



Standard Practice for Selection of Vapor Retarders for Thermal Insulation¹

This standard is issued under the fixed designation C 755; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ϵ) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice outlines factors to be considered, describes design principles and procedures for vapor retarder selection, and defines water vapor transmission values appropriate for established criteria. It is intended for the guidance of design engineers in preparing vapor retarder application specifications for control of water vapor flow through thermal insulation. It covers commercial and residential building construction and industrial applications in the temperature range from -40 to $+80^\circ\text{F}$ (-40 to $+27^\circ\text{C}$) within the structure. Emphasis is placed on the control of moisture penetration by choice of the most suitable components of the system.

1.2 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*²

2. Referenced Documents

2.1 ASTM Standards:

D 828 Test Method for Tensile Properties of Paper and Paperboard Using Constant-Rate-of-Elongation Apparatus³

E 84 Test Method for Surface Burning Characteristics of Building Materials⁴

E 96 Test Methods for Water Vapor Transmission of Materials⁵

F 372 Test Method for Water Vapor Rate Transmission of Flexible Barrier Materials Using an Infrared Detection Technique³

2.2 TAPPI Standard:

T803, Puncture Test of Containerboard⁶

3. Terminology

3.1 Definitions:

3.1.1 *dew-point temperature (Dp), n*—the temperature at

which a specific atmosphere is saturated with water vapor. (Cooling below the dew point will cause release of water vapor in the form of condensation. In problem analysis for vapor barrier selection it is the dew-point temperature, not the relative humidity, that is pertinent. Dew-point temperature is directly related to saturation water vapor pressure and may be obtained from tables.)

3.1.2 *thermal insulation system, n*—thermal insulation for resistance to heat flow combined with means for attachment to the surface to be insulated, and with facings, vapor retarders, joint sealants, or protective coatings as installed.

3.1.3 *vapor retarders, n*—those materials or systems which adequately retard the transmission of water vapor under specified conditions. (For practical purposes it is assumed that the permeance of an adequate retarder will not exceed 1 perm, although at present this value may be adequate only for residential construction. For certain other types of construction the permeance must be very low.)

3.1.4 *water vapor diffusion, n*—the process by which water vapor spreads or moves through permeable materials caused by a difference in water vapor pressure.

3.1.5 *water vapor permeability (permeability), n*—the water vapor transmission of a homogeneous material under unit vapor pressure difference between two specific surfaces, per unit thickness. An acceptable unit of permeability is the perm-inch: grain-in./h-ft²-in. Hg (the metric perm-cm = 1 g-cm/24 h-m²-mm Hg).

3.1.6 *water vapor permeance (permeance), n*—the water vapor transmission of a material under unit vapor pressure difference between two specific surfaces. An acceptable unit of permeance is the perm: grain/h-ft² in. Hg (1 metric perm = 1 g/24 h-m² mm Hg).

3.1.7 *water vapor transmission (WVT), n*—the steady-state time rate of water vapor diffusion or flow through unit area of a material, normal to specific parallel surfaces under specific conditions of temperature and humidity at each surface. An acceptable unit of WVT is grain/h-ft² (1 g/24 h-m²).

4. Significance and Use

4.1 Experience has shown that uncontrolled water entry into thermal insulation is the most serious factor causing impaired performance. Water entry into an insulation system may be through diffusion of water vapor, air leakage carrying water vapor, and leakage of surface water. Application specifications for insulation systems that operate below ambient dew-point

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² Discontinued; see 1983 Annual Book of ASTM Standards, Vol 15.09.

³ Annual Book of ASTM Standards, Vol 15.09.

⁴ Annual Book of ASTM Standards, Vol 04.07.

⁵ Annual Book of ASTM Standards, Vol 04.06.

⁶ Available from TAPPI, P.O. Box 105113, Atlanta, GA 30348.

temperatures should include an adequate vapor barrier system. This may be separate and distinct from the insulation system or may be an integral part of it. For selection of adequate retarder systems to control vapor diffusion it is necessary to establish acceptable practices and standards.

