WALL DRYING IN HOT AND HUMID CLIMATES

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ABSTRACT

Moisture and subsequent mold problems in buildings are a serious and increasing concern for the building industry. Moisture intrusion in buildings is especially pertinent in hot and humid climates because the climate conditions provide only limited drying potential while at the same time providing a high potential for mold growth. To reduce moisture accumulation in wall systems, it is important to design wall systems that not only reduce moisture intrusion, but also allow drying. Yet often a wall's ability to dry is not considered during the design or material selection process. No cladding system or installation is perfect, therefore wall systems should be designed with the assumption that some moisture will enter and then consider the effects and how that moisture can be managed. This paper explores the mechanisms of wall drying, focusing on how wood frame walls dry in hot, humid climates. This paper describes laboratory drying studies of conventional sheathing / weather resistive barrier systems under a variety of temperature and humidity conditions including those typical of hot humid climates. Additionally, a computer simulation is used to examine the implications of drying to the interior, drying to the exterior, or drying to both the interior and exterior. Traditional rules of thumb for construction in hot humid climates rely on drying to the interior, but we will show that walls can and do dry to the exterior in these climates.

INTRODUCTION – MOISTURE MANAGEMENT STATEGIES

It is important to design wall systems that manage moisture. Moisture management is commonly thought to mean keeping water (bulk and vapor) out of the structure. An often-overlooked part of moisture management is drying out moisture that happens to get in. The ability of a wall system to promote drying helps to minimize any potential for moisture accumulation and damage. No cladding system or installation is perfect; therefore wall systems should be designed to effectively dissipate any water entering the wall.

In hot-humid climates, many practitioners concentrate on preventing inward vapor drive. While this phenomenon does exist, design for good building performance must account for all of the methods of moisture movement and not focus on one aspect. Since the potential amount of moisture ingress associated with vapor diffusion is small in relation to the amount associated with a wetting event from liquid water or air leakage, the vapor diffusion mechanism can be taken advantage of to add drying capability in a wall system.

In section 24.14 the current (2001) ASHRAE Handbook on Fundamentals states:

> *"Liquid water and water vapor migrate by a variety of moisture transport mechanisms. The following are some of the most important mechanisms:*
>
> - *Liquid flow by gravity or air pressure differences*
> - *Capillary suction of liquid water in porous building materials*
> - *Movement of water vapor by air movement*
> - *Water vapor diffusion by vapor pressure differences*
>
> *Although in the past many moisture control strategies focused on control of vapor diffusion through the installation of vapor (diffusion) retarders, the other mechanisms, when present, can move far greater amounts of moisture. Thus, liquid flow, capillary suction, and air movement should be controlled first"* [1]

Moisture associated with bulk water intrusion and air infiltration is most damaging to wall systems because they are associated with large volumes of moisture and thus are the prime contributors for moisture accumulation. A review of literature reports that air leakage accounts for anywhere from six to 100 times as much moisture transfer as vapor diffusion.[2] Another study concludes that point source water intrusion accounts for 20 times the moisture associated with air infiltration and air infiltration accounts for 25 times the moisture movement associated with diffused moisture.[3] Although moisture movement by diffusion cannot be discounted, it should not be the primary focus for moisture intrusion control.

Once the largest potential sources of water ingress (liquid flow, capillary suction, and air movement) have been adequately addressed, careful attention can then be given to vapor diffusion. Typically in hot-humid climates the attention has been paid to how much moisture enters a wall system through vapor diffusion with little attention on capitalizing upon vapor diffusion properties to dry walls out. The general assumption has been that either there will be no water in the wall (a theoretical possibility but practical impossibility) or it will dry to the interior because it cannot dry to the exterior. However, this paper takes the position that if designed appropriately walls can dry to the exterior also. A vapor permeable secondary weather membrane is a key component in providing adequate drying potential in building components and wall systems.

COMPUTER MODELING OF INWARD VAPOR DRIVE AND WALL DRYING

A series of modeling simulations were run to evaluate any theoretical differences that a high permeability membrane (58 perms) and a vapor barrier (0.07 perms) would have on drying as well as on inward vapor drive in wall systems in various climates including hot-humid.

Experimental Simulation Model.

WUFI 3.3 Pro[4] 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 by liquid flow 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.

Environment.

Weather files for a 10% cold year for Chicago, St Louis and New Orleans were chosen to represent the cold, mixed and hot–humid climates respectively. The model uses hourly weather data for that region to calculate the expected dynamic moisture response of the wall system over time based on the varying weather conditions.

Constant interior conditions of 70°F and 55% RH were chosen. This corresponds to typical interior temperatures and a high level of moisture production within the house. This was chosen as a worse case scenario moisture load.

Construction.

A typical wall construction was selected. Material properties were assigned from the material property database included as part of the modeling software. This data was augmented with published vapor permeability data[5] and manufacturer's literature.

The wall system from exterior to interior was as follows:

- **Vinyl siding**: Because of its high degree of air leakage, the siding was represented only as a shield to rain water and no resistance to vapor diffusion was included. This is an over simplification but represents a worse case scenario for inward vapor drive.
- **Vapor barrier** (0.07 perms) **or vapor permeable membrane** (58 perms): The material property data for the vapor barrier was taken from the simulation database. The vapor permeable membrane simulated was a flashspun, spunbonded polyolefin (SBPO) and its material property data was taken from the manufacturer's literature.
- **Plywood**: The plywood sheathing provides a surface for a simulated wetting event. The material property data was taken from the simulation database and the permeability is shown in Figure 1.
- **R-19 Fiberglass Insulation:** The material property data was taken from the simulation database.
- **Interior vapor barrier** (if used - 0.07 perms): The material property data was taken from the simulation database.
- **Interior gypsum board with primer and 2 coats of primer:** The material property data was taken from published vapor permeability data.

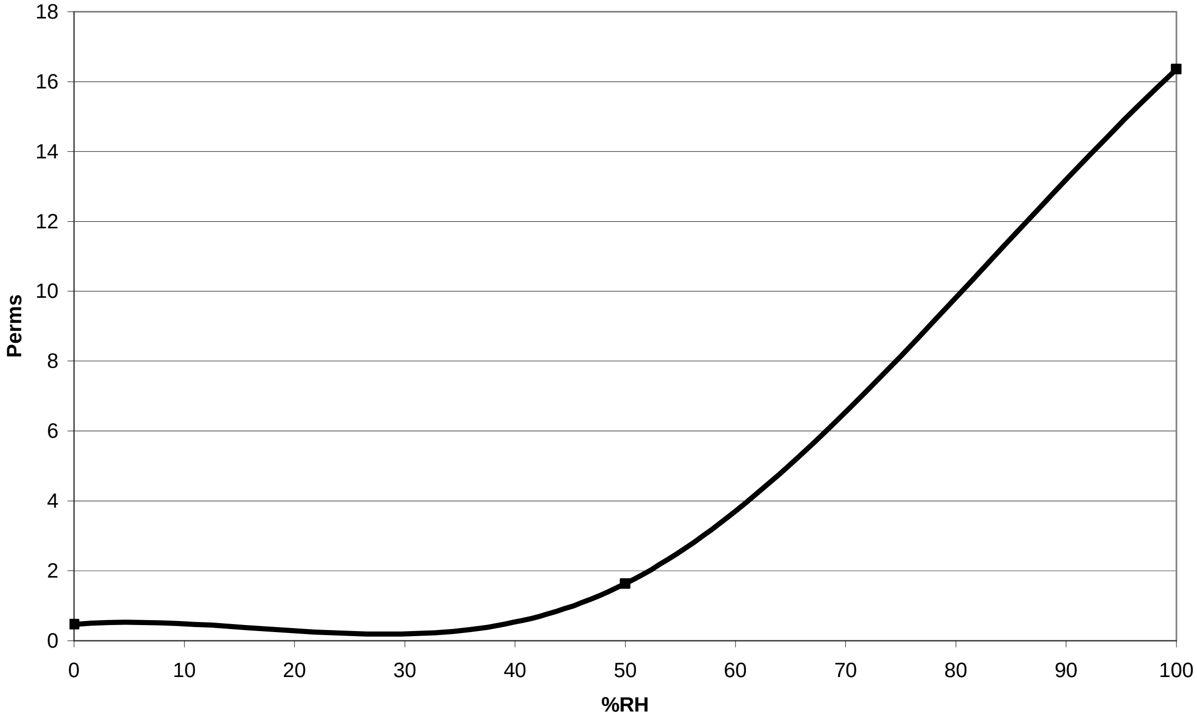


Figure 1: Plywood Permeability

Simulation.

