*Proceedings of BS2013:*
*13th Conference of International Building Performance Simulation Association, Chambéry, France, August 26-28*

# ASSESSING THE SIMULATION CAPABILITY OF THE *ACCURATE* ENGINE IN MODELLING MASSIVE CONSTRUCTION ELEMENTS

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## ABSTRACT

Simulation is often utilised in the regulatory assessment of building performance as in the case of the Australia's Nationwide House Energy Rating Scheme (NatHERS). A recent government discussion paper (SOG-EE, 2012) proposes increased use of simulation as a method for building compliance assessment; however, responses to this document demonstrate a lack of confidence in the accuracy of the approved thermal assessment software used in the Scheme. Through empirical and intermodal comparisons, this paper examines the capacity of the computational engine. The examination highlights deficiencies in the input capabilities of the front end and the protocols governing its regulatory use and not in the engine itself.

## INTRODUCTION

In efforts to reduce energy use and carbon emissions from residential buildings, many countries use House Energy Rating Schemes (HERS) to predict and rank a proposed dwelling's energy consumption. Commonly performed via simulation, the building is modelled in order to predict its thermal performance and subsequent energy use required to maintain comfort. There is a general public expectation that there is some level of comparability between the HERS determination and the actual energy use of the house during operation; however, research has shown that there is often poor or no correlation between them (Williamson et al, 2010; 2001; Stein et al, 2000). Discussion of this deficiency, referred to as the 'gap' between predicted and actual energy use (or carbon emission), often engenders a lack of confidence in the HERS and the incorporated software tools. This paper seeks to address this issue for the situation in Australia; however, it is likely an issue inherent to HERS worldwide (Williamson et al, 2006).

In Australia, the Nationwide House Energy Rating Scheme (NatHERS) is one method of demonstrating compliance with the Energy Efficiency requirements in the National Construction Code (NCC) 2012. NatHERS was developed in the early 1990's as a response to Australia's signing of the UN Framework Convention on Climate Change in 1991 and the resulting National Greenhouse Response Strategy (Williamson, 1997). From its inception the rating Scheme incorporated a developed version of CSIRO's response factor calculation program, which became known as *Chenath*. NatHERS was designed as a tool to assist the public and building industry in designing new (residential) buildings which required minimal heating and cooling in order to reduce greenhouse gas emissions. It was not originally intended to be used for regulation compliance (Williamson, 1997). In 2003, the Scheme was incorporated into the NCC and has since been known and used mainly as a rating tool.

The simulation tool used within NatHERS is the *Australian Government Endorsed calculation engine*; second generation *AccuRate*. *AccuRate* simulates the buildings' thermal conditions and, based on a 'comfort range', estimates heating and cooling fuel neutral energy loads. The energy load is presented as area adjusted MJ/m$^2$ which is then converted to a 'star rating' from zero to ten. A ten star rating infers little or no heating or cooling is required to keep the habitable spaces within the comfort range. Current NCC regulation requires a minimum six star rating for all new homes.

In the 'rating' mode of operation, *AccuRate*, has preset input parameters and output options due to its regulatory nature. Assumptions about the 'typical user' are prescribed by the NatHERS protocols, including; hours of occupancy window and door operation for natural ventilation, casual loads generated from cooking and appliance use, thermostat settings and internal window covering use.

Throughout the development of *AccuRate*, validation studies have sought to test the sufficiency of the core computational engine to model the thermal performance of the building envelope. The original iteration of the simulation engine, *Cheetah*, was included in a substantial validation study reported by Lomas, et al in 1997 (study completed in 1992). The authors assessed the predicted temperatures of 25 dynamic thermal simulation programs against measured temperatures from three constructed test cells and demonstrated a general level of comparability between Cheetah, the other simulation programs and the measured data. Following the progression of *Cheetah* to *Chenath*, Delsante completed inter-program (inter-modal) and empirical validation (using International Energy Agency (IEA) methodologies) studies to test the recent enhancements of the tool (Delsante, 1995a; 1995b). Whilst minor discrepancies were reported, Delsante concludes that the evolution from *Cheetah* to *Cheenath* did not result in the corruption of the original engine and *"should lead to increased confidence in its use."* (Delsante, 1995a, pp 18). In 2004, Delsante completed a subsequent inter-program validation of the *AccuRate* simulation engine, using the IEA BESTEST method. Results again indicated a good agreement with the reference programs and only minor over estimation of heating and cooling demands due to the way the program calculates and controls temperature (Delsante, 2004).