4.2 Vapor Retarder Function—Water entry into an insulation system may be through diffusion of water vapor, air leakage carrying water vapor, and leakage of surface water. The primary function of a vapor retarder is to control movement of diffusing water vapor into or through a permeable insulation system. The vapor retarder system alone is seldom intended to prevent either entry of surface water or air leakage, but it may be considered as a second line of defense.

4.3 Vapor Retarder Performance—Design choice of retarders will be affected by thickness of retarder materials, substrate to which applied, the number of joints, available length and width of sheet materials, useful life of the system, and inspection procedures. Each of these factors will have an effect on the retarder system performance and each must be considered and evaluated by the designer.

4.3.1 Although this practice properly places major emphasis on selecting the best vapor retarders, it must be recognized that faulty installation techniques can impair vapor retarder performance. The effectiveness of installation or application techniques in obtaining design water vapor transmission (WVT) performance must be considered in the selection of retarder materials.

4.3.2 As an example of the evaluation required, it may be impractical to specify a lower “as installed” value, because difficulties of field application often will preclude “as installed” attainment of the inherent WVT values of the vapor retarder materials used. The designer could approach this requirement by selecting a membrane retarder material that has a lower permeance manufactured in 5-ft (1.5-m) width or a sheet material 20 ft (6.1 m) wide having a higher permeance. These alternatives may be approximately equivalent on an installed basis since the wider material has fewer seams and joints.

4.3.3 For another example, when selecting mastic or coating retarder materials, the choice of a product having a permeance value somewhat higher than the lowest obtainable might be justified on the basis of its easier application techniques, thus ensuring “as installed” system attainment of the specified permeance. The permeance of the substrate and its effects on the application of the retarder material must also be considered in this case.

5. Factors to Be Considered in Choosing Vapor Retarders

5.1 Water Vapor Pressure Difference is the difference in pressure of the water vapor content of the air on one side of the insulation system or insulated structure and the other side which provides the principal driving force causing water vapor diffusion. In general, for a given permeable structure, the greater the vapor pressure difference, the greater the rate of diffusion. Vapor pressure differences for specific conditions can be calculated from psychrometric tables showing thermodynamic properties of water at saturation.

5.1.1 Fig. 1 shows the variation of dew-point temperature with water vapor pressure.

5.1.2 Fig. 2 illustrates the magnitude of vapor pressure differences for four ambient air conditions and cold-side operating temperatures between + 40 and – 40°F (+ 4.4 and – 40°C). When it is considered that a permeance of 1 perm represents 1 grain of moisture per hour-ft²-in. Hg, one year adds up to 1.25 lb of water per square foot of surface area. A permeance of 0.1 perm represents 0.125 lb in one year. This order of permeance may also represent the “as installed” performance of a 0.01 perm retarder material or insulation system, because of the factors cited in 4.3.

5.1.3 At a stated temperature the water vapor pressure is proportional to relative humidity but at a stated relative humidity the vapor pressure is not proportional to temperature.

5.1.4 Design conditions in summer can be as high as 93°F (34°C), 63 % relative humidity, 78.4°F (26°C) dew point (Biloxi, Miss.) and in winter as low as – 35°F (–37°C), 67 % relative humidity, – 42°F (–41°C) dew point (International Falls, Minn.). These design conditions have vapor pressures of 0.9795 in. Hg (dew point 78.4°F) and 0.003 in. Hg (dew point – 42°F) (1 in. Hg = 25.4 mm Hg = 70.7 lb/ft² = 3386.4 N/m²). These values represent extremes but the magnitude of the range emphasizes the necessity to calculate rather than to estimate design data. The vapor pressure difference that will be developed across the wall of a – 10°F (–23°C) cold-storage facility located in the very severe summer conditions given above will be: 0.98 – 0.02 (vapor pressure at – 10°F, 90 % relative humidity) = 0.96 in. Hg or 67.9 lb/ft². In the continental United States the design dew point seldom exceeds 75°F (24°C) **(16)**.⁷

5.1.5 The expected vapor pressure difference is a very important factor that must be based on realistic design data (not estimated) to determine vapor retarder requirements.

