The Influence of Design on Drying of Wood-Frame Walls Under Controlled Conditions

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ABSTRACT

Construction practices for multi-unit wood-frame residential buildings in British Columbia, Canada, are changing in response to a large number of envelope failures experienced in the period from 1985 to 1999. The new design approach includes the use of enhanced deflection and a drained cavity. While this approach will manage a large portion of the exterior moisture load, we have to assume that some moisture will enter the wall during the life of the building; consequently, designs also need to incorporate enhanced drying capabilities. A research program conducted in Vancouver, British Columbia, has evaluated the relative drying rates of wall assemblies under controlled laboratory conditions. Test conditions included Vancouver wintertime drying only. Test panels incorporated polyethylene vapor retarder and sealed poly air barrier construction. The research ranks test wall panels in terms of their relative drying capacities, identifies potential wall locations at greater risk of slow drying (thus requiring enhanced material durability), and derives baseline data that can be used to improve parametric models of wall performance.

INTRODUCTION

The envelope drying rates analysis (EDRA) experiment was set up as part of the program of the Building Envelope Research Consortium (BERC), an industry/government consortium formed by Canada Mortgage and Housing Corporation to solve the leaky condominium problem in British Columbia. In 1998, the BERC produced *Best Practice Guide for Wood Frame Envelopes in the Coastal Climate of British Columbia* (CMHC 1999a). The central design thesis of this guide is that walls have to manage moisture by incorporating four features—deflection, drainage, drying, and durability—the four Ds (Hazleden and Morris 1999). Deflection, drainage, and durability have been studied, but relatively little attention has been paid to the effect of wall design on drying rates (Trechsel 1994). Building envelopes have to be constructed to deflect and drain the bulk (i.e., 95% to 99%) of the moisture incident on them. In Vancouver, this could be over 400 kg/m^2 (82 lb/ft^2) of wall area per year (Salonvaara and Karagiozis 1998). Adoption of the best practices guide by the building industry is expected to result in a near total elimination of moisture ingress into walls. However, small defects or the deterioration of a building's deflection and drainage system can still cause moisture to accumulate if drying does not occur. We need to know to what extent drying can contribute to our overall moisture management plan for wall designs. We acknowledge there is no possibility that walls can be made to dry at a rate that would equal or exceed the ingress of moisture in a leaky wall typical of recent problems in the British Columbia coastal climate. The test panels (of wood-frame wall assemblies) in this study were not intended to be indicative of walls that could manage large amounts of water ingress by drying alone—they represent a selection of wall designs in current use. The study was not designed to justify the selection or rejection of various wall assemblies.

Building science has evolved significantly over the past 20 years; however, most testing of wall systems in Canada has been directed at testing for the continental climate with

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exterior temperatures ranging from a wintertime low of –30ºC (–22ºF) to a summertime high of +30ºC (86ºF) (Wilson and Morrison 1992).

Typically, we predict the drying rate of walls in terms of their calculated permeance. Vapor permeance values have been determined for various claddings, sheathing protection membranes, and sheathing materials (ASHRAE 1985). There is enough information about material properties to be able to sort walls according to their calculated permeances. If this approach were sufficient, this research would not have been necessary. However, this does not take into account the fact that the effective permeance of a wall may be several times greater than the calculated permeance. This is a result of accelerated transfer of moisture through the wall assembly by mass flow of air through a vented cavity and can result in walls that have an effective permeance substantially greater than their calculated permeance.

The concept of calculated permeance vs. effective permeance was studied by Forrest and Walker (1990) by measuring the drying of wall panels in an outdoor test hut in Alberta. Studies in the Atlantic region used outdoor test huts in a variety of locations to collect data on the drying of walls (CMHC 1987). The Ontario wall drying project further demonstrated how drying could be studied in outdoor test huts (Burnett and Reynolds 1993). Similar work done by Stewart (1982) looked at the drying regime in an outdoor test chamber with a continental climate. The EDRA experiment differs principally in its use of an indoor, fully regulated test chamber to simulate a controlled climate. A precedent for the EDRA experiment was conducted in 1991 with an indoor test chamber in which both summer and winter drying conditions for the climate of southern Ontario were simulated (CMHC 1991).

Part of the BERC drying rates program was another indoor chamber study by (CMHC 1999b) in which six stucco-clad panels were tested. All of these studies provided us with insights into the problems of testing wall panels in an indoor chamber. Their methodological weaknesses included such factors as variations in wood from panel to panel, problems with uneven wetting, problems with insufficient driving forces for drying, and problems with mechanical systems and instrumentation breakdowns. All of these combined to make the results of these previous tests difficult to replicate and resulted in performance comparisons between panels lacking validity.

Given the scope and cost of the EDRA experiment, it was not possible to have a large number of replicates. Recognizing the problems experienced by previous studies and drawing upon the experience of the steering committee and outside experts, the experiment was designed to yield valid results with no replicates. It was important, therefore, that the test include the least number possible of variables between test panels and test conditions. Part of the approach was to subject all the wall panels to the same drying forces. This would enable us to quantify the differences in the drying rates between the panels based on their designs without having to factor out differing drying conditions, seasonal variations, solar orientations, wind effects, etc. Significant additional effort was invested to mitigate the natural variability of wetting and drying of wood used in the panels. The test sought to handicap the panels equally such that the differences in their drying rates could only be attributed to their designs. Also, in this series of tests, all wall panels dried to the exterior only.

One of the goals of the envelope drying rates analysis (EDRA) research project was to provide baseline data on the drying rates of wall panels under controlled laboratory conditions to assist in the validation of hygrothermal models. These models will ultimately simulate wall designs with the same sort of security and economy that presently exists in the modeling of structural systems. This will contribute to improved design and construction practice, which will reduce the risk of wall failures in coastal British Columbia to an acceptable level. This project is particularly closely linked with the ongoing enhancement of CMHC's WALLDRY model. The project is also linked to the NRC-IRC Moisture Management in Exterior Wall Systems (MEWS) consortium program, where the results of EDRA will be compared to NRC's parametric model HYGIRC.

The test method consisted of the fabrication of test panels, which were then wetted and inserted into openings of an indoor test chamber for up to three months to measure their drying. The mechanisms for drying were vapor diffusion, driven by the vapor pressure differential between the laboratory, the panels' interior, and the interior of the chamber; the adsorption and desorption effect off the surface of the panels into the chamber; and the airflows through the cavities of the vented panels into the chamber. Drying by mass flow from the interior of a building to the exterior is contrary to the air barrier objectives of the *Best Practice Guide* (CMHC 1999a) and the *National Building Code of Canada* (Canadian Commission on Building and Fire Codes 1995) and was not part of this experiment. Mass flow by air movement through the panels from the lab to the chamber was effectively eliminated from the experiment.

Objectives

The overall objective of the project was to evaluate the effect of wall design on the drying capability of wood-frame test wall panels in a controlled laboratory environment simulating one condition (5ºC [41ºF] at 70% RH) from the winter climate of Vancouver.

The following specific objectives were addressed:

- Determine how long specimen wall panels wetted to > 25% moisture content (MC), under test conditions and without re-wetting, take to dry out.
- Determine which test wall panels dry faster than others and what the variations between the test panels' drying rates are.
- Determine if the drainage cavity width affects drying, and by how much.

- Determine the correlation between the predicted moisture movement within the framing lumber and the sheathing and the actual moisture movement by comparison to prior runs of CMHC's WALLDRY computer model (Onysko 1999).
- Compare the calculated permeance to the effective permeance.
- Compare the effect of the solar simulation on test wall panels.

MATERIALS AND METHODS

The Facility

A 12-panel chamber with exterior dimensions of 2.6 m (8.67 ft) wide by 5.1 m (16.67 ft) high by 15 m (50 ft) long was constructed inside the Wood Engineering Laboratory (see Figures 3, 6, and 11). The chamber contained a multi-component mechanical system for regulating internal conditions. The setup allowed for the independent control of airflow, temperature, and relative humidity within the chamber. The building's HVAC system controlled the environmental conditions within the lab in which the chamber was located.

The size of the space available in the laboratory, as well as the access by overhead crane for panel insertion/removal, dictated that the chamber be double sided with six panels on each side. One consideration was the reduction of edge effects caused by the floor and ceiling of the chamber. The chamber design accommodated a transom and base of 1200 mm (4 ft) above and below the panels. The interior of the chamber was 2440 mm (8 ft) wide. The overall width was governed by the allowable space in the lab and the desire to keep the volume of air to be conditioned at the minimum. The center 600 mm (2 ft) of the chamber was taken up by a steel frame holding the HVAC ducting and the heat lamps for the solar simulation (see Figure 12).

