Stucco-Clad Wall Drying Experiment

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ABSTRACT

Effective rainwater management depends on a combination of limiting the wetting of components that are susceptible to deterioration and enhancing the drying of components that become wet. The rainscreen principle is a design approach that achieves the first half of the combination by limiting the wetting of wall components. However, an unresolved issue is whether it will enhance the drying of these components, i.e., achieve the second half of the combination.

An experiment was conducted to measure the effect of drainage cavity design on the drying of water from the insulated stud cavities of wood-framed, plywood-sheathed walls. Five test specimens, all finished with stucco cladding, were included in the experiment. At the start of the experiment, a measured quantity of water was injected into the stud cavities. During the experiment, temperature and vapor pressure differences were controlled across the specimens, and the drying of the specimens was monitored. After 5 1/2 months the specimens were examined for evidence of moisture absorption and decay.

The following conclusions were drawn from the experiment:

- *The drying process for all specimens was very slow and took months to achieve any significant effect.*
- *The rainscreen design does not enhance drying of water that penetrates into the stud cavity, nor is the drying rate affected by cladding design or by drainage cavity design.*
- *Moisture movement within the specimens was very limited. From a practical perspective, where water initially accumulated is where it stayed.*

The experiment showed the importance of designing for effective rainwater management since it is essential that little, if any, water should be permitted to get into the insulated stud cavity.

INTRODUCTION

It has been well publicized that many recently constructed wood-framed buildings in the Vancouver area are suffering major rot problems due to water entry into their walls. In Vancouver, most but not all of these buildings are stucco-clad. Research into the problem in Vancouver (Morrison 1996) has shown that the main cause of the deterioration is rainwater penetration into the walls, especially at construction details. There is documentation of similar problems with similar causes in other regions and climates, including the Pacific Northwest and North Carolina (Brown et al. 1997; Sorenson 1998; Steffen 2000).

The solution to such problems must address measures to limit the exposure of walls to water and limit the amount of water ingress past the outer face of the walls. However, it can be assumed that such measures will not always be effective, and the solution must also address measures to facilitate removal of water that penetrates past the face of the wall.

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A large number of the rotting wood-framed walls are clad with face-sealed stucco. Face-sealed designs rely on the outermost face of the cladding to prevent water ingress and they have no strategy to manage or dissipate moisture that gets past this face. An alternative design strategy is the rainscreen approach that incorporates a drainage cavity inside the cladding but outside the underlying structural wall components. As well as providing an ability to manage water that gets past the cladding, the drainage cavity provides a capillary break between the porous stucco and the underlying components. The City of Vancouver has mandated rainscreen systems, or equivalent, for all stucco-clad buildings within its jurisdiction that are not covered by the part of the Building Code that deals with small buildings.

Several methods have been proposed and used to create a drainage cavity behind stucco cladding on wood-framed buildings. Most use a moisture-resistant membrane (building paper or sheathing membrane) installed over the sheathing as a second layer of moisture protection to shed water before it reaches the moisture-sensitive sheathing. Some define this element as a *drainage plane*. Flashing, appropriately lapped under the moisture-resistant membrane, is installed at the bottom of the cavity to direct the drained water to the exterior. A number of approaches have been used to provide a drainage space or cavity between the stucco and the moisture-resistant membrane. In Vancouver, the most common methods have involved vertical treated-wood strapping, typically nominal 1 in. (actual 3/4 in. or 19 mm). Alternatives include materials that were designed to provide drainage below grade.

The primary rationale for applying the rainscreen principle is that it will limit the wetting of the sheathing and structural components of the wall. An unresolved issue is whether it also enhances drying of these components should they become wet.

An experiment was designed and executed with the objective of determining the effect of drainage cavity design on the capacity for drying water in the stud cavity of stucco-clad walls.

TEST METHOD

The experiment was designed to assess the drying potential driven by temperature and vapor pressure differences. The temperature difference across the test specimens was controlled, and design of the drained cavity was the variable. Drying by vapor diffusion to the interior (warm side) was limited by a 10 mil polyethylene sheet. Air leakage was limited by the airtight design of the specimens and the negligible air pressure difference across the specimens. Solar effects were not included in the driving potentials.

The method of water injection was chosen to mimic rain penetration. The same amount of liquid water was injected into each test specimen while they were being exposed to the same condition in a test chamber.

