



Technical Notes on Brick Construction

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7D

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MOISTURE RESISTANCE OF BRICK MASONRY WALLS CONDENSATION ANALYSIS

Abstract: Moisture, formed by the condensation of water vapor, can cause many problems in brick masonry walls. Among these are: efflorescence, spalling, corrosion and interior finish damage.

This *Technical Notes* outlines a method used by designers to assess the possibility of condensation occurring in a given wall section; and, describes how to alleviate condensation problems through the use of vapor barriers and/or ventilation.

Key Words: brick, condensation, dew point, humidity, permeance, relative humidity, saturated vapor pressure, saturation, vapor barrier, vapor pressure, vapor resistance, walls.

INTRODUCTION

When a vapor pressure differential exists, water vapor will move independently of air. The vapor movement through common building materials is at a relatively high rate for common pressure differentials. When vapor passes through pores of homogenous walls, which are warm on one side and cold on the other, it may reach its dew point and condense into water within the wall; but, if the flow of vapor is impeded by a vapor-resistant material in the wall, the vapor may not reach that point in the wall at which the temperature is low enough to cause condensation.

Condensation problems are most frequent during the heating season when buildings of tight, highly insulated construction have occupancies and/or heating systems which produce humidity. This gain in moisture content of the interior air increases the interior vapor pressure substantially above that existing in the outdoor atmosphere. This tends to drive vapor outward from the building through any vapor-porous materials that comprise the wall assembly. This may be controlled either by the use of a properly placed vapor barrier or by decreasing the vapor pressure differential across the wall section through the use of ventilation.

Technical Notes 7C contains a discussion of the principles of condensation of water vapor, both on the wall surface and within the wall system. This *Technical Notes* is devoted to the analysis of wall systems to determine at what point or points in the wall assembly condensation might be expected to occur.

EFFECTS OF CONDENSATION

Many building materials are affected by water. For example, wood expands with increasing moisture content. If conditions of varying humidity occur in different parts of

the cross-section of a single wood framing member, there will be a tendency to warp. High humidity can also cause the decay of wood. Water promotes the corrosion of metal, and many insulating materials show permanent change over the course of time when in contact with water. The insulating value of most materials is greatly reduced by the presence of free water. Volumetric changes in fired clay masonry units due to gains in moisture content are to be expected and should be given consideration in the design process. Alternate freezing and thawing of clay products when saturated may lead to eventual deterioration, such as cracking and spalling. If soluble salts are present in or in contact with brick masonry, moisture caused by condensation may contribute to efflorescence.

CONDENSATION ANALYSIS

This *Technical Notes* describes the method used to determine the temperature and vapor pressure gradients of a wall when the exterior and interior design temperatures and relative humidities are known. Accompanying this method is an example of determining the points in a wall system where condensation may be expected to occur.

Method

The step-by-step method outlined assumes a steady-state heat loss procedure. The wall section and the interior and exterior temperatures and relative humidities are therefore held constant. This procedure is easily adapted to the cooling season by keeping in mind that the temperature and vapor pressure gradients are always plotted across the wall section from the warm side to the cool side.

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Procedure

An 11-column table is set up, similar to that shown in Table 3.

The wall components, including the inside air, inside air film and exterior air film, are listed in Column 1.

The thermal resistance (deg. F * sq. ft. * hr/Btu) of each wall component is entered in the rows of Column 2 respectively. Values of thermal resistance may be found in *Technical Notes 4 Revised*, Table 1.

The component thermal resistances are totaled and entered at the bottom of Column 2.

The component thermal resistance percentage is calculated by dividing the component thermal resistance by the total thermal resistance of the wall assembly and multiplying this quotient by 100. The results are entered in the rows of Column 3, respectively. Check the total of the component percentages to make sure that they equal 100.

The temperature drop across each component is calculated by multiplying the component thermal resistance percentage by the total temperature drop across the wall section ($T_i - T_o$), and dividing this product by 100. The results are entered in the rows of Column 4 respectively. A quick check is to total the component temperature drops. They must equal the total temperature drop across the wall section.