Chamber Conditions

The interior of the chamber was conditioned to 5ºC (41ºF) and 70% RH, with a temperature variance of not more than ±1.5ºC (2.7ºF) and an RH variance of not more than ±5%. The exterior of the chamber (the lab space) was conditioned to 20ºC (68ºF) and had an average RH of 40%. The Wood Engineering Laboratory was monitored for RH and temperature conditions for five years prior to the test. There have been some hourly fluctuations in RH and temperature as doors were opened and material was brought in and out. The daily average for the lab was between 20ºC and 22ºC (68ºF and 72ºF) and between 30% and 40% RH in the period from January 1, 1999, to March 31, 1999. The chamber HVAC directed a continuous airflow of 1 m/s (3 ft/s) at the lower half of the exterior cladding side of the panels. This produced a pressure differential between the top and bottom of the panel of 1 to 5 Pa (0.004 to 0.02 in.sp.). During Phase 2 in which the solar cycle was employed, the panels were evenly subjected to light sources providing an eight-hour solar cycle. Lights were switched on at 8:00 a.m. and ramped up in power from 0 to 120 W/m^2 maximum at 11:00 a.m. and staying at 120 W for two hours. From 1:00 p.m. to 4:00 p.m., they were dimmed down gradually, returning to 0 W/m^2. The panels were in darkness for 16 hours. The goal of the solar cycle was to achieve a combined ambient and solair temperature of up to 15ºC (59ºF) at the surface of the panel.

Test Panels

The panel configurations are described in Table 1. Each test wall panel was 1220 mm by 2440 mm (4 ft × 8 ft) in size, constructed as per Figures 1, 5, and 6. The center stud space would provide data from a representative wall section, which was effectively buffered by the side stud spaces. The material for the base panel frame was nominal 38 mm × 89 mm (2 in. × 4 in.) J grade lodgepole pine, with either 11.5 mm (15/32 in.) oriented strand board (OSB) sheathing or 12.5 mm (1/2 in.) plywood sheathing applied horizontally, with a 3 mm (1/8 in.) gap at mid-panel. All panels were insulated in the stud space with RSI 2.45 (R14) glass-fiber friction-fit insulation. All panels were edge sealed with vapor impermeable roofing membrane.

The interior finish was 12.5 mm (1/2 in.) plywood used as a substitute for conventional gypsum board. Plywood was chosen as an interior finish to provide a more durable material than gypsum board. The vapor barrier was provided by 6 mil polyethylene film. Since 6 mil polyethylene is a type 1 vapor barrier (permeance less than 60 ng/Pa·s·m^2 [1 perm]), the interior environment (lab space) would not add to or remove moisture from the wall panel assembly. The interior plywood faces were painted with gray paint to minimize weight changes during the experiment as hourly RH conditions in the lab fluctuated. The panels incorporated a breather-type sheathing membrane and used either two layers of 30-minute asphalt-impregnated building paper or one layer of spun-bonded polyolefin. The cavity between the sheathing membrane and the back side of the cladding was created by using 19 mm × 38 mm (3/4 in. × 1 1/2 in.) CCA treated plywood furring at 400 mm (16 in.) o.c., or 10 mm × 38 mm (3/8 in. × 1.5 in.) CCA treated plywood furring at 400 mm (16 in.) o.c. The furring was applied vertically, directly opposite the studs.

All the OSB for the test was drawn from the same bundle of 50 sheets sourced from a single mill in the interior of British Columbia. All the sheathing plywood for the test was drawn from one bundle, sourced from a single mill on the coast of British Columbia.

The vent area was created by a standard stucco J mold and a base flashing of pre-painted 28 gauge steel. The base flashing rests on a piece of laminated veneer lumber (LVL). The LVL was totally encased in epoxy resin to prevent any water uptake or loss from this portion of the wall panel assembly.

Prior to wetting, the panels were fully clad and instrumented but left uninsulated and with no interior finish. This allowed the panels to be placed studs (inside face) down in shallow tanks of water to evenly wet the lumber.

Lumber Selection Criteria

Lumber variability has been a problem in previous experiments. If a test panel were constructed of randomly selected lumber, it is possible that all the lumber in one panel could be fast drying sapwood and all the lumber in another panel could be slow drying heartwood. To offset this, a procedure for selecting the lumber was implemented. J grade was chosen for the test wall framing because it is the grade with the narrowest range of wood variability. One bundle of lodgepole pine was purchased from a B.C. interior mill.

Ninety-six studs were required for the construction of the 12 test panels and 4 sacrificial panels. The selection process started with 251 pieces; these were visually sorted into 195 pieces by eliminating pieces with minor defects. The 195 pieces were weighed then wetted in a pressure retort. A record of weight gains was taken for 195 pieces. They were then kiln dried, and a record of weight losses was taken. From this, the 195 pieces were sorted as to maximum wetting and maximum drying. To construct the panels, we then chose 100 pieces straddling the median. The 100 pieces were separated into four classes or groups (see chart in Figure 1):

- Group A—maximum wetting (63% s.d.* 5) / maximum drying (30% s.d. 4)
- Group B—maximum wetting (59% s.d.* 7) / minimum drying (19% s.d. 5)
- Group C—minimum wetting (45% s.d.* 5) / maximum drying (20% s.d. 2)
- Group D—minimum wetting (40% s.d.* 5) / minimum drying (12% s.d. 3)

*(s.d. - standard deviation)

Panels were constructed using a piece from each of Groups A, B, C, and D for each of the four studs and plates as described in Figure 1.

By this procedure, we are able to ensure that the variations in wood wetting and drying capability are equally distributed among the panels. Additionally, we instrumented the same class of wood in each panel. Therefore, we believe that data gathered are more comparable from panel to panel because variations in wood characteristics have been reduced as much as possible.

Panel Cladding

There were 12 panels in Group A, with claddings as described in Table 1. In summary, nine panels had OSB sheathing and three had plywood. Nine panels had building paper and three had spun-bonded polyolefin (SBPO). Four panels had 0 mm (or no) cavity, two had a 10 mm (3/8 in.) cavity, and six had a 19 mm (3/4 in.) cavity. Four panels had no venting, four panels had cavity venting at the bottom only, and four panels had cavity venting at top and bottom. The vent areas at top and bottom were each 0.8% of the panel area and consisted of a 19 mm (3/4 in.) high, continuous horizontal slot.

Ten panels had stucco cladding and two had cedar siding. Stucco cladding was applied according to the specification derived from the BC Wall and Ceiling Association's Stucco Resource Guide. This is the standard 21 mm (7/8 in.) thick sand cement lime, three-coat application procedure as found in the *National Building Code of Canada*. Western red cedar channel siding was applied according to the manufacturer's recommendations. The panels with cedar siding had an edging strip on both sides installed with caulking to prevent lateral diffusion of moisture and simulate an infinite length of wall. (see Figures 13 and 14).

TEST PROCEDURE

Phase 1—Panels Drying without Solar Effect

1. Panels were fully constructed and clad with all instrumentation in place, not including interior finish plywood, polyethylene vapor barrier, insulation, and RH and temperature sensor. Dry panel weights were taken. Fully loaded panels weighed up to 231 kg (510 lb).
2. Panels were wetted to achieve 25% to 30% moisture content (MC) by weight in the studs and plates and 20% to 25% MC in the OSB and plywood, by immersing the panels, studs down, in a shallow tank of water (Figure 15). After removal from the tank, panels were laid in a horizontal position on dunnage and were allowed to drain off excess water for one hour. Panels were weighed suspended from a 340 kg (750 lb) capacity load cell.
3. Final assembly of panels included weighing separately the plywood interior finish, poly vapor barrier, insulation, and RH and temperature sensor. Technicians installed insulation, the RH and temperature sensor (in the center of the insulation), a polyethylene vapor barrier with acoustic sealant on the perimeter of the panel, and plywood interior finish. The instrumentation cables were all routed through an airtight drywall electrical box. The polyethylene vapor barrier was sealed to the framing and the plywood interior finish was installed. The load cell mounted on the overhead crane was calibrated to known weights and tare established. Panel weights were taken by the load cell.
4. Dummy panels were removed from the chamber bays just prior to panel insertion and the test panels were inserted into the fully operational chamber (Figure 16). Instrumentation was connected within one hour of panel insertion. Panels weights were taken by the chamber mounted load cell.
5. Panels were subjected to total darkness (no solar) and continuous wind effect (to achieve 1 to 5 Pa [0.004 to 0.02 in.sp.] pressure difference between the top and bottom of the panels). Panels were monitored in the chamber for 1500 hours. During monitoring, their drying was evaluated to determine whether the panel weights had returned to 15% moisture content by weight of the original panel and sheathing. This arrangement allowed the panels to

be modeled with the same driving forces as the WALLDRY computer simulation.

6. After 1500 hours, the instrumentation was disconnected from the data acquisition system (DAS) and panels were removed from the chamber bays. Immediately upon removal, each panel was weighed. The plywood interior finish, insulation, and polyethylene vapor barrier were then removed. The bare panel was weighed and the interior finish plywood, insulation, and polyethylene were weighed. The data from the weights are summarized in Table 3.
7. Experiment phase complete.

Phase 2—Panels Drying with Solar Effect

Steps 1 through 6 were repeated, except in this phase during step 5 the chamber was operated with the solar effect as follows:

5. Panels were subjected to a cycle of solar radiation (to simulate winter sun on east elevation in Vancouver) and continuous wind effect (to achieve 1 to 5 Pa [0.004 to 0.02 in.sp.] pressure difference between the top and bottom of the panels). Panels were monitored in the chamber for 2000 hours.

