IMPACTS OF AN INNOVATIVE RESIDENTIAL CONSTRUCTION METHOD ON INTERNAL CONDITIONS

ROGER BIRCHMORE, ANDY PIVAC, ROBERT TAIT

Unitec Institute of Technology, Mt Albert, Auckland, New Zealand

ABSTRACT

New Zealand houses are known for producing sub-optimal internal thermal conditions and unacceptably high internal relative humidities. These contribute to poor levels of health, mould and can coincide with the decay of structural timber frames. A proposed solution is to provide an alternative structure utilising plywood instead of building paper, a wrap on the internal face of the timber frame and an additional air gap serving as an internal service cavity, followed by the internal lining. The internal wrap is designed to perform as a vapour check to prevent moisture vapour diffusion from inside into the frame and to permit moisture diffusion from outside through the structure to the internal environment. Two full scale houses had temperatures, dew points and humidity levels monitored over a full season. To avoid different occupant behaviour influencing internal moisture generation and heating patterns, the buildings are monitored in passive, unoccupied conditions. The test case house for the research incorporated the innovative construction solution. The second, control house was of identical design and location, using standard construction practice. The houses were situated to prevent shading each other, but in close enough proximity to be on identical sites. Results indicated that the calculated internal moisture content profile appeared to be unrelated to the external moisture content as expected in unoccupied conditions. Instead it followed the profile of the changing internal temperature. Whilst the innovative construction appeared to prevent moisture diffusion into the structure in winter and permit it inside in summer this resulted in a generally higher internal relative humidity than the control house.

KEYWORDS:

Housing; internal moisture; innovative construction.

INTRODUCTION

Mackintosh (2001) summarises New Zealand's climate as:

> "Warm subtropical in the far north to cool temperate climates in the far south, with severe alpine conditions in the mountainous areas. Mean annual temperatures range from 10°C in the south to 16°C in the north of New Zealand. Most of New Zealand would have at least 2000 sunshine hours annually"

This data does not describe harsh external conditions but instances where combinations of low temperatures and high moisture levels lead to poor internal environments are documented widely by a number of authors (Howden Chapman et al 2005, NZBCSD 2008, de Groot 2009, Howden Chapman et al 2011)

The World Health Organisation (2009) links poor internal conditions to a range of health problems that are also reported in New Zealand research. In response to the concerns there has been research on solutions that tackle the problems directly or indirectly through improving the sustainability of homes (Howden Chapman et al, 2007), (Easton & Saville Smith 2010), (Callau 2010), (Burgess et al 2010). This work has tended to focus on the thermal solutions and energy consumption aspects. Su (2006, 2013) researched the prevention of winter mould growth in occupied New Zealand houses employing primarily passive and active ventilation and thermal insulation prevention measures. Comparing the static and dynamic simulation methods de Groot (2009) expanded the research to explore in detail the impacts of moisture transfer through the envelope. He simulated alternative retrofit solutions over a three year period in Auckland, demonstrating that a vapour barrier was effective in preventing interstitial condensation occurring to levels that might encourage mould growth. He cautioned that the increase of thermal insulation without the consideration of interstitial moisture might move the visible mould problem to an invisible one. Leardini & van Raamsdonk (2010) also extend the concerns beyond occupant health to include structural degradation. They outline concerns that increasing levels of thermal insulation increases chances of interstitial condensation. The vapour barrier treatment risks trapping moisture vapour driven from outside rather than inside, into the structure. They propose that a solution is to provide a vapour check that prevents vapour transfer from inside to the wall structure but also permits this externally driven vapour to pass through the structure to the inside. This vapour check provides all the benefits of an airtight barrier, prevents the possibility of interstitial condensation but exacerbates the challenge of increased internal moisture levels and its associated risks. De Groot and Leardini (2012) identified a lack of information on the success of retrofit solutions and the general need to improve understanding of the impacts of combining insulation airtightness and humidity control. This paper outlines the early findings of a research project that moves research from desktop simulation to exploring the impact of a construction employing such a vapour check on unoccupied conditions in a real house. Investigating occupied conditions will follow.

METHODOLOGY

The fundamental aim of this project is to allow comparison testing of individual or combinations of building materials and techniques that have the potential for improving the building performance of this standard New Zealand house type.

Control House

The houses are single storied with three bedrooms and two bathrooms and are constructed as part of the Unitec carpentry programmes. The houses are completed by students to be relocated, and they are undecorated and without floor coverings or wall finishes. Electrical and plumbing fittings are installed but not connected. Table 1 summarises the materials used in the construction of these houses and identifies the elemental R values in m^2K/W. Overhangs on the north side of the house provide complete shading from direct solar gain through glazing during the hottest periods of the summer months. A standard floor plan is given in Figure 4. These houses are similar in design and construction to thousands of houses found in suburban areas and provide an ideal basis for examining the potential for improvements to a common housing type.

