Acceptable Designs for Timber Framed Parapet Walls

Overton, G.
BRANZ, NZ
(email: greg.overton@branz.co.nz)
Bassett, M.
BRANZ, NZ
(email: mark.bassett@branz.co.nz)
McNeil, S.
BRANZ, NZ
(email: stephen.mcneil@branz.co.nz)

Abstract

There have been numerous cases of rotting timber in New Zealand parapet walls. This study, funded by the New Zealand Building Research Levy, aimed to experimentally verify whether a parapet design detail from the New Zealand compliance document for weathertightness (E2/AS1) resisted condensation accumulation.

Parapets are likely to experience much colder temperatures than the bulk of the wall. It was proposed that on clear, cold nights that this temperature difference within the wall may cause water vapour to be transported to the top of the parapet where it could condense. This could then lead to rotting of the top-plate and/or the sloped packer. It was also proposed that solar-driven moisture could ultimately end up at the head of the wall, again increasing the risk of timber decay.

A test wall was built in one of the outdoor facilities at BRANZ and was split into three different sections: an open rainscreen (vented at the base of the wall only); a drained and vented section (vented at the top and bottom of the wall); an open rainscreen with vented battens (to provide cross-ventilation between cavities).

The ventilation levels in the various parts of the wall cavity were measured using a tracer gas (CO_2) and the constant emission rate method. The results agreed well with a model of the wall, based on a simple duct flow representation of the interconnected wall cavities.

Pieces of absorbent material were located on the interior face of the cladding and were dosed daily with 40 ml of water in the morning and evening. Moisture content sensors throughout the wall were used to determine if any condensation occurred at the head.

Over a period of two years, no evidence of moisture accumulation was recorded at the head of the wall under normal climatic conditions. During this time two types of capping were applied: a metal capping; and a simulated torch-on capping. A more severe climate, simulated using dry ice, was required to accumulate significant moisture in the parapet framing.

A simple mathematical model was developed to predict the level of moisture accumulation and was found to agree reasonably well with the experimental observations. WUFI, a hygrothermal simulation tool, was then used to model the drying of the wall. This also agreed reasonably well with the experimental observations. The validation of the two models under these conditions means that they could be used to assess the E2/AS1 parapet detail for other regions if necessary.

Keywords: Parapet, condensation, ventilation, drying, WUFI.

1. Introduction

New Zealand, like many other countries, suffered from a leaky home crisis in the late 1990s and early 2000s – the cost of which continues to escalate (Gibson, 2009). The causes of the problem were manifold, but it is acknowledged that one factor was an increase in the popularity of 'Mediterranean' style housing in New Zealand (Groufsky, 2008).

A particularly weak point of these designs was parapet walls. Parapets are an inherently vulnerable point of any building because they are exposed to the elements on three sides and are somewhat isolated from the main structure (Oliver, 1997). Numerous building surveyors witnessed widespread decay of walls that seemed to originate from the head of the parapet (Figure 1). Many failures were likely to be from relatively simple gravity leaks facilitated by poor design. Cappings were not inherently waterproof (worsened by any cracks due to movement) and were often not sloped to encourage run-off. This allowed water to penetrate, track along to fixing points and eventually reach timber.

Figure 1: Examples of decay at head of parapet walls – notice lichen growth on left-hand photo

In response to the leaky building crisis, the Department for Building and Housing modified the weathertightness compliance document E2/AS1 of the New Zealand Building Code (DBH, 2005). Many of the changes were based on the 4D's (Deflection, Drainage, Drying & Durability) approach developed in Canada (Hazledon & Morris, 1999) and incorporated the idea of a cavity behind the outer cladding layer.

This study aimed to gain confidence in the E2/AS1 parapet detail and also to clarify if there was a mechanism that resulted in air-carried moisture accumulating at the head of the wall. Questions were asked by the remediation industry as to whether moisture was being carried in air flows to the head of the wall from elsewhere in the structure – driven either by solar radiation or by cooling of the head of the wall to the night sky. The desired end result was to either accept the current details or develop recommendations for improvements that could be considered for inclusion in the Building Code.