Data Collection

All panels were instrumented as shown in Figure 2. Each panel was connected to the DAS for online continuous measurement to: one load cell, up to 22 moisture content points, up to 12 temperature points, and up to 2 relative humidity points. Wood moisture was measured using the circuit shown in Figure 7. Epoxy-coated steel resistance measurement pins were embedded at set depths or gold resistance measurement pins were installed at the surface of the framing and the sheathing. Every 15 minutes, a voltage was applied across the circuit (Figure 7) for two seconds. The resultant resistance values in the wood were collected. The resistance values were later converted to wood moisture content with corrections made for sample temperature and species. Semiconductor temperature sensors were fixed to the surface at various points. One RH and temperature sensor in a sealed desiccant package tube was placed in the center of the batt insulation. Data were collected and recorded from each measurement point every 15 minutes.

Differences in Panel Wetting

Panels were wetted by placing them studs down in a tank of water for 240 hours. The water level was kept 6 mm (1/4 in.) below the sheathing in Phase 1. Preliminary tests had indicated that this would result in a moisture content of 30% in the framing and 22% in the sheathing. However, in Phase 1, the plywood-sheathed panels absorbed more water than the OSB-sheathed panels. As a result, the gap between the sheathing and the water was increased to 20 mm (3/4 in.) in Phase 2. The differences in mass of water absorbed are shown in Table 3. In Phase 1, the OSB panels absorbed an average of 7.17 kg (15.8 lb) and the plywood panels absorbed an average of 9.43 kg (20.8 lb). In Phase 2, the OSB panels absorbed an average of 7.35 kg (16.2 lb) and the plywood panels absorbed an average of 7.62 kg (16.8 lb). The Phase 1 weight differences were substantial, while the effect of increasing the gap to 20 mm during the wetting resulting in no substantial difference between OSB- and plywood-sheathed panels in average total mass of water absorbed in Phase 2.

Measurements of moisture levels in the framing and the sheathing with hand-held meters indicated that there was no substantial difference between the panels in moisture content levels in the framing. The differences were in the sheathing. In Phase 1, the OSB sheathing was averaging 25% and the plywood sheathing was averaging 31%. In Phase 2, the OSB sheathing was averaging 23% and the plywood sheathing was averaging 37%.

Calculated and Effective Permeance Calculations

Effective permeance is dependent on the formula (Hutcheon and Handegord 1983)

$$M_e = W / (A^* \ \theta(p_1 - p_2))$$

where

M_e	=	effective permeance, ng/Pa·s·m^2,
W	=	mass of moisture vapor moving through the panel, ng,
A	=	panel area, m^2,
θ	=	time, s,
p_1	=	vapor pressure inside the stud space,
p_2	=	vapor pressure inside the chamber.

The moisture loss ranged from 680 g to 2850 g.

Vapor pressure p_1 varied from stud space to stud space, from hour to hour, but, for a simplified calculation, the average temperature and RH from sensors H1 and E1 were used for this comparison. Vapor pressure p_2 was relatively constant at 0.61 kPa. For convenience, we are considering the effective permeance to be constant over each phase. Further data analysis is planned to define how effective permeance changes during the course of the experiment.

Over 1500 hours, for the full panel size of 1.22 m by 2.44 m, this produced a range of effective permeance of 87 ng/Pa·s·m^2 to 395 ng/Pa·s·m^2 (1.5 perms to 6.9 perms) in Phase 1 and 78 ng/Pa·s·m^2 to 485 ng/Pa·s·m^2 (1.4 perms to 8.5 perms) after 2000 hours in Phase 2.

The calculated permeances are based on the material properties as noted.

- Stucco, 21 mm at 70% RH, 390 ng/Pa·s·m^2 (Kumaran and Lackey 1999)
- Vent cavity, 19 mm, 9211 ng/Pa·s·m^2 and 10 mm, 17,500 ng/Pa·s·m^2 (Hutcheon and Handegord 1983)
- Building paper, one-layer 30-minute at 60% RH,

1080 ng/Pa·s·m^2 (Handegord 1996) (note two layers used in calculation)

- SBPO, one layer at 60% RH, 1500 ng/Pa·s·m^2 (Onysko 1999)
- The plywood and the OSB were monitored for moisture content throughout the test. To calculate the permeance of the sheathing, we have used the average moisture content at the end of the test to estimate RH in the plywood and OSB. The high moisture content levels of the plywood average 36% and correlate to RH of >96%. The lower moisture content levels of the OSB average 22% and correlate to RH of 90% (Hutcheon and Handegord 1983)
- 60% OSB, 11.5 mm at 90% RH, 372 ng/Pa·s·m^2 (Handegord 1996)
- Plywood, 12.5 mm at 100%RH, 2376 ng/Pa·s·m^2 (Handegord 1996)
- RSI 2.46 (R14) batt insulation, 89 mm at RH, 1910 ng/Pa·s·m^2 (Hutcheon and Handegord 1983)

The calculated permeance is based on the following formula (Hutcheon and Handegord 1983):

$$M_c = 1/R_c = 1/(R_1+R_2+\ldots R_n)$$

where

R = $1/M = R / F$,

M_c = permeance, ng/Pa·s·m^2,

R = thickness of material, m,

F = permeability, ng/ s·m·Pa,

R = resistance, s·m^2· Pa/ng.

RESULTS AND DISCUSSION

This study has been designed to gather data under specific test conditions. It does not replicate how walls will perform in the field. The results cannot be used to determine whether walls built to code in the period from 1985 to 1998 were inadequate in their drying capabilities. Some of the variations from field conditions are as follows:

- The panels in this study were not wetted to simulate the wetting of walls in the field. The wetting procedure used was intended to distribute the moisture in a controlled manner, to apply the same moisture load to all the panels. Panels were not re-wetted during the phases of the test.
- All the wall panels were exposed to the same environmental conditions. These conditions were steady state, rather than representative of real weather data.
- The panels in this study were not subjected to the kind of random wind and air movement of walls in the field. The air movements in the chamber were consistent from panel to panel.
- The panels in this study were not subjected to solar radiation as experienced in the field. A consistent solar cycle was applied equally to all panels.
- The wall panels in this study deal only with the field portion of the typical wall. The wall panels did not include any envelope penetrations (windows, vents, etc.) in the panel assembly.
- The panels in this study were not built with the same kind of airtightness as those in the field and were not subjected to pressure differentials similar to those in the field. All panels were constructed as laboratory specimens with consistent sealing and tested in steady-state conditions with less than 5 Pa (0.02 in.sp.) pressure differential across them.
- The drying regime included steady-state temperature and relative humidity conditions for wintertime in Vancouver only.

Where data have been gathered using resistance type measurements and converted to an estimate of wood moisture content (MC), the normal ranges of accuracy for these measurements apply. Estimates of moisture content in the framing were corrected for species and temperature. In the range of 15% to 25% MC, they are within $\pm$2%. Estimates of moisture content in the OSB and plywood sheathing are an indicator only.

In response to objective 1, drying occurred in all panels. The moisture content in the studs at the time of installation averaged 29% and at the time of removal averaged 12%. There were no test panels in which all locations in all components dried to below 19% moisture content by the end of the test (1500 hours in Phase 1 and 2000 hours in Phase 2). The proposition that panels would dry into the chamber was confirmed by the test, and some panels had substantial moisture loss (see Figures 8 and 9). However, the drying was not uniform over all components of the panels and some of these slower drying areas might have been at risk of decay if the test were to continue indefinitely. No decay was found after the 3500 hours (five months) of testing.

The framing dried on average to below 19% in less than 500 hours in both phases. The OSB and the plywood sheathing generally stayed above 19% moisture content to beyond the end of the test in both phases. Examination of moisture sensor data (not shown here) indicates redistribution of moisture from the framing to the sheathing over the first 500 hours. Once the redistribution is complete, there follows 1500 hours of very slow drying in the panel overall, but in most cases, very little change in the moisture content of the sheathing.

On closer examination, the 38 mm × 89 mm (2 in. × 4 in.) framing, made up of studs and double plates, can be divided into two zones: Zone 1, more than 20 mm (3/4 in.) from the sheathing, and Zone 2, within 20 mm (3/4 in.) of the sheathing. Zone 1 dried to below 19% within 500 hours. Zone 2 dried more slowly than Zone 1. In some panels, Zone 2 in the upper part of the stud dried to below 19% within 1000 hours. However, in the bottom 600 mm of the stud, Zone 2 generally stayed above 19% for over 1500 hours in Phase 1 and over 2000 hours in Phase 2.

Panels with OSB sheathing started Phase 1 with average sheathing moisture content in the 20% to 29% range and finished the test with average moisture content in the 18% to 28% range. Most panels had a drop in average sheathing moisture content of 1% to 3%. The exceptions were Panel 1, which had an increase of 1%, and Panels 2 and 8, which had a drop in average moisture content of 8%. Only the wood-clad panels numbers 8 and 9 had final average moisture contents in their sheathing below 19%. All OSB-sheathed panels had spot moisture content readings in the sheathing of over 30% in the lower areas of the panels.

The plywood-sheathed panels started Phase 1 with higher average sheathing moisture content than the OSB-sheathed panels. The range was 26% to 37% average MC. The plywood-sheathed panels ended Phase 1 with two panels showing no change in average sheathing MC and one panel having an 8% increase in average sheathing MC.

