VAPOR RETARDERS FOR MEMBRANE ROOFING SYSTEMS

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Moisture is harmful to the components of roofs.[1,2] Roofing systems must be able to resist moisture penetration both from the exterior and from the interior.

If cold air could hold as much moisture as warm air can, there would be no condensation on window panes or within roofing systems and no need for equipping roofs and walls with elements that defend against entry of moisture from within the building (i.e., there would be no need for vapor retarders).

As air is cooled, the amount of moisture in it does not change but, unfortunately, its relative humidity increases. Relative humidity (RH) means the amount of moisture in the air, *relative* to the maximum amount of moisture that air can hold at that temperature. When the relative humidity of air reaches 100 percent, condensation commences. That's the problem.

PSYCHROMETRICS

A simplified psychrometric chart (Figure 1) can help explain why condensation problems occur. The vertical axis of that chart represents the amount of moisture in the air. To move up or down on the "psych" chart, moisture must be added to or removed from the air. That is not supposed to happen in roofs, so the idea is to stay at one level on the chart (i.e., don't move up or down). To see what happens as air is cooled, move to the left. If it is warmed, move right.

For example, as air at 68 F and 30 percent RH (point A on the Figure 1 psychrometric chart) is cooled, its relative humidity increases (proceed due left from point A) to 40 percent at 60 F, 60 percent at 49 F, and, finally, 100 percent (i.e., saturation) at 36 F (point B in Figure 1). The temperature at which saturation occurs is called the dew point temperature. Cooling air below its dew point causes it to slide down the 100 percent RH saturation line. By moving down the "psych" chart, the air loses moisture—in our case, to the roofing components it is in contact with. The colder those components are, the further the air slides down the saturation line and the more moisture it looses.

When the air temperature is 20 F (point C in Figure 1), it has lost less moisture than when its temperature drops to 0 F (point D in Figure 1). This illustrates that the potential for condensation in a roof increases in cold regions.

Cold outdoor air, even if it has a high relative humidity, has very little moisture in it (see how the height of the left side of the Figure 1 psychrometric chart tapers off to almost nothing). When cold outdoor air is brought indoors and heated, its relative humidity drops significantly. For example, 0 F, 100 percent RH outdoor air (point D in Figure 1) has a relative humidity of only 5 percent when it is heated to 68 F (point E in Figure 1).

If only the moisture in the outdoor air is considered, there is no need for vapor retarders in buildings to avoid condensation in cold weather. However, occupants, process equipment and the ground on which a building rests may add moisture to the indoor air, increasing its relative humidity and thus, the potential for condensation. Adding moisture sounds like a bad idea but it may be necessary for reasons of comfort and health. When the relative humidity of 68 F indoor air falls below 30 percent, skin cracks and mucous membranes dry out, causing most occupants to feel uncomfortable. The need for moisture in indoor air may necessitate the installation of humidification equipment.

Moisture may also be needed indoors to avoid problems with static electricity or to permit processes that utilize hygroscopic materials, such as paper, to function properly.

Table 1 shows some typical indoor relative humidities for a range of buildings. Additional information is available in the 1982 Applications Volume of the ASHRAE Handbook.[3]

If too much moisture is added by occupants, by process equipment or by the ground, *de*humidification may be necessary for reasons of comfort and health or to control condensation.

The increased potential for condensation in humid buildings is shown as follows. If the 68 F, 30 percent RH air in the earlier example had, instead, an RH of 60 percent (point F in Figure 1), the dew point temperature of that air would increase to 54 F (point G in Figure 1), and far more moisture would be available for condensation. This is illustrated by comparing vertical distances 1 and 2 in Figure 1.

The "psych" chart is a convenient way to show that a building with a high indoor temperature and RH has a much greater potential for condensation than a building with a lower indoor temperature and RH.

