VAPOR DRIVE MAPS OF THE U.S.

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ABSTRACT

The thermal performance of most insulations used in building envelopes will be seriously degraded if the insulation becomes wet. Problematic moisture can come from within the building, and a barrier to that moisture may be needed to prevent condensation within the building envelope. Guidance on when to use "air-vapor retarders" needs improvement. As a step in this direction, weather records have been analyzed and two series of maps have been made that relate the relative humidity within a building to the vapor pressure gradients across the building envelope. Each map in the first series is for a specific ratio of cold weather wetting potential to warm weather drying potential. Each map in the second series is for a specific cold weather wetting potential.

To determine which map in each series is most appropriate to use as design criteria, we are requesting guidance from the building profession. Individuals that read this paper and have experience with moisture in building envelopes are encouraged to provide us with their observations and recommendations on this issue.

INTRODUCTION

Most building envelopes do not experience condensation problems but some do. For many years the primary defense against condensation within a building envelope has been the installation of a vapor barrier on the warm side and ventilation of the cold side. This places the vapor barrier on the inside of most buildings in the USA. Because vapor control measures slow down but do not stop the diffusion of vapor, there is a trend in the USA to acknowledge this by calling them "vapor retarders" instead of "vapor barriers." It is also recognized that exfiltration of moist building air into and through the building envelope is the primary cause of condensation problems (Hutcheon and Handegord 1983). In most cases, diffusion of vapor through the components of the building envelope is usually a minor issue. To emphasize the importance of controlling air movement in building envelopes, Canadians often use the term "air-vapour barrier" (Eyre and Jennings 1984). We have combined the current U.S. and Canadian terms and henceforth will call them "air-vapor retarders."

For those building envelopes where air leakage is a major issue (e.g., wood-frame construction with batts of fibrous glass insulation) the forces that promote vapor flow (i.e., differences in indoor and outdoor vapor pressure) only indirectly address the key problem of air leakage. Wind effects, chimney drafts, and mechanical ventilation pressures are more important considerations. However, for some components of building envelopes such as compact membrane roofing systems (Figure 1), air leakage can be minimal (Tobiasson 1985). In such systems, indoor-outdoor vapor pressure differences are a good basis for developing design guidelines on condensation control.

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Compact membrane roofing systems suffer from few direct condensation problems, but they suffer from numerous moisture problems generated by flaws in their waterproofing membranes. When flaws occur and an air-vapor retarder is present below, large "cancers" of wet insulation can grow undetected within the roof. By eliminating air-vapor retarders from sucn roofs wherever possible, the wet "cancer" problem can be reduced. This was the incentive for this work. Our objective was to develop better condensation control criteria for compact membrane roofs that will result in use of air-vapor retarders only where they have a net beneficial effect.

Current calculations, maps, and other guidelines for designing building envelopes against condensation are based on quantifying the diffusion characteristics of the envelope (ASHRAE 1981). Guidelines on when and where to use vapor retarders have been summarized by Achenbach and Trechsel (1982). The two primary issues are the climate of the place where the building is located and the amount of moisture in the air within the building.

ASHRAE (1982) contains general information on the relative humidity of various types of buildings, but additional information is needed on the actual relative humidity within buildings used for various purposes in various locations.

Various maps of the USA are available that base the need for vapor control measures on average January air temperatures of 35 F (1.7°C) (Anderson and Sherwood 1974) and 40 F (4.4°C) (NRCA 1985) and on winter design temperatures of +20 F (-6.7°C), 0 F (-17.8°C) and -20 F (-28.9°C) (ASHRAE 1981). Figure 2 shows where air-vapor retarders are needed on the basis of a mean average January temperature below 40 F (4.4°C). The National Roofing Contractors Association (1985) recommends the use of a 1-perm (57 PERM) or tighter air-vapor retarder in roofs in the shaded area of Figure 2 whenever the relative humidity within the building in winter is 45% or more.

While the Figure 2 map is a valuable design guide, it provides no information on the variation in vapor drive within the shaded area. It is obvious that the potential for condensation problems in a building located just north of the southern boundary of the shaded area is far less than the potential in a similar building located in the northern tier of states. One of our goals was to develop a map or maps that reflect an appreciation for this issue and for the variation in indoor relative humidity among buildings. Numerous compact membrane roofing systems (Figure 1) have been built within the shaded area without air-vapor retarders. Those that have internal relative humidities (RH) in excess of 45% and have not incurred condensation problems are a living testimonial that the boundary is too far south for some such roofs. However, we also know that textile mills and other buildings with very high inside relative humidities need air-vapor retarders to prevent condensation problems even in the South. Thus it would be unwise to shift the region where air-vapor retarders are needed to a more northerly position by basing the map on a colder January air temperature.