In Phase 2, the panels with OSB sheathing started at a lower MC in the sheathing than in the framing. The average MC in the OSB sheathing started at 23% and, through redistribution of moisture from the studs, rose during the test to finish at 34%. The plywood-sheathed panels started Phase 2 with an average MC in the sheathing of 37%. The plywood-sheathed panels with vented cavities had a decline in sheathing MC and ended the test with average sheathing MC of 27% and 31%. The plywood-sheathed panel with no cavity had an increase in sheathing MC and ended the test with an average sheathing MC of 42%.

Time of drying is an important consideration in assessing effectiveness of a design. Parts of the panels (especially the surface of the studs) dried to below 19% in under 100 hours. This result allows us to speculate that a panel can be designed such that it will dry rapidly in all areas and could therefore tolerate repeated minor wetting.

However, the slow drying that occurred in other parts of the panels indicates that the designs as tested would not be effective at preventing decay by drying if allowed to be wetted to the test levels (see Figure 9). These wall types have to rely on a more perfect deflection and drainage system as well as proper construction quality management practices to avoid trapping moisture during construction.

Addressing objective 2, the following results were found:

1. Panels with cavities dried faster than comparable panels without cavities.
2. Panels with plywood sheathing dried faster than comparable panels with OSB sheathing.
3. There was no substantial difference in the drying rates of panels with building paper vs. panels with spun-bonded polyolefin.
4. Panels with top and bottom vented cavities dried faster than comparable panels with bottom-only vented cavities
5. Panels with wood siding dried faster than comparable panels with stucco cladding in Phase 1; however, this trend was reversed in Phase 2 (with solar).

To address objective 3, three cavity widths (depth from cladding to sheathing protection membrane) were tested—0 mm, 10 mm, and 19 mm (0 in., 3/8 in., and 3/4 in.). Cavity width appears to be a major determinant in affecting drying rates. In both phases, panels with large cavity widths dried faster than panels with small cavity widths.

Addressing objective 4, it was not within the scope of this project to validate computer models. However, we have made some observations on the apparent consistencies and deviations between the predictions of the test using WALLDRY (Onysko 1999) and the data gathered from EDRA. The WALLDRY model was reasonably accurate in its predictions of change in moisture levels in the framing and in the sheathing. The computer model of the outer shell of the stud was consistent with the EDRA data for Zone 1 of the framing (more than 20 mm [3/4 in.] from the sheathing). The model prediction of the inner core of the stud was consistent with the EDRA data for Zone 2 of the framing (within 20 mm [3/4 in.] of the sheathing). The WALLDRY model prediction of the outer layer of the sheathing was consistent with the EDRA data for average sheathing moisture content. The model prediction for the inner layer of the sheathing deviated from the EDRA data. The WALLDRY model predicted lower rates of overall moisture (mass) loss than was found in EDRA over the 1500 hours of the EDRA test (Phase 1).

Addressing objective 5, the overall drying rates of panels can perhaps best be summed up by looking at their effective permeance (Table 6). The effective permeance of the panels was measured for both the nonsolar and solar phases. Calculations in this report were based on total moisture loss over the test period. Further work is planned to examine effective permeance at different stages in the moisture redistribution and drying process.

Several reviewers noted an apparent relationship between water gained and percentage of weight lost and expressed concern that the differences between the panels were not the result of their design but rather the amount of water they had absorbed. In both Phase 1 and Phase 2, the plywood-sheathed panels had a higher initial moisture content in the sheathing and therefore had their initial moisture distributed in a more favorable position to dry than the OSB-sheathed panels. Figure 10 illustrates water gained vs. percentage of weight loss with OSB and plywood-sheathed walls shown separately. For OSB-sheathed walls, there is no relationship between weight gained and percentage of water loss in either Phase 1 or Phase 2. This holds true for plywood-sheathed walls.

The total calculated permeance of the panels ranged from 246 ng/Pa·s to 398 ng/Pa·s (4.3 perms to 7.0 perms). We expected that the effective permeances would be greater in the case of vented cavity panels. This turned out to be correct.

In Phase 1, the effective permeance was greater than the calculated permeance in 10 out of 12 of the panels. In Phase

2, the effective permeance was greater in 11 out of 12 of the panels. In Phase 1, the effective permeance ranged from 0.6 to 3.4 times the calculated permeance. In Phase 2, the effective permeance ranged from 0.9 to 4.2 times the calculated permeance.

The plywood-sheathed panels had higher effective permeance than OSB-sheathed panels. The difference between calculated permeance and effective permeance was heightened in Phase 2 where the solar effect was present. Top- and bottom-vented large cavities showed the greatest effective permeance gain from the solar effect. (It is interesting to note that Panel 7 ran contrary to the trend in Phase 2. After running the experiment, we found that it had a partially blocked vent cavity. This confirms our conclusion that cavity width affects drying and the effective permeance number.)

The total effective permeance of the panels in Phase 2 ranged from 233 ng/Pa·s to 1444 ng/Pa·s (4.0 perms to 25.3 perms) or from 0.9 to 4.2 times the calculated permeance. Panel 11, with stucco, on a 19 mm cavity, bottom vented, with building paper, on plywood sheathing, had the highest total effective permeance at 1444 ng/Pa·s. This provides us with a "benchmark" effective permeance to better with future tests.

Addressing objective 6, the simulated solar condition produced a difference in drying between Phase 1 and Phase 2. The effective permeances were higher with the solar effect. Additionally, there were differences in the final moisture distribution in the sheathing between Phase 1 and Phase 2.

At the end of 1500 hours in Phase 1, both the OSB and plywood sheathing remained close to the same moisture content as at the start of the test. In Phase 2, after 2000 hours (with the solar effect), the moisture content of the OSB in panels with vented cavities had risen an average of 11% while the moisture content in the plywood-sheathed panels with vented cavities had dropped an average of 7.5%.

Part of the differences between the phases could be attributed to the differential in the start points of the moisture content in the framing and the sheathing. The plywood sheathing had 13% higher moisture content than the OSB sheathing at the start of Phase 2. The faster drying rates of the plywood-sheathed panels with cavities may be partly due to the extra moisture in the sheathing being in the best location to dry to the exterior.

The data suggest that moisture was leaving the framing and migrating into the plywood and OSB sheathing. All panels lost moisture during the test. However, in Phase 2, moisture was not leaving the OSB sheathing at the rate it was entering in either the vented or the unvented panels. In the plywood-sheathed panels with vented cavities, the data suggest that moisture was leaving the plywood sheathing at a greater rate than it was entering. Both of these plywood-sheathed panels ended the test with a lower sheathing moisture content (27% and 31%) than they started the test (39% and 34%). Without replicates, these results are not statistically significant. However, the differences do suggest that cavity venting of plywood-sheathed panels (starting at >35% moisture content) has a substantial effect on drying, but that the same venting has less of an effect on drying for OSB-sheathed panels (starting at >25% moisture content).

CONCLUSIONS

The intent of this study was to evaluate the relative drying rates of test panel assemblies under controlled laboratory conditions. Test conditions included wintertime drying to the exterior only. Test panels incorporated polyethylene vapor retarder and sealed poly air barrier construction. The panels were subjected to steady-state conditions of wind, interior to exterior pressure differential, temperature and relative humidity, and a consistent solar regime. Panels were wetted to above 30% moisture content in the framing at the start of the test. There was no rewetting during the test. The conditions of wetting and drying are relevant to the climate and field conditions of walls in Vancouver, but they are not intended to simulate actual wetting in the field. The chamber conditions were chosen to represent a standard test drying regime for the wintertime climate of Vancouver, Canada. Conclusions drawn from the study were:

- Panels with cavities dried faster than comparable panels without cavities.
- Panels with wider cavities dried faster than panels with narrow cavities.
- Panels with top and bottom vented cavities dried faster than comparable panels with bottom-only vented cavities.
- Panels with plywood sheathing dried faster (but also absorbed more initial moisture during panel wetting) than comparable panels with OSB.
- Panels with wood siding dried faster than comparable panels with stucco cladding without solar effect; however, this trend was reversed with solar effect.
- There were no substantial differences in drying rates between panels with building paper and panels with SBPO.
- Many areas of the framing dried to below 19% MC in under 100 hours.
- The area of the framing next to the sheathing did not dry to below 19% in either Phase 1 or Phase 2.
- The sheathing components of the panels stayed above 19% moisture content for the entire test in both phases.
- The sheathing and framing at the bottom of the panel dried more slowly than the other parts of the panel, possibly due to the presence of impervious flashing.
- Generally, the predictions from the WALLDRY model were in reasonably good agreement with the results from the EDRA experiment; however, the EDRA panels lost more overall moisture mass than was predicted by WALLDRY.

The simulated solar regime resulted in the following:

- Little or no effect on panels without cavities.

- An increase in the difference between panels' effective permeance and calculated permeance.
- Panels with bottom venting performing similarly to panels with top and bottom venting, indicating sufficient airflow in the cavities to eliminate the need for large areas of top venting.
- The fastest drying panel with solar effect had an effective permeance of 1444 ng/Pa·s (25.3 perms), a "benchmark" on panel performance for future tests.

RECOMMENDATIONS

Further testing should be conducted in the field of the wall areas and areas of the wall incorporating large concentrations of lumber such as window headers and rim joists. Testing should include

- other cladding systems,
- airtight drywall and vapor retarder > 60 ng/Pa·s·m^2 (1 perm),
- summertime drying conditions,
- innovative wall systems designed to enhance effective permeance.