5.2 Service Conditions—The direction and magnitude of water vapor flow are established by the range of ambient atmospheric and design service conditions. These conditions normally will cause vapor flow to be variable in magnitude, and either unidirectional or reversible.

5.2.1 Unidirectional flow exists where the water vapor pressure difference is constantly higher on one side of the system. With buildings operated for cold storage or frozen food storage the summer outdoor air conditions will usually determine vapor retarder requirements, with retarder placement on the outdoor (warmer) side of the insulation. In buildings for human occupancy the winter outdoor air conditions would require retarder placement on the indoor (warmer) side of the insulation.

5.2.2 Reversible flow can occur where the vapor pressure may be higher on either side of the system, changing usually because of seasonal variations. The inside temperature and vapor pressure of a refrigerated structure may be below the outside temperature and vapor pressure at times, and above the outside temperature and vapor pressure at other times. Cooler rooms with operating temperatures in the range from 35 to 45°F (2 to 7°C) at 90 % relative humidity and located in northern latitudes will experience an outward vapor flow in

⁷ The boldface numbers in parentheses refer to the list of references at the end of this practice.

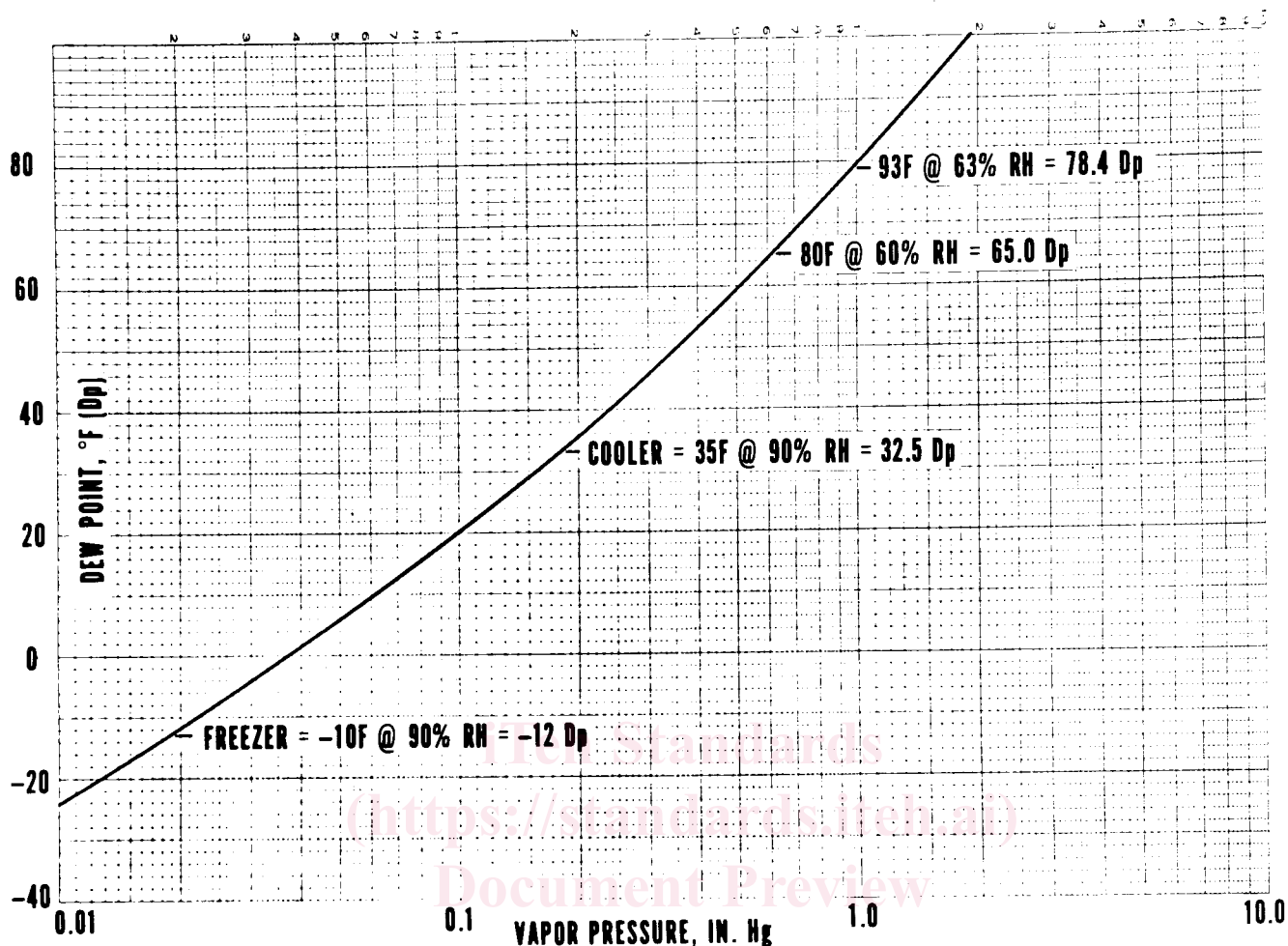


FIG. 1 Dew Point (Dp) Relation to Water Vapor Pressure

winter and an inward flow in summer. This reversing vapor flow requires special design consideration.

5.3 *Properties of Insulating Materials with Respect to Moisture*—Insulating materials permeable to water vapor will allow moisture to diffuse through at a rate defined by its permeance and exposure. The rate of movement is inversely proportional to the vapor flow resistance in the vapor path. Insulation having low permeability and vapor-tight joints may act as a vapor retarder. Water or ice in insulation joints that are parallel to the heat flow path provide higher conductance paths with consequent increased heat flow.