WEATHER RECORDS

We have examined weather records to better relate the potential for condensation to the physical forces that cause it. For systems such as compact membrane roofs, where air leakage is minimal, these forces are caused by differences in indoor and outdoor vapor pressure, which vary greatly with season.

At 260 National Weather Service (NWS) and at 103 USAF Air Weather Service (AWS) locations in the 50 states, mean monthly outside air temperatures are available. The saturation vapor pressure for each month can be calculated from tables or equations in ASHRAE (1981). At the NWS stations, the average monthly relative humidity is also available. With this information, the average outside vapor pressure can be determined for each month. It is equal to the saturation vapor pressure times the relative humidity divided by 100. At the AWS locations, the average monthly outside vapor pressure is available directly.

Figure 3 shows the variation in the monthly outside air temperature, saturation vapor pressure, and average outside vapor pressure with time of year for Washington, DC. Since the outside air is used indoors, the indoor vapor pressure is equal to the outside vapor pressure as long as no sources of moisture or dehumidifiers are present within the building. When no moisture is added or removed indoors, there is no vapor drive across the building envelope, no potential for condensation problems, and thus no need for air-vapor retarders.

INDOOR MOISTURE

If moisture is added to maintain a certain desired relative humidity within the building, the indoor vapor pressure will increase above the outside vapor pressure. For example, the vapor pressure for room air at 68 F (20°C) with a relative humidity of 45% is shown as a horizontal line in Figure 3. Note that in the summer, the average outside vapor pressure rises above this line, and no humidification is needed to maintain a relative humidity of at least 45% within the building. In fact, if dehumidification is not provided, the indoor relative humidity will rise above 45% during the summer in Washington, DC, as fresh, but humid, outside air is brought indoors for ventilation purposes.

If the Washington building is humidified in winter to a relative humidity of 45%, the vapor drive then is from the warm moist indoor air to the colder, drier outside air. This drives moisture up into the roofing system. Since the membrane on top is essentially impermeable, moisture accumulates on its underside, causing the vapor pressure there to increase to the outside saturation vapor pressure. Thus the winter vapor drive is upward and its intensity is a function of the difference between the indoor vapor pressure and the saturation vapor pressure of the outside air (Baker 1980).

The two areas labeled "wetting" in Figure 3 represent the magnitude of the winter vapor drive for this example (i.e., a building in Washington with an indoor temperature of 68 F [20°C] and an indoor relative humidity of 45% - except in summer when it increases above 45%). In March it becomes warm enough in Washington for this roof to no longer be subjected to upward vapor drive (i.e., the indoor vapor pressure and outside saturation vapor pressure lines cross). Thereafter, the vapor drive is downward and the roof attempts to dry out downward into the building. The area in Figure 3 labeled "drying" represents the summer drying potential for this example.

Had the building been dehumidified to a relative humidity of 45% from late April to late October, much more drying potential would be present (i.e., the drying area would extend downward to the horizontal 68 F, 45% RH line).

In November, the potential for downward drying ceases and again upward vapor drive begins. For this example, the total wetting area is 0.30 in of Hg•month (1.01 kPa•month) and the drying area is 1.73 in of Hg•month (5.85 kPa•month). Here the potential for cold weather wetting is overpowered by the much larger potential for warm weather drying. Whatever moisture accumulates in the roof during cold weather should all be dried out in warmer weather. The ratio of the wetting area to the drying area (i.e., the wetting/drying ratio) is 0.2 for this example.

Figure 4 presents similar curves for a building in Washington that has a year-round indoor relative humidity of 75%. Here the wetting area of 1.35 in of Hg•month (4.56 kPa•month) exceeds the drying area of 1.27 in of Hg•month (4.29 kPa•month). The wetting/drying ratio is 1.1. Since the ratio is greater than 1.0, the roof will not completely dry out in warm weather.

RELOCATION TO A COLD REGION

Figure 5 presents similar curves for the above two examples relocated to Minneapolis, MN, where the cold weather wetting potential is greater and the warm weather drying potential is less. The wetting/drying ratio for the building with an indoor relative humidity of 45% is 0.9. That ratio for the building with a relative humidity of 75% is 3.7. Wetting and drying values for the four example buildings are summarized in Table 1. That information shows that both climate and indoor relative humidity greatly influence wetting and drying potentials.