A preliminary experiment was conducted to develop an understanding of the instrumentation and of how water was absorbed and distributed in a test specimen. Two wood-framed test specimens were constructed for this preliminary experiment. An array of sensors was installed to measure temperature, relative moisture content, and relative humidity in these specimens. After being injected with water, the moisture movement was monitored for 35 days under controlled conditions.

For the main experiment, five wood-framed, stucco-clad test specimens were constructed. One specimen was constructed with a face-sealed design; the remaining specimens were constructed with different drainage cavity designs. Sensors were installed in the stud cavities to measure temperature, moisture content, and relative humidity. After being injected with water, the moisture movement was monitored for 5 1/2 months under controlled conditions.

Test Facility

Specimens were mounted in a 1.83 m by 4.88 m wood-framed test facility. A refrigeration unit controlled the temperature inside the chamber at the exterior test conditions. The chamber was constructed within a larger room where two electric heaters controlled the temperature at the interior test conditions. Relative humidity was not controlled directly either inside or outside the chamber. However, the dew point temperature and vapor pressure of the air inside the chamber (the exterior condition) were governed by the temperature of the cooling coil in the refrigeration unit.

Test Specimens

Each specimen measured 1.21 m wide by 2.43 m high and contained three stud spaces. The specimens were constructed of the following layers:

1. 12 mm unpainted gypsum wallboard, to function as the air barrier.
2. 10 mil polyethylene sheet, to function as the vapor barrier. This was lapped over the sides of all specimens to minimize drying through the edges of the specimen.
3. 38 x 89 mm wood studs with RSI 2.1 (R-12) glass fiber batt insulation.
4. 12 mm plywood sheathing, installed horizontally with a 3 mm gap at joint.
5. 60 minute building paper,[1] shingle-lapped.
6. Drainage cavity, various designs, vented and flashed at top and bottom.
7. 19 mm cement stucco cladding with acrylic finish coat, reinforced with welded-wire mesh (50 mm square grid). The stucco was cured for a minimum of 28 days prior to testing.

1. Rated according to test methods and criteria of UUB 790a.

Waterproofing membrane was applied to the exterior of the bottom plate to prevent water from draining out at the base of the specimens.

One of the specimens for the preliminary experiment was constructed with face-sealed cladding (i.e., without a drainage cavity). The other was uninstrumented and constructed without stucco in order to provide direct access to the sheathing. Sheathing moisture readings were taken with a hand-held moisture meter.

Five wood-frame test specimens were constructed for the main experiment (WA-1 to WA-5). The drainage cavity of each specimen was constructed as shown in Table 1.

Detailing of the metal flashing was the same at the top and bottom of all drainage cavities. It mimicked the flashing used at each floor of ventilated, drained cavity wall systems. Figures 7 and 8 show WA-1 and WA-2 respectively. It is worth noting that specimens WA-2, WA-4, and WA-5 have an additional layer of 30 minute building paper installed over the strapping to prevent stucco penetration into the drainage cavity. Figure 1 shows a test panel with the interior finish and insulation removed.

TABLE 1

Test Specimen	Drainage Cavity Details
WA-1	No cavity (a face-sealed specimen)
WA-2	19 mm vertical wood strapping @ 200 mm o.c.
WA-3	10 mm dimpled plastic sheet foundation drainage mat (without geotextile backing)
WA-4	Open plastic mesh type foundation drainage mat (without geotextile backing)
WA-5	10 mm vertical wood strapping @ 200 mm o.c.

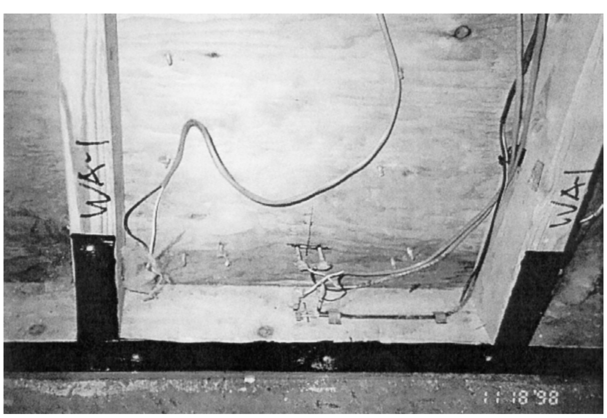

Figure 1 *Test specimen WA-1 removed from test chamber after 5 1/2 months. Note moisture sensors installed in specimen; also note discoloration of sheathing at base of specimen.*

Water injection tubing was installed in each specimen to provide for controlled injection of water into the insulated stud cavities (see Figure 2). It was covered with ABS pipe, cut in half lengthwise, to direct the water to the surface of the sheathing.