5.3.1 If condensation of water occurs within the insulation its thermal properties can be significantly affected where wetted. Liquid water resulting from condensation has a thermal conductivity some fifteen times greater than that of a typical low-temperature insulation. Ice conductivity is nearly four times that of water. Condensation reduces the thermal effectiveness of the insulation in the zone where it occurs, but if the zone is thin and perpendicular to the heat flow path, the reduction is not extreme. Generally, hygroscopic moisture in insulation can be disregarded.

5.3.2 Thermal insulation materials range in permeability from essentially 0 perm-in. to greater than 100 perm-in. Because insulation is supplied in pieces of various size and

thickness, vapor diffusion through joints must be considered in the permeance of the materials as applied. The effect of temperature changes on dimensions and other physical characteristics of all materials of the assembly must be considered as it relates to vapor flow into the joints and into the insulation.

5.4 *Properties of Boundary or Finish Materials at the Cold Side of Insulation*—When a vapor pressure gradient exists the lower vapor pressure value usually will be on the lower temperature side of the system, but not always. (There are few exceptions, but these must be considered as special cases.) The finish on the cold side of the insulation-enclosing refrigerated spaces should have high permeance relative to that of the warm side construction, so that water vapor penetrating the system can flow through the insulation system without condensing. This moisture should be free to move to the refrigerating surfaces where it is removed as condensate. When the cold side permeance is zero, as with insulated cold piping, water vapor that enters the insulation system usually will condense within the assembly and remain as an accumulation of water, frost, or ice.