In spite of these validations, concerns have been voiced about the capacity of *AccuRate* to model heavyweight building elements, arising from the perceived gap between the often 'poor' predicted thermal performance and testimonial 'good' performance expressed by occupants of dwellings incorporating earth construction components. Addressing this issue, Delsante compared predicted data from *AccuRate* with measured data from a mud brick house (2006). While not strictly a validation exercise, the study found that there was no significant discrepancy between *AccuRate* simulation and measured data. Importantly, Delsante suggests that any discrepancies may be attributable to the difference between behaviour and occupant assumptions included within the program and actual occupant perceptions. This is similarly supported by Soebarto's (2009) findings in reference to houses incorporating rammed earth walls; that lower energy bills were not directly attributable to the use of rammed earth wall construction but instead the occupants' perceptions that influence behaviour related to energy use (Soebarto, 2009, pp 1536).

These studies indicate that it is likely that the gap between predicted and actual performance is caused by inappropriate occupancy and user assumptions used within the software rather than by the algorithms used to calculate the physics of heat flow per se.

Criticisms levelled at the simulation engine are often due to some peoples' inability to distinguish between the capabilities of the computational engine itself, from the front end input capabilities and the protocols governing the regulatory use of the tool as a whole. This study therefore seeks to clarify the adequacy of the *Chenath* engine in order to focus the area of further discourse and research to the appropriateness of the *AccuRate* front end (in regards to input) and the prescribed occupancy related settings.

Underpinning, the need for this research is the current prominence of the NatHERS method of compliance assessment in Australia. Approximately 70 per cent of all new homes gain compliance via building performance simulation (HIA pers comm, 2012). Similarly, the proposed progression of Energy Efficiency regulation (SOG-EE, 2012) reiterates an increasing reliance on simulation as a tool for building performance assessment, necessitating accuracy and confidence in both the Scheme and software.

## METHODOLOGY

Intermodal and empirical comparisons have been used to validate the *Chenath* computational engine. In this study the other simulation engines are *EnergyPlus* (with *DesignBuilder* as the interface) and *EnerWin*. *EnergyPlus* has been selected as it is a simulation tool that has been validated in numbers of studies and is used worldwide. The heat calculation is based on determining a surface heat balance using a finite-difference technique (Crawley, et al. 2008). *EnerWin*, the second comparison tool selected, was developed in the US and is used mostly in research. *EnerWin* calculates heat flow based on the modified TETD/TA method (Degelman & Soebarto 1995). These two simulation engines have been selected because of their similar features and input requirements to *Chenath*.

The comparisons were conducted for two constructed test cells and three occupied residences. All five models were simulated in 'free running' mode, with no artificial heating or cooling. These five comparisons can be considered as validation investigations determining whether the *Chenath* simulation model is an accurate representation of a "real" system. The extent to which the results match will provide an indication of the confidence we can have in using this software.

### Simulation models

#### Test cells

The first analysis comprises of intermodal and empirical comparison of the measured and predicted internal temperatures from two constructed test cells. Built by The University of Technology Sydney as part of a collaborative study, the test cells are identical except for the walling materials (Heathcote, 2007; 2008; 2011). This study utilises data from the test cells with mud brick walls and brick veneer walls. The test cells are located in Yarramundi, New South Wales, Australia, which has the Köppen climate classification *'Cfa' Humid subtropical*. Both cells were unconditioned and unventilated throughout the monitoring period.