Test House

The modification made to the test house was to replace the building paper with 7 mm thick Ecoply Barrier treated to H3.2 CCA (Copper Chrome Arsenate) in accordance with AS/NZ 1604.3 (SNZ 2012a) to meet AS/NZS 2269.0 (SNZ 2012b). Vertical sheet joints were sealed with flashing tape. This feature was felt to have significant potential as an alternative that provided the functions of bracing and rigid air barrier in a single element. On the internal surfaces of external walls and ceilings the INTELLO vapour check was placed. A 45mmm cavity batten was then added before fixing of the plasterboard.

	Vapour Diffusion Resistance MNs/g	
Average Ambient Humidity	20%	85%
Direction of Diffusion Flow	Out towards the air barrier	Inwards towards the air barrier
INTELLO	60	5

Table 1. Vapour Diffusion Resistance of the INTELLO membrane.
(Moll & van Raamsdonk 2009)

Element	**Common to Control House and Test House**			
Construction	Timber Frame on pile foundation			
Sub-Floor	150x25 radiata pine boards with 20mm gap			
Floor	Particle board, foil insulation draped 100mm between joists (R= 1.3)			
Ceiling	R3.6 polyester ceiling batts (R= 2.9),10mm plasterboard			
Glazing	R m^2K/W	SHGC	Shading Coefficcient	Visible transmittance
	0.34	0.74	0.86	80%
	Control House		**Test House**	
Roof	Trussroof (radiata pine treated) Coloursteel roofing on building paper (stapled)		Trussroof (radiata pine treated) Coloursteel roofing on building paper (stapled) INTELLO wrap on bottom chord of trusses.	
Walls	cedar weatherboard cladding, natural finish		cedar weatherboard cladding, natural finish	
	20mm cavity battens		20mm cavity battens	
	Building wrap (stapled)		7 mm Eco ply	
	90x45 radiata pine framing		90x45 radiata pine framing	
	R2.6 polyester batts (R = 1.9 m^2K/W)		R2.6 polyester batts (R = 1.9 m^2K/W)	
			INTELLO Vapour check	
			45mmx45 battens	
	10mm plasterboard		10mm plasterboard	