5.5 *Effect of Air Leakage*—Water vapor can be transported readily as a component of air movement into and out of an air-permeable insulation system. This fact must be taken into account in the design and construction of any system in which

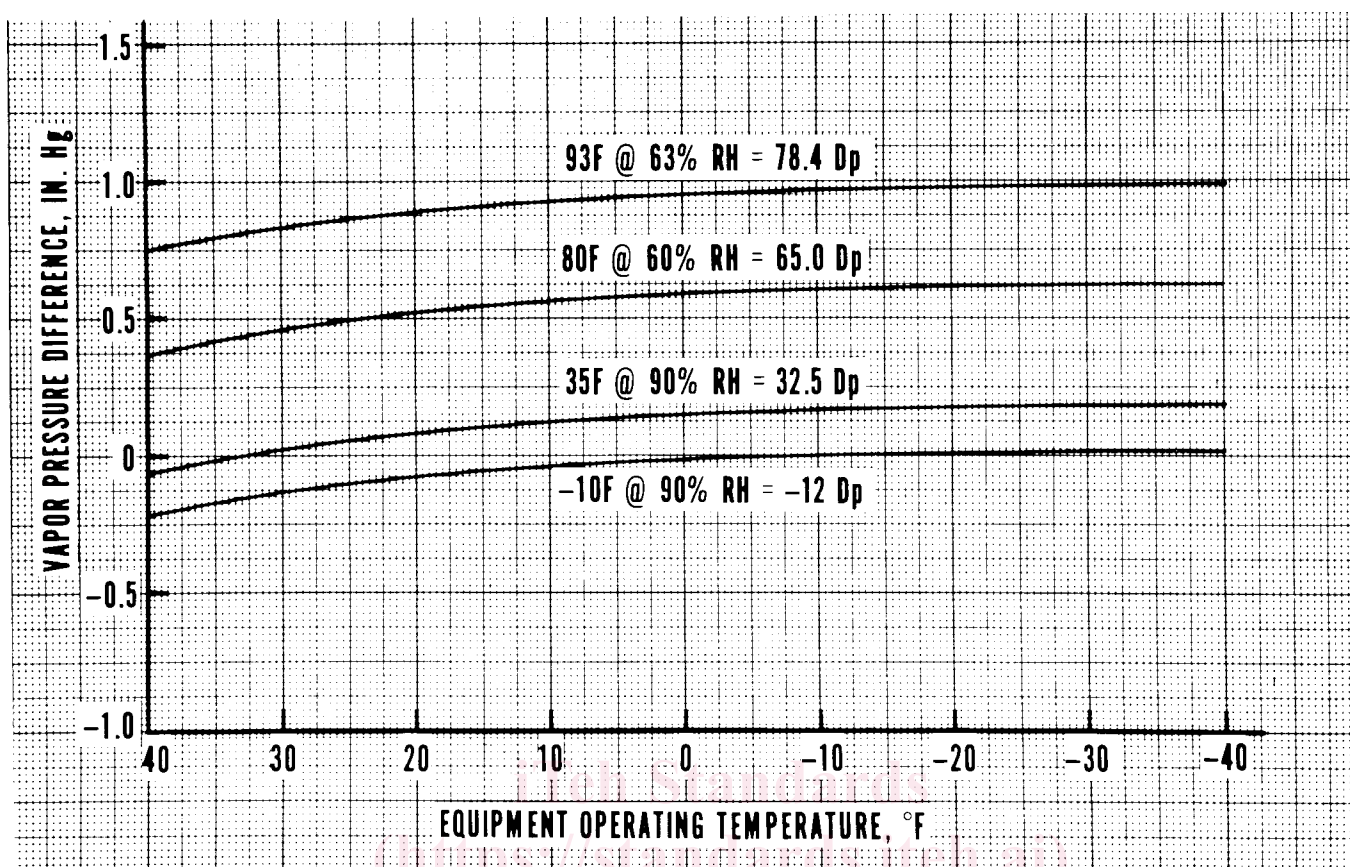


FIG. 2 Magnitude of Water Vapor Pressure Difference for Selected Conditions (Derived from Fig. 1)

moisture control is a requirement. The quantity of water vapor that can be transported by air leakage through cracks or air-permeable construction can easily be several times greater than that which occurs by vapor diffusion alone.

