MOISTURE RECOVERY RATES FOR WALLS IN TEMPERATE CLIMATES

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ABSTRACT

Moisture recovery rates have been measured in 24 specimen walls fixed to an experimental building in New Zealand. All of the walls were timber framed and most included a water management system between the building wrap and the cladding of one of the following types, drained and ventilated, open rainscreen or drainage plane. The remaining walls were direct-fixed systems. Controlled introduction of water into the insulated spaces of each wall was undertaken eight times over one year and cavity humidity records used to plot drying times as a function of climate and the physical properties of the walls. The strongest factor in drying time was the sophistication of the water management system, followed by climate differences due to the season and wall orientation. This is not surprising in walls built for temperate New Zealand without vapour barriers, air barriers and sheathing. WUFI2D simulations of the drying process also illustrated the importance of ventilation processes in removing moisture from insulated spaces in the wall. A similar series of moisture recovery measurements was completed following the introduction of water into the water managed cavities of 22 of the 24 walls. In this case, drying times were deduced from timber surface moisture content measurements. These results underline the importance of non-absorbent drainage paths on the backs of claddings and give useful hygrothermal responses to water trapped in the water managed parts of walls. One interesting outcome of these measurements is an explanation for the successful moisture management record of weatherboard claddings on New Zealand houses.

INTRODUCTION

Three steps were taken in New Zealand to improve the weathertight performance of walls following a leaking building problem in the 1990s: the introduction of more effective flashings around junctions in the approved document “E2/AS1 External Moisture” of the New Zealand Building Code; more demanding framing timber treatment requirements (NZS 4303); and a wider application of water managed cavity designs. Most of the new designs being built are open rainscreens with a 20 mm deep battened cavity vented at the base of the wall. Drained and ventilated walls are still popular in brick veneer walls with open perpend vents at the top and base of the wall. Drainage plane solutions using mesh or dimpled drainage mats attract considerable interest but are not accepted in regulations. Direct-fixed claddings are still common on low rise buildings with eaves and few of the high risk water entry points associated with leaking buildings.

The design of water managed cavities will eventually be supported by a complete model of all the heat, airflow and moisture diffusion processes available to transport water around in walls, but until this is possible, researchers have been measuring drying rates in climate chambers and in experimental buildings to understand the processes involved. Two drying rate studies by Lawton et al (2001) and Hazleden and Morris (2001) are examples of measurements carried out in climate chambers. The first of these measured drying rates from wet framing in stucco walls and concluded the rate of moisture loss was too slow to avoid timber decay following a major water leak. The second group also reported slow drying rates in 12 sample walls with mixed claddings and found that framing moisture dried faster in walls with wide cavities than where the cavities were smaller, or significantly slower in direct-fixed walls. It is difficult to more closely compare the two sets of results because they were measured in climate chambers simulating some, but not all, of the driving forces of moisture movement. Later drying rate measurements have been measured in test buildings to make sure that all of the solar, wind, ambient temperature and humidity drivers that apply in buildings are present in the experiment.

An ASHRAE-sponsored project (ASHRAE 1091) developing the physics of heat, moisture and air transport in walls has provided theoretical support for ventilation assisted drying (Burnett and Straube 1995) and field drying rate measurements (Straube et al 2004) for a range of wall cladding types and cavity dimensions. Drying rates were measured in an experimental building exposing 1.2 m wide by 2.4 m high walls to the weather and to typical indoor temperatures and relative humidity. Water was introduced in a reproducible way through dosing tubes to an absorbent material fixed to the insulated cavity side of the sheathing. This in turn soaked the sheathing, and readings of the sheathing moisture content were used to track the drying process. Although the drying rates reported reflect North American climate and building styles, they arrive at the following helpful conclusions:

- Useful outward drying through the sheathing takes place and the presence of a water managed cavity assists with the drying process.
- Ventilated wall cavity designs with large vent openings top and bottom dried faster than bottom vented designs. These faster drying designs coped with repeated wetting over several years and remained in perfect condition.

Quite different drying rates are expected in New Zealand walls with different construction (an absence of solid sheathing, vapour barriers and special detailing to improve the airtightness of walls) and significant climate differences.

DRYING FROM INSULATED CAVITIES

A series of New Zealand-based drying rate measurements have been completed in specimen walls mounted in the test building shown in Figure 1. The north and south facing long walls each contain 10 wall panels 1.2 m wide by 2.4 m high, and there are two panels on the east and west sides. The internal frame in each wall creates an 800 mm by 600 mm central measurement zone surrounded on four sides by a guard area. All of the walls have the same building wrap (spun bonded polyolefin), insulation (R 2.2 fibreglass) and internal lining (painted paper-faced gypsum board), but have different claddings and water management details as outlined in Table 1. Some of the fibre-cement walls were painted on their inwards facing surface to factor in cladding absorbency as a system variable. All of the walls follow New Zealand building practice in omitting vapour barriers, sheathing and air tightening of the wall wrap at joints.