Table 2. Construction details for the Control and Test Houses

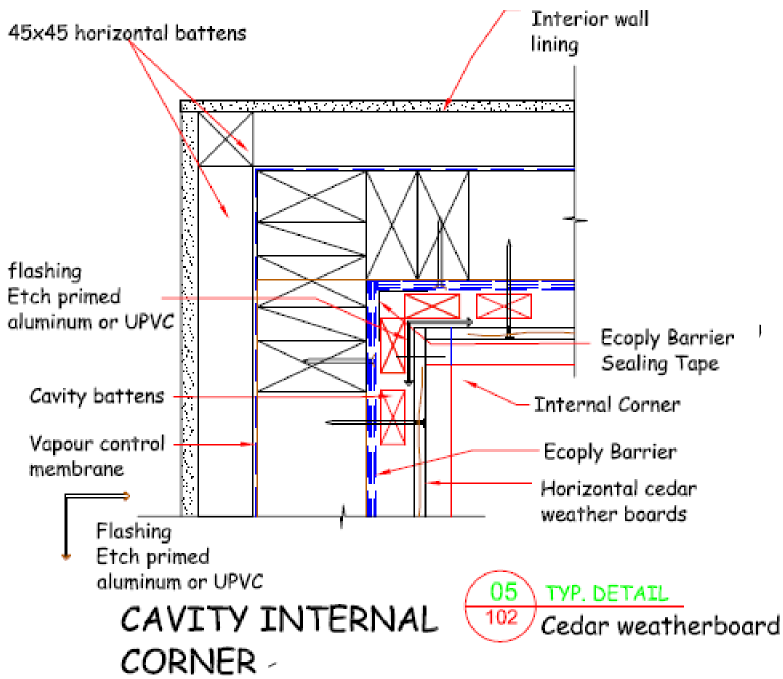

Figure 1. Construction Detail Though an Internal Corner of the Test House

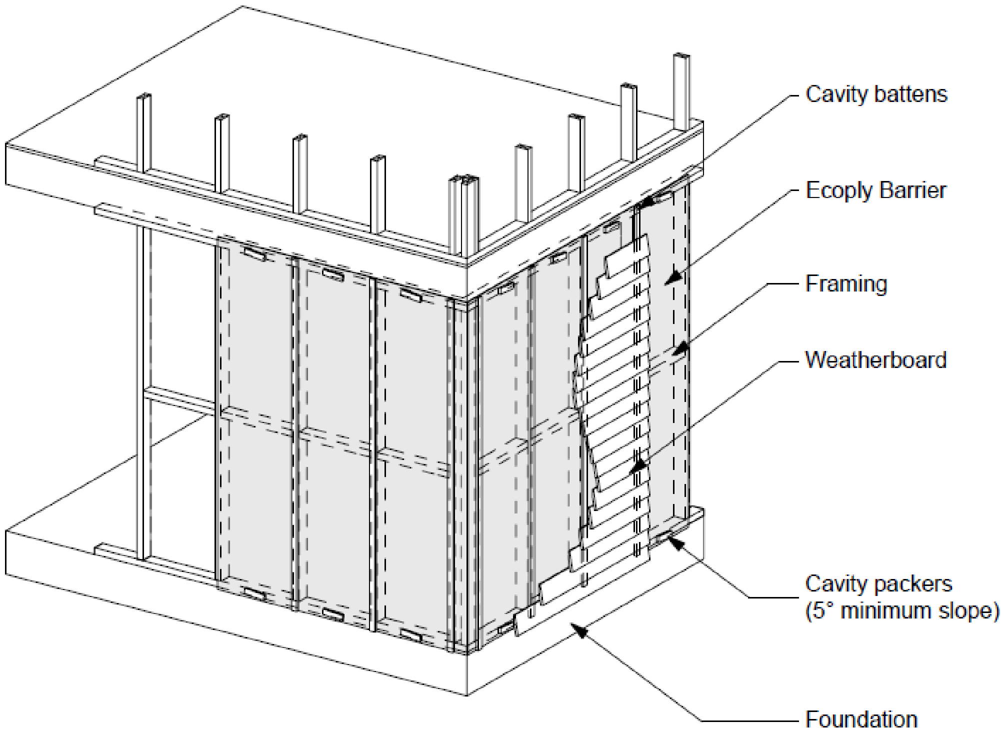

Figure 2. Construction details of the Plywood Rigid Air barrier in the Test House. (Carter Holt Harvey 2014)

Site

The site is on the Unitec Institute of Technology campus in Mt Albert Auckland. The site is relatively exposed with an open grassed area to the northwest. Surrounding buildings are reasonably distant to the south, north and east. Behind the houses to the southeast is a hilly incline and the student building yard. The houses are located with identical orientations but separated to avoid mutual shading. They are monitored in a passive, unoccupied condition.

