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Vents and Vapor Retarders for Roofs

Wayne Tobiasson

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by
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INTRODUCTION

Vents and vapor retarders are features incorporated into roofing systems to prevent moisture from condensing within the roof.

The need for vents and vapor retarders in building envelopes depends on the climate of the place, the temperature and moisture conditions within the building, and the type of materials and systems used for the envelope. Condensation problems in roofs are usually caused by moisture in indoor air that moves upward into the roofing system in cold weather. However, problems can also occur in hot, humid regions when moisture in outdoor air condenses within a roof, particularly above air-conditioned spaces. Most of this paper is concerned with condensation in cold weather, but the warm weather problem is also considered.

Moisture in the wrong place can rot wood, corrode metal, cause leaching, efflorescence, and spalling of concrete and masonry, and delaminate or disintegrate other building components.[1] Moisture causes insulation to lose some of its insulating ability,[2] adds unwanted dead load to a roof, and can result in annoying, damaging leaks into the rooms below.

Roofs suffer more than their share of moisture problems but most of the problems are due to flaws in the exterior waterproofing system of the roof, not to improper control of condensation. Roofs are waterproofed by water-shedding surfaces such as shingles and metal panels or by water-tight membrane and flashing systems made of bitumens, elastomers, or flexible plastics. Membrane and water-shedding roofing systems are shown in Exhibit 1. Flaws at flashings and penetrations are the primary cause of roof leaks for low-slope membrane roofs. In cold regions, ice damming at the eaves of steeply sloped water-shedding roofs is a major cause of leaks.

Since most types of roofs do not suffer condensation problems, it appears that current measures used to prevent condensation in roofs are doing their job well. Some recommendations for condensation control are not being used and since no adverse effects are occurring, I believe those recommendations are unnecessary. However, a few kinds of roofs suffer chronic condensation problems that need to be eliminated.

Valuable guidance on vapor retarders and vents is presented in Chapters 20 and 21 of the ASHRAE Fundamentals Handbook.[3] I will overview that guidance as it applies to roofs, expand on ways to ensure that it is incorporated into the "as-built" world of buildings, and take exception to one aspect of it on venting of compact membrane roofs.

AIR LEAKAGE IS THE PROBLEM

Perhaps the most important thing to realize about condensation control is that diffusion of moisture through the components of a roofing system is a very slow process that seldom causes problems. Where problems occur, movement of moist indoor or outdoor air into a roofing system is almost always present. By directing attention to the elimination of air leakage, most condensation problems can be avoided.[4]

The following three quotes from the ASHRAE 1985 Fundamentals Handbook[3] are worth remembering:

1. "Rarely is vapor diffusion a major factor."
2. "... air movement that carries water vapor with it is far more powerful in transporting water vapor to the point of condensation."
3. "The best defense against harmful condensation ... is by airtight construction."

Once air leakage is acknowledged as the problem, it is clear why some types of roofs suffer condensation problems while others do not.

COMPACT AND FRAMED ROOFING SYSTEMS

When studying condensation problems in roofs it is important to distinguish between compact and framed roofing systems.

A cross-section through a "compact" membrane roofing system is shown in Exhibit 2. A barrier to air and vapor may or may not be present. In either case the system contains no air spaces and offers little opportunity for air movement since air cannot flow readily through most of the insulations used. Moreover, there is seldom anything recessed up into a compact roof nor should any electrical wires or conduits be placed there. Water-shedding systems can also be built as compact roofs but most are not. Compact roofs have few condensation problems.

A cross-section through a framed membrane roofing system is shown in Exhibit 3. The insulation is placed below the deck, between the framing members. Often, relatively inexpensive batts of fibrous glass or rock wool insulation are used. A barrier to air and vapor may or may not be present. An air space may exist above the insulation, and it may be open to outside air at each end for ventilation. Quite often electrical wires run in among the insulation batts and an assortment of fixtures are recessed up into the roof. Framed roofing systems can be used for water-shedding and membrane roofs. Framed roofing systems that leak a lot of air are apt to have condensation problems.

COMPACT ROOFING SYSTEMS

Vapor Retarders. Various guidelines on where to use vapor retarders for compact membrane roofing systems are summarized in Reference 5. They range from the entire United States to only areas where the average January temperature is less than 35°F (or 40°F or 45°F). Some guidelines recommend vapor retarders for all occupancies while others call for their use only if the indoor relative humidity in winter exceeds 40% (or 45%) or where there is "excessive moisture within the building." Perhaps the most commonly used guideline for compact roofs is to install a vapor retarder with a permeability of 0.5 perms or less when the average January temperature is below 40°F (Exhibit 4) and the indoor winter relative humidity equals or exceeds 45%.[6]

Recently, to improve upon this guidance, Marcus Harrington and I generated a series of vapor drive maps of the United States, each map representing a different winter vapor drive.[7] One of those maps is presented in Exhibit 5. The isolines represent the indoor relative humidity at which the winter vapor drive equals 0.6 in. of Hg·mo. This map can be used to define the indoor relative humidity of 68°F indoor air at which compact roofs need vapor retarders across the nation. The map "calibrates" rather well with my experience as to when and where compact roofs need vapor retarders. In Reference 7 we have asked for reader feedback on which map calibrates best to their experience.

