Ventilation Drying in Enclosure Walls with Vinyl Cladding

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ABSTRACT

A comprehensive, multi-institutional project, funded largely by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., on ventilation drying in screen-type enclosure wall systems was recently completed. The project encompassed laboratory testing, field testing, and computer modeling. This paper presents the results of that portion of the laboratory testing program that was directed at evaluating ventilation drying in walls with vinyl siding claddings. These tests involved full-scale wall panels with vinyl siding. For the tests, three 1.2 × 2.4 m (4 × 8 ft.) wall panels, each with a spun-bonded polyolefin sheathing membrane, were constructed, instrumented, and then tested under different climate conditions. Testing was carried out in the climate chamber test facility in the Building Enclosure Testing Laboratory at Pennsylvania State University. Three representative climates were imposed, namely, winter in Minneapolis, Minnesota, fall in Baltimore, Maryland, and summer in Tampa, Florida. Consideration was also given to exposure to solar radiation. The primary focus of the study was on the nature and extent of ventilation drying in each wall system with different physical parameters. Vinyl siding was representative of a low mass, air permeable, and nonstorage cladding. Performance with respect to the extent, nature, and rate of ventilation drying was studied.

INTRODUCTION

A comprehensive, multi-institutional project on ventilation drying in screen-type wall systems, funded largely by the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc. (ASHRAE), was recently completed. The project involved laboratory testing, field testing, and computer modeling. This paper documents a test program to study ventilation drying in wall panels with vinyl siding cladding under different climatic conditions.

Ventilation Drying

In North America, it is fairly common to provide wall systems with vented and, in some cases, ventilated air spaces behind the cladding. These walls have some potential for ventilation drying. Ventilation drying occurs when moist air in the air space is displaced by drier air. The movement of air is driven by either a wind pressure differential or natural buoyancy, or both. Ventilation drying is commonly employed in residential roofing systems to remove, in winter, moist air from the attic spaces of North American houses.

Ventilation has, in theory, the ability to increase the drying potential of screen-type, drained wall systems. This characteristic is especially important for assemblies with cladding that can store a significant amount of water, e.g., brick veneer, or that have a vapor resistance high enough to significantly retard outward vapor diffusion, e.g., metal cladding. If any significant wetting were to occur in a wall with a high-vapor-resistance cladding, outward diffusion drying would be slow and the moisture content in the air space and other wall components would be elevated. As a result, a moisture-related problem could occur. Ventilation of the air space behind the cladding not only provides a moisture-transfer mechanism but also nullifies or compensates for the vapor resistance of the cladding.

However, it is also possible that ventilating the air space behind the cladding can cause wetting, especially when the outside air has a high moisture content or vapor pressure. Very

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few studies have been done on ventilation wetting in enclosure wall systems.

As part of the ASHRAE project, Straube et al. (2004) provided a comprehensive and detailed review of both the theoretical and experimental work on ventilation drying. At that time there was no real consensus as to the benefit of providing ventilation drying in wall systems.

Vinyl Siding Cladding

Vinyl siding is a cladding commonly used in North American residential construction. Since polyvinyl chloride (PVC) is its main component, vinyl siding as a material is airtight and vapor impermeable. However, vinyl siding as a system usually includes drainage holes and lap joints, making the cladding system permeable to air, water, and water vapor. Vinyl siding is often directly applied on the sheathing membrane and the exterior sheathing. Although there is no spacer such as vertical strapping, the profile of the vinyl siding creates an air space. Under wind-induced pressure, airflow can occur in the air space. If the vinyl siding is vertically applied, natural buoyancy would also contribute to enhancing the ventilation airflow. Vinyl siding can also be applied with spacers, a common example being 1 × 2 (19 × 38 mm) wood vertical strapping. The spacer creates a continuous air space behind the vinyl siding and, therefore, provides a capillary break and could potentially enhance the ventilation airflow.

Objectives

The main objective of this test series was to study the nature and extent of ventilation drying in screen-type wall systems with a vinyl siding cladding. Climatic conditions, framing, and the manner of vinyl siding application were the primary variables. Furthermore, these tests were to also serve as a comparison to similar tests on walls with a nonstorage and vapor-impermeable cladding (metal cladding) and with a storage and vapor-permeable cladding (brick veneer).

TEST FACILITY, PROGRAM, AND SETUP

Test Facility

A climate chamber test facility was designed and built in the Building Enclosure Testing Laboratory facility at The Pennsylvania State University. The variables that can be controlled are climate-side (exterior) temperature, climate-side relative humidity, climate-side solar radiation, room-side (interior) temperature, and room-side relative humidity.

The climate chamber test facility consists of a well-insulated, two-space chamber and several climate control systems. Figure 1 shows the climate chamber, the control systems, and the data acquisition system.

Experimental Parameters

In this test series, three wall panels, each with a vinyl siding cladding, were constructed, instrumented, and tested. These panels were installed side by side and formed the division wall between the room sides and climate sides of the climate chamber.