The four wall designs, as shown in Table 1, were simulated for environmental vapor diffusion with no added bulk water or air leakage events over a two-year period starting January 1. All wall components were initially at equilibrium moisture content with 65% relative humidity and 69.8°F. The dynamic response to diffusion was analyzed by monitoring the total moisture content of the wall. See Figures 2 to 6.

Table 1: Simulated Wall Systems

	Exterior Wall	Interior Wall
1	Vapor Barrier	Vapor Barrier
2	Vapor Barrier	No Vapor Barrier
3	Vapor Permeable Membrane (SBPO)	Vapor Barrier
4	Vapor Permeable Membrane (SBPO)	No Vapor Barrier

Simulations of drying after a wetting event were also conducted. They were conducted to consider the effect of moisture intrusion on the wall and the capacity for each design to enable drying under the expected weather conditions for the climate. All wall components except the plywood sheathing were initially at equilibrium moisture content with 65% relative humidity and 69.8°F. The simulation used high moisture content in the plywood sheathing (equilibrium moisture content with 100% RH and 69.8°F) to simulate the occurrence of a moisture event wetting the wall. The simulation began on July 1 and ran for 3 months. The drying rate was analyzed by monitoring the total moisture content of the wall. See Figures 7 thru 11.

Simulation Results

In general, the results indicate only small differences in the wall moisture performance due to climatic vapor diffusion. However, simulations of the drying of a moisture event (e.g. rain leak, air leakage condensation, or plumbing leak) indicated faster drying of the highly permeable membrane wall system vs. that of the vapor barrier wall system.

The simulations indicate that there is no significant difference for inward moisture vapor migration in the wall system when a high permeability membrane is selected instead of a vapor barrier during hot humid or summer conditions. [For example in Figure 5: New Orleans Vapor Diffusion Performance; there are minimal differences in the total moisture content of the wall system consisting of an Exterior Vapor Barrier (no interior vapor barrier) and the system consisting of SBPO (no interior vapor barrier). It is hypothesized that the plywood (with a much lower vapor permeance than the SBPO) impedes the moisture from entering the wall cavity and the higher vapor permeance of the SPBO allows any moisture to evaporate.] The only significant moisture accumulation noted in any of the wall systems was during winter climates when no interior vapor barrier was used. In all cases, however, the amount of water in the wall was less than that expected from the "wetting events". Based on the simulations conducted, one could conclude that moisture migration into the wall assembly due to diffusion alone is inconsequential regardless of whether a vapor barrier or permeable membrane is used. This suggests that inward vapor diffusion alone should not be the prime factor for consideration in either wall design. These results can be observed through careful examination of the Vapor Diffusion Performance charts (figures 2 through 6).

Figure 2 shows the simulation results for a dry double vapor barrier wall and is included to show baseline performance. It is not a wise decision to actually construct a building with a double vapor barrier. Any moisture entering would be trapped.

Figures 3 and 4 show the simulation results for a dry wall in Chicago and St. Louis, respectively. In Chicago and St. Louis, internal vapor barriers are required by building codes. These vapor barriers prevent driving the wintertime interior moisture into the wall system. With this internal vapor barrier in place, the differences in the exterior vapor barrier and the highly permeable membrane are minor.

Figure 5 shows the simulation results for a dry wall in New Orleans. In the hot-humid climate of New Orleans, the results show that there is essentially no difference in the performance of an exterior vapor barrier, and highly permeable membrane regardless of the use of an internal vapor barrier.

Figure 6 shows the simulation results for a dry wall utilizing a vapor permeable membrane without an internal vapor barrier. This chart was included to show that climate does impact the amount of moisture entering a wall system. However, the amounts are small. As stated previously, the Chicago and St. Louis examples are of climates where internal vapor barriers are required.

Figure 2: Double Vapor Barrier Vapor Diffusion Performance
(Starting Jan 1)

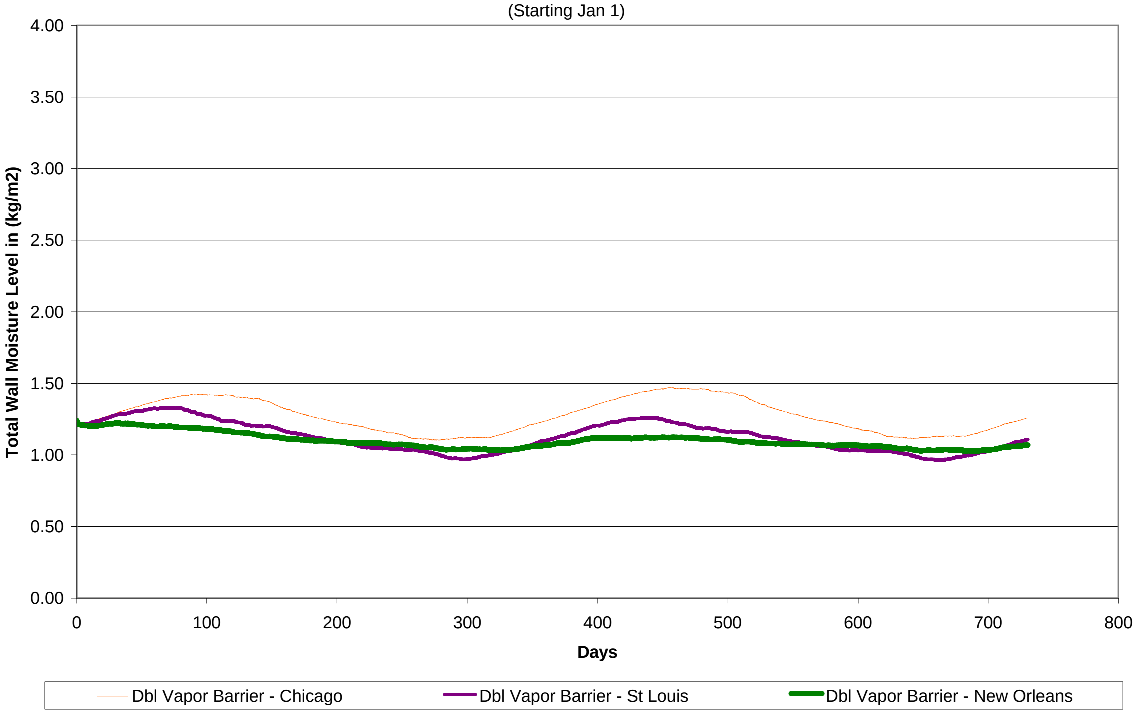


Figure 3: Chicago - Vapor Diffusion Performance
(Starting Jan 1)