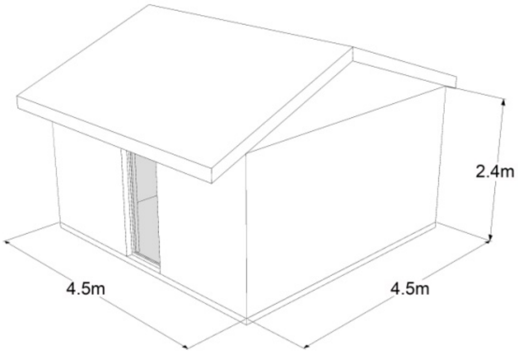


*Figure 1 Diagram of the test cell configuration*

Occupied residence A

The second comparison utilises measured dry bulb temperatures from two rooms in an occupied residence located in Ironbank, South Australia, Australia. Ironbank has the Köppen climate classification *'Cfb' Marine west coastal*. The external walls are primarily mud brick with limited reverse block veneer. The pitched roof is corrugated steel with R1.5 mineral fibre batt insulation and generally raked timber lined ceilings. The floors are bare pavers or poured concrete, both constructions in direct contact with the ground. A high proportion of windows face the equator (North) with single glazing and timber frames.

Occupied residence B

The third analysis, occupied residence B, similarly compares measured dry bulb temperatures from two rooms to predicted internal temperatures from the three simulation engines. Occupied residence B is located in Aldinga, South Australia, Australia, which has the Köppen climate classification *'Csa' Dry-summer subtropical*. The walls are approximately 20 per cent un-insulated 400mm rammed earth and 80 per cent insulated timber framed wall with fibre-cement sheet external cladding and plasterboard internal lining. All ceilings are raked with 'butterfly' corrugated steel sheet roof and R3.5 mineral fibre batt insulation. The floors are concrete-slab in direct contact with the ground, either tiled or bare. The windows, 6.38mm grey tint single glazed and aluminium framed, in the main living area and bedroom, primarily face north, north-west.

Occupied residence C

The final residence is also located Aldinga and compares measured dry bulb temperature and predicted temperature from one room only. The external walls are insulated timber framed walls with metal sheet external cladding and plasterboard internal lining. An internal compressed earth block spine wall runs east-west and provides thermal mass for the north facing living area. The ceiling in the main living area is raked, whilst all other ceilings are flat, and all have R5.0 mineral fibre batt insulation. The pitched roof is corrugated steel sheet. Northern facing double-glazed, timber framed windows provide solar access to the main living area.