The first step in the experiment consisted of building a parapet wall and measuring its airtightness characteristics. This information was then used to benchmark a multi-zonal model of cavity ventilation against tracer gas measurements. The subsequent part of the program involved delivering water to the back of the cladding and observing the conditions within the wall. Over the course of the experiment, different cappings were used to explore the sensitivity of moisture accumulation to this detail. In all cases, no moisture accumulation was observed at the top of the wall. A more severe climate was then simulated to force air-carried moisture to condense at the top of the wall. This enabled the drying ability of the wall to be observed. This behaviour was then compared to a WUFI model of the parapet.

BRANZ's role is to inform and educate the building sector. This study has proved that the E2/AS1 parapet detail is reliable. However, it may be a long time before the public has the belief that homes with parapets are not necessarily 'leaky'.

An interesting phenomenon observed by remediation specialists is that even if a parapet can be successfully remediated, the owners can still be left with an 'unsellable' house because potential buyers now associate parapets with leaky homes and will avoid them. Some remediation specialists now prefer to replace the roof with a more traditional design that includes eaves (Figure 2). This can solve the moisture problems and positively alter the appearance of a house such that it is free from the leaky home stigma, and can often be achieved for a relatively small extra cost that is easily recuperated in the onward value of the home.

Figure 2: Example of 'removal' of parapets to completely change the appearance of a building

2. Experimental method

An existing test building at BRANZ was modified to include a parapet wall on its north (warm) face. The wall was clad with texture-coated fibre-cement and the parapet extended 1 m above the roofline. The wall was split into three sections across its length. Each section had a different cavity style since it was proposed that different ventilation levels may affect the amount of condensation accumulated at the head of the wall.

The first section is referred to as an open rainscreen (ORS). This is a wall that is ventilated at the base but has no specific vent at the top. Infiltration paths exist, however, so there will be some air flow through the cavity and from other parts of the wall. The second section included specific vents at the head of the wall and is referred to as a drained and vented (D&V) wall. This provided ventilation levels that could be expected in a brick veneer wall having open head joints and weep holes. The third section of the wall had no specific vent at the head of the wall, but the cavity was formed using vented battens to provide a higher level of cross-ventilation between cavities. This was referred to as a vented batten (VB) wall. The layout of the whole wall (as viewed from the inside) is shown in Figure 3. Instrumentation was placed in the middle cavity of each section, with neighbouring cavities acting as a guard between the different test cavities.

The construction at the head of the wall was the same as the parapet solution for cavity walls in E2/AS1 and is shown in Figure 4.

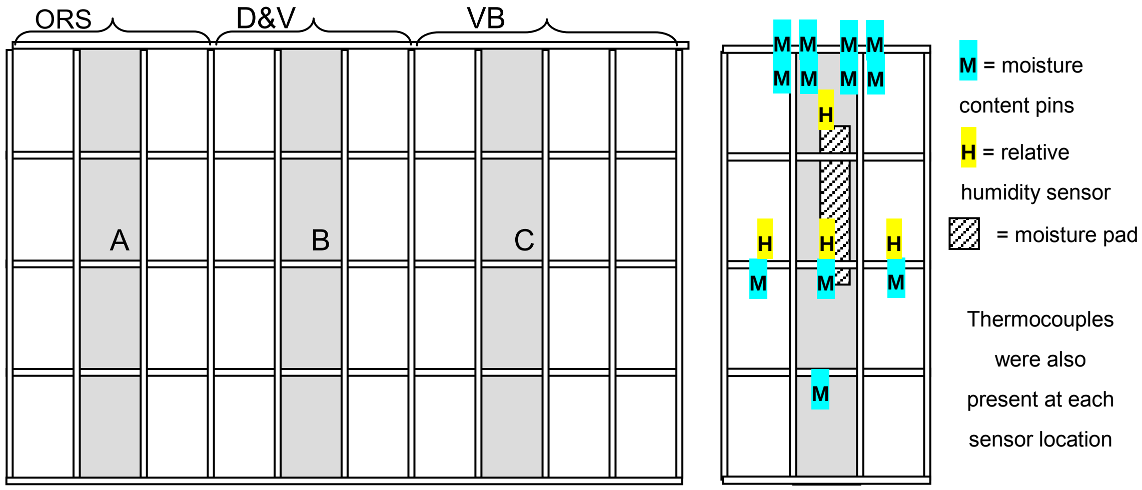

Figure 3: Schematic of wall framing and cavity instrumentation

In the first year of the experiment, the detail was as per Figure 4 but infiltration at the head was minimised by sealing the cladding to the packer. In the second year, typical levels of infiltration to the underside of the capping were introduced (effective leakage area at 1Pa $\approx 130 mm^2/m$) (Bassett et al, 2009) by drilling small holes through the packer into the cavity.