Parameters varied during these tests were:

- **Climate and Exposure Conditions.** Minneapolis, Baltimore, and Tampa were the target locations. These conditions were designated: WH for winter temperatures and high solar or southwest orientation in Minneapolis (ambient temperature between –15°C (5°F) and –5°C (23°F), ambient relative humidity (RH) between 40% and 70%); FH for fall temperatures and high solar or southwest orientation in Baltimore (ambient temperature between 2°C (36°F) and 12°C (54°F), ambient RH between 50% and 80%); SH for summer temperatures and high solar or southwest orientation in Tampa (ambient temperature between 24°C (75°F) and 30°C (86°F), ambient RH between 50% and 70%).
- **Framing.** Two of the panels in the cladding series were constructed on an idealized backup—a sealed polyisocyanurate "bathtub" involving a wood fiberboard sheathing (WFBS) membrane over a 1 × 2 (19 × 38 mm) frame. The bathtub design was sealed on five sides to force all drying out through the front of the panel and eliminate any possibility of moisture storage in the framing. Two of the panels for the vinyl siding test series (panels 1 and 3) were constructed using the same idealized backup, while the third (panel 2) was constructed on a 2 × 6 (38 × 140 mm) frame with R-20 (RSI-3.5) fiberglass batt insulation and an interior finish of melamine board (as the vapor barrier). This panel was constructed in precisely the same manner as the panels installed in the field test hut at the University of Waterloo (Van Straaten et al. 2004b).

Figure 1 *Overview of the climate chamber test facility.*

- **Air Space Shape and Depth.** Two different air space shapes were used in the vinyl siding test series. Panels 1 and 2 employed vinyl siding installed horizontally on 19 mm (0.75 in.) wood strapping; for the first of the two vinyl test series, panel 3 employed contact-applied vertical vinyl siding; for the second of the two vinyl test series, panel 3 employed contact-applied horizontal vinyl siding.
- **Sealing/Venting Considerations.** The joints between the ends of the vinyl siding pieces and the J-trim on the sides of the test panels were sealed for all of the vinyl siding test panels. In the first test series, none of the lap joints or drain holes were sealed. In the second test series, the lap joints and drain holes were sealed on panels 1 and 2 while these joints and holes were left open on panel 3.
- **Ventilation Flow Rate.** In the first of the two vinyl siding test series, only the 0.8 L/s (1.69 cfm) ventilation airflow rate was tested. In the second of the two vinyl siding test series, 1.6 L/s (3.39 cfm) and 0.4 L/s (0.85 cfm) ventilation airflow rates as well as a no-forced-flow rate were tested. Note that these flow rates refer to the rate of forced supply air measured by the orifice plate. Because of the air leakiness of vinyl siding, the real flow rate behind the siding was not necessarily equal to the flow rate that was measured by an orifice plate.

Simulation of Climate and Solar Exposure

A climate chamber control profile was developed for each of the three sets of climate conditions. Three variables were set as the control parameters for the climate side of the chamber: ambient air temperature, outside relative humidity, and surface temperature of the vinyl siding.

Ambient air temperature and outside relative humidity profiles were developed from historical weather data. The ambient temperature profile takes the form of a sinusoidal curve with minimum and maximum temperatures selected to reflect historical extremes for the city and season of choice. The cladding surface temperatures were predicted using a transient heat transfer program. The assumed ambient temperature profiles and solar radiation profiles were based on historical weather data. The solar radiation profiles take the form of compound sinusoidal curves selected to reflect the solar radiation levels that would be representative of a given wall orientation in the season of interest. The room-side temperature and relative humidity were maintained at 22°C (72°F) and 50%, respectively, during the tests.

Test Setup

Three panels were constructed, instrumented, and installed in the climate chamber. All three of the panels were clad with vinyl siding. Panels 1 and 2 had vinyl siding installed on 19 mm (0.75 in.) strapping over an SBPO sheathing membrane, while the vinyl siding on panel 3 was installed directly over the SBPO. In all cases, the joint between the siding and the J-trim was sealed using weather stripping and caulking. In test series V2, the lap joints and drain holes in panels 1 and 2 were sealed, and the orientation of the siding on panel 3 was changed from vertical to horizontal. Figure 2 shows an isometric view of a representative test panel and instrumentation. Water was dosed into the WFBS (three doses