5.5.1 Air movement occurs as a result of air pressure differences. In insulated structures these may be due to wind action, buoyancy forces due to temperature difference between interconnected spaces, volume changes due to fluctuations in temperature and barometric pressure, and the operation of mechanical air supply or exhaust systems. Air leakage occurs through openings or through air-permeable construction across which the air pressure differences occur. Water vapor in air flowing from a warm humidified region to a colder zone in an insulation system will condense in the same way as water vapor moving only by diffusion.

5.5.2 If there is no opportunity for dilution with air at lower vapor pressure along the flow path, there will be no vapor pressure gradient. Condensation may occur when the air stream passes through a region in the insulation system where the temperature is equal to or lower than the dew point of the warm region of origin. The air flow may be from a warm region on one side of the system through to a cold region on the other side, or it may consist of recirculation between interconnected air spaces at different temperatures forming only a part of the system. Sufficient air flow rate could virtually eliminate the temperature gradient through the insulation.

5.5.3 When air flows from a cold region of low vapor pressure through the system to the warm side there will be a

drying effect along the flow path; the accompanying lowering of temperatures along the flow path, if significant, may be undesirable.

5.5.4 In any insulation system where there is a possibility of condensation due to air leakage, the designer should attempt to ensure that there is a continuous unbroken air barrier on the warm side of the insulation. Often this can be provided by the vapor retarder system, but sometimes it can best be provided by a separate element. Particular attention should be given to providing airtightness at discontinuities in the system, such as at intersections of walls, roofs and floors, at the boundaries of structural elements forming part of an enclosure, and around window and service openings. The insulation system should be designed so that it is practical to obtain a continuous air barrier under the conditions that will prevail on the job site, keeping in mind the problem of ensuring good workmanship.

5.5.5 Recirculation of air between spaces on the cold side of the insulation and a region of low vapor pressure (usually on the cold side of the insulation system) can be utilized advantageously to maintain continuity of vapor flow, whether due to diffusion or air leakage, and thus to avoid condensation. This will often be the only practical approach to the control of condensation and maintenance of dry conditions within the system. In thus venting the insulation system, whether by natural or mechanical means, care must be taken to avoid adverse thermal effects.

5.6 *Other Factors*—Other physical properties of retarder material, insulations, and structures that are not within the

scope of this practice may affect choice of barrier. These include such properties as combustibility, compatibility of system components, damage resistance, and surface roughness.

6. Design Principles of Vapor Control

6.1 *Flow-Through Design*—The flow-through principle is limited to essentially unidirectional vapor flow in installations where any water vapor that diffuses into the insulation system is permitted to pass through without significant accumulation. This concept is acceptable only:

- 6.1.1 Where vapor can escape beyond the cold side of the system, or
- 6.1.2 Where vapor cannot so escape it may continuously be purged out, or
- 6.1.3 Where provision is made to collect it as condensation and to remove it periodically.

6.2 *Moisture-Storage Design:*

6.2.1 Thus far the discussion has dealt with methods of avoiding any condensation. In many cases, however, some condensation can be tolerated, the amount depending on the water-holding capacity or water tolerance of a particular construction under particular conditions of use. The moisture-storage principle permits accumulation of water vapor in the insulation system but at a rate designed to prevent harmful effects. This concept is acceptable when:

- 6.2.1.1 Unidirectional vapor flow occurs, but during severe seasonal conditions, accumulations build up, which, in less severe (compensating seasonal) conditions are adequately expelled to the low vapor-pressure side.
- 6.2.1.2 Reverse-flow conditions regularly occur on a seasonal cycle and can occur on a diurnal cycle. Possible design solutions include:

- (a) Prevention of reverse flow by flushing the usually colder side with low dew-point air. This procedure requires a supply of conditioned air and means for its adequate distribution in passages.
- (b) Limitation of the magnitude of one reversed flow cycle to a level of accumulation that can be absorbed safely by system materials without insulation deficiency or damage. System design must enable the substantial removal of the vapor accumulation during the opposite cycle.
- (c) Use of an insulation system of such low permeability that an accumulation of vapor during periods of flow reversal is of little importance. Such a design must ensure that the

expulsion of the accumulation during the opposite cycle is adequate.