SEASONAL WETTING VS PROGRESSIVE WETTING

Figure 6 shows long-term wetting and drying trends for the roofs of these four buildings. The vertical axis is not quantified since the amount of moisture that enters is not only a function of vapor pressures but also depends on the resistance of the system to entry of moisture. By assuming that these four example roofs are built the same, the resistance issue can be set aside in this discussion. The two buildings with an indoor relative humidity of 45% are subjected to seasonal wetting only. A little seasonal wetting occurs for the one in Washington and that moisture is removed rapidly in warmer weather. For a large portion of the year that roof is dry. The roof of the 45% RH Minneapolis building takes on much more moisture during cold weather and this moisture is just barely removed when the next wetting cycle begins. Some moisture is almost always present under that membrane.

The two 75% RH buildings are subjected to progressive wetting. The warm weather drying is not sufficient to dry out all the moisture that enters in cold weather. These roofs are always wet and they become wetter with time. Moisture accumulates in the Minneapolis roof much faster than it does in the Washington roof.

The information in Figures 3-6 and Table 1 is useful for developing an understanding of the dynamic nature of the wetting and drying of compact membrane roofing systems, but it tends to predict more serious wetting and less effective drying than may actually occur. This is because snow cover on a roof provides insulation, significantly reducing the rate of winter wetting, and sunlight that strikes the dark roof membrane warms it above the outdoor air temperature, greatly enhancing the roof's tendency to dry downward. Because of this, progressive wetting may not occur even when the wetting/drying ratio is 2 or more. We acknowledge that these simplistic wetting and drying tendencies must be "calibrated" to the real world before air-vapor retarder guidelines can be based on them. To accomplish this, we developed two series of maps. The first series is concerned with progressive wetting and the second series is concerned with seasonal wetting. The maps are based on analysis of mean monthly air temperatures and vapor pressures available at 363 locations across the USA.

PROGRESSIVE WETTING MAPS

The three maps in this series are presented together in Figure 7. Figure 7a shows indoor relative humidities at which the wetting/drying ratio equals 1.0. This map indicates that indoor relative humidities must exceed 80% in the "Deep South" to cause progressive wetting, but in the northern tier of states, progressive wetting is possible at indoor relative humidities of 40% or less. As stated above, sunlight that heats and snow cover that insulates a roof both reduce wetting and improve drying, thus it is likely that indoor relative humidities would have to be somewhat higher to cause progressive wetting.

The second and third progressive wetting maps (Figures 7b and 7c) show indoor relative humidities at wetting/drying ratios of 2.0 and 3.0 respectively. As the ratio on which the map is based increases, more moisture must be present within a building at any location to cause progressive wetting.

SEASONAL WETTING MAPS

The second series of maps is directed at the issue of seasonal wetting. The maps in Figures 8-11 are for wetting potentials of 0.2, 0.4, 0.6, and 0.8 in of Hg•month (0.67, 1.35, 2.03, and 2.70 kPa•month), respectively. Isolines on each map show the relative humidity at which 68 F (20°C) indoor air causes that level of seasonal wetting potential. For example, Figure 8 shows that a building in central Minnesota with an indoor relative humidity of 20% has the same seasonal wetting potential as a building in central Texas with an indoor relative humidity of 60%.

As the "allowable" level of seasonal wetting increases (i.e., by progressing from the Figure 8 map to the Figure 11 map), the relative humidity causing the mapped level of wetting potential also increases. If the mapped isolines are construed to mean the indoor relative humidity above which air-vapor retarders are required, then Figure 8 calls for more vapor retarders than does Figure 11. For example, in central Texas the maximum allowable relative humidity without an air-vapor retarder increases from 60% to 80% from Figure 8 to Figure 11 and in central Minnesota the maximum allowable relative humidity increases from 20% to about 40%.

Each map represents a consistent way of looking at seasonal wetting potential, but which map to use as a guideline for installing air-vapor retarders is a matter of judgment.

COMPARING MAPS

All things considered, we suggest use of the Figure 7b map as a guideline for when to expect progressive wetting, but our current objective is not to select a specific map but rather to present a series of maps for examination by others who collectively possess the "real world" experience needed to select the proper map.

Our experience also indicates that the Figure 8 seasonal wetting map calls for too many air-vapor retarders, since it calls for them in northern New England for buildings with relative humidities as low as 25%. We know of many compact roofs in this area that do not have air-vapor retarders and do not suffer condensation problems. We believe that the winter relative humidities of these buildings range between 25% and 35%. On the other hand, we know that condensation problems have developed when indoor relative humidities have been increased to between 45% and 50% to assure proper functioning of newly purchased computers. This points to Figure 10 (the 0.6 in of Hg•month [2.03 kPa•month] map) as an appropriate guideline for the use of air-vapor retarders.