INDOOR AND OUTDOOR CONDITIONS

Some individuals feel that if the potential for condensation exists within a roof or wall, that element must have a vapor retarder. They determine (or estimate) the temperature and relative humidity of the indoor air, and calculate its dew point temperature from psychrometric tables[4] or a "psych" chart (Figure 1). They then compare that temperature to the winter design temperature where the building is located (Figure 2). If the winter design temperature is below the dew point temperature, they install a vapor retarder.

In the first example in this paper, the dew point temperature was 36 F. Figure 2 shows that most of North America has a winter design temperature far below 36 F and, using this logic, roofs of most buildings with an indoor RH of 30 percent should have vapor retarders.

In fact, that is not true: Membrane roofing systems of most buildings in North America with an indoor RH of only 30 percent do *not* need vapor retarders. The reason for this is that "winter design temperature" represents the very coldest portion of the winter. A small amount of moisture may condense then without doing any real harm.

The National Roofing Contractors Association (NRCA) acknowledges this in the *NRCA Roofing and Waterproofing Manual*.[5] That guideline recommends installing a vapor retarder only where the indoor RH equals or exceeds 45 percent *and* the average January outdoor temperature is below 40 F. The shaded area of the United States in Figure 3 has an average January temperature below 40 F.

The NRCA guideline is reasonable but it also says that buildings in the northern tier of states do not need vapor retarders unless they have an indoor RH of 45 percent or more. This does not fit with the collective experience of many researchers, designers, builders and building owners in cold regions. Their experience indicates that, in those states, buildings with relative humidities as low as 30 percent may need vapor retarders.

A better way of relating the need for vapor retarders to outdoor climate and indoor relative humidity is needed. Marcus Harrington and I have attempted to fill that need by developing a series of maps of the United States, with each map representing a different winter vapor drive (i.e., a different winter condensation potential).[6] Weather records were analyzed and maps were made that relate the relative humidity within a building to the vapor pressure gradients across the building envelope. We looked at the entire winter, not just the coldest portion. With assistance from many architects, engineers and contractors, we selected the one map in that series that best represents "real world" conditions. This calibration process resulted in the selection of the map shown in Figure 4.

Using this map, designers can see that buildings with a 68 F indoor temperature and a 30 percent indoor relative humidity need a vapor retarder only if they are in very cold areas, such as northern Minnesota or most of Alaska. The indoor RH must be much higher in more southerly areas before a vapor retarder is needed (e.g., in Tennessee the indoor RH needs to be about 60 percent before a vapor retarder is needed).

The Figure 4 map is for buildings with an indoor temperature of 68 F. If that is not the indoor temperature of a building being investigated, the mapped RH obtained from Figure 4 should be corrected using Figure 5. For example, in New York City the Figure 4 map indicates that roofs need vapor retarders if the indoor relative humidity exceeds 50 percent. If the indoor temperature in a factory in cold weather is 75 F, the limiting relative humidity drops to 40 percent. The arrows in Figure 5 show how this was determined.

The Figure 4 map is starting to be used by various groups in government and industry. It appears in NRCA's recently revised *Energy Manual*.

When they are not needed, vapor retarders should not be used, since they are expensive and allow "cancers" of wet insulation to grow within a compact roof having membrane or flashing flaws. Flawed roofs without vapor retarders tend to leak sooner, which often reduces the lateral extent of wet insulation.

AIR LEAKAGE

Air leakage is the primary mechanism behind condensation problems in buildings.[4] Diffusion of moisture through the components of a roofing system is a relatively slow process that seldom causes problems. Roofing systems that resist air leakage have few condensation problems.

Framed Roofing Systems

In "Vents and Vapor Retarders for Roofs,"[7] I describe how framed roofing systems that contain batts or rolls of permeable insulations such as fibrous glass or rock wool between framing members have a relatively high risk of incurring condensation problems. They are apt to leak a lot of air.

For such systems, it is quite important to seal air leakage paths. Vapor retarders are often installed for this purpose. Since the real purpose of vapor retarders is to reduce air leakage, not resist vapor diffusion, it is far more important to build them with the continuity needed to resist air leakage than to utilize materials of very low permeability. The term *air vapor retarder* more accurately describes their dual purpose.