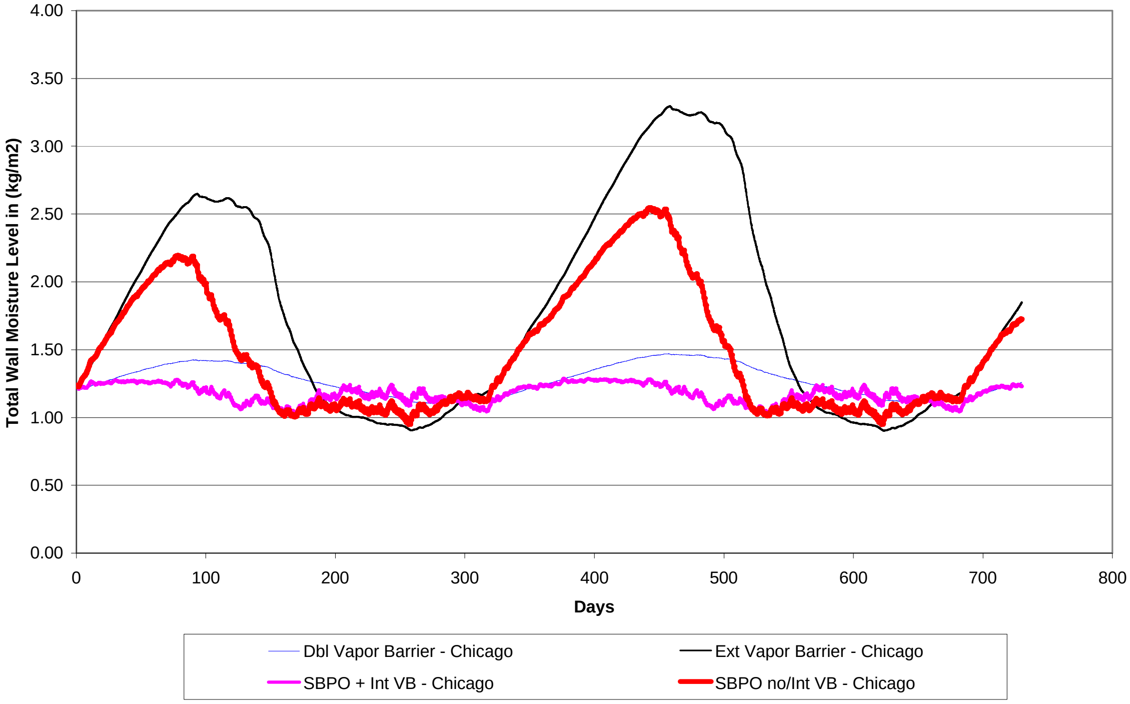


Figure 4: St. Louis- Vapor Diffusion Performance
(Starting Jan 1)

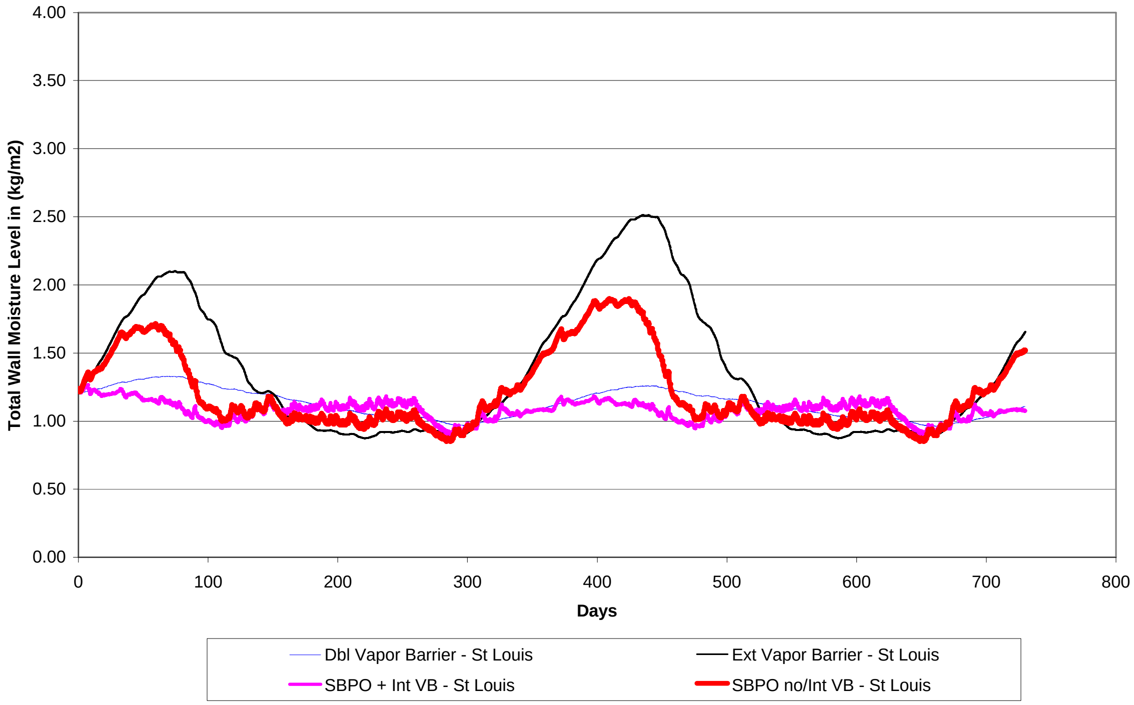
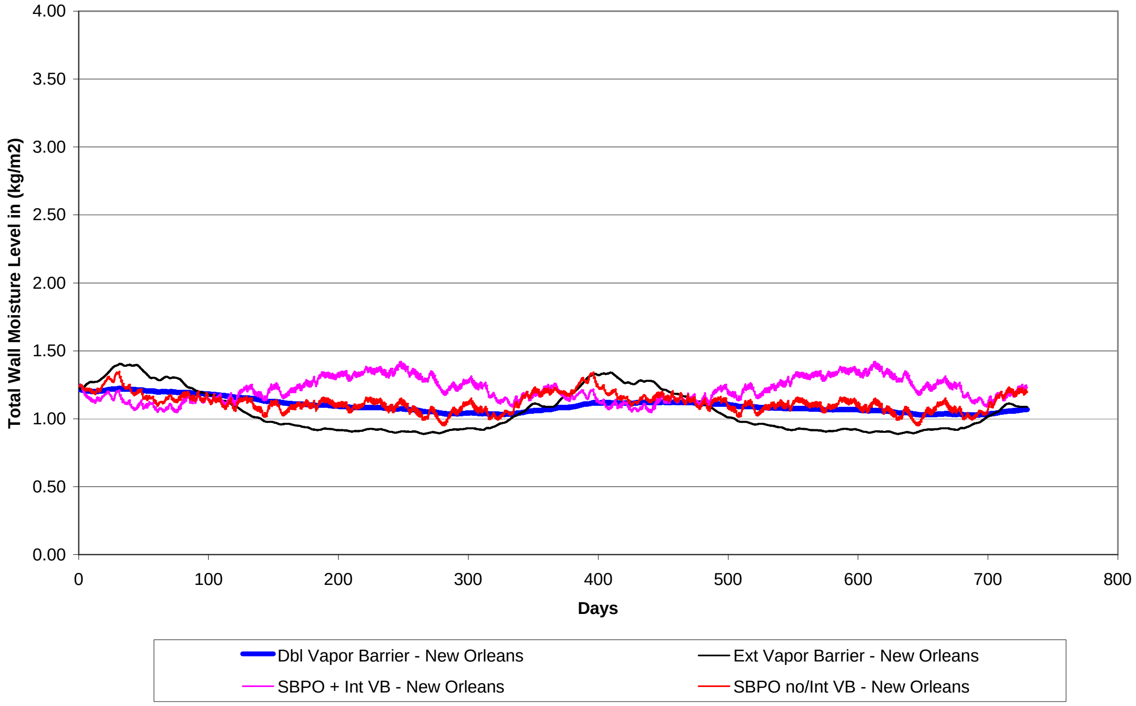
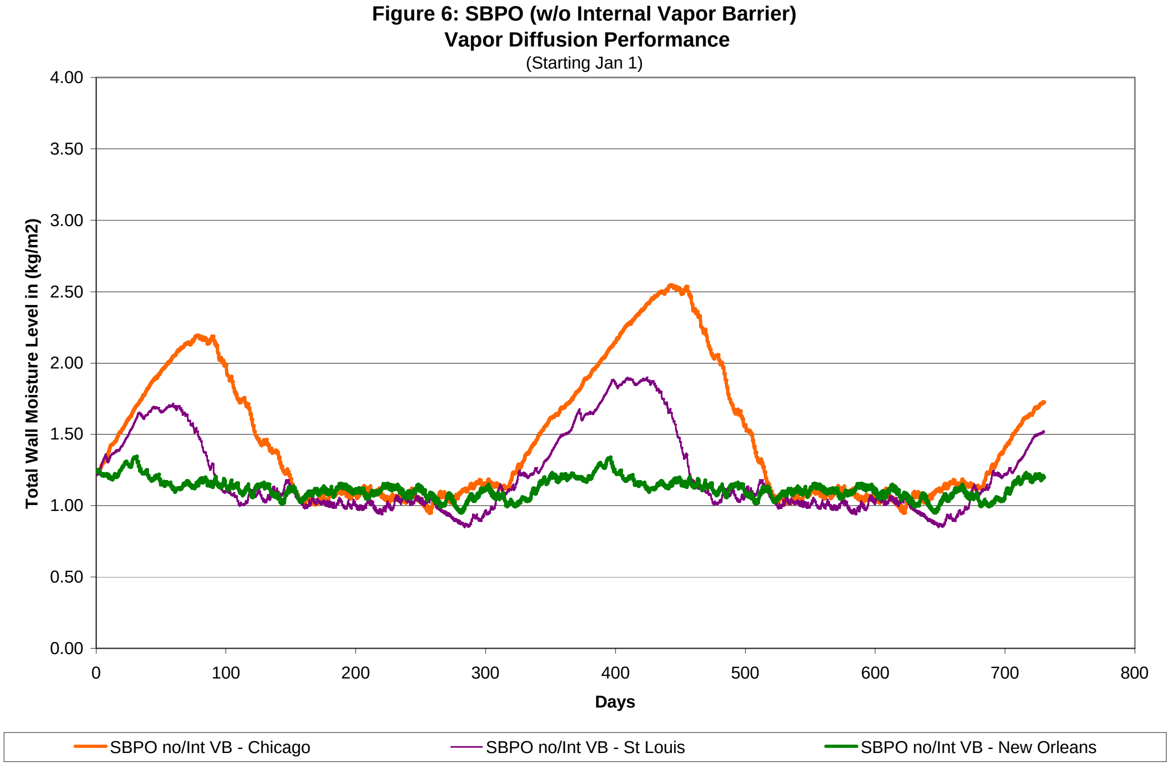


