# The Function and Performance of Weather-Resistive Barriers during Building Construction

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**ABSTRACT**

*Weather-resistive barriers (WRB) are being increasingly recommended by practitioners and required by codes because of their role in reducing moisture problems in buildings. Specifications for these products rightfully focus on their performance over the service life of the building. These products, however, play another very important role, which is to protect moisture-sensitive building components while a building is under construction. Construction built-in moisture has been noted to be a significant factor in the performance of buildings, especially during the first two to three years of service life. This paper combines laboratory testing, field observations, and hygrothermal modeling to understand the effect of WRB properties (water resistance, and water vapor permeance) on the moisture loading of building components during construction.*

## INTRODUCTION

*Weather-resistive barrier* is a term used by the building codes to describe the membrane that is placed between a building's cladding and sheathing (or studs when no sheathing is used). A weather-resistive barrier has four basic functions:

1. Provide resistance to moisture intrusion, thus protecting the underlying wall structure from intrusion from water and moisture that penetrates the cladding.
2. Provide resistance to airflow.
3. Provide a durable barrier.
4. Allow moisture vapor to pass, to allow the wall to dry if it becomes wet for any reason.

Weather-resistive barriers must manage water in a wall during two time periods: during construction and during the building's lifetime. The performance of a wall during construction will set the stage for the wall's subsequent performance over the life of the building. Although the construction phase is short in duration, the weather-resistive barrier sees more extreme exposure to the elements. This paper examines the needed performance of weather-resistive barriers during construction, focusing on water resistance and the ability to allow construction and incidental moisture to dry.

### Weather-Resistive Barrier Properties

Water resistance and vapor permeability are primary properties of weather-resistive barriers during service, but these properties come into even sharper perspective when the performance of weather-resistive barriers is examined during the construction phase of buildings. Weather-resistive barriers are required under code to have certain water-resistance capabilities (ICBO 2000). Weather-resistive barriers are also designed to be permeable to moisture vapor to allow walls to dry and to not trap moisture in the walls. The codes currently describe vapor-permeable membranes as having vapor permeability of greater than 5 perms (ICC 2003a, 2003b). A review of manufacturers' literature and testing of commercially available weather-resistive barriers show the moisture management properties of these products can vary widely. Water resistance, as measured by hydrostatic head (AATCC 1990a), ranges from 10 cm to as high as 260 cm and vapor permeability ranges from 6.7 perms to 58 perms (see Figure 1). One category of weather-resistive barrier, the perforated housewrap, is a thin

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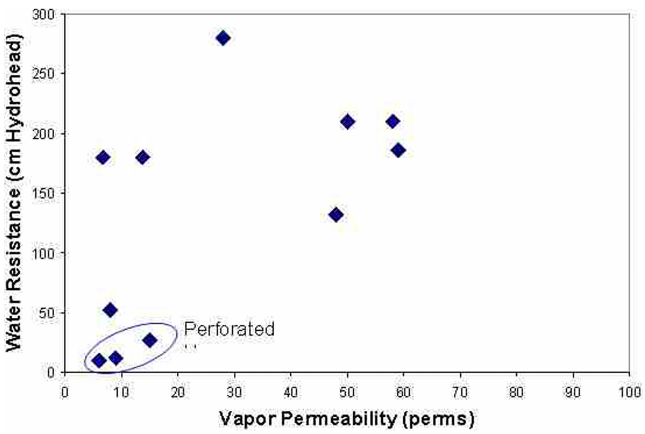



*Figure 1* *Water resistance and vapor permeability of commercially available housewraps.*

*Figure 2* *Rain has intruded directly through a perforated housewrap.*

film product that is mechanically punctured to provide drying capability. Perforated housewraps have the lowest water resistance and also have relatively low water vapor permeability.

## FIELD EXPERIENCE OF WETTING DURING THE CONSTRUCTION PHASE

During construction, prior to the application of the final exterior wall cladding, the weather-resistive barrier serves as the primary barrier to water intrusion that can damage moisture-sensitive construction materials. Examination of the performance of weather-resistive barriers in the field shows that although they generally perform well, proper product selection and installation practices are necessary. More specifically, the WRB must have a high degree of water resistance, and proper detailing at penetrations is required. If incidental water does penetrate between the weather-resistive barrier and the sheathing, the WRB must be vapor permeable enough to allow that moisture to dry. Here are several field examples of how water intrudes behind the weather-resistive barriers. In each case, changes in material selection and/or installation practices could have reduced the water intrusion.