The guidelines provided by Figures 4 and 5 define where vapor retarders are needed for membrane roofing systems. However, in framed roofing systems where air leakage is a potential problem, it is often appropriate to install "air barriers" even where vapor retarders are not needed. In such cases, they are installed to block air leakage.

Since it is difficult to seal all air leakage paths in framed roofing systems, it is usually appropriate to ventilate on the cold side of the insulation.

This paper is not about framed roofing systems, but it is important to know why their needs for air barriers, vapor retarders and cold-side ventilation differ significantly from those needs of membrane roofing systems.

Membrane Roofing Systems

Membrane roofing systems suffer more than their share of moisture problems, but most of those problems are due to flaws in the exterior waterproofing system, not to improper control of condensation. Flaws at flashings and penetrations are the primary cause of moisture problems for low-slope membrane roofs.

The primary reason membrane roofing systems suffer few condensation problems is that most are built as tightly sandwiched *compact* systems (Figure 6) that are quite resistant to air leakage.

Compact roofing systems with their membrane fully attached with hot bitumen and with low permeability insulation adhered with hot bitumen are remarkably resistant to air leakage even if no deliberate vapor retarder is present.

Loose Membranes

Loose-laid and mechanically attached single-ply roof membranes have some advantages since they are not as sensitive to substrate movements as are fully adhered membranes. However, their lack of complete attachment increases the potential for air leakage and condensation problems.

Air can move laterally under a membrane that is not completely attached, particularly during windy periods when localized suctions create a pumping action. When this is possible, warm, moist indoor air can be drawn up into the roofing system and condensation can occur on the underside of the membrane.

Beads of water are being found on the underside of an unexpectedly high number of loose-laid and mechanically attached EPDM rubber membranes. Studies have shown that the permeability of EPDM rubber increases significantly when the membrane is hot.[8] This has caused speculation that in warm weather outside moisture can enter compact roofing systems through EPDM membranes, while in colder weather the permeability of the EPDM decreases, trapping moisture within the system. However, the study of EPDM's changing permeability concluded that "moisture can accumulate, but not a significant amount."[8]

It is likely that leakage of indoor air, not diffusion of outdoor water vapor, has brought moisture to the underside of the EPDM. More evidence is needed to settle this matter, but air leakage is so very often around when problems occur that I expect it is the cause.

PERMEANCE

Since air leakage is the key issue, the resistance of the material to vapor diffusion (i.e., its permeance) is a relatively minor concern. Generally materials with a permeance of 0.5 perms or less are considered to be vapor retarders in roofs. Table 2 lists the permeance of several materials used in roofs. As shown in that table, steel is impermeable, but a steel deck should not be considered to be a vapor retarder since it contains numerous seams that permit air leakage. In fact, any system can only avoid condensation problems if it can resist air leakage. For that reason, even low permeance insulation boards, such as cellular glass, are not considered to be self-vapor retarders since an assembly of them contains numerous seams that may facilitate air leakage.

MECHANICAL ATTACHMENT

The trend toward mechanical attachment of insulation to decks—steel decks in particular—has somewhat increased the air leakage potential of membrane roofs. However, the concurrent trend toward two or more layers of insulation with joints staggered has compensated for this increase and, according to the feedback I have received, few condensation problems have resulted.

Using the Figure 4 map and the Figure 5 graph, some compact roofs will be found to need vapor retarders. If the vapor retarder is placed between the deck and the insulation, it will be penetrated by mechanical fasteners. In most situations this will not pose a serious problem, because the vapor retarder is squeezed tightly between the insulation and the deck by the fasteners, thereby resisting air leakage. However, where the indoor relative humidity greatly exceeds that determined from Figures 4 and 5, or where air leakage potential is particularly high (e.g., in pressurized buildings, in high-rise buildings or where the insulation has a high permeability), violating the vapor retarder with numerous mechanical fasteners should be avoided.