We would like to refer to only one map for air-vapor guidelines rather than two maps. By comparing the two series of maps, it is evident that seasonal wetting is likely to be the controlling issue. For example, if Figure 10 (the 0.6 in of Hg•month [2.03 kPa•month] seasonal wetting map) and Figure 7b (the progressive wetting map with a wetting/drying ratio of 2) are selected to best represent "real world" conditions, the seasonal wetting map (Figure 10) controls (i.e., at any location it requires an air-vapor retarder at a lower indoor relative humidity than does the progressive wetting map [Figure 7b]. Thus, we expect that one map can be used alone to provide guidance that addresses both seasonal and progressive wetting.

Assuming the Figure 10 map is selected as a guideline, it is interesting to compare it to existing guidelines such as those in Figure 2. The new map seems better since it changes the Figure 2 guidelines to (1) require vapor retarders for buildings with very high relative humidities in the Deep South, (2) eliminate vapor retarders for many buildings in the central part of the U.S. unless they have relative humidities of 50% to 60%, and (3) require vapor retarders in the northern tier of states for some buildings with relative humidities below 45%.

CHANGES IN INDOOR TEMPERATURE

Our maps are based on an indoor temperature of 68 F (20°C). To use the maps for buildings with different indoor temperatures, first determine the relative humidity from the map, and then correct that value using Figure 12. For example, the Figure 10 map indicates that the indoor relative humidity at which a building in central Missouri requires an air-vapor retarder is 50%. If that building is a warehouse maintained at 55 F (13°C), Figure 12 indicates that it would require an air-vapor retarder only if its indoor relative humidity exceeds 80%. However, if it were an industrial building with an 80 F (27°C) indoor temperature, the maximum allowable indoor relative humidity without an air-vapor retarder would drop to 33%.

CONCLUSION

The need for an air-vapor retarder in building envelope components with minimal air leakage is related to the climate where the building is located and the indoor vapor pressure. That need increases in colder regions and where high humidities are maintained indoors. Two series of maps have been developed to better represent the potential for condensation problems and the need for air-vapor retarders. The maps are most appropriate for building envelope components where air leakage is minimal, but they are also an improvement over existing diffusion-based air-vapor retarder guidelines for any building envelope component.

One series of maps shows the potential for seasonal wetting and the other series shows the potential for progressive wetting. From our experience, it appears that seasonal wetting is the controlling issue, and thus guidelines can be based on a single seasonal wetting map. While our experience suggests that the seasonal wetting map based on a maximum cold weather wetting potential of 0.6 in of Hg•month (2.03 kPa•month) (i.e., Figure 10) may be best, our selection of that map is more to show how guidelines can be boiled down to a single map than to promote Figure 10.

We strongly solicit the views and experience of all readers on the issue of map selection. Obviously the more quantitative evidence provided to support a map choice, the better. All who forward their comments to us at CRREL, 72 Lyme Road, Hanover, NH 03755 will be periodically appraised of the information we are gathering on this issue. Perhaps within a year we will have enough information to recommend a map that is the consensus of the profession.

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TABLE 1

Summary of Wetting and Drying Values for the Four Example Buildings

	Washington, DC		Minneapolis, MN	
	45% RH	75% RH	45% RH	75% RH
Cold weather wetting potential in of Hg•month (kPa month)	0.30 (1.01)	1.35 (4.56)	0.98 (3.31)	2.43 (8.21)
Warm weather drying potential in of Hg•month (kPa•month)	1.73 (5.85)	1.27 (4.29)	1.12 (3.79)	0.65 (2.20)
Wetting/drying ratio	0.2	1.1	0.9	3.7