The temperature of the inside air, T_i , is entered in Row 2 of Column 5.

The component temperatures (the temperature of the component's exterior face) are calculated by subtracting the component temperature drop from the temperature of the component preceding it. The results are entered in the rows of Column 5 respectively.

Check the calculated temperature of the outside air film. It must equal the temperature of the outside air, T_o .

The component saturated vapor pressures are taken from Table 1 for the temperature of each component, and entered in the rows of Column 6 respectively.

The component vapor resistances (in. Hg * sq. ft. * hr/gr), taken from Table 2, are entered in the rows of Column 7 respectively.

The total vapor resistance of the wall section is calculated by totaling the component vapor resistances. This total is entered at the bottom of Column 7.

The component vapor resistance percentage is calculated by dividing the component vapor resistance by the total vapor resistance of the wall section and multiplying this quotient by 100. The results are entered in the rows of Column 8 respectively. Check the total of the component vapor resistance percentages to make sure that they equal 100.

The actual vapor pressure of the interior and exterior air is calculated by multiplying their saturated vapor pressures by their respective relative humidities. The results are entered in the rows of Column 10 respectively.

The total vapor pressure difference is calculated by subtracting the exterior actual vapor pressure from the interior actual vapor pressure. The result is entered at the bottom of Column 9.

The component vapor pressure difference is calculated

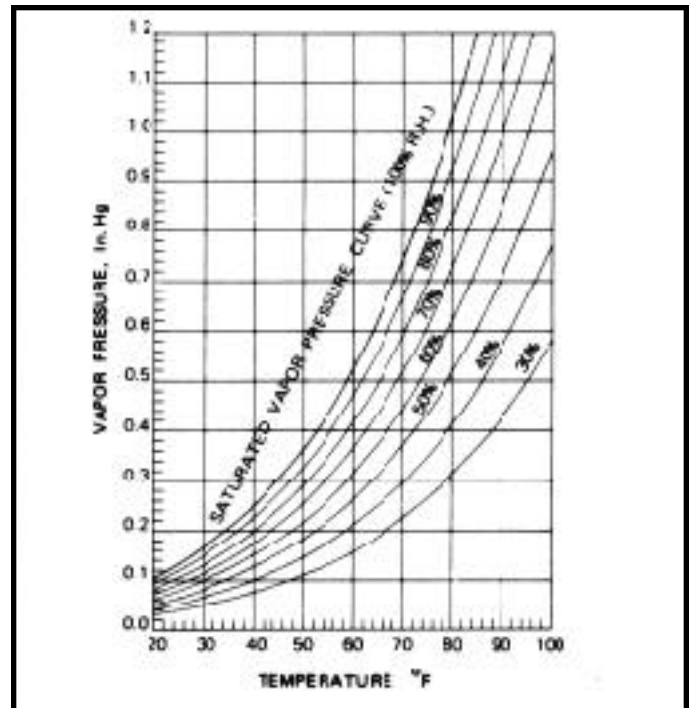
by multiplying the component vapor resistance percentage by the total vapor pressure difference and dividing this product by 100. The result is entered in the rows of Column 9 respectively. Total the component vapor pressure differences. This total must equal the total vapor pressure difference, entered at the bottom of Column 9.

The component actual vapor pressure is calculated by subtracting the component vapor pressure difference from the actual vapor pressure of the component preceding it. The results are entered in the rows of Column 10 respectively.