Water was introduced into an absorbent pad attached to the back of the wall wrap inside the insulated cavity. This reproducibly placed water in the insulated cavity without directly wetting the timber, simulating a water leak through the wall wrap into the insulation. Each drying sequence began with the introduction of 30 cc of water down a dosing tube to the absorbent pad occupying most of the central cavity. Timber moisture contents were measured on the surface of framing timber surrounding the cavity with pin resistance probes and logged every 15 minutes together with the temperature and RH in the cavities. The time between the initial sharp rise in cavity RH and its eventual return to the long-term daily cyclic pattern was recorded as the drying time. Additional drying rates were measured for comparison with WUFI2D estimates of humidity and framing moisture contents. In these measurements, 2D symmetry was preserved as much as possible by dosing absorbent pads in the guard areas at the same area weighted rate as applied to the central measurement area.

Figure 1. Test building at BRANZ Ltd used to measure wall drying rates.

Table 1. Cladding and water management descriptions for 24 wall panels.

Wall	Cladding	Water management	Wall	Cladding	Water management
1	Fibre-cement	Open rainscreen	13	Fibre-cement	Direct-fixed
2	Fibre-cement	Open rainscreen	14	Fibre-cement	Direct-fixed
3	Fibre-cement	Open rainscreen	15	Brick veneer	Drained & ventilated
4	Fibre-cement	Drainage plane	16	Fibre-cement	Drained & ventilated
5	Stucco	Direct-fixed	17	Fibre-cement	Drained & ventilated
6	EIFS	Drainage plane	18	Weatherboard	Direct-fixed
7	Fibre-cement	Direct-fixed	19	Fibre-cement	Open rainscreen
8	Fibre-cement	Open rainscreen	20	Fibre-cement	Direct-fixed
9	Weatherboard	Direct-fixed	21	EIFS	Drainage plane
10	Fibre-cement	Drained & ventilated	22	Stucco	Direct-fixed
11	Fibre-cement	Drained & ventilated	23	Fibre-cement	Drainage plane
12	Brick veneer	Drained & ventilated	24	Fibre-cement	Drainage plane

The temperature and humidity were maintained in the experimental building with intermittent heating to 20°C morning and evening and 3litres/day of humidification to simulate occupancy. Quarter hourly records of indoor and outdoor temperature, wall surface temperatures, humidity and climatic variables: wind speed, direction and solar radiation (global and diffuse) were collected during the drying periods.

Average monthly temperature and RH values inside and outside the experimental building are given in Figure 2 to illustrate the temperate maritime climate that is typical of the more densely occupied coastal cities in New Zealand. The difference between indoor and outdoor conditions is shown shaded and the year averages were: outdoor temperature 13°C, outdoor RH 85%, indoor temperature 18°C and indoor RH 60%. Surface temperatures were measured on the textured coated faces of fibre-cement clad open rainscreen walls on each side of the building. North surface temperatures were 3°C higher than ambient on average while those on the south were only 0.2°C above ambient. The building site is in a rural area reasonably sheltered from wind by terrain and trees. Wind speed and direction were measured 10 m above ground on the building site and the average of 2.5 m/s is lower than is normal for coastal sites around Wellington. Annual rainfall measured on site during 2005 was 860 mm. Overall, the climate for the drying measurements reported here is humid, temperate, windy and wet with relatively minor seasonal fluctuations.