### Rain Penetration through the WRB

Housewraps with low water resistance can allow water to penetrate. Figure 2 shows rain that has intruded directly through a perforated housewrap during construction. When subjected to a direct water spray test, perforated housewraps will allow water to pass while nonperforated housewraps resist water entry. This is demonstrated in a simple laboratory test method (AATCC 1990b). The weather-resistive barrier sample is placed over a blotter paper and sheathing and then sprayed with a calibrated nozzle (see Figure 3). Water penetration is measured by weighing the change in weight of the blotter paper. Figure 4 shows the results for three perforated housewraps, all of which allow water to penetrate to the blotter

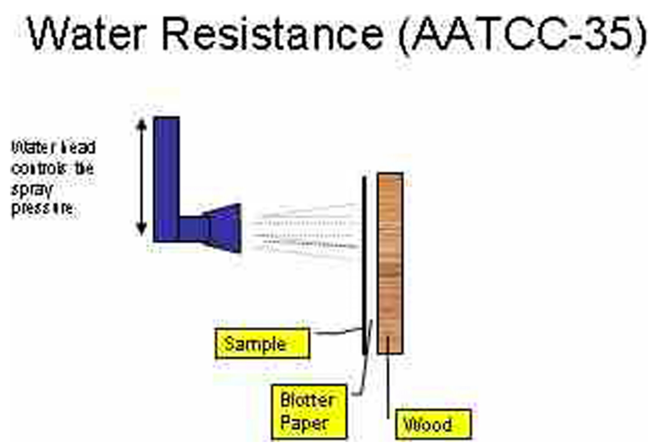



*Figure 3* *Schematic of laboratory spray test.*

paper, and for one nonperforated housewrap, which does not allow water intrusion. It has been noted in other studies that perforated housewraps will allow water to penetrate when tested under direct water contact with capillary effects or when subjected to a direct water spray (Hall 2004; Weston et al. 2004). This water can be minimized by choosing a housewrap with higher resistance to water penetration.

When absorptive materials such as building papers and felts are used, although they may provide initial water penetration to the sheathing, the water they absorb during a wetting event may be held in the wall for an extended time. Also, water absorbed by building papers and felts has been noted to lead to the deterioration of the paper or felt itself (CMHC 1999; *Building Insight* 1995; Morrison Hershfield 1996; Page 1997).

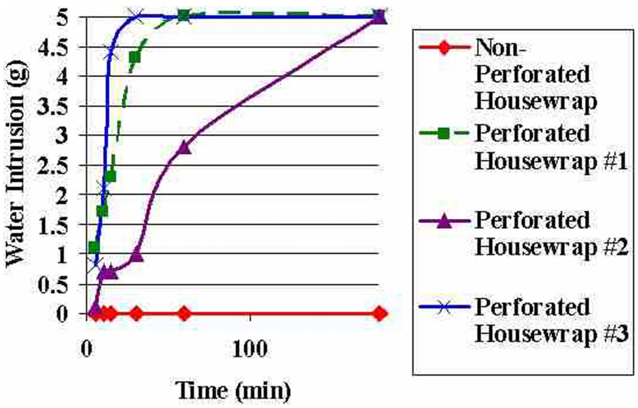



***Figure 4*** *Water spray test data for perforated and nonperforated housewraps.*

***Figure 5*** *House during construction with water intrusion behind weather resistive barrier at window opening.*

## Rain Penetration at Interfaces

Field studies have also shown that water can intrude behind the weather-resistive barrier at interfaces, such as those with windows (see Figure 5). In a field study of building failures in Vancouver, BC, 62% of incidences of water intruding past the sheathing paper (WRB) were due to discontinuities or at flashings or penetrations (Morrison Hershfield 1996). Closer attention to the design and implementation of window installation and flashing details is required to reduce this water.

## Dew Condensation behind the Weather-Resistive Barrier

A third way for moisture to end up between the weather-resistive barrier and the sheathing is from condensation in the form of dew or frost. Although not reported in research literature, dew or frost condensation behind a weather-resistive barrier is not uncommon. However, until the recent introduction of low-permeability housewraps, it had not been an issue as the condensation would dry rapidly through the weather-resistive barrier. The case history described in this paper illustrates the performance of housewraps with regard to dew condensation as a function of their vapor permeability.

