Conklin Company Inc.
TECHNICAL BULLETIN
B-10-19-71
Commercial Roofing System Moisture Management

Understanding Moisture Vapor Transmission

Water may be present in our environment in any of its three physical states: ice (solid), liquid, and vapor (gas). The key to understanding the effects of moisture in a roof assembly or in a building envelope is dependent on the interior and exterior environment.

NOTE:

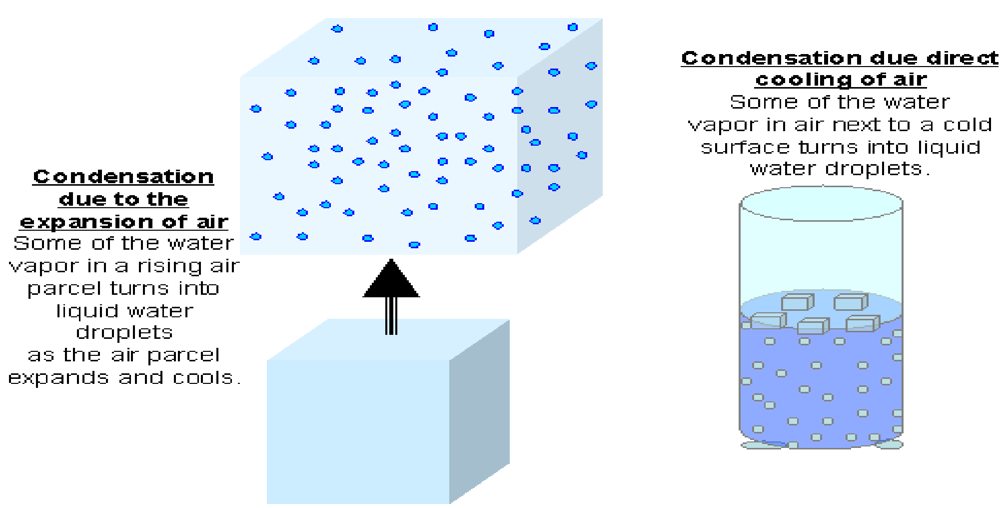
1) *Water vapor transmission (assuming air leakage has been eliminated) is affected by the following factors:*
   a) *The chemical composition of the building materials*
   b) *The thickness of the building materials*
   c) *The absolute humidity on each side of the building component (absolute humidity differential)*
2) *Conklin Company Inc. cannot design a system to help control the effects of water vapor transmission in any roofing system or building envelope. To avoid creating a vapor transmission problem, it is advised to seek the expert assistance of a trained engineer.*

Condensation

Condensation is defined as the following:

1) Water droplets on a cold surface when humid air is in contact with it.
2) The conversion of vapor or gas to a liquid.

Figure #1



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If the building envelope is altered, the vapor drive is affected

Any change made to a building envelope will affect how moisture moves. For example: if a gray metal roof system is coated with a highly reflective roof coating, the temperature of the roof will be cooler in the summer. For this reason (depending on the current insulation system and the absolute humidity in the building) conditions conducive to condensation can be created.

The basics

This technical document should be used as a reference in understanding some of the basic factors involved when dealing with vapor drive. Understanding the Dew point is one of the most important factors when dealing with moisture migration. (See figure 2 & 3)

Figure #2

Table 3: Dew point Based on Varying Temperature

Inside Temperature	Inside Humidity	Dew point	Outside Temperature	Condensation
70° F	20%	27° F	20° F	Yes
70° F	20%	27° F	30° F	No
70° F	30%	37° F	30° F	Yes
70° F	40%	44.6° F	40° F	Yes
Dew point calculations show that condensation can easily form inside a poorly insulated metal building with interior humidity as low as 20%.				

Figure #3

SPFA-118 – General – Moisture Management

TABLE 1

THERMAL AND MOISTURE TRANSMISSION PROPERTIES OF CONSTRUCTION MATERIALS

Material	R-Value	Perm Rating
Built-up Roof Membrane Decks	0.33	0.0
Steel Deck (forgetting seams)	Negl.	0.0
Steel Deck (considering seams)	Negl.	>1.0
Uncracked Concrete Structural Deck (6 in.)	0.5	approx. 0.5
Films, Felts, and Foils		
Aluminum Foil	Negl.	0.0
Polyethylene 4-mil	Negl.	0.08
Polyethylene 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 Saturated and Coated Felt No. 43	0.06	0.3
Construction Boards		
Plywood: ¼ in. Exterior	0.32	0.7
Plywood: ½ in. Exterior	0.64	0.35
Gypsum Wall Board 3/8 in.	0.32	50.0
Insulations		
Cellular Glass 1 in.	2.9	0.0
Polyurethane 1 in.	5.6-6.3	2-3
Extruded Polystyrene 1 in.	5.0	1.2
Expanded Polystyrene 1 in.	3.9-4.4	2-5.8
Mineral Fiber 1 in. (unprotected)	3.2	116.0
Cork Board 1 in.	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	
Still Air: Heat Flow downward	0.92	
Moving Air: 15 mph wind (winter)	0.15	
Moving Air: 7.5 mph wind (summer)	0.25	