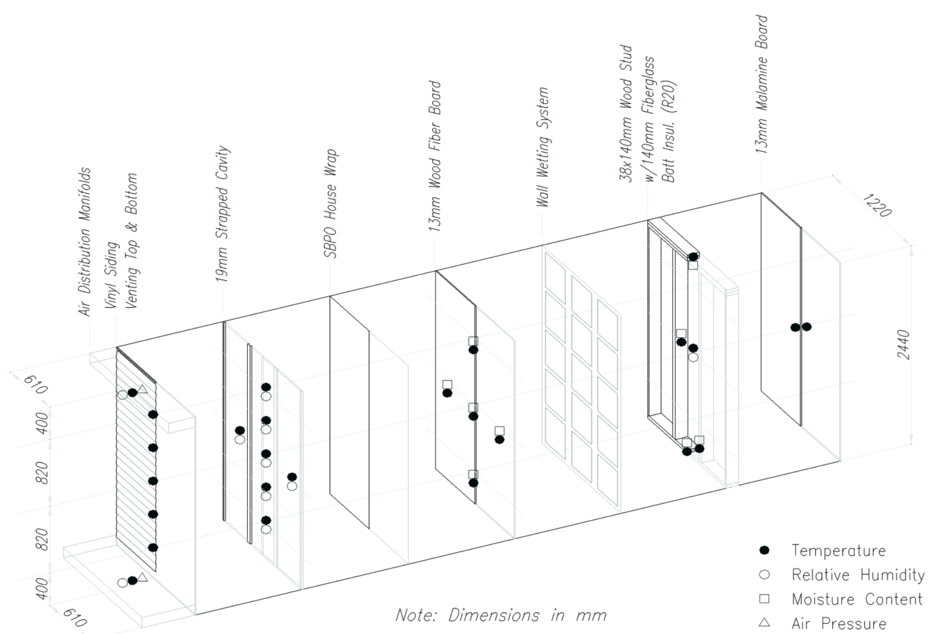

Figure 2 *Isometric view of the vinyl siding test panel and instrumentation.*

Table 1. Test Program

Test Series	Test	Test Panel	Climate*	Means of Attachment	Siding Direction	Framing	Joints and Drainage Holes	Flow Rate
V1	V1a	V1aP1	SH	19 mm (0.75 in.) strapping	Horizontal	Idealized	Sealed	0.8 L/s (1.69 cfm)
		V1aP2		19 mm (0.75 in.) strapping	Horizontal	2 x 6 (38 x 140mm)		
		V1aP3		Contact applied	Vertical	Idealized		
	V1b	V1bP1	WH	19 mm (0.75 in.) strapping	Horizontal	Idealized		
		V1bP2		19 mm (0.75 in.) strapping	Horizontal	2x6 (38x140mm)		
		V1bP3		Contact applied	Vertical	Idealized		
	V1c	V1cP1	FH	19 mm (0.75 in.) strapping	Horizontal	Idealized		
		V1cP2		19 mm (0.75 in.) strapping	Horizontal	2x6 (38x140mm)		
		V1cP3		Contact applied	Vertical	Idealized		
V2	V2a	V2aP1	FH	19 mm (0.75 in.) strapping	Horizontal	Idealized	Sealed	1.6. L/s (3.39 cfm)
		V2aP2		19 mm (0.75 in.) strapping		2x6 (38x140mm)	Sealed	
		V2aP3		Contact applied		Idealized	Open	
	V2b	V2bP1	FH	19 mm (0.75 in.) strapping	Horizontal	Idealized	Sealed	0.4 L/s (0.85 cfm)
		V2bP2		19 mm (0.75 in.) strapping		2x6 (38x140mm)	Sealed	
		V2bP3		Contact applied		Idealized	Open	
	V2c	V2cP1	FH	19 mm (0.75 in.) strapping	Horizontal	Idealized	Sealed	No flow
		V2cP2		19 mm (0.75 in.) strapping		2x6 (38x140mm)	Sealed	
		V2cP3		Contact applied		Idealized	Open	

* SH = summer and high solar; WH = winter and high solar; FH = fall and high solar.

of 450 g [1.00 lb] of water or a total of 1.35 kg [2.97 lbs] for each panel) and the drying process was monitored. Ventilation airflow was induced by a fan that forced air into the bottom manifold, up through the air cavity behind the vinyl siding, and out through the top manifold. Moisture content pins were installed at five different positions in the WFBS. These five locations are designated upper center (uc), middle left (ml), middle center (mc), middle right (mr), and lower center (lc). Since the WFBS provides the only appreciable storage for the moisture introduced to the panel during the wetting event, any changes in the measured moisture content of the WFBS must be indicative of either redistribution of the moisture or drying of the moisture (i.e., removal from the panel).

Test Series

Table 1 summarizes the tests in the two vinyl siding test series. The first series comprises three tests, each intended to simulate different climate conditions and each involving three test panels. The second series comprises three tests, each intended to simulate a different ventilation flow rate and each involving three test panels. Since there are two test series and the same climate conditions are used for more than one test, tests are identified by code and panel number.

TEST RESULTS AND ANALYSIS

Shi et al. (2004) previously conducted an experimental program to confirm and quantify both ventilation and ventilation drying in a representative wall system. These tests employed gravimetric measurement of the whole panel, which provided clear and unequivocal information about the nature and rate of drying of the test panel or wall assembly. Because of the limited room in the climate chamber for this study, gravimetric measurement was not possible. As is the case for many hygrothermal test programs, one cannot assume that "spot" measurement (a sample or portion of, or even a complete layer within the assembly) represents the performance of the whole test assembly or that of the wall being tested. Although measurements of vapor pressure and moisture content do not provide a direct measure of the amount of water in the test panel at any point in time, they do provide an indication of the rate and direction of moisture movement. The vapor pressure of the air in the top and bottom manifolds and the moisture content of the WFBS sheathing are therefore used as indicators of the performance of the wall panel assembly.