Fortunately this is relatively easy to accomplish by installing the vapor retarder between the two layers of insulation as shown in Figure 7. This approach (with or without a vapor retarder) is known as the "nail one–mop one" method of constructing a compact roofing system with hot bituminous materials. I do not know of a better way to achieve airtightness in a roof, increase its wind uplift resistance and reinforce it against stresses and strains.

Even if a deliberate vapor retarder is not installed in a nail one–mop one system, the bitumen used to attach the upper layer of insulation, which has its joints offset from those of the bottom layer, tightens and strengthens the roof and improves its moisture resistance.

Whenever possible, the nail one–mop one method of construction should be used.

POSITION OF A SANDWICHED VAPOR RETARDER

If Figures 4 and 5 indicate that a vapor retarder is barely needed, it can be placed relatively close to the cold side of the roof and still do its job. If the expected indoor relative humidity is far above the mapped and corrected value from Figures 4 and 5, the vapor retarder must be placed closer to the warm side of the roof in winter.

With the approach used to develop Figure 4,[6] I have developed the Figure 8 graph to define the maximum percentage of the total thermal resistance of the roof that can be on the warm side of the vapor retarder.

For example, if Figures 4 and 5 generate a value of 30 percent but the expected indoor relative humidity is 45 percent, then intersecting the 30 percent curve with a vertical 45 percent line, and moving horizontally to the left will show that up to 62 percent of the thermal resistance of the roof can be on the warm side of the vapor retarder.

A protected membrane roofing system is shown in Figure 9. Its waterproofing membrane is below at least some of its insulation. In that position the membrane can also serve as a vapor retarder. The amount of insulation that can be located under the membrane without introducing condensation problems can be found using Figures 4, 5 and 8.

VAPOR TRAPS

The incorporation of a vapor retarder in a compact roofing system (Figures 6 and 7) creates a potential trap for vapor between the waterproofing membrane and the vapor retarder. The need to vent potential vapor traps in roofs is considered essential by some.[9,10] The ASHRAE 1985 Fundamentals Handbook states, "Any water vapor passing through an inadequate or defective vapor retarder in an unventilated flat roof with a highly impermeable exterior membrane will be trapped between the two layers, leading to premature roof failures."[4]

It is difficult to ventilate a compact roof. Attempts to provide ventilation include the use of kerfed wood nailers around the perimeter and the use of roof breather vents over the rest of the roof. One-way, two-way, and solar-powered breather vents are available. I am convinced that such vents do more harm than good.[11]

The National Roofing Contractors Association (NRCA) recommends use of one breather vent for every 1,000 square feet of roof surface for roofs with vapor retarders,[5] but this practice is seldom followed. Acres of compact membrane roofs with vapor retarders exist without edge or breather vents. There is no evidence that these roofs perform any worse than others with vents. I have examined several *framed* roofs with problems caused by inadequate venting but I have yet to find a compact membrane roof with problems attributable to lack of vents.

Concerns about pressurization of the unventilated space between the membrane and the vapor retarder in a compact roof because of changes in the temperature of that space are unfounded. Pressures that cause membrane blisters do not develop in that space.[12] Installing breather vents is not a viable way to prevent membrane blistering.

Flaws in an imperfect vapor retarder do allow small quantities of moisture to enter a compact roofing system in cold weather. However, those flaws do not close once the moisture has entered. When the vapor drive reverses in warmer weather, the system can dry out downward through the same flaws.[6] As long as the system can resist air leakage, the amount of moisture that enters by diffusion during winter is rather small and not a problem in most cases.

A membrane perforated with a field of breather vents contains just that many more penetrations that may be flawed, allowing external moisture to enter the system. The installation of breather vents or other venting features in compact roofing systems makes little sense.[11]

ROOFING OVER WET SUBSTRATES

When roofing over a deck that may contain moisture, such as concrete or gypsum, or over a poured-in-place lightweight material placed to provide insulation or slope to drain, the potential for moisture problems increases.

Of course, the wet material should be allowed to dry as much as possible before the roofing system is installed over it. In addition, the design should permit the wet material to dry downward. Perforated steel decks are available to accomplish this for lightweight insulating concretes.