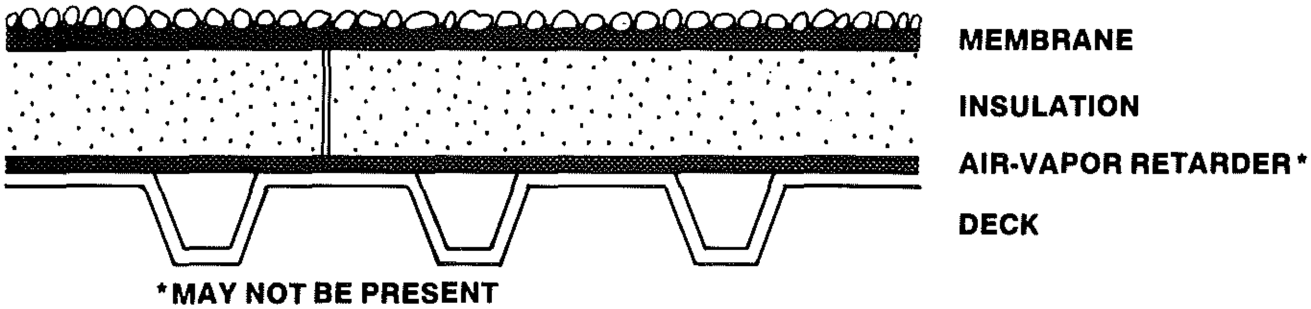


Figure 1. Compact membrane roofing system. This system has a minimal air leakage even without an air-vapor retarder

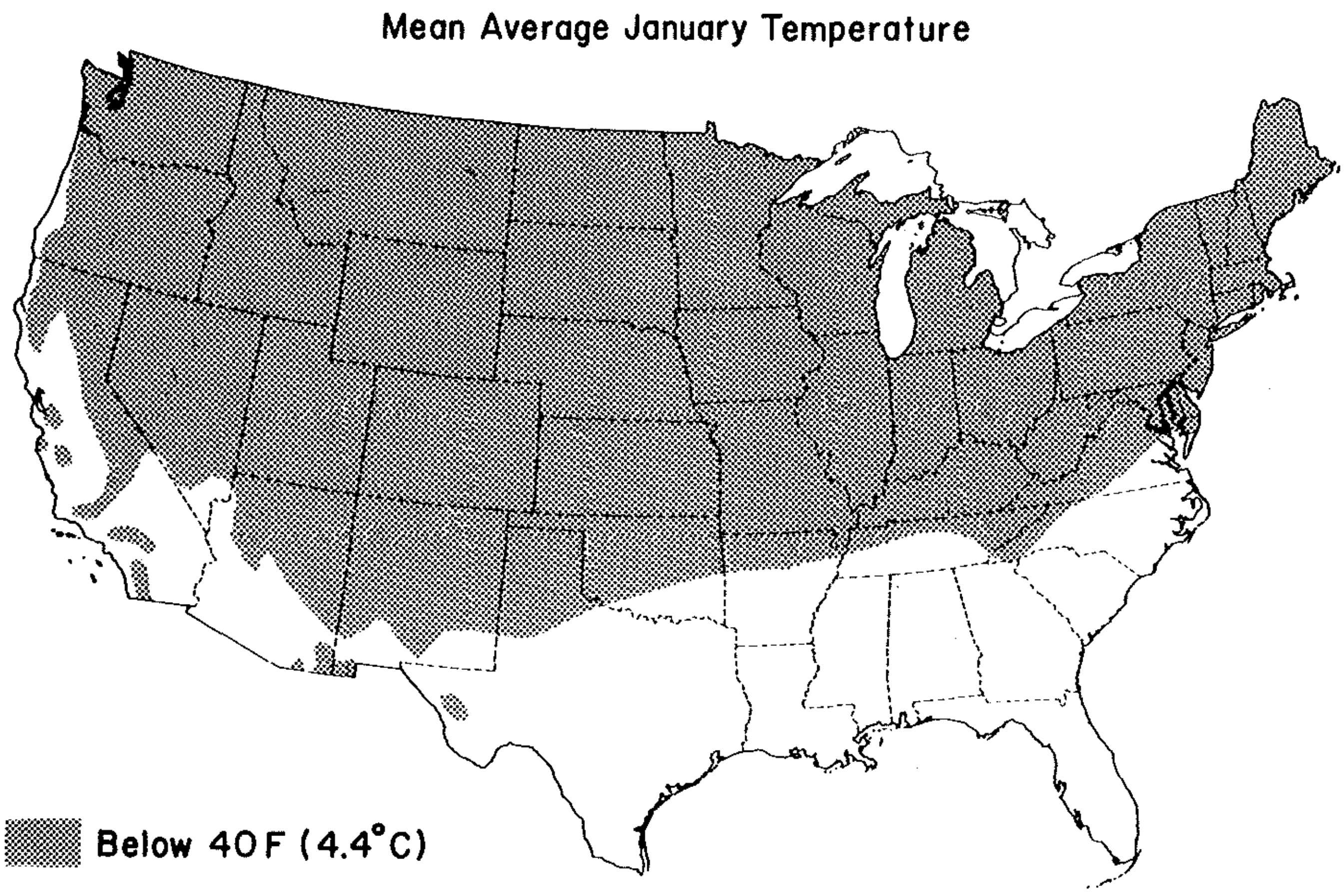


Figure 2. Large portion of the United States has a mean average January temperature below 40 F (4.4°C)