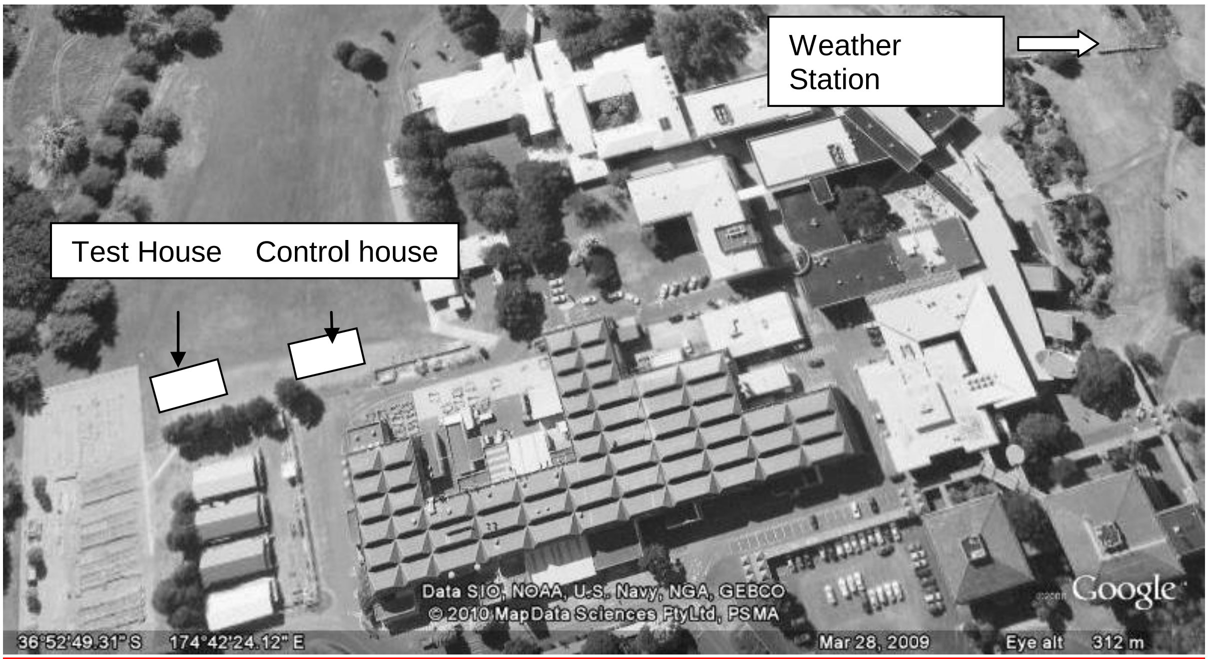

Figure 3. House and Weather station location details

Monitoring process

Temperature sensors have been set up to sample the internal air temperature at hourly intervals. Sensors used are Lascar EL-USB-2 Humidity & Temperature USB data loggers. These measure and store relative humidity, dew point and temperature readings over 0%RH to 100%RH and -35°C to +80°C measurement ranges. Sensors were located identically in the two houses to align with practice outlined by Barley et al (2005) at a height of 1500m above ground level suspended from the ceiling by builders twine. Sensor layout is given in Figure 4. In order to check the appropriate test location for the sensor, a second sensor was located at the edge of the room to check initial operation and determine the degree of variability experienced across each space. It was found that the average variation between measurements from the centre of the room and from the edge of the room vary by an average of 0.2°C over the 168 hourly measurements, with the maximum variation less than 0.5°C. This is well within the accuracy stated for the sensors, and indicates that a single measurement in the chosen position is representative of the overall room conditions.

Dew point measurement has been used as this single figure provides an indicator of absolute moisture content. Localised weather data is measured at a weather station indicated in Figure 3

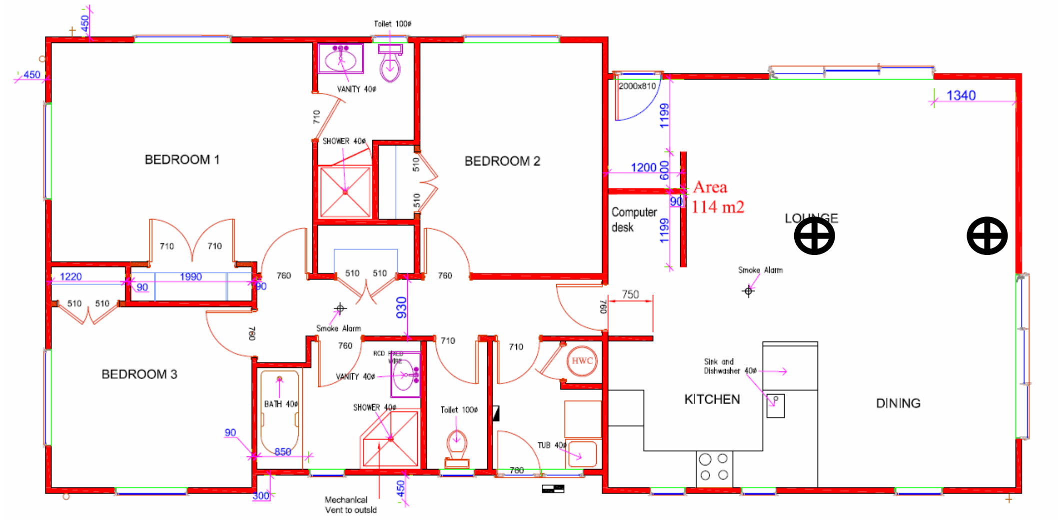

Figure 4. House plan with Sensor Locations

⊕ Sensor Locations

Air Tightness

Both houses were tested for air tightness using the standard blower door test following European standard EN 13829:2000. Openings associated with extract ventilation and unconnected waste pipes were sealed for testing

Room Being Analysed

The room chosen for analysis in this paper was the Lounge Kitchen Dining Room. This is the largest space in the house and is has external walls on the South, East and North Face with glazing in each with a window to wall ratio of 29%. Its inclusion of the kitchen also examines a space where occupancy may generate significant additional internal moisture.

Room	Floor Area	Wall area	Window Area m^2 and Orientation			
	m^2	m^2	South	East	North	West
Lounge Kitchen Dining room	44.6	36.5	2.8	5.4	7.0	0

Table 3. Details of Room being Analysed.

RESULTS

Seasonal Data

The averages of Dry Bulb (DB) Relative Humidity (RH) and Dew Point (DP) measured at hourly intervals for the winter and summer seasons are summarised in the table below for each building. The summer season is defined as December 1 – February 28. The winter season is defined and June 1-August 31.

	Control			Test			Difference (Test – Control)		
	DB ^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C
Average	25.2	51	14.3	24.6	59	15.9	-0.6	7.3	1.6
Maximum	35.5	69	22.3	34.0	69	23.5	-1.5	0.0	1.2
Minimum	15.0	37	5.8	15.5	46	8.6	0.5	8.5	2.8
Range	20.5	32	16.5	18.5	24	14.9	-2.0	-8.5	-1.6

Table 4. Summary of Summer Season Data

	Control			Test			Difference (Test – Control)		
	DB ^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C	DB^{0}C	RH%	DP^{0}C
Average	16.3	61	8.6	16.2	63	9.0	-0.1	1.9	0.4
Maximum	28.5	73	16.7	28.5	74	17.5	0.0	1.5	0.8
Minimum	7.0	43	0.0	7.0	47	1.4	0.0	4.0	1.4
Range	21.5	30	16.7	21.5	28	16.1	0.0	-2.5	-0.6

