Water vapor permeability measurement and significance of various corrections

Mukhopadhyaya, P.; Kumaran, M. K.; Lackey, J. C.; van Reenen, D.

Publisher's version / Version de l'éditeur:
https://doi.org/10.1520/JAI100621
Journal of ASTM International, 4, September 8, pp. 1-12, 2007-09-01

Water vapor transmission measurement and significance of corrections

NRCC-45589

Mukhopadhyaya, P.; Kumaran, K.; Lackey, J.; van Reenen, D.

A version of this document is published in / Une version de ce document se trouve dans:
Journal of ASTM International, v. 4, no. 8, Sept. 2007, pp. 1-12

Journal of ASTM International (JAI), Sept XXXX Vol XX, No. X
Paper ID:
Available online at: www.astm.org
Published XXXX

JOURNAL PAPER

Phalguni Mukhopadhyaya[1], Kumar Kumaran[2], John Lackey[3] and David van Reenen[3]

Water Vapor Transmission Measurement and Significance of Corrections

---

ABSTRACT: Water vapor transmission properties of building materials play an important role in the overall moisture management and durability of the exterior building envelopes. The cup method, as described in the ASTM Standard Test Methods for Water Vapor Transmission of Materials (E 96), is widely used in North America and other parts of the world for this purpose. Recently the latest ASTM standard (E 96/E 96M – 05) has started taking into account various corrections (e.g. buoyancy correction, correction for resistance due to still air and specimen surface, edge mask correction etc.) while analyzing the results obtained from the cup methods. This paper presents the results obtained from the laboratory tests carried out on more than fifty building materials. These results have been used to demonstrate the significance of various corrections on the measured water vapor permeability or permeance of various commonly used building materials or components. The results presented in this paper were discussed in the ASTM technical task group to underline the importance of various corrections for the calculation of water vapor transmission properties of various building materials.

KEYWORDS: Water vapor transmission, permeability, permeance, building materials, corrections.

Introduction

Water vapor transmission characteristic of a building material is the most significant moisture transport property that is looked upon for the assessment of moisture management capability of

---

[1] Research Officer, Institute for Research in Construction, NRC Canada, Ottawa, Ontario, Canada.
[2] Principal Research Officer, Institute for Research in Construction, NRC Canada, Ottawa, Ontario, Canada.
[3] Technical Officer, Institute for Research in Construction, NRC Canada, Ottawa, Ontario, Canada.

the building envelope systems. Simply put, a building envelope designer or engineer would not recommend or use a construction material without knowing the implications of its water vapor transmission characteristics on the overall moisture response of the building envelope. On many instances, one material is preferred over another based on its water vapor transmission properties [1]. In particular, for membrane and coating materials (e.g. vapor barrier, sheathing paper, latex coating etc.) the water vapor transmission characteristic is the single most important property that determines its utility and effectiveness from the moisture management point of view [2]. Hence, one cannot overemphasize the need to evaluate the water vapor transmission characteristics of building materials accurately by a standard test procedure.

Research Background

There are three terminologies that are commonly used to describe the water vapor transmission properties of building materials. These terminologies are: (1) water vapor transmission rate, (2) water vapor permeability, and (3) water vapor permeance (defined as the reciprocal of the water vapor resistance). As per the standard definitions described in the ASTM C 168, these terminologies are described in the following paragraphs:

Water Vapor Transmission Rate

The water vapor transmission rate is the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces, under specific conditions of temperature and humidity at each surface.

$$\text{Rate of Water Vapor Transmission (WVT)} = \frac{G}{tA} = \frac{(G/t)}{A} \qquad (1)$$

where:

G	=	Amount of water vapor flow, kg,
t	=	Time, s,
G/t	=	Slope of the straight line, g/s,
A	=	Test area (cup mouth area), m^2, and

Water Vapor Permeance

The water vapor permeance is the time rate of water vapor transmission through unit area of flat material or construction induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

$$\text{Water Vapor Permeance } (WVP) = \frac{WVT}{\Delta p} = \frac{WVT}{S\left(R_1 - R_2\right)} \qquad (2)$$

where:

Δp	=	Vapor pressure difference, mm Hg (1.333×10^2 Pa),
S	=	Saturation vapor pressure at test temperature, mm Hg (1.333×10^2 Pa),
R_1	=	Relative humidity at the source expressed as a fraction (the test chamber for desiccant method; in the dish for water method), and
R_2	=	Relative humidity at the vapor sink expressed as a fraction.

Water vapor resistance (Z) is the reciprocal of the water vapor permeance, (i.e. $Z=1/WVP$).

Water Vapor Permeability

The water vapor permeability is the time rate of water vapor transmission through unit area of flat material of unit thickness induced by unit vapor pressure difference between two specific surfaces, under specified temperature and humidity conditions.

It is to be mentioned here that water vapor permeability is a property of a material and water vapor permeance is a performance evaluation indicator/property of a component and not a property of a material. Mathematically, permeability is the arithmetic product of permeance and thickness.

$$\text{Water Vapor Permeability} = \text{Water Vapor Permeance} \times \text{Thickness} \qquad (3)$$

The units used to express the water vapor transmission properties of building materials depend on the trade and location. The conversion factors for commonly used units are given in Table 1.

The water vapor permeability is a function of relative humidity (*RH*) and temperature (*T*). The relationship between water vapor permeability and relative humidity is very well established [3,4,5]. For non-hygroscopic materials, water vapor permeability values show little or no change with the variation of relative humidity. However, for hygroscopic materials, the water vapor permeability of materials increases with the increase of relative humidity [6,7].

On the other hand, temperature dependency of water vapor permeability (WVP) has been of interest to researchers for quite some time [3,8,4,9,10]. However, the extent of this influence of temperature on the water vapor permeability is not well known for most building materials. Though in general it is found that the temperature effect on water vapor permeability is negligible [11] but there are research findings [12] that indicate an increase of water vapor permeability by 3 % per oC change (+ve) in temperature. Further investigation would be required to confirm these findings.

Table 1 - Metric Units and Conversion Factors [A, B]

Multiply	by	To Obtain (for the same test condition)
	WVT	
g/(h·m^2)	1.43	grains/(h·ft^2)
grains/(h·ft^2)	0.697	g/(h·m^2)
	Permeance	
g/(Pa·s·m^2)	1.75×10^7	1 Perm (inch-pound)
1 Perm (inch-pound)	5.72×10^{-8}	g/(Pa·s·m^2)
	Permeability	
g/(Pa·s·m)	6.88×10^8	1 Perm inch
1 Perm inch	1.45×10^{-9}	g/(Pa·s·m)

[A]These units are used in the construction trade. Other units may be used in other standards.