Figure 5: New Orleans - Vapor Diffusion Performance
(Starting Jan 1)





Of more significance is the expected response of the wall system when a wall component is simulated as wet at the start of the evaluation. This is important because it illustrates the drying capacity of the wall system in the presence of a single moisture intrusion event. These evaluations indicate that the wall components for a vapor barrier system take a substantially longer time to dry to an equilibrium state and stay wet with localized elevated RH for an extended period of time. This localized humidity can contribute to the formation and growth of fungi within the wall system. These results can be observed through careful examination of the Drying Performance charts (figures 7 through 11).

Figures 7, 8 and 9 show the simulation results for drying walls in Chicago, St. Louis and New Orleans respectively. In each city, the performance of each of the wall systems is similar. As expected the wall constructed with a double vapor barrier does not dry. The wall constructed with a highly permeable membrane on the exterior and no internal vapor barrier dries the quickest, (at least 2 times as fast as the walls with an exterior vapor barrier and no internal vapor barrier), because it has the ability to dry to both the interior and the exterior versus just to the interior.

Figures 10 and 11 show the simulation results of an exterior highly vapor permeable membrane and an exterior vapor barrier respectively. (Neither system utilizes an interior vapor barrier.) These charts are included to demonstrate the range of performance that can be observed from city to city.

Figure 7: Chicago - Drying Performance
(Starting Jul 1)

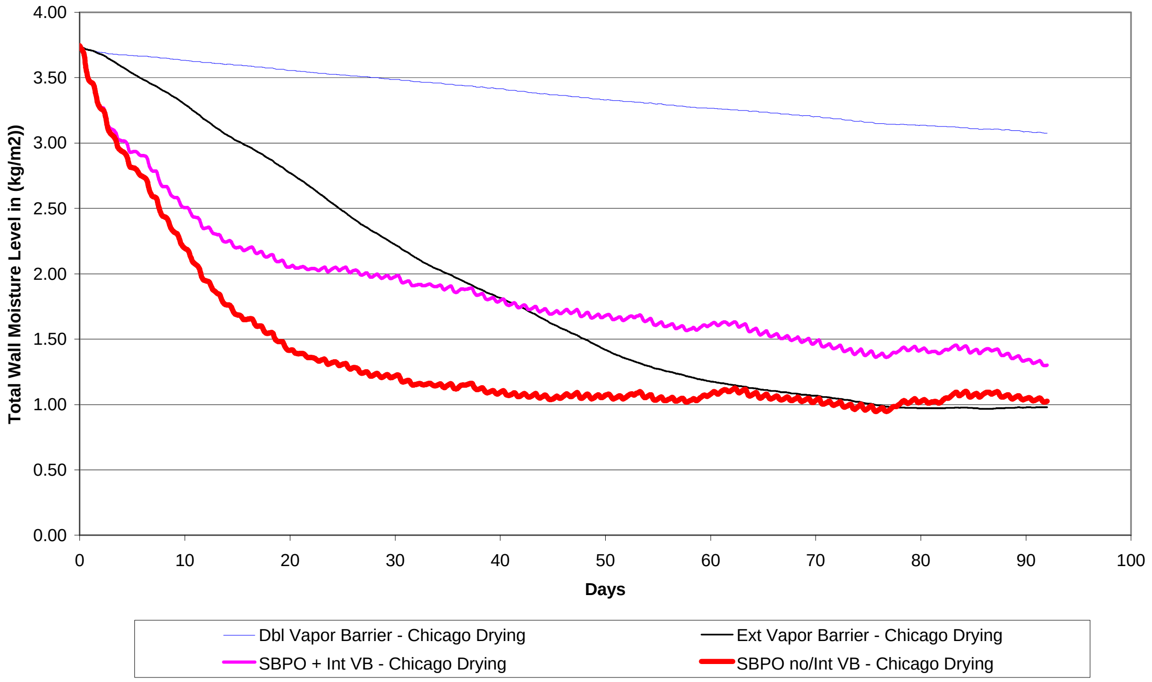


Figure 8: St. Loius - Drying Performance
(Starting July 1)