# CASE HISTORY OF HOUSEWRAP PERFORMANCE DURING CONSTRUCTION

## Field Observations

It is a unique situation when you get the opportunity to compare two products side by side, on the same structure and exposed to the same elements and conditions. This case study provides such an opportunity. The case involves a townhouse development in Chapel Hill, NC, which was wrapped in a patchwork quilt fashion with two housewraps, one with a reported vapor permeability of 6.7 perms, the other with a permeability of 58 perms. Both housewraps had reported high water-resistance properties.

**Table 1. Reported and Measured Housewrap**

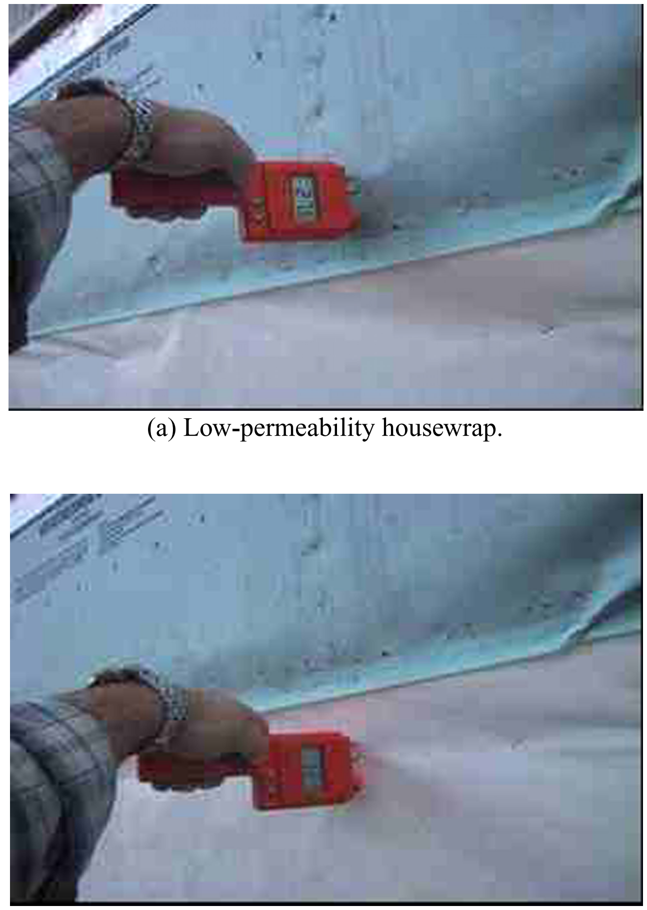
| | Reported Vapor Permeability (perms) | Measured Vapor Permeability (perms) |
|---|---|---|
| Housewrap #1 | 6.7 | 5.5 |
| Housewrap #2 | 58 | 56 |

The townhouses were visited on November 1, while they were under construction. Samples of the installed materials were tested for permeability with the results shown in Table 1. Given the error and repeatability of vapor permeability methods, the materials appeared to be representative of such products.

The townhouses visited were in the framed stage of construction and the roof and roofing underlayment were already in place. This region had suffered the worst drought in decades, and it had not rained in this area for approximately six days. The interiors of the buildings were in an open frame condition and dry. The exterior was covered with the two different housewraps in a patchwork configuration. The windows were already installed.

Visual inspection of the site indicated that moisture was present behind the low-permeability housewrap. No moisture was observed behind any of the high-permeability housewrap. Visual streaks of moisture and staining were present behind all locations where the low-permeability housewrap was installed. These were most severe on the west and north exposure sides where sun exposure was limited, thus implying that drying in these areas was slower. The condition and extent of the moisture indicated that this condition had persisted for an extended period of time. Visual signs of staining from the moisture were present on the back side of the low-permeability membrane as well as the sheathing material in contact with this membrane. In some locations, this staining was considered extensive. There was no such evidence of moisture


***Figure 6*** *Overlap area between the high- and low-permeability housewraps.*



(a) Low-permeability housewrap.

(b) High-permeability housewrap.