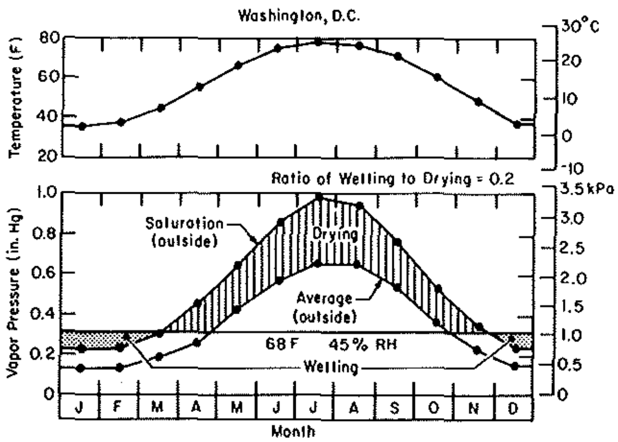


Figure 3. *Seasonal variations in outdoor air temperature and vapor pressure for Washington, D.C. create potentials for cold weather wetting and warm weather drying for a roof with the indoor relative humidity at 75%*

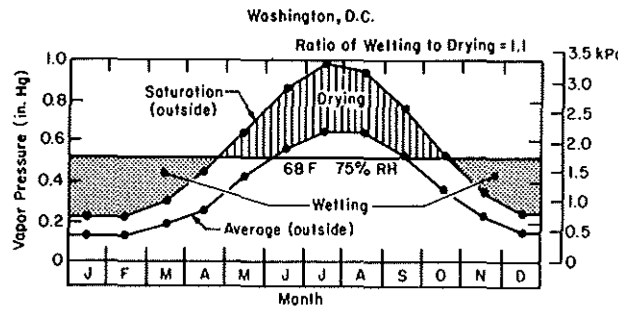


Figure 4. *Wetting and drying potentials for a roof in Washington, D.C., with the indoor relative humidity at 75%*

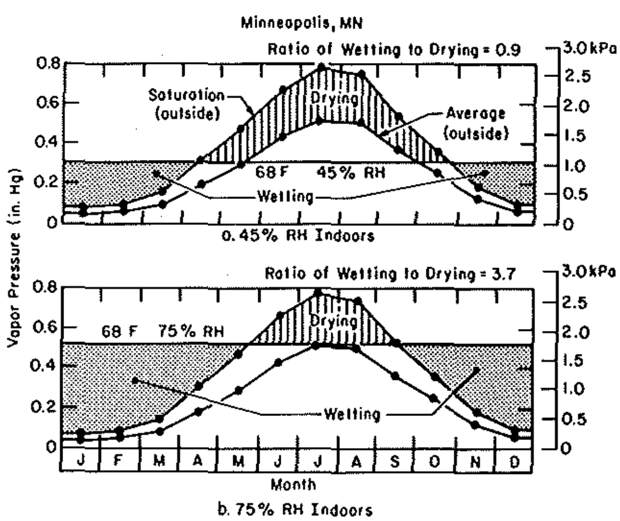


Figure 5. *Wetting and drying potentials for roofs in Minneapolis, MN, with indoor relative humidities at 45% and 75%*