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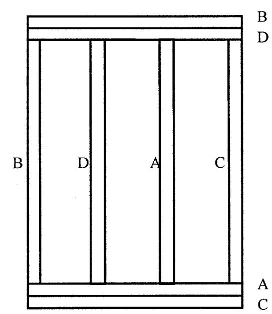

	Max. Drying	Min. Drying
Max. Wetting	A	B
Min. Wetting	C	D

Figure 1 *Distribution of lumber types (in terms of wetting and drying) in each panel.*

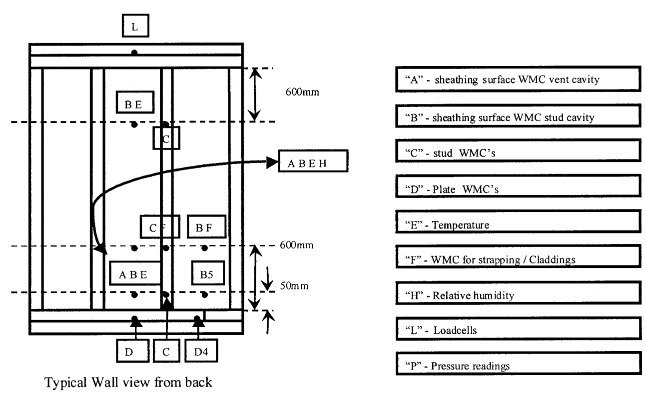

Figure 2 *Typical wall panel locations and details for test points.*

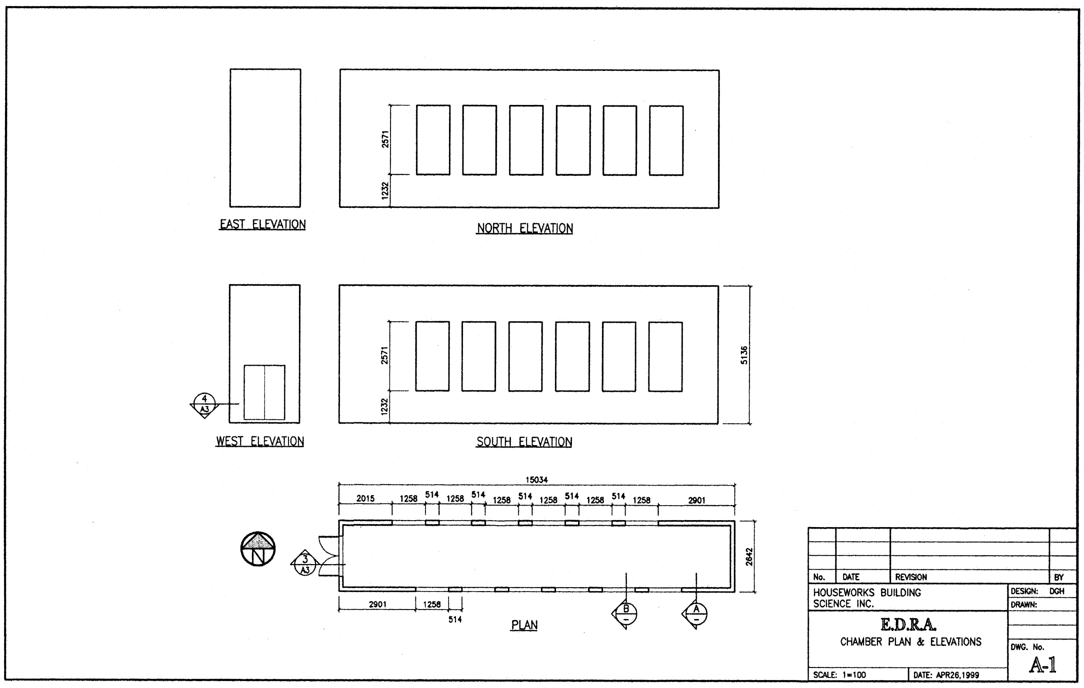

Figure 3 *Chamber plan and elevations.*

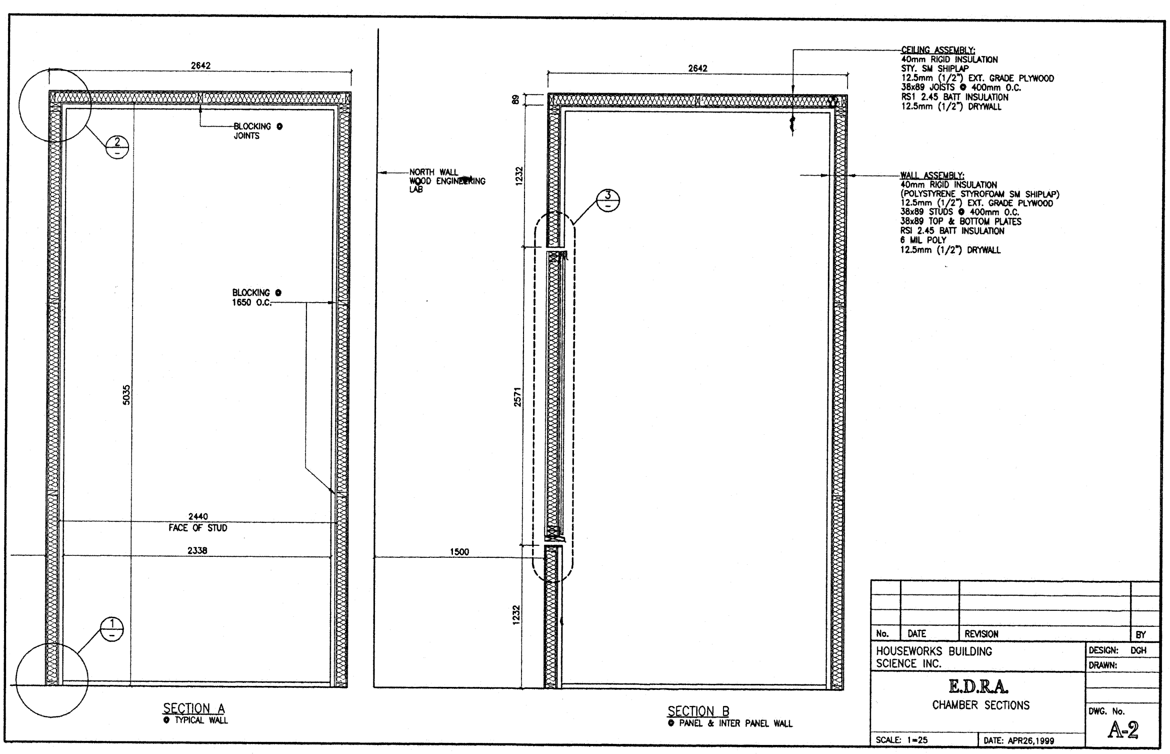

Figure 4 *Chamber sections.*

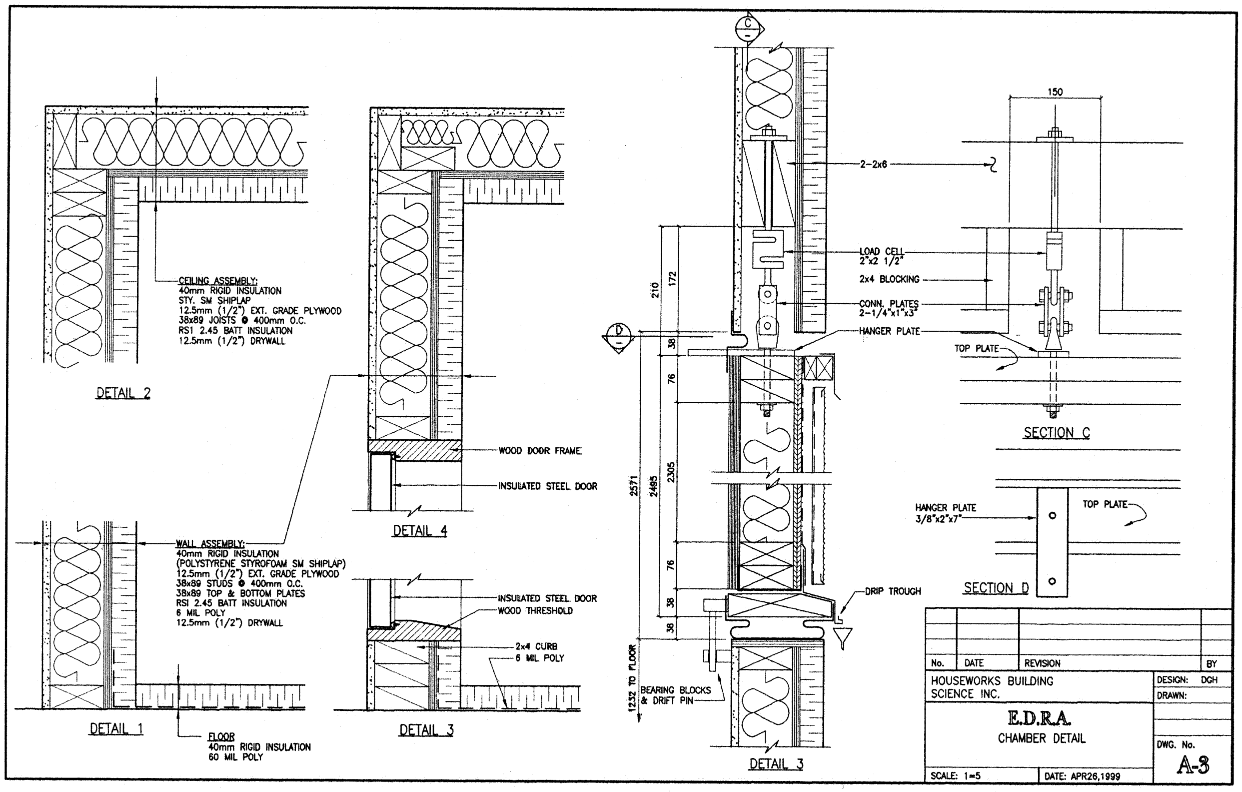

Figure 5 *Chamber details.*

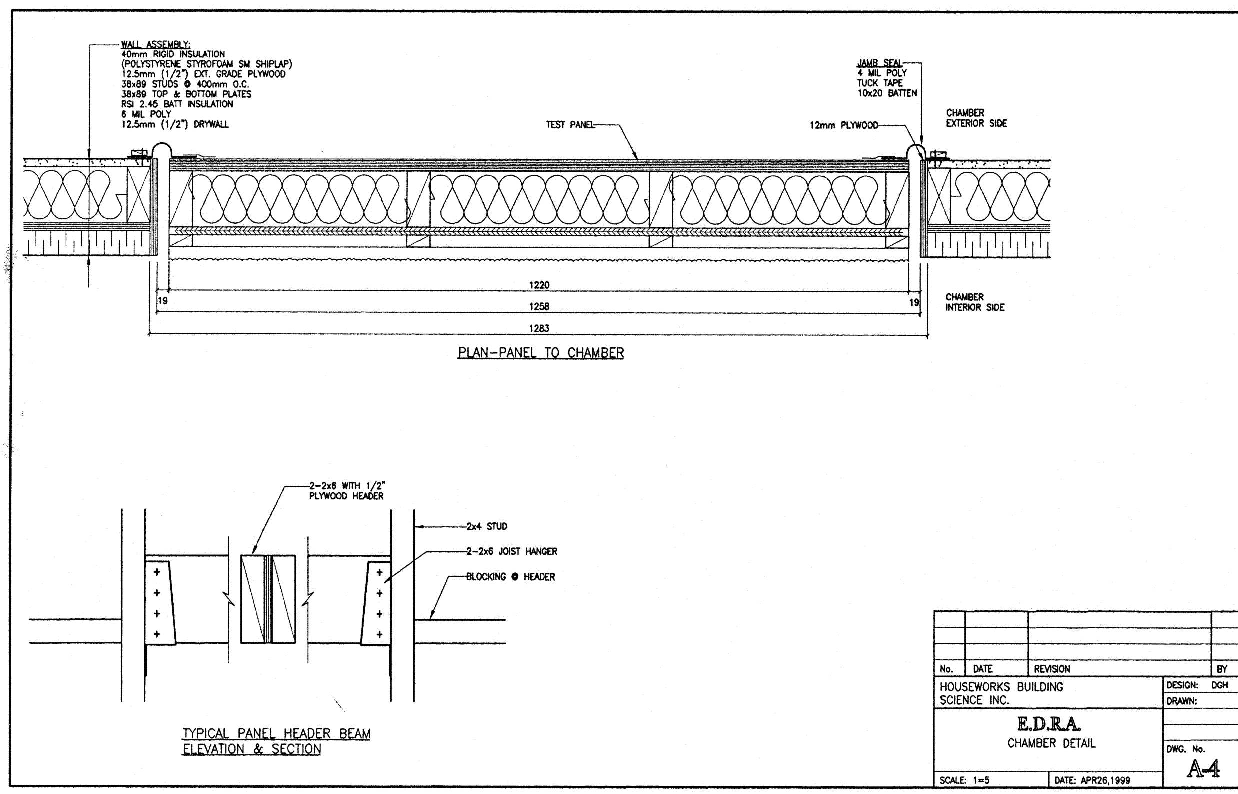

Figure 6 *Chamber details.*

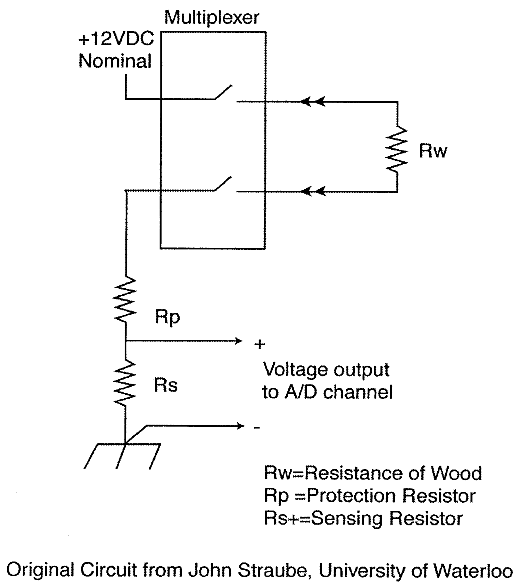

Figure 7 *Resistance measurement circuit from DAS.*

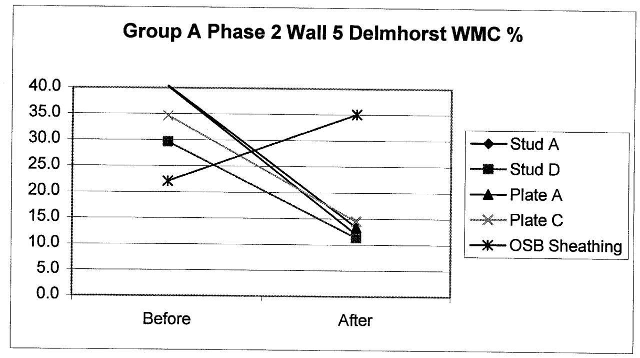

Figure 8 *Moisture content of panel components—before and after drying.*

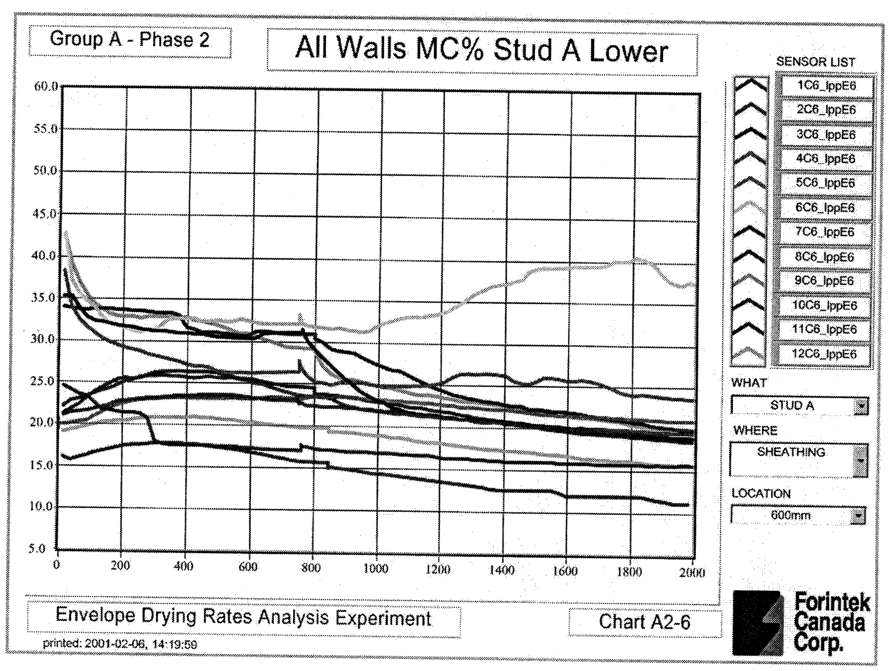

Figure 9 *Change in moisture content, Stud A near sheathing—Phase 2.*

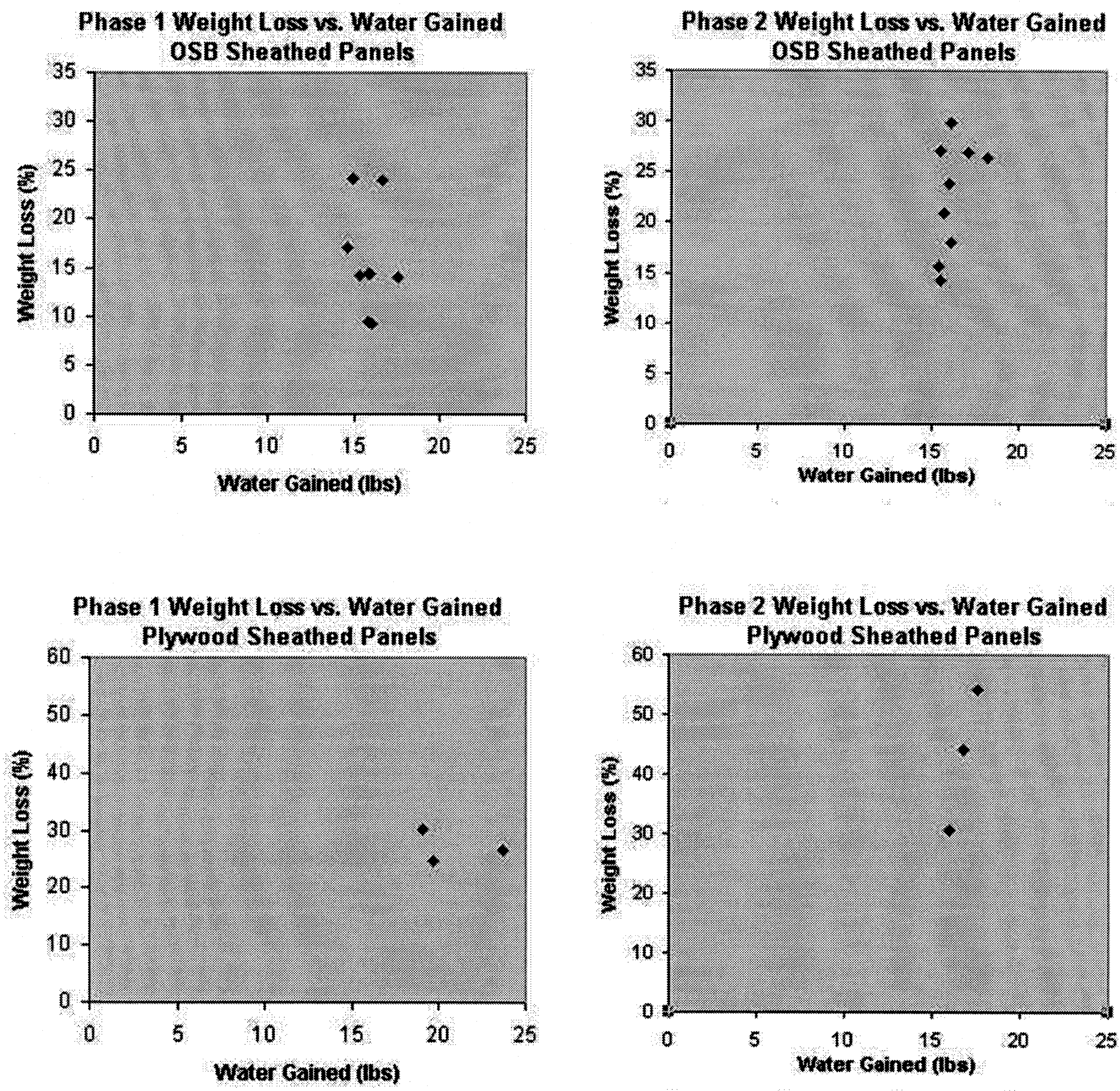

Figure 10 *Relationship between initial water gain and percent water loss in OSB-sheathed panels and plywood-sheathed panels.*

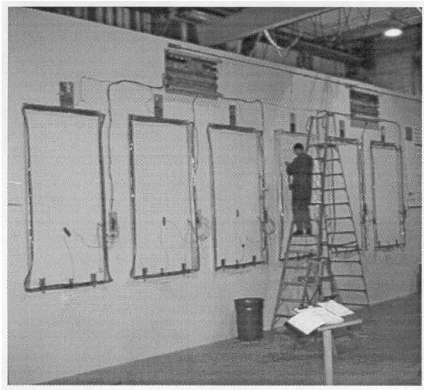

Figure 11 *View of EDRA chamber in lab.*

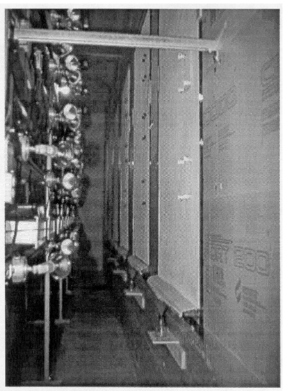

Figure 12 *View of EDRA chamber interior.*

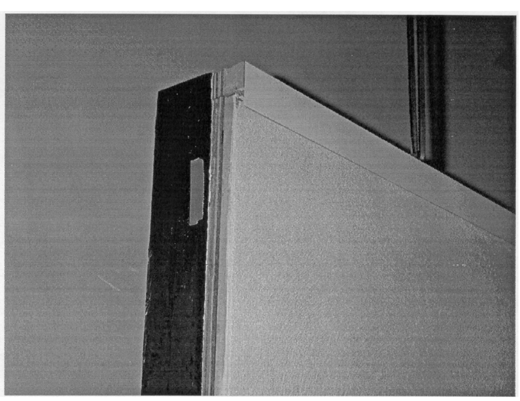

