SPRAY POLYURETHANE FOAM ALLIANCE

SPFA

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American Plastics Council

MOISTURE VAPOR TRANSMISION

Spray Polyurethane Foam Alliance

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Revised 1/99

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MOISTURE VAPOR TRANSMISSION

Water may be present in our environment in any of its three physical states: ice (solid), liquid and vapor (gas). This paper discusses the effects of the interactions between water vapor, liquid water, building materials and building components.

WATER VAPOR TRANSMISSION

Water vapor will tend to migrate from regions of relatively high absolute humidity to regions of low absolute humidity. This was vapor migration is normally of no particular concern to the building occupant or the designer unless the water vapor condenses into liquid water. Should water vapor condense within a building component (i.e. a wall or roof), water drippage to the interior or destruction of the building components may occur.

Building components should, therefore, be designed to prevent the condensation of water vapor within them.**

Water vapor transfers through building walls or roof systems by two mechanisms: air leakage and diffusion. Air leakage is generally the major culprit in the transfer of water vapor. However, because spray applied polyurethane foam is seamless and closed celled, air leakage is less a concern than diffusion.

A sheet of plastic or rubber may completely stop the flow of liquid water but may permit the diffusion of water vapor: water in the gaseous state may penetrate what appears to be a solid membrane.

Water vapor transmission (assuming air leakage has been eliminated) is affected by the following factors:

- The chemical composition of the building materials.
- The thickness of the building materials.
- The absolute humidity on each side of the building component (absolute humidity differential).

These factors affect water vapor transmission in the following ways:

Chemical Composition

The chemical composition of a building material has a profound effect on its ability to restrict water vapor diffusion. Spray applied polyurethane foam, silicone and acrylic

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**Some design strategies, such as the self-drying roof concept, allow for limited amounts of moisture to condense within the building component with the expectation that the moisture will vaporize when conditions permit and that the net accumulation will never reach detrimental levels. This takes the traditional approach of avoiding condensation at design conditions. The underlying principles of water vapor flow, condensation and evaporation are the same in either design method.

coatings all have measurable water vapor diffusion rates. Metals and glass, on the other hand, restrict diffusion so much they can rightfully be considered true vapor barriers.

Thickness

The greater the thickness of the materials, the lower the rate of water vapor diffusion. A material that might normally be considered a breathable material may successfully be used as a vapor retarder by increasing its thickness (conversely, a material normally considered a vapor retarder might be a breather if installed very thin).

Absolute Humidity Differential

Water vapor always diffuses from the regions of high absolute humidity to regions of low absolute humidity. The greater the difference in absolute humidity across a building component, the faster the diffusion rate will be.

Absolute humidity is a measure of the actual amount of water vapor contained in a unit volume of air. (Absolute humidity is distinct from "relative humidity" which is the ratio of air's absolute humidity to the air's water vapor holding capacity.)

Under the normal conditions seen in most building situations, warm air tends to have higher absolute humidity than cool air. This gives rise to the adage that "water vapor goes from hot to cold". While this is true with many building situations, it is not necessarily so for buildings assembled with wet or moisture laden components.

THE MEASURE OF WATER VAPOR TRANSMISSION

The most common method of evaluating a material's water vapor diffusion rate is by the ASTM E-96 method (Standard Test Method for Water Vapor Transmission of Materials). E-96 determines the "water vapor permeance" for a given material at a given thickness. The permeance is often referred to as the "perm rating"; the higher the perm rating, the faster the diffusion rate.

A variety of test conditions are allowed; vapor transmission rates for different materials reported in the literature may have been tested under differing conditions. Reported perm ratings should, therefore, be considered approximations.

CLASSIFICATION OF MATERIALS BY MOISTURE VAPOR TRANSMISSION RATE

Building materials may be classified as either vapor retarders (lower perm ratings) or vapor transmitters (higher perm ratings). The terms are relative; what may be a retarder in one case may be a transmitter in another. (**Remember**: thickness is as important as chemical composition.)

MOISTURE VAPOR TRANSMISSION

A material can only be considered a vapor retarder when it is compared to the other materials with which it is used.