Note: These 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

©SPFA 2015 Page 16 of 20

Commercial Roofing System Moisture Management

General Moisture Management

The following information is based on the SPFA-118 General-Moisture Management technical document and should be used as a reference before recruiting the services of an engineer or industry expert.

ABOUT SPRAY POLYURETHANE FOAM ALLIANCE (SPFA)

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DISCLAIMER

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TECHNICAL OVERSIGHT COMMITTEE

Mission Statement

The mission of the Technical Committee is to provide a wide range of technical service to the SPF (spray polyurethane foam) industry such as, but not limited to:

(1) Review existing documents and serve as a clearing house to ensure the "Continuity of Value" of technical information published by SPFA and others concerning the products and services to the SPF industry;
(2) Review, research, develop, and issue documents concerning new products, systems and services; and
(3) To identify, explore, develop, and communicate an understanding of technical issues facing to the SPF industry.

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 type of 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 into the interior or destruction of the building components may occur.

Building assemblies should, therefore, be designed to prevent the condensation of water vapor within those assemblies.[1]

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 (SPF) is seamless and closed cell, air leakage is less of 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 because 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)

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The following factors affect water vapor transmission:

CHEMICAL COMPOSITION

The chemical composition of a building material has a profound effect on its ability to restrict water vapor diffusion. SPF, silicone, and acrylic coatings all have measurable water vapor

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[1] 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 for either design method. Diffusion rates: Metals and glass, on the other hand, restrict diffusion so much they can 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 thinly.)

ABSOLUTE HUMIDITY DIFFERENTIAL

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

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 the absolute humidity of air to the water vapor holding capacity of air.)

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 the water vapor diffusion rate of a material is by the ASTM E-96 method, “Standard Test Method for Water Vapor Transmission of Materials.” ASTM E-96 determines the water vapor permeance of a given material at a specified thickness. The permeance is often referred to as the perm rating; the higher the perm rating, the faster the diffusion rate.

There are a variety of test conditions to measure water vapor transmission. Therefore, the water vapor transmission rates for different materials reported in the literature may have been tested under differing conditions. Reported perm ratings should, therefore, be considered as 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 because what may be a retarder in one case may be a transmitter in another. (Remember: Thickness is as important as chemical composition.)

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 that it may be considered 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 previously mentioned, water vapor transmission, per se, is not particularly a problem. However, 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 the water vapor entering the building component
- increasing the water vapor leaving the building component

Condensation problems are most seen at exterior building walls and roofs. The 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 SPF'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 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 to install the building materials such that relative vapor retardance increases toward the side with the higher absolute humidity (usually the warm side). Conversely, building materials should be installed 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.
- 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

SPF is 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 built-up membrane and the SPF 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 with a high perm rating to the exterior surface of the SPF to prevent the buildup of humidity within the foam; thus, avoiding condensation.

CASE 2

SPF 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 (e.g., during winter), the metal deck would prevent the internal humidity from diffusing into the SPF. The perm rating of the covering system is not critical; its selection can be based on other factors.

CASE 3

SPF applied to the top surface of a concrete deck over a swimming pool. (See Example Calculation.)

The interior of a building that houses an indoor swimming pool 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 SPF must provide sufficient insulation to avoid condensation on the underside of the deck.

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

CASE 4

SPF 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

SPF roofing and wall insulation can be designed and installed to avoid the buildup of humidity and the subsequent problem of condensation.