Two cappings were applied in the second year – a torch-on membrane was simulated using flashing tape and then the original metal capping was replaced. Torch-on cappings should theoretically seal perfectly against the packer. If this were the case there would be no scope for air flow underneath the capping. It was proposed that there must be regions where the membrane was not adhered to, in order to allow some air to be transported up to that space. To simulate this, a piece of house wrap was placed under the capping to act as a bond-breaker.

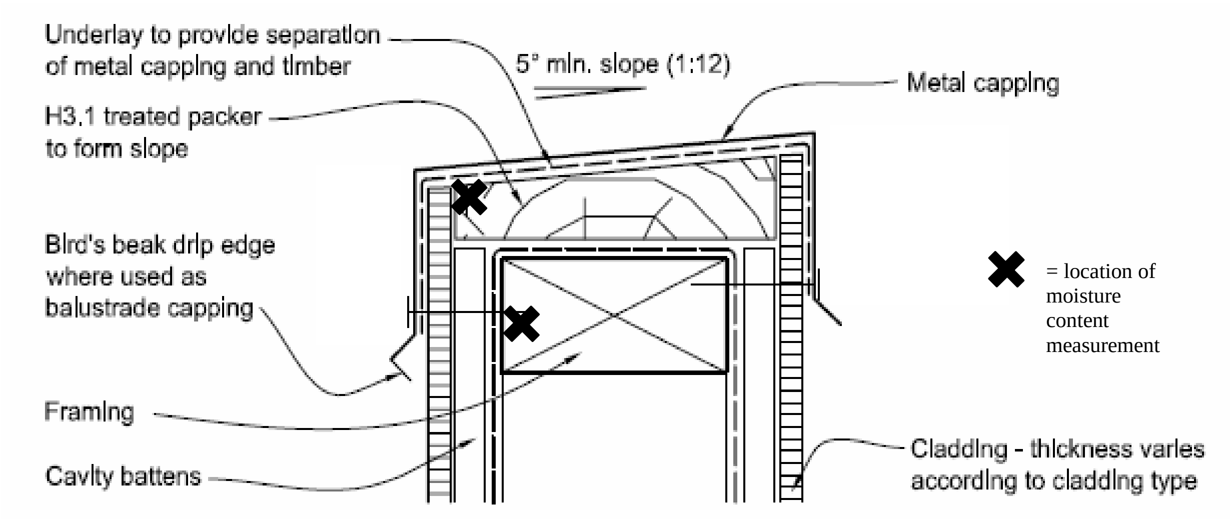

Figure 4: Detail at the head of the wall and location of moisture content sensors (adapted from E2/AS1)

2.1 Wall instrumentation and moisture dosing

Cavities A, B and C were all instrumented in the same manner. Each section of the wall had 12 pairs of moisture content pins and four relative humidity sensors as shown in Figure 3. T-type thermocouples were installed in the framing at each moisture pin location to allow for temperature correction and at the location of each humidity sensor to enable calculation of vapour pressure. All sensors were logged at 15 minute intervals.

Cavities A, B and C were all dosed with 40 ml of water twice-daily at approximately 8am and 8pm. The water was delivered to an absorbent pad on the interior face of the cladding using a peristaltic pump. The use of the absorbent pad meant that water would not simply drain away and that there was an effectively constant moisture source in the wall. This was considered more severe than typical cladding leaks.

It was proposed that this source of moisture could result in condensation forming at the head of the wall on clear, still nights. At these times the top of the parapet would radiate heat to the night sky, lowering its temperature to below ambient levels. This temperature difference could result in warmer moist air migrating to the head of the wall by convection, where it could condense. Since the pad was dosed in the morning as well as the evening, solar (i.e. stack pressure) driven effects would also have been observed if they were active.

Towards the end of the winter in the second year, it was decided to simulate a more severe, alpine-like climate. This was achieved by applying dry ice to the exterior of the head of the wall. Approximately 20 kg of dry ice was placed in a polystyrene trough at the head of the wall on each weekday afternoon for two weeks. Once the timber moisture level recovered the dry ice experiment was repeated with a metal capping in place of the flashing tape.

2.2 Airtightness measurements

Prior to dosing the wall, a series of airtightness measurements were conducted to establish the flow resistance between the various cavities in the wall. This information was needed to model ventilation rates within the wall.