Table 5. Summary of Winter Season Data

The tables indicate that in the unoccupied condition, the Test House construction appeared to have only a very small effect on the average internal conditions over either season. Over the summer the average RH for the Control was 51% and 59% for the Test House with extremes of 37% and 69%. Over the winter period the average RH for the Control was 61% the Test House higher at 63% with extremes ranging between 43% and 74 %. The internal vapour check therefore maintained slightly higher internal RH readings and internal dewpoints over each season. This supports the intended performance of the vapour check, by preventing moisture being absorbed into the structure of the envelope and could explain this elevation. The property of the vapour check, that permits vapour to pass through from outside to inside, could also explain the higher internal dewpoints especially in the summer when external dewpoints tended to be higher than internal measures.

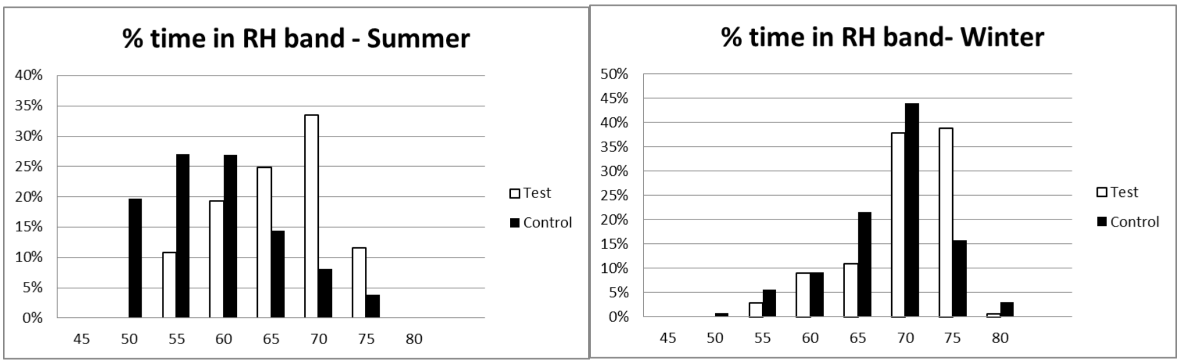

Figure 5. Percentage of Time Spent in Relative Humidity Bands

Research summarised by WHO (2009) indicates that mould formation is dependent upon combinations of dry bulb, RH, time of wetness, surface material, ventilation rate and initial spore concentrations. This prevents the recommendation of a single threshold level but cites work suggesting that surfaces can be kept free of fungal growth "if surfaces are kept below 75% within a temperature range of 5– 40 °C" (WHO 2009, pp38).The graphs above confirm that the test house has smoothed the range of measures by reducing the range of RH's experienced and increased the instance of higher RH. This is more pronounced in the summer than the winter. However the instances of RH readings above 75% in winter have increased to nearly 40% in the Test House from 18% in the Control House.

Detailed Results of Selected days

The detailed results of a few days in each season are shown in figures 6 and 7. They have been chosen to illustrate the strong influence of solar gain on internal conditions. This indicates that the internal dry bulb temperatures follow the cyclical pattern of the external solar gain. The period of the cycle appears identical but with a lag of between four and six hours. The internal dewpoint also follows with the same period but with slightly reduced amplitudes. There is a very weak connection if any, with the dewpoint of the external air. As there were no occupant generated sources of internal moisture the changing dew points over a daily cycle could be resulting from residual construction moisture. As the temperature rises, moisture still present in the construction evaporates into the air. As it cools it is re-absorbed into the structure. Whilst the test house vapour check is designed to reduce this, the floors of both houses are exposed particle board. The test house is one year newer than the control house which might account for the higher starting values.

