

National Exams Dec. 2014

**07-Bld-A7, Building Envelope Design**

3 hours duration

**NOTES:**

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. This is a CLOSED BOOK EXAM.  
Casio or sharp calculator allowed
3. FIVE (5) questions constitute a complete exam paper.  
The first five questions as they appear in the answer book will be marked.
4. Each question is of equal value.
5. For questions that require an answer in essay format, clarity and organization of the answer are important.
6. Equations and data required for calculations are provided in the appendix of this exam booklet.

## Question 1 (20 marks)

**1.1: (15 Marks) Decide for each statement whether it is true or false. Provide the answers directly on this question sheet.**

No.	Statement	True	False
1	It is not possible to have vapor diffuse through a wall in the direction opposite to air leakage		
2	Wetting by condensation is promoted on cold indoor surfaces and on cold surfaces within the construction.		
3	The magnitude of moisture damage to building envelope due to different sources ranks in descending order as: rainwater, vapour diffusion, and air leakage		
4	Cold outdoor air entering through a building enclosure because of wind, exhaust fans, or stack effect will usually be at a low relative humidity but at a high humidity ratio.		
5	In any climate condition, the vapor barrier is beneficial to prevent moisture-induced damage if placed on the interior or indoor side of the wall.		
6	The suction pressure on the roof perimeter is more severe when wind blows perpendicular to the face of the building than when wind blows towards the corner of the building.		
7	The moisture accumulation in the building envelope can induce material decay and mold growth, but won't affect the thermal performance of the envelope.		
8	Asphalt impregnated building paper can be considered as an air barrier		
9	Sealed extruded polystyrene can be considered as a water resistive barrier		
10	Air barrier must be installed on the warm side of the wall		
11	In cold climate, if the air barrier is positioned on the outside of the insulation, the air barrier material needs to be 10-20 times more permeable to water vapor diffusion than the vapor barrier material.		
12	The principal function of masonry mortar is to develop a complete, strong and durable bond with masonry units. Mortar must also create a water resistant seal.		
13	Differences in air density due to differences in temperature between indoors and outdoors give rise to stack effect, which promotes vapor diffusion.		
14	For safety reason it is good to use a mortar that has more compressive strength than required by the structural		

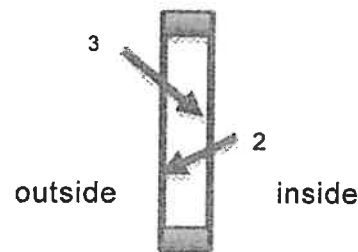
	requirements of the project.		
15	When given a choice during renovation, insulation should be placed on the interior of the structure to achieve energy efficiency.		

**1.2: (5 Marks). Single choice questions. Provide your answers directly on this question sheet.**

There is only one correct answer for all the questions listed below and each question is worth 1 mark.

1. An air barrier can also function as
  - I. water resistant barrier
  - II. vapour retarder
  - III. thermal insulation

A. Only I; B. Only II; C. Only III; D. I and II, E. I, II and III
2. The vapour permeability of materials is normally measured using dry-cup, or wet-cup or both methods. The results can be considerably different. What will influence your choice when selecting material property values?
  - A. Wet-cup test values for placement in the surroundings with higher relative humidity, dry cup test for drier surroundings, since the vapour permeability of some materials changes depending on the surrounding conditions
  - B. Wet-cup test values for placement in the surroundings with lower relative humidity and dry cup test for more humid surroundings, since given material needs to provide adequate resistance to the water vapour flow
  - C. Either one; values are so small that it does not actually make any difference
3. A drainage plane must be made of
  - A. Tyvek house wrap
  - B. Rigid foam insulation
  - C. Sheathing membrane
  - D. A contiguous system of water repellent material
4. In cold climate, the most beneficial position to apply low-e coating to a glazing surface of an air-filled double-glazed unit is surface:
  - A. Surface 2
  - B. Surface 3
  - C. Either surface 2 or 3, does not matter



5. The primary functions of the air space in a rainscreen wall to deal with rainwater penetration are to provide:
  - i. Capillary break
  - ii. Drainage
  - iii. Ventilation when both top and bottom vents are present
  - iv. Water vapour diffusion

- A. I and II      B. II and III      C. III and IV      D. I, II, and III

**Question 2 (20 marks):**

A typical wood-frame brick veneer wall construction that is commonly used in Part 9 low-rise residential building is made up of the following components:

- 100mm exterior brick (RSI 0.13)
- 25mm air space (RSI 0.22)
- one layer of Tyvek water resistive membrane, 0.2mm
- 12.5 mm plywood sheathing (RSI 0.11)
- 140mm glass fiber insulation (RSI 3.67)
- 6 mil polyethylene as vapour and air barrier
- 12.5mm gypsum board (RSI 0.08)

To improve the energy efficiency of homes, the thermal resistance of walls, roofs, and below grades will need to be significantly improved.