Fans were attached to ports which extended from the water-managed cavity to the interior of the building. By judicious taping of vents, and using a variable speed controller on the fans, it was possible to isolate the flow resistance associated with an individual batten or vent.

The flow resistances were expressed as a power law relationship that was extrapolated back to a working-pressure level. The ‘real’ pressures that drive ventilation in cavities are of the order of only a few Pascals (Bassett & McNeil, 2006), and so these flow resistance relationships have been used to calculate an effective leakage area due to a pressure difference of 1 Pa.

The flow resistance data was subsequently used to model ventilation in CONTAM[8], a multi-zone air flow and contaminant transport analysis software package. This allowed comparison between measured ventilation rates (Section 2.3) and those calculated using a relatively simple zonal model of the wall. Pressure coefficients for the vents were derived from an online database.[9]

2.3 Ventilation measurements

Ventilation levels in the three wall types were monitored over several weeks in early 2008. This was achieved using a constant injection tracer method (Charlesworth, 1988; Bassett & McNeil, 2006). Carbon dioxide was used as the tracer gas.

The generalised mass balance equation for the tracer gas in an enclosure is:

$$V\frac{dC}{dt} = F - Q(C_{(t)} - C_{ambient}) \qquad (1)$$

Where

V = Volume of enclosure, m^3

Q = Air flow through enclosure, m^3s^{-1}

$C_{(t)}$ = Concentration of tracer gas at time t

F = Rate of tracer generation, m^3s^{-1}

In a constant injection tracer experiment, it can be shown that if the ventilation rate is constant then the tracer guess will reach equilibrium after a certain amount of time:

$$Q = \frac{F}{C_{(t)} - C_{ambient}} \qquad (2)$$

The interior face of the cladding was painted to minimise tracer gas absorption.

3. Results

3.1 Airtightness

Figure 5 shows the effective leakage areas at a pressure difference of 1 Pa.

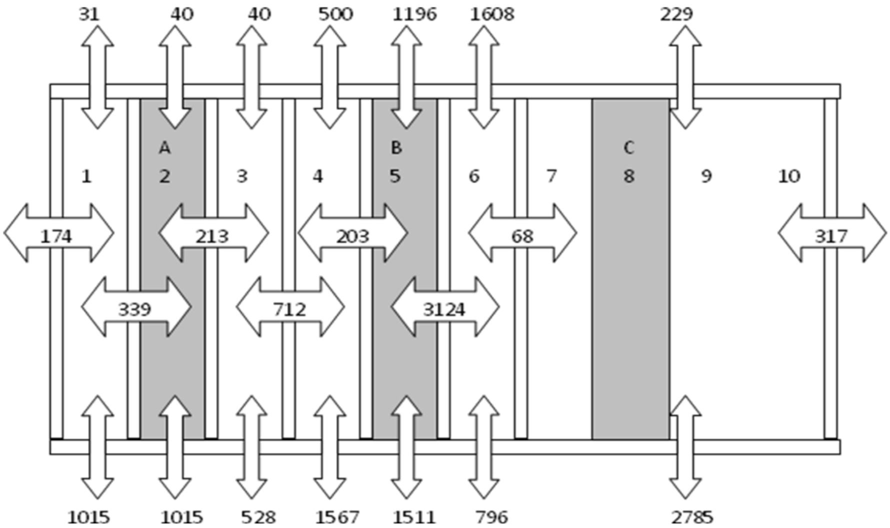

Figure 5: Effective leakage areas (mm^2) at 1 Pa

The leakage areas at the head of the ORS and VB cavities are relatively low because the cladding was sealed to the packer at the time of the measurement. Also of note is the high leakage area associated with one of the battens in the D&V wall. This is roughly equivalent to having a 1 mm gap along the height of the batten, which was not intended.

3.2 Ventilation

Figure 6 shows the comparison between the measured ventilation levels and those from CONTAM for the ORS wall over a period of one week. Note that data is hour averaged i.e. a running average taken over four 15 minute intervals. This aligns with earlier studies of ventilation in wall cavities (Bassett & McNeil, 2006), effectively validating the use of the model to predict ventilation rates for the different parts of the wall.

