diffuse solar radiation and the residual values from each zone of the test cells. Figure 5.21 and Figure 5.22 illustrate the correlation analysis of zone residual value and calculated diffuse solar radiation.

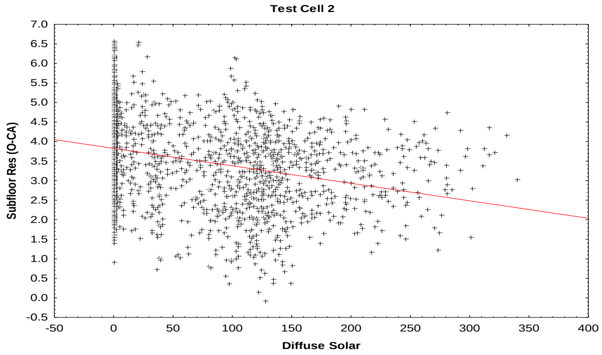

Figure 5.21 – Subfloor Residual v Diffuse Solar Radiation Correlation

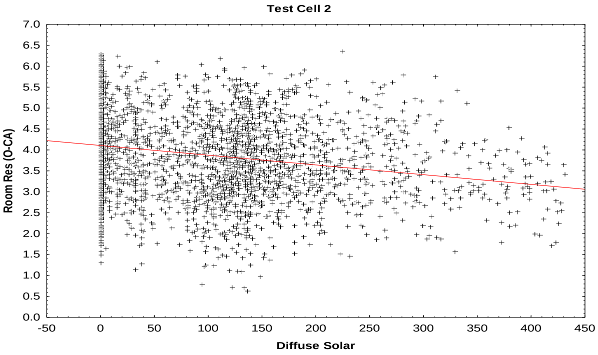

Figure 5.22 – Room Residual v Diffuse Solar Radiation Correlation

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6 Conclusion

The aim of this research was to empirically validate the AccuRate house energy rating software for lightweight buildings in a cool temperate climate. This case study illustrates that this involved the establishment of several key components and methods, namely:

- The construction of a test building in Launceston. The building type was an enclosed-perimeter platform-floored test cell, built to Australian standards and regulations.
- The installation of data acquisition, data storage systems and equipment to measure the internal and site environmental conditions
- The completion of a detailed building envelope simulation using the AccuRate HER software
- The collation and cleaning of measured and simulated data sets
- The graphical and statistical analysis of the measured and simulated data sets

All the stages of the research were completed in a rigorous manner to enable the aim of the research activity to be achieved.

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