***Figure 7*** *Moisture readings being taken at housewrap overlap.*

behind any of the areas where the high-permeability housewrap was installed, indicating that while the high-permeability housewrap is allowing the moisture to dry, it is being trapped by the low-permeability housewrap. Additionally, there was a stark contrast in the areas where the two housewraps overlapped. Areas behind the low-permeabillity material indicated moisture distress, while the areas behind the adjacent high-permeability material were clean and dry. This was true regardless of what product was on top or below. Figure 6 shows a typical area with overlap of the two housewraps. The upper area of the sheathing shows signs of moisture distress and staining, while the lower area is clean and dry. These areas correspond to the low- and high-permeability housewraps, respectively. It was also noted that the area where the two membranes overlapped had moisture trapped between the membranes when the low-permeability product was oriented toward the exterior. This further substantiates that the low-permeability product was, in effect, trapping moisture behind it that was trying to escape or dry toward the exterior.

Moisture readings were taken at several locations around the building, concentrating on the north and west exposures since these indicated widespread signs of moisture distress that were easily accessible. Moisture readings were taken using a Delmhorst contractor grade moisture meter, model BD-2100, serial# 19456. Figure 7 shows moisture readings being taken at representative areas where the two products overlapped. In each of these cases, moisture readings were taken at adjacent points where one housewrap ended and the other started. For every one of these cases, the moisture readings in the sheathing behind the low-permeability product exceeded 25% moisture content. In the adjacent areas where the high-permeability product was installed, moisture readings never exceeded 13.1% and decreased rapidly as the distance from the overlapped area increased. Based on the weather conditions and the exposure of the building, it would be expected that the moisture content of the sheathing would likely be <15% depending on exposure and orientation. The average moisture content in the sheathing behind each WRB for each orientation of the building is shown in Table 2. In general, moisture readings in the sheathing behind the low-permeability housewrap ranged between 20% and 30%. Prolonged exposure in these ranges is sufficient to produce decay in wood products. Several areas in the field of the low-permeability housewrap yielded readings >40% moisture content. This is the upper limit of the moisture detection device used.

Sheathing moisture readings were also taken on the inside of the structure. Behind the low-permeability housewrap, the

**Table 2. Measured Moisture Content on Walls with Different Exposures—Values Are an Average of Six Readings Representative of Each Orientation**

| Wall Orientation | Exposure | Moisture Content | |
|---|---|---|---|
| | | Behind Low-Permeability Housewrap | Behind High-Permeability Housewrap |
| East | Direct sun exposure | 11.20% | 8.70% |
| South | Moderate sun exposure | 19.10% | 11.40% |
| West | Low sun exposure | 25.70% | 12.30% |
| North | Low sun exposure | 27.80% | 12.10% |

moisture readings ranged between 10.2% and 13.4%. These moisture readings are consistent with the expected readings for a structure in this stage of construction, climate, and exposure. The moisture readings were increasingly higher as the probes penetrated deeper into the sheathing (toward the exterior), suggesting that the sheathing located behind the low-permeability membrane must rely on drying toward the interior of the structure. The moisture content of the interior of the sheathing behind the high-permeability housewrap is consistent with the expected readings for a structure in this climate at this stage of construction, indicating that the structure is drying effectively toward the exterior.

The information collected during this visit was sufficient to substantiate that the low-permeability housewrap was adversely affecting the walls' capacity to dry toward the exterior and was, in effect, trapping moisture against the sheathing (OSB). This is supported by laboratory results that show the drying rate of OSB can be severely impacted by the vapor permeability of weather-resistive barriers less than 18 to 24 perms (Boone et al. 2004). During construction, building materials get wet through exposure or may arrive at the site wet. This moisture needs to escape these products as they dry over time. Additional moisture sources occur from condensation and weather. Because of the dry climatic conditions that had persisted in the area at the time of the investigation, rain was not considered a dominating factor for this structure. As a component of the wall system, the housewrap properties must enable moisture to escape to the exterior, enabling building materials to dry effectively. Otherwise this moisture can become trapped on the exterior, resulting in mold, mildew, and rot.

## Computer Simulation of Case History

To evaluate our hypothesis that the difference in performance between the two housewraps observed in the field could be explained by the difference in housewrap vapor permeability, a computer simulation of the walls during construction was conducted. Only qualitative agreement between the model and field data were expected. The parameters and characteristics of the simulation are described below.

**Simulation Program.** WUFI 3.3 Pro was chosen as the simulation model because it is a well validated and benchmarked model for hygrothermal applications. It is important to note that due to the inherent limitations of the model, results of the simulations are predictive of relative performance and not specific material moisture content. The model only considers vapor and liquid diffusion. It does not consider moisture transport in liquid form or by mass transport of water vapor (air currents). This model considers the surface wetting of materials and can include an initially wet component. The model uses historical weather data for a particular region to calculate the hygrothermal response of the wall system.