Consideration must be given to seam treatment for certain materials. While steel sheeting may be considered a vapor retarder (virtually total), a steel roof deck usually has so many seams and holes as to be a vapor transmitter.

Usually, materials selected as vapor retarders have very low perm ratings (such as 6 mil polyethylene at 0.06 perms).

USING VAPOR RETARDERS/TRANSMITTERS TO PREVENT CONDENSATION

As was mentioned at the beginning of this paper, water vapor transmission, *per se,* is not particularly a problem. Water vapor condensation is a problem.

As discussed, water vapor concentration (absolute humidity) can build up within building components through the action of water vapor diffusion. This water vapor can then condense into liquid water if its temperature drops below the saturation temperature (dew point).

Water vapor condensation can be avoided by:

- Preventing building component temperatures from dropping below the saturation temperature (dew point)
- Reducing water vapor entering the building component
- Increasing water vapor leaving the building component

Condensation problems are most seen at exterior building walls and roofs. Temperatures of these components vary with the exterior temperature over which the designer/contractor has no control.

The designer/contractor can influence the temperature of building components with spray polyurethane foam's insulating quality. The water vapor entering a building component can be reduced by the use of vapor retarders. Furthermore, the use of breathable materials on the low humidity side can permit water vapor to flow through the building component.

Using these three tools (insulation, vapor retarders and flow through) in an appropriate arrangement can stop condensation.

The rule is: Install the building materials such that relative vapor retardance increases toward the side with the higher absolute humidity (usually the warm side). Conversely, install building materials such that relative vapor transmitters are toward the side with the lower absolute humidity (usually the cold side).

If this practice cannot be followed, install a vapor retarder such that:

- The vapor retarder is positioned as close to the side with the highest absolute humidity as possible and
- The vapor retarder has an installed perm rating substantially less than that of the next lowest component.

For example, examine the following cases:

Case 1 Spray applied polyurethane foam installed over a built-up roof suspected of containing small amounts of water, normal occupancy building.

The region of high absolute humidity will be the existing built-up roof. Water vapor diffusion will be in two directions: upward through breaks in the build-up membrane and the polyurethane foam toward the exterior and downward through the deck toward the interior.

Assuming a normal occupancy building, the interior temperatures will never drop below the saturation temperature; diffusion in the direction of the interior will never present a problem.

If night or winter temperatures are cool enough, the water vapor normally diffusing harmlessly through the foam may condense. It is important to provide a vapor transmitting covering system (high perm rating) to the exterior surface of the polyurethane foam to prevent the build up of humidity within the foam and, thus, avoiding condensation.

Case 2 Spray applied polyurethane foam applied to a metal deck (seams sealed), normal occupancy building.

The metal deck, because its seams are sealed, acts as an excellent vapor retarder. While temperatures might favor condensation (i.e. during winter), the metal deck would prevent the internal humidity from diffusing into the polyurethane foam. The perm rating of the covering system is not critical; its selection can be based on other factors.

Case 3 Spray applied polyurethane foam applied to the top surface of a concrete deck over a swimming pool (See Example Calculation).

The interior of this building will have extremely high humidity. As the concrete deck itself has a fairly high perm rating, a vapor retarder should be applied to the underside of the deck.

The thickness of the spray polyurethane foam must provide sufficient insulation to avoid condensation on the underside of the deck.

Additionally, the covering system for the polyurethane foam should be a vapor transmitter to allow diffusion out of the roofing system of any water vapor that may have diffused through or by-passed the vapor retarder.

Case 4 Spray applied polyurethane foam applied to a freezer.

Freezers present a reversal in the direction of water vapor diffusion expected in normal occupancy buildings. There will be a long-term tendency for exterior water vapor to diffuse toward the freezer interior.

The high humidity side in this case is the exterior and that is where the vapor retarder belongs. Thus, a vapor retarding covering system (i.e. a low perm rating coating system) should be located on the exterior side of the foam.

SUMMARY

Spray applied polyurethane foam roofing and wall insulation can be designed and installed to avoid the build up of humidity and the subsequent problem of condensation.