Vapor Pressure of the Ventilation Air

As the ventilation air moved upward, it collected moisture that diffused from behind the sheathing membrane and removed it from the test panel. Therefore, one would expect to see a clear pattern in the vapor pressure distribution in the air cavity (vapor pressure is equal to the saturated vapor pressure multiplied by relative humidity, and the saturated vapor pressure can be calculated using temperature). This pattern provides an indication of the direction of moisture flow in the panel, and the air cavity and can also provide confirmation of drying.

Figure 3 illustrates the vapor pressure distribution in the air cavity for V1aP1 ("V1" denotes test series 1, "a" denotes test a in the series, and "P1" denotes panel 1) in summer and high solar exposure climate (note that 1 Pa is equal to 1.45e-4 PSI). These vapor pressures were calculated using the temperature and RH measured at five locations in the cavity: upper center (2.0 m [80 in.] from bottom), eye level center (1.6 m [64 in.] from bottom), middle center (1.2 m [48 in.] from bottom), waist level center (0.8 m [32 in.] from bottom), and lower center (0.4 m [16 in.] from bottom).

The plots shown in Figure 3 indicate two clear and important trends:

- Between 9:00 a.m. and 7:00 p.m., the order of magnitude of the vapor pressure in the cavity at different positions, from low to high, was: lower center, waist level center, middle center, eye level center, and upper center. It is clear that the vapor pressure increased as the air moved from lower positions to higher positions. This pattern confirms that as the ventilation air moved upward in the cavity, it accumulated moisture and removed it from the air space. Therefore, the panel was drying from 9:00 a.m. to 7:00 p.m.
- The pattern described above was reversed during the night. From 7:00 p.m. to 9:00 a.m., the vapor pressure decreased as the air moved upward through the air cavity. This suggests that the ventilation air was losing moisture to the panel during this period. This nighttime ventilation wetting phenomenon has also been noted in the field test (Van Straaten et al. 2004b).

The area between the highest and lowest curves indicates the relative magnitude of the moisture movement. The area between the curves and during the drying hours (9:00 a.m. to 7:00 p.m.) is larger than the area between the curves during the wetting hours (7:00 p.m. to 9:00 a.m.), demonstrating that the net moisture movement is in the direction of drying.

The addition or removal of moisture can also be seen by inspecting the vapor pressure differential between the air entering the wall through the bottom manifold and the air leaving the wall through the top manifold. Figure 4 shows the vapor pressure of the air in the top and bottom manifolds. Their difference is illustrated in Figure 5.

The pattern shown in Figure 5 is consistent with that found in Figure 3. During the daytime (from 9:00 a.m. to 7:00 p.m.), the ventilation air removed moisture from the panel and caused drying. In the night (from 7:00 p.m. to

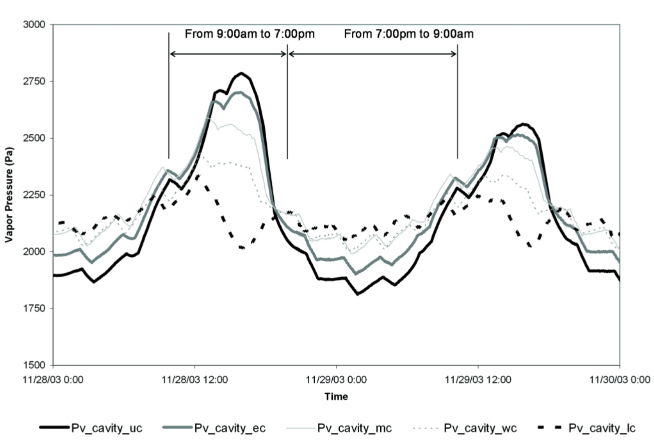

Figure 3 *Vapor pressure distribution of the ventilation air in the air cavity for V1aP1 (SH).*

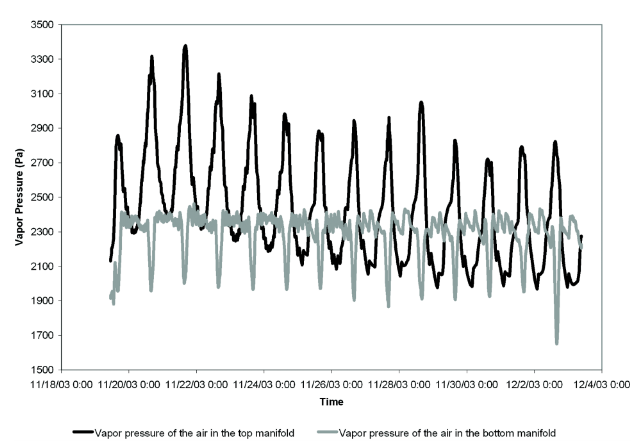

Figure 4 *Vapor pressure of the air in the top and bottom manifolds for V1aP1 (SH).*