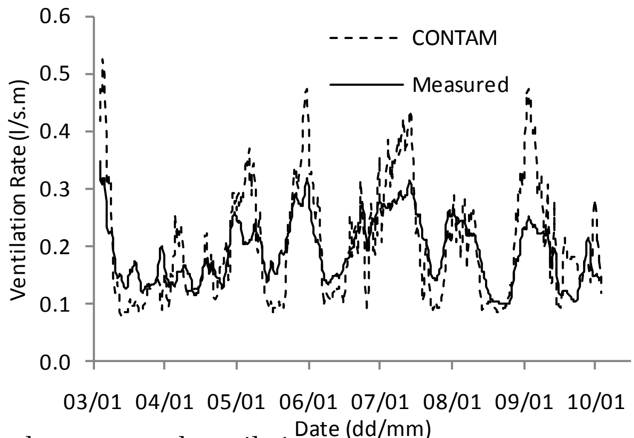

Figure 6: Calculated vs measured ventilation rates

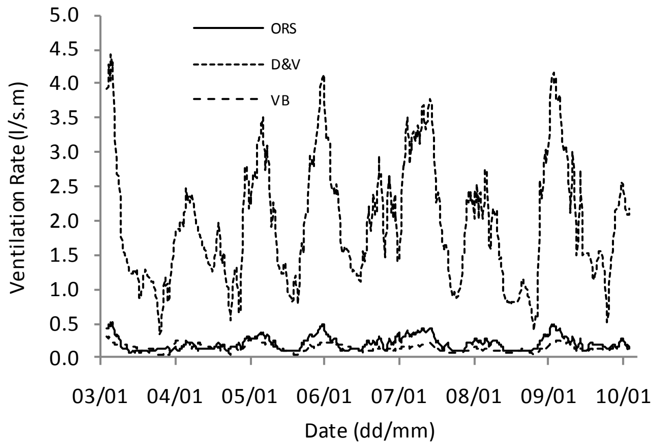

Figure 7: Ventilation rates for the different cavity types

Figure 7 shows the calculated ventilation levels for all walls for the period of 3/1/08 to 10/1/08. It can be seen that the D&V cavity had the highest ventilation rate, due to the pressure difference between the top and bottom vents. Of interest is the similarity between the ventilation rates in the ORS and VB walls. In this case vented battens have not significantly increased the overall ventilation rate compared to standard battens. In this particular wall the variation in pressure coefficient along the top and bottom edges was not particularly large in the region of the VB wall, so therefore there was limited scope for lateral ventilation. Also, lateral flow into and out of the zone was ultimately controlled by a conventional batten. If the building had only vented battens, there would be scope for higher ventilation levels as lateral flow would occur from regions with a high pressure coefficient to those with a lower pressure coefficient e.g. around corners.

3.3 Dosing phase

In the first year of the experiment, no accumulation of moisture was detected at the parapet at all. The region where the building is located is not the coldest part of New Zealand, but there were several hard frosts over the winter. It was these conditions that were thought to lead to condensation and possible moisture accumulation.

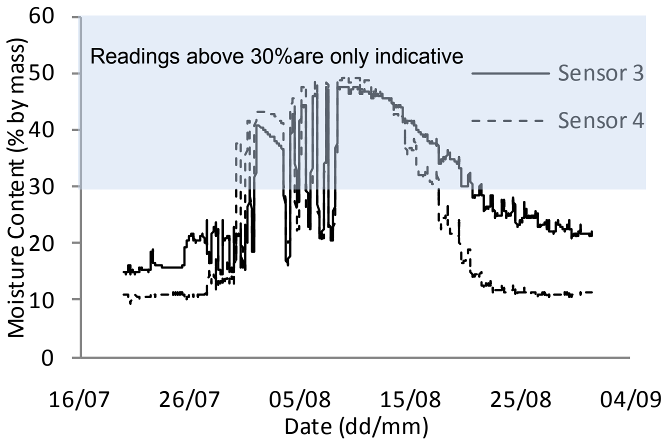

Figure 8: Moisture response of ORS wall when dry ice was applied to the head

In the second year, with normal levels of air infiltration and two types of capping, there was also no moisture accumulation under normal climatic conditions.

The application of dry ice did lead to elevated moisture content levels in the timber at the head of the wall. Figure 8 shows the measured moisture content for the packer in the ORS section of the wall. The bracketed regions represent the times when dry ice was applied. The pin measurements were only reliable between 10% and 27% moisture content, but all the readings are plotted for completeness. Similar results apply to the D&V section of the wall as well. For some reason, the VB section of the wall did not cool down as much as the other sections and there was a smaller moisture content increase in the packer.