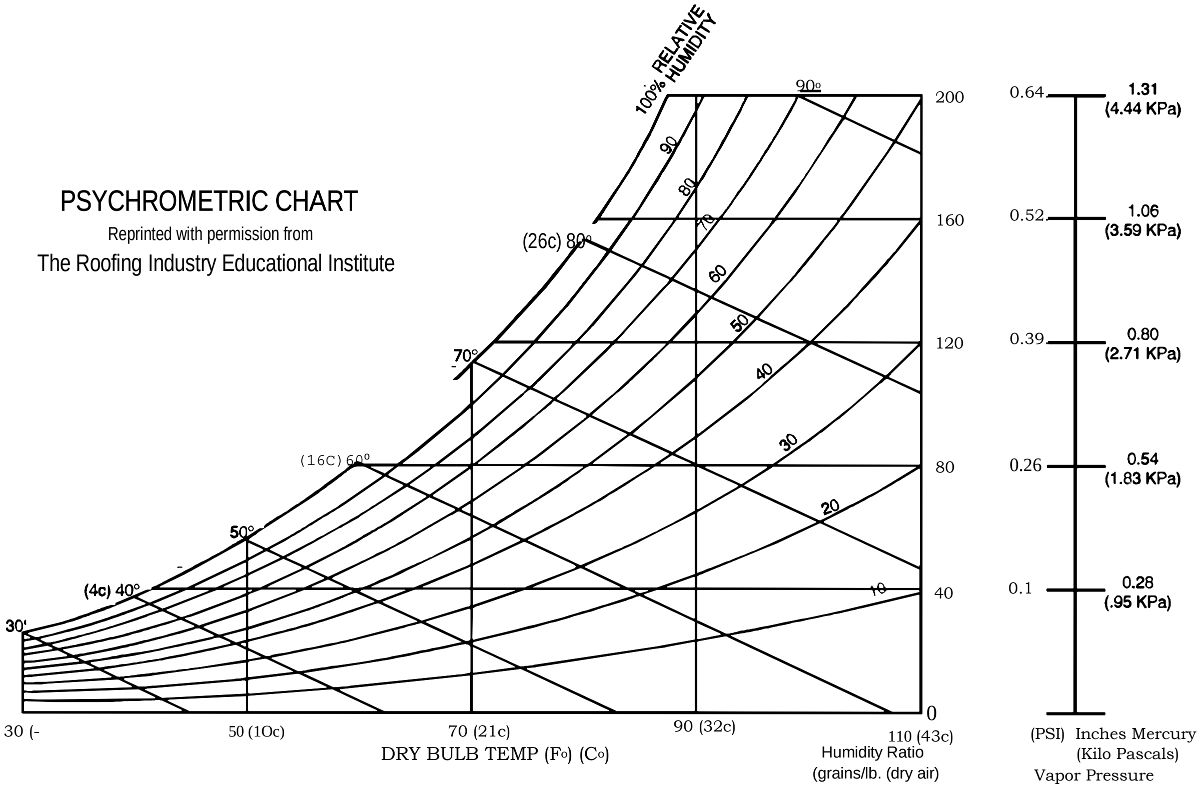
Existing building materials and interior/exterior conditions must be considered in order to:

1. Determine the R value (and, therefore, the thickness) of polyurethane foam needed;
2. Select the polyurethane foam covering system; and
3. Determine the need for a vapor retarder.

A vapor retarder improperly placed could result in condensation as surely as severe interior and exterior conditions could.

By thoroughly understanding the effects of water vapor diffusion and condensation and by the correct use of insulation, water vapor retarding and water vapor transmitting materials, designers and contractors can insure these problems will not occur.

PSYCHROMETRIC CHART



The psychrometric chart is used to determine and correlate the following properties of humid air:

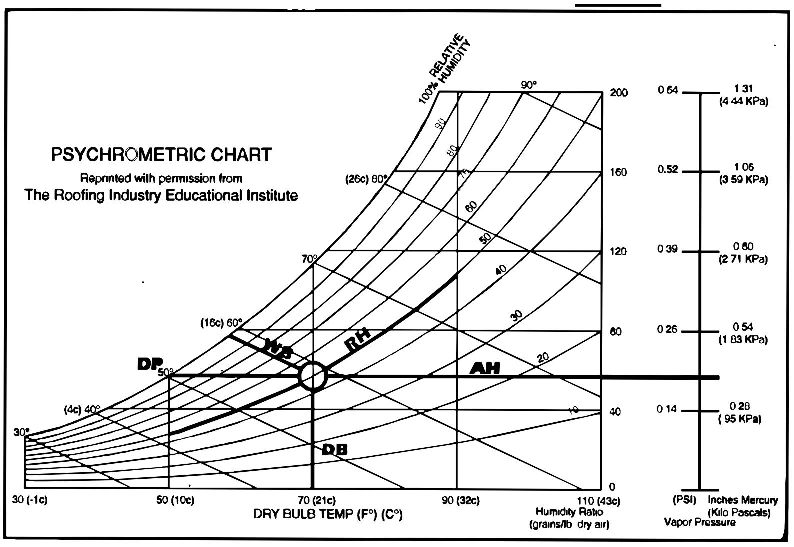
- Dry Bulb Temperature
- Wet Bulb Temperature
- Dew Point
- Relative Humidity
- Absolute Humidity.

> *When two of these properties are known, the other three can be determined from the psychrometric chart.*

Normally, the measurements taken in the field to measure temperature and humidity are the dry bulb and wet bulb temperatures. The dry bulb temperature is the air temperature as measured by a normal thermometer. The wet bulb temperature is the air temperature as measured using a normal thermometer which has had a water wetted wick installed on the bulb end of the thermometer.

As an example, let's assume the dry and wet bulb temperatures in a room read:

Dry Bulb (DB)	70.0°F
Wet Bulb (WB)	58.5°F



From the psychrometric chart, the following information can be determined:

Relative Humidity (RH)	50 %
Absolute Humidity (AH)	54 grains/lb. dry air 0.37 in. Hg
Dew Point (DP)	50°F.

EXAMPLE CALCULATION

PROBLEM:

Water has been dripping from the exposed concrete ceiling over a swimming pool. The roof deck is 6" structural concrete; the roofing system consists of a built-up roof over one inch fiberboard which appears to be saturated. The roof is slightly pitched, no ponding occurs. It is proposed to tear-off the built-up roof, spray apply one inch of polyurethane foam, and coat the foam with an acrylic coating. Will the proposed roof system stop the drippage and avoid future condensation problems?

Design conditions: Interior: 75^oF, 85% rel. humidity
Exterior: 20^oF, 90% rel. humidity

STEP 1:

DETERMINE WATER VAPOR PRESSURE (ABSOLUTE HUMIDITY) AT INTERIOR AND EXTERIOR ROOF SURFACES

Inside is 75^oF and 85% relative humidity. From Table 2, P_{sat} (saturation vapor pressure) for $75^oF = 0.875$ in Hg (inches in mercury pressure).

At 85% rel. hum., P_i (inside vapor pressure) = $0.875 \times 0.85 = 0.74$ in Hg. (Absolute humidity may also be determined from the Psychormetric Chart.)

Exterior is 20^oF and 90% relative humidity. From Table 2, P_{sat} for $20^oF = 0.103$ in Hg.
At 90% rel. hum., P_e (exterior vapor pressure) = $0.103 \times 0.90 = 0.093$ in Hg.

STEP 2:

DETERMINE THERMAL AND VAPOR RESISTANCES

Find the thermal resistances and the perm ratings from Table 1, "Thermal Resistances and Perrn Ratings for Construction Materials." (See page 10) The vapor resistance can be determined by calculating the reciprocal of the perm rating.

Component	Thermal Resistance (R)	Perm Rating (M)	Vapor Resistance (1/M)
Exterior Air Film	0.17	—	0.00
Acrylic Coating	0.00	2.5	0.40
Polyurethane Foam 1"	6.00	2.5	0.40
Concrete Deck	0.50	0.5	2.00
Inside Air Film	0.61	—	0.00
	7.28		2.80

STEP 3:

CALCULATE TEMPERATURES AT ROOF COMPONENT SURFACES

Use the following formula to calculate temperatures within the proposed roof structure:

$$T_x = T_i - \frac{\sum R_x}{\sum R} (T_i - T_e)$$

Where:

T_X= Temperature at surface x
T_i= Inside temperature
T_e= Exterior temperature
$\sum R_x$= Sum of R values between the inside and surface x
$\sum R$ = Total R value.