Even when these two guidelines are followed, there still may be enough moisture in the wet material when the roofing system is installed to cause problems. Thus it is essential that a moisture barrier (i.e., a vapor retarder) be installed over the potentially-wet material to prevent any moisture in it from reaching the materials installed above.

It is usually not appropriate to fully adhere such a vapor retarder to the wet substrate. Instead it should be spot adhered or mechanically attached. Mechanical attachment is favored over insulating concretes, even though the fasteners puncture the base layer of the vapor retarder. This is remedied by adding one or two unpenetrated vapor-stopping layers above. Felts laid in solid moppings of hot bitumen are ideal for this purpose. Because the underside of this vapor retarder is likely to be subjected to 100 percent RH until the wet material has dried, it must be well built with all joints and penetrations sealed.

Having done all this, insulation and a waterproofing membrane can be installed above with little risk of damage from the wet materials below. The wet materials will dry out slowly into the building.

However, it is also common to ventilate the wet materials to the exterior around the perimeter of the roof and to install breather vents that open into the space *below* the vapor retarder. It is generally acknowledged that these vents will not dry out the wet material. They are installed with the expectation that they will prevent potentially damaging pressures from occurring in the space below the vapor retarder. As I see no way for such pressures to develop under the vapor retarder, I see no reason to install such vents.

Other individuals install vents within the new roofing system above the vapor retarder to remove any moisture that passes the inevitably imperfect retarder. For the reasons discussed in the prior section on vapor traps, I would not do this.

When adding a second membrane (and perhaps insulation) over a potentially wet, existing membrane roofing system, some individuals advocate chopping holes in the existing membrane to allow any moisture trapped below to move up into the new system, which they ventilate.

In my judgment, deliberately allowing moisture access to new materials is wrong. If anything, the existing membrane should be repaired to enhance its ability to serve as a moisture barrier, not deliberately converted to a moisture sieve.

If much moisture is trapped in the existing roofing system, new materials should not be added above until after the wet "cancers" have been removed. Nuclear, capacitance and infrared roof moisture surveys can locate such problems.[13]

SUMMARY

The potential for condensation in roofing systems is related to the climate outdoors and the temperature and relative humidity indoors. Maps and graphs have been developed to determine when and where vapor retarders should be installed. In most cases, vapor retarders should have a perm rating of 0.5 or less.

Since air leakage, not vapor diffusion, is the primary mechanism behind condensation problems in buildings, air leakage paths must be sealed. This is difficult to achieve in framed roofing systems but relatively easy to accomplish in compact roofing systems.

When membranes are loose laid, air leakage potential increases and condensation problems may result. When the lower layer of insulation is mechanically attached to the deck, it is often best to place the vapor retarder above that layer of insulation where it is not penetrated by fasteners.

Potential vapor traps are created in the insulated layer between waterproofing membranes and vapor retarders in compact roofing systems, but there is no need to ventilate these areas.

Over wet substrates, tightly sealed vapor retarders are needed to keep that moisture from entering roofing components above. Such substrates must be able to dry downwards into the building.

New roofing systems should not be placed above existing roofs that contain wet insulation. Roof moisture surveys should be used to locate the wet insulation, which should be removed before materials are added above.

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Offices	30 - 50%
Hospitals	30 - 55%
Computer Rooms	40 - 50%
Department Stores	40 - 50%
Swimming Pools	50 - 60%
Textile Mills	50 - 85%

Table 1 *Typical indoor relative humidities in winter.*

Material	Perm Rating*
Bituminous built-up membrane	0.0
45 mil EPDM	0.04
60 mil EPDM	0.03
Aluminum foil (no holes, no laps)	0.0
4 mil polyethylene	0.08
6 mil polyethylene	0.06
4 mil polyvinylchloride (PVC)	more than 0.8
Kraft paper laminates	less than 0.3
No. 15 asphalt-saturated felt	1.0
No. 43 asphalt-saturated and coated felt	0.3
Steel deck (forgetting seams)	0.0
Steel deck (considering seams)	more than 1.0
Uncracked structural concrete deck	about 0.5
Plywood, ¼ inch thick, exterior glue	0.7
Gypsum wall board, ⅜ inch thick	50.0
Insulation boards	
☐ Cellular glass, 1 inch thick	about 0.0
☐ Polyurethane, 1 inch thick	about 1.0
☐ Polystyrene, extruded, 1 inch thick	about 1.2
☐ Polystyrene, expanded, 1 inch thick	about 4.0

*grains/hr•sq ft•inch mercury.