Little guidance is available on how to seal compact-roof vapor retarders at flashings and penetrations. No particular attention is given to such seals in most situations. However, when the vapor retarder serves as a waterproofing membrane for some time during the construction process, excellent seals are often achieved since, to serve as waterproofing, it must be flashed at all penetrations.

In warm, humid weather the low permeability of the waterproofing layer of a compact membrane roof prevents moisture in the outdoor air from entering the roofing system. In other words, the membrane then serves as a vapor retarder.

A recent study[8] determined that the permeability of loose-laid membranes made of EPDM rubber increases significantly when the membrane is hot. It has been speculated that in warm weather this is allowing outside moisture to enter compact roofing systems with EPDM membranes. Since the permeability decreases when the EPDM is cold, the moisture may be trapped within the system. However, the study concluded that "moisture can accumulate, but not a significant amount." Upward air leakage of indoor air into loose-laid compact roofing systems during cold weather offers a better explanation as to the source of the moisture being found in some such roofs.

In spite of the broad differences that exist among vapor retarder guidelines for compact roofs, few such roofs suffer condensation problems. This suggests that the more stringent guidelines are excessive.

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

Steel is the most commonly used material for the decks of compact roofing systems. Since adhering insulation to a steel deck is very difficult, mechanical attachment is now the norm. If a vapor retarder is present below the insulation it is penetrated by the fasteners. To eliminate moisture problems that might be caused by penetration of the vapor retarder and to improve the insulating ability of the system, two layers of insulation are used. The bottom layer is attached to the deck with mechanical fasteners, and the upper layer is adhered to it with hot bitumen. When a vapor retarder is needed, it is placed between the two layers of insulation (Exhibit 6). By designing the roof so that most of its insulating ability is in the top layer of insulation, the dew-point temperature of the indoor air can be kept above the vapor retarder, preventing condensation within the insulation below. This is called the "nail one - mop one" system.

The protected membrane roof (Exhibit 7) has its waterproofing layer below all or at least some of the insulation. The protected membrane can also serve as a vapor retarder in that position, eliminating the chance of introducing a vapor trap.

Vents. If a compact roof has no vapor retarder, it should not be ventilated since ventilation may cause more harm than good by promoting air leakage.[9]

Some compact roofs with vapor retarders are ventilated to prevent accumulation of moisture within them and to avoid the possibility of pressurization of the "vapor trap" created between the waterproofing membrane and the vapor retarder. Ventilation of such potential vapor traps is considered essential by some.[10 11] I disagree.

The ASHRAE 1985 Fundamentals Handbook[3] 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."

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.

The National Roofing Contractors Association (NRCA) recommends use of one breather vent for every 1000 square feet of roof surface for roofs with vapor retarders,[6] 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.

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.

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 in compact roofs makes little sense to me.[12]

It is clear that breather vents are all rather ineffective at removing moisture from wet insulation.[9 13]

FRAMED ROOFING SYSTEMS

Sloped roofs are easier to ventilate than are "flat" roofs. Dead flat roofs are a design mistake: all roofs should be sloped to drain. "Flat" in this report refers to roofs with a slope of 1 in./ft or less.

"Flat" roofs. Most roofing systems that suffer condensation problems leak a lot of indoor air and require that air to travel laterally some distance in enclosed rafter spaces on the cold side of the insulation before it reaches exhaust openings in the roofing system. Condensation commonly occurs during the lateral movement. Exhibit 3 shows a membrane roof insulated below its deck with layers of batt insulation placed between framing members. The ceilings of some such roofs leak a lot of air. Exhibit 8 shows some of the many air leakage paths that may be present. These paths are not eliminated by the installation of a vapor retarder on the underside of the insulation unless the vapor retarder is sealed at all penetrations.

For "flat" timber-framed roofs in the United States, guidelines commonly recommend a vapor retarder with a permeability of 1 or 0.5 perm or less below the insulation. One guideline[3] recommends a very low permeability (0.05 perms) in heavily insulated wood-framed roofs without attics. I question the need, in most cases, for a permeability less than 0.5 perms since vapor diffusion is a very slow process. The National Building Code of Canada[14] discusses "vapour barriers," the importance of sealing openings in them, and other measures, such as separate air barriers, to prevent condensation. In Canada the separate functions of air and vapor barriers are well established.[15] Unfortunately, American model building codes[16 17] say little or nothing about condensation control.