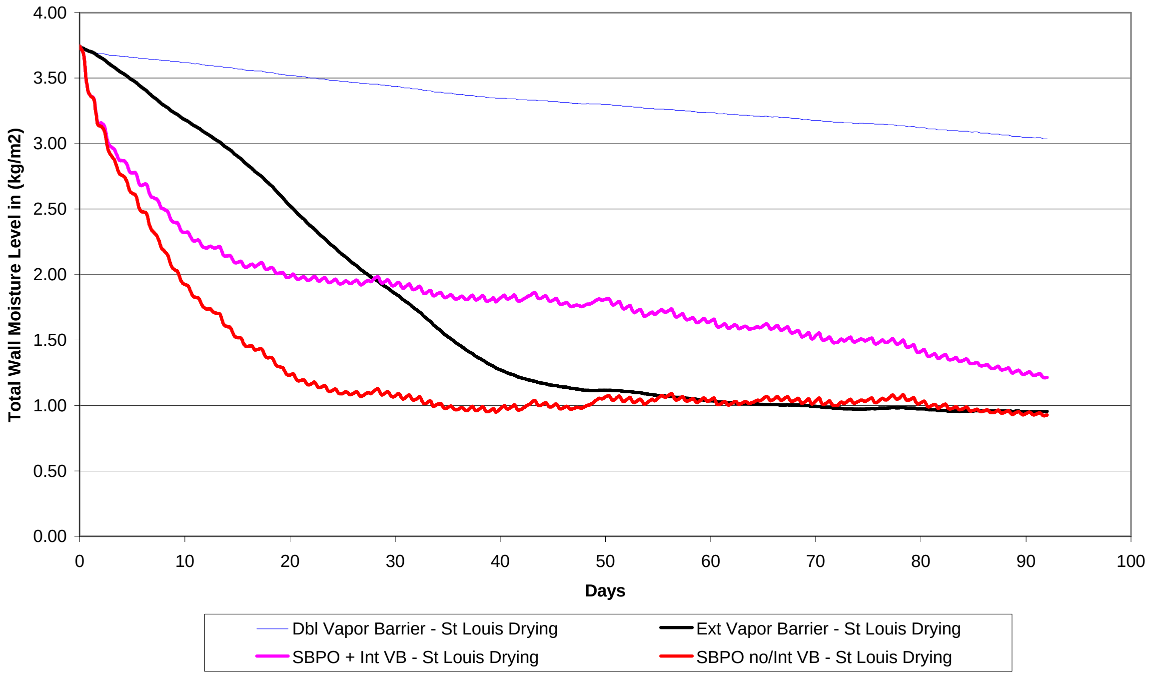


Figure 9: New Orleans - Drying Performance
(Starting July 1)

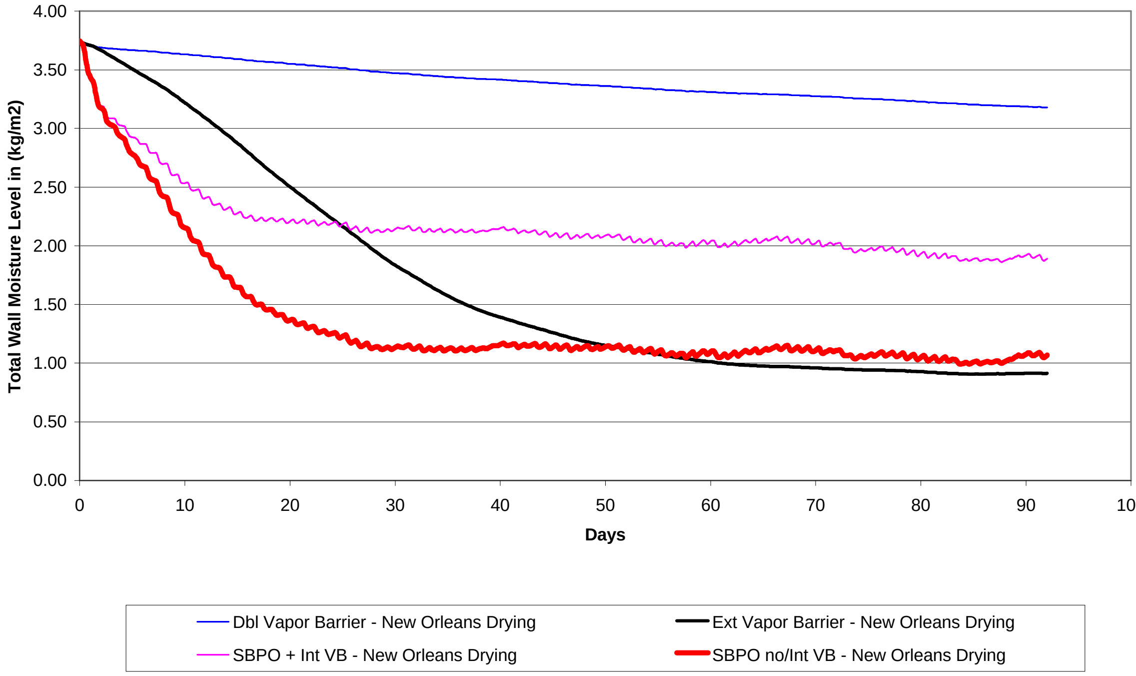


Figure 10: SBPO / no Int Vapor Barrier - Drying Performance
(Starting July 1)