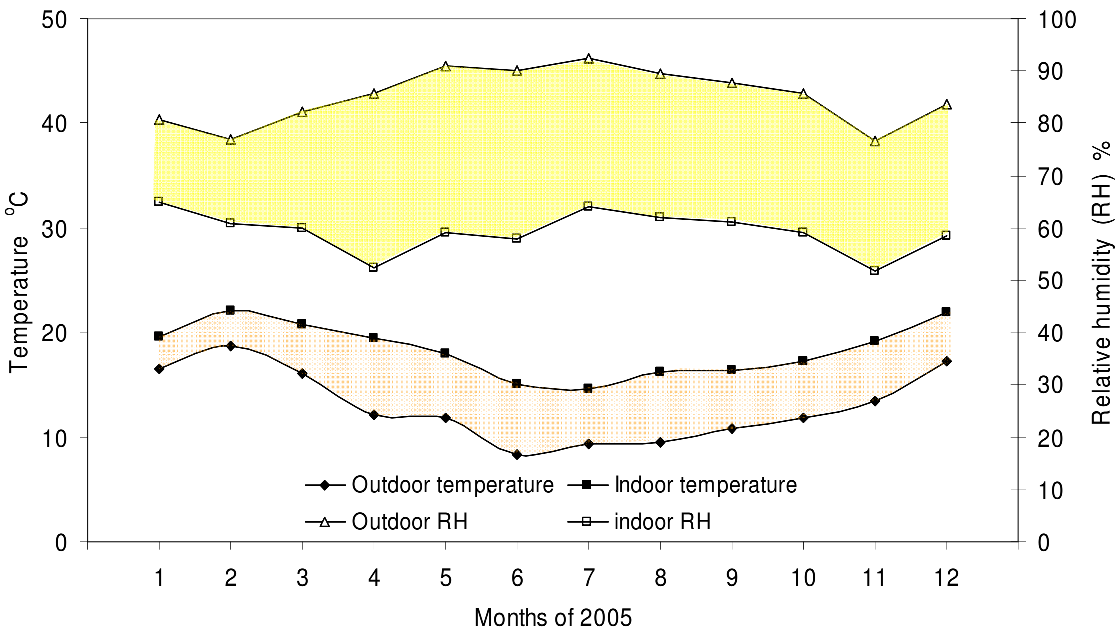

Figure 2. Average temperatures and RH inside and outside the experimental building.

Drying times were measured eight times during a full year and data for the 20 walls facing north and south plotted in Figure 3 against category "water management system". The drying times in Figure 3 clearly increase in the direction of "drained and ventilated" to "open rainscreen" to "drainage plane" to "direct-fixed", although it might be argued that the most significant difference is between the water managed walls and the direct-fixed examples. The range of drying times (indicated separately as a shaded envelope for north and south) is particularly wide for direct-fixed walls for which stucco had the slowest and weatherboard the fastest drying time (averaged over north and south orientations 460 and 300 hours respectively). This is not unexpected, since weatherboard claddings are known to have drainage and ventilation paths and behave more like one of the cavity designs.

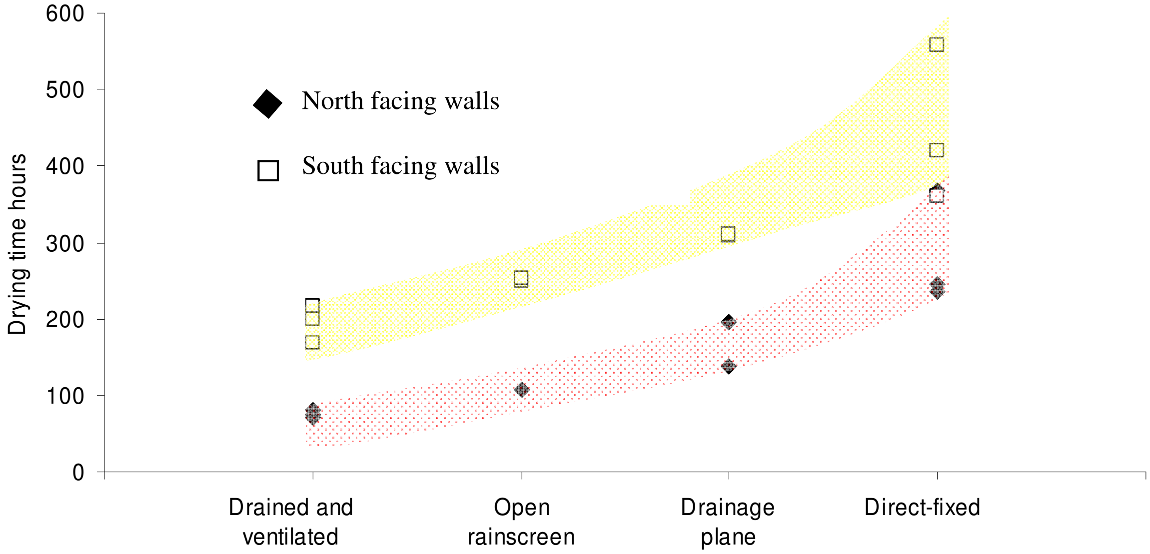

Figure 3. Year average drying times from the insulated spaces of walls facing north and south.

Drying times averaged for a full year, summer and winter, are provided in Table 2 for comparison with drying times from water managed spaces reported later in the paper. These are expressed in drying times per gram of water (h/g). These drying times are not a fundamental time constant of the drying process because they will reflect the experimental arrangement and the quantity of water added, but the relativity between the results will however reflect differences in the water management detailing in the walls. The dominant factor in drying times was the water management system (2.5:1 effect) followed by the season (2.2:1 effect), wall orientation (1.9:1 effect) and cladding differences in the direct-fixed walls (1.5:1 effect).

Table 2. Drying times from insulated spaces averaged over orientation and season.

Wall type	Year and orientation averaged (h/g)	Summer and orientation averaged (h/g)	Winter and orientation averaged (h/g)
Drained and ventilated	4.5	3.0	7.3
Open rainscreen	6.6	4.2	11.5
Drainage plane	7.7	5.9	10.7
Direct-fixed	11.1	8.0	16.8
Average – all wall types	7.5	5.3	11.6

A strong seasonal pattern in drying times can be seen in Figure 4. Here the average drying times for all walls in the experimental building are plotted for each of the eight drying runs. All walls dried slower in winter than summer. One factor in this will be higher summer stack-driven ventilation rates in north facing walls, and another will be higher temperature and vapour pressure gradients in warmer walls.

