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Standard Practice for Selection of Water Vapor Retarders for Thermal Insulation[1]

This standard is issued under the fixed designation C755; 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.

~~ε1 NOTE—Table 2 and Table X1.1 were editorially corrected in September 2015.~~

1. Scope

1.1 This practice outlines factors to be considered, describes design principles and procedures for water 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 service temperature range from −40 to +150°F (−40 to +66°C). Emphasis is placed on the control of moisture penetration by choice of the most suitable components of the system.

1.2 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.3 *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. Referenced Documents

2.1 *ASTM Standards:*[2]

C168 Terminology Relating to Thermal Insulation
C647 Guide to Properties and Tests of Mastics and Coating Finishes for Thermal Insulation
C921 Practice for Determining the Properties of Jacketing Materials for Thermal Insulation
C1136 Specification for Flexible, Low Permeance Vapor Retarders for Thermal Insulation
E96/E96M Test Methods for Water Vapor Transmission of Materials

3. Terminology

3.1 For definitions of terms used in this practice, refer to Terminology C168.

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 temperatures should include an adequate vapor retarder 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.

[1] This practice is under the jurisdiction of ASTM Committee C16 on Thermal Insulation and is the direct responsibility of Subcommittee C16.33 on Insulation Finishes and Moisture.

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[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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 Water Vapor Retarders

5.1 *Water Vapor Pressure Difference* is the difference in the pressure exerted on each side of an insulation system or insulated structure that is due to the temperature and moisture content of the air on each side of the insulated system or structure. This pressure difference determines the direction and magnitude of the driving force for the diffusion of the water vapor through the insulated system or structure. In general, for a given permeable structure, the greater the water vapor pressure difference, the greater the rate of diffusion. Water vapor pressure differences for specific conditions can be calculated by numerical methods or 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 water vapor pressure differences for four ambient air conditions and cold-side operating temperatures between +40 and −40°F (+4.4 and −40°C).

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.