The importance of vapor retarder continuity is acknowledged in most technical publications, but little guidance is provided to designers and to the trades on what it takes to achieve the desired results. Consequently, many vapor retarders are not sealed or they are inadequately sealed. As an acknowledgement of the impossibility of creating a perfect vapor retarder, it is also common to ventilate such roofs.

For "flat" roofs with enclosed rafter spaces, guidelines on the net area of openings for natural ventilation range from 1/300 (i.e. 0.33%) of the area of the space to be ventilated[3 14] to 1/150 (i.e. 0.67%) of that area.[16 17] When the roof slope is less than 2 in./ft, the National Building Code of Canada[14] requires the air space to be at least 1 inch high and also requires cross-purlins at least 1-1/2 inch high above the rafters. This interconnects all the individual enclosed rafter spaces to avoid dead spots where condensation is likely.

In "flat" roofs, as shown in Exhibit 8, there is no stack effect to cause a draft between the intake and exhaust openings. Thus, ventilation is slight except during windy periods. This type of roof is prone to condensation problems.

It may be possible to solve problems in such roofs by sealing the paths of air leakage. Although difficult, especially after the fact, it is often well worth the effort. Two recent Canadian booklets[18 19] provide a wealth of practical guidance.

Some years ago in Canada, moisture problems in such roofs were also solved by installing fans on the roof that, in winter, blew cold, dry, outside air into the space above the insulation. This not only increased ventilation but it also reduced the leakage of moist indoor air up into that pressurized space.[20]

In England it is common to ventilate "flat" timber-framed roofs by providing openings totalling at least 0.4% of the roof plan area. However, problems are occurring that suggest that this should be increased to 0.6%. When such roofs have long spans (i.e. the moist air must travel laterally quite a distance before being exhausted) or when they are located above kitchens or other high-humidity occupancies there appears to be a need to force-ventilate the air space by installing fans.[21]

Recent studies in Denmark[22] determined that the incorporation of a ventilated air space above insulation in a "flat" roof may do more harm than good since such ventilation promotes air leakage. Unvented panels above high-humidity "flat"-roofed buildings constructed as shown in Exhibit 3, accumulated somewhat less moisture than did most vented panels. Some reduction in moisture was achieved when the space was force-ventilated with fans, but whenever the fans were stopped for a few days, moisture accumulated rapidly. The Danish study found that edge-to-edge ventilation of the type shown in Exhibit 8 "seems to function satisfactorily" for "flat" roofs in the Danish climate (about 6600 heating degree days Fahrenheit and winter design temperatures of about 19°F) for homes and other small buildings having reasonably tight ceilings and an indoor-air dew-point temperature below 32°F. This corresponds to an indoor relative humidity in winter below 26% at a room temperature of 68°F. (Humidifiers are seldom used in Danish homes.) However, condensation problems are likely if similar roofs are used for larger buildings or buildings with higher indoor relative humidities whether the roofs are ventilated or not. Great care in installing the ceiling vapor retarder so it is airtight reduces the risk of condensation but with normal construction practices, moisture problems are to be expected. The Danish study concluded that ventilated wood-framed "flat" roofs with below-deck insulation are inappropriate for buildings with a dew-point temperature above 52°F (this corresponds to 56% RH at 68°F indoors). They also indicate that some problems are likely in Denmark's climate for drier buildings.

When unventilated frame construction is used, only a portion of the insulation should be placed below the deck. The rest of the insulation should be placed on a vapor retarder above the deck so as to create an unvented compact roof above the framed portion. This dual insulation method is shown in Exhibit 9. As the relative humidity in the building increases, the amount of insulation allowed in the wood-frame portion decreases. In Denmark, for houses and other low-humidity occupancies, no more than half of the insulation should be there. When the dew-point temperature of the inside air is between 32°F and 52°F, no more than one third of the total thermal resistance of the roof should be below the deck. If the dew-point temperature is above 52°F, essentially all the insulation should be in the compact portion of the roof. The intent of these guidelines is to keep the dew-point temperature of the indoor air above the deck and vapor retarder during most of the winter, thereby eliminating the possibility of condensation in the framed portion of the deck where moist indoor air is likely to have access.

There is ample evidence that "flat" wood-framed roofs have a relatively high risk of incurring condensation problems. That risk can be reduced by installing a vapor retarder, by making the ceiling airtight at all penetrations, and by ensuring that the space above the insulation is well ventilated. However, it is probably better to place a portion of the insulation above the deck and vapor retarder in the form of a compact roofing system and not ventilate any air spaces below the deck. In fact, eliminating air spaces in such a hybrid roofing system is preferred to further reduce the chance of air leakage.

