Technical Series 01-139

The Envelope Drying Rates Analysis Study

INTRODUCTION

The Envelope Drying Rates Analysis (EDRA) Study was conducted as part of the program of the Building Envelope Research Consortium (BERC), an industry/government consortium led by Canada Mortgage and Housing Corporation (CMHC), British Columbia Housing Management Commission (BCHMC) and the Homeowner Protection Office (HPO) of British Columbia. In 1998, CMHC published the *Best Practice Guide for Wood-Frame Envelopes in the Coastal Climate of British Columbia*; the central design thesis of which is that walls have to manage moisture by a combination of, Deflection, Drainage, Drying and Durability. Deflection, drainage and durability has been studied but relatively little attention has been paid to the effect of wall design on drying rates. 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 within the wall assembly if drying does not occur. Therefore, there is a need to know to what extent drying can contribute to our overall moisture management plan for wall designs.

RESEARCH PROGRAM

The test methodology consisted of fabricating, wetting and installing test wall assemblies into a climate conditioned test chamber for up to three months to measure the drying rate of each wall panel. The wall assemblies were tested concurrently within the test chamber ensuring the drying forces were identical for all panels. A lumber sorting procedure was developed to mitigate the natural variability of wetting and drying of wood used in the panels, handicapping the panels equally such that the differences in their drying rates could only be attributed to their designs.

This research was undertaken by Forintek Canada Corp at their western laboratory in Vancouver, B.C. The project was financially supported by a consortium including: Canada Mortgage and Housing Corporation, Forintek Canada Corp, the BC Homeowner Protection Office, BC Housing, Dupont, HAL Industries, Canadian Wood Council and Polygon Homes Ltd. Material donations to the project were provided by B.C.Wall & Ceiling Association, the Structural Board Association, CanPly and Richmond Plywood Corporation.

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 typical Vancouver winter climate condition; 5°C (41°F) at 70% R.H.

The following specific objectives were addressed in the study:

1. Determine how long specimen wall panels, wetted to a moisture content (MC) exceeding 25%, under test conditions and without re-wetting, take to dry out.
2. Determine which test wall panels dry faster than others, and what the variations in drying rates are between the test panels.
3. Determine if the drainage cavity width affects drying, and by how much.
4. Determine the correlation between the predicted moisture movement within the framing lumber and the sheathing (using CMHC's WALLDRY computer model) and the actual moisture movement.
5. Compare the calculated permeance to the effective permeance.
6. Compare the effect of the solar simulation on the drying rates of the test wall panels.

The Test Facility and Environmental Conditions

A twelve-panel test chamber with exterior dimensions of 2.6 m wide by 5.1 m high by 15 m long was constructed inside the Forintek Wood Engineering Laboratory. The interior of the chamber was conditioned to 5°C and 70% RH with a temperature and RH variance of ±1.5°C and ±5%, respectively. The exterior of the chamber (the lab space) was conditioned to 20°C and had an average RH of 40%. Within the chamber, the HVAC diffusers directed a continuous air-flow of 1 m/sec (3 ft/sec) towards the lower half of the panels. This airflow induced a pressure differential of 1 to 5 Pa between the top and bottom of the panel.

The testing program was carried out in two phases. During the Phase 1 test, the wall assemblies were exposed to complete darkness within the test chamber. In Phase 2, a solar effect, simulating a Vancouver northern exposure, was employed for only eight continuous hours in a 24-hour cycle. The goal of the solar cycle was to achieve a combined ambient and solar temperature of up to 15°C at the surface of the test panels.

Test Panels

The following describes the construction of the 1,220 mm by 2,440 mm test wall panels:

1. The panel framing (studs, baseplates and top-plates) was nominal 38 mm x 89 mm J Grade Lodgepole Pine. The exterior perimeter of the framing was sealed with vapour impermeable roofing membrane (to prevent moisture movement through the edges of the panels).
2. Sheathing board comprised either 11.5 mm oriented strand board (OSB) sheathing or 12.5 mm Canadian Softwood Plywood (CSP) sheathing applied horizontally; a 3 mm horizontal gap was included at panel mid-height. 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, obtained from a single mill on the coast of British Columbia.
3. All panels were insulated in the stud space with RSI 2.45 glass fiber friction fit insulation.