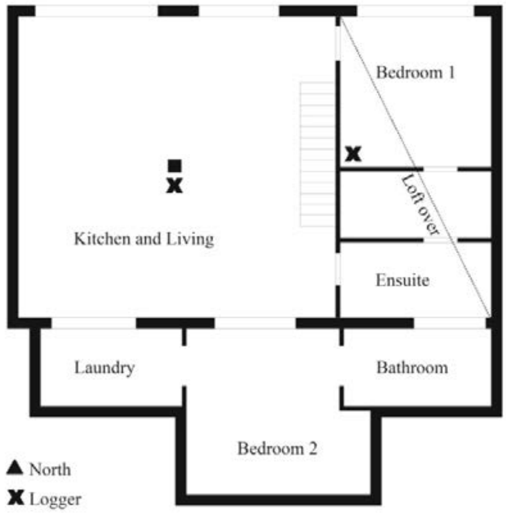


*Figure 2 Floor plan diagram - occupied residence A*

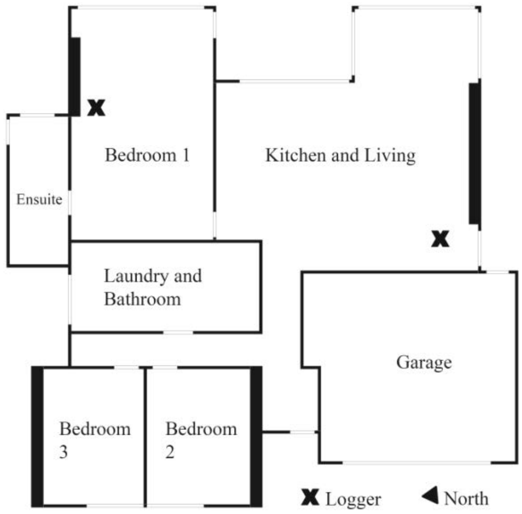


*Figure 3 Floor plan diagram - occupied residence B*

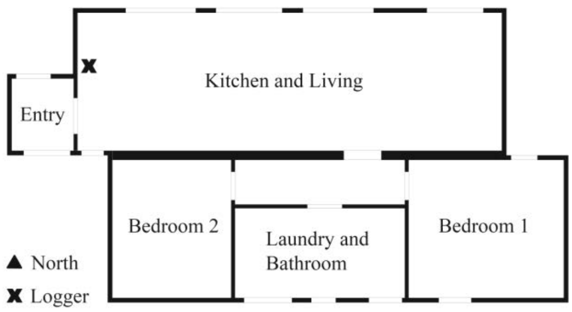


*Figure 4 Floor plan diagram - occupied residence C*

**Climate files and weather data**

The climate file used for simulation of the test cells was created using a 'base' file (*Chenath* format) for the Richmond RAAF location approximately 12km from Yarramundi (weather data from December 2006 - January 2007). This includes estimates of hourly solar radiation derived Bureau of Meteorology (BOM) satellite data for the actual location. Measured external temperatures from the Yarramundi test cell location were used to replace the Richmond RAAF temperatures for greater accuracy. The *.TXT file was then converted to the appropriate formats for *EnergyPlus* and *EnerWin.*

For occupied residence A, a climate file was compiled from measurements (temperature, RH%, wind speed & direction, and solar radiation) from a HOBO weather station installed approximately 1km from the residence for the period January to July 2012.

The climate file for the occupied residence B and C simulations was created by *Energy Partners* using a similar method as Yarramundi climate file; a base file was created using weather data from Adelaide Airport (approximately 40kms north from Aldinga) and synthetic solar radiation data for the actual location. External temperatures were replaced with measured data from a weather station located approximately 15kms north of the two residences.

**Thermal properties of materials**

The thermal properties used to simulate the materials were consistent across all three of the simulation engines and were generally the default values from the *Chenath* material library. No measured data specific to the test cells or houses was available. Previous research by the authors (Daniel et al, 2012) identified the most appropriate thermal property values for the mud brick construction, which can vary greatly dependant on moisture content (Rees et al, 2001).

*Table 1 Thermal properties of materials used in simulation models*

| Material | Density Kg/m$^3$ | Conductivity W/m.K | Specific heat J.kg/K |
|---|---|---|---|
| Mud brick [1] | 2080 | 1.69 | 795 |
| Concrete [2] | 2400 | 1.44 | 880 |
| Steel [2] | 3900 | 50 | 500 |
| Glass fibre batt [2] | 10.6 | 0.044 | 880 |
| Fibre cement sheet [2] | 1680 | 0.5 | 840 |
| Plaster board [2] | 832 | 0.12 | 1300 |
| Compressed earth block rammed earth [3] | 2050 | 1.25 | 1000 |
| Brick [3] | 1700 | 0.84 | 800 |

*Source; 1 Roos (2003); 2 AccuRate; 3 Szokolay (2008).*

A computer model developed by Williamson (1994) was used to calculate ground temperatures directly underneath the slab for the *EnergyPlus* (*DesignBuilder*) simulations. Both *Chenath* and *EnerWin* independently calculate ground temperatures based the weather data in the climate files.