Figure 13 *Stucco cladding on test panel.*

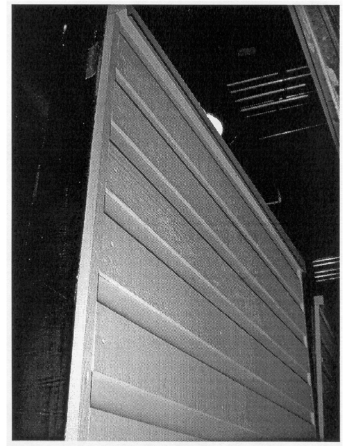

Figure 14 *Wood cladding on test panel.*

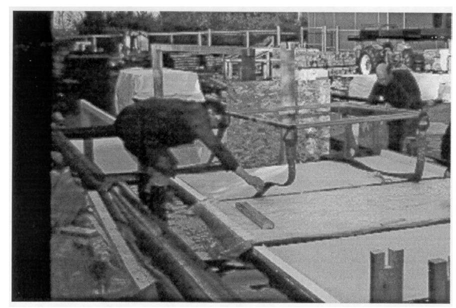

Figure 15 *Panel being removed from wetting tanks.*

Figure 16 *Panel being inserted in test chamber.*

TABLE 1
Group A—12 Test Panels' Specifications (Panel Numbers Shown as #*n*)

	Venting Location					
Insulation **1**	No Vent	No Vent	Bottom Only	Bottom Only	Top & Bottom	Top & Bottom
Venting % **2**	0%	0%	0.8%	0.8%	0.8% and 0.8%	0.8% and 0.8%
Cavity Size, mm (in.)	Bldg. Paper **3**	SBPO **4**	Bldg. Paper **3**	SBPO	Bldg. Paper **3**	SBPO
0	#1. Stucco **5** on OSB **6**	#2. Stucco on OSB				
10 (3/8)					#7. Stucco on OSB	
19 (3/4)			#3. Stucco on OSB	#4. Stucco on OSB	#5. Stucco on OSB	#6. Stucco on OSB
0	#8. Wood **8** on OSB					
19 (3/4)			#9. Wood on OSB			
0	#10. Stucco on Plywood **7**					
10 (3/8)					#12. Stucco on Plywood	
19 (3/4)			#11. Stucco on Plywood			

1. All panels had RSI 2.45 (R-14) friction fit glass-fiber batt insulation.
2. Venting % = the face area of the vent / the area of the panel × 100.
3. Two layer 30-minute asphalt-impregnated kraft paper.
4. All SBPO was one-layer, continuous sheet with no laps.
5. All stucco was from the same batch of sand cement lime mix, 21 mm (7/8 in.) three-coat application; the finish coat was sand cement lime with integral color (no acrylic).