Table 1 Group A - 12 Test Panel Assemblies

	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% & 0.8%**	**0.8% & 0.8%**
Cavity Size mm (in)	Bldg Paper[3]	SPBO[4]	Bldg Paper[3]	SPBO	Bldg Paper[3]	SPBO
0	Panel #1. Stucco[5] on OSB[6]	Panel #2. Stucco on OSB				
10 (3/8)					#7. Stucco on OSB	
19 (3/4)			Panel #3. Stucco on OSB	Panel #4. Stucco on OSB	Panel #5. Stucco on OSB	Panel #6. Stucco on OSB
0	Panel #8. Wood Siding[8] on OSB					
19 (3/4)			Panel #9. Wood Siding[8] on OSB			
0	Panel #10. Stucco[7] on Plywood					
10 (3/8)					Panel #12. Stucco on Plywood	
19 (3/4)			Panel #11. Stucco on Plywood			

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1. all panels fitted with RSI 2.45 (R 14 friction fit glass fibre batt insulation)
2. venting % = the face area of the vent / the area of the panel x 100
3. two layers 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”) three coat application, the finish coat was sand cement lime with integral colour, (no acrylic)
6. all OSB sheathing, 11.5mm (15/32”) thick, fastened directly to the framing
7. all Plywood sheathing, 12.5 mm (1/2”) thick, Canadian Softwood Plywood fastened directly to the framing
8. wood siding, 19 mm X 140 mm (3/4”X6”) channel profile, western red cedar, backprimed and stained with a solid colour stain.

4. A polyethylene (Type 1 vapour barrier) sheet and 12.5 mm (CSP) plywood sheathing with painted interior surface was applied to the interior surfaces of the framing. The plywood (in lieu of conventional gypsum wall board) provided the required stiffness needed for panel transport and installation into and out of the chamber. The polyethylene ensured drying occurred into the chamber. The interior paint mitigated moisture transport into or out of the interior plywood sheathing due to the laboratory environmental conditions.
5. Breather type sheathing membranes comprised of either two layers 30 minute asphalt impregnated building paper (lapped as per field application) or one layer spun bonded polyolefin.
6. For those panels with air cavities between the sheathing membrane and the cladding, the cavities were created with either 19 mm x 38 mm CCA treated plywood furring @ 400 mm o.c., or 10 mm x 38 mm CCA treated plywood furring @ 400 mm o.c. The furring was applied vertically, directly opposite the studs. 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.

Panel Cladding

Group A panels comprised of 12 wall assemblies as described in Table 1. Ten panels had stucco cladding and two had cedar siding. Stucco cladding was applied according to the standard 21 mm 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.

Test Procedure

Phase 1 - Panels Drying Without Solar Effect

1. Test panel framing, sheathing, sheathing membrane and cladding were assembled. Sensors, located outboard of the sheathing, were installed as were the wood moisture sensors in the stud cavity. The initial mass of the assembly was then recorded; panels weighed in the order of 231 Kg.
2. Panels were immersed studs down into a shallow tank of water (ensuring the sheathing did not come into direct contact with the water) in order to wet the studs and plates to a moisture content of 25-30% by weight and the sheathing to a moisture content of 20 to 25%. After removal from the tank, panels were laid horizontally on dunnage for one hour to drain off excess water. Panels were weighed following the wetting process.
3. The interior plywood finish, polyethylene vapour barrier, insulation, RH and Temperature sensors were weighed separately and installed on the panels. The instrumentation cabling was routed through an air-tight drywall electrical box and the polyethylene vapour barrier sealed to the wood framing. Finally, the weight of the fully assembled panels was taken using a calibrated load cell.
4. The test panels were inserted into the pre-conditioned test chamber; cladding side facing into the chamber. The instrumentation was connected to the Data Acquisition System (DAS) within one hour of the panel being inserted into the chamber. The chamber-mounted load cell is used to once again measure the initial weight of the fully assembled test panel.
5. Panels were subjected to total darkness (No Solar) and continuous wind effect (to achieve 1 to 5 Pa pressure difference between the top and bottom of the panels). Panels were monitored in the chamber for 1,500 hours. Readings were taken from all sensors every 15 minutes.
6. After 1,500 hours, the instrumentation was disconnected from the DAS and the panels were removed from the test chamber. Each panel was weighed. The interior plywood finish, insulation and polyethylene vapour barrier was then removed and weighted. The bare panel was also weighed.
7. Experiment phase complete.

Phase 2 - Panels Drying With Solar Effect

The Phase 2 testing procedure follows Steps 1 through 6, as outlined above, except that a solar effect was introduced into step 5, as follows:

Light sources provided an even distribution of solar load onto the test panels during an eight hour period in a 24 hour cycle. The solar loads simulated the conditions typically found on a north wall exposure, in Vancouver, during the winter months. Light intensity was increased from 0 to 120 Watts/m^2 during the first three hours, maintained at 120 watts/m^2 for two hours and then gradually dimmed to 0 watts/m^2 over the next three hours. The test panels remained in total darkness for 16 hours. This cycle repeated itself for the 2,000 hours of the test.