[B] For all calculations 1mm of Hg = 133.3 Pa.

Test Procedure

The water vapor transmission measurements are usually done under isothermal conditions. A test specimen of known area and thickness separates two environments that differ in relative humidity (RH). Then the rate of water vapor flow across the specimen, under steady-state conditions (with known RHs as constant boundary conditions), is gravimetrically determined.

In the Desiccant or Dry Cup Method the test specimen is sealed to the open mouth of a test dish containing a desiccant, and the assembly placed in a controlled atmosphere (Figure 1). Periodic weighings determine the rate of water vapor movement through the specimen into the desiccant.

In the Water or Wet Cup Method, the dish contains distilled water, and the weighings determine the rate of water vapor movement through the specimen from the water to the controlled atmosphere. The water vapor pressure difference is nominally the same in both methods except in the variation with extremes of humidity on opposite sides.

ASTM Standard E 96, Test Methods for Water Vapor Transmission of Materials, prescribes two specific cases of this procedure - a dry cup (desiccant) method that gives the permeance or permeability at a mean RH of 25 % and a wet cup (water) method that gives the permeance or permeability at a mean RH of 75 %. Various technical aspects, limitations of the test method, and procedures for analyses of the test data are available in published literatures [13, 14, 15, 6].

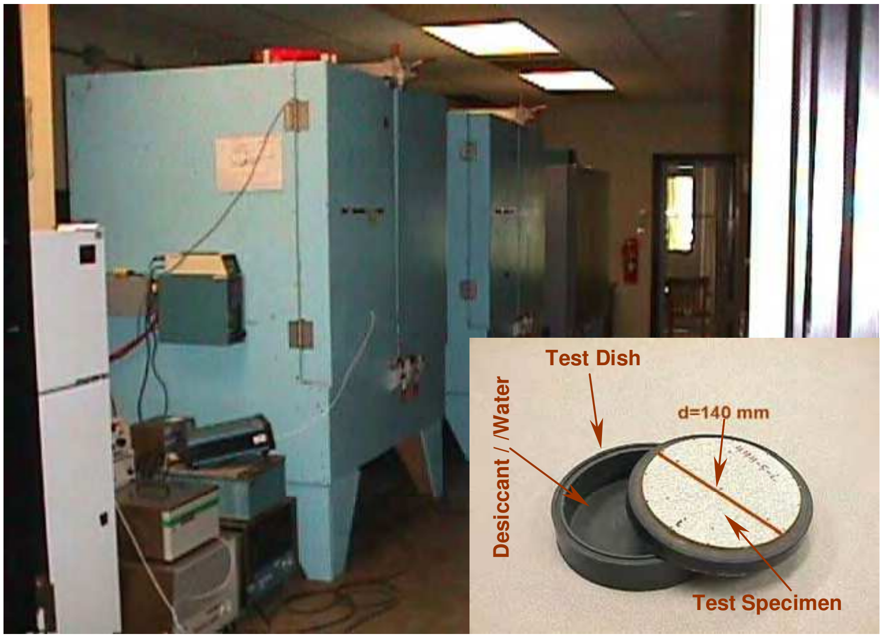

FIG. 1 – Test Chamber (Controlled Atmosphere) and Test Assembly

Corrections and Why?

Corrections are important because they reduce the uncertainty of the test results and generate more realistic/accurate water vapor transmission properties that would positively influence the design process for moisture management. It is important that all applicable corrections are made appropriately. The procedures for making various corrections, as summarized below, are found in the literature [16,17,18,14].

Buoyancy Correction

The duration for one set of measurements can be many days or weeks. The atmospheric pressure may significantly change during such periods. If the test specimen is highly water vapor resistant, the changes in mass due to water vapor transport may be overshadowed by the apparent gravimetric changes observed. In such cases, all gravimetric data should be corrected to vacuum or any base line pressure (e.g. pressure at first weighing). The following equation [16] can be used for buoyancy correction

$$\frac{m_2}{m_1} = 1 + \frac{\rho_a(\rho_1 - \rho_2)}{\rho_1(\rho_2 - \rho_a)} \quad (4)$$

where,

m_1 = Mass recorded by balance, kg

m_2 = Mass after buoyancy correction, kg

ρ_a = Density of air, kg m^{-3}

ρ_1 = Density of material of balance weights, kg m^{-3}

ρ_2 = Bulk density of test assembly, kg m^{-3}

The density of air can be calculated using the ideal gas law for the measured atmospheric pressure and ambient temperature. The buoyancy correction is important [15] when measured mass changes are in the range of 0 to 100 mg.

Corrections for Resistance due to Still Air and Specimen Surface

In general, if the material is highly permeable, these corrections are more significant. With known thickness of the still air layer in the cup, the corresponding water vapor resistance can be calculated using the following equation [17] for permeability.

$$\delta_a = \frac{2.306\text{x}10^{-5} P_o}{R_v TP}\left(\frac{T}{273.15}\right)^{1.81} \quad (5)$$

where,

δ_a = Permeability of still air, $kg\cdot m^{-1}\cdot s^{-1}\cdot Pa^{-1}$

T = Temperature, K

P = Ambient pressure, Pa

P_o = Standard atmospheric pressure, i.e. 101325 Pa and

R_v = Ideal gas constant for water, i.e. 461.5 $J\cdot K^{-1}\cdot kg^{-1}$.

In the absence of any measured data, the surface resistances (i.e. inside and outside surfaces of the specimen) may be approximated using Lewis' relation [18]. For cup methods that follow this Standard, the total surface resistance [14] should be ≈ 4 x 10^7 $Pa\cdot s\cdot m^2\cdot kg^{-1}$.

Edge Mask Correction

The following equation [9] is to be used to correct the excess water vapor transmission (WVT) effect due to edge masking:

$$\text{Percent excess WVT} = \frac{400t}{\pi S_1}\log_e\left(\frac{2}{1+e^{-(2\pi b/h)}}\right) \qquad (6)$$

where,

h = Specimen thickness, m

b = Width of masked edge, m

S_1 = Four times the test area divided by the perimeter, m

If the cup assembly includes any edge masking this correction shall be made.