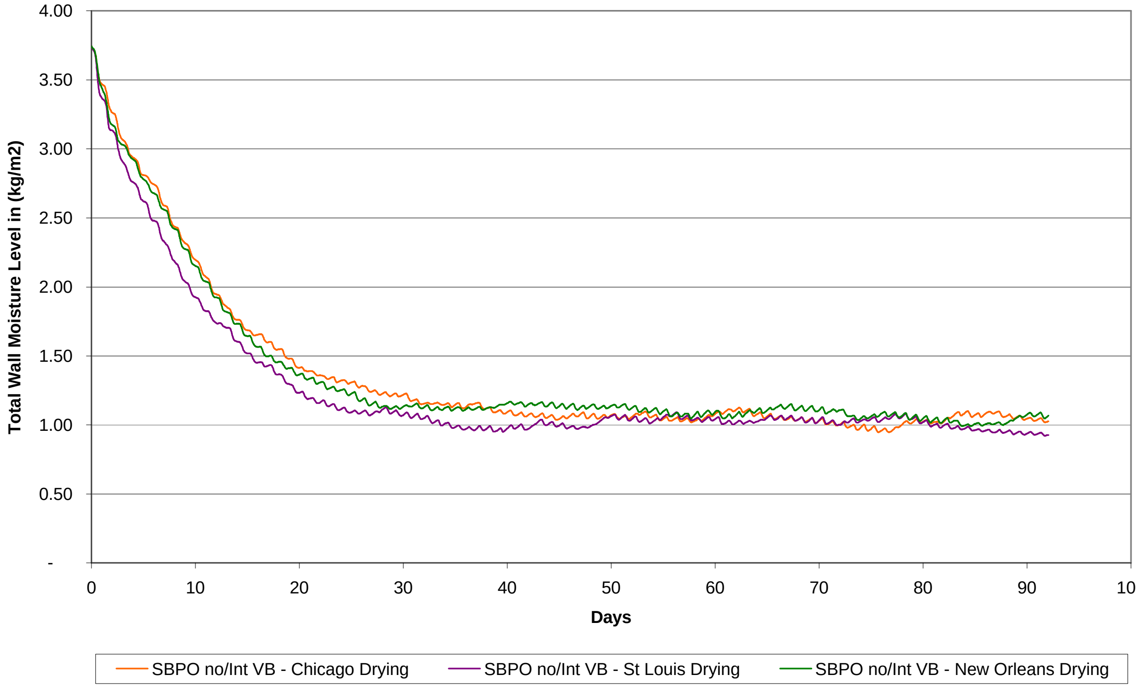
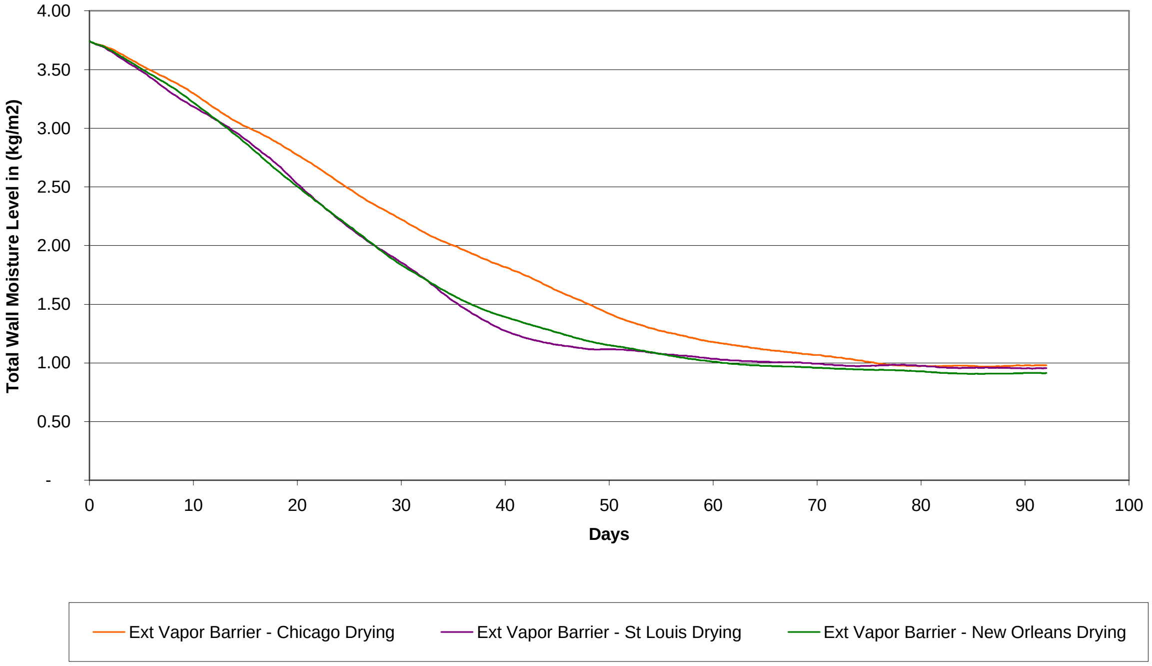
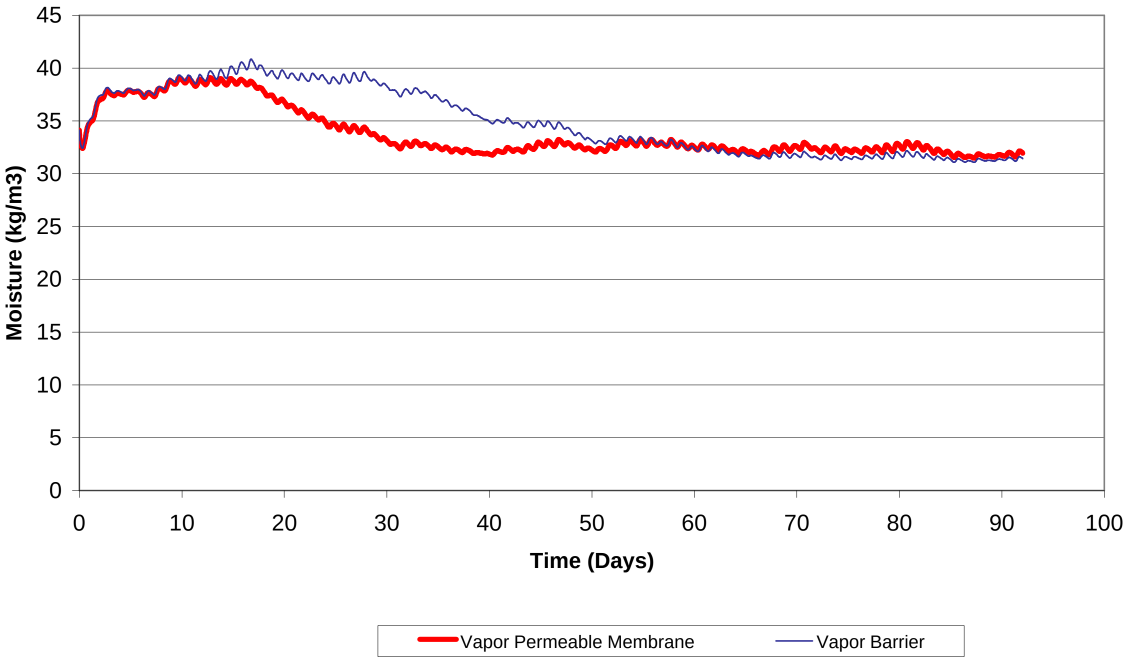


Figure 11: Exterior Vapor Barrier- Drying Performance
(Starting July 1)



Drying to the interior is clearly present when no internal vapor barrier is present. The increased rate of drying when a vapor permeable exterior membrane is used in conjunction with no internal vapor barrier is evidence that in these walls drying to both the exterior and interior is occurring, even in New Orleans. An additional benefit of drying occurring to both the interior and exterior is that the period of time when the gypsum board is at elevated moisture content is significantly reduced. See Figure 12.

Figure 12: Gypsum Board Moisture Content
New Orleans



ORIENTED STRAND BOARD (OSB) DRYING – LABORATORY TESTING

The computer modeling simulations are supported by practical laboratory testing examining the drying of wood which has been exposed to one significant wetting incident, such as a burst pipe or leaky window. Wood will attempt to come to equilibrium moisture content (EMC) in any environment it is placed. This equilibrium moisture content varies with the temperature and relative humidity of the environment. The theoretical EMC for non-living wood, natural or cut, at or below the fiber saturation point can be calculated using the formula[6]:

$$M = 1800/W\ [KH/(1-KH) + (K_1KH + 2K_1K_2K^2H^2) / (1 + K_1KH + K_1K_2K^2H^2)]$$

Where:

M = moisture content (%)

T = temperature (^oF)

H = relative humidity (%)