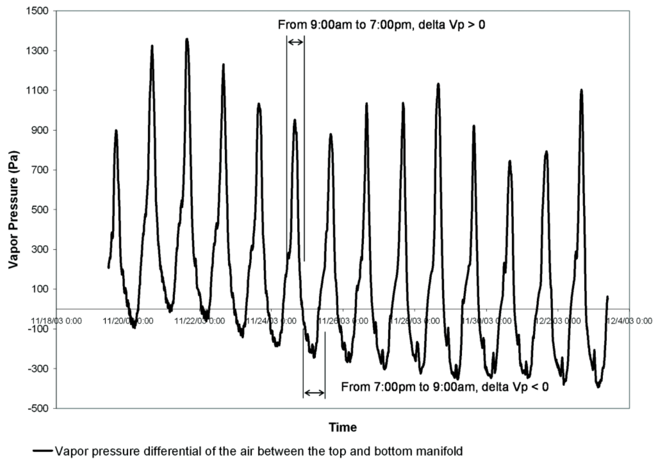

Figure 5 *Vapor pressure differential of the air between the top and bottom manifolds for V1aP1 (SH).*

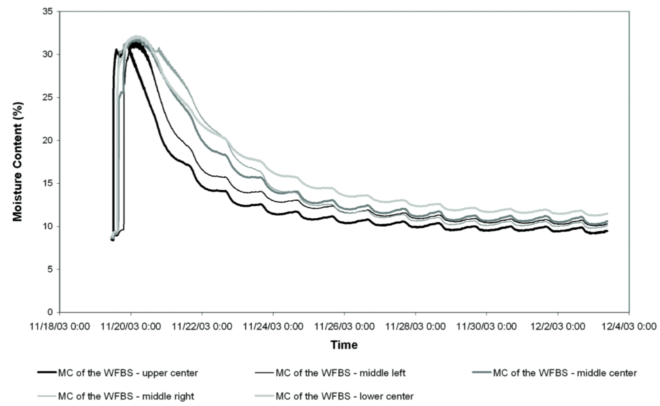

Figure 6 *Moisture content measured in the WFBS for V1aP1 (SH).*

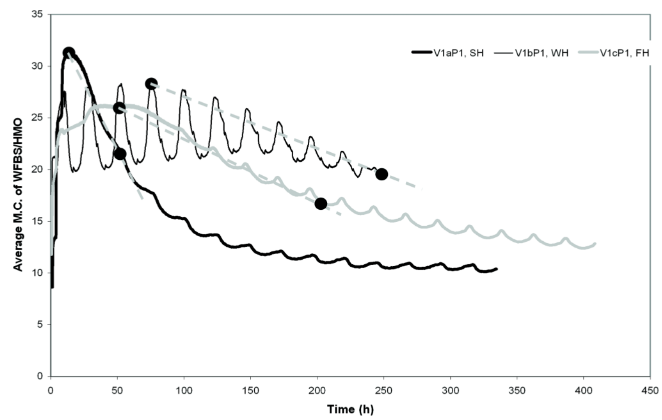

Figure 7 *Determination of the drying rates for panel 1 in V1 series.*

9:00 a.m.), the ventilation air deposited moisture into the panel and caused wetting. Since the positive vapor pressure differential greatly exceeded that of the negative vapor pressure differential, the net effect was removal of moisture, and the drying of the panel is confirmed. This is supported by the fact that the peak vapor pressure differential decreased with time, suggesting that less moisture was available for removal from the WFBS sheathing.

It should be noted that the ventilation flow rate was kept constant during each test (0.8 L/s [1.69 cfm] for V1aP1). Under real conditions, the ventilation flow rate varies with wind speed and the temperature and vapor pressure difference between the air in the cavity and the air outside. For most walls, there will be more ventilation during the day (due to solar heating) and less at night, so the effect of any nighttime wetting will likely be even smaller than that measured here, compared to drying that occurs over the course of the day.

Moisture Content of the Sheathing

Figure 6 shows the moisture content measurements for five locations of the WFBS for V1aP1. The measured moisture content of the sheathing appeared to drop quickly over the first two days that followed the wetting event and then at a steadily decreasing rate over the next 10 to 14 days. While the initial drop in the moisture content is likely the result of a combination of redistribution and drying, the fact that the measured moisture content returned to the pre-wetting levels confirms that the panel did dry.

Determination of the Drying Rate

As the total amount of moisture in each of the test panels was not gravimetrically tracked, the relative drying rates of each panel could not be determined. Instead, the moisture content of the WFBS was used as an indicator of panel performance. But the reader should be aware that the nature of drying of a single, wood-based layer is not precisely the same as the whole multilayer assembly.