Effects of Various Corrections

Over a period of last ten years or more, authors have measured water vapor transmission properties of numerous building materials commonly used in North America [19,20,21]. These materials included almost all the contemporary building materials used for the construction of exterior building envelopes (*Table 2*).

Table 2 – Materials in the database

1. Wood (pine, cedar, spruce etc.)	2. Stone (lime, sand, granite etc.)	3. Fiber cement board	4. Wall paper
5. Gypsum board (interior and exterior)	6. Polyurethane foam	7. Oriented strand board	8. Plywood
9. Brick (cementicious, clay etc.)	10. Cellulose fiber insulation.	11. Mortar	12.Polyisocyanurate foam insulation
13. Glass fiber insulation.	14. Vapour barrier.	15. Portland cement stucco.	16. Acrylic stucco.
17. Wood siding.	18. Vinyl siding.	19. Sheathing membrane or building paper.	20. Calcium silicate insulation.

The minimum thickness of the material specimen was 0.141 mm and the maximum thickness was not over 32 mm, as required by the ASTM E 96 standard, except highly porous glass fiber (88 mm) and cellulose fiber insulation (64.5 mm) materials. The water vapor transmission properties were determined according to the wet and dry cup methods at 23 ±1 °C temperature. The dry cup tests with desiccant method test setup but with variable chamber RH levels were carried out at three nominal chamber RH levels: 50 ± 1%, 70 ± 1% and 90 ± 1%, and wet cup measurements with water method test setup but with variable chamber RH were carried out at two nominal chamber RH levels: 70 ± 1% and 90 ± 1%. These tests were necessary to derive the functional relationship between RH and water vapor permeability. A detailed discussion on the principle and test data analysis techniques can be found in the relevant publication authored by [6]. Results from these tests were analyzed at first with the conventional method using equations

1 to 3, and then they were corrected appropriately using the steps outlined in equations 4 to 6. A sample calculation on the test data is shown in Appendix 1.

It is to be mentioned here that the water vapor transmission properties presented in this paper were measured, using high precision equipments, by the trained technical staffs. But this does not mean that the physical quantities measured are known within a few fractions of one percent. In addition, the basic inhomogeneity of all building products introduces uncertainties in the derived water vapor transmission properties that are far greater than the uncertainties in the measurements of the basic physical quantities. The magnitude of these uncertainties depends on the building products under investigation. A rigorous laboratory test data analysis indicates that water vapor transmission property for one test specimen can be determined well within a percent [22]. But when all measurements on all test specimens used are combined to designate the water vapor permeability or permeance of the product, the uncertainty may be as large as 30% [22].

The general effects of corrections on all water vapor permeability and permeance values are shown in Figures 2 and 3. These figures clearly quantify the differences between the permeance and permeability values after and before corrections. These corrections are always positive (i.e. higher values after corrections are applied) and the differences varied between 0.003% and 84%. The upper limit of these variations is certainly a significantly large number to adequately justify the importance of various corrections. In order to look further into the effects of various corrections, following paragraphs present the results obtained for two of the most common types of building materials: wood or wood based materials (i.e. wood, plywood, oriented strand board etc.), and membranes (i.e. sheathing membranes, building papers, vapor barrier, wall papers etc.). The water vapor permeance of the wood or wood based components normally stays within the relative range of high to moderate and the same for the membrane is considered to be in the lower range.