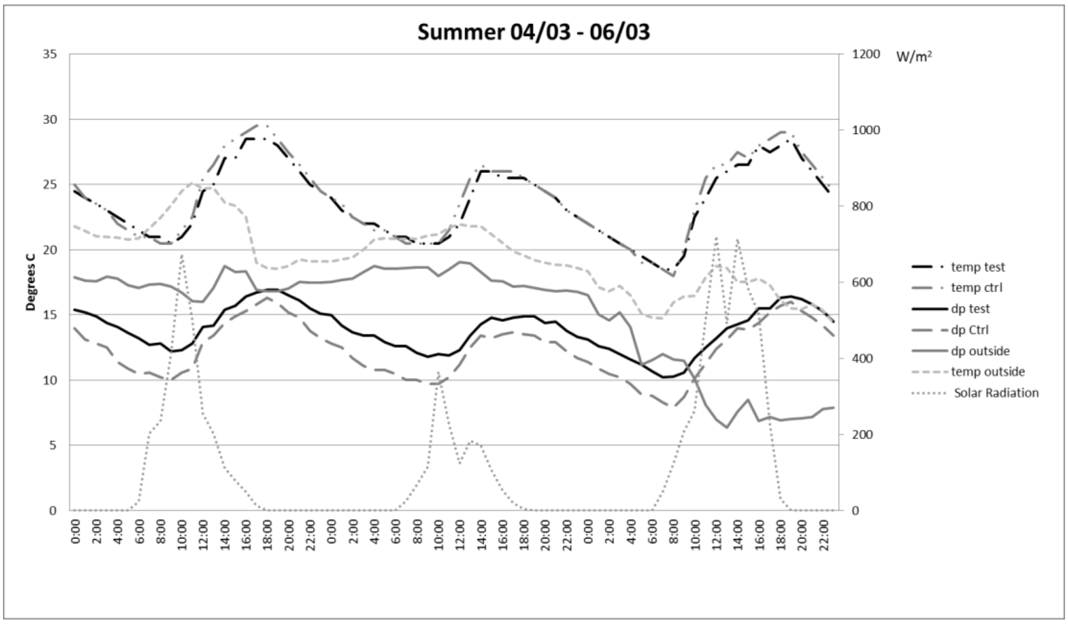

Figure 6. Temperatures and Dew Point comparisons for Houses with External Summer Conditions

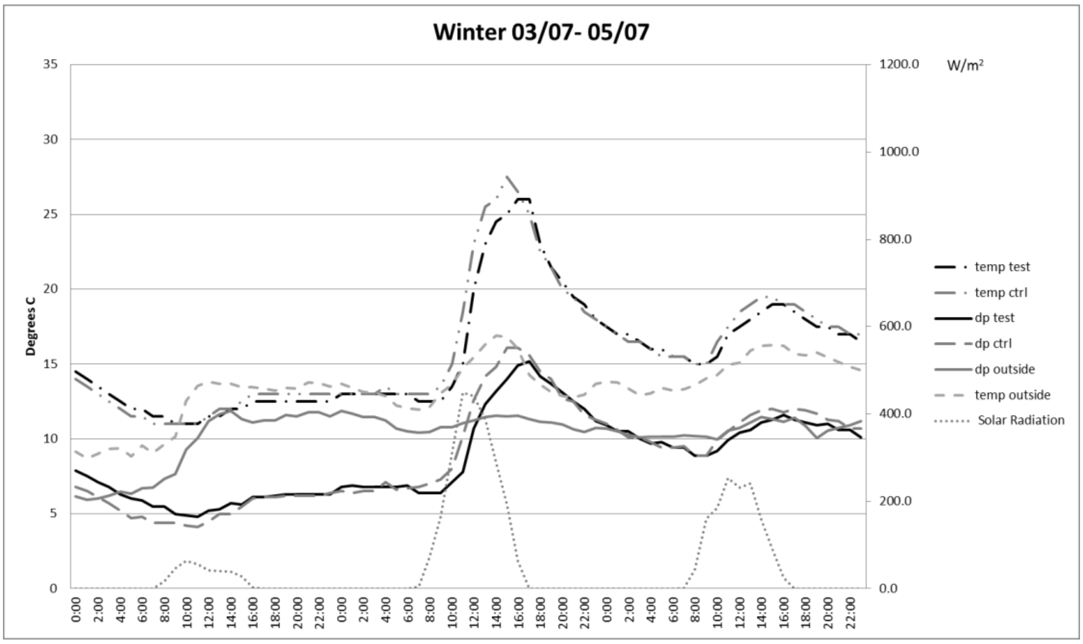

Figure 7. Temperatures and Dew Point comparisons for Houses with External Winter Conditions

The daily cyclical evaporation and re-absorption explanation is supported by comparison of daily results over a whole season. The difference between daily maxima and minima of dewpoints ranges between 6.8^{0}C in the summer and 8.4^{0}C in the winter. Comparison of Dew points in Tables 4 and 5 indicate that the average dewpoint has reduced over the seasons from by 5.7^{0}C for the Control House and by 6.9^{0}C for the Test House. The apparent disconnection with external dewpoints shown in figures 6 and 7 supports an explanation that some long term drying is taking place.