**Analysis**

As there is no standard for hourly temperature model calibration the primary statistical indicator of performance was the Coefficient of Variance of the Root Mean Square Error (CV(RMSE)), recommended in the ASHRAE *14-2002 Guideline for Measurement of Energy and Demand Savings*. This Guideline is based on the analysis of energy use, however in this paper the CV(RMSE) is of the predicted internal temperatures when compared to the measured internal temperatures. According to the Guideline;

> *"Typically, models are declared to be calibrated if they produce ... CV(RMSE)s within ± 30 per cent when using hourly data" (ASHRAE, 2002, pp 43).*

A CV(RMSE) value of between 10-20 per cent has been cited as acceptable for empirical models by several other authors (Bou Saada & Haberl, 1995; Kreider & Haberl, 1994). In this study iterations were made to refine the simulation models until a CV(RMSE) of <15 per cent was achieved for the period of measured data.

# RESULTS

**Test cells**

The predicted temperatures from the three simulations engines generally show good agreement with the measured internal temperatures for both the mud brick and brick veneer test cells, Table 2.

*Table 2 CV(RMSE), mean difference and maximum difference of Chenath (AccuRate), EnergyPlus (DesignBuilder interface) and EnerWin predicted results compared to measured results for the Test cells from 14 Decmeber 2006 – 18 January 2007*

| Simulation engine | CV(RMSE) % | Mean difference °C | Max difference °C |
|---|---|---|---|
| Mud brick test cell | | | |
| Chenath | 3.33 | 0.70 | 4.37 |
| EnerWin | 4.08 | 0.84 | 5.17 |
| EnergyPlus | 5.50 | 1.14 | 4.33 |
| Brick veneer test cell | | | |
| Chenath | 3.39 | 0.66 | 3.87 |
| EnerWin | 5.37 | 1.14 | 4.67 |
| EnergyPlus | 9.03 | 1.78 | 6.11 |

The *Chenath* results give the lowest CV(RMSE) value for both test cells, while the *EnergyPlus* predicted temperatures displayed the largest divergence from the measured, particularly for the brick veneer test cell. The sporadic deviation of the *Chenath* temperatures from the measured temperatures in the lead up to the daily external peak is likely due to over estimation of solar radiation heat gains from the glazed door facing the equator, visible in Figure 5 and Figure 6. The *EnerWin* model predicts considerably more thermal lag for both test cells than the *Chenath* or *EnergyPlus* models. The *EnergyPlus* results for the brick veneer test cell more closely correspond to external temperature, peaking higher than the other two simulation engines, appearing to act more like a lightweight building when compared to the mud brick test cell *EnergyPlus* results.

**Occupied residence A**

Simulation results from the three engines produce CV(RMSE)s between 7.25 per cent and 13.5 per cent when compared to measured data from the occupied residence A, Table 3.

The *Chenath* predictions over estimate internal temperatures particularly when the external daily maximum is between 20 and 30 °C; less divergence is present at lower daily maximums, refer to Figure 7. The *EnerWin* results demonstrate the best agreement with the measured data in both the Living and Kitchen area and the Bedroom. The *EnergyPlus* model consistently under estimates internal temperatures, displaying considerably lower turning points than the measured temperatures, exhibited by the high maximum difference of 6.7 °C in the Living and Kitchen area.

**Occupied residence B**

The CV(RMSE)s for occupied residence B range from 6.09 per cent, the lowest CV(RMSE) for the occupied residences, to 13.07 per cent, Table 4. The predicted temperatures from all three models align more closely with the measured temperatures from the Living and Kitchen area than the measured temperatures from the Bedroom. The *Chenath* and *EnergyPlus* predicted temperatures for the Living and Kitchen area generally peak higher than the measured temperatures, while the *Enerwin* predictions peak noticeably lower, Figure 8. The predicted lower turning points of the predicted temperatures from all three engines correspond well with those of the measured data. Notably, the *EnerWin* model again predicts more thermal lag than the *Chenath* or *EnergyPlus* models, resembling observations of the *EnerWin* test cell results.