$W = 330 + 0.452T + 0.00415T^2$

$K = 0.791 + 0.000463T - 0.000000844T^2$

$K_1 = 6.34 + 0.000775T - 0.0000935T^2$

$K_2 = 1.09 + 0.0284T - 0.0000904T^2$

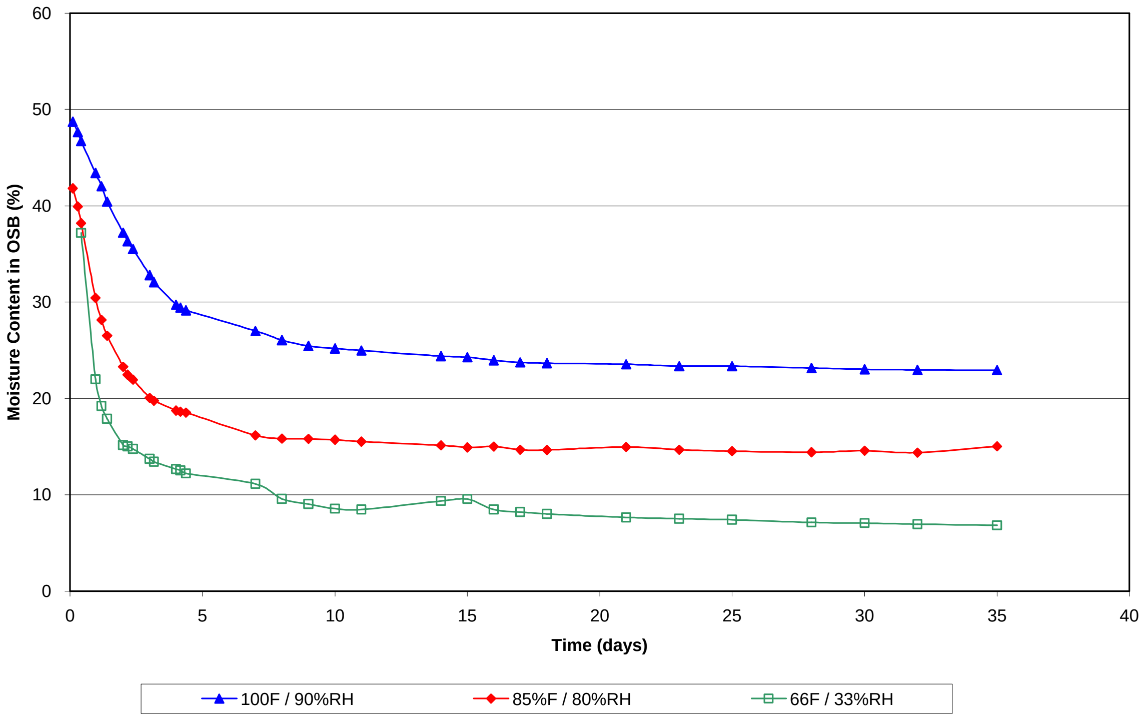
It is important to note that this is a generalized formula and each wood species behaves slightly different.

This can also be seen through examination of the drying curve for a particular species of wood. Although the actual EMC is different in various environments the drying curve appears to be the same in all environments. If OSB is saturated it will naturally loose most of the moisture within a few days, drying at an exponential rate. Then as it approaches EMC the rate will taper off (see Figure13).

The data for Figure 13 was generated in a laboratory test examining the relative impact of water vapor permeability (WVP) on the natural drying rate of OSB.

If OSB is surrounded by another material, it is expected that the drying rate of OSB would be reduced. A laboratory experiment was designed to measure the degree of reduction in drying rate based on material properties of the surrounding material.

Figure 13: OSB Drying Rate



Experimental

Test Protocol.

Pouches were constructed of 2 pieces of pristine test material. Three edges of the pouch were sealed using a vapor impermeable tape. The pouches were constructed such that the outside of the pouch represented the outside of the home (i.e. for commercial materials the printed side was on the outside) and the inside of the pouch was the side of the test material that typically comes in contact with the OSB in an actual wall system.

Several pieces of OSB were exposed to ambient conditions and allowed to come to equilibrium moisture content. Initial moisture content was determined through the use of a moisture content meter. Each piece of OSB was weighed and then submerged in water. Upon removal, excess water was wiped from the surface; the wet OSB was weighed and immediately placed in a pouch constructed of the test material. The final side of the pouch was then sealed. The pouch was then weighed and hung to dry. The weight of each pouch containing the OSB was measured at intervals to determine the change in moisture content of the OSB. The test continued until many of the samples approached EMC.

To simulate the natural drying rate of the OSB, a piece of OSB enclosed in an open mesh (screen) bag was also tested**.**

Environmental Conditions.

The specimens were placed in different temperature and humidity controlled environments to simulate variable climate conditions. The test covered North America’s diverse climate ranges, which included:

- 85°F/80%RH
- 100°F/90%RH
- 66°F/33%RH
- 70°F/50% RH

Material Selection.

OSB was chosen because it is a commonly used sheathing material in North America. An assortment of commercially available housewraps was chosen primarily based on vapor permeability. The membranes are listed in Table 2.

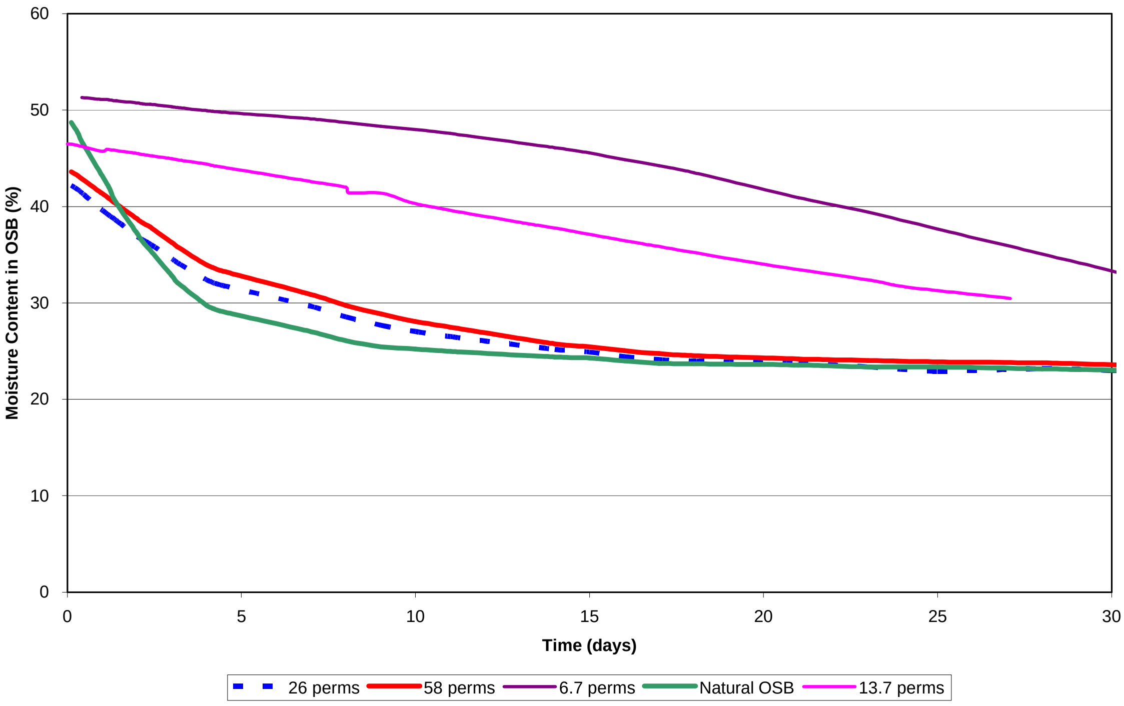
Table 2: Manufacturer's Published WVP of Test Housewraps

Sample ID	**Membrane**	**WVP** (ASTM E96 B) (perms)
SBPO-1	flashspun, spunbonded polyolefin	**58**
SBPO-2	flashspun, spunbonded polyolefin	**26**
BFL-1	spunbonded polypropylene & breathable film laminate	**13.7** (method A)
BFL-2	nonwoven fabric & breathable film laminate	**6.7** (method A)

Drying Results

This study demonstrates that even in hot-humid climates wall systems can dry to the exterior if designed appropriately. The drying curves show that in each of the environmental conditions studied the natural OSB quickly approached the EMC for its environment. The other specimens approached the EMC at a slower rate based on the vapor permeability of the pouch material. The higher the permeability the quicker the OSB approaches its EMC. Even in the hot-humid environment OSB naturally quickly approaches its EMC when not inhibited by a low vapor permeable membrane. An example of the typical drying curve is listed in Figure 14.