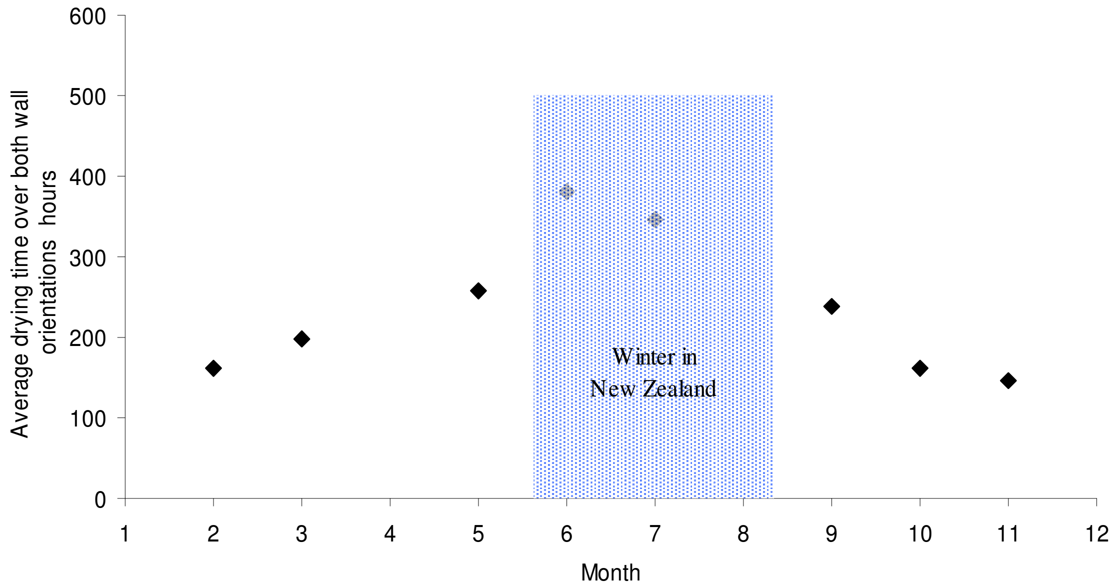

Figure 4. Seasonal changes in average drying times from insulated cavities in experimental walls.

Figure 5 shows shortening drying times for drained and ventilated and direct-fixed walls with increasing surface temperatures, but it is clear that other factors are also involved. It remains for more comprehensive modeling to explain the drying processes in detail.

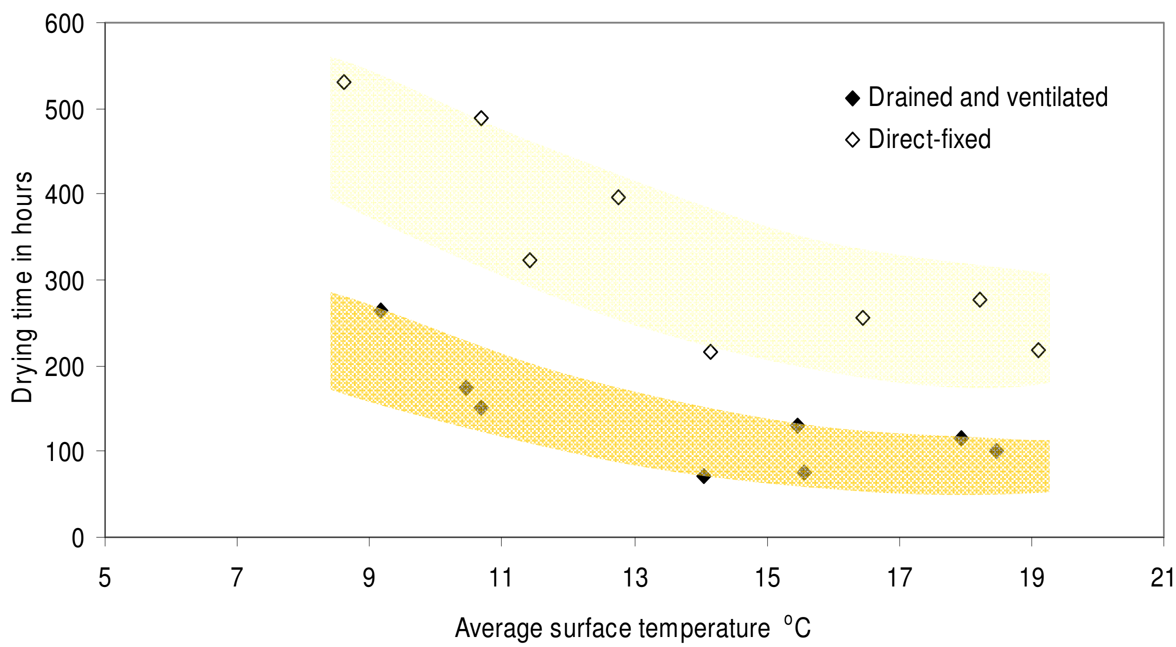

Figure 5. Drying times from insulated cavities for direct-fixed and drained and ventilated walls as a function of average cladding surface temperature.