**Occupied residence C**

The predictions from the three simulation engines produce CV(RMSE)s between 7.48 per cent and 10.29 per cent, Table 5. The maximum differences from all three engines are generally high than those from the occupied residence A and B simulations, however the mean differences remain comparable. The predicted temperatures are all consistently lower than the measured temperatures, shown in Figure 9. *Chenath* and *EnerWin* occasionally have comparable peaks with the measured data, generally coinciding with periods of consistent diurnal range. The *EnergyPlus* predictions share a similar pattern to the measured data, however the temperatures are persistently one to two degrees lower.

*Table 3 CV(RMSE), mean difference and maximum difference of Chenath (AccuRate), EnergyPlus (DesignBuilder interface) and EnerWin predicted results compared to measured results for Occupied residence A from 1st April – 31st May 2012*

| **Simulation engine** | **CV(RMSE) %** | **Mean difference °C** | **Max difference °C** |
|---|---|---|---|
| Living/kitchen area | | | |
| Chenath | 10.8 | 1.52 | 5.40 |
| EnerWin | 7.25 | 1.01 | 4.05 |
| EnergyPlus | 13.50 | 1.87 | 6.70 |
| Main bedroom | | | |
| Chenath | 11.22 | 1.57 | 5.14 |
| EnerWin | 8.22 | 1.20 | 4.28 |
| EnergyPlus | 11.26 | 1.59 | 4.36 |

*Table 4 CV(RMSE), mean difference and maximum difference of Chenath (AccuRate), EnergyPlus (DesignBuilder interface) and EnerWin predicted results compared to measured results for Occupied residence B from 6th May – 28th August 2011*

| **Simulation engine** | **CV(RMSE) %** | **Mean difference °C** | **Max difference °C** |
|---|---|---|---|
| Living/kitchen area | | | |
| Chenath | 7.86 | 0.97 | 4.80 |
| EnerWin | 10.43 | 1.33 | 4.80 |
| EnergyPlus | 6.09 | 0.73 | 4.21 |
| Main bedroom | | | |
| Chenath | 12.12 | 1.42 | 7.12 |
| EnerWin | 13.07 | 1.65 | 5.34 |
| EnergyPlus | 11.98 | 1.28 | 7.34 |

*Table 5 CV(RMSE), mean difference and maximum difference of Chenath (AccuRate), EnergyPlus (DesignBuilder interface) and EnerWin predicted results compared to measured results for Occupied residence C from 6th May – 11th September 2011*

| **Simulation engine** | **CV(RMSE) %** | **Mean difference °C** | **Max difference °C** |
|---|---|---|---|
| Living/kitchen area | | | |
| Chenath | 7.48 | 1.02 | 5.00 |
| EnerWin | 9.69 | 1.27 | 9.80 |
| EnergyPlus | 10.29 | 1.58 | 5.72 |

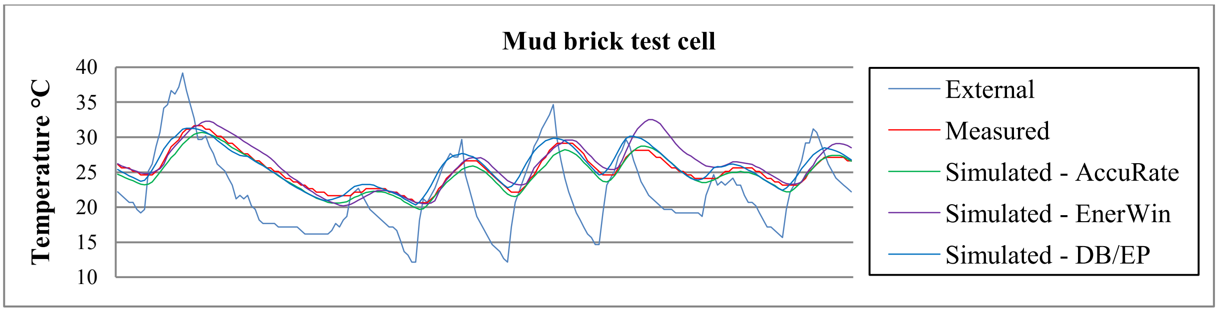


*Figure 5 Mud brick test cell measured and predicted indoor temperatures from 14th – 21st December 2006*