Figure 14: OSB Drying Curves (100F / 90%RH)



To better understand the drying phenomenon another round of testing was performed. It was desired to expand the range of vapor permeabilities studied. To accomplish this, membranes which are not commercially available were included. The materials selected are listed in Table 3. Additionally 1 set of replicates was included.

The test was performed at 75°F and 55% relative humidity and conducted for 42 days. At the conclusion the pouches were opened and the OSB examined.

Again it was noted that the natural OSB dried at an exponential rate while the other specimens approached the EMC at a slower rate based on the permeability of the pouch material. An example of the drying curves for several of the membranes can be seen in Figure 15.

Examination of the OSB revealed staining as well as "mold"-like substances growing on some of the specimens. The front and back of each specimen was rated and the four values (2 specimens per membrane, front and back of each) were averaged to produce an average mold rating for each membrane (see Table 4). The rating was visual and used a scale of zero to three. A zero indicated no mold and a three indicated significant mold. Figures 16, 17 and 18 illustrate typical scores of 1, 2, and 3 respectively.

Table 3: Measured Vapor Permeability of Test Membranes

Sample ID	**Membrane**	**WVP** (ASTM E96 B) (perms)	
		Measured	Published
SBPO-1	flashspun, spunbonded polyolefin	53.9	58
SBPO-3	flashspun, spunbonded polyolefin	23.7	28
SBPO-4	flashspun, spunbonded polyolefin	17.8	N/A
P-1	woven, perforated, polyethylene slit film	18.1	12
P-2	woven, perforated, polyethylene slit film	5.8	10 (method A)
BFL-1	Spunbonded polypropylene & breathable film laminate	10.8	13 (method A)
BFL-2	nonwoven fabric & breathable film laminate	5.4	6.7 (method A)

Figure 15: OSB Drying Curves (75F/55%RH)

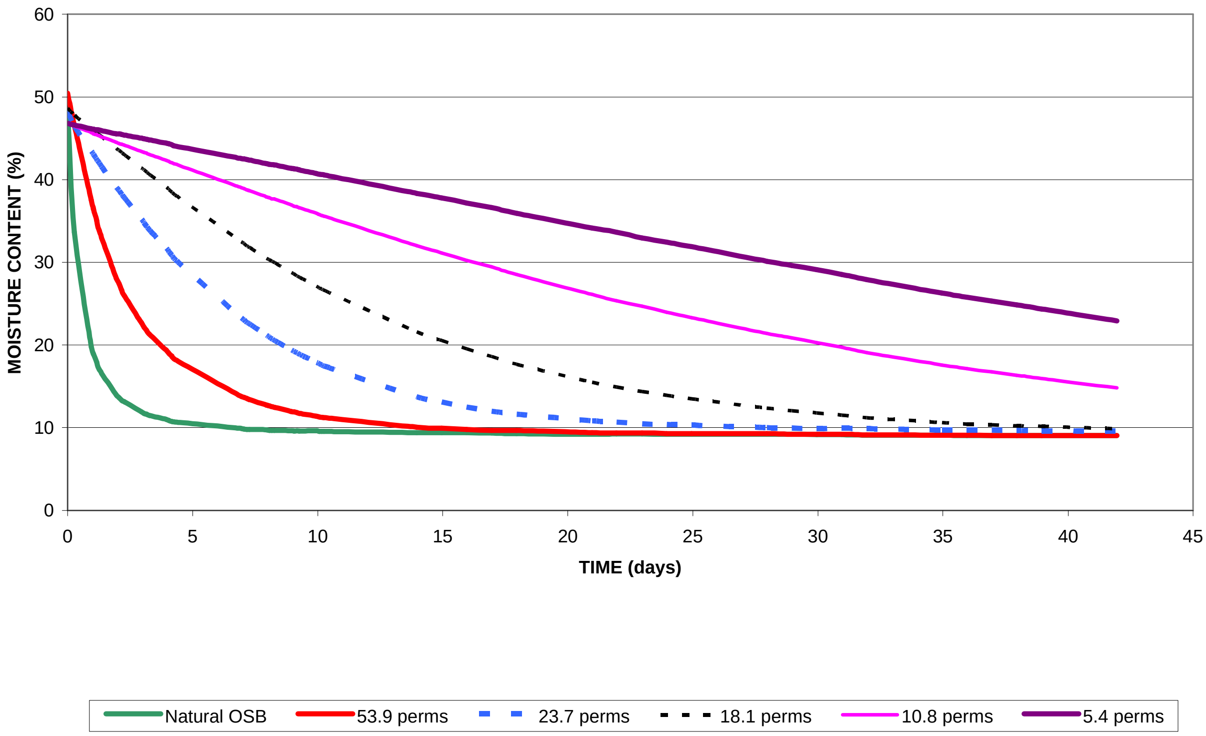


Table 4: Mold Development on OSB

Sample ID	**MEASURED WVP** (ASTM E96 B) (perms)	**Average Mold Rating** (0= none; 3= significant)
Screen	N/A	0
SBPO-1	53.9	0
SBPO-3	23.7	0
SBPO-4	17.8	1
P-1	18.1	1
P-2	5.8	2.5
BFL-1	10.8	2.5
BFL-2	5.4	2.75

Figure 16: OSB with mold rating of 1

Figure 17: OSB with mold rating of 2

Figure 18: **OSB with mold rating of 3**

All of the specimens with a vapor permeability greater than 24 perms scored a zero on the mold rating. This was not true of the specimens with a vapor permeability of 18 or less. The samples in the high teens grew a small amount of mold and rated a 1. The other lower permeability membranes (less than 11 perms) grew significant amounts of mold and rated mostly 2 and 3. This leads one to conclude that at the specified temperature and relative humidity of 75°F and 55%, the breakpoint between allowing/promoting drying and prohibiting drying is somewhere between 18 and 24 perms.

CONCLUSION

Computer modeling and laboratory testing both support the idea that drying to the exterior as well as interior can occur even in hot-humid climates. The data also supports the idea that one significant wetting event overwhelms the amount of moisture transported into a wall system through inward vapor drive. While drying to the interior is the primary mechanism in a hot-humid climate, the opportunity for exterior drying should not be overlooked. Moisture can be transported out of the wall system through careful design, material selection and installation.

Additional work in computer modeling, laboratory testing and field studies designed to study the impact of the drying capability of a wall system should be conducted. Additionally, further study of vapor permeable membranes in hot-humid climates may indicate the breakpoint permeability between impeding and promoting drying.

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[1] ASHRAE Handbook, *Fundamentals*, S-I Edition, 2001. pp. 23.11 – 23.17, 24.2 – 24.16

[2] *Thermal and Moisture Protection Manual*, Christine Beall, 1999. pp.154-159

[3] Moisture Management and Condensation Control in Building Envelopes, ASTM Manual 40, 2001, *"Moisture Primer"*, Heinz R. Trechsel, Tables 4 and 5

[4] WUFI 3.3 Pro was developed by the Franhofer Institute of Building Physics and adapted for use in North America by the Oak Ridge National Laboratory under contract with the U. S. Department of Energy.

[5] Kumaran, M. K. et. al., A Thermal and Moisture Transport Property Database for Common Building and Insulating Materials – Final Report from ASHRAE Research Project 1018-RP, July 4, 2002

[6] CSGNetwork and Computer Support Group, http://www.csgnetwork.com/empctablecalc.html 2972 Vincentia Road Palm Springs, CA 92262