If enough insulation is placed above the deck and vapor retarder to cause the dew-point temperature of the indoor air to occur in the compact system above the vapor retarder at the winter design temperature, condensation problems are highly unlikely.

A compromise solution is also possible. It involves placing a vapor retarder and some insulation above the deck but not the full amount required to keep the dew-point temperature above the deck. Economics is the primary incentive to use less above-deck insulation, since rigid insulation boards are a more expensive way of providing insulation than are batts. A sealed but admittedly imperfect second vapor retarder would be placed below the batt insulation to reduce the amount of moisture that can move up through it to the underside of the deck in cold weather. The combination of these two imperfect systems, provided they are both reasonably good, can work together to control condensation. I do not worry much about the "trap" created by the two vapor retarders for the reasons already stated when discussing potential vapor traps in compact roofs.

Most framed-roof condensation problems occur in cold regions and are from indoor moisture. However, outdoor moisture can cause problems for air-conditioned buildings in hot humid regions. Air spaces for roof ventilation may allow outdoor air to enter the roof. If a vapor retarder is present below the insulation, "summer condensation" can form on it when its temperature is below the dew point of the outdoor air. For this reason, vapor retarders are usually not wanted in framed roofs in hot, humid areas. There, ceilings should have a high permeability to water vapor to allow small amounts of moisture to pass into the occupied space below rather than accumulate in the roof. Although such ceilings should not contain a vapor retarder, they should be well sealed against air leakage.

Referring to the map in Exhibit 5, few roofs in the warm regions of the United States need vapor retarders. However, the ASHRAE 1986 Fundamentals Handbook[3] recommends ceiling vapor retarders for flat roofs in these areas. I expect that is a response to the real need for air leakage control rather than a need for low water vapor transmission of ceilings in hot, humid regions.

Sloped roofs. When slope is provided to framed roofs, condensation problems are less likely because chimney draft enhances ventilation in cold weather.

When the exhaust ports of the space to be ventilated are at least 3 ft above the intake ports, two American model codes[16,17] reduce the net area of openings for ventilation from 1/150 (i.e. 0.67%) of the area of the space to be ventilated to 1/300 (i.e. 0.33%) of that area. The National Building Code of Canada[14] requires 1/300 no matter what the slope, but eliminates the need for interconnecting all the enclosed rafter spaces at a slope of 2 in./ft or more.

The improvement in ventilation achieved by slope is why it is common at slopes of 3 on 12 or more to omit ceiling vapor retarders in ventilated wood-framed roofs in the warmer regions of the United States (i.e. in Condensation Zone III of Figure 6 in the ASHRAE 1985 Fundamentals Handbook[3]). Such construction has been successful where air leakage is controlled. However, the lack of need of a vapor retarder has been mistakenly construed by some designers and builders to mean that no provisions need to be taken to control leakage of indoor air into the roof. In such cases some moisture problems have developed.

When an attic is present below a sloped roof, it is relatively easy to ventilate away any moisture that moves upward through the ceiling. Continuous vents at the eaves and ridge are usually quite effective, provided, once again, that leakage of moist indoor air is limited. Unfortunately, current design and construction practices seldom include the sealing of penetrations and gaps often exist in ceilings through which indoor moisture enters the attic. Exhibit 10 shows a typical unsealed pipe penetration. Exhibit 11 shows a well-sealed pipe penetration.

Ceilings below attics often contain a hatch to provide access into the attic. If the hatch is not tightly sealed against air exfiltration, a lot of moisture can enter the attic. Most hatches are not well sealed. In temperate areas attic ventilation may be able to remove all the moisture from exfiltrating air, but in cold regions large quantities of frost can grown even in well-ventilated attics when hatches, electrical fixtures, and pipes are not well sealed. Exhibit 12 shows what can happen. In warmer weather the frost melts, the insulation is soaked, the ceiling is damaged, and leaks occur in the rooms below.

Because of the importance of controlling air leakage, construction specifications should not only require that penetrations in the building envelope be sealed but they should also contain specific guidance on the type of seals needed. Such seals should be inspected and approved before other materials conceal them.

Since snow is a good insulator, a warm (unventilated) roof tends to melt snow that forms on it even in relatively cold weather. This does not usually create problems if the meltwater produced moves to drains located above the warm building. However, if the meltwater moves to cold portions of the roof such as its cold eaves, icicles and ice dams will develop that can result in roof leaks. In areas where snow remains on roofs for long periods, roofs that slope to cold eaves should be cold (ventilated) systems to reduce the risk of eave icings.

As cold dry outdoor air moves from the eaves to the ridge of a cold (ventilated) attic-less roof, it picks up moisture and heat. By the time it has travelled about 20 ft in the narrow spaces above the insulation, it is no longer very effective at keeping the surface of the roof cold. This limits the size of cold (ventilated) attic-less roofs in snow country. The 20 ft limitation can be increased somewhat by increasing the roof insulation above R20.