Finally, it must be remembered that the drying rates reported here are indicative of water drying from insulation materials rather than from framing timber. A further phase of the experimental work is measuring drying from framing.

MODELED DRYING RATES FROM INSULATED CAVITIES

WUFI2D, developed at the Fraunhofer Institute for Building Physics, and based on Künzel (1995) has been used for a series of simulations of drying from the insulated space that can be compared with measured drying rates described earlier. These simulations used climate and temperature data collected from the building's instrumentation system, material properties taken from the WUFI2D database, and ASHRAE 1018 RP (2002), supplemented with material properties measured in our laboratory. Simulations were limited to three walls representing three particular experimental walls: a drained and ventilated cavity fibre-cement clad system representing wall 17; a direct-fixed fibre-cement clad system representing wall 20; and a direct-fixed rigid backed stucco system representing wall 22. The WUFI2D simulations have modeled processes that move moisture around except for ventilation, so some departure from the measured moisture history is expected in wall 17. All three wall specimens were located on the north face of the test building.

All of the experimental walls were preconditioned in-situ over four months before drying time measurements began, and the same period was simulated in walls 17, 20 and 22 to establish initial RH and T fields in the air cavities and timber framing. From this point, a full year of moisture and temperature conditions was modeled covering eight water dosing events. Figure 6 summarises the drying responses of the three walls expressed as the ratio of the drying time calculated by WUFI2D and the measured drying time.

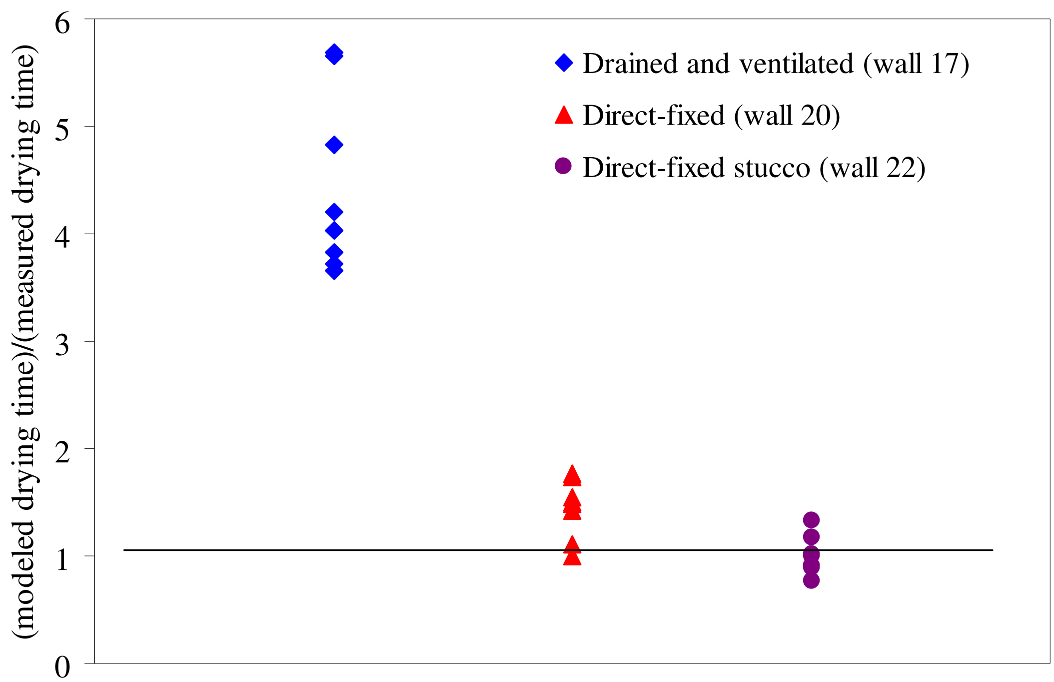

Figure 6. Ratio of modeled drying time to measured drying time for three walls.

Figure 6 shows the WUFI2D drying time of the drained and ventilated system to be over-estimated 3–6 times, illustrating the significance of ventilation in the drained and ventilated wall design. In contrast, the drying times for the two direct-fixed walls are similar to those measured experimentally. The closeness of the stucco results to those measured can probably be attributed to the very low natural ventilation rate in this wall. Examples of measured and calculated humidity in the insulated space of walls 17 and 22 are shown below in Figures 7 and 8.