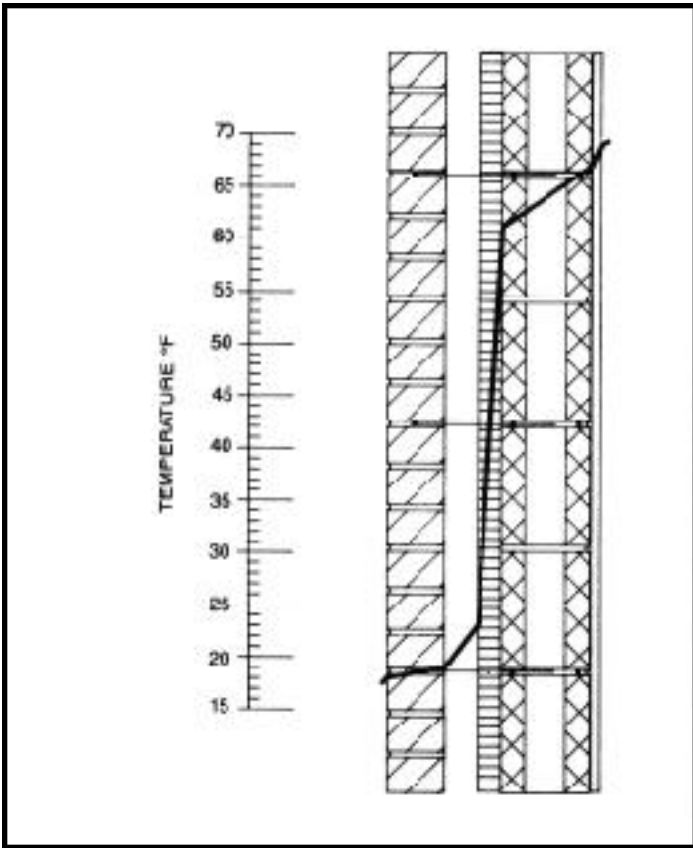
The component actual vapor pressures (Column 10) are checked against the component saturated vapor pressures (Column 6). If any wall component has an actual vapor pressure which is larger than its saturated vapor pressure, condensation is likely to occur in that area of the wall section, as indicated by the asterisks in Column 11.

Table 3 shows an example of this condensation analysis procedure. The wall being considered is an insulated brick and block cavity wall system. It is assumed that the wall is located in Washington, DC. The analysis is for a winter day with an exterior temperature of 17 deg. F @ 73% relative humidity, and an interior temperature of 72 deg. F @ 50% relative humidity.

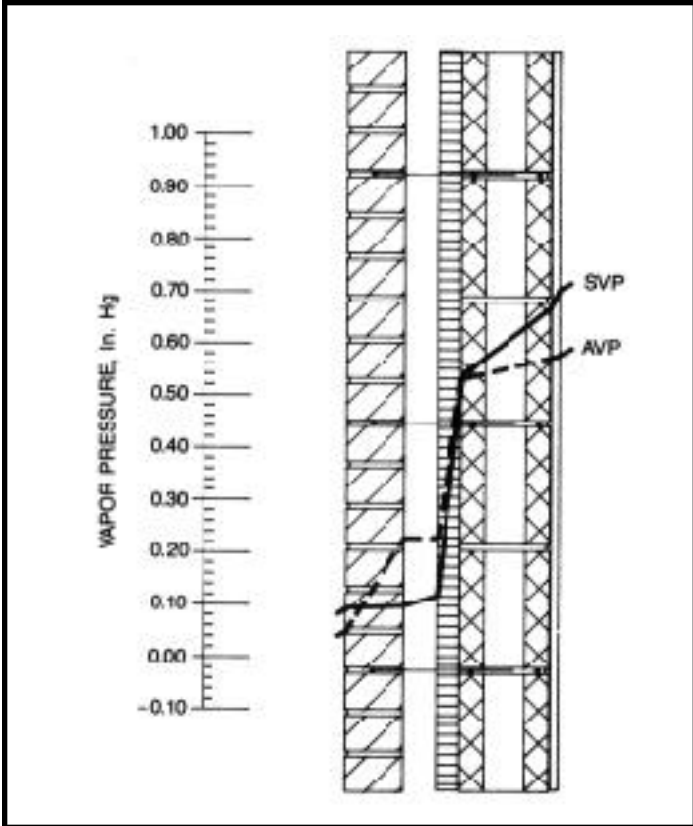
The temperature gradient, as well as the saturated vapor pressure and actual vapor pressure gradients, can be plotted across the wall section, as shown in Figures 2 and 3 respectively. When plotting the saturated and actual vapor pressure gradients, the areas where the actual vapor pressure gradient is above the saturated vapor pressure gradient are where condensation is likely to occur.