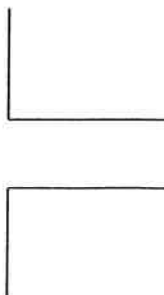
- 1) Calculate the effective RSI value of the wall assembly given using the Parallel path method. The wood stud spacing is 16" at centre, and assume the thermal conductivity of the wood stud is 0.11W/m•K. The actual dimension of 2x6 wood stud is 38mm by 140mm. A frame factor of 25% can be assumed in the calculation.
- 2) Propose one wall configuration to achieve an effective thermal resistance of R30 (RSI5.28) using the wall assembly given as the base case.
- 3) Comment on the moisture performance of your solution in comparison to the conventional 2x6 wood-frame wall given.
- 4) Sketch a typical floor/wall junction with the wall construction you have chosen. On your drawing, label and trace the air barrier, vapour barrier, water resistive barrier, and rain shedding surface.

In your calculation, you can assume a RSI 0.12 for the interior surface thermal resistance, a RSI 0.03 for the exterior surface thermal resistance, and a RSI 0.22 for the thermal resistance of rainscreen air cavity. Material properties are provided in the appendix.

**Question 3 (20 marks):**

**Part A (12 marks)**

- 1) Complete the horizontal joint in figure below by adding and labeling components.
- 2) Explain the function of each component.
- 3) Comment on the requirement of the relative dimensions (give dimensions or range where you can);
- 4) With the aid of sketches, explain what sealant failures it would result if the joint is too wide or too deep.



- 5) Explain the difference between single-stage joint and two-stage joint with the help of sketches, and state the advantages of two-stage joint over single-stage joint.

**Part B (4 marks)**

Briefly explain the following failure mechanism

- a. Efflorescence
- b. Blister

**Part C (4 marks)**

Explain the failure mechanism shown in photo 1 and how to reduce the risk of such failures.

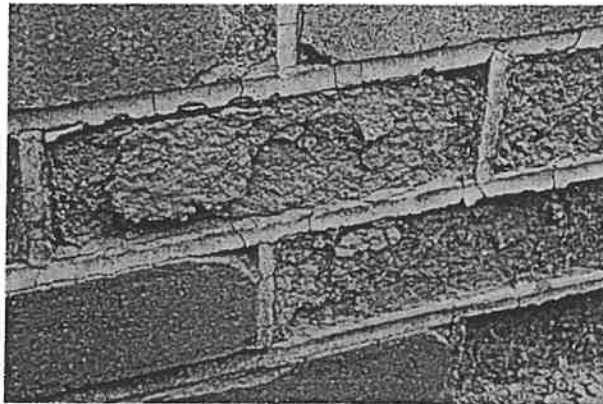


Photo 1

**Question 4 (20 marks):**

**Part A: (15 marks)**

Sketch a vertical cross-section of a brick veneer cavity wall with steel stud including the roof and floor section.

- a. Label all the components and explain the function of each component.
- b. Mark the air barrier on the drawing and list the elements that form the air barrier system in this case.
- c. Explain why a soft joint is normally required between the top of the brick veneer and the bottom of the shelf angle supporting the bricks of the next storey in a multi-story building.

**Part B (5 marks)**

Figure 1 below shows the detail of a structural expansion joint in a brick veneer/Concrete Masonry Unit wall assembly.