Let:

0 = Inside condition
1 = Inside Air Film-Deck Surface
2 = Deck-Polyurethane Foam Interface
3 = Polyurethane Foam-Coating Interface
4 = Coating-Exterior Air Film Surface
5 = Exterior condition

T_o= 75^oF (Inside condition)
T_1= $75 - (0.61 / 7.28) (75 - 20) = 70^oF$
T_2= $75 - ((0.61 + 0.5) / 7.28) (75 - 20) = 67^oF$
T_3= $75 - ((0.61 + 0.5 + 6) / 7.28) (75 - 20) = 21^oF$
T_4= $75 - ((0.61 + 0.5 + 6 + 0) / 7.28) (75 - 20) = 21^oF$
T_5= 20^oF (Exterior condition)

STEP 4:

CALCULATE VAPOR PRESSURES (ABSOLUTE HUMIDITIES) AT THE ROOF COMPONENT SURFACES

Use the following formula to calculate vapor pressures within the proposed roof structure:

$P_x = P_i - \underline{\quad\quad\quad} \quad P_i - P_e)$

$\Sigma(1/M_x)$

Where:
P_x = Vapor pressure at surface x
P_i = Inside vapor pressure
P_e = Exterior vapor pressure
$\Sigma(1/M_x)$ =Sum of vapor resistance values between the inside and surface x
$\Sigma(1/M)$ =Total vapor resistance value.
P_o =0.74 in. Hg (Inside condition)
P_1 0.74 - (0 / 2.8) (0.74 - 0.093) = 0.74 in. Hg
P_2 0.74 - ((0 + 2.0) / 2.8) (0.74 - 0.093) = 0.28 in. Hg
P_3 0.74 - ((0 + 2.0 + 0.40) / 2.8) (0.74 - 0.093) = 0. 19 in. Hg
P_4 0.74 - ((0 + 2.0 + 0.40 + 0.40) / 2.8) (0.74 - 0.093) = 0.093 in. Hg
P_5 0.093 in. Hg (Exterior condition)

STEP 5:

TRANSPOSE THE TEMPERATURE AND VAPOR PRESSURE (ABSOLUTE HUMIDITY) VALUES ONTO THE TABLE FROM STEP 2; COMPARE WITH SATURATION VAPOR PRESSURE

Component	Thermal Resistance (R)	Perm Rating (M)	Vapor Resistance (1/M)	Temperature (T_x)	Calculated Vapor Pressure (P_x)	Saturation Vapor Pressure (P_{sat})
				20	0.093	0.103
Exterior Air Film	0.17	—	0			
				21	0.093	0.108
Acrylic Coating	0	2.5	0.40			
				21	**0.19**	**0.108**
Polyurethane Foam 1"	6.0	2.5	0.40			
				67	0.28	0.667
Concrete Deck	0.5	0.5	2.0			
				70	**0.74**	**0.739**
Inside Air Film	0.6	1	0			
				75	0.74	0.875
	7.28		2.8			

The above table summarizes all the information and calculations from Steps 1-4. In addition, the last column, P_{sat}, gives the saturated vapor pressure for the temperature at the corresponding surface. The saturated vapor pressure is read off of Table 2 for the appropriate surface temperature (T_x).

Of significance in these data is that the calculated vapor pressure (P_x) exceeds the saturation vapor pressure (P_{sat}) at two locations:

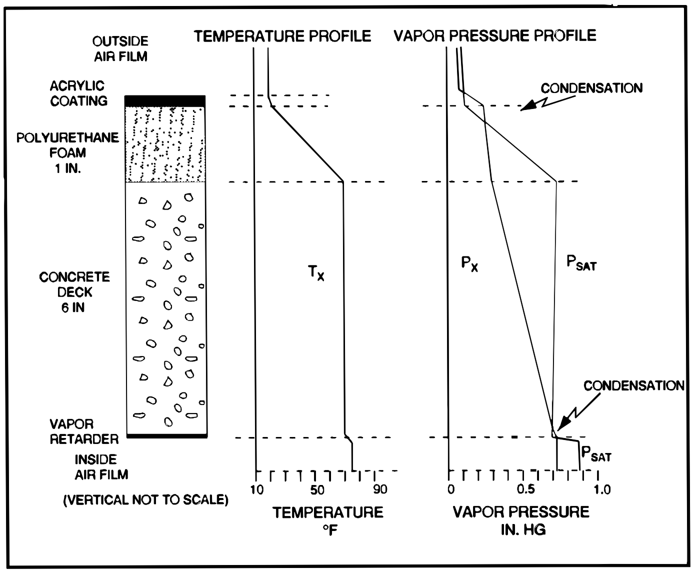
1. Underside of the deck, and
2. Coating-polyurethane foam interface.