Saturated Vapor Pressure Curves
FIG. 1



Temperature Gradient
FIG. 2



Saturated Vapor Pressure and
Actual Vapor Pressure
FIG. 3

TABLE 1
Pressure of Water Vapor at Saturation
Note: To Convert Pressure in Inches of Mercury
(in. Hg) to psi; $(0.49116) (\text{In. Hg}) = \text{psi}$

Temp. °F	Saturated Vapor Pressure In. Hg	Temp. °F	Saturated Vapor Pressure In. Hg
-20	.01259	41	.25748
-19	.01333	42	.26763
-18	.01411	43	.27813
-17	.01493	44	.28899
-16	.01579	45	.30023
-15	.01671	46	.31185
-14	.01767	47	.32386
-13	.01868	48	.33629
-12	.01974	49	.34913
-11	.02086	50	.36240
-10	.02203	51	.37611
-9	.02327	52	.39028
-8	.02457	53	.40492
-7	.02594	54	.42004
-6	.02738	55	.43565
-5	.02889	56	.45176
-4	.03047	57	.46840
-3	.03214	58	.48558
-2	.03388	59	.50330
-1	.03572	60	.52159
0	.03764	61	.54047
1	.03967	62	.55994
2	.04178	63	.58002
3	.04401	64	.60073
4	.04634	65	.62209
5	.04878	66	.64411
6	.05134	67	.66681
7	.05402	68	.69019
8	.05683	69	.71430
9	.05978	70	.73915
10	.06286	71	.76475
11	.06608	72	.79112
12	.06946	73	.81828
13	.07300	74	.84624
14	.07670	75	.87504
15	.08056	76	.90470
16	.08461	77	.93523
17	.08884	78	.96665
18	.09327	79	.99899
19	.09789	80	1.0323
20	.10272	81	1.0665
21	.10777	82	1.1017
22	.11305	83	1.1379
23	.11856	84	1.1752
24	.12431	85	1.2135
25	.13032	86	1.2529
26	.13659	87	1.2934
27	.14313	88	1.3351
28	.14966	89	1.3779
29	.15709	90	1.4219
30	.16452	91	1.4671
31	.17227	92	1.5135
32	.18035	93	1.5612
33	.18778	94	1.6102
34	.19456	95	1.6606
35	.20342	96	1.7123
36	.21166	97	1.7654
37	.22020	98	1.8199
38	.22904	99	1.8759
39	.23819	100	1.9333
40	.24767		