Sensors installed in the specimens (see Figure 1) included brass moisture pins to measure moisture content of selected wood elements, Duff gauges to measure relative humidity, Type T thermocouples to measure surface and air temperatures, and a remote sensor to measure temperature and relative humidity within the stud space. The following gives a brief description of the sensors referred to in this paper.

Preliminary Experiment

The preliminary experiment was performed to

- define the number, type, and location of sensors to be used,
- assess the method of introducing water into the specimens,

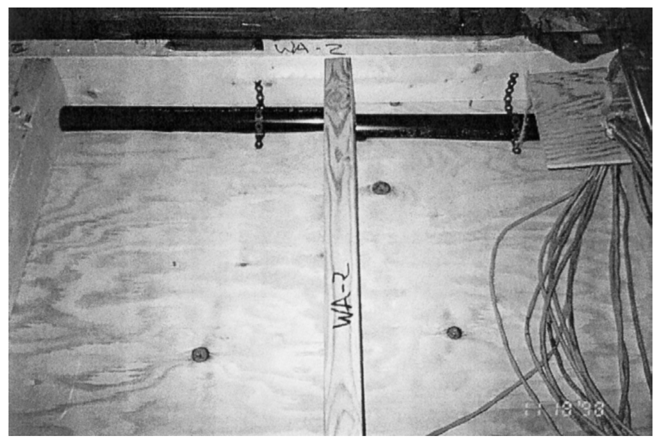

Figure 2 *Close-up of water injection tube (covered with ABS) and detail of entry point for water injection tube and instrumentation wiring.*

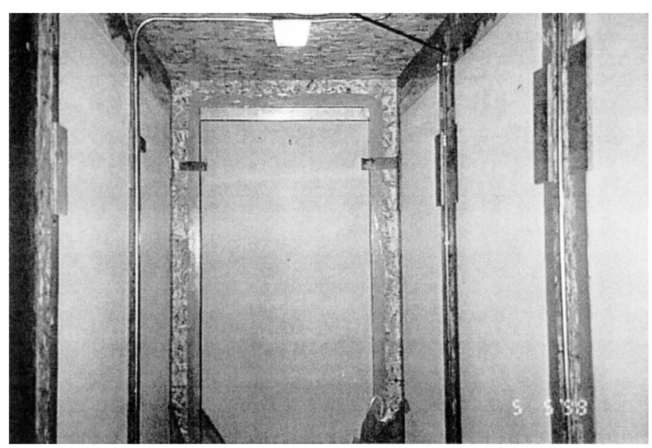

Figure 3 *Interior of test chamber showing test specimens inserted in openings in chamber walls; sealing into openings to follow.*

TABLE 2

Temp/RH Remote Sensors	
Description:	EH 020A remote temperature and relative humidity sensor by ACR Systems Inc.
Data Collection Method:	Smartreader 2 data logger with Trendreader software
Precision/accuracy:	Temp – 0.2ºC @ 0 to 70ºC; RH – 4% at 10% to 90%
Thermocouples	
Description:	Type T (copper constantan); 24 gauge
Installation Method:	Self-adhering membrane placed over thermocouple; staples over membrane with wood and gypsum sheathing
Data Collection Method:	Comark 9001 Digital Thermocouple Meter
Precision/accuracy:	– unknown –
Brass Moisture Pins	
Description:	Two 50 mm long moisture pins spaced 25 mm apart; pins cut from brass rod and coated with epoxy except for the sharp-ened tip
Installation Method:	Pre-drill holes to 1/8” less than insertion depth (approximately mid-depth of sheathing and framing)
Data Collection Method:	Delmhorst RC-1E moisture meter
Precision/accuracy:	–0.5% at 6-12%; 1.0% at 12-20%; 2% at 20%-fiber saturation (generally around 30%); fiber saturation to 80%, readings are of limited value: usually lower than actual moisture content; erratic and change with species. Calibration against production probe of Delmhorst RC-1E moisture meter carried out before and after experiment.
Duff Gauges	
Description:	A calibrated piece of wood approximately 3/32” wide by 1” long with instrument wire secured to opposite faces
Data Collection Method:	Delmhorst RC-1E moisture meter
Precision/accuracy:	see Moisture Pins

- determine how the water would be absorbed and redistributed within the specimens, and
- define how much water to introduce into each specimen in the main test.

