TIMBER MOISTURE CONTENTS IN 800 NEW ZEALAND HOUSES

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ABSTRACT

Timber moisture contents (MC) have been systematically measured in over 800 houses in New Zealand, and the database of results is reportedly the first and largest of its kind in the world. The wall microclimate is a complex mix of thermodynamic and other interactions, and these influence and control dimensional stability, aspiration, fungal growth, and structural damage. The timber moisture content is the most important factor in any wall system and each wall when ‘dry’ has its own natural equilibrium moisture content. The moisture content of timber is typically highest in the bottom plate, and is prone to fluctuation. The mechanisms that result in the accumulation of water in the bottom plate include gravity, intercellular drainage, condensation, gaseous phase and capillary movement, and thermal gradients. Permanent probes installed in the bottom plates of a timber wall provide the highest certainty method of determining how a wall is relative to its natural state. Permanent probes provide ongoing data that can be used to manage this passive system. The results of over 80,000 timber moisture content measurements, in over 800 houses, found more than 10% were above 25% moisture content and will require remedial work. This highlights the extent to which leaky building issues affect New Zealand housing stock and the need for moisture management.

THE IMPORTANCE OF MOISTURE MANAGEMENT IN BUILDINGS

Moisture management is important in the construction and maintenance of buildings. The avoidance of excessive moisture accumulation and fluctuation is especially important for buildings relying on timber framing for their structural strength – as is the case for the majority of residential buildings in New Zealand.

The Report of the Overview Group on the Weathertightness of Buildings to the Building Industry Authority (Hunn et al, 2002) stated there was clear evidence of a significant and growing leaking home problem, and warned it could lead to a $240 million repair bill. It is now generally accepted the repair cost will be significantly higher. As at the 30th September 2008, a total of 5,810 properties have been registered with the New Zealand Government’s Weathertight Homes Resolution Service (Department of Building and Housing, 2008)

Excess moisture affects both buildings and their occupants. High moisture environments can cause the loss of structural strength due to specific fungi and insects eating the structural components of a building. In NZ, radiata pine is typically used and is highly susceptible to brown rot and borer infestation. Moulds, fungi, bacteria and insects all grow in high moisture environments, and can cause occupant health problems. Moisture lowers the thermal insulation and heat energy retention in materials. Excessive moisture changes in materials results in instability in material dimensions, and causes building faults from fatigue due to expansion and contraction.
MOISTURE BEHAVIOUR INVESTIGATION IN BUILDINGS

An in-depth knowledge of moisture behaviour in buildings is required in order to measure and manage moisture. It is important to know where moisture is likely to accumulate. Significant research was done with computer models by MEWS (Beaulieu et al, 2002), and by BRANZ with prototype buildings (McNeil and Bassett, 2007), but little has been done in systematic analysis of typical residential buildings. This paper focuses on a combination of laboratory experiments, in-situ building microclimate analysis and in-situ timber MC surveys conducted in concert to establish understanding of moisture behaviour in in-situ buildings.

All MC readings were done using Protimeter Surveymasters in ‘direct resistance’ mode. The timber’s electrical conductivity or resistance is measured via two electrical pins inserted along the grain between 8-40mm from each other and translated into a moisture content measurement, correlated to radiata Pine. Values reported are unadjusted for temperature, treatment or sap content.

INTENSIVE SURVEYS OF TIMBER MC DISTRIBUTION IN BUILDINGS

A number of existing and occupied buildings in different conditions and situations were intensively surveyed for timber MC.

‘Christmas Tree’ Effect Leak Pattern Observed

The external face timber MC distribution of a closet in a property that had isolated leak problems is shown in Fig. 1. The leak source had been at the top of the wall, yet the heaviest accumulation of moisture was in the bottom plate and the lower half of the studs. This is called the ‘Christmas tree’ effect of moisture distribution, where moisture moves down and fans out across a building wall. The mechanisms for this are firstly gravity, and secondly capillary intercellular movement inside the straw-like microstructure of timber (see fig 2).

Fig. 1: (Left) MC distribution measurements highlighting the ‘Christmas tree’ effect from a leak at the top. MCs shown by light green (10-14% MC) with 2% MC increments between colours to dark blue (30-39% MC) and purple (40-100% MC).
Drainage of radiata pine via its internal cellular structure was researched by standing a piece of uniformly ‘wetted’ timber on end (Holyoake, 2003). The timber MC distribution after 7 days is plotted in fig 3. On both the surface of the timber (front blue and back yellow columns) and in the centre of the timber (centre red columns), the MC was significantly higher at the bottom compared to the top. Small pools of water formed at the base of the vertical timber confirming that intercellular gravity drainage was happening.

Fig. 2: Cellular structure of radiata pine (Kininmonth & L J Whitehouse, 1991)

Fig. 3: (Right) MC distribution of a uniformly wetted 1m piece of vertical timber after 7 days allowing MC to redistribute and dry (Holyoake, 2003).