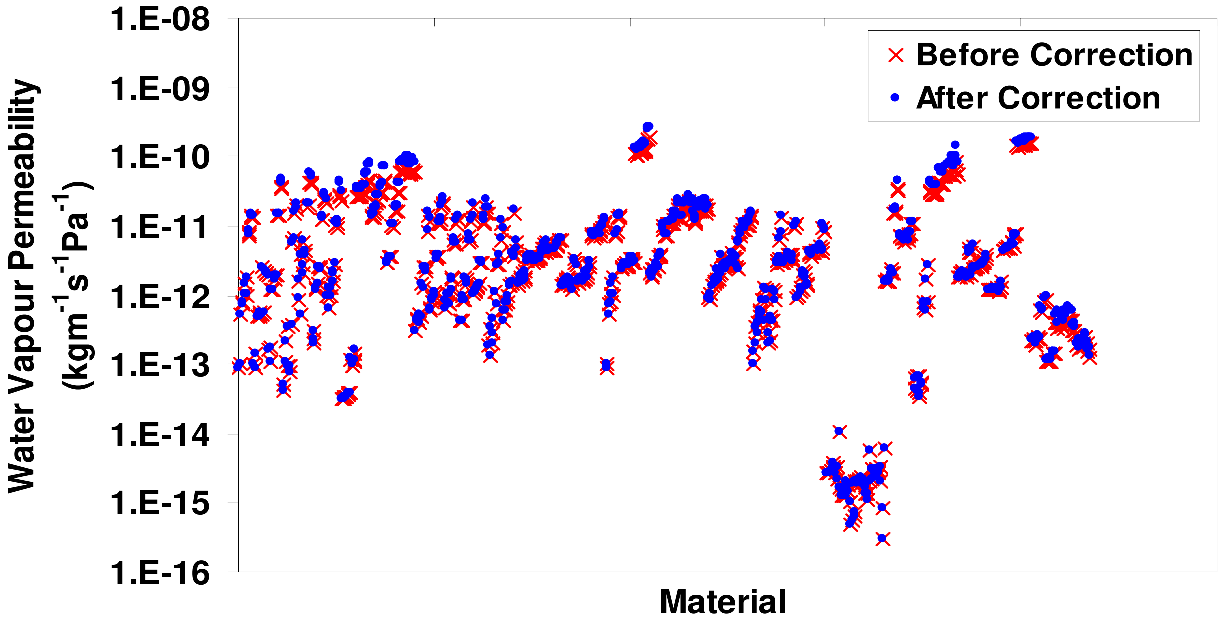

FIG. 2 – Water Vapor Permeability: Before and After Corrections

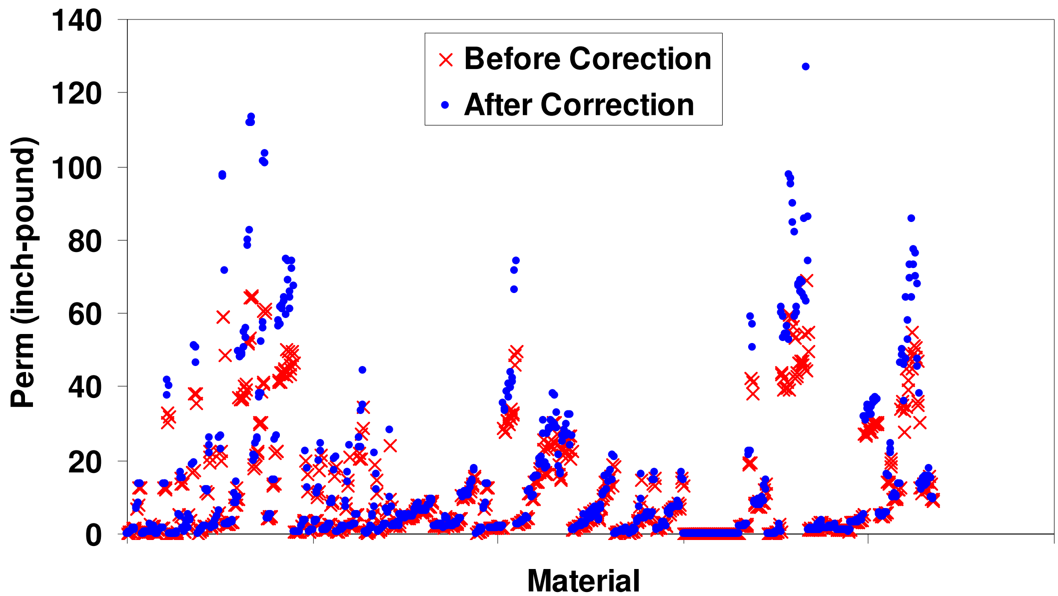

FIG. 3 – Water Vapor Permeance: Before and After Corrections

Correction Effects on Wood or Wood Based Materials

The water vapor permeability or permeance characteristic of wood or wood based materials is a very important parameter for the determination of its moisture management capability in a particular application. The water vapor permeance and permeability values of various woods (Pine, Cedar, Spruce etc.) and wood based building materials (OSB, Plywood etc.) are shown in Figures 4 and 5. The thickness of the materials under consideration varies between 9 and 20 mm. These plots clearly indicate that water vapor permeability and permeance values of the wood or wood based materials and components vary over a wide range. The permeance values varied between 0.08 and 38 perm (inch-pound) before correction and 0.08 and 51 perm (inch-pound) after correction. The maximum overall percentage change of the water vapor permeance values due to applied corrections is 34 percent. It also appears that the effect of corrections is larger, in terms of percentage difference, for higher water vapor permeability or permeance values.

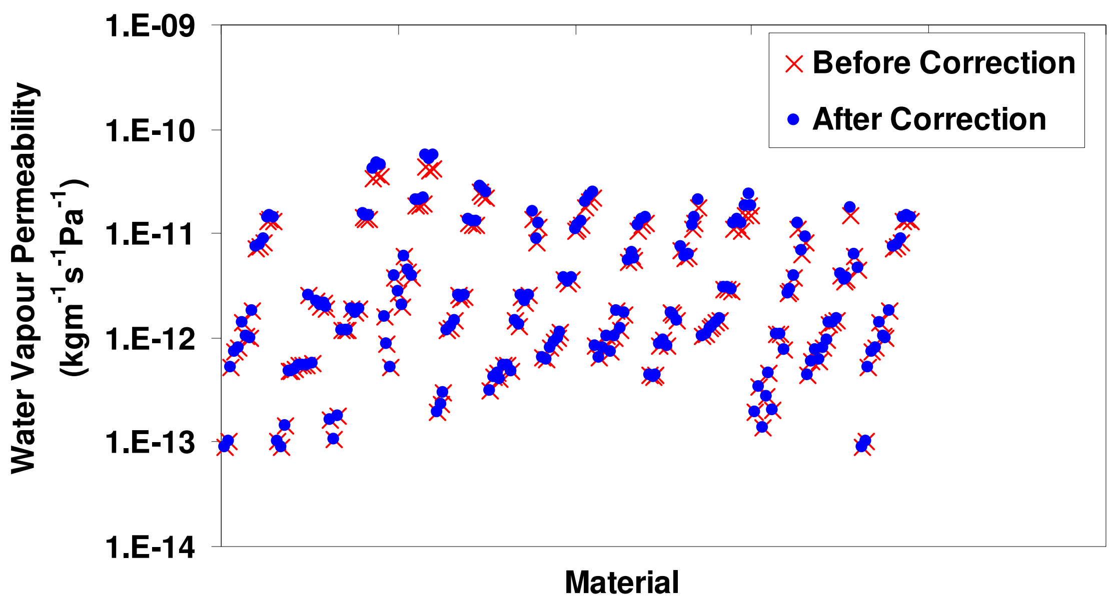

FIG. 4 – Water Vapor Permeability (Wood & Wood Based Materials): Before and After Corrections

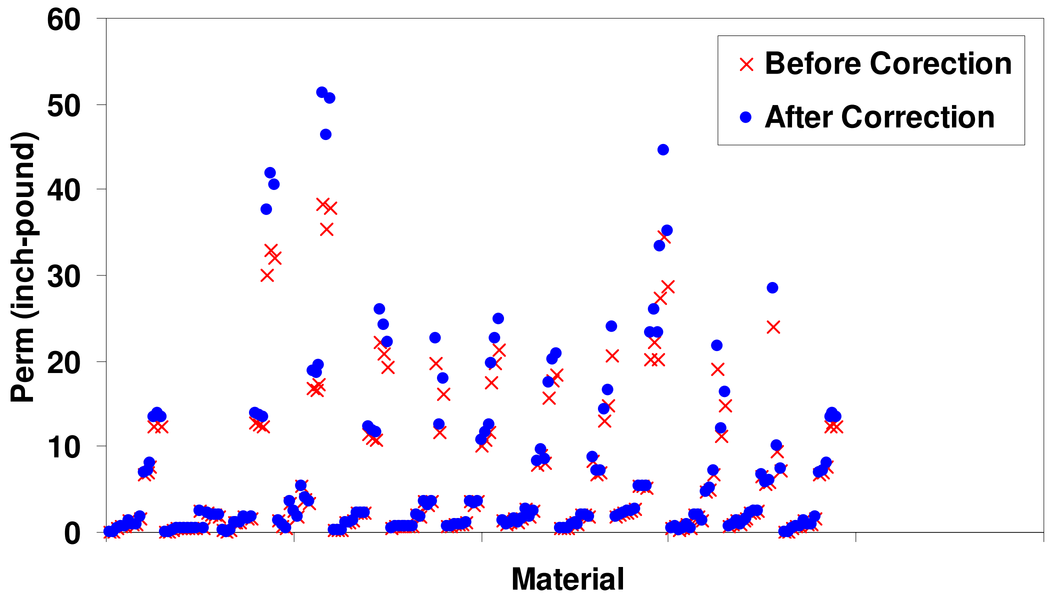

FIG. 5 – Water Vapor Permeance (Wood & Wood Based Materials): Before and After Corrections