We elected to inject sufficient water into the stud cavities to raise the moisture content of all wood elements by about 25% MC. Given that the specimens contained approximately

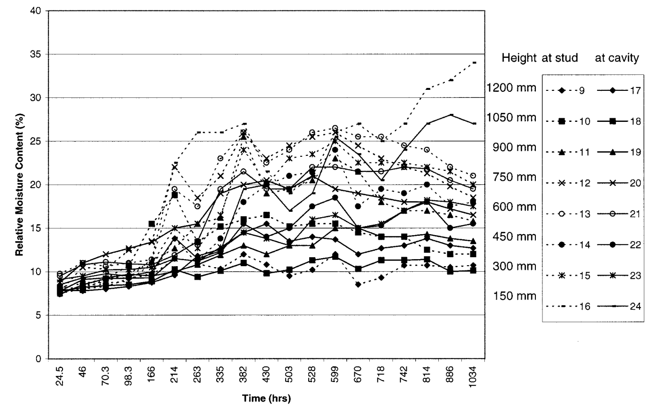

Figure 4 *Moisture content of sheathing of panel without stucco.*

40 kg of wood, we injected 10 liters, one liter at a time over a period that totaled 16 days.

Moisture content, temperature, and relative humidity were monitored during the 16 days while the water was being introduced and for an additional 35 days. The sheathing of the specimen without cladding was probed through the building paper using a moisture meter to assess moisture distribution across the height and width of the sheathing. Figure 4 shows moisture content readings measured at 16 of the measured points: eight on a line over a stud and eight on a line over the center of a cavity.

The preliminary experiment provides the following observations and conclusions with respect to the main experiment:

- Very little moisture was observed to migrate to the upper half of the specimen. Therefore, less water should be injected.
- The moisture content gradients were very shallow in the upper half of the specimens. Therefore, fewer sensors could be installed.
- The surface moisture probes and thermocouples gave little additional information. Therefore, none were installed.
- Drying, even of the panel without cladding, was very slow. A long experiment was to be expected.
- Moisture was absorbed into the framing and sheathing at the base of the specimens in unpredictable but explainable patterns. For example, water apparently wicked up the end grain of some studs but not others.

Main Experiment

The main test specimens were instrumented with moisture pins, Duff gauges, and remote sensors. The sensor locations are shown in Figure 9.

The initial weight of each specimen was measured with a floor scale (precision 0.05 kg). The test specimens were mounted into the test chamber with the stucco cladding facing into the chamber. The temperature setpoints were set to provide an interior temperature of 23°C and an exterior temperature of 10°C, a condition typical of winter conditions in British Columbia's coastal climate. Specimens were left for two weeks to stabilize under test conditions. During the final week before beginning the test, all moisture content measurements (moisture pins) were read and observed to be stable within 0.5%.

Water was then injected into the stud spaces of the specimens through the water injection tubes. Four liters were injected at the rate of one liter per day.

A quantity of water was observed to seep out of some of the specimens into the polyethylene wrapped around the bottom specimen. We attempted to collect and quantify the water that was not absorbed in the specimens. Table 3 summarizes the observations.

Setpoints for interior and exterior temperatures were maintained constant for the duration of the test, and temperature and relative humidity inside and outside of the chamber were recorded during this time. Moisture content, temperature, and relative humidity data continued to be collected following the injection of the water. The moisture content data collection was by hand at frequencies of two to three times a week initially, which extended to approximately twice a month as the experiment proceeded and the slow rate of drying became evident.

The experiment was terminated after approximately 5 1/2 months. The specimens were removed from the test chamber, and the final weight of each specimen measured with the same scale that had been used for the initial measurements.

The interior finish and insulation were removed from each specimen to observe the condition of the studs and sheathing. Moisture content readings were taken, using a moisture meter, adjacent to the moisture pins and at other selected locations to verify calibration of the moisture pins and to obtain a more complete mapping of the moisture distribution in the sheathing.

FINDINGS

Specimen Weights

The initial and final weights measured for the specimens are shown in Table 4. The weight of water added to the specimens, 4 kg, is not included in the initial value.