**Wall Construction.** The wall construction used in the simulation was representative of that observed during the site visit, which is housewrap covering oriented strand board (OSB) sheathing. No cladding was on the exterior. No insulation or finish materials were installed on the inside. To better focus on the exterior surface of the OSB, the OSB in the simulation was modeled as two separate layers, both with the same properties. A very thin airspace was placed in the construction between the weather-resistive barrier and the sheathing. This space was used to represent a film of condensation water by initiating the simulation runs with an amount of water equal to the density of liquid water.

**Material Properties.** The material properties used were derived from a database provided with the simulation program or from manufacturer's reported data.

**Environmental Conditions.**Weather files for Wilmington, NC, were used for the exterior climate as it was the closest city to field studies provided in the simulation database. As the field study was conducted prior to the building walls being insulated or the building being conditioned, the interior conditions were set as a moderated version of the exterior conditions.

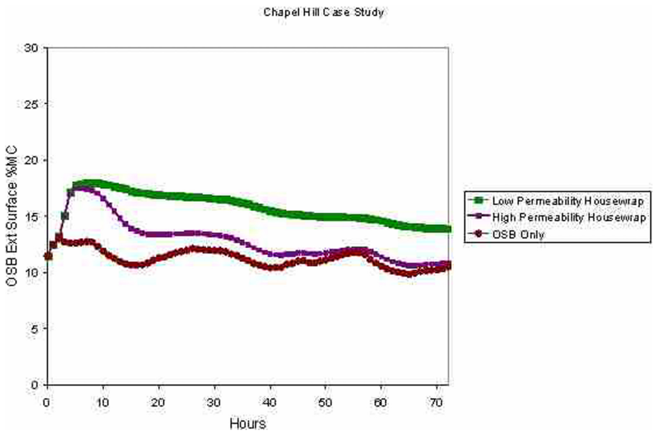



*Figure 8* *Simulation results: Effect of a single wetting event on the moisture content of the exterior surface of the sheathing.*

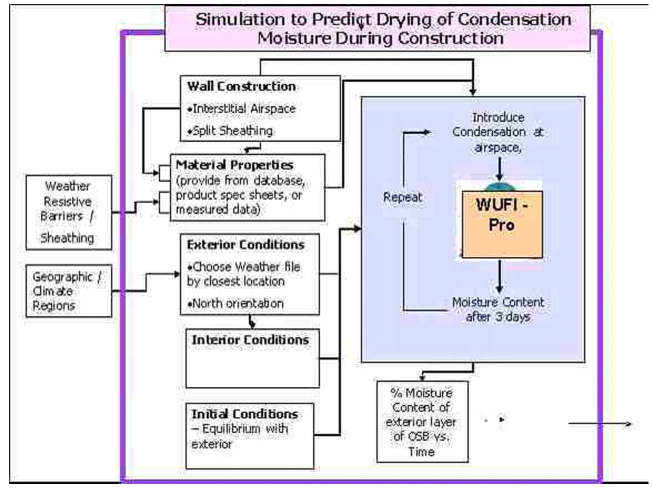



*Figure 9* *Interactive simulation procedure.*

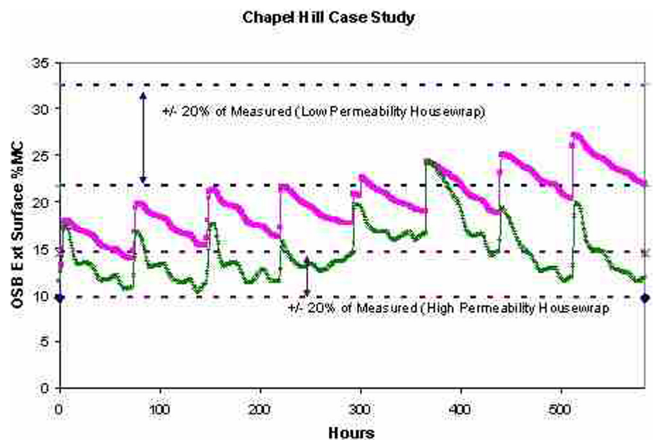



*Figure 10* *Results of iterative results compared to field measurements—moisture content of exterior portion of OSB.*

**Initial Conditions.** Initial moisture content of the construction was in equilibrium with 70% RH and 16°C (60°F), except for the air layer with the "injected" moisture.