In the discussion that follows, the initial drying rate is defined by the ratio of the mass loss involved in a 10% moisture content (MC) drop divided by the time required for the moisture content of the WFBS sheathing to decrease from the peak moisture content value to a value that is 10% MC (wt) lower than the peak. This approach is in accordance with that used to analyze the results of the field tests (Van Straaten et al. 2004b).

To determine the time required for a representative 10% MC decrease, a point is selected near the peak measured moisture content and a straight line is fitted to a point 10% lower on the peak measured MC curve. This straight line, shown in Figure 7, provides a drying rate that is representative of the response of the sheathing. In Figure 7, the three tests are V1aP1 in summer and high solar exposure climate, V1bP1 in winter and high solar exposure, and V1cP1 in fall and high solar exposure climate. Other test panels were analyzed in the same manner; the results are summarized in Table 2.

Table 2. Summary of Drying Times and Rates

Test	Test Panel	Climate	Siding Attachment	Framing	Joint Sealing	Flow Rate, L/s	Time For 10% MC Drop, days	Drying Rate For 10% MC Drop, g/h
V1a	V1aP1	SH	19 mm strapping	Idealized	Sealed	0.8	1.5	44.3
	V1aP2		19 mm strapping	2 × 6			1.0	65.4
	V1aP3		Contact applied (vertical)	Idealized			1.0	65.4
V1b	V1bP1	WH	19 mm strapping	Idealized			8.0	8.1
	V1bP2		19 mm strapping	2 × 6			7.5	8.7
	V1bP3		Contact applied (vertical)	Idealized			7.5	8.7
V1c	V1cP1	FH	19 mm strapping	Idealized			6.0	10.9
	V1cP2		19 mm strapping	2 × 6			5.5	13.1
	V1cP3		Contact applied (vertical)	Idealized			5.5	11.9
V2a	V2aP1	FH	19 mm strapping	Idealized	Sealed	1.6	3.5	18.7
	V2aP2		19 mm strapping	2 × 6	Sealed		3.3	19.8
	V2aP3		Contact applied (horizontal)	Idealized	Open		3.5	18.7
V2b	V2bP1	FH	19 mm strapping	Idealized	Sealed	0.4	7.5	8.7
	V2bP2		19 mm strapping	2 × 6	Sealed		5.0	13.1
	V2bP3		Contact applied (horizontal)	Idealized	Open		8.0	8.1
V2c	V2cP1	FH	19 mm strapping	Idealized	Sealed	No forced flow	10	6.5
	V2cP2		19 mm strapping	2 × 6	Sealed		8.3	7.9
	V2cP3		Contact applied (horizontal)	Idealized	Open		11	5.9

PARAMETRIC CONSIDERATIONS

In the V1 test series, three parameters were intentionally varied: backup (idealized or framed), siding attachment (19 mm [0.75 in.] strapping or direct applied), and climate condition (WH, SH, FH).

In the V2 test series, four parameters were intentionally varied: backup (idealized or framed), siding attachment (19 mm [0.75 in.] strapping or direct applied), joint sealing (sealed or open lap and J-trim joints), and ventilation flow rate (1.6 L/s [3.39 cfm], 0.4 L/s [0.85 cfm], and no flow).

The effect of these parameters on the drying of the test panel is examined in this section.

2 x 6 Wood Frame and Idealized Frame

Most of the test panels were constructed using the idealized backup. The idealized backup was intended to force all of the moisture introduced during testing to dry through the front of the panel, simplifying the interpretation of the test results and assessment of the relationships between the test variables and the drying of the panel.

One conventionally framed test panel (panel 2) was included in the two vinyl siding test series. This panel was constructed with 2 × 6 (38 × 140 mm) wood framing, insulated with R-20 (RSI-3.5) fiberglass batt, and finished on the interior with a sheet of melamine board. It was constructed in the same manner as the test panels used in the field tests at the University of Waterloo (Van Straaten et al. 2004b) and was intended to enable comparisons between the climate chamber and the field tests.

A review of drying rates summarized in Table 2 suggests that there is little difference between the drying curves and times for the sheathing of panel 2 (the framed panel) and panel 1 (identical to panel 2 but with idealized backup). Panel 2 did appear to dry faster when the flow rates were lower (0.4 L/s [0.85 cfm] and no flow tests) and might also dry faster when the outside conditions are warmer (SH).

The WFBS sheathing in the framed panel may dry faster than in the idealized panel, but it is likely that much of the moisture in the framing redistributes to the wood framing rather than actually leaving the test panel through the ventilated air space.

This redistribution of moisture becomes much more obvious when the conditions for inward vapor drives are present.

Inward vapor drive is a phenomenon that occurs when an absorptive material in the outer layers of the wall (e.g., brick or stucco cladding, wood sheathing, etc.) becomes wet and is then heated, by ambient air or solar radiation, above the temperature of the interior layers of the wall. Under these conditions, the vapor pressure in the exterior layers of the wall can be higher than the vapor pressure of the interior layers, and the resulting vapor pressure differential (2000–15000 Pa) drives moisture toward the inner layers. If any of the inner layers are cool enough, moisture may condense.