The variation among the initial weights of the specimens is likely due to minor differences in stucco thickness. The difference between the initial and final weight of the specimens will be largely, if not entirely, due to changes in the moisture content of the specimens. However, it is not possible to differentiate between moisture changes in the sheathing and framing and moisture changes in the stucco cladding. There was also some variation in the amount of water that drained out of specimens at the time of injection. Hence, a change in the weight of the specimens is, at best, a crude indicator of the drying performance of the test specimens. The fact that the sample with the least difference between final and initial weight was the one without a drain cavity is interesting but not necessarily significant.

Temperature and Relative Humidity

The interior and exterior temperatures and relative humidity exhibited daily fluctuations as well as some long-term drift. The exterior condition temperature setpoint was 10°C and measured values ranged between 5°C and 14°C. The exterior condition RH ranged between 45% and 85%. The interior temperature was maintained between 19°C and 25°C. The interior condition RH ranged between 35% and 60% but this should not be a factor in the experiment since test specimens were isolated from the interior condition with a sheet of polyethylene.

The temperature measured within the insulated stud space of the specimens was fairly consistent between specimens. Temperatures within the specimens typically ranged between 10ºC and 15°C during the experiment. The initial RH measured at the center height of the stud cavities was constant and ranged between 50% and 60%. It rapidly increased to between 85% and 90% after the water was injected, settled back to between 70% and 75%, and then gradually decreased for the duration of the experiment.

TABLE 3

Specimen	Injected Water Lost from Specimens
WA-1	< 5%
WA-2	negligible
WA-3	< 5%
WA-4	negligible
WA-5	<10%

TABLE 4

Specimen	Drainage Cavity	Initial (kg)	Final (kg)	Difference (kg)
WA-1	None	193.85	194.80	0.95
WA-2	19 mm strapped cavity	205.65	207.30	1.65
WA-3	Dimpled drain mat	182.15	183.80	1.65
WA-4	Mesh drain mat	187.15	189.50	2.35
WA-5	10 mm strapped cavity	199.05	200.55	1.50

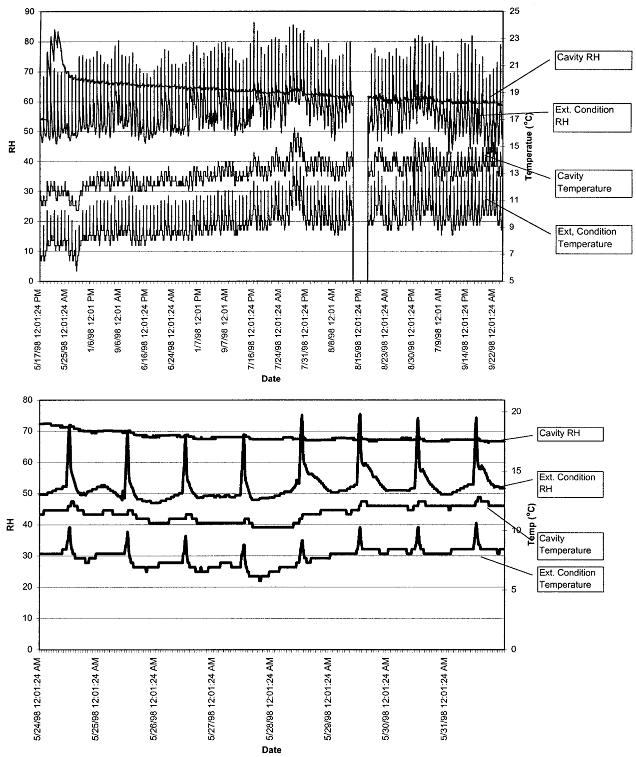

Figure 5 *Temperature and relative humidity of exterior condition and specimen WA-1.*

Figure 5 shows example plots of internal temperature and RH for one specimen (WA-1) on two time scales: the whole experiment and for a one week period. The shorter time base provides a better indication of how temperature and relative humidity of the exterior condition cycled with the daily defrost cycle of the refrigeration system.

Relative Moisture Content

The relative moisture contents measured at some of the measurement locations in each test specimens are shown Figure 6. Each graph presents the relative moisture content readings from a similar sensor location in each specimen. The relative moisture content values are actual meter readings with no adjustments for temperature or wood species. It is assumed that relative performance can be compared without the correction because similar locations on different specimens would be the same material at similar temperatures. Where the moisture content reading was beyond the range of the moisture meter (80%), a value of 80% was recorded.