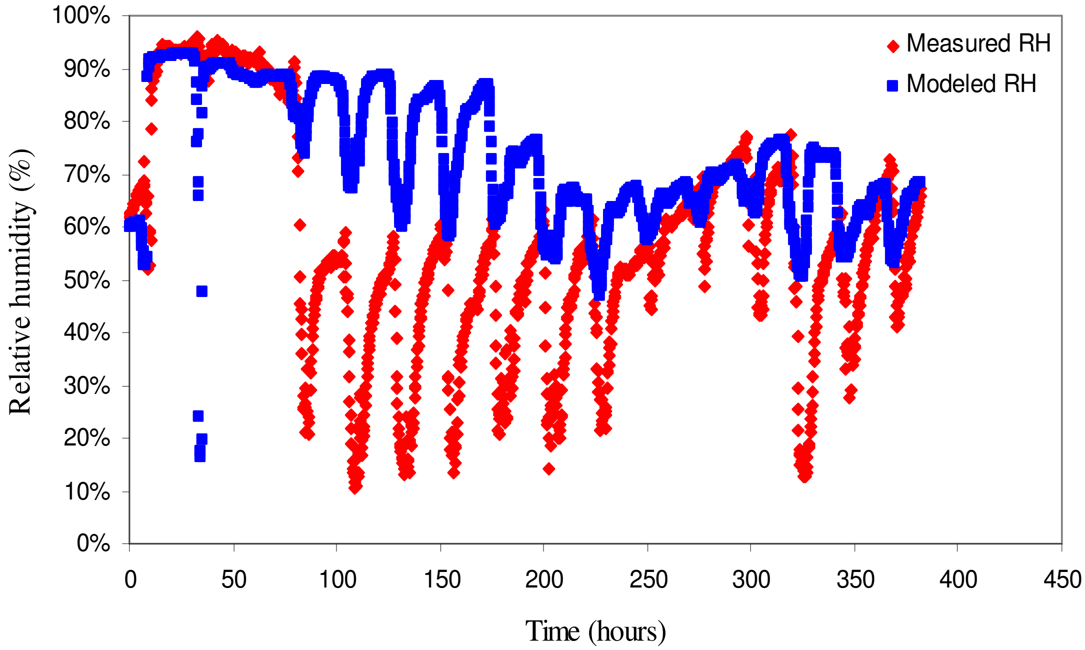

Figure 7. Measured and modeled RH data for the drained and ventilated wall 17.

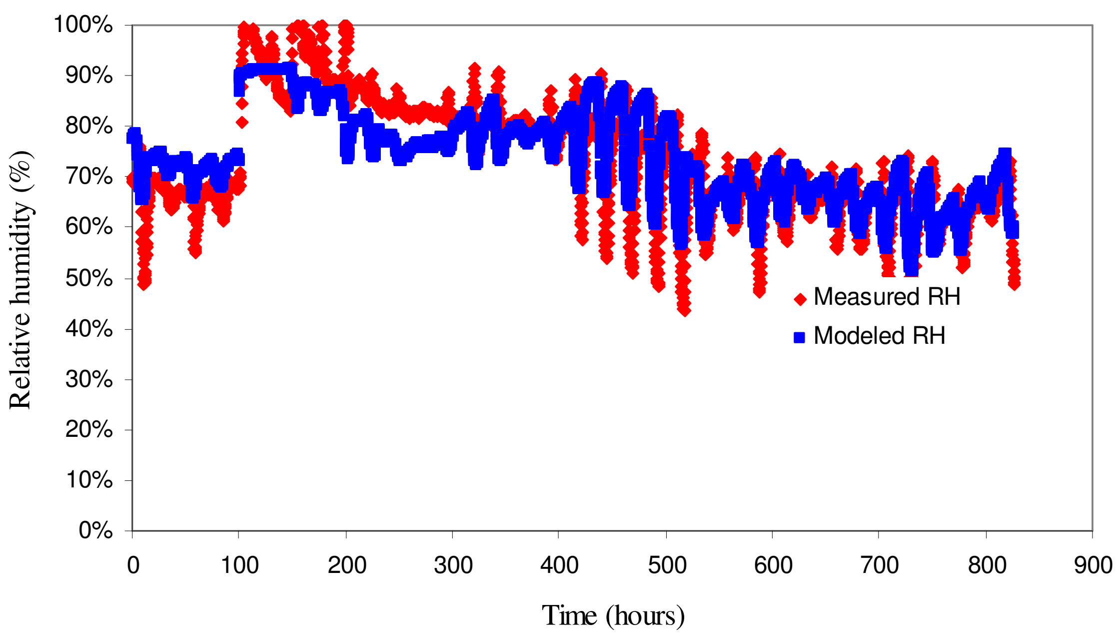

Figure 8. Measured and modeled RH data for the stucco clad wall 22.

Figure 7 shows that the large RH swings measured in the drained and ventilated wall have not been reproduced by WUFI2D. Once again, this is thought to reflect ventilation effects in the drained and ventilated wall. The extended drying time predicted by WUFI2D is also quite evident in Figure 7. The measured and modeled humidity in the insulated space of wall 22 in Figure 8 is predicted much more accurately by WUFI2D, a good indication of the reduced role of ventilation in this direct-fixed stucco wall. More satisfactory agreement between WUFI2D simulations and experimental data is expected when the simulation includes ventilation.