Table 2 *Permeance of some roofing components.*[4]

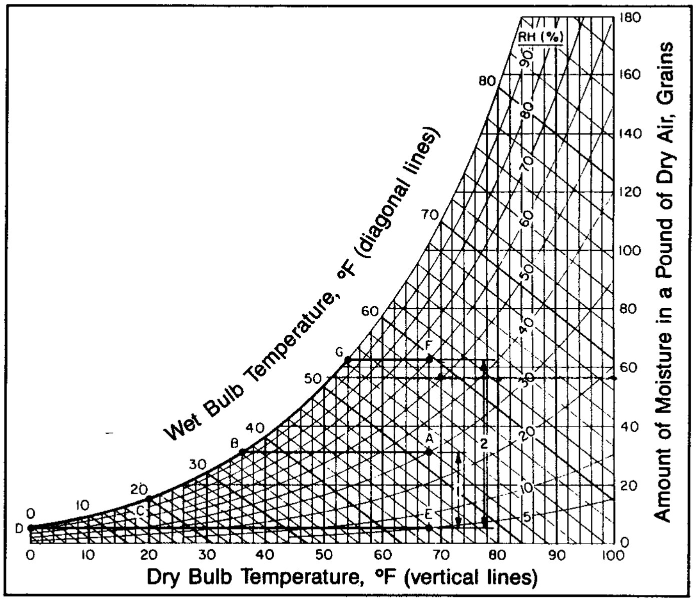

Figure 1 *Simplified psychrometric chart with example from text shown on it*

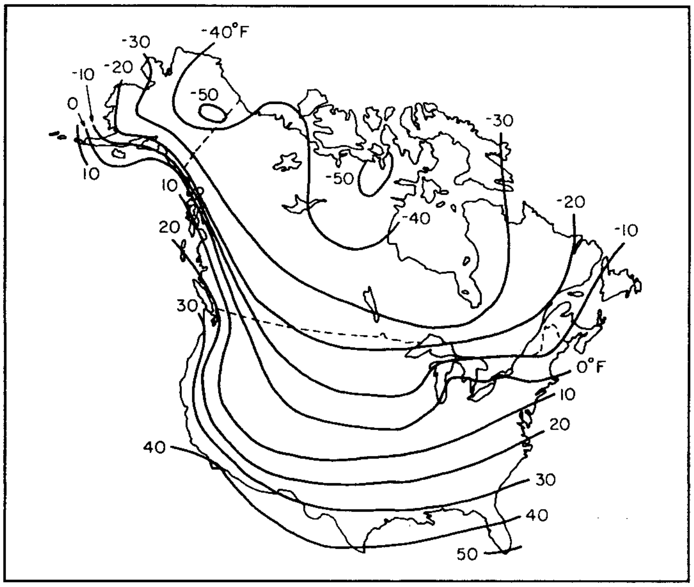

Figure 2 *Distribution of winter design temperature over North America*

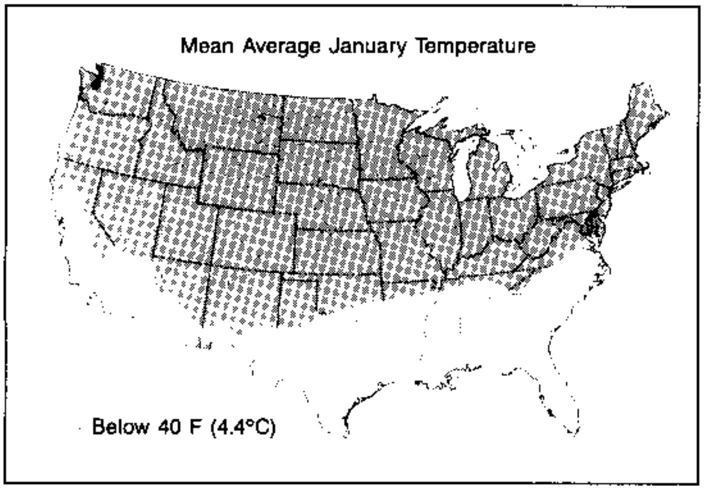

Figure 3 Area of the United States that has a mean average January temperature below 40 F