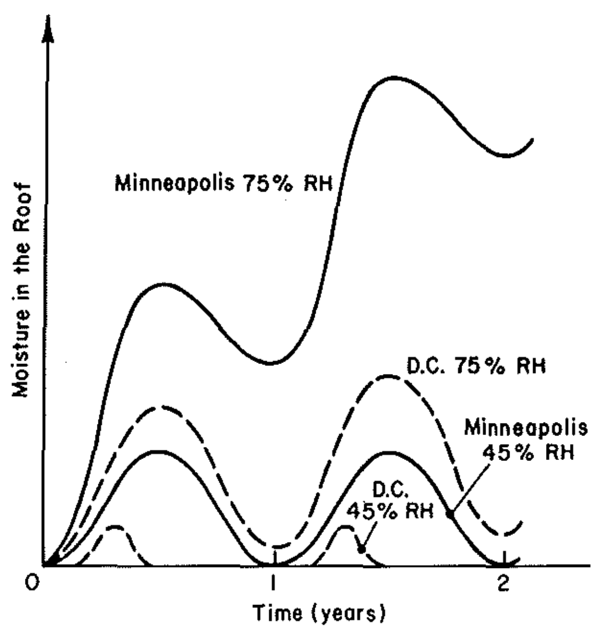
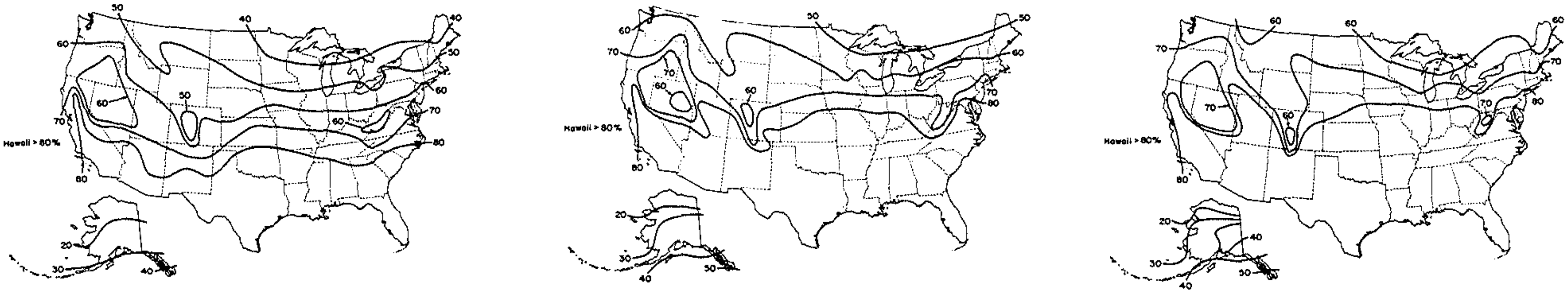


Figure 6. *Two humid-occupancy (75% RH indoors) roofs subjected to progressive wetting. The other two are subjected only to seasonal wetting.*



a. *Wetting/drying ratio = 1*

b. *Wetting/drying ratio = 2*

c. *Wetting/drying ratio = 3*

Figure 7. Indoor relative humidities at which progressive wetting is possible for wetting/drying ratios of 1, 2, and 3

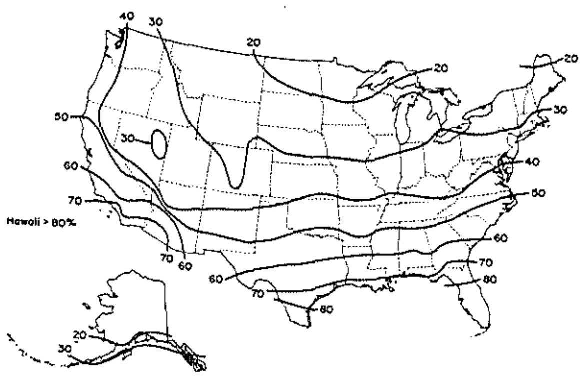


Figure 8. Indoor relative humidities at which the seasonal wetting potential equals 0.2 in of Hg•month (0.67 kPa•month)

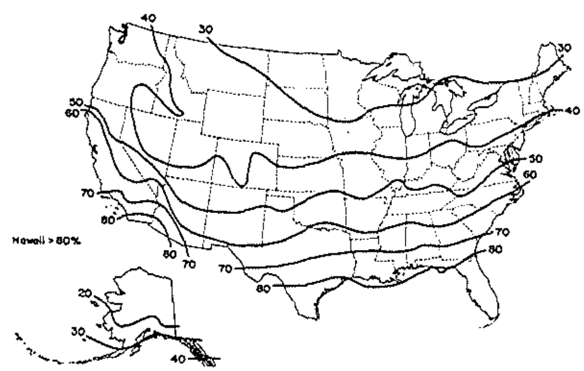


Figure 9. Indoor relative humidities at which the seasonal wetting potential equals 0.4 in of Hg•month (1.35 kPa•month)

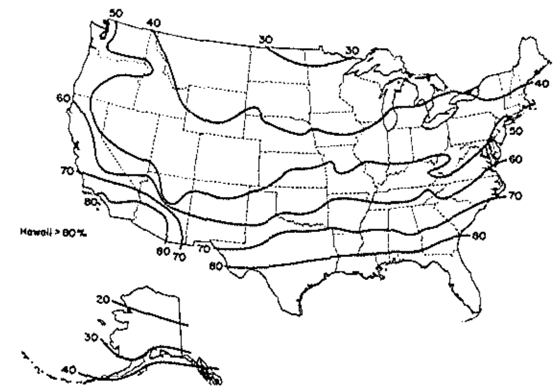


Figure 10. Indoor relative humidities at which the seasonal wetting potential equals 0.6 in of Hg•month (2.03 kPa•month)