6. OSB indicates 11.5 mm (15/32 in.) OSB sheathing fixed directly to the framing.
7. Plywood indicates 12.5 mm (1/2 in.) plywood sheathing fixed directly to the framing.
8. Wood indicates 19 mm × 140 mm (3/4 in. × 6 in.) channel profile, western red cedar siding, backprimed and stained with a solid color stain.

TABLE 2
Handheld Moisture Reading Summary—Group A, Phases 1 and 2

Group A—Phase 1, No Solar				
	All Panels Average % MC*		All Panels Median % MC	
	Before†	After†	Before†	After†
Stud A	30.5	12.5	29.3	12.7
Stud D	26.4	11.9	26.8	11.8
Studs A & D	28.5	12.2	28.1	12.2
Plate A	31.3	13.7	31.3	13.8
Plate C	25.7	15.5	26.2	15.7
Plates A & C	28.5	14.6	28.7	14.8
OSB Sheathing	24.6	22.1	24.3	21.0
Plywood Sheathing	31.0	33.4	29.6	26.5
All Sheathing	27.8	27.7	26.9	28.8

Group A—Phase 2, with Solar				
	All Panels Average % MC*		All Panels Median % MC	
	Before†	After†	Before†	After†
Stud A	39.5	11.6	39.1	11.8
Stud D	34.0	11.2	33.5	11.3
Studs A & D	36.7	11.4	36.3	11.6
Plate A	37.5	13.8	38.1	13.6
Plate C	34.8	15.1	34.3	14.9
Plates A & C	36.2	14.4	36.2	14.3
OSB Sheathing	23.0	34.0	23.0	34.1
Plywood Sheathing	36.7	33.1	37.1	30.9
All Sheathing	29.8	33.6	30.0	32.5

* MC = moisture content, readings taken with handheld resistance-type meter set for SPF at 21ºC.
† Readings taken before installation in chamber and after removal from chamber.