Correction Effects on Membranes

As far as the moisture management is concerned, the water vapor permeability or permeance characteristic of the membranes is the most important criterion that determines its suitability for a particular application. The membranes under consideration here include paper based building papers, polymeric sheets, vinyl wall paper, felt paper, self adhering and torch applied membranes etc. The thickness of the membranes varies within the range 0.14 and 2.44 mm. The water vapor permeability values of these membranes vary considerably (Figure 6) and it can be clearly seen in Figures 6 and 7 that many of these membranes are highly impermeable (water vapor permeance less than 0.1 perm (inch-pound)). The overall water vapor permeance values vary between 0.004 and 55 perm (inch-pound) before correction, and 0.004 and 86 perm (inch-pound) after correction. The maximum effect of correction on the water vapor permeance value is found to be about 57 percent and minimum is 0.003 percent. Very much like wood or wood based materials or components, in this case also the percentage correction values are higher for the membranes with higher water vapor permeability or permeance values.

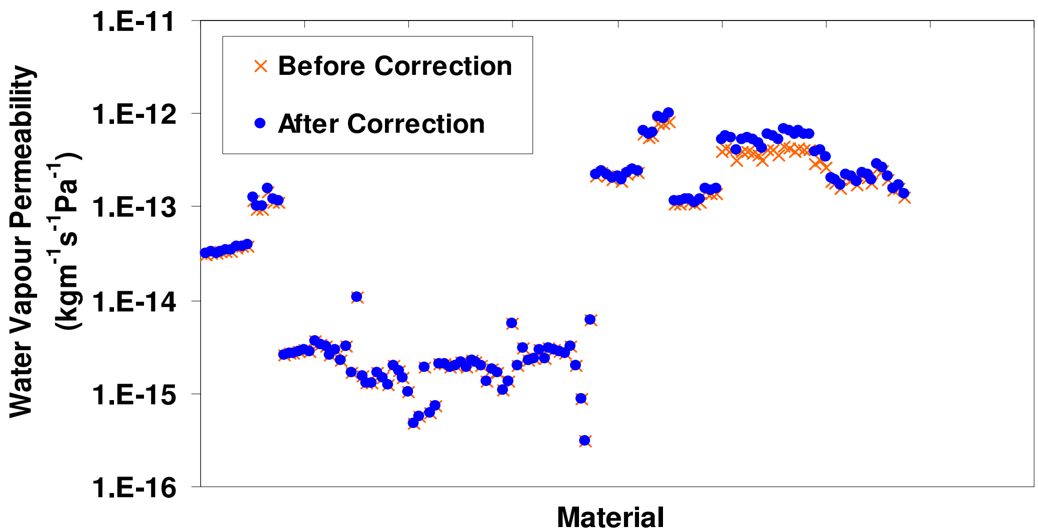

FIG. 6 – Water Vapor Permeability (Membranes): Before and After Corrections

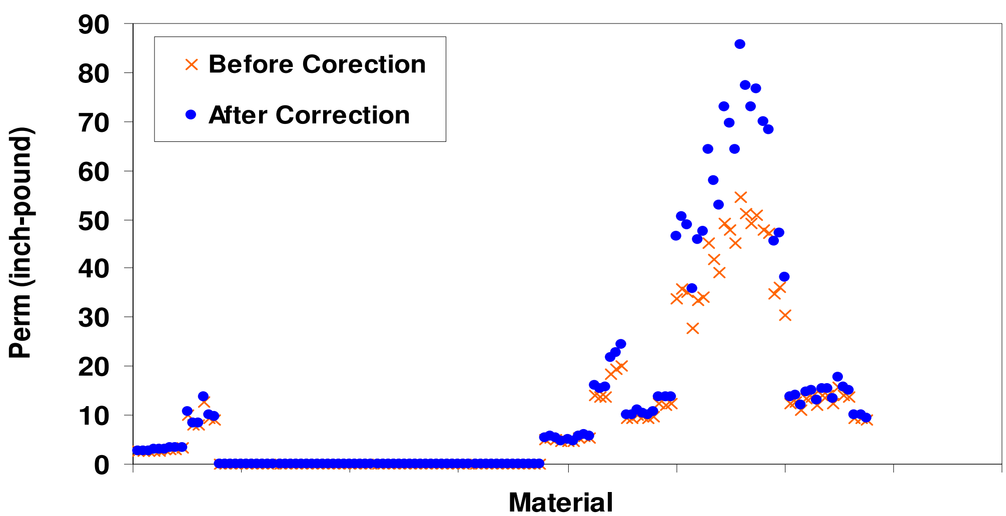

FIG. 7 – Water Vapor Permeance (Membranes): Before and After Corrections

Water Vapor Permeance and Corrections

It has been shown so far that corrections due to buoyancy, still air resistance, specimen surface, and edge mask can significantly change the results of the water vapor transmission tests done according to the test method prescribed in the ASTM Standard Test Methods for Water Vapor Transmission of Materials (E 96 - 00e1). In this paper, close to nine hundred (900) test points/results have been analyzed to establish this phenomenon. In general, it has also been observed that the effect of corrections is higher for relatively more permeable materials. Figures 8 and 9 show the relationship between the water vapor permeance and correction effect (% difference) for all the nine hundred (900) test points obtained from fifty eight (58) building materials. These plots make it very clear that the effects of corrections are more significant for material components that have higher water vapor permeance values. As mentioned earlier and quite naturally the effect of corrections is always positive (i.e. corrected water vapor permeance values are higher than the values before correction). It is also interesting to note that the effect of correction (% difference) is functionally related with the measured permeance value before correction (Figure 9). In fact, the measured data indicate that it is possible to predict the corrected permeance values using a simple polynomial function (Figure 9) without even doing the detailed calculation on the correction factors. However, it is to be mentioned here that this is a simplistic attempt to estimate the correction effects and this polynomial function is valid only for the values generated at the IRC using the existing test setup. It is very likely that the polynomial shown on Figure 9 will depend on the laboratory and the test setup being used.