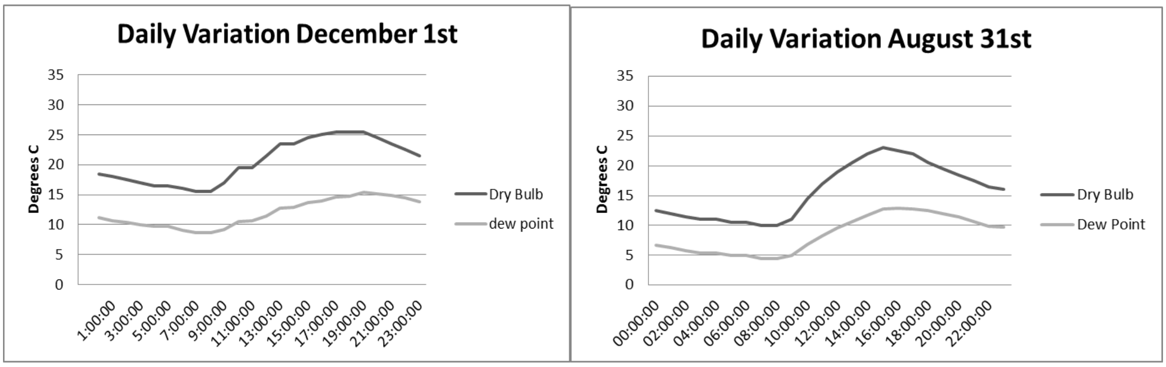

Figure 8. Sample Daily Variations of Dew Points in Both Seasons

Using a Psychrometric chart Moisture Contents in kg of moisture per kg of dry air can be read for given dew points. Using the mean density of the air for the day and the volume of the space, the actual volume of moisture being evaporated and re-absorbed on a daily cycle can be estimated as 0.5 litres. TenWolde & Pilon (2007) suggest that a family of four would produce up to 15 litres per day.

		Summer Dec 1st		
	Dry Bulb ^{0}C	Dew Point ^{0}C	density kg/m^3	Moisture Content kg/kg (Dry Air)
Max	25.5	15.4	1.163	0.0109
Min	15.5	8.6	1.211	0.0069
Difference		6.8		0.004
Mean density kg/m^3			1.187	
Space volume m3		108.54		
Space mass kg		128.809		
Moisture mass kg		0.52		
Moisture volume l		0.52		

Table 6. Data for Estimation of the Moisture Volume Being Evaporated and Re-absorbed

Airtightness

	Control house ac/h	Test house ac/h
Depressurisation	6.58	1.92
Pressurisation	6.93	2.10
Average	6.75	2.01

Table 1. Results of airtightness testing

The figures above represent the air changes per hour of the whole house volume under the standard test conditions of 50Pa +ve and 50 Pa –ve. It indicates that the Test House has an air leakage rate of less than a third of the Control House. The Control House sits just outside the Airtight classification for New Zealand houses which peaks at an airtightness of 5 ac/h. (Stocklein & Bassett 1999) The test house is comfortably in the Airtight classification but is still well above the requirements of the Passive House Institute (2012) of 0.6 ac/h.

CONCLUSION

The internal spatial data supports the expected performance of the vapour check. In winter, higher internal dew points and RH measurements in the Test House compared to the Control House suggest that internal vapour is not being permitted to enter the structure. The risk of interstitial condensation should be reduced. In summer, higher internal dew points and RH measurements suggest that vapour is being allowed to pass through the structure to the inside. This prevents the moisture getting trapped, creating the potential to cause interstitial condensation when the climate permits. This differentiates the performance of the vapour check from a conventional vapour barrier which would trap the moisture within the timber structure.

Minimal differences between the average dry bulb temperatures over both seasons in the control and test buildings suggest that the airtightness properties are having a small effect on unoccupied thermal conditions. This is not what was expected especially during the winter season where it was thought that increased infiltration in the Control House would lower temperatures noticeably. Figure 7 shows that on cloudy winter days the difference between internal and external temperatures was minimal so differences between Control and Test Houses could also be very small. However on sunny winter days, internal temperatures rose nearly ten degrees higher than outside. The Test House was actually slightly cooler than the Control House. This suggests that the heat losses due to infiltration through the closed structure in an unoccupied condition might be much smaller than anticipated or are not being prevented by increased airtightness of the envelope.

Both houses spend significant amounts of time close to conditions that might support mould growth in their unoccupied state. One explanation is that this moisture comes from the construction drying out. The tendency of the vapour check to produce slightly higher internal dew points and RH’s emphasises the need to combine this type of structure with minimal ventilation rates to ensure the moisture is ventilated to outside. The combination of the increased time spent in this band, with the recognition that surface RH’s may well be higher and that occupant behaviour may exacerbate conditions further underlines the importance of ventilating moisture sources to outside.

Work is underway with the detailed monitoring of temperature and humidity in each layer of the wall construction of each building. This will enable tracking in detail of the passage of vapour through the envelope and the identification of interstitial condensation risk and help confirm the performance of the internal vapour check by keeping moisture out of the structure. Further work will include monitoring conditions under controlled, active heating, cooling and moisture generation.

ACKNOWLEDGEMENTS

This research has been carried out with the support of Thomas Raamsdonk of ProClima and the Unitec Internal Research Fund.

REFERENCES

Barley, D., Deru, M., Pless, S., & Orcellini, P. 2005. Procedure for measuring and reporting commercial building energy performance, Technical Report NREL/TP-550-38601, National Renewable Energy Laboratory, Battelle, USA.