- 1) State the purpose of a structural expansion joint;
- 2) Identify the main components of the expansion joint;

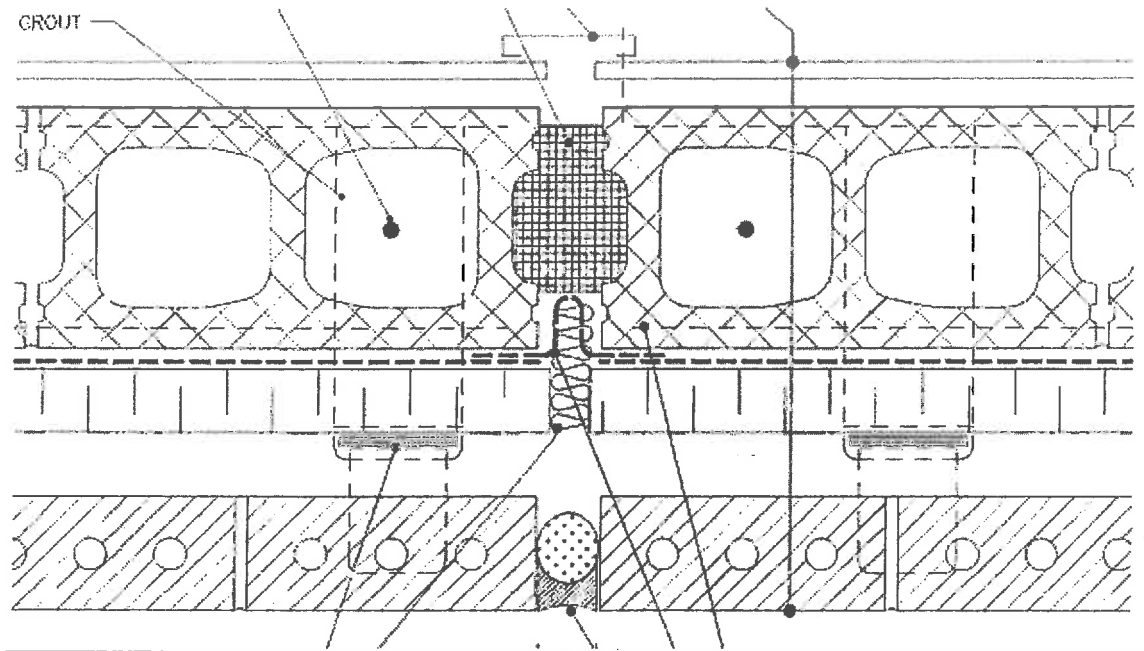


Figure 1

### **Question 5 (20 marks)**

- 1) (10 marks) Sketch a sloped roof with ventilated attic and label the main components of the roof sections, and explain their functions.
- 2) (3 marks) Explain how the attic ventilation is achieved and indicate the intended ventilation flow paths.
- 3) (7 marks) In photo shown below, note that icicles are formed at the eaves of a sloped roof. Explain what has caused it and how to avoid such a problem.

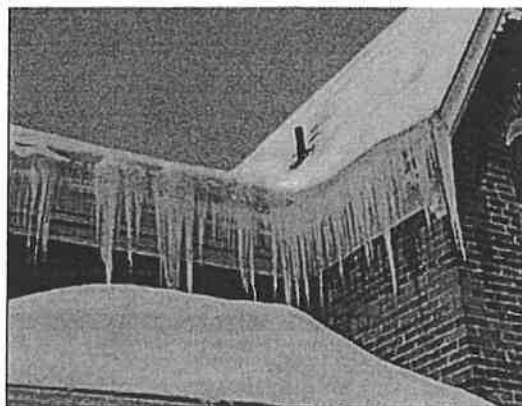


Photo 2

### **Question 6 (20 marks)**

Review the case study "the brick is falling". 1) Explain the failure mechanism of this case with the aid of sketch. 2) Comment on how to avoid such failures from occurring by providing a cross-section of a brick veneer wall showing the proper wall/floor connection details.

Appendix: equations

- Vapor flow equation:

$$W = MA\theta(p_1 - p_2) \quad (1)$$

where:

$W$  = total mass of vapor transmitted, ng

$M$  = permeance coefficient, ng/(s·m<sup>2</sup>·Pa),  $M = \frac{\bar{\mu}}{l}$

$\theta$  = time during which flow occurs, s

$l$  = thickness, m

$\bar{\mu}$  = average permeability, ng/(s·m·Pa)

$A$  = cross-section area of the flow path, m<sup>2</sup>

$(p_1 - p_2)$  = vapor pressure difference applied across the specimen, Pa.