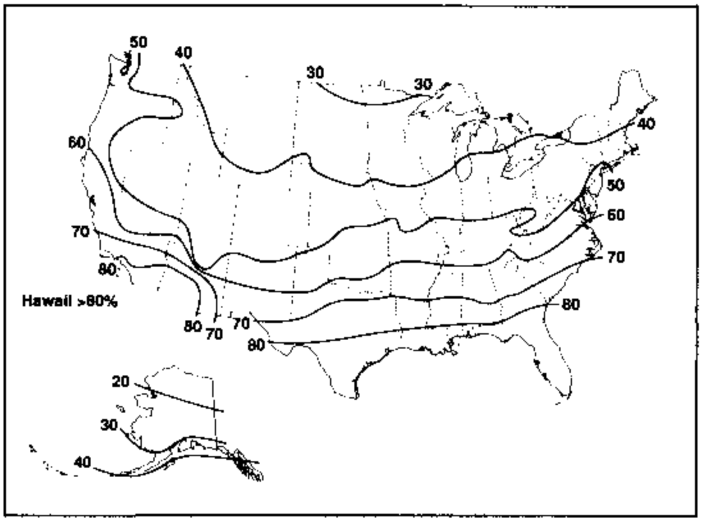

Figure 4 Indoor relative humidities at 68 F, above which a vapor retarder is needed in membrane roofing systems. If the indoor temperature is not 68 F, use Figure 5 to modify these values

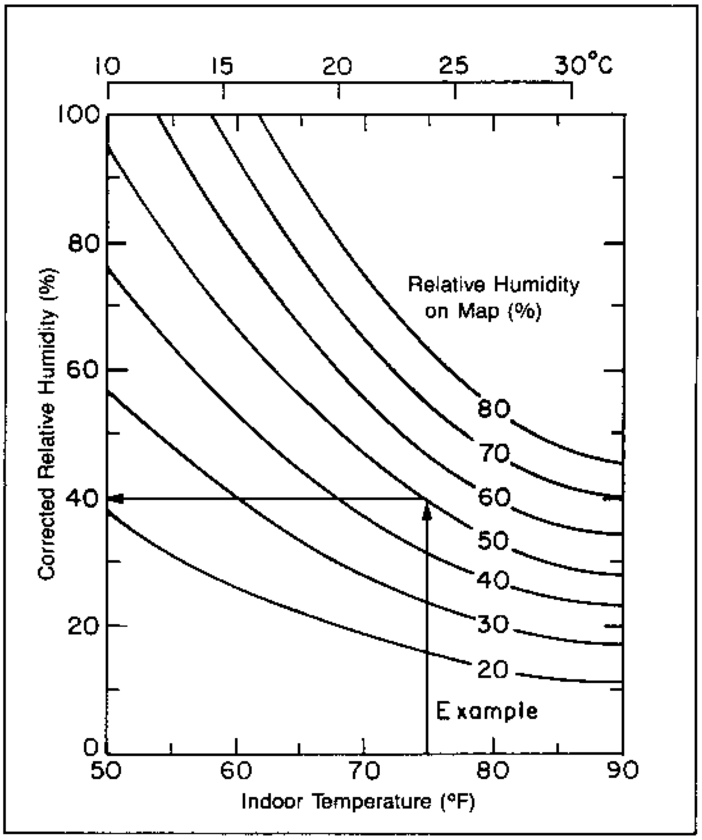

Figure 5 Graph for correcting the mapped values in Figure 4 for indoor air temperatures other than 68 F