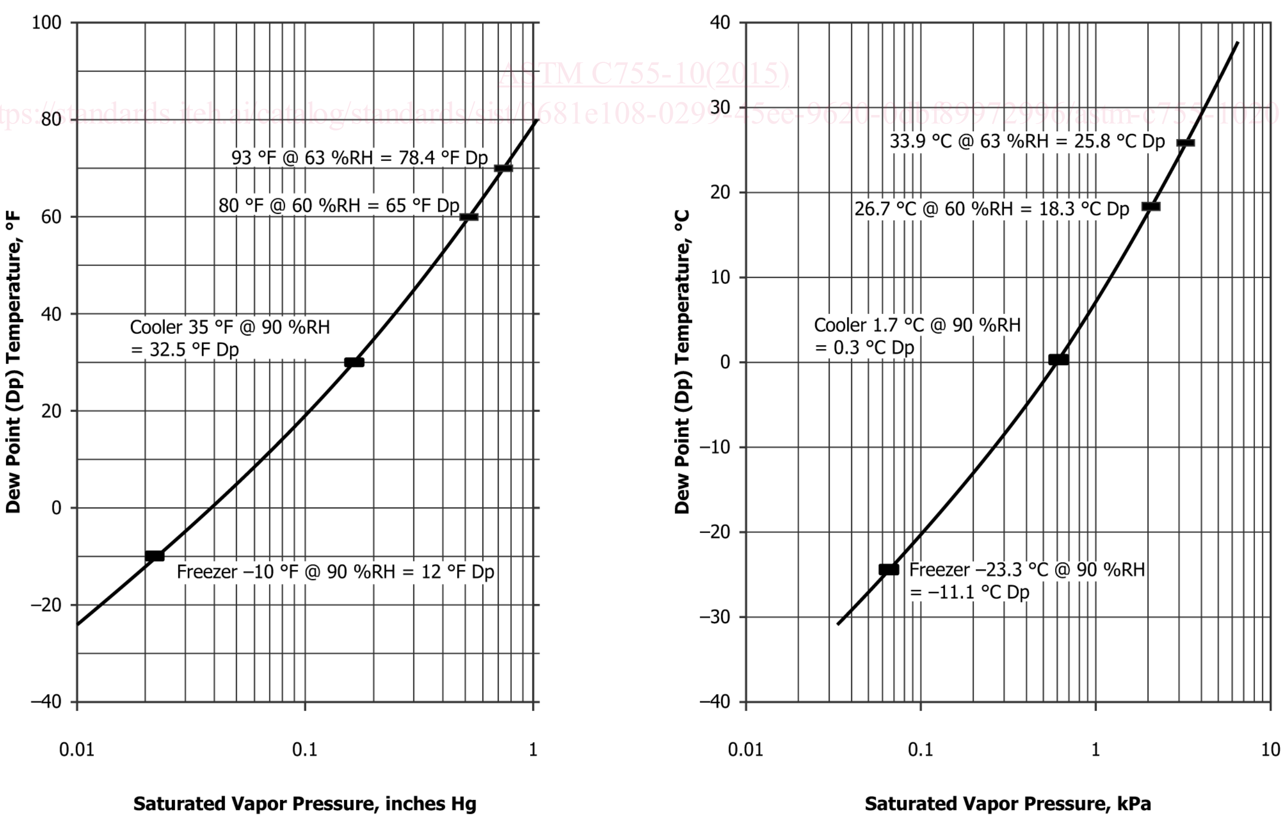

FIG. 1 Dew Point (Dp) Relation to Water Vapor Pressure

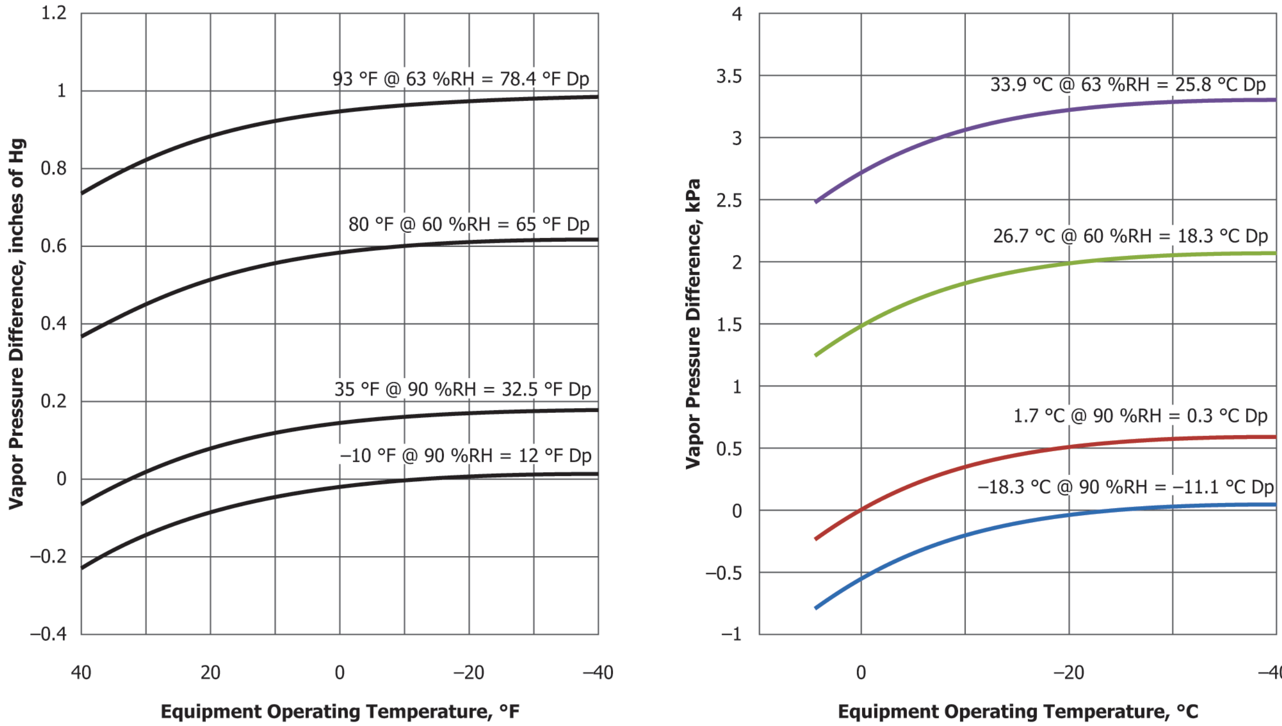

FIG. 2 Magnitude of Water Vapor Pressure Difference for Selected Conditions (Derived from Fig. 1)