The findings do not show a difference that is explainable by the nature of the drainage cavity. At all locations where stud moisture content was measured and at sheathing locations more than 50 mm above the bottom plate (e.g., Locations A, C, and D), the pattern of relative moisture content for a given location was similar for all specimens. There was more variation with measurement in the bottom plate and bottom of the sheathing. We note that when comparing measurements from the two locations on the bottom plate (locations G and H) in the same specimens, one can see obvious differences. The differences can be easily attributed to factors such as variations in how moisture was absorbed into the wood elements and the precision of the construction.

We note that the specimen without a drainage cavity, WA-1, dried at least as quickly as specimens with drainage cavities.

The results lead to the conclusion that the rate of drying was independent of the design of the drainage cavity.

It was also observed that moisture did not redistribute within the specimens after it had drained to the bottom of the specimens. Some locations that did reach high relative moisture content dried, but the rate of drying was very slow and occurred over several months. At all locations where relative moisture content rose above 30% after water injection, relative moisture content was still above 20% after two months of drying at the test conditions.

Physical Observations

When the inner finish and insulation were removed, dark staining was observed at the base of the plywood sheathing of each specimen (see Figure 1). The staining extended about 150 mm up from the bottom plate, with occasional excursions to 300 mm. Different patterns of staining were visible, likely due to variations in moisture transport characteristics of the plywood. The sheathing exhibited little or no structural deterioration. Less pronounced staining was visible at the base of the studs. A few specimens had visible moisture at the base of the sheathing, and selective relative moisture content measurements showed each specimen to have locations where the wood relative moisture content was above 20%. The high relative moisture content in the sheathing generally did not extend higher than 150 mm.

DISCUSSION AND CONCLUSIONS

The following conclusions are drawn from the results and observations of the experiment.

For the tested wall assemblies:

- The process of drying the amount of injected water (approximately 10% of the weight of wood in the specimens) was very slow for all specimens and took months to achieve any significant effect.