Burgess, J.C., Buckett, N.R., Camilleri, M.J.T., Burrough, L.J. & Pollard, A.R. 2010. Papakowhai Retrofit Project – Improving the Thermal Envelope and Space Heating. New Zealand Sustainable Building Conference, Wellington, New Zealand, 26 May- 28 May 2010. Innovation and Transformation. New Zealand Sustainable Building Conference.

Callau M. 2010. Upgrading Housing in NZ for thermal efficiency. New Zealand Sustainable Building Conference, Wellington, New Zealand, 26 May - 28 May 2010. Innovation and Transformation. New Zealand Sustainable Building Conference.

Carter Holt Harvey. 2014. Ecoply- Barrier. [Online]. Available: http://www.chhwoodproducts.co.nz/ecoply-barrier/. [11 June 2014].

Easton & Saville Smith. 2010. Homesmart Renovations - testing tools to promote sustainable Renovation. New Zealand Sustainable Building Conference, Wellington, New Zealand, 26 May - 28 May 2010. Innovation and Transformation. New Zealand Sustainable Building Conference.

de Groot, H. (2009). Indoor Air Quality and Health. An Analysis of the Indoor Air Quality and Health in New Zealand's Homes. [Online]. Available: http://www.archigraphic.de/_originals/pdfs/indoor_air_quality_and_health.pdf. [11 June 2014].

European Committee for Standardization CEN/TC 89 2000. EN 13829:2000, Thermal performance of buildings - Determination of air permeability of buildings - Fan pressurization method (ISO 9972:1996, modified)

Howden-Chapman, P., Saville-Smith, K., Crane, J., Wilson, N. 2005. Risk factors for mould in housing: a national survey, Indoor Air: International Journal of Indoor Environment and Health, Volume 15, Issue 6, September, 2005, pp. 469-476.

Howden-Chapman, P., Matheson, A., Crane, J., Viggers, H., Cunningham, M., Blakely, T., Cunningham, C., Woodward, A., Saville-Smith, K., O'Dea, D., Kennedy, M., Baker, M., Nick, N., Chapman, R.,Davie, G. 2007a. Effect of insulating existing houses on health inequality: cluster randomised study in the community. British Medical Journal 334, 460.

Howden-Chapman, P., Crane, J., Chapman, R., & Fougere, G. 2011. Improving health and energy efficiency through community-based housing interventions. International Journal of Public Health, 56(6), 583-588

Leardini, PM ; van Raamsdonk, T.2010. Design for airtightness and moisture control in New Zealand housing, New Zealand Sustainable Building Conference, Wellington, New Zealand, 26 May - 28 May 2010. Innovation and Transformation. New Zealand Sustainable Building Conference.

Mackintosh L., 2001. NIWA Overview of New Zealand climate. [Online]. Available: https://www.niwa.co.nz/education-and-training/schools/resources/climate/overview. [11 June 2014].

Moll, L., van Raamsdonk, T., (2009). A New Zealand Based Study on Airtightness and Moisture Management, ProClima NZ Ltd, Wellington'

New Zealand Business Council for Sustainable Development (NZBCSD). 2008. Media Release: $20 billion cost of fixing country's homes less than 4% of their value. [Online]. Available: http://www.scoop.co.nz/stories/BU0812/S00020.htm [11 June 2014].

Passive House Institute (2012) Passive House Requirements. [Online]. Available: http://www.passiv.de/en/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm. [11 June 2014].

Pro Clima. 2014. Intello Vapour Check. [Online]. Available: http://www.proclima.co.nz/intello-airtightness-membrane. [11 June 2014].

SNZ 2012a AS/NZ 1604.3 Specification for preservative treatment Part 3: Plywood Wellington, New Zealand: Standards New Zealand

SNZ, 2012b, AS/NZS 2269.0:2012 Plywood- Structural Part 0: Specifications Wellington, New Zealand: Standards New Zealand

Stoecklein, A., Bassett, M., 1999. ALF3 - A design tool for energy efficient houses. (Thermal simulation software) Building Research Association of New Zealand, Judgeford.

Su, B., 2006. Prevention of inter Mould Growth in Housing. Architectural Science and Review. 49 (4): 385-390.

Su, B., (2013). Indoor Moisture Control of Auckland Houses with Different Ventilation Systems. International Journal of Civil, Architectural Science and Engineering. 7 (10): 411-415.

TenWolde, A., & Pilon, C., (2007). The Effect of Indoor Humidity on Water Vapor Release in Homes, [Online]. Available: http://web.ornl.gov/sci/buildings/2012/2007%20B10%20papers/071_TenWolde.pdf. . [11 June 2014].

World Health Organisation. 2009. Guidelines for Indoor Air Quality: Dampness and Mould. [Online]. Available: http://site.ebrary.com/lib/unitech/Doc?id=10367463&ppg=55. [11 June 2014].