**Simulation Results.** Initially a single wetting event was simulated. The results for a high-permeability housewrap (58 perms) and a low-permeability housewrap (6.7 perms) are compared with a simulated wall with no housewrap in Figure 8. The results demonstrate how drying is reduced and moisture buildup occurs in the exterior region of the sheathing. The high-permeability housewrap is significantly closer to the natural drying rate of the sheathing.

A simulation of repeated wetting, as would be seen in the field if dew condensation were taking place, was desired. This was accomplished by running iterative simulations in which at the end of each short time period (either 24 or 72 hours) the simulation was stopped and moisture was "re-inserted" into the airspace behind the weather-resistive barrier. At the beginning of each iteration, the OSB sheathing was assigned the moisture distribution the sheathing had at the conclusion of the previous iteration. Figure 9 shows a description of this iterative process. Parametric evaluation showed that the primary factors in determining the moisture content of the sheathing were the frequency of moisture introduction and the vapor permeability of the housewrap. The iterative process was run to simulate the three-week period observed in the field investigation. Results in which the moisture was "injected" every three days show qualitative agreement with both the measured moisture content and sheathing moisture distribution observed in the field (Figures 10 and 11). This agreement between model and field data supports the conclusion that the low-permeability housewrap was impeding wall drying and that sufficient wall drying occurred when a high-permeability housewrap was used.

## CONCLUSIONS AND RECOMMENDATIONS

A field study showing the effect of weather-resistive barrier vapor permeability on sheathing drying and the moisture performance of wall assemblies was discussed. Computer simulations of this field study supported the conclusions from the field study that low-permeability housewraps can reduce drying to the extent that significant moisture can accumulate in sheathing during construction. In contrast, high-permeability housewraps allow sufficient wall drying to occur and provide for a wall with better water management.

Observations of weather-resistive barriers during construction can be instructive when considering the specification of these products because during the construction phase these products are exposed to more extreme conditions.

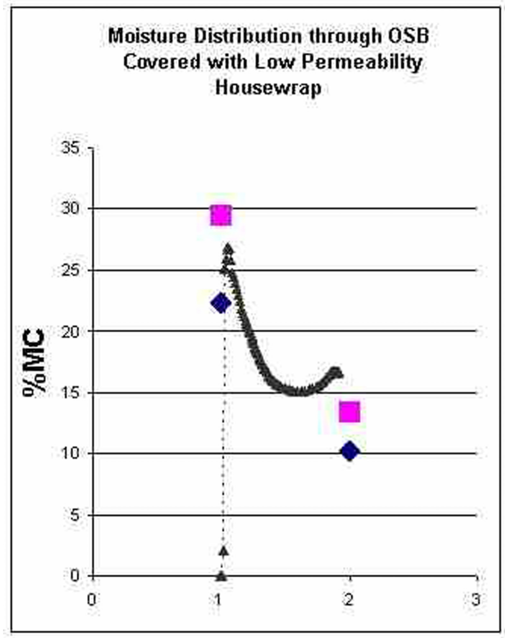



***Figure 11*** *Comparison of simulation results to measured data—moisture content profile through OSB.*

### Reduction of Wall Wetting

Water intrusion behind the weather-resistive barrier has been observed to occur in several ways:

- directly through the weather-resistive barrier if it has low water resistance, as with perforated housewraps,
- at interfaces with other wall components, such as windows, especially where there is reverse shingling at these interfaces, and
- through dew or frost condensation behind the weather-resistive barrier. The conditions under which dew condensation occurs have not been fully identified. It is likely dew or frost formation is increased by poor detailing and resulting small-scale air leakage.

Specifying weather-resistive barriers with water resistance that is above code minimums is required to reduce moisture loads during the construction phase of a building. Proper attention to the design and installation of interface and flashing details is also required.

### Drying Considerations

Although choosing a weather-resistive barrier with high water resistance (above code minimums) and using good flashing details and installation methods will do a lot to reduce moisture between the weather-resistive barrier and sheathing, some moisture may still persist there due to condensation from dew or frost or possibly from construction moisture that is transported from other building materials. Therefore, drying through the weather-resistive barrier and, thus, high vapor permeability is required.

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