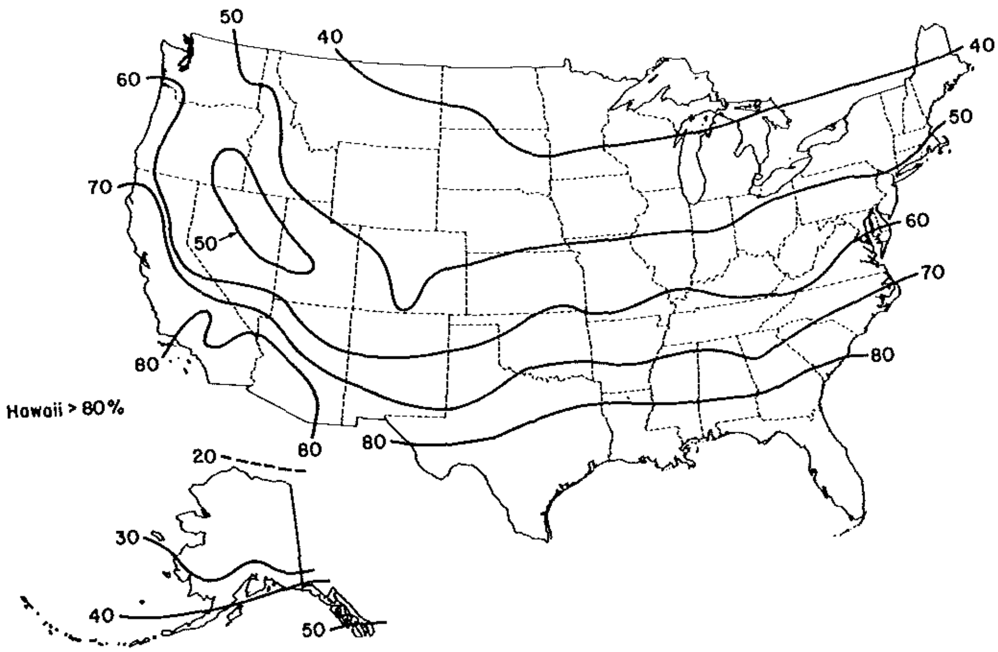


Figure 11. Indoor relative humidities at which the seasonal wetting potential equals 0.8 in of Hg•month (2.70 kPa•month)

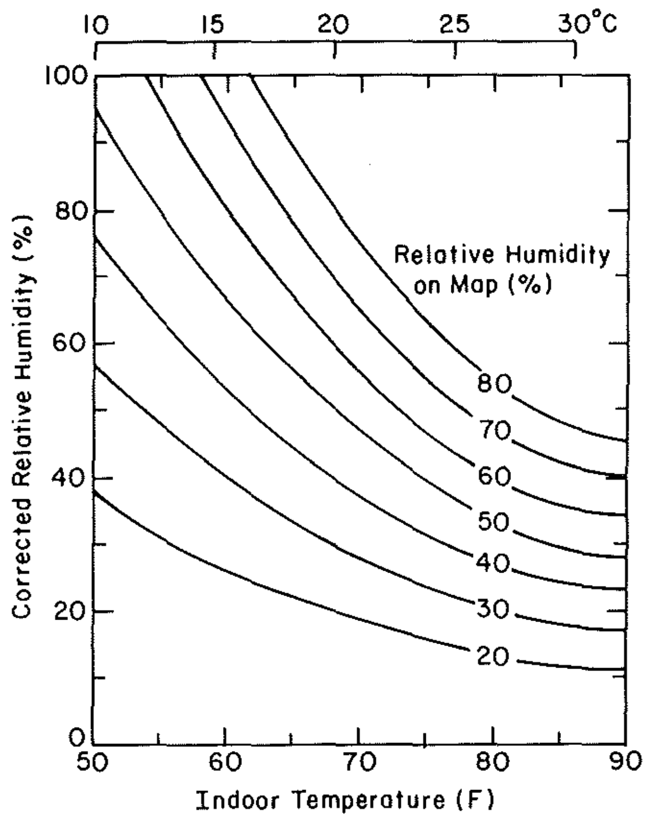


Figure 12. Graph for correcting mapped relative humidity for indoor air temperatures other than 68 F (20°C)