TABLE 3
Group A—Phases 1 and 2: Pre- and Post-Test Wall Panel Weights

Phase 1—No solar

Wall no.	Total wet weight (kg)	Total wet weight (lb)	Water gained (kg [lb])	Removal weight (kg)	Removal weight (lb)	Total water loss * (kg [lb])	Total % weight loss †
1	198.95	438.6	7.26 (16.0)	198.27	437.1	0.68 (1.5)	9.3
2	217.36	479.2	7.17 (15.8)	216.32	476.9	1.04 (2.3)	14.4
3	227.48	501.5	6.62 (14.6)	226.34	499.0	1.13 (2.5)	17.0
4	217.36	497.2	7.17 (15.8)	216.68	477.7	0.68 (1.5)	9.4
5	227.25	501.0	7.53 (16.6)	225.44	497.0	1.81 (4.0)	24.0
6	228.25	503.2	7.94 (17.5)	227.11	500.7	1.13 (2.5)	14.1
7	210.97	465.1	7.21 (15.9)	209.92	462.8	1.04 (2.3)	14.4
8	101.88	224.6	6.94 (15.3)	100.88	222.4	1.00 (2.2)	14.2
9	105.87	233.4	6.76 (14.9)	104.24	229.8	1.63 (3.6)	24.1
10	205.21	452.4	8.94 (19.7)	202.98	447.5	2.22 (4.9)	24.8
11	226.48	499.3	8.66 (19.1)	223.85	493.5	2.63 (5.8)	30.3
12	225.89	498.0	10.75 (23.7)	223.03	491.7	2.86 (6.3)	26.5

Phase 2—With solar

Wall no.	Total wet weight (kg)	Total wet weight (lb)	Water gained (kg [lb])	Removal weight (kg)	Removal weight (lb)	Total water loss* (kg [lb])	Total % weight loss†
1	200.58	442.2	7.12 (15.7)	199.08	438.9	1.50 (3.3)	21.0
2	218.77	482.3	7.30 (16.1)	217.45	479.4	1.32 (2.9)	18.0
3	229.61	506.2	7.26 (16.0)	227.88	502.4	1.73 (3.8)	23.8
4	219.99	485.0	7.76 (17.1)	217.91	480.4	2.09 (4.6)	26.9
5	229.02	504.9	7.03 (15.5)	227.11	500.7	1.91 (4.2)	27.1
6	231.11	509.5	8.26 (18.2)	228.93	504.7	2.18 (4.8)	26.4
7	213.14	469.9	7.03 (15.5)	212.15	467.7	0.99 (2.2)	14.2
8	103.01	227.1	6.99 (15.4)	101.92	224.7	1.09 (2.4)	15.6
9	107.95	238.0	7.30 (16.1)	105.78	233.2	2.18 (4.8)	29.8
10	205.70	453.5	7.26 (16.0)	203.48	448.6	2.22 (4.9)	30.6
11	228.84	504.5	7.98 (17.6)	224.53	495.0	4.31 (9.5)	54.0
12	224.85	495.7	7.62 (16.8)	221.49	488.3	3.36 (7.4)	44.0

* Fully assembled panel weight prior to testing less fully assembled panel weight after testing.
† Total % weight loss = total water loss / water gained × 100.

TABLE 4
Group A—Phases 1 and 2: All Panels—Sorted by % Weight Loss*

Phase 1—No solar							
Wall No.	**Sheathing**	**Membrane**	**Cavity (mm [in.])**	**Venting***	**Cladding**	**Weight Loss (%)†**	**Relative Drying Factors‡**
11	Plywood	Paper	19 (3/4)	B	Stucco	30.3	3.3
12	Plywood	Paper	10 (3/8)	T&B	Stucco	26.5	2.9
10	Plywood	Paper	0	0	Stucco	24.8	2.7
9	OSB	Paper	19 (3/4)	B	Wood	24.1	2.6
5	OSB	Paper	19 (3/4)	T&B	Stucco	24.0	2.6
3	OSB	Paper	19 (3/4)	B	Stucco	17.0	1.8
2	OSB	SBPO	0	0	Stucco	14.4	1.6
7	OSB	Paper	10 (3/8)	T&B	Stucco	14.4	1.5
8	OSB	Paper	0	0	Wood	14.2	1.5
6	OSB	SBPO	19 (3/4)	T&B	Stucco	14.1	1.5
4	OSB	SBPO	19 (3/4)	B	Stucco	9.4	1.0
1	OSB	Paper	0	0	Stucco	9.3	1.0

Phase 2—With solar							
Wall No.	**Sheathing**	**Membrane**	**Cavity (mm)**	**Venting***	**Cladding**	**Weight Loss (%)†**	**Relative Drying Factors‡**
11	Plywood	Paper	19 (3/4)	B	Stucco	54.0	2.6
12	Plywood	Paper	10 (3/8)	T&B	Stucco	44.0	2.1
10	Plywood	Paper	0	0	Stucco	30.6	1.5
9	OSB	Paper	19 (3/4)	B	Wood	29.8	1.4
5	OSB	Paper	19 (3/4)	T&B	Stucco	27.1	1.3
4	OSB	SBPO	19 (3/4)	B	Stucco	26.9	1.3
6	OSB	SBPO	19 (3/4)	T&B	Stucco	26.4	1.3
3	OSB	Paper	19 (3/4)	B	Stucco	23.8	1.1
1	OSB	Paper	0	0	Stucco	21.0	1
2	OSB	SBPO	0	0	Stucco	18.0	0.9
8	OSB	Paper	0	0	Wood	15.6	0.7
7	OSB	Paper	10 (3/8)	T&B	Stucco	14.2	0.7

* B = venting bottom only, T and B = venting top and bottom.
† See definition 2, Table 3.
‡ Relative drying factor = weight loss % wall n/ weight loss % wall 1.

TABLE 5
Moisture Readings in Wall Panels at Installation and Removal*

Wall #	Stud A Before	Stud A After	Stud MC Change	Sheathing Before	Sheathing After	Sheathing Change	Panel Weight Loss (g)	Panel % Weight Loss
Group A—Phase 1, No solar								
OSB-sheathed walls:								
1	29	13	-16	25	26	1	681	9
2	39	13	-26	32	22	-10	1044	14
3	29	12	-17	24	22	-2	1135	17
4	32	12	-20	22	18	-4	681	9
5	31	12	-19	22	21	-1	1816	24
6	28	12	-16	29	28	-1	1135	14
7	29	13	-16	21	21	0	1044	14
8	29	13	-16	27	20	-7	999	14
9	34	13	-21	20	19	-1	1634	24
Average	**31**	**13**	**-19**	**25**	**22**	**-3**	**1130**	**16**
Plywood sheathed walls:								
10	28	13	-15	37	37	0	2225	25
11	30	12	-18	27	27	0	2633	30
12	28	13	-15	30	37	7	2860	27
Average	**29**	**13**	**-16**	**31**	**34**	**2**	**2573**	**27**
Average all walls, Phase 1	**31**	**13**	**-18**	**26**	**25**	**-2**	**1491**	**19**
Group A—Phase 2, with solar								
OSB-sheathed walls:								
1	39	12	-27	24	33	9	1498	21
2	48	12	-36	25	33	8	1317	18
3	39	12	-27	23	36	13	1725	24
4	40	12	-28	23	34	11	2088	27
5	40	12	-28	22	35	13	1907	27
6	41	12	-29	25	35	10	2179	26
7	38	12	-26	21	31	10	999	14
8	43	12	-31	21	36	15	1090	16
9	39	12	-27	22	34	12	2179	30
Average	**41**	**12**	**-29**	**23**	**34**	**11**	**1665**	**23**
Plywood sheathed walls:								
10	36	11	-25	37	42	5	2225	31
11	38	11	-27	39	27	-12	4313	54
12	35	11	-24	34	31	-3	3360	44
Average	**36**	**11**	**-25**	**37**	**33**	**-3**	**3299**	**43**
Average all walls, Phase 2	**40**	**12**	**-28**	**26**	**34**	**8**	**2073**	**28**

* Handheld moisture readings taken with resistance-type meter set for SPF at 21ºC.

TABLE 6
Calculated Permeance vs. Effective Permeance (ng/Pa·s)

Panel #	Total Calculated Permeance	Total Effective Permeance Over 1500 hrs	Total Effective Permeance Over 2000 hrs
	Phases 1 and 2	Phase 1, no solar	Phase 2, with solar
1	296	259	396
2	389	486	472
3	265	326	389
4	337	199	408
5	265	787	504
6	337	389	537
7	266	359	233
8	249	331	252
9	246	364	557
10	398	768	1014
11	344	1175	1444
12	346	1030	990

Calculated Permeance vs. Effective Permeance (grains/[h] [in. Hg])

Panel #	Total Calculated Permeance	Total Effective Permeance Over 1500 hrs	Total Effective Permeance Over 2000 hrs
	Phases 1 and 2	Phase 1, no solar	Phase 2, with solar
1	5.2	4.5	6.9
2	6.8	8.5	8.3
3	4.6	5.7	6.8
4	5.9	3.5	7.1
5	4.6	13.8	8.8
6	5.9	6.8	9.4
7	4.6	6.3	4.1
8	4.4	5.8	4.4
9	4.3	6.4	9.7
10	7.0	13.4	17.7
11	6.0	20.6	25.3
12	6.1	18.0	16.5