Where the calculated vapor pressure exceeds the saturated vapor pressure, condensation is likely to occur.

In this case, condensation is likely to occur at the deck underside and at the coating-polyurethane foam interface. These two condensation points reflect two different condensation problems and must be treated separately.

1. Underside of deck. Condensation on this surface is the result of too low a temperature (below the dew point). This cannot be corrected by the use of a vapor retarder but may be corrected by increasing the surface temperature through the use of additional insulation. Increasing the polyurethane foam thickness from I " to 2" will solve this problem.

2. Coating-polyurethane foam interface. Condensation at this plane is due to water vapor diffusing up through the deck and polyurethane foam and reaching a temperature below the dew point. Corrective action would be the installation of a vapor retarder on the bottom of the deck.



STEP 6:

MODIFY DESIGN AND RECHECK

Repeat Steps 1-5 for the system consisting of 2" polyurethane foam, acrylic coating, and a 30 mil butyl vapor retarder applied to the underside of the deck.

Component	Thermal Resistance (R)	Perm Rating (M)	Vapor Resistance (1/M)	Temperature (T_x)	Calculated Vapor Pressure (P_x)	Saturation Vapor Pressure (P_{sat})
				20	0.093	0.103
Exterior Air Film	0.17	----	0	21	0.093	0.108
Acrylic Coating	0	2.5	0.40	21	0.096	0.108
Polyurethane Foam 2”	12.0	1.25	0.8	70	0.10	0.739
Concrete Deck	0.5	0.5	2.0	72	0.12	0.791
Vapor Retarder	0	0.015	67	72	0.74	0.791
Inside Air Film	0.61	---	0	75	0.74	0.875
	13.28		70.2			

With the revised design (2" polyurethane foam and a vapor retarder), none of the calculated vapor pressures (P,,) exceed the saturated vapor pressures (Pat). This design should be safe from the problems associated with condensation.