The dips in moisture content level correspond to the times of minimum temperature and are likely to be an artefact of using the moisture content/resistance relationship beyond its calibrated range. The salient point is that the moisture content of the packer significantly increased due to the application of the dry ice. The timber began to dry out immediately, with the timber measured by sensor 4 returning to pre-dry ice levels after two weeks. This drying time was similar irrespective of the type of capping at the top of the wall.

4. Analysis and discussion of wall data from dosing phase

The key questions regarding the likelihood of condensation accumulation at the head of the parapet wall were: how much moisture was in the cavity air?; how much of this moisture was deposited at the packer?; and for how long did this moisture remain?

The first question can be answered relatively easily for the experimental wall since humidity sensors and thermocouples were installed. The saturation water vapour pressure in the cavity (P_{ws}, Pa) was approximated using the following equation (Straube & Burnett, 2005), where temperature T is measured in Kelvin:

$$P_{ws} = 1000 \cdot e^{\left(52.58 - \frac{6790.5}{T} - 5.028 \ln T\right)} \qquad (3)$$

This was then factored using the relative humidity measurement to give the vapour pressure in the water-managed cavity (P_w).

Alternatively the vapour pressure, P_w, can be estimated using the method developed by Davidovic (2005). That study modelled convective drying of wall cavities using the general transport equation. The vapour pressure at the head of the cavity was shown to be:

$$P_w = KP_{ws} + \overline{\Phi}\Delta P \qquad (4)$$

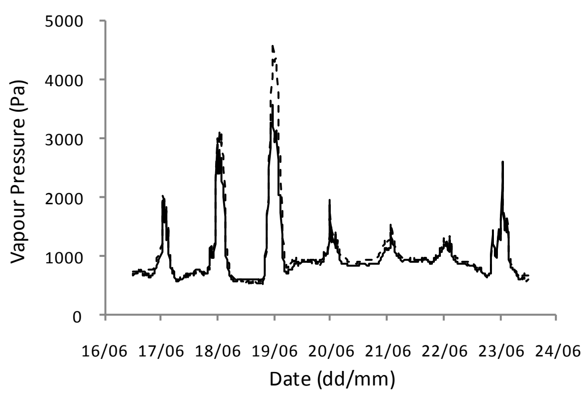

Figure 9: Measured vs calculated vapour pressure (Top of DandV Cavity –Year 2)

Where K is a coefficient that accounts for the wetted area of the wall, $\overline{\Phi}$ is the mean value of a parametric correction function and $\Delta P = P_{w,outdoor} - KP_{ws}$ i.e. the driving water vapour differential. The co-efficient K was chosen to be 0.94 as it led to the best agreement with the experimental data. Note that this was far in excess of the actual dimensions of the real wetted area of the wall, though Davidovic discusses this phenomenen in his paper. One possibility is that moisture is redistributed over the rest of the wall surface due to air movement.

Figure 9 compares the vapour pressure calculated from the humidity probe in the D&V cavity with data generated using the Davidovic equation, and there is excellent agreement. This relationship could be used to approximate the humidity in common wall cavities if the cavity dimensions, cavity temperature and ventilation rate are known or can be calculated, although there is still uncertainty about the nature of the wetted area coefficient.

The second question – i.e. how much of this moisture is deposited at the head of the parapet? – is less straightforward. It is possible to see when there is potential for condensation because the temperature of the air in the vicinity of the head needs to be lower than the dew point of the cavity air. Assuming that condensation occurs by vapour transfer one can use the following approach.

Amount of condensate (c, grams) in a given time period, t,

$$c = Ah \times (P_{cav} - P_{packer,saturation}) \times t \qquad (5)$$

Where the area, A (m^2), over which condensation can occur was taken to be 0.12 m^2 and the surface transfer coefficient, h ($g/s.m^{2}\cdot Pa$), was taken to be taken to be $2x10^{-5}$.

Experimentally, it was found that any condensation that did occur under normal conditions was too little to influence the moisture content of the packer. This strongly argues that air-carried moisture is unlikely to be a concern in parapet walls built in accordance to E2/AS1.

Figure 10 shows the result of using (5) to calculate the amount of condensate deposited and suggests why no moisture was detected at the packer under normal conditions. Condensation was assumed to occur over 20 cm of the perimeter of the packer.