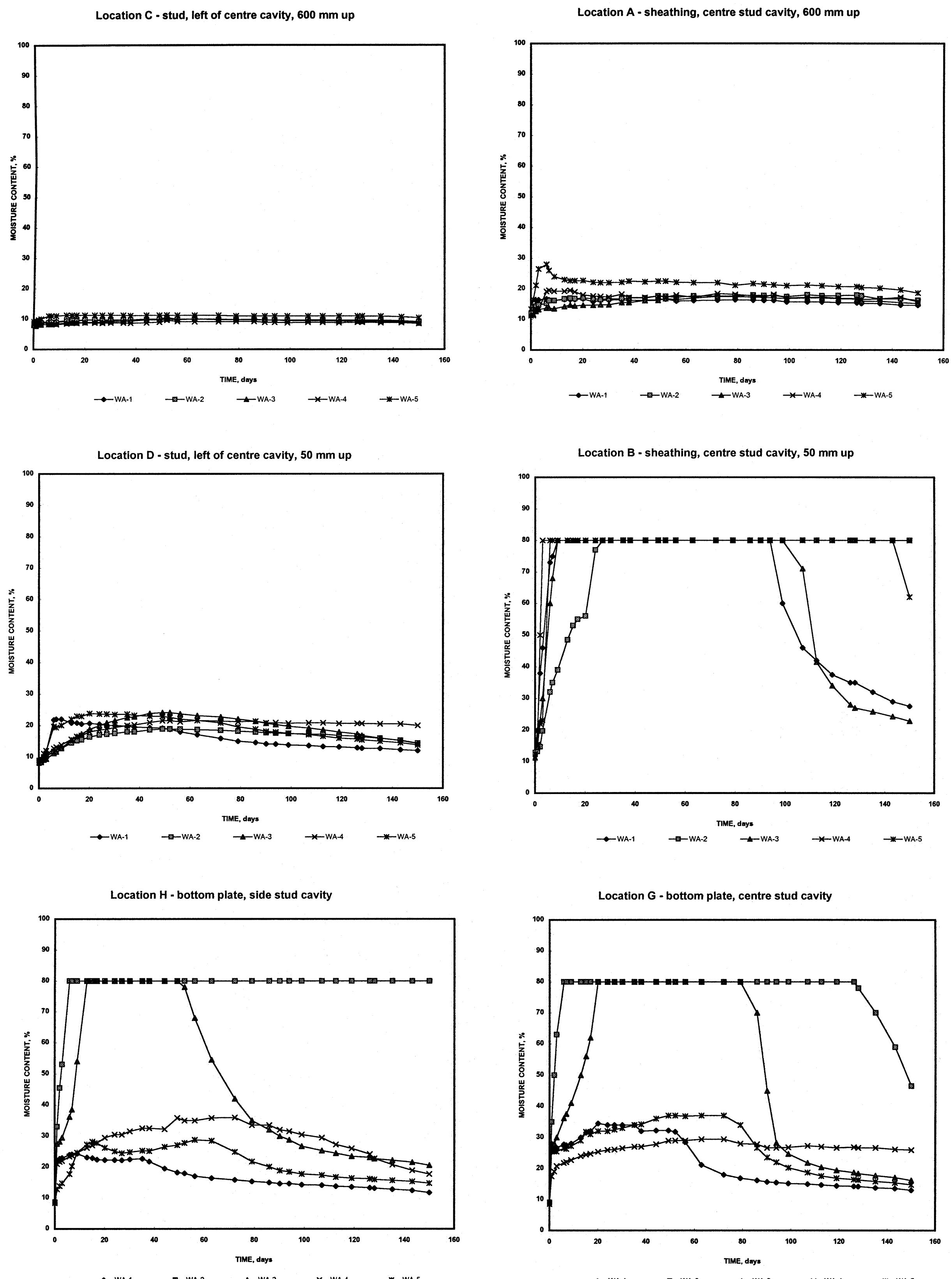

Figure 6 *Moisture content graphs organized by relative location in test specimen.*