While the Danish recommendation to convert cold (ventilated) roofs to hot (unventilated) roofs is applicable to internally drained roofs, it may not be the appropriate solution in snow country when drainage is to cold eaves. In this case it may be necessary to add a ventilated space above the insulation as shown in Exhibit 13.

SUMMARY

Framed roofing systems suffer many more condensation problems than compact roofing systems do. The relative air tightness of compact systems explains why. Control of air leakage is the key to condensation control.

Not all compact roofing systems should have vapor retarders. The need for a vapor retarder arises in cold regions and where high relative humidities are maintained within buildings. A map has been developed that considers both these factors (Exhibit 5). The guidelines call for ventilation of compact roofs, but usually they are not ventilated. Since unventilated compact roofs perform well, the need for ventilating them is questioned.

Low-slope framed roofing systems suffer condensation problems. It is almost always wrong to assume that such difficulties can be avoided by lots of ventilation or by use of vapor retarders with very low permeabilities. In fact, some recent studies indicate that ventilation may, at times, do more harm than good since it promotes air leakage. The best way to avoid condensation problems in low-slope framed roofing systems is to minimize their air leakage by sealing all gaps and penetrations. Since this is often difficult to achieve, some cold-side ventilation is usually necessary.

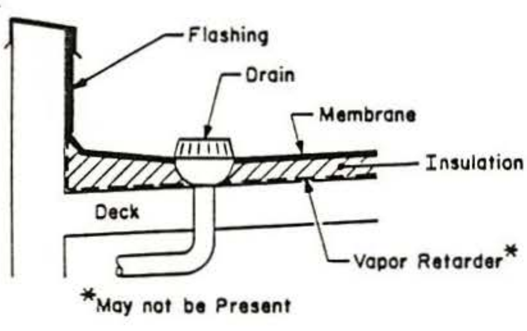
Low-slope framed roofs are apt to create problems in situations where they are subjected to high vapor drives for sustained periods. It may be appropriate to use other systems there. Condensation risks can be reduced significantly by using a hybrid system consisting of a compact roof above an unventilated framed system or by using a compact roof.

Slope generally reduces the risk of condensation for framed roofs since more reliable ventilation can be achieved. The use of attics for ventilation is usually beneficial, but the primary objective must still be to reduce air leakage into the attic.

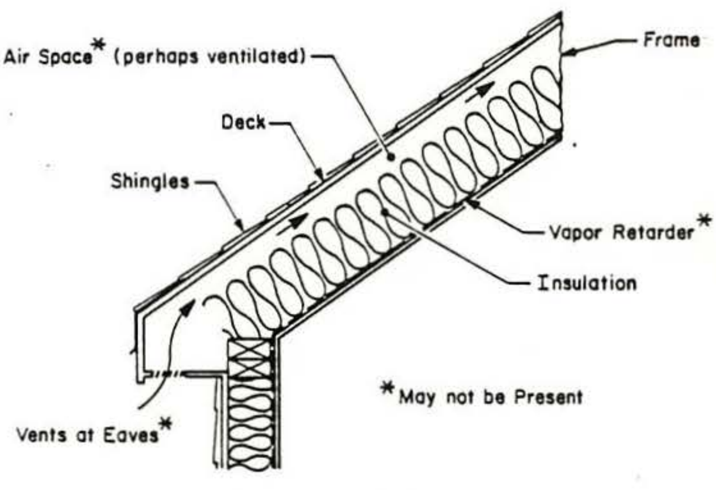
In hot, humid areas it is often best to avoid use of vapor retarders on the underside of the roof since summer condensation may result.

In areas where snow remains on roofs for long periods, roofs that slope to cold eaves should be ventilated to reduce the risk of ponding water behind ice dams at the eaves as well as to avoid condensation problems.

Current design and construction practices often result in excessive air leakage in framed roofs. Because of the importance of controlling air leakage, construction documents should contain specific guidance on the type of seals needed, and such seals should be inspected and approved before other materials conceal them.



a. Membrane System



b. Water-shedding System

Exhibit 1. Membrane and water-shedding roofing systems.

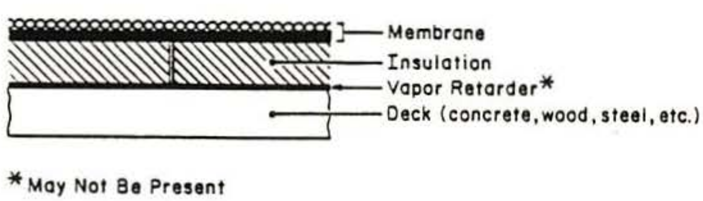


Exhibit 2. Cross-section of a compact membrane roofing system.