LIMITATIONS

This experiment has been designed to gather performance 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 specific variations between the experiment and field conditions are as follows:

- The test panels were not wetted to simulate the manner in which wetting of walls occurs in the field. The wetting procedure used was intended to distribute the moisture in a controlled manner and to apply the same moisture load to all the panels. Panels were wetted only once, at the start of each phase of the experiment; panels were not re-wetted during the test.
- All the wall panels were tested concurrently to steady-state environmental conditions; not "real" weather conditions.
- The panels in this study were not subjected to air movements representative of wind loads and gusts. Air currents of 5m/s were directed at all the test panels to induce a 1 to 5 Pa pressure differential between the bottom of the panel and the top of the 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 test panels were representative of the "field" portion of a typical wall. The wall panels did not include any envelope penetrations (such as windows, vents, balconies, etc) in the panel assembly.
- The test panels were air-tight assemblies. The drying (or wetting) performance of walls due to air leakage into or out of the wall assemblies was not investigated in this test program.
- The environmental test conditions included a steady state temperature and relative humidity, 5°C and 70%, respectively, representing a typical Vancouver winter condition.

FINDINGS

Objective 1: Drying occurred in all panels.The moisture content in the studs at the time of installation averaged 29%, drying to an average 12% moisture content at the time of removal from the chamber. There were no test panels in which all panel locations and all panel components dried to below 19% moisture content by the end of the test; in either Phase 1 (1,500 hours) or Phase 2 (2,000 hours). The proposition that panels would dry into the chamber was confirmed by the test; some panels demonstrating substantial moisture loss. However, the drying was not uniform over all components of the panels. Some of these slower drying components may, as a result of prolonged exposure, be at risk of decay.

The framing dried, on average, to below 19% moisture content in less than 500 hours in both phases. On the other hand, the OSB and the plywood sheathing generally stayed above 19% moisture content through to the end of the test, in both phases. An examination of moisture sensor data indicated a redistribution of moisture from the framing to the sheathing over the first 500 hours, followed by very slow panel drying over the following 1,500 hours. In most cases, there was very little change in the moisture content of the sheathing.

The 38 mm x 89 mm framing (studs and double sill and top plates) can be divided into two zones; Zone 1, more than 20 mm from the sheathing and Zone 2, within 20 mm of the sheathing. Zone 1 dried to below 19% moisture content within 500 hours. Zone 2 dried slower than Zone 1. In some panels, Zone 2 in the upper part of the stud dried to below 19% within 1,000 hours. However, in the bottom 600 mm of the stud, Zone 2 generally stayed above 19% for over 1,500 hours in Phase 1 and over 2,000 hours in Phase 2.

Changes in Sheathing Moisture Content

Panels with OSB sheathing started Phase 1 with average sheathing moisture contents in the 20% to 29% range and finished the test with averages in the 18% to 28% moisture content range. Most panels experienced a drop in the average sheathing moisture content of 1% to 3%. The exceptions were Panel 1, which had an increase of 1% moisture content and Panels 2 and 8, which had a drop in average moisture content of 8%. Only the wood-clad assemblies, Panel 8 and Panel 9, exhibited final average sheathing moisture contents below 19%. All OSB-sheathed panels showed handheld moisture content readings in the sheathing exceeding 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 average moisture content range was 26% to 37% in the plywood-sheathed panels. At the end of the Phase 1 test, two plywood-sheathed panels showed no change in average sheathing moisture content and one panel showed an 8% increase in average sheathing moisture content. In Phase 2, the OSB sheathing started at a lower moisture content than the framing, at 23% then, through redistribution of moisture from the studs, rose to finish at 34%. The plywood-sheathed panels started Phase 2 with an average moisture content in the sheathing of 37%. The two plywood-sheathed panels with vented cavities had a decline in sheathing moisture content and ended the test with average sheathing moisture content of 27% and 31%. The plywood-sheathed panel with no cavity had an increase in sheathing moisture content and ended the test with an average sheathing moisture content of 42%.

Objective 2: The following drying rates and differences 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).

One concern was an apparent relationship between water gained and percentage of weight loss and whether the differences between the panels were not the result of their design but the amount of water they had absorbed. In both Phase 1 and Phase 2, the plywood sheathing absorbed more moisture than OSB, thereby starting at a higher initial moisture content.The initial moisture in the plywood was also distributed in a more favorable position to dry than the OSB sheathed panels. For both OSB and plywood sheathing, there is no relationship between weight gained and percentage of water loss in either Phase 1 or Phase 2 results; that is, the percentage of weight loss within the group of panels with similar sheathing types was independent of the water gained. The variation between the panels with the same sheathing is attributable to their design differences and the initial location of moisture.

Objective 3: Three cavity widths (the air space between the cladding and the sheathing membrane) were tested; 0 mm, 10 mm and 19 mm. Cavity width appears to be a major determinant in affecting drying rates. In both Phase 1 and Phase 2, panels with large cavity widths dried faster than panels with small cavity widths.