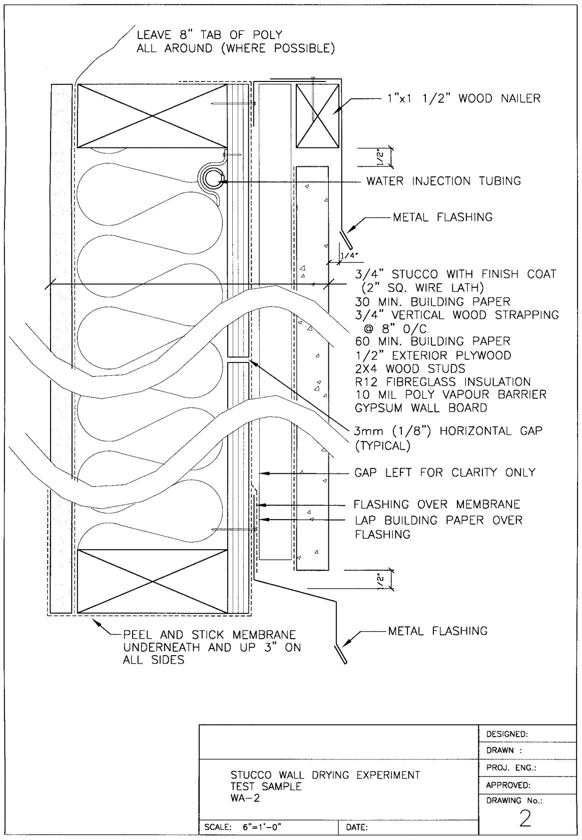

Figure 7

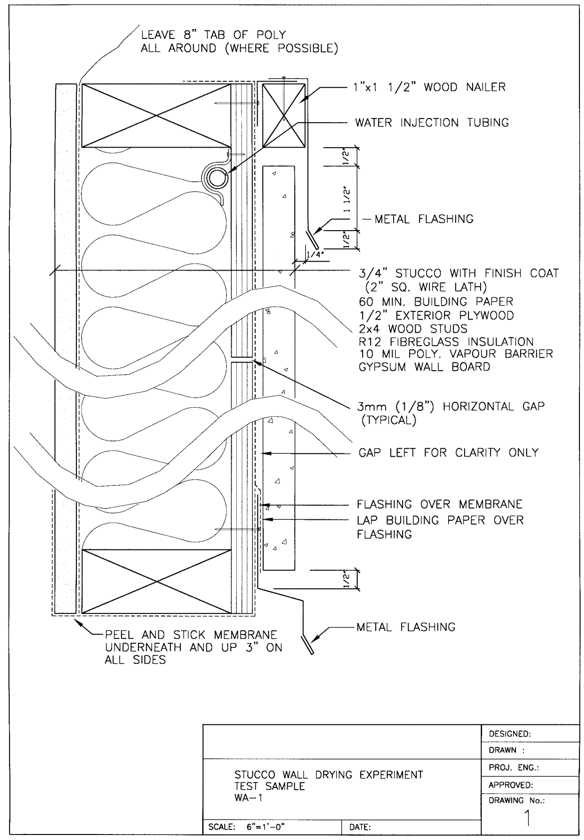

Figure 8

- Improved drying of water that penetrates into the insulated stud cavity is **not** a benefit of the rainscreen design. The drying rate was not affected by cladding design, either face-sealed or rainscreen, nor by drainage cavity design. It also follows that the cladding system type (stucco, vinyl siding, brick veneer, etc.) will not improve the rate of drying any water that enters the insulated stud cavity.
- Moisture movement within the specimens was very limited. From a practical perspective, where water collects in a wall is where it stays. A small leak can lead to a serious local problem.

This experiment has shown that design for effective rainwater management is important. In our opinion, the results of this experiment indicate that if a significant amount of water penetrates into the insulated stud cavity, deterioration is virtually inevitable, at least with the fully sheathed walls that are the norm in the Vancouver area. The authors are convinced of the merit of rainscreen wall designs as part of an effective rainwater management approach. However, the presence of the rain screen cladding system does not appear to increase the potential of the wall system to dry out water that has penetrated into the insulated stud cavity. We note that a very high proportion of the problems found in Vancouver were associated with elements that effectively bypass the rainscreen cavity. It remains critical that these elements be detailed to eliminate water entry into the insulated cavity of the wall because the rainscreen provides no additional “forgiveness.”

It has been postulated that other environmental factors such as solar radiation and wind would:

- Improve the potential to dry water from the insulated cavity of walls to the point that designs could assume that the wall will forgive modest amounts of rain penetration.
- Improve potential to dry water from the insulated cavity of walls with a ventilated drainage cavity (i.e., one with openings at the top and bottom to allow airflow in the drainage cavity) relative to walls without such a cavity.

Our results do not support these opinions. In the preliminary test, one wall panel had no cladding at all. The moisture content of the air in contact with the sheathing paper was the same as the outdoor condition. Even this specimen exhibited very slow drying.

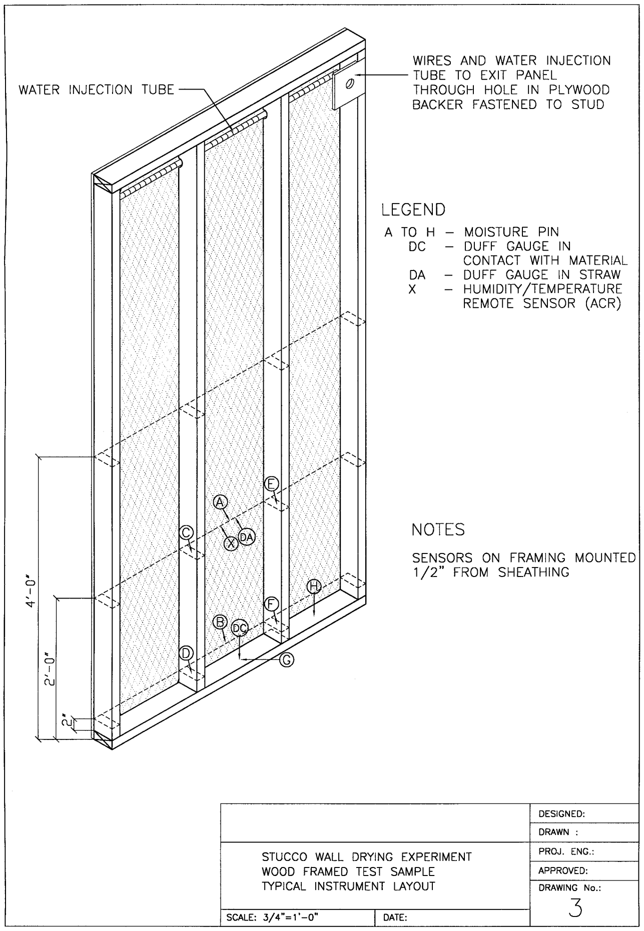

Figure 9

Further experimental studies would provide insight into these issues and into the rain penetration control performance of wall assemblies. Such studies, including monitoring of existing buildings, will determine how effective exterior wall designs can be in addressing the problems of moisture egress into, and deterioration of, wood-framed walls in southwestern British Columbia.

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