TABLE 2^k
Permeance and Permeability of Materials to Water Vapor^{a,*}

Materials	Thickness (In.)	Resistance (Rep)ⁱ
Materials Used in Construction		
Concrete (1:2:4 Mix)	1	0.31
Brick Masonry	4	1.3 ^f
Concrete Block (Cored, Limestone Aggregate)	8	0.4 ^f
Tile Masonry, Glazed	4	8.3 ^f
Asbestos Cement Board	0.12	0.1-0.2 ^d
With Oil Based Finishes	0.12	2-3 ^d
Plaster on Metal Lath	0.75	0.067 ^f
Plaster on Wood Lath		0.091 ^e
Plaster on Plain Gypsum Lath (With Studs)		0.050 ^f
Gypsum Wall Board (Plain)	0.375	0.020 ^f
Gypsum Sheathing (Asphalt Impreg.)	1	0.05 ^d
Structural Insulating Board (Sheathing Qual.)	1	0.05-0.02 ^f
Hardboard (Standard)	0.5	0.02-0.011 ^f
Hardboard (Tempered)	0.125	0.091 ^f
Wood, Sugar Pine	0.125	0.2 ^f
Plywood (Douglas Fir, Exterior Glue)	1	2.5-0.19 ^{fb}
Plywood (Douglas Fir, Interior Glue)	0.25	0.53 ^f
Acrylic, Glass Fiber Reinforced Sheet	0	8.3 ^d
Polyester, Glass Fiber Reinforced Sheet	0.048	20 ^d
Thermal Insulations		
Air (Still)	1	0.0083 ^f
Cellular Glass	1	^d
Corkboard	1	0.48-0.38 ^d
Mineral Wool (Unprotected)	1	0.0086 ^e
Expanded Polyurethane (R-11 Blown) Board		
Stock	1	2.5-0.62 ^d
Expanded Polystyrene-Extruded	1	0.83 ^d
Expanded Polystyrene-Bead	1	0.5-0.17 ^d
Phenolic Foam (Covering Removed)	1	0.038
Unicellular Synthetic Flexible Rubber Foam	1	5.0-6.7 ^d
Plastic and Metal Foils and Films^{c,d}		
Aluminum Foil	0.00035	20
Polyethylene	0.002	6.3
Polyethylene	0.006	17
Polyethylene	0.010	33
Polyvinylchloride, Unplasticized	0.002	1.5
Polyvinylchloride, Plasticized	0.004	1.3-0.72
Polyester	0.001	1.4
Polyester	0.0032	4.3
Polyester	0.0076	12.5
Cellulose Acetate	0.01	0.2
Cellulose Acetate	0.125	3.1
Materials	Weight^h	Resistance (Rep)ⁱ
Building Paper, Felts, Roofing Papers^{g,d}		
Duplex Sheet, Asphalt Laminated, Aluminum		
Foil -- One Side	8.6	500
Saturated and Coated Roll Roofing	65	20
Kraft Paper and Asphalt Laminated, Reinforced		
50-120-30	6.8	3.3
Blanket Thermal Insulation Backup Paper, Asphalt		
Coated	6.2	2.5
Asphalt -- Saturated and Coated Vapor Retarder Paper	8.6	5.0-3.3
Asphalt -- Saturated but not Coated Sheathing Paper	4.4	0.3
15-16 Asphalt Felt	14	1.0
15-16 Tar Felt	14	0.25
Single -- Kraft, Double	3.2	0.032

TABLE 2 (Cont.)
Permeance and Permeability of Materials to Water Vapor^{a,*}

Materials	Thickness (In.)	Resistance (Rep)ⁱ
Liquid-Applied Coating Materials^f		
Commercial Latex Paints (Dry Film Thickness) ^j		
Vapor Retarder Paint	0.0031	2.22
Primer Sealer	0.0012	0.16
Vinyl Acetate/Acrylic Primer	0.002	0.13
Vinyl-Acrylic Primer	0.0016	0.12
Semi-Gloss Vinyl-Acrylic Enamel	0.0024	0.15
Exterior Acrylic House and Trim	0.0017	0.18
Paint -- 2 Coats		
Asphalt Paint on Plywood		2.5 ^e
Aluminum Varnish on Wood		3.3-2.0 ^d
Enamels on Smooth Plaster		2.0-0.66 ^d
Primers and Sealers on Interior Insulation Board		1.1-0.48 ^d
Various Primers Plus 1 Coat Flat Oil Paint on Plaster		0.63-0.33 ^d
Flat Paint on Interior Insulation Board		0.25 ^d
Water Emulsion on Interior Insulation Board		0.03-0.012 ^d
Materials	Oz / Ft²	Resistance (Rep)ⁱ
Paint -- 3 Coats		
Exterior Paint, White Lead and Oil on Wood Siding		3.3-1.0
Exterior Paint, White Lead Oxide and Oil on Wood		1.1
Styrene-Butadiene Latex Coating	2	0.09
Polyvinyl Acetate Latex Coating	4	0.18
Chloro-Sulfonated Polyethelene Mastic	3.5	0.59

* In this chapter the permeance, resistance, permeability and resistance per unit thickness values are given in the following units:

Permeance	Perm	=	gr/h.ft ² .in.Hg
Resistance	Rep	=	in.Hg.ft ² h/gr
Permeability	Perm.in.	=	gr/h.ft ² (in.Hg/in.)
Resistance/ unit thickness	Rep/in.	=	(in.Hg.ft ² h/gr)/in.