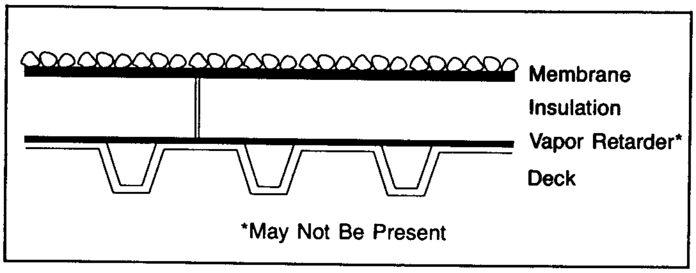

Figure 6 *Cross-section of a compact membrane roofing system*

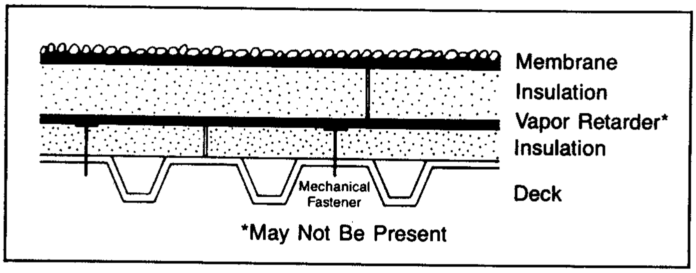

Figure 7 *Cross-section of a compact membrane roofing system with the vapor retarder installed between insulation layers*

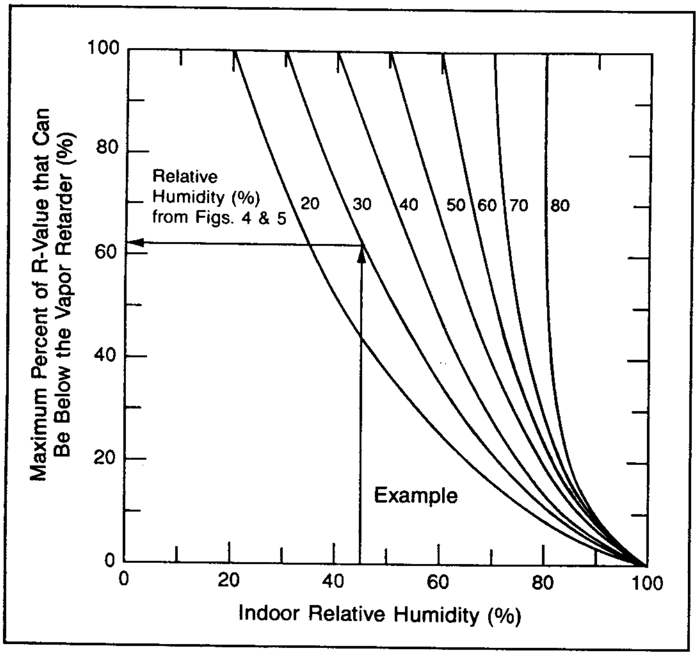

Figure 8 *Graph used with Figures 4 and 5 to determine the maximum percent of the thermal resistance of the roof that can be on the warm side of the vapor retarder*

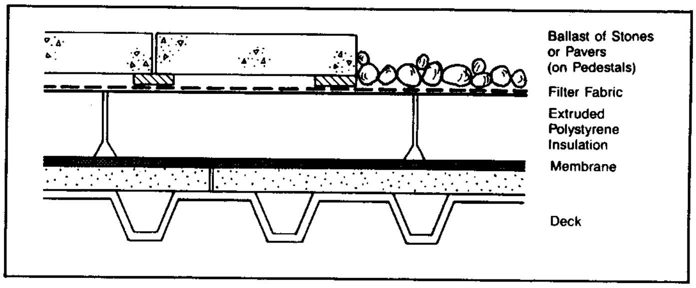

Figure 9 *A protected membrane roofing system*