DRYING FROM WATER MANAGED CAVITIES

The role of water managed cavities and drainage planes in removing water from the wall structure is well enough understood in qualitative terms, but a series of drying rate measurements has been undertaken here to find out more about the consequences of water trapped on the backs of absorbent claddings. Two drying rate trials were conducted in 22 of the 24 experimental walls during the summer months of 2005/6. The two stucco walls had to be excluded from these measurements because they do not have a drainage path outside the insulated cavity. A controlled leak through the cladding of each wall onto the back of the cladding was maintained for seven hours with a peristaltic pump delivering water at 100 g/hour through a port high on the wall and slightly off-centre to avoid wetting humidity sensors in the cavity. A drainage tray was positioned to catch water draining from the samples so this could be weighed to determine the mass of water retained within the wall.

Most of the water introduced into walls with non-absorbent claddings drained out at the base of the wall leaving at most 10% of the applied dose unaccounted. The only exceptions to this were the two direct-fixed bevel-backed weatherboard walls which effectively drained out at lap joints just below the water entry point, where the water was quickly lost by evaporation. In contrast, the walls with absorbent fibre-cement or brick claddings retained most (at least 70%) of the applied dose.

The hygrothermal response of the walls was followed over the two months after dosage and a drying time estimated from records of framing timber moisture contents and the relative humidity in the cavities. As with the hygrothermal response to water leaks in the insulated cavities, the drying times in the water managed cavities were well defined when the wall recovered in a few days and less distinct when the process of recovery took several weeks. Figure 9 gives the drying times for absorbent walls expressed in hours per gram of retained water.

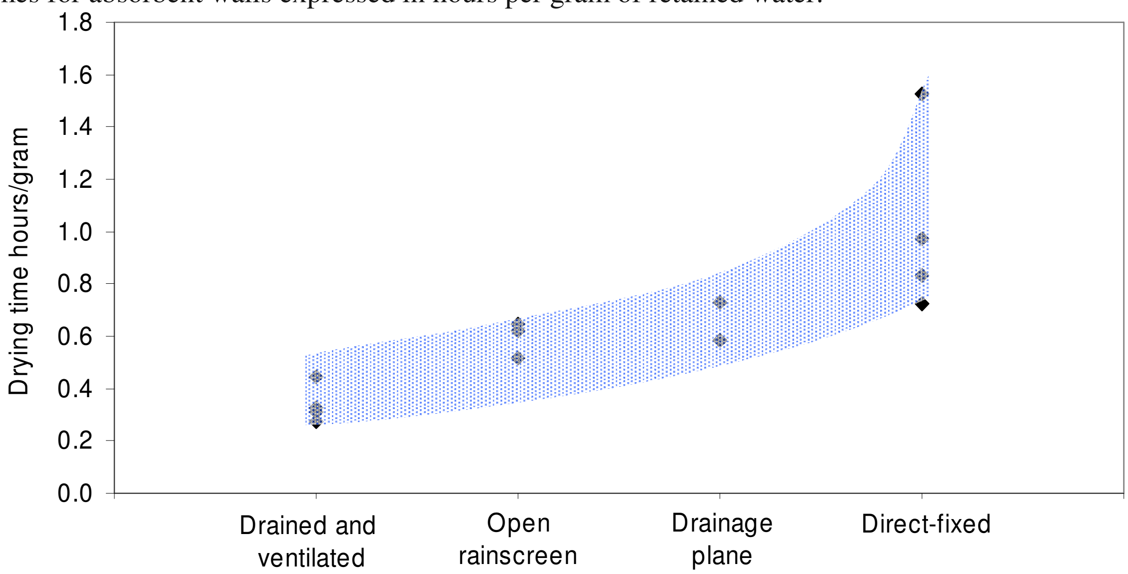

Figure 9. Summer drying rates from the water managed cavities in 22 experimental walls with absorbent wall claddings.

The shape of the shaded envelope is reminiscent of Figure 3, but the drying times in h/g from the water managed space (given in Table 3) are about one tenth of the summer drying rates from the insulated spaces. Apart from this, the same trend of increasing drying times from drained and ventilated, to open rainscreen, to drainage plane and direct-fixed wall type is the same as is the overall range in drying time. Another common feature with insulated space drying rate data is the wide spread in the data for direct-fixed walls. As before, this is a consequence of different claddings and wall orientation.

Average summer drying times in h/g are given in Table 3 for the different wall types on the north and south side of the building. While there is no winter data for comparison, the summer drying times for the water managed walls fall within a tight range (0.3 to 0.7 h/g for both north and south walls), indicating that moisture on the back of a cladding is more effectively removed by ventilation than moisture in the insulated space.

Table 3. Average drying times for the water managed cavities of walls with absorbent claddings.