Objective 4: The WALLDRY model was found to be reasonably accurate in its predictions of change in moisture levels in the framing and in the sheathing. Consistency in the moisture contents between the computer model predictions and the EDRA test results were found in the following areas:

- Outer shell of the stud framing in Zone 1, more than 20 mm from the sheathing
- Core of the stud framing in Zone 2, within 20 mm from the sheathing, and
- The outer layer of the sheathing board

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 1,500 hours of the EDRA test (Phase 1).

Objective 5: The calculations of effective permeance of the panels for both the non-solar and solar phases were based on total moisture loss over the duration of the test period; 1,500 hours for Phase 1 and 2,000 hours for Phase 2. The results are provided in Table 2. The total calculated permeance of the panels (based on published data for the materials used in the experiment) ranged from 246 ng/Pa.sec to 398 ng/Pa.sec.

Table 2 Calculated Permeance vs Effective Permeance ng/Pa•sec

Panel #	Total Calculated Permeance	Total Effective Permeance Over 1500 hrs	Total Effective Permeance Over 2000 hrs
	Phase 1 & 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

Given that Phase 1 and Phase 2 results are based on different time scales, it would not be appropriate to make a direct comparison of effective permeance between the two. More analysis would be required to compare the change in drying rates over time as the panels go through the three stages of drying: initial drop (0 to 100 hours); redistribution (100 hours to 500 hours) and final drying (after 500 hours).

The plywood-sheathed panels had higher effective permeance than OSB-sheathed panels with the differences as noted in Objective 2.

Panels with vented cavities generally showed higher effective permeances than unvented panels. Top and bottom vented large cavities showed the greatest effective permeance gain due to the solar effect. It is interesting to note that Panels 7 and 12 (stucco walls with a 10 mm cavity with OSB and Plywood sheathing, respectively) performed contrary to the trend in the Phase 2 test. Both panels began the experiment with a planned 10 mm cavity. After the experiment was completed, it was observed that the cavity widths were significantly less than the 10 mm desired. This confirms that cavity width affects drying and the effective permeance value.

The total effective permeance of the panels in Phase 2 ranged from 233 ng/Pa.sec to 1,444 ng/Pa.sec or from 0.9 to 4.2 times the calculated permeance. Panel 11, (stucco, 19 mm cavity, bottom vented, with building paper on plywood sheathing) had the highest total effective permeance at 1,444 ng/Pa.sec; a “benchmark” effective permeance to aim for and exceed with future tests.

Objective 6: Overall, the drying performance of the wall assemblies was not significantly affected by the application of a solar load. However the final moisture contents in the sheathings varied between Phase 1 and Phase 2. At the end of the Phase 1 test (1,500 hours), both the OSB and plywood sheathing finished close to the same moisture content they started with. In Phase 2, after 2,000 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 starting points in moisture content in the framing and the sheathing.

The data suggests 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. For the plywood-sheathed panels with vented cavities, the data suggests 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%, respectively). However, the differences do suggest that cavity venting of plywood-sheathed panels (starting at >35%MC) 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%MC).

IMPLICATIONS FOR THE HOUSING INDUSTRY

It is estimated that rain falling on a wall in Vancouver can amount to over 400 kg/m^2 per year. Should moisture penetrate the envelope, the maximum effective permeance observed in this study drying could remove <1% of this. Therefore 99% of the moisture has to be managed by deflection and drainage. The results of this study confirm that builders and designers should follow the 4-D principles of the *Best Practice Guide* with particular emphasis on deflection and drainage. However, they also demonstrate that the use of rainscreen cavities to improve deflection (by reducing pressure differentials) and drainage, also contributes to drying.

In order for drying to be effective, builders and designers should:

- Employ rainscreen cavities with a minimum width of 19 mm.
- Provide for venting and drainage at the bottom and a small amount of venting at the top of cavities.
- Consider relocating impermeable cross-cavity flashings away from the rim joist areas of a wall where high concentrations of lumber can store larger quantities of water.
- Consider using vapour permeable flashings around windows and doors where higher concentrations of lumber can store larger quantities of lumber.

ADDITIONAL RESEARCH NEEDS

Further research and testing should be conducted of typical wall areas and specific areas of the wall incorporating large concentrations of lumber such as window headers and rim joists. Testing should include:

- other cladding systems; vinyl, masonry, hardiboard, etc.
- air tight drywall and vapour retarder $> 60\ \text{ng/Pa}^{x}\text{sec}^{x}\text{m}^{2}$ (1 perm)
- summertime drying conditions
- air leakage; from interior and exterior sources; into and out of the wall assembly.
- innovative wall systems designed to enhance effective permeance

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