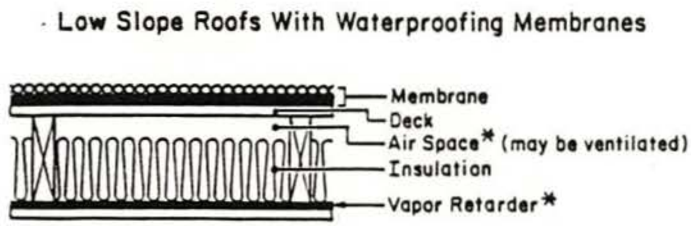


Exhibit 3. cross-section of a framed membrane roofing system.

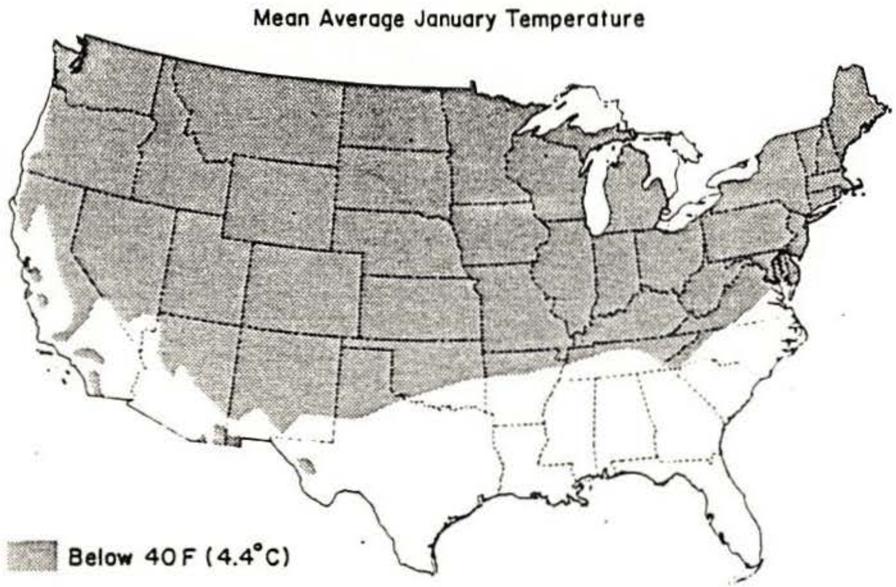


Exhibit 4. The shaded area has an average January temperature below 40°F.

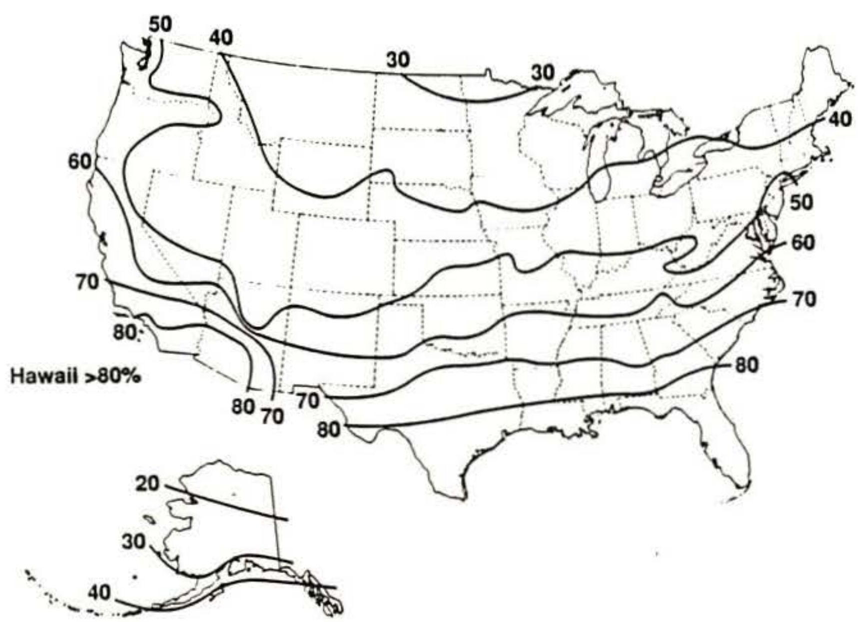


Exhibit 5. Indoor relative humidities at which the seasonal wetting potential equals 0.6 in. of Hg·mo.

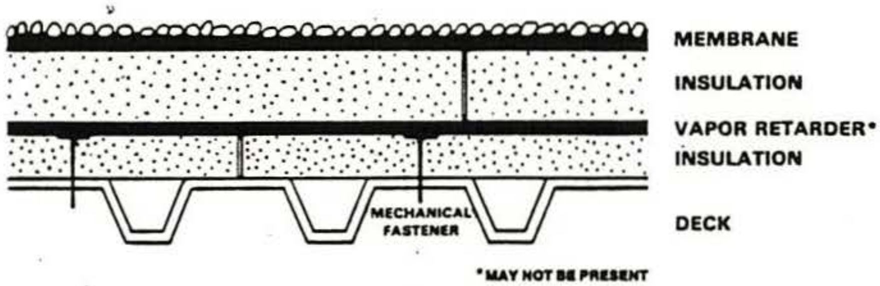


Exhibit 6. The "nail one - mop one" system.