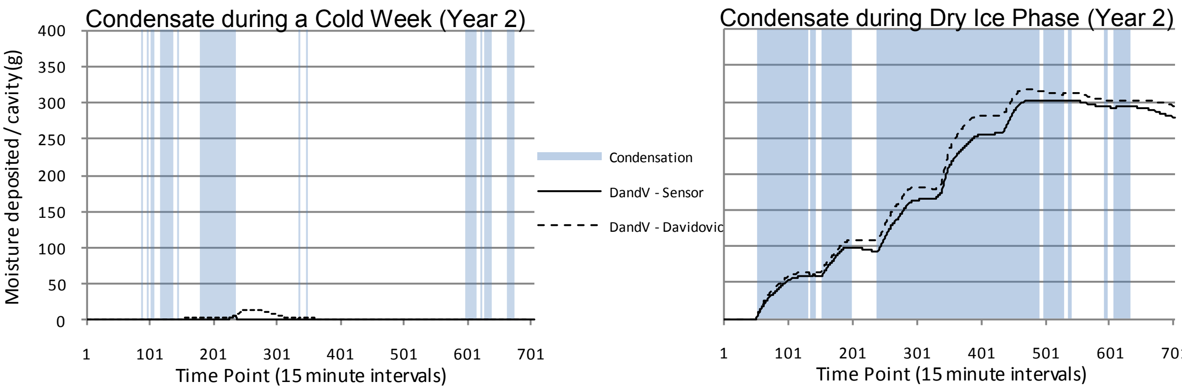

Figure 10: Prediction of condensation and accumulation in the D&V cavity

other cavity types as well). The first graph corresponds to the coldest week in 2009, and the second graph corresponds to later in 2009 when dry ice was applied to the head for five consecutive weekdays – chilling parts of the wall to approximately -20°C. The shaded areas represent the times when the packer temperature was below the dewpoint of the cavity air i.e. condensation was theoretically possible.

In the first case it can be seen that there are times when condensation was feasible, but the equation predicted no significant accumulation of moisture. In general this was because the difference between the moisture level in the cavity and the saturation level near the packer was relatively small. This was in agreement with the timber moisture pins which observed no elevated readings.

When the parapet was artificially cooled with dry ice it is clear that there was a larger proportion of time when condensation was possible. Also, by the end of the week approximately 300 ml of a litre of condensate is predicted. The extremely cold temperatures at the head lead to a much larger difference between the moisture level in the cavity and the capacity of the air near the packer. This was in rough agreement with the timber moisture content pins which observed elevated moisture readings.

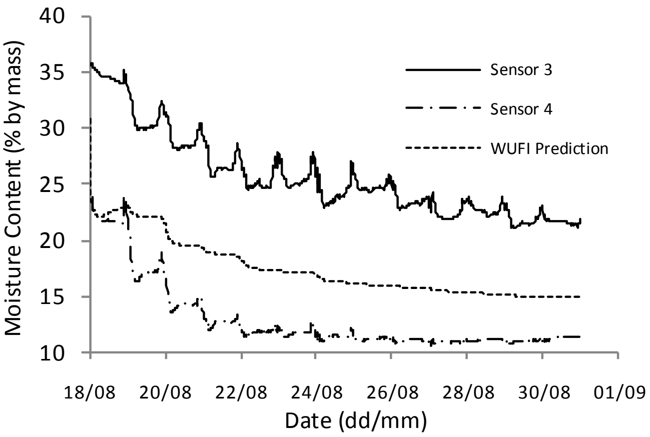

Figure 11: Drying of wall – WUFI vs measured results

The final question – i.e. how long does moisture remain? – was answered in the experimental wall using the timber moisture content pins. However it was desirable to simulate the drying process so that the results could be made applicable to different climates.

WUFI (Wärme und Feuchte Instationär – Transient Heat and Moisture) is a software package developed by the Fraunhofer Institute for Building Physics.[13] It allows the calculation of heat and moisture transport in building components. A slightly customised version of WUFI 2D, with a provision for simple well-mixed ventilation and an ability to split the boundary conditions on one of the faces, was used to investigate the drying of the parapet wall.

To simulate drying of the parapet, the packer was set to be fully saturated in WUFI. Data from the local weatherstation and from sensors on the interior side of the parapet wall were used to define the boundary conditions for the model. Figure 11 shows the comparison for the drying portion of Figure 8. The start point for this analysis was taken to be 12pm on 18/08/09 when the polystyrene trough used to house the dry ice was removed.