(d) Supplementation of design (c) by the use of selected vapor retarders at the boundaries of the insulation.

6.2.2 The moisture storage design practice is in widespread use throughout industry. However, a thorough understanding of a given system is necessary. The effect of moisture accumulation on thermal conductivity, frost action on wet materials, dimensional changes produced by changes in moisture content, and many other factors must be considered before this solution is adopted. References 8, 14, 15, and 16 contain information on results taken from in-use systems and studies on moisture accumulation in insulation products and systems under varied environmental conditions. A realistic design approach normally assumes there will be some moisture accumulation but desirably within controllable limits to do the job intended.

7. Vapor Retarder Materials

7.1 Vapor retarder materials should be water resistant, puncture resistant, abrasion resistant, tear resistant, fire resistant, noncorrosive, rot and mildew resistant, and of strong tensile strength, in addition to having low permeance.

7.2 *Types:*

7.2.1 Membrane retarders are non-loaded bearing, prefabricated laminated sheets, plastic films, or metal foils of low permeance. Table 1 indicates the relative importance of the stated physical property of a membrane for specific situations of use.

Puncture resistance, Beach units (see TAPPI Standard T 803):	
Low	15
Moderate	25
High	50
Fire resistance (see Test Method E 84):	
Maximum flame spread	25
Tensile strength, lb/in. width (see Test Method D 828):	
Low	15
Moderate	20
High	35

These retarders may be applied with adhesives or mechanical fasteners. Careful sealing of joints, holes and penetrations, and cuts made during application is required to attain vapor diffusion resistance.

7.2.2 *Mastic and Coating Retarders:*

7.2.2.1 Mastic and coating retarders are field-applied semi-liquid compositions of low permeance after curing, based on ingredients such as bitumens, resins or polymers, pigments,

TABLE 1 Desirable Properties for Membrane Retarders

NOTE 1—L = low, M = moderate, H = high, X = desirable.

Type	Puncture Resistance	Abrasion Resistance	Tear Resistance	Fire Resistant	Noncorrosive	Rot Resistant	Mildew Resistant	Tensile Strength	Remarks
Wall (residential)	L	L	L						
Underslab (residential and commercial)	H	H	L			X	X		
Roof deck	L	H	M						
Pipe insulation (over 32°F (0°C))	M	M	M	X	X			L	
Pipe insulation (under 32°F (0°C))	H	H	H	X	X			M	
Duct insulation	M	M	M	X	X			M	
Metal building insulation	M	M	M	X	X			M	
Cold storage (refrigeration)	H	H	H		X	X	X		nonshrinking

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fillers, and volatile solvent or water. They are intended for application by spraying, brushing, or troweling. The specified thickness must be applied, in one or more continuous coats, and suitable membrane reinforcement may also be required. The system must be adequately strong to resist cracking caused by substrate movement. Good workmanship in application is essential to attain design vapor diffusion resistance.

7.2.2.2 The permeance of mastics and coatings varies with varying dry thickness, and data showing this relationship for specific products are available from manufacturers. Comparison of permeance values for various mastics and coatings should not be based on wet thickness, but rather on dry thickness (after curing and evaporation of all volatile ingredients).

7.2.3 Structural retarders may be formed from rigid or semirigid materials of low permeability, which form a part of the structure. They include some insulation materials, as well as prefabricated composite units comprising insulation and finish, and metal curtain walls. They require careful sealing of joints and seams.