- Conductive heat transmission equation

$$\frac{q}{A} = U(t_i - t_o) \quad (2)$$

where

$q/A$  = heat-flow rate, W/m<sup>2</sup>

$U$  = overall coefficient of heat transmission, W/(m<sup>2</sup>·K)

$t_i, t_o$  = inside and outside temperature, K

- Thermal resistance of composite section

$$R = \frac{1}{U} = R_1 + R_2 + R_3 \quad (3)$$

- Average U-value by parallel method (area-weighted average)

$$U = \frac{A_1}{A_1 + A_2} U_1 + \frac{A_2}{A_1 + A_2} U_2 \quad (4)$$

## The Brick Is Falling

Although masonry construction has been around for up to 12,000 years, we occasionally need to be reminded of some basic principles of its proper use. The photo depicts a failure caused by a practice that defies common sense as well as all published works on masonry veneer construction.

The brick faces have spalled off, revealing the toe of a shelf angle at approximately mid-height of the brick course. When I first visited this eight-story university library, ropes had been strung around the building to prevent falling pieces of brick from striking the public.

A shelf angle's purpose is, of course, to support the prism of masonry above. Good practice dictates that the bottom masonry course be seated directly

on the steel (or rather, on a flashing material, which is also conspicuously absent in this photo). A space should be left between the shelf angle and the masonry course below it. Theoretically, a shelf angle does not take any load until it deflects; so, if it bears on solid masonry below, it passes the loads from above into the masonry below rather than back to the building frame.

In this case, the masonry courses did not line up with the previously erected steel shelf angles. Apparently, to preserve even course lines around the building, the bricks were modified to fit around the steel wherever it occurred. Called "soaps," these cut bricks were typically either L-shaped or thin, flat fronts only. In some areas, there is space below the steel (as in the photo), so the shelf angles did deflect, carrying the masonry above with them. However, the soaps were mortared in solid to the course above, and they were crushed when the weight of the deflecting masonry bore on the thin face cross section.

In addition to the masonry structural failures, the walls leaked like a sieve. Criticisms could be



Courtesy the author

made about the mortar joint profiles (raked joints have significantly lower resistance to water penetration than concave joints) and the numerous cracks and spalls in the masonry. However, the obvious problem related to the mislocated shelf angle was that there was no way for a flashing to drain out of the wall. A flashing should terminate outside the masonry, but that is impossible when it is placed at a row of soaps instead of a horizontal joint.

### Sharing the Blame

Although the masonry contractor can be easily criticized for these practices, the general contractor also shares the blame for the lack of coordination between the steel and masonry, and no doubt the architect is responsible for the poor detailing of the shelf angles.

I also criticize the conventional practice, as done here, of structural engineers showing the steel shelf angles on their drawings but indicating the masonry only by a phantom line. This is an intentional abdication of any responsibility for the masonry's behavior, yet engineers are the best hope of preventing this type of failure. The structural drawings should show the steel/masonry coordination. To continue not doing so is to condemn more buildings to this type of failure. ♦

**DAVID H. NICASTRO, P.E.**, is founder and president of Engineering Diagnostics, Inc., in Houston, Texas. Mr. Nicastro specializes in the investigation and remedy of construction problems and the resolution of related disputes.

**Masonry courses did not line up with previously erected shelf angles.**

By David H. Nicastro



Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values<sup>2</sup> (Continued)