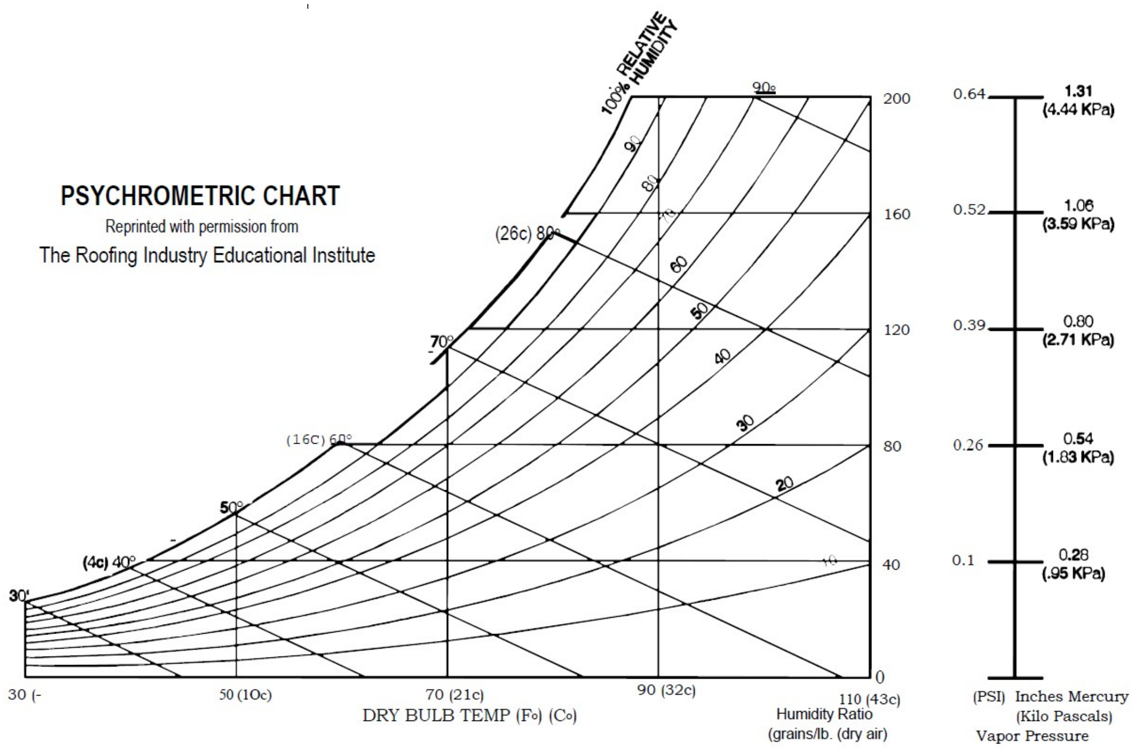
Existing building materials and interior/exterior conditions must be considered in order to:

(1) determine the R-Value and, therefore, the thickness of SPF needed
(2) select the SPF covering system
(3) determine the need for a vapor retarder

An improperly placed vapor retarder could increase the likelihood and severity of condensation.

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

PSYCHROMETRIC CHART



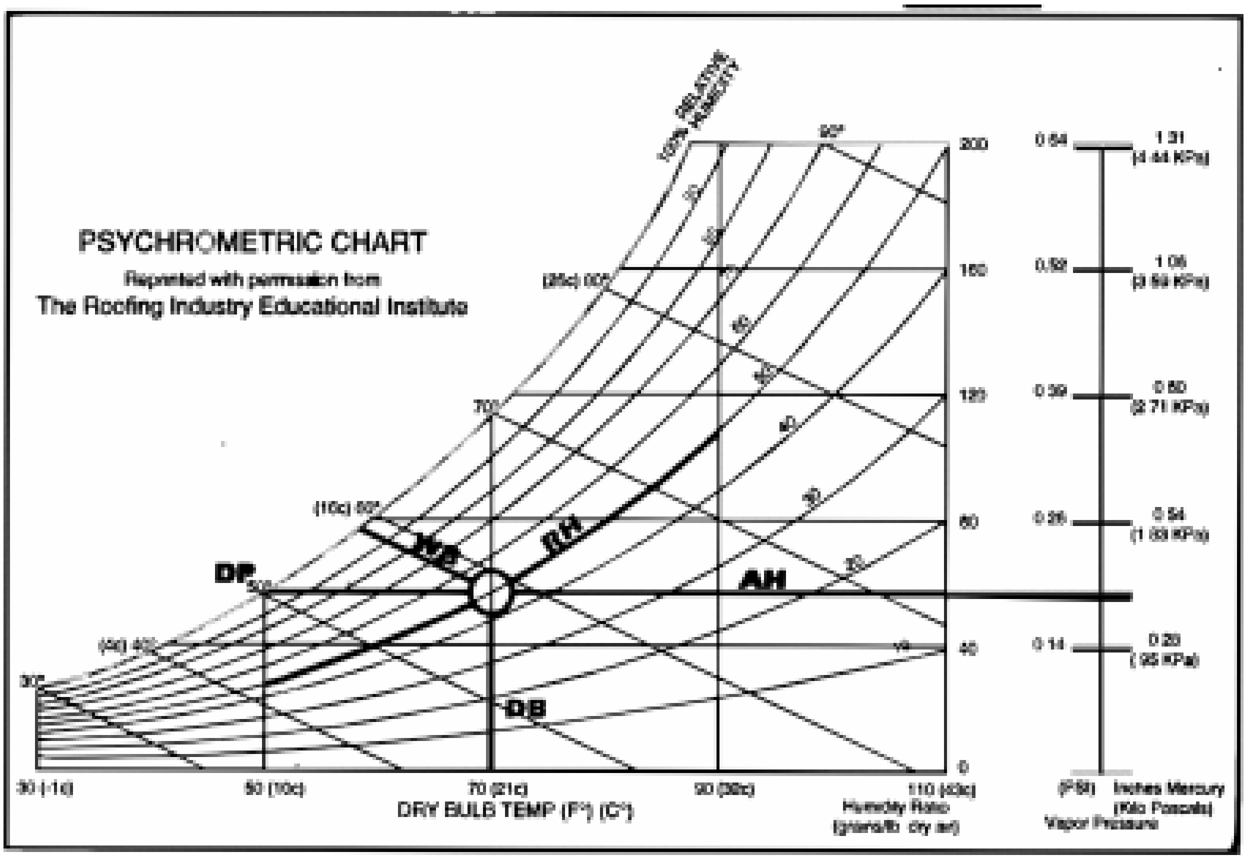
The psychrometric chart is used to determine and correlate the following properties of humid air:

- 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 that has had a water wetted wick installed on the bulb end of the thermometer.

As an example, let's assume that 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 in. of structural concrete. The roofing system consists of a built-up roof over 1 in. fiberboard, which appears to be saturated. The roof is slightly pitched and no ponding occurs. It is proposed to tear off the built-up roof, spray apply 1 in. of SPF, and coat the foam with an acrylic coating. Will the proposed roof system stop the drippage and prevent future condensation problems? Design conditions: Interior: 75°F, 85% relative humidity.

STEP 1: DETERMINE WATER VAPOR PRESSURE (ABSOLUTE HUMIDITY) AT THE INTERIOR AND EXTERIOR ROOF SURFACES.

Inside is 75°F, with 85% relative humidity. From Table 2 (see page 17), the P_{sat} (saturation vapor pressure) for 75°F = 0.875 in. Hg (inches in mercury pressure).

At 85% relative humidity, P_i (inside vapor pressure) = 0.875 x 0.85 = 0.74 in. Hg. (Absolute humidity may also be determined from the Psychrometric Chart.)

The exterior is 20°F with 90% relative humidity. From Table 2, the P_{sat} for 20°F = 0.103 in. Hg. At 90% relative humidity, P_e (exterior vapor pressure) = 0.103 x 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 Perm 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-SPF Interface

3 = SPF-Coating Interface

4 = Coating-Exterior Air Film Surface

5 = Exterior condition

T_0 = 75°F (Inside condition)

T_1 = 75 - (0.61/7.28)(75 - 20) = 70°F

T_2 = 75 - ((0.61 + 0.5)/7.28)(75 - 20) = 67°F

T_3 = 75 - ((0.61 + 0.5 + 6)/7.28)(75 - 20) = 21°F

T_4 = 75 - ((0.61 + 0.5 + 6 + 0)/7.28)(75 - 20) = 21°F

T_5 = 20°F (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:

$$P_x = P_i - (\sum \frac{1}{M_x} P_i - P_e)$$

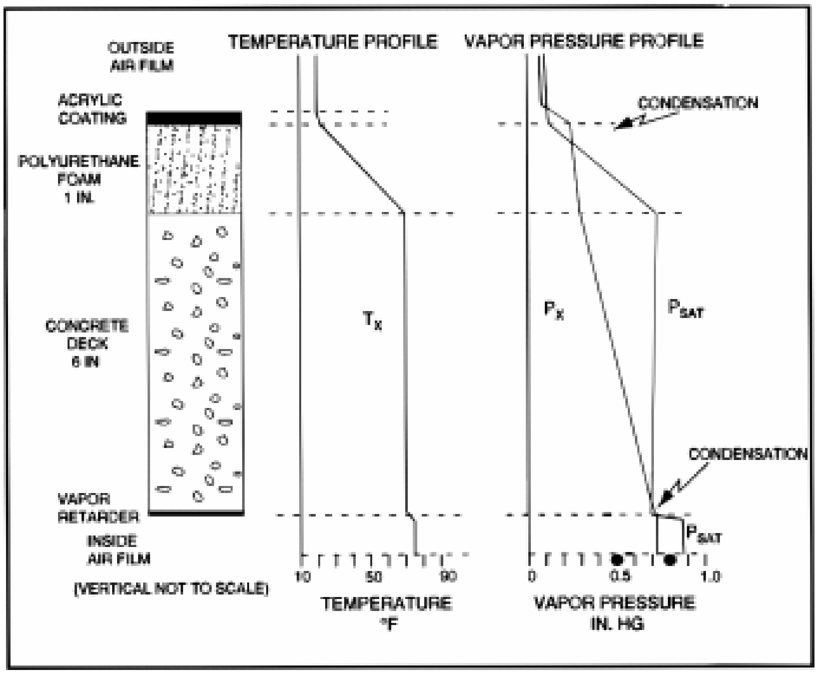
Where:

P_x = Vapor pressure at surface x
P_i = Inside vapor pressure
P_e = Exterior vapor pressure
$\sum(1/M_x)$ = Sum of vapor resistance values between the inside and surface x
$\sum(1/M)$ = Total vapor resistance value
$P_0 = 0.74$ 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 THE 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	--	0.00	21	0.093	0.108
Acrylic Coating	0.00	2.5	0.40	21	0.19	0.108
Polyurethane Foam 1”	6.00	2.5	0.40	67	0.28	0.667
Concrete Deck	0.50	0.5	2.00	70	0.74	0.739
Inside Air Film	0.61	1	0.00	75	0.74	0.875
	7.28		2.80			



The table in Step 5 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 Table 2 for the appropriate surface temperature (T_x).

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

(1) Underside of the deck
(2) SPF interface coating

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

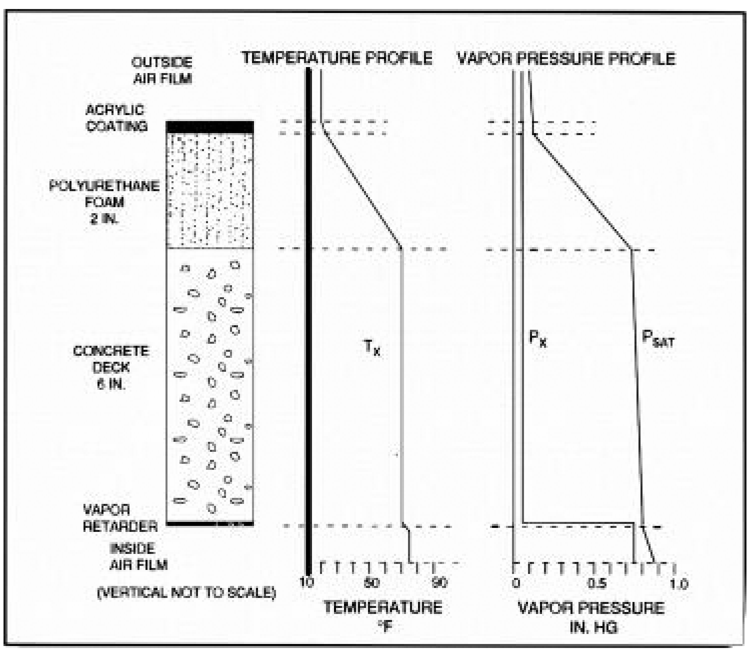
In this case, condensation is likely to occur at the deck underside and at the SPF-coating interface. These two condensation points reflect two different condensation problems and must be treated separately.

(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 SPF thickness from 1 in. to 2 in. will solve this problem.
(2) SPF-coating interface. Condensation at this plane is because of water vapor diffusing up through the deck and SPF, and reaching a temperature below the dew point. Corrective action would be to install 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 in. SPF, 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
SPF 2 in.	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 in. SPF and a vapor retarder), none of the calculated vapor pressures

(P_x) exceed the saturated vapor pressures (P_{sat}). This design should be safe from the problems associated with condensation.

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Polyurethane 1 in.	5.6-6.3	2-3
Extruded Polystyrene 1 in.	5.0	1.2
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Cork Board 1 in.	3.9	2.1-2.6
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Asphalt Mastic 60 mils	Negl.	0.003-0.004
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Note: These 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 °F	**P_{sat} in. Hg**	**Temp °F**	**P_{sat} in. Hg**	**Temp °F**	**P_{sat} in. Hg**
-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 Dry	in. Hg (or grains H_2O/lb dry air)
DB	bulb temperature	°F
DP	Dew point temperature	°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-°F-hr/Btu
RH	Relative humidity	percent
Ti	Interior temperature	°F
T_e	Exterior temperature	°F
T_x	Temperature at surface “x”	°F
WB	Wet bulb temperature	°F

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