Based on the observations presented in the above paragraphs, the experts and the members of the ASTM C16.33 E 96 task group have decided recently that it is important that all applicable corrections be made to all measurements that result in water vapor permeance value more than 2-perm (inch-pound). For permeance values 2-perm (inch-pound) or less the effect correction is negligible 2 percent or lower. These observations or decisions have been implemented in the latest revision of the ASTM Standard Test Methods for Water Vapor Transmission of Materials (E 96/E 96M – 05).

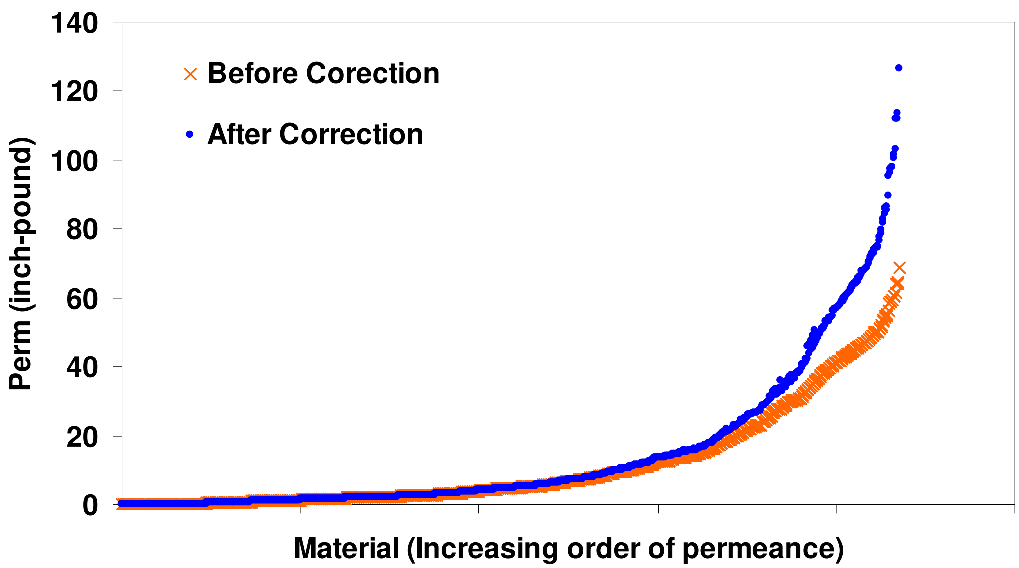

FIG. 8 – Water Vapor Permeance Before and After Corrections, and Percentage Differences

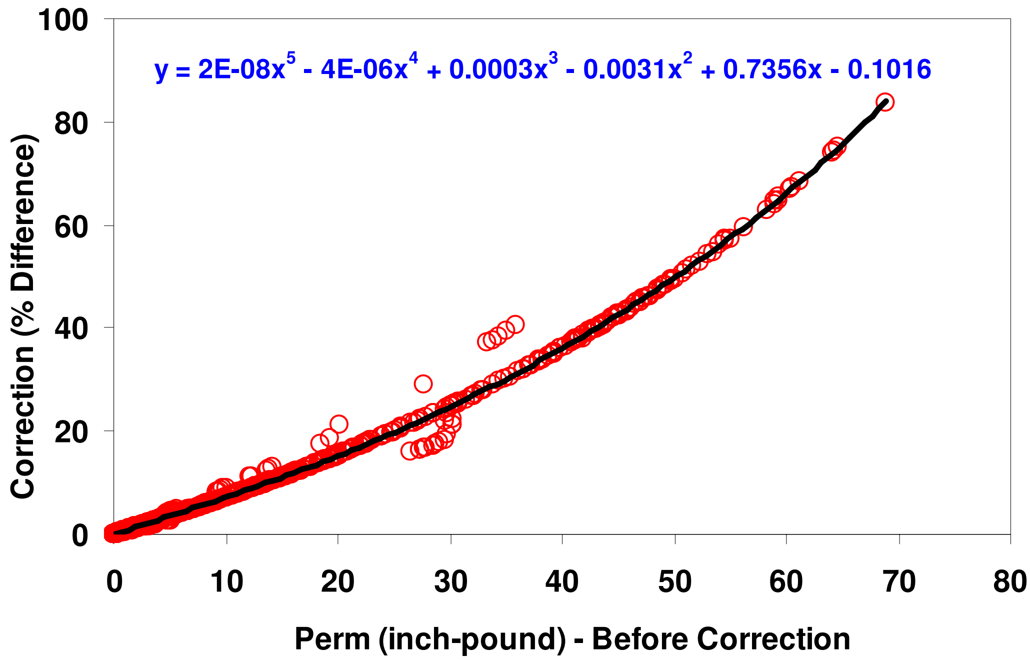

FIG. 9 – Relationship Between Water Vapor Permeance and Corrections

Conclusions

Close to nine hundred (900) water vapor transmission properties measurement test data obtained from fifty-eight (58) building materials are presented in this paper with the objective to demonstrate the effect of various corrections on the measured water vapor transmission properties. The critical observations and discussion on these results have been used as the basis for changes in the latest revision of the ASTM Standard Test Methods for Water Vapor Transmission of Materials (E 96/E 96M – 05). The observations and discussion presented in this paper clearly demonstrate:

1. Corrections applied to the water vapor transmission properties measurement can be significant for many building materials.
2. Resulting corrected water vapor transmission properties are higher than the same before correction.
3. The effect of corrections is relatively higher for material components that have lower resistance to water vapor transmission.
4. Based on these observations ASTM C16.33 - E 96 task group has recommended that all applicable corrections be made to all measurements that result in water vapor permeance value more than 2-perm (inch-pound).

References

[1] Mukhopadhyaya, P., Kumaran, M.K., Tariku, F., and van Reenen, D., "Final Report from Task 7 of MEWS Project at the Institute for Research in Construction: Long-Term Performance: Predict the Moisture Management Performance of Wall Systems as a Function of Climate, Material Properties, etc. Through Mathematical Modeling", Research Report, Institute for Research in Construction, National Research Council Canada, 132, pp. 384, February 01, 2003, (IRC-RR-132), URL: http://irc.nrc-cnrc.gc.ca/fulltext/rr132/.