Wall type	Orientation averaged (h/g)	North averaged (h/g)	South averaged (h/g)
Drained and ventilated	0.37	0.30	0.44
Open rainscreen	0.64	0.62	0.65
Drainage plane	0.66	0.73	0.58
Direct-fixed	1.19	0.84	1.53
Average – all wall types	0.71	0.63	0.80

Another observation in direct-fixed walls is the unpredictability of the drainage path. In some cases water held between the cladding and the wall wrap has passed through to the framing and raised surface moisture content above fibre-saturation. Figure 10 illustrates this effect in wall 7.

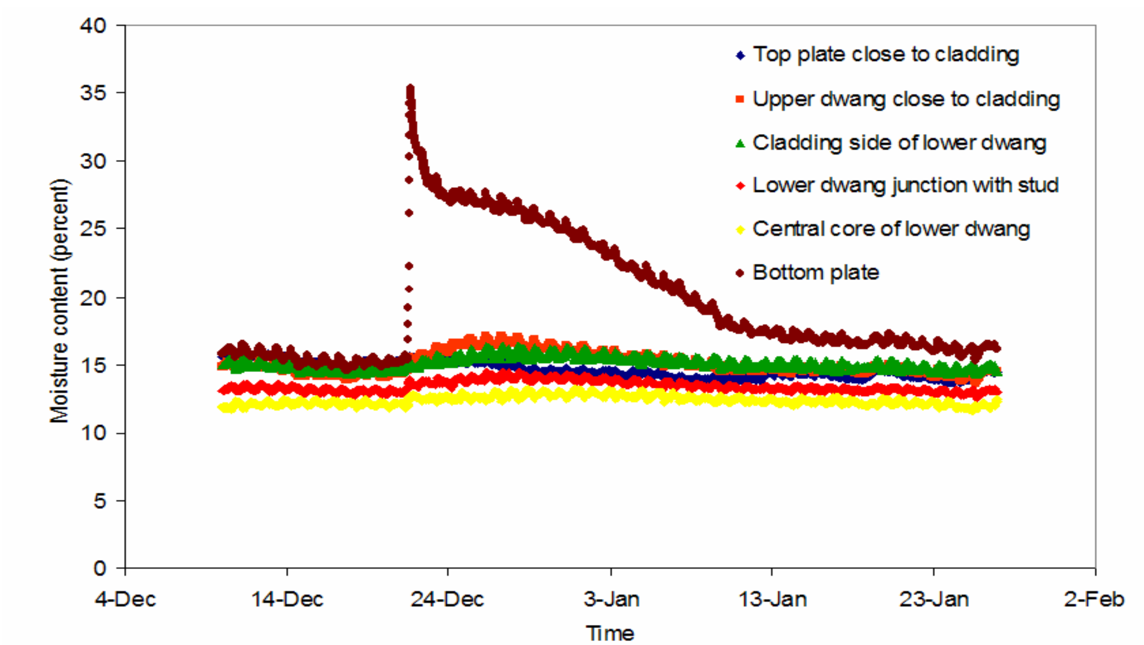

Figure 10. Timber moisture contents in wall 7, evidence of water tracking through the wall wrap in a direct-fixed wall.

The hygrothermal response of the non-absorbent cladding walls (including bevel-backed weatherboards) was spectacularly different to the data for absorbent systems shown in Figure 9. In fact we were unable to see any change in relative humidities or framing timber moisture contents that lasted longer than the dosing period, because most of the water leaked away. We think this illustrates one of the advantages of a non-absorbent drainage path in managing water leaks through claddings or flashings.

CONCLUSIONS

Drying rates have been measured in 22 specimen walls on an experimental building following the controlled introduction of water into the insulated spaces and the water managed cavities. Although these simulate only two of an infinite number of moisture failures in walls, the results offer useful insight into how the hygrothermal response of walls depends on the approach to water management. In these relatively simple New Zealand walls (omitting vapour barriers, sheathing and detailing for airtightness) and in a temperate climate, drying rates from both spaces generally improved from direct-fixed to drainage plane to open rainscreen to drained and ventilated wall types. However, other factors were found to be important as outlined in these conclusions:

Drying from insulated spaces –

- The year and orientation averaged drying rates show the water managed walls dealing with moisture trapped in the insulated areas more effectively than the non-water managed direct-fixed designs.
- Warmer summer conditions and north orientations (where higher surface temperatures were recorded) approximately halved the drying times in all wall types.
- Modeled drying times for direct-fixed monolithic walls were similar to those measured experimentally. For a drained and ventilated wall, excessively long predicted drying times were attributed to ventilation effects not yet modeled.
- Cladding types were found to influence drying rates in the insulated cavities of direct-fixed walls. Here the drying times were higher (by a factor or 1.5) in walls with stucco and other monolithic claddings than weatherboard claddings (which are naturally ventilated).

Drying from water managed cavities –

- Summer and orientation averaged drying rates for walls with absorbent claddings progressively increased from drained and ventilated to open rainscreen to drainage plane to direct-fixed wall types.
- The hygrothermal response of walls with non-absorbent water managed cavities was minimal beyond the wetting period.
- Bevel-backed weatherboard successfully drained out any introduced water within two or three laps below the water leak.

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