Description	Density, kg/m <sup>3</sup>	Conductivity <sup>b</sup> <i>k</i> , W/(m·K)	Resistance <i>R</i> , (m <sup>2</sup> ·K)/W	Specific Heat, kJ/(kg·K)	Reference <sup>a</sup>
<b>Finish Flooring Materials</b>					
Carpet and rebounded urethane pad..... 19 mm	110	—	0.42	—	NIST (2000)
Carpet and rubber pad (one-piece)..... 9.5 mm	320	—	0.12	—	NIST (2000)
Pile carpet with rubber pad..... 9.5 to 12.7 mm	290	—	0.28	—	NIST (2000)
Liaoleum/cork tile..... 6.4 mm	465	—	0.09	—	NIST (2000)
PVC/Rubber floor covering.....	—	0.40	—	—	CIBSE (2006)
Rubber tile..... 25 mm	1900	—	0.06	—	NIST (2000)
Terazzo..... 25 mm	—	—	0.014	0.80	
<b>Insulating Materials</b>					
<i>Blanket and batts<sup>c,d</sup></i>					
Glass-fiber batts..... 85 to 90 mm	10 to 14	0.043	—	0.84	Kumaran (2002)
..... 50 mm	8 to 13	0.045 to 0.048	—	0.84	Kumaran (2002)
Mineral fiber..... 140 mm	30	0.036	—	0.84	Kumaran (1996)
Mineral wool, felted.....	16 to 48	0.040	—	—	CIBSE (2006), NIST (2000)
.....	65 to 130	0.035	—	—	NIST (2000)
Slag wool.....	50 to 190	0.038	—	—	Raznjevic (1976)
.....	255	0.040	—	—	Raznjevic (1976)
.....	305	0.043	—	—	Raznjevic (1976)
.....	350	0.048	—	—	Raznjevic (1976)
.....	400	0.050	—	—	Raznjevic (1976)
<i>Board and slabs</i>					
Cellular glass.....	130	0.048	—	0.75	(Manufacturer)
Cement fiber slabs, shredded wood with Portland cement binder.....	400 to 430	0.072 to 0.076	—	—	
..... with magnesia oxysulfide binder.....	350	0.082	—	1.30	
Glass fiber board.....	160	0.032 to 0.040	—	0.84	Kumaran (1996)
Expanded rubber (rigid).....	70	0.032	—	1.67	Nottage (1947)
Expanded polystyrene extruded (smooth skin).....	25 to 40	0.022 to 0.030	—	1.47	Kumaran (1996)
Expanded polystyrene, molded beads.....	15 to 25	0.032 to 0.039	—	1.47	Kumaran (1996)
Mineral fiberboard, wet felted.....	160	0.038	—	0.84	Kumaran (1996)
..... core or roof insulation.....	255 to 270	0.049	—	—	
..... acoustical tiles.....	290	0.050	—	0.80	
.....	335	0.053	—	—	
..... wet-molded, acoustical tiles.....	370	0.061	—	0.59	
Perlite board.....	160	0.052	—	—	Kumaran (1996)
<i>Polyisocyanurate, aged</i>					
unfaced.....	25 to 35	0.020 to 0.027	—	—	Kumaran (2002)
..... with facers.....	65	0.019	—	1.47	Kumaran (1996)
Phenolic foam board with facers, aged.....	65	0.019	—	—	Kumaran (1996)
<i>Loose fill</i>					
Cellulosic (milled paper or wood pulp).....	35 to 50	0.039 to 0.045	—	1.38	NIST (2000), Kumaran (1996)
Perlite, expanded.....	30 to 65	0.039 to 0.045	—	1.09	(Manufacturer)
.....	65 to 120	0.045 to 0.052	—	—	(Manufacturer)
.....	120 to 180	0.052 to 0.061	—	—	(Manufacturer)
<i>Mineral fiber (rock, slag, or glass)<sup>d</sup></i>					
..... approx. 95 to 130 mm	10 to 30	—	1.92	0.71	
..... approx. 170 to 220 mm	10 to 30	—	3.33	—	
..... approx. 190 to 250 mm	10 to 30	—	3.85	—	
..... approx. 260 to 350 mm	10 to 30	—	5.26	—	
..... 90 mm (closed sidewall application)	30 to 55	—	2.1 to 2.5	—	
<i>Vermiculite, exfoliated.....</i>					
.....	110 to 130	0.068	—	1.34	Sabine et al. (1975)
.....	64 to 96	0.063	—	—	(Manufacturer)
<i>Spray-applied</i>					
Cellulosic fiber.....	55 to 95	0.042 to 0.049	—	—	Yarbrough et al. (1987)
Glass fiber.....	55 to 70	0.038 to 0.039	—	—	Yarbrough et al. (1987)
<i>Polyurethane foam (low density).....</i>					
.....	6 to 8	0.042	—	1.47	Kumaran (2002)
.....	40	0.026	—	1.47	Kumaran (2002)
..... aged and dry..... 40 mm	30	—	1.6	1.47	Kumaran (1996)
..... 50 mm	55	—	1.92	1.47	Kumaran (1996)
..... 120 mm	30	—	3.69	—	Kumaran (1996)
Ureaformaldehyde foam, dry.....	8 to 20	0.030 to 0.032	—	—	CIBSE (2006)

Table 8 Water Vapor Permeability of Building Materials at Various Relative Humidities