^aTable 2 gives the water vapor transmission rates of some representative materials. The data are provided to permit comparisons of materials; but in the selection of vapor retarder materials, exact values for permeance or permeability should be obtained from the manufacturer of the materials under consideration or secured as a result of laboratory tests. A range of values shown in the table indicate variations among mean values for materials that are similar but of different density, orientation, lot or source. The values are intended for design guidance and should not be used as design or specification data. The compilation is from a number of sources; values from dry-cup and wet-cup methods were usually obtained from investigations using ASTM E96 and C355; values shown under others were obtained from investigations using such techniques as two-temperature, special cell, and air-velocity. Values included were obtained from Ref.14 to 29 and other sources. Some values were obtained from unpublished tests conducted by Pennsylvania State University and the Building Research Div., National Research Council of Canada.

^bDepending on construction and direction of vapor flow.

^cUsually installed as vapor retarders, although sometimes used as exterior finish and elsewhere near cold side where special considerations are then required for warm side barrier effectiveness.

^dDry-cup method.

^eWet-cup method.

^fOther than dry- or wet-cup method.

^gLow permeance sheets used as vapor retarders. High permeance used elsewhere in construction.

^hBasic weight in lb per 100 ft² (lb per square ft)

ⁱResistance and resistance/in. values have been calculated as the reciprocal of the permeance and permeability values.

^jCast at 10 mils wet film thickness.³¹

^kFrom ASHRAE Handbook of Fundamentals.

TABLE 3
Example⁵

1	2	3	4	5	6	7	8	9	10	11	
1	Material	T.R.	%	T.D.	°F	S.V.P.	V.R.	%	V.P.D.	A.V.P.	
2	Inside Air	0.00	0	0	72	0.791	0.008	0	0	0.396	
3	Inside Air Film of Still Air	0.68	5	3	69	0.714	0	0	0	0.396	
4	1/2" Drywall (Gypsum)	0.45	4	2	67	0.667	0.027	1	0.003	0.392	
5	6" Block	1.53	11	6	61	0.540	0.300	7	0.023	0.369	
6	1 1/2" Rigid Insulation Expanded Polyurethane	9.38	69	38	23	0.119	2.34	59	0.195	0.174	*
7	1" Air Space	0.97	7	4	19	0.098	0.008	0	0	0.174	*
8	4" Block	0.44	3	1	18	0.093	1.3	33	0.109	0.065	
9	Outside Air Film 15 MPH	0.17	1	1	17	0.089	0	0	0	0.065	
	Total	13.62	100	55			3.983	100	0.031		

ABBREVIATIONS

T.R.	Thermal Resistance
T.D.	Temperature Difference (°F)
S.V.P.	Saturated Vapor Pressure (in Inches Mercury)
V.R.	Vapor Resistance (in Inches Mercury)
V.P.D.	Vapor Pressure Difference (in Inches Mercury)
A.V.P.	Actual Vapor Pressure (in Inches Mercury)
Ti	Inside Air Temperature (°F)
To	Outside Air Temperature (°F)
RHi	Relative Humidity Inside
RHo	Relative Humidity Outside

NOTES

- See Table 1 of *Technical Notes 4 Revised*.
- See Table 1
- See Table 2
- Condensation is likely to occur in these areas.
- Information Required for this example

Ti	=	72
To	=	17
RHi	=	50%
RHo	=	73%

SUMMARY

The analysis procedure presented in this *Technical Notes* may be used as an indicator of where condensation may occur in a wall section. It may also be used to analyze the effect on condensation potential of varying wall components and vapor barriers. The information contained in this *Technical Notes* is based on the available data and experience of the technical staff of the Brick Institute of America. This information should be recognized as recommendations and should be used with judgment. Final decisions on the use of the information discussed herein are not within the purview of the Brick Institute of America, and must rest with project owner, designer or both.