[2] Mukhopadhyaya, P., Goudreau, P., Kumaran, M. K. and van Reenen, D. “Influence of material properties on the hygrothermal response of an ideal stucco wall - Results from hygrothermal simulations”. 6th Nordic Building Physics Symposium, 2002, Trondheim, Norway, pp. 611-618.

[3] Tveit, A., “Measurements of Moisture Sorption and Moisture Permeability of Porous Materials”, Norwegian Building Research Institute, Report 45, Oslo, 1966, p. 39.

[4] Chang, S. C. and Hutcheon, N. B., “Dependence of Water Vapour Permeability on Temperature and Humidity”, Transactions American Society of Heating and Air-Conditioning Engineers (ASHRAE), Vol. 62, No. 1581, 1956, pp. 437-449.

[5] Burch, D. M., Thomas, W. C. and Fanney, A. H., “Water Vapour Permeability Measurements of Common Building Materials”, ASHRAE Transactions: Symposia, 1992, pp. 486-494.

[6] Kumaran, M.K., "Alternative Procedure for the Analysis of Data from the Cup Method Measurements for Determination of Water Vapour Transmission Properties”, Journal of Testing and Evaluation, 26, (6), November, pp. 575-581, November 01, 1998 (NRCC-38556).

[7] Kumaran, M.K., “Hygrothermal Properties of Building Materials”, ASTM Manual on Moisture in Buildings, September 01, 2001, pp. 29-65.

[8] Barrer, R. M., “Diffusion in and Through Solids”, Cambridge: The University Press, London, UK, 1951.

[9] Joy, F. A., and Wilson, H. G., “Standardization of the Dish Method for Measuring Water Vapor Transmissions,” National Research Council of Canada, Research Paper 279, January 1966, p. 263.

[10] Galbraith, G. H., Guo, J. S. and McLean, R. C., “The Effect of Temperature on the Moisture Permeability of Building Materials”, Building Research and Information, Vol. 28, No. 4, 2000, pp. 245-259.

[11] Mukhopadhyaya, P., Kumaran, M. K., and Lackey, J., “Use of the 'Modified Cup Method' to Determine Temperature Dependency of Water Vapor Transmission Properties of Building Materials”,

Journal of Testing and Evaluation, American Society for Testing and Materials, September, 2005, West Conshohocken, PA, USA.

[12] Hedenblad, G., “Materialdata för fukttransportberäkningar”, T19:1996. ISBN 91-540- 5766-3. Byggforskningsrådet, Stockholm, Sweden.

[13] Hedenblad, G., “Moisture Permeability of Some Porous Building Materials”, Proceedings of the 4th Symposium, Building Physics in the Nordic Countries, Espoo, Volume 2, 1996, 747-754.

[14] Hansen, K. K. and Lund, H. B., “Cup Method for Determination of Water Vapor Transmission Properties of Building Materials. Sources of Uncertainty in the Methods”, Proceedings of the 2nd Symposium, Building Physics in the Nordic Countries, Trondheim, 1990, pp. 291-298.

[15] Lackey, J. C., Marchand, R. G., and Kumaran, M. K., “A Logical Extension of the ASTM Standard E96 to Determine the Dependence of Water Vapor Transmission on Relative Humidity”, Insulation Materials: Testing and Applications; 3rd Volume, ASTM STP 1320, R. S. Graves and R. R. Zarr, Eds., American Society for Testing and Materials, West Conshohocken, PA, 1997, pp. 456-470.

[16] McGlashan, M. L., “Physico-Chemical Quantities and Units,” Royal Institute of Chemistry Monographs for Teachers, No. 15, 1971, p. 8.

[17] Schirmer, R. ZVDI, Beiheft Verfahrenstechnik , Nr. 6, S.170, 1938.

[18] Pedersen, C. R., Ph.D thesis, Thermal Insulation Laboratory, The Technical University of Denmark, 1990, p. 10.

[19] Kumaran, K., Lackey, J., Normandin, N., van Reenen, D. and Tariku, F. “Summary report from Task 3 of MEWS project”. Institute for Research in Construction, National Research Council, Ottawa, Canada, (NRCC-45369), 2002, pp. 1-68.

[20] Kumaran, K., Lackey, J., Normandin, N., Tariku, F and van Reenen, D. “A Thermal and Moisture Transport Property Database for Common Building and Insulating Materials”, Final Report from ASHRAE Research Project 1018-RP, 2004, pp. 1-229.

[21] Mukhopadhyaya, P., Lackey J., Normandin N., Tariku F., and van Reenen, D., "Hygrothermal Performance of Building Envelope Retrofit Options: Task 1 - A Thermal and Moisture Transport Property Database", IRC/NRC, National Research Council Canada, Ottawa, Client Final Report, 2004, pp. 1-37, (B-1137.5).

[22] Kumaran, M.K., "A Thermal and Moisture Property Database for Common Building and Insulation Materials", ASHRAE Transactions, 112, (pt. 2), pp. 1-13, June 01, 2006.

APPENDIX I

In a desiccant test on a sample of medium density glass fiber insulation the following results were recorded (see Table A1).

Thickness of the specimen	= 25.81 mm
Test area	= 0.01642 m²
Mass of the test specimen	= 20.44 g
Mass of the desiccant	= 554.8 g
Initial mass of the test assembly	= 1.257810 kg
Thickness of air layer in the cup	= 15 mm

Table A1 – Recorded Test Data

Elapsed Time	Mass of the Test Assembly	Change in Mass	Chamber Temperature	Chamber RH	Barometric Pressure
(h)	(g)	(g)	(°C)	(%)	mm Hg (kPa)
0.000	1257.810	0.000	22.83	52.60	744.7 (99.27)
6.067	1259.469	1.659	22.84	52.6	741.11 (98.79)
26.633	1264.609	6.799	22.78	52.2	744.41 (99.23)
53.150	1271.062	13.252	22.82	52.1	743.21 (99.07)
143.767	1290.773	32.963	22.74	52.2	757.69 (101.00)
168.283	1296.389	38.579	22.78	52.1	749.81 (99.95)
192.883	1301.953	44.143	22.78	52.1	758.44 (101.10)

Buoyancy Correction –

The buoyancy effect will be insignificant for this set of readings as recorded changes of mass are all above 100mg. However, for example, the corrected mass of the test assembly weight 1257.810 g (1^{st} reading) can be calculated using equation 4.