Material	Permeability at Various Relative Humidities, ng/(Pa·s·m)					Water Absorption Coefficient, (kg·s <sup>2</sup> )/m <sup>2</sup>	Mean Air Permeability, kg/(Pa·s·m)	References/ Comments
	10%	30%	50%	70%	90%			
<b>Building Board and Siding</b>								
Asbestos cement board, 3 mm thickness with oil-base finishes	← 0.66 to 1.37 →			← N/A →				Dry cup*
Cement board, 13 mm, 1130 kg/m <sup>3</sup>	7.4	7.4	9.3	12	16	0.013	3 × 10 <sup>-8</sup>	Kumaran (2002)
Fiber cement board, 8 mm, 1380 kg/m <sup>3</sup>	0.21	0.58	1.6	4.7	14.8	0.025	3 × 10 <sup>-12</sup>	Kumaran (2002)
Gypsum board		21		23	30			Kumaran (1996)/NRC
asphalt impregnated	← 0.038 →			← 44.7 →		0.0019 <sup>c</sup>	4.2 × 10 <sup>-9</sup>	Kumaran (2002)
Gypsum wall board, 13 mm, 625 kg/m <sup>3</sup> with one coat primer	23.4	27.2	31.9	37.6	44.7	N/A	2.2 × 10 <sup>-4</sup>	Kumaran (2002)
with one coat primer/two coats latex paint	6.83	14.9	22.0	28.9	35.9	N/A	2.5 × 10 <sup>-9</sup>	Kumaran (2002)
Hardboard siding, 11 mm, 740 kg/m <sup>3</sup>	1.1	2.1	4.0	8.0	16.5	0.00072	4.5 × 10 <sup>-9</sup>	Kumaran (2002)
Oriented strand board (OSB), 9.5 mm, 660 kg/m <sup>3</sup>	3.92	4.28	4.67	5.10	5.58	0.0016	1 × 10 <sup>-9</sup>	Kumaran (2002)
11.1 mm	0.0064	0.177	0.487	1.35	3.83	0.0022	2 × 10 <sup>-9</sup>	Kumaran (2002)
12.7 mm	0.026	0.60	1.23	2.30	4.08	0.0016	1 × 10 <sup>-9</sup>	Kumaran (2002)
Particleboard	0.044	0.344	0.90	1.70	2.75			Kumaran (1996)
Douglas fir plywood, 12 mm, 470 kg/m <sup>3</sup>		4.4	6.0	10.2	15.2	0.0042 <sup>d</sup>	4 × 10 <sup>-11</sup>	Kumaran (2002)
15 mm, 550 kg/m <sup>3</sup>	0.19	0.59	1.46	3.19	6.50	0.0031	1 × 10 <sup>-9</sup>	Kumaran (2002)
Canadian softwood plywood, 18 mm, 445 kg/m <sup>3</sup>	0.15	0.41	1.09	2.91	7.99	0.0037	2 × 10 <sup>-11</sup>	Kumaran (2002)
Plywood (exterior-grade), 12 mm, 580 kg/m <sup>3</sup>	0.06	0.57	2.28	6.12	13.30			Burch et al.
Wood fiber board, 11 mm, 320 kg/m <sup>3</sup>	0.21	0.36		0.80	8.62	0.00094	2.5 × 10 <sup>-7</sup>	Kumaran (2002)
25 mm, 300 kg/m <sup>3</sup>	12.4	13.6	15.0	16.4	18.1			Burch and Desjarlais (1995)
71.5	58.4		86.7	77.2				
<b>Masonry Materials</b>								
Aerated concrete, 460 kg/m <sup>3</sup>	11.2	15.9	22.9	33.4	50	0.036	5 × 10 <sup>-9</sup>	Kumaran (2002)
600 kg/m <sup>3</sup>	18	21.6	22	42	63			Kumaran (1996)
Cement mortar, 1600 kg/m <sup>3</sup>	13.6	16.5	20.1	24.5	30.2	0.02	1.5 × 10 <sup>-9</sup>	Kumaran (2002)
Clay brick, 100 by 100 by 200 mm, 1980 kg/m <sup>3</sup>	4.14	4.44	4.77	5.12	5.50	0.17	2 to 5 × 10 <sup>-10</sup>	Kumaran (2002)
Concrete, 2200 kg/m <sup>3</sup>		1.26	1.4	2.5	6.5			Kumaran (1996)
Concrete block (cored, limestone aggregate), 200 mm	← 27.4 →			← 18.7 →				Kumaran (1996)