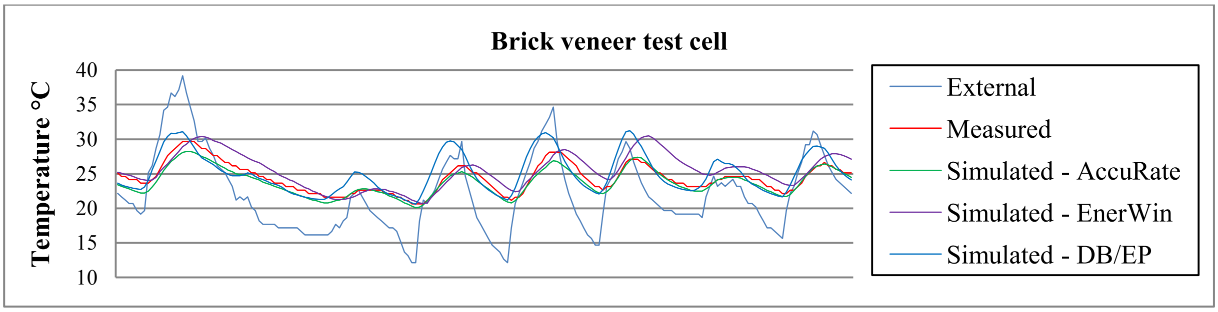


*Figure 6 Brick veneer test cell measured and predicted indoor temperatures from 14th – 21st December 2006*

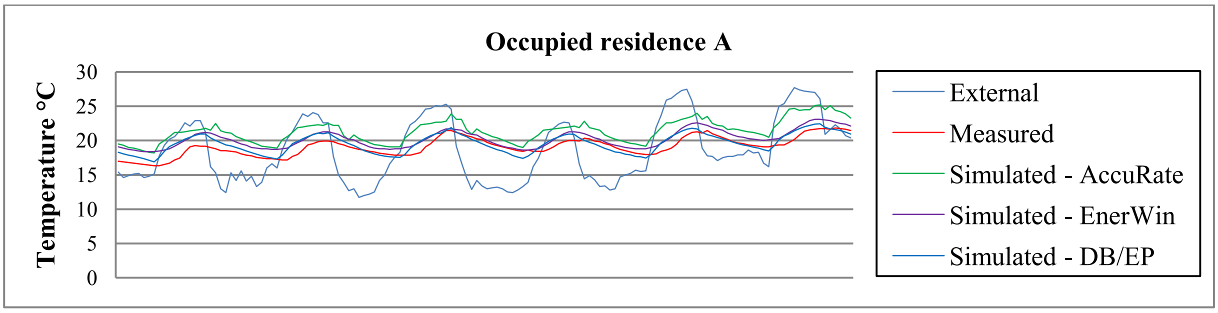


*Figure 7 Occupied residence A Living/kitchen area measured and predicted indoor temperatures from 12th – 18th April 2012*


*Figure 8 Occupied residence B Living/kitchen area measured and predicted indoor temperatures from 25th - 31st May 2011*