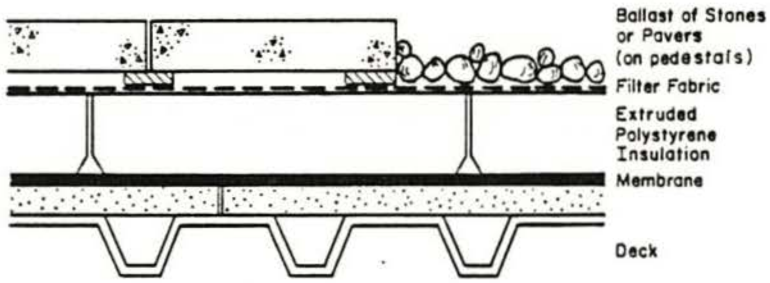


Exhibit 7. The "protected membrane" system.

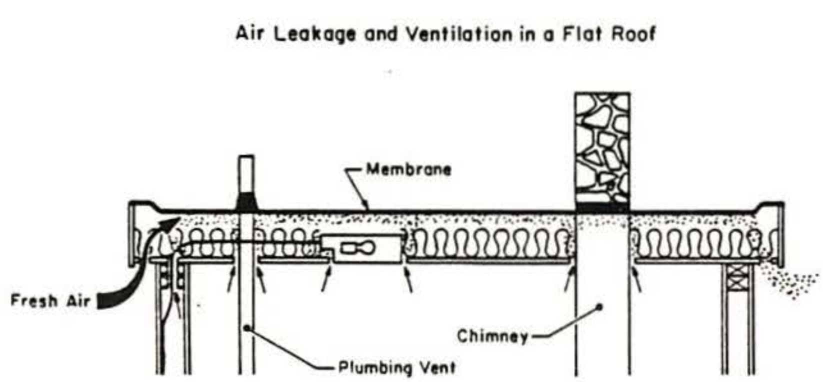


Exhibit 8. Air leakage paths into a ventilated flat roof with below-deck insulation.

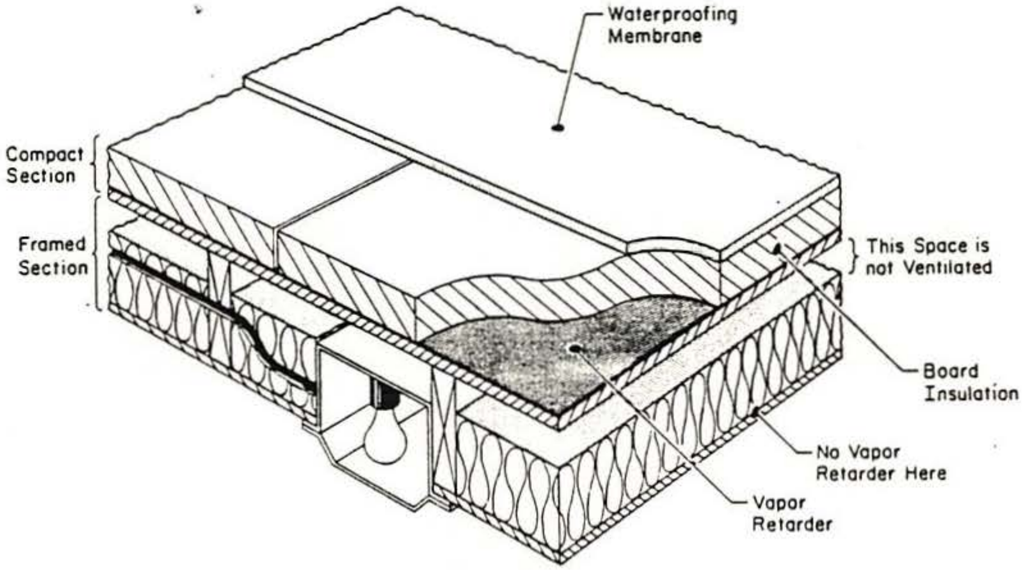


Exhibit 9. Unventilated wood-framed roof with insulation in compact and framed portions.