This phenomenon of inward vapor drive was observed in only one of the vinyl siding tests. Figure 8 shows the moisture content measurements at four locations in the 2 × 6 (38 × 140 mm) wood frame of V1aP2 in the SH climate condition. As shown in the graph, the moisture content at the interior of the bottom plate increased sharply at point A, indicating liquid water accumulated at that position. This phenomenon occurred because the finish of the melamine board has a very low vapor permeance (i.e., it is a vapor barrier). The high exterior surface temperatures associated with the summer test drove the moisture in the WFBS inward. The driven moisture could not diffuse through the melamine board and, since it was cool enough, condensed on it. The condensed liquid water ran down to the bottom plate and caused the moisture content of the plate to increase.

19 mm Strapping and Contact Applied

Vinyl and other lap sidings were installed on 19 mm (0.75 in.) strapping to encourage drainage and/or ventilation. Theoretically, ventilation air will move vertically (i.e., in-plane vertical flow) when the siding is installed on strapping and also horizontally within the profile of the siding. Ventilation air will move only within the profile of the siding (i.e., in-plane horizontal flow) when the siding is contact-applied (provided the siding is not flexible enough to deform laterally). The flow resistance along various flow paths for both contact-applied and strapped vinyl siding was measured, and the findings are summarized by Van Straaten et al. (2004a), Straube et al. (2004), and Pinon et al. (2004). The pressure differentials necessary to drive in-plane horizontal flow behind contact-applied vinyl siding are up to two orders of magnitude larger than those necessary to drive in-plane vertical flow behind vinyl siding installed on 19 mm (0.75 in.) strapping. A pressure difference of approximately 2.0 Pa is required to induce a horizontal flow rate of 0.8 L/s (1.69 cfm) in a contact-applied wall, whereas a pressure difference of less than 0.1 Pa will induce the same vertical flow rate in a strapped wall.

Given that the drying rate increases with flow rate, the flow test findings seem to support the theory that walls will dry faster when vinyl siding is installed over strapping. However, there was little difference between the contact-applied and strapped panels installed in the field test hut at the University of Waterloo (Van Straaten et al. 2004b). It may be that there were smaller ventilation flow rates behind the contact-applied walls, yet these were sufficient to remove the water introduced to the sheathing in the wetting events.

Ventilation flow in narrow cavities like those found behind contact-applied vinyl may be effective because most of the air that does flow through the cavity is forced into contact with the wet surfaces, maximizing drying. This theory was tested in the V1 test series. The vinyl siding on panel 1 was installed over 19 mm (0.75 in.) strapping while the siding on panel 3 was contact-applied with a vertical orientation. By installing the siding vertically, the ventilation air flowed with the profile of the vinyl as if it were in-plane horizontal flow. A ventilation flow rate of 0.8 L/s (1.69 cfm) was introduced to each panel. Figure 9 compares the average measured-moisture contents in the sheathing of the two panels.

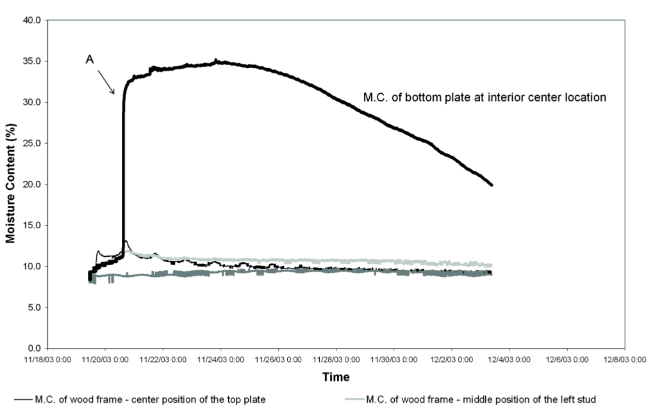

Figure 8 *Moisture measured in the wood frame members in V1aP2 (SH).*

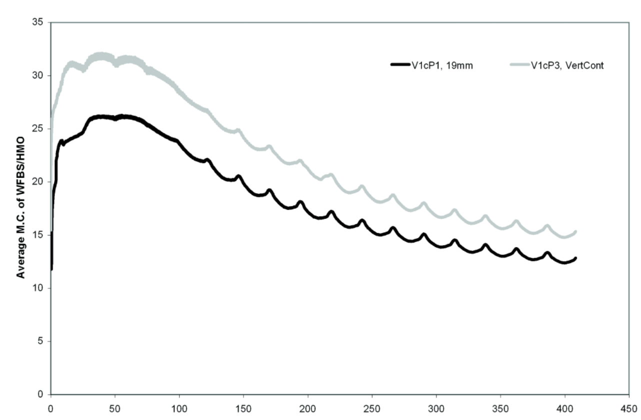

Figure 9 *Comparison of drying for 19 mm (0.75 in.) strapping and direct-applied vinyl siding panels (V1cP1, V1cP3, FH).*