5.1.4 Outdoor design conditions vary greatly depending upon geographic location and season and can have a substantial impact on system design requirements. It is therefore necessary to calculate the actual conditions rather than rely on estimates. As an example, consider the cold-storage application shown in Table 1. The water vapor pressure difference for the facility located in Biloxi, MS is 0.96 in. Hg (3.25 kPa) as compared to a 0.001 in. Hg (3 Pa) pressure difference if the facility was located in International Falls, MN. In the United States the design dew point temperature seldom exceeds 75°F (24°C) (**1**).[3]

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.

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

TABLE 1 Cold Storage Example

Location Season	Biloxi, MS Summer	International Falls, MN Winter
Outside Design Conditions		
Temperature , °F (°C)	93 (34)	-35 (-37)
Relative Humidity, %	63	67
Dew Point Temperature, °F (°C)	78.4 (26)	-42 (-41)
Water Vapor Pressure in. Hg (kPa)	.9795 (3.32)	.003 (0.01)
Inside Design Conditions		
Temperature, °F (°C)	-10	-10
Relative Humidity, %	90	90
Water Vapor Pressure in. Hg (kPa)	.02	.02
System Design Conditions		
Water Vapor Pressure Difference in. Hg (kPa)	0.9795	0.001 (0.067)
Direction of Diffusion	From outside	From inside

5.2.1 Unidirectional flow exists where the water vapor pressure 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 heating only buildings for human occupancy, the winter outdoor air conditions would require retarder placement on the indoor (warmer) side of the insulation. In cooling only buildings for human occupancy (that is, tropic and subtropic locations), the summer outside air conditions would require retarder placement on the outdoor (warmer) side.

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 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 permeance and vapor-tight joints may act as a vapor retarder.

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. Water or ice in insulation joints that are parallel to the heat flow path provide higher conductance paths with consequent increased heat flow. Generally, hygroscopic moisture in insulation can be disregarded.

5.3.2 Thermal insulation materials range in permeability from essentially 0 perm-in. (0 g/Pa-s-m) to greater than 100 perm-in. (1.45×10^{-7} g/Pa-s-m) 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 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 airflow 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 airflow 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. Fundamental Design Principles of Vapor Control

6.1 *Moisture Blocking Design*—The moisture blocking principle is applied in a design wherein the passage of water vapor into the insulation is eliminated or minimized to an insignificant level. In such a design, unless a totally impermeable vapor retarding system can be provided, condensation will occur in the system eventually, probably limiting service life. It is applicable in cases of predominantly or exclusively unidirectional vapor flow. The design must incorporate the following:

6.1.1 A vapor retarder with suitably low permeance.

6.1.2 A joint and seam sealing system which maintains vapor retarding system integrity.

6.1.3 Accommodation for future damage repair, joint and seam resealing, and reclosing after maintenance.

6.2 *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:

6.2.1 Where vapor can escape beyond the cold side of the system, or

6.2.2 Where vapor cannot so escape it may continuously be purged out, or

6.2.3 Where provision is made to collect it as condensation and to remove it periodically.

6.3 *Moisture-Storage Design:*

6.3.1 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:

6.3.1.1 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.

6.3.1.2 Reverse-flow conditions regularly occur on a seasonal cycle and can occur on a diurnal cycle. Possible design solutions include:

(1) 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.

(2) 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.

(3) 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.

(4) Supplementation of design (*3*) by the use of selected vapor retarders at the boundaries of the insulation.