Wall Timber MC Survey of House 433
A timber MC survey of a building wall on House 433 (Fig. 4), directly after the cladding was removed, shows that the bottom plate of the particular wall on both levels is consistently showing excessive moisture (orange to blue) when there is excess moisture in that wall system above or beside it.

Fig. 4: Timber MC readings in leaky wall of House 433. Colours indicate different MC levels measured: Red: > 20%, Orange 18-20%, Yellow 15-18%, Green <15%.

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Moisture Profile on Bottom Plate of House 433
A section of bottom plate from the wall in Fig. 4, from the bottom left hand portion under the window, was systematically MC surveyed across its accessible top, exterior and interior faces. Its MC profile (see Fig 5) reveals the internal face was 16% MC while its front bottom face was 40% MC – a 24% MC difference inside the distance of just 100mm. This dry-interior-to-wet-exterior profile pattern was consistent across House 433 and in over 800 other houses surveyed.

Damage Profile on Bottom Plate of House 433
A section of partially decayed bottom plate was removed from the surveyed wall of House 433 close to the piece above in Fig 5. The damage observed was typical of the bottom plate on that wall. The damage was centred on the external bottom corner (facing outside), with the internal and top side largely unaffected. This is representative and consistent of the vast majority of low-level damage observed in over 800 timber-framed buildings – where some parts of the timber survived it was the internal, warmer side.

Moisture Spike Only in Bottom Plate During Controlled Leak Experiments
McNeil and Bassett (2007) conducted controlled leak experiments introducing water into a wall, at a position 800mm above the bottom plate. Five MC sensors close to the wetting area showed insignificant change, whereas only a MC sensor in the bottom plate showed a significant increase (see Fig. 6).

Fig. 5: (Left) Bottom plate from House 433 next to sample in Fig 6 shows large timber MC profile present across the cross-section.
Fig. 6: (Right) Bottom plate from House 433 from wall shown in Fig. 4 shows timber deteriorated from outer bottom edge first (red area), where it is lowest and coldest.

Fig. 6: (Left) Timber MC in wall with controlled leak. (McNeil & Bassett, 2007)
LABORATORY AND IN-SITU MICROCLIMATE ANALYSIS

Experimental set-ups were created, typically mimicking previous set-ups from MEWS research (Beaulieu et al, 2002), but with alterations made to suit equipment available, cost, local construction techniques and experimental design. Drying research, with 2 mock walls, concluded a wet bottom plate in a wall system could dry out in 30 days (Austin et al 2003). Laboratory microclimate investigations, replicating the drying process in a wall, showed there were many complex interactions occurring during the drying process (Holyoake, 2003) including intercellular drainage and capillary movement, condensation, natural and forced convection. Studies conducted (Beezley, 2004) showed temperature and humidity profiles across a wall fluctuated daily under normal operation exposed to the sun, whereas the timber MC stayed relatively constant. Under dry and wet conditions in normal operation, different wall set-ups produced different temperature, relative humidity and moisture profile results.

In-situ building wall microclimate investigations (Holyoake and Holyoake, 2004) complimented these laboratory results by microclimate measurements in 4 different existing walls in occupied buildings under normal operation. In comparison with Beezley (2004), the patterns of microclimate observed under each wall set up were similar for upper walls. The Beezley experiments did not take into account ground temperature effects, as they were set on top of an 8-storey building.

OBSERVATIONS FROM SURVEYS, LABORATORY, IN-SITU ANALYSIS

A number of consistent patterns were observed:
(1) MC distribution in timber framing is not constant, nor homogenous, and MC readings often change depending on where and when they are measured.
(2) The wall microclimate is a complex mix of thermodynamics and other interactions.
(3) Timber is the most important single indicating factor in a building wall when estimating a wall’s overall moisture loading and microclimate. The timber internal MC consistently gives the accumulated sum of the past atmospheric and leak conditions due to its comparatively gradual response to atmospheric conditions.
(4) When excess moisture is in a building wall, this moisture will tend to accumulate on the bottom plate on the exterior face directly below or beside the entry point.

Thermal gradients and condensation were observed in a test rig (Holyoake, 2003). The thermal gradient in a typical residential room was measured at between 2°C and 4°C over a 24-hour period. Houses are typically constructed with a concrete slab on which the bottom plate is directly fixed, and this concrete slab is colder than the wall. These vertical temperature gradients provide a mechanism for downward movement of water. Moisture evaporates from higher warmer locations during the day, and then condenses at night at the coldest locations – often at the bottom and external face of the wall.