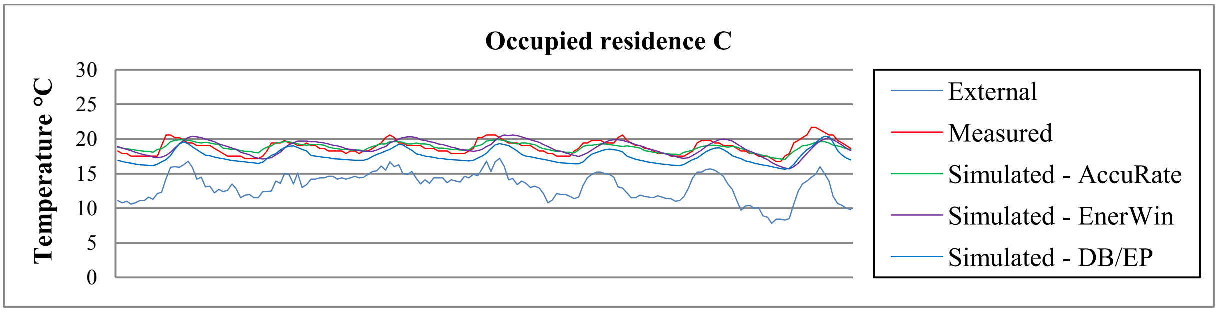


*Figure 9 Occupied residence C Living/kitchen area measured and predicted indoor temperatures from 10th – 16th May 2011*

## DISCUSSION

The results presented above are noteworthy when considering the proportion of unknown variables present, particularly in the occupied test cases. The relatively low CV(RMSE)s of the test cell comparisons and the higher CV(RMSE)s demonstrate that to accurately simulate *dwellings* incorporating heavyweight construction elements careful consideration needs to be given to occupancy related variables. Despite this, the results lend confidence to the accuracy of the ability of *Chenath* to accurately account for the physics of heat flow in models incorporating heavyweight elements.

Two key areas of modelling had considerable effect on the accuracy of the predictions; natural ventilation and ground coupling. The former is related to how the *actual* occupants operate the house, an exogenous variable, while the later reflects the varying capacities of the programs to model ground coupling.

Modelling the occupied residence B captures the issue with natural ventilation and the impact of individual occupant's behaviour. The initial *Chenath* simulations used the default natural ventilation algorithms, which are based on the relationship between indoor and outdoor temperature, and hours of zone occupancy. These initial results displayed considerably higher peaks when compared with the measured indoor temperatures; this is because the occupant usually opened the windows in the morning and closed them in the evening with little regard for outdoor temperature. Modifying the input to reflect this, and air movement between zones, had a marked impact on the correlation of the predicted and measured temperatures; bringing the predicted peaks in line with the measured.

The modelling process of all five buildings similarly highlights differences in the way that the three simulation engines account for ground coupling. Both *Chenath* and *EnerWin* do not require any input of ground temperatures, rather, internally calculating them based on the weather data in the climate file. *DesignBuilder*/*EnergyPlus*, however, requires the input of monthly ground temperatures, which considerably impact on the predicted indoor temperatures. In each case the thermal properties of the ground were unknown so default values were used; investigations of changing these values had a noticeable effect.

As evident from the discussion above; natural ventilation settings are critical to accurately simulating the thermal performance of buildings. This is particularly pertinent when the software is applied as a tool in the design and assessment of free-running (no heating or cooling) dwellings. Whilst the ventilation issues are largely HERS specific, the ground temperature and coupling calculations present an impediment for all *DesignBuilder/EnergyPlus* users and is indicative of the need for more investigations and refinement in this area of building modelling.

## CONCLUSION

The results demonstrate a good correlation between the *Chenath*, *EnergyPlus* and *EnerWin* predicted temperatures, and the measured data, indicating that the results presented above are positive and support the capability of the *Chenath* computational engine to adequately simulate buildings incorporating heavyweight construction components. However, many of the necessary changes to the *Chenath* input were done through modifying the 'SCRATCH' file (*.txt input file) rather than through the *AccuRate* front end, indicating that the front end in its current regulatory form does not allow the user to take into consideration occupancy related variables.. The results highlight the pressing need for a discussion about the appropriateness of current assumptions within NatHERS.

## ACKNOWLEDGEMENT

Monitoring data for Test Cells was supplied by Dr Kevan Heathcote, recorded during UTS/CSR/EBAA research into the thermal performance of three test buildings at Yarrawood, NSW. Thanks also to Dr Zhengdong Chen, CSIRO for assistance and explanation of *Chenath* and to Trevor Lee (*Energy Partners*) for the supply of the Yarramundi and Aldinga weather data set.

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