One of the first things noted in the figure is the difference between the two peak moisture contents. Panel 1 started at approximately 12% MC and reached a peak of 27% MC, while panel 3 started at 16% MC and reached a peak of 32% MC. The panels did not start at the same moisture content because they were not equally dried during the WH test that preceded the FH test shown in the plot. It would be reasonable to expect panel 3 to dry faster because it started at a higher moisture content and the forces driving drying would be larger; however, the two panels appear to have very similar drying curves. This result appears to be valid for other flow rates as well (1.6 L/s [3.39 cfm], 0.4 L/s [0.85 cfm], and no induced flow).

It can be concluded that any differences in flow pattern caused by the method of attachment of the siding will not have a noticeable affect on drying as long as the ventilation flow rates in the two walls are the same. It may, however, be necessary to apply vinyl over strapping for reasons other than increasing ventilation (e.g., better drainage, less contact, easier detailing). It is important to note that the same flow rate was forced for both the panels (directly applied and strapping applied). However, in natural conditions and under the same flow driving force, the strapping-applied vinyl panel would have a much larger flow rate and, thus, a larger potential for drying.

Climate Conditions

The effect of climate conditions on drying can be studied by comparing the performance of the same panel in the SH, WH, and FH tests. Table 2 summarizes the times required for 10% reductions in moisture content. All three panels tested appear to dry fastest in the summer. The SH drying rates are approximately five times faster than the FH drying rates and approximately eight times faster than the WH drying rates.

The test panels dried more quickly in the SH test for two reasons. First, the temperature of the ventilation air in the cavity for the SH test was much higher because of the greater solar radiation and warmer ambient air. The warmer air provides the heat that is needed for moisture to evaporate from the WFBS. Second, the vapor pressure differential that drives the moisture from the WFBS into the air cavity was larger in the SH test. These factors both lead to faster drying of the panel.

Ventilation Airflow Rate

A subset of the two vinyl siding test series was examined to identify the relationship between drying rate and ventilation flow rate. Tests V1cP1, V2aP1, V2bP1, and V2cP1 had the same setup and were all conducted under the fall and high sun climate. They differed in flow rates: 0.8 L/s (1.69 cfm), 1.6 L/s (3.39 cfm), 0.4 L/s (0.85 cfm), and no induced flow ("no flow"), respectively.

The drying rate was defined as the time required for a 10% drop in measured moisture content. Table 2 summarizes the drying rates for each test. An interesting pattern emerges from a review of the table data. As expected, the fastest drying time is associated with the highest flow rate (1.6 L/s [3.39 cfm]) and the slowest drying time is associated with the lowest flow rate (no induced flow). The drying time for the "no flow" test is approximately 10 days, while the drying rate for the 1.6 L/s (3.39 cfm) test is approximately 3.5 days. The drying rates for both the 0.8 L/s (1.69 cfm) and 0.4 L/s (0.85 cfm) tests are in the range of 6 to 8 days.

CONCLUSIONS

Vinyl itself is a vapor-impermeable material; however, vinyl siding incorporates drain holes, lap joints, and trim joints that allow ventilation air to move behind the cladding. The following conclusions can be drawn from the vinyl-cladding test series:

- Ventilation drying was confirmed in all of the tests.
- The drying rate increased as the ventilation flow rate increased. The initial drying rates for the panels tested at 1.6 L/s (3.39 cfm) flow were approximately two times faster than the panels tested at 0.8 L/s (1.69 cfm) and 0.4 L/s (0.85 cfm) and approximately three times faster than the panels tested with no induced ventilation flow.
- The drying rate, as expected, is influenced by the climate conditions. The initial drying rates for all three of the panels in the summer (hot weather) tests were approximately five times faster than in the fall (moderate weather) tests and eight times faster than in the winter (cold weather) tests.
- When wood framing is hygrothermally connected to the sheathing and air space, some portion of the moisture can redistribute from the wet sheathing to the framing. As the temperatures on the exterior of the cladding and on the surface of the sheathing membrane become larger, this effect is amplified. The resulting inward vapor drive can cause condensation on the back of the vapor barrier (in this case, melamine). If sufficient condensation occurs, the moisture can run down the vapor barrier and accumulate in the bottom plate.

Although the flow patterns behind strapped and contact-applied vinyl siding are different, the drying rates are the same for the practical range of ventilation flow rates. Recall, however, that the pressures required to induce vertical flow behind contact-applied vinyl siding can be several orders of magnitude larger than the pressures required to induce the same flow behind vinyl siding installed on 19 mm (0.75 in.) strapping. Although high ventilation rates can be expected in service due to horizontal flow in contact-applied vinyl siding, vertical flow behind strapping will in most cases be much greater. The flow rates in both cases are likely high enough to allow fast drying, although further research is recommended to define this behavior.

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