6.3.2 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 (**1**, **2**, **3**) and (**4**) 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-structural laminated sheets, plastic films, or metal foils of low permeance. See ~~Specifications~~Specification C1136 or Practice C921 for required physical properties. The vapor retarders may be applied with adhesives or mechanical fasteners. All joints, penetrations, holes and cuts, or any other discontinuities in the vapor retarder must be sealed to maintain system integrity. Proper sealants, methods, and workmanship must be employed to insure overall design vapor resistance of the installed system.

7.2.2 *Mastic and Coating Retarders:*

7.2.2.1 Mastic and coating retarders are field-applied semiliquid compositions of low permeance after curing. 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 resist cracking caused by substrate movement. Good workmanship during application is essential to attain design vapor diffusion resistance. See Guide C647 for properties of mastics and coatings.

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.

7.2.4 Caulks and mastics are the typical sealants used in conjunction with vapor retarder materials. Pressure sensitive tapes are also employed as a sealing method. Consideration must be given in the selection of the product most appropriate to the specific application, including installation, ambient, and system operating conditions. Manufacturers' recommendations for proper application must be followed.

7.3 *Test Method and Values:*

7.3.1 Test Methods E96/E96M 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" method, Procedure A (desiccant method), relative humidity inside is approximately 0 % and approximately 50 % on the outside. In the "wet cup" method or water method, the relative humidity inside is approximately 100 % and usually 50 % on the outside. 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.

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

7.4.1 The moisture blocking principle eliminates or minimizes the passage of water vapor into the insulation, utilizing a virtually impermeable vapor retarding system. It is generally used in unidirectional vapor flow.

7.4.2 The intent of the flow-through principle is to eliminate condensation within the insulation system to continuously periodically purge condensation from the insulation system; therefore, this system is used with insulation materials with higher permeability to prevent accumulation of moisture.

7.4.3 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.

7.4.4 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.

7.4.5 Table 2 outlines the general recommended vapor retarder practices presently advocated in various field applications by

TABLE 2 Recommended Maximum Permeance of Water Vapor Retarders for Blocking Design[A]

Insulation Application	Insulation Permeability Less than 4.0 perm-in.[B] (5.8×10^{-9} g/Pa-s-m)	Insulation Permeability, 4.0 or greater perm-in.[B] (5.8×10^{-9} g/Pa-s-m)
	Vapor Retarder Permeance, perms[A]	Vapor Retarder Permeance, perms1
Wall (residential)	1.0 (5.72×10^{-8})	1.0 (5.72×10^{-8})
Underslab (residential and commercial)	1.0 (5.72×10^{-8})	0.4 (2.29×10^{-8})
Roof deck	1.0 (5.72×10^{-8})	0.4[C] (2.29×10^{-8})
Pipe and vessels (33 to Ambient (1°C to Ambient))	0.05 (2.86×10^{-9})	0.05 (2.86×10^{-9})
Pipe and vessels (−40 to 32°F (−40 to 0°C))	0.02 (1.14×10^{-9})	0.02 (1.14×10^{-9})
Ducts (39°F and below (4°C and below))	1.0 (5.72×10^{-8})	0.03[C] (1.72×10^{-9})
Ducts (40°F to Ambient (4°C to Ambient))	0.02 (1.14×10^{-9})	0.02 (1.14×10^{-9})
~~Metal buildings~~	~~1.0 (5.72×10^{-8})†~~	~~1.0[C] (5.72×10^{-8})~~
Metal buildings	1.0 (5.72×10^{-8})	1.0[C] (5.72×10^{-8})
~~Cold storage~~	~~1.0 (5.72×10^{-8})†~~	~~0.1 (5.72×10^{-9})~~
Cold storage	1.0 (5.72×10^{-8})	0.1 (5.72×10^{-9})

[A] Water vapor permeance of the vapor retarder in perms when tested in accordance with Test Methods E96/E96M.

[B] Water vapor permeability of the insulation material when tested in accordance with Test Methods E96/E96M, Desiccant Method at 73.4°F (23°C) at 50 % RH.

[C] Subject to climatic and service conditions.

~~† Editorially corrected in September 2015.~~