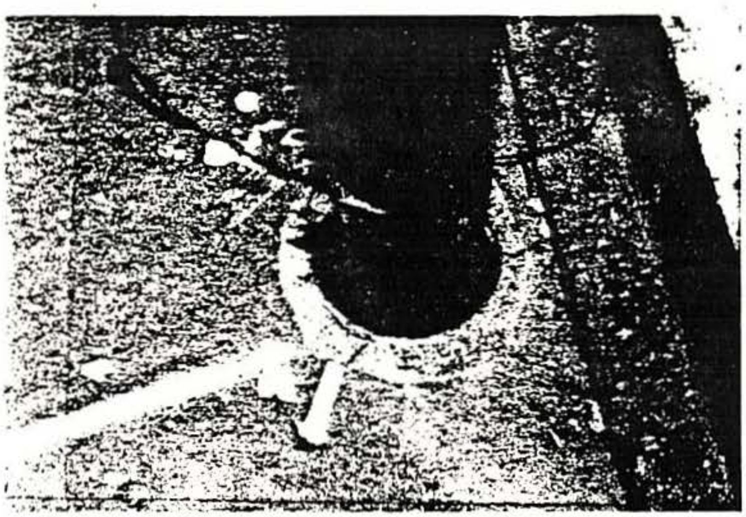


Exhibit 10. Unsealed ceiling vapor retarder at a pipe penetration.

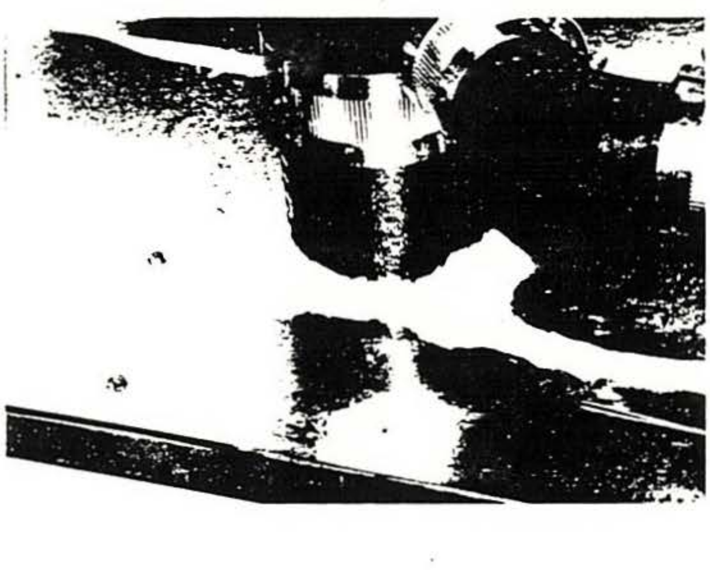


Exhibit 11. Properly sealed pipe penetration.

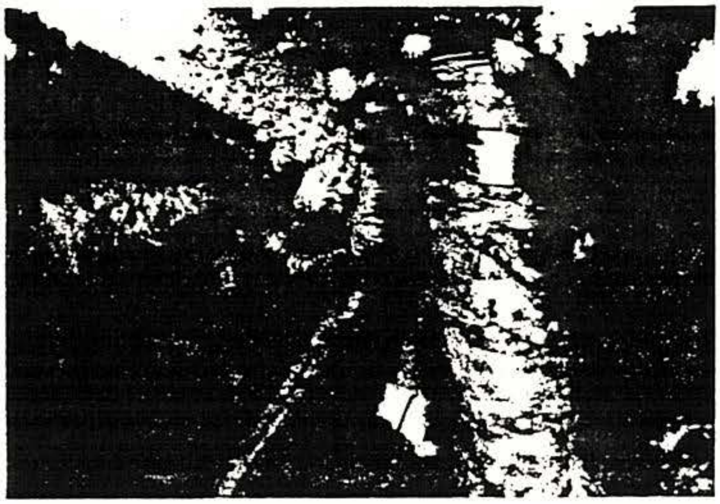


Exhibit 12. Attic frost caused by leakage of indoor air by an unsealed vapor retarder.

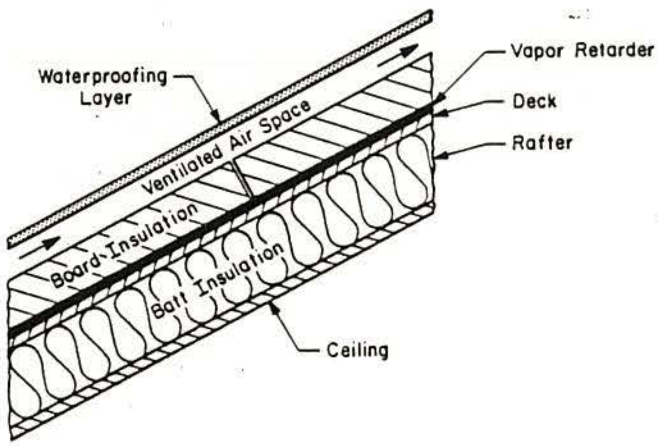


Exhibit 13. A cold (ventilated) roof with insulation in compact and framed portions.

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