7.3 Test Method and Values:

7.3.1 The latest issue of Test Methods E 96 is acceptable for determining water vapor transmission of materials.

7.3.1.1 This test method provides isothermal conditions for testing materials by the cup method. In the “dry cup” or desiccant method, relative humidity inside is approximately 0 %. In the “wet cup” or water method, the relative humidity inside is approximately 100 %. When evaluating WVT data it is preferable to use data obtained by the procedure in which the test conditions approximate the service conditions.

7.3.1.2 This test method does not permit measurement of WVT values under all conditions of temperature and moisture found in service. It does provide values that permit the selection of suitable barrier materials.

7.3.2 Test Method F 372 covers a rapid procedure for determining the rate of water vapor transmission of flexible retarder materials in film or sheet form. The test method is applicable to sheets and films up to 3 mm in thickness, consisting of single or multilayer synthetic or natural polymers and metal foils including coated materials.

7.3.2.1 A dry chamber is separated from a wet chamber of known temperature and humidity by the retarder material to be tested. The time for a given increase in water vapor concentration of the dry chamber is measured by monitoring the differential between two bands in the infrared spectral region,

one in which water molecules absorb and the other where they do not. This information is then used to calculate the water vapor movement through a known area of retarder material.

7.4 *Recommended Vapor Retarder Practices*—Two design principles of vapor control have been presented: flow-through and moisture storage. Both systems are used in general practice.

7.4.1 The intent of the flow-through principle is to eliminate all possibility of condensation within the insulation system; therefore, this system is used with insulation materials with higher permeability to prevent accumulation of moisture.

7.4.2 The moisture-storage principle allows some accumulation of moisture within the insulation system. This principle is used with lower permeability insulation systems because the rate of accumulation is small.

7.4.3 The rate and quantity of moisture accumulation in insulation used in a given end-use application is a function of the permeability of the insulation and the operating conditions of the application as well as being a function of the vapor retarder materials. Therefore, the vapor retarder requirements necessary to control moisture and ensure successful operation can deviate from indicated theory. A case in point is the practice of using higher permeance vapor retarder systems with lower permeability insulations, whereas the flow-through theory would indicate the opposite. This is where the moisture-storage theory comes into practice. From a practical standpoint, a lower permeability insulation collects and stores less water in case of moisture entry, and, therefore, a higher permeance vapor retarder is tolerable.

7.4.4 Table 2 is published to outline the general recommended vapor retarder practices presently advocated in various field applications by specifiers and manufacturers. In this table, the recommended permeance for vapor retarder systems is listed for two groups of insulations: those with permeabilities of 0.3 to 4.0 perm-in. and those greater than 4.0 perm-in. For insulations having permeabilities of less than 0.3 perm-in. where the joints and seams have a permeance equal to or less than that of the insulation, no separately applied vapor retarder is normally recommended except under severe service conditions.

7.4.5 These are general recommendations which should be used in conjunction with the design principles of this practice.

8. Problem Analysis and Vapor Retarder Selection

8.1 Building Construction:

TABLE 2 Recommended Maximum Permeance of Vapor Retarder Systems^A

Insulation Application	Group 1	Group 2
	Insulation Permeability 0.3 to 4.0 perm-in.	Insulation Permeability, Greater than 4.0 perm-in.
Vapor Retarder Permeance, perms ^A		
Wall (residential)	1.0	1.0
Underslab (residential and commercial)	1.0	0.4
Roof deck	1.0	0.4 ^B
Pipe and vessels (33 to 80°F (1 to 27°C))	1.0	0.3
Pipe and vessels (−40 to 32°F (−40 to 0°C))	0.05	0.02
Ducts	1.0	0.03 ^B
Metal buildings	0.1	0.3 ^B
Cold storage	0.1	0.1

^A Water vapor permeance of the vapor retarder system in perms when tested in accordance with Test Methods E 96.

^B Subject to climatic and service conditions.