It can be seen that the model does not exactly predict the same response as that measured. This is unsurprising, given that the two measured results shown are from nearby sensors on the same piece of timber and give differing results themselves, showing that the moisture content of the packer was far from uniform along its length. There are also differences between the model geometry and the actual wall, and a more advanced (e.g. Computer Fluid Dynamics (CFD)) approach may be necessary to realistically model air-carried moisture within the wall. However, WUFI did predict a similar drying time to what was measured, indicating that the model could be used to generalise the results to other areas. Also of interest is the fact that the drying took place over several weeks (of fairly mild weather). This shows that the parapet framing does have an ability to dry out. If the rate of moisture intrusion was to exceed this drying capacity, there would be scope for continued accumulation of moisture and consequent decay of the parapet head.

5. Conclusions

The study has monitored the moisture content in framing timber within the head of a parapet wall in an experimental building in Wellington. Over two years, the water-managed cavities of this wall were dosed twice a day with 40 ml of water to maintain humid air in the cavities. With two configurations of parapet capping (airtight and loose) the framing and packer timber remained dry through the winter months.

It was only possible to accumulate moisture at the wall by subjecting it to temperatures far lower than seen in New Zealand cities. This accumulated moisture dried out within two weeks of the climate returning to normal.

Ventilation rates in the wall cavities were measured using tracer methods. A multi-zonal model based on air flow resistance data was found to agree well with these tracer measurements. This formed the basis for calculating the moisture transport rates into cooler regions of the wall close to the parapet capping.

A relatively simple mathematical model of the moisture transport was found to concur reasonably well with the experimental observations. WUFI was used to simulate the drying of the parapet from its elevated moisture level and was found to agree reasonably well with the drying times observed experimentally. A CFD type of capability is probably required to simulate the air/moisture movement within the cavity to the head. The combination of the relatively simple mathematical model and WUFI could be used to estimate the rate of moisture accumulation and drying for other climatic conditions and regions.

Prior to this study, it was known that parapet walls represented a high risk of timber decay as evidenced by numerous building failures. As a result of this study, it appears that the E2/AS1 parapet design detail can be specified with confidence. It has been shown to be very tolerant to moisture originating from elsewhere in the cavity and has displayed an ability to recover from a wetting event. The general design requires inherently waterproof cappings which are hoped to encourage run-off. This means that it will be less susceptible to leaks that originate at the head if the integrity of the capping is maintained.

References

Gibson A. (2009). ‘Rotting Homes Bill Tipped to Top $11b’. *NZ Herald,* 19 August 2009.

Groufsky G. (2008). *Build* 103: 47-48. BRANZ Ltd, Judgeford, New Zealand.

Oliver A. (1997). *Dampness in Buildings*. Blackwell Science Ltd.

Department of Building and Housing. (2005). *Approved Document E2/AS1 External Moisture*. DBH, Wellington, New Zealand.

Hazleden DG & Morris PI. (1999). 'Designing for Durable Wood Construction: The 4 Ds'. *8th International Conference on Durability of Building Materials and Components*. Vancouver, Canada.

Bassett MR, McNeil S & Overton G. (2009). 'Ventilation and Evaporation Rates in Wall Cavities in New Zealand". *Proc 12th Canadian Conference on Building Science and Technology*. Montreal, Canada.

Bassett MR & McNeil S. (2006). 'Measured Ventilation Rates in Water Managed Wall Cavities'. *3rd International Building Physics Conference*. Montreal, Canada.

Charlesworth P. (1988). *Air Exchange Rates and Airtightness Measurement Techniques – An Applications Guide*. AIVC, UK.

CONTAM, National Institute of Standards and Technology, USA.

Tokyo Polytechnic University. *Wind Effects on Buildings and Urban Environments: A Wind Pressure Database.* www.wind-arch.t-kougel.ac.jp/eng/w_it.html

Straube J & Burnett E. (2005). *Building Science for Building Enclosures*. Building Science Press Inc.

Davidovic D, Srebric J & Burnett EFP. (2005). 'Modelling Convective Drying of Ventilated Wall Chambers in Building Enclosures'. *International Journal of Thermal Sciences* 45: 180-189.

WUFI 2D, Fraunhofer Institute for Building Physics, Germany.