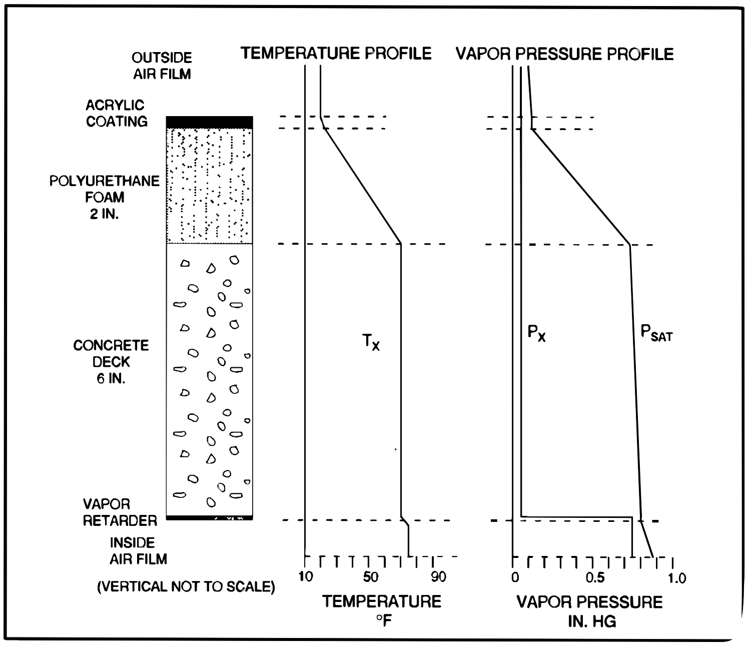


TABLE 1

THERMAL AND MOISTURE TRANSMISSION PROPERTIES OF CONSTRUCTION MATERIALS

Material	R-Value	Perm Rating
Built-up Roof Membrane	0.33	0.0
Decks		
Steel Deck (forgetting seams)	Negl.	0.0
Steel Deck (considering seams)	Negl.	>1.
Uncracked Concrete		
Structural Deck (6”)	0.5	appx. 0.5
Films, Felts and Foils		
Aluminum Foil	Negl.	0.0
Polyethylene 4-mil	Negl.	0.08
6-mil	Negl.	0.06
Polyvinylchloride (PVC) 4-mil	Negl.	0.5
Kraft Paper Laminate	Negl.	0.25
Asphalt Saturated Felt No. 15	0.06	1.0
Asphalt Saturaded and		
Coated Felt No. 43	0.06	0.3
Construction Boards		
Plywood ¼” Exterior	0.32	0.7
½” Exterior	0.64	0.35
Gypsum Wall Board 3/8”	0.32	50.
Insulations		
Cellular Glass 1”	2.9	0.0
Polyurethane 1”	5.6-6.3	2-3
Extruded Polystyrene 1”	5.0	1.2
Expanded Polystyrene 1”	3.9-4.4	2-5.8
Mineral Fiber 1” (unprotected)	3.2	116.
Coark Board 1”	3.9	2.1-2.6
Coatings		
Acrylic 30 mils	Negl.	2-3
Asphalt Mastic 60 mils	Negl.	0.003-0.004
Butyl 30 mils Negl.	0.015	
Chlorinated Synth. Rubber 15-30 mils	Negl.	0.2-0.4
Silicone 20 mils	Negl.	2.9
Urethane 20-35 mils	Negl.	0.3-2.5
Air Surface (Horizontal)		
Still Air		
Heat Flow upward	0.61	
Heat Flow downward	0.92	
Moving Air		
15 mph wind (winter)	0.15	
7.5 mph wind (summer)	0.25	

Note: The above figures represent approximations from a variety of published sources. When determining moisture vapor drives for a particular system, use thermal resistance and perm ratings provided by the manufacturer for each specific product.

TABLE 2

WATER VAPOR PRESSURE AT SATURATION

Temp in.Hg	P_{sat} °F	Temp in.Hg	P_{sat} °F	Temp in.Hg	P_{sat} °F
-20	.013	30	.165	80	1.03
-18	.014	32	.180	82	1.10
-16	.016	34	.197	84	1.18
-14	.018	36	.212	86	1.25
-12	.020	38	.229	88	1.34
-10	.022	40	.248	90	1.42
-8	.025	42	.268	92	1.51
-6	.027	44	.298	94	1.61
-4	.030	46	.312	96	1.71
-2	.034	48	.336	98	1.82
0	.038	50	.362	100	1.93
2	.042	52	.390	102	2.05
4	.046	54	.420	104	2.18
6	.051	56	.452	106	2.31
8	.057	58	.486	108	2.45
10	.063	60	.522	110	2.60
12	.069	62	.560	112	2.75
14	.077	64	.601	114	2.91
16	.085	66	.644	116	3.08
18	.093	68	.690	118	3.26
20	.103	70	.739	120	3.45
22	.113	72	.791		
24	.124	74	.846		
26	.137	76	.905		
28	.150	78	.967		

LIST OF ABBREVIATIONS

AH	Absolute Humidity	in Hg. grains/lb dry air
DB	Dry bulb temperature	^{o}F
DP	Dew point temperature	^{o}F
M	Permeance (perm rating)	grains H_2O/ft^2-hr-in. Hg
P_i	Interior vapor pressure	in. Hg
P_e	Exterior vapor pressure	in. Hg
P_{sat}	Saturated water vapor pressure at a given temperature condition	in. Hg
P_x	Vapor pressure at surface "x"	in. Hg
R	Thermal resistance (R value)	ft^2-^{o}F-hr/Btu
RH	Relative humidity	per cent
T_i	Interior temperature	^{o}F
T_e	Exterior temperature	^{o}F
T_x	Temperature at surface "x"	^{o}F
WB	Wet bulb temperature	^{o}F

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