m_1 = Mass recorded by balance, kg = 1257.810×10^{-3} kg

P = Barometric pressure, Pa = 99.27×10^{3} Pa

R = Gas constant for dry air = 287.055 J/(kg.K)

T = Chamber temperature = 22.83 + 273.15 = 295.98 K

ρ_a = Density of air, kg m^{-3}= 1.1684 kg m^{-3}

ρ_1 = Density of material of balance weights, kg m^{-3} = 8000 kg m^{-3}

h_1 = Height of the test assembly, m = 44.7×10^{-3} m

d_1 = Diameter of the test assembly, m = 168.0×10^{-3} m

ρ_2 = Bulk density of test assembly, kg m^{-3} = $\dfrac{4 \times m_1}{\pi \times d_1^2 \times h_1}$ =1269.4 kg m^{-3}

m_2 = Mass after buoyancy correction = 1258.78××10^{-3} kg

A graphic analysis of the data gives the following (Figure A1):

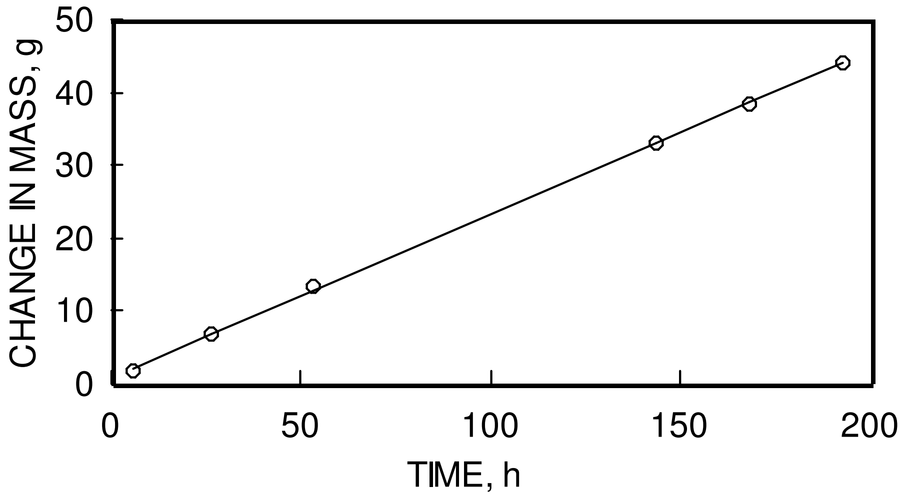

FIG. A1 – Graphic Analysis of the Test Data

A linear least-squares analysis of the data gives the slope of the straight line as 0.225 ± 0.002 g·h^{-1}, with a linear regression coefficient > 0.998.

WVT = 0.225 g.h^{-1}/ 0.01642 m²

= 19.595 grains.h^{-1}.ft^{-2} (≈3.81 x 10^{-6} kg·m^{-2}·s^{-1})

S = 2775.6 Pa

R_1 = 0.523

R_2 = 0

Permeance = 3.81 x 10^{-6} kg·m^{-2}·s^{-1}/ (2775.6 Pa x 0.523)

= 2.63 x 10^{-9} kg·m^{-2}·s^{-1}·Pa^{-1}

Corrections for Resistance due to still air and Specimen Surface -

Permeability of still air layer (equation 5) = $\delta_a = \frac{2.306x10^{-5}x101325}{461.5\times(22.79+273.15)\times 99860}\left(\frac{22.79+273.15}{273.15}\right)^{1.81}$

= 1.98062×10^{-10} kg·m^{-1}·s^{-1}·Pa^{-1}

Permeance of 15 mm still air layer = (1.98062×10^{-10})/(0.015) kg·m^{-2}·s^{-1}·Pa^{-1}

=1.32041×10^{-08} kg·m^{-2}·s^{-1}·Pa^{-1}

Hence, the 15 mm air layer offers a vapor resistance =1/(1.32041×10^{-08}) m^2·s·Pa·kg^{-1} ≈ 7.6 x 10^7 m^2·s·Pa·kg^{-1}

Surface resistances ≈ 4.0 x 10^7 m^2·s·Pa·kg^{-1}

Total corrections for resistance due to still air and specimen surface = (7.6 x 10^7 + 4.0 x 10^7) m^2·s·Pa·kg^{-1}

Edge Mask Correction -

The test assembly used does not include any edge masking. However, for example, if it includes an edge mask of width 5 mm then following correction is to be made.

h = Specimen thickness, m =25.81×10^{-3} m

b = Width of masked edge, m= 5×10^{-3} m

Test area = 0.01642 m²

Perimeter = 0.4541 m

S_1 = four times the test area divided by the perimeter = $\frac{4\times 0.01642}{0.4541}$ =0.1446 m

Percent excess WVT = $\frac{400 \times 25.81 \times 10^{-3}}{\pi \times 0.1446} \log_e \left(\frac{2}{1 + e^{-(2\pi \times 5 \times 10^{-3})/(25.81 \times 10^{-3})}} \right)$ = 9.86 %

The applicable corrections required for the analysis of the test results in this case are due to resistance of still air and specimen surface.

Water vapor resistance of the test specimen + corrections = 1/Permeance

= (1/2.63 x 10^{-9}) $m^2 \cdot s \cdot Pa \cdot kg^{-1}$ = 3.80 x 10^8 $m^2 \cdot s \cdot Pa \cdot kg^{-1}$

The water vapor resistance of the test specimen = (3.80 x 10^8 - (7.6 x 10^7 + 4.0 x 10^7)) $m^2 \cdot s \cdot Pa \cdot kg^{-1}$ = 2.64 x 10^8 $m^2 \cdot s \cdot Pa \cdot kg^{-1}$

Permeance of the test specimen = 1/(2.64 x 10^8 $m^2 \cdot s \cdot Pa \cdot kg^{-1}$)

= 3.79 x 10^{-9} $kg \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$

= 3790 $ng \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$

Permeability = 3.79 x 10^{-9} $kg \cdot m^{-2} \cdot s^{-1} \cdot Pa^{-1}$ x 0.02581 m

= 9.78 x 10^{-11} $kg \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$

= 97.8 $ng \cdot m^{-1} \cdot s^{-1} \cdot Pa^{-1}$

% Difference in water vapor permeance/permeability due to corrections = ((2630 –3790)/(2630)) x 100= 44.1 %