Four characteristics of the bottom plate that encourage the accumulation of moisture on its outer face are:
(1) Acts as a moisture barrier that impedes moisture flow from the studs above.
(2) External timber face has a lower temperature relative to the interior face.
(3) Location is underneath or close beside a leak entry point.
(4) Outside face is typically the first face to get wet from an external leak.
SYSTEMATIC MOISTURE SURVEY OF 800 HOUSES

Over 800 houses were systematically surveyed for timber MC. The MC readings were taken by drilling a small hole through the skirting, taking the inner MC reading, then drilling through the bottom plate until there was approximately 10-15mm left, and then a patented permanent moisture probe (see Fig. 8) was installed into the hole. Two stainless steel wires were embedded into the bottom plate timber near the exterior face (Fig. 9). The MC readings were taken with a Protimeter Surveymaster in ‘direct resistance’ mode (Fig. 10). During this process timber samples were collected and analysed and timber strength readings taken, but this is outside the scope of this publication, and will be included in future work. Probes were installed in the bottom plate in on average 50-70 locations around the perimeters of the houses in the identified risk points – nominally under or beside known historical leak points identified by building surveyors. Two MC measurements were taken across the profile of the bottom plate: ‘outer MC’ and ‘inner MC’ as shown in Fig. 8. Scan readings were also taken, by Protimeter Surveymasters in ‘scan’ mode at the location indicated. In over 300 houses, all three inner MC, outer MC and scan readings were taken. To the authors’ knowledge no other survey of this kind has been conducted worldwide.

RESULTS AND DISCUSSION

The results of moisture surveys of over 800 houses, taking over 80 000 MC outer MC readings, when plotted (Fig. 11), reveal a bell-shaped distribution centred on ideal equilibrium conditions around 13% MC but with a long, wet tail out to 100% MC. Houses involved in the survey were a combination of houses that were either known to
have leak problems, or believed to have no leak problems. In the wet tail (Fig. 12), 29% of results are higher than ideal conditions (18-100% MC) and 10% are much higher than ideal conditions (25-100% MC). These results show an average 71% of areas in buildings with acceptable moisture levels, 19% with low-level excess moisture and 10% with severe excess moisture that needs to be rectified. In order to assist interpretation of results, MC readings are colour coded depending on their result based on ideal equilibrium conditions.

Fig. 11: Distribution from Outer MC readings.

Each house has about 50 to 70 probes, and on average each probe was measured approximately twice. Based on Fig. 11, 10.4% of results are above 25% MC, suggesting that there were 3-4 locations of leaks in the ‘average house’ surveyed, and this pattern of ‘isolated moisture problems’ was generally found in the field. With over 70% of areas in an ‘average house’ in an acceptable moisture range, the results suggest that localised repairs are the most appropriate form of remediation, and the total reclad of buildings in many cases is not justified.

Fig. 12 to Fig. 14 shows data from 19310 assessment locations taken at the same time. Comparisons show that moisture accumulation above 18% is significantly higher on the outer face of the bottom plate (37.4% - outer MC) compared to the inner face (19.6% - inner MC). Scan readings at the same locations were even lower (10.1%). This confirms that the outer face is the best position to measure the highest moisture content on the bottom plate.

Each point on Fig. 15 represents an assessment point, and its location on the graph represents its scan reading and corresponding outer MC reading. The results show a significant amount of scatter with no apparent correlation. Fig. 16 indicates that in comparison there is a slightly stronger correlation between inner MC and outer MC readings. Further analysis suggest that in using scan results to predict outer MC results, 43% of the time the outer MC will be underestimated, and 17% of the time it will be overestimated. In using inner MC results to predict outer MC results, 32% of the time the MC outer will be underestimated, and 8% of the time it will be overestimated. Therefore, if inner MC or scan results are relied upon to assess a building’s excess moisture, there will be a significant probability of a misdiagnosis.
Fig. 12: Distribution from Outer MC readings

Fig. 13: Distribution from Inner MC readings

Fig. 14: Distribution from scanning readings
Moisture management and the avoidance of excess moisture accumulation and fluctuation is important in the construction and maintenance of buildings, to prevent unwanted consequences such as materials degradation and health effects. From this research, including systematic timber MC surveys of over 800 houses, it is concluded:

1. Excess moisture in a building wall accumulates in the bottom plate directly below or beside the entry point.
2. Gravity drainage and capillary intercellular movement through the straw-like microstructure of timber are significant mechanisms for moisture movement.
3. 71% of positions surveyed had acceptable moisture levels below 18% MC.
4. 10% of positions surveyed had excess moisture levels above 25% MC, and remedial work is required.
5. The best position to systematically monitor for excess moisture in a timber wall is in the outer face of the bottom plate.
6. Permanent probes in the bottom plate are the best way of obtaining ongoing data for managing moisture in buildings.
7. There is a significant probability of misdiagnosis when using inner MC and scan readings to assess if there is excess moisture in a wall.
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FUTURE WORK

Due to restraints in this publication, more comprehensive analysis of existing database results could not be shown. It was chosen to exclude timber condition from results, discussion and analysis and this will be included in future publications. More data and further product, material, design, time, event and location-based analysis are needed to gain deeper knowledge of the reasons behind the patterns published in this paper.

REFERENCES


Weathertight Homes Resolution Service. www.dbh.govt.nz/whrs-claims