Lightweight concrete, 1100 kg/m <sup>3</sup>		12.3		11.4	18.7	0.00033	negligible	Kumaran (2002)
Limestone, 2500 kg/m <sup>3</sup>	0.26	0.26	0.26	0.26	0.26			Kumaran (1996)
Perlite board		28		33	82			Kumaran (1996)
Plaster, on metal lath, 19 mm	← 16.3 →			← 21.7 →				
on wood lath	← 12.0 →			← 21.7 →				
on plain gypsum lath (with studs)	← 21.7 →			← 2.7 →				
Polystyrene concrete, 530 kg/m <sup>3</sup>		0.88		1.1	2.7			Kumaran (1996)
Portland stucco mix, 1985 kg/m <sup>3</sup>	0.81	1.15	1.63	2.31	3.26	0.012	1 × 10 <sup>-11</sup>	Kumaran (2002)
Tile masonry, glazed, 100 mm	← 0.69 →			← 2.7 →				
<b>Woods</b>								
Eastern white cedar, 20 mm, 360 kg/m <sup>3</sup> (transverse)	0.013	0.078	0.48	3.05	20.9	0.0016	negligible	Kumaran (2002)
Eastern white pine, 19 mm, 460 kg/m <sup>3</sup> (transverse)	0.47	0.17	0.67	2.58	10.2	0.0066	1 × 10 <sup>-12</sup>	Kumaran (2002)
Pine	0.35	0.51	1.1	3.1	6.3			Kumaran (1996)
Southern yellow pine, 20 mm, 350 kg/m <sup>3</sup> (transverse)	0.12	0.404	1.37	4.7	16.9	0.0014	3 × 10 <sup>-11</sup>	Kumaran (2002)
Spruce (longitudinal)	53	74	84	86	87			Kumaran (1996)
20 mm, 400 kg/m <sup>3</sup> (transverse)	0.37	1.08	3.13	9.27	29.5	0.002	5 × 10 <sup>-11</sup>	Kumaran (2002)
Western red cedar, 18 mm, 350 kg/m <sup>3</sup> (transverse)	0.106	0.228	0.491	1.06	2.29	0.001	<1 × 10 <sup>-12</sup>	Kumaran (2002)
<b>Insulation</b>								
Air (still)	← 174 →			← 250 →				
Cellular glass	← 0.0 →			← 178 →				
Cellulose insulation, dry blown, 30 kg/m <sup>3</sup>	112	140	156	168	178	0.1	2.9 × 10 <sup>-4</sup>	Kumaran (2002)
Corkboard		3.0 to 3.8		14				
Glass fiber batt, 11.5 kg/m <sup>3</sup>	172	172	172	172	172	N/A	2.5 × 10 <sup>-4</sup>	Kumaran (2002)
Glass-fiber insulation board, 24 mm, 120 kg/m <sup>3</sup> facer, 1.6 mm, 880 kg/m <sup>3</sup>		238		152				Burch et al.
Mineral fiber insulation, 30 to 190 kg/m <sup>3</sup>	0.004	0.00251		0.0184	0.0389			Burch et al.
Mineral wool (unprotected)		70		88	250			Kumaran (1996)
	← 245 →			← 250 →				

Table 8 Water Vapor Permeability of Building Materials at Various Relative Humidities (Continued)

Material	Permeability at Various Relative Humidities, ng/(Pa·s·m)					Water Absorption Coefficient, (kg·s <sup>2</sup> )/m <sup>2</sup>	Mean Air Permeability, kg/(Pa·s·m)	References/ Comments
	10%	30%	50%	70%	90%			
Phenolic foam (covering removed)	←————— 38 —————→							
Polystyrene								
expanded, 14.8 kg/m <sup>3</sup>	2.85	3.36	3.96	4.66	5.50	N/A	1.1 × 10 <sup>-8</sup>	Kumaran (2002)
extruded, 28.6 kg/m <sup>3</sup>	1.22	1.22	1.22	1.22	1.22	N/A		Kumaran (2002)
Polyurethane								
expanded board stock [(R = 1.94 W)/(m <sup>2</sup> ·K)]	0.58 to 2.3							
sprayed foam, 39.0 kg/m <sup>3</sup>	2.34	2.54	2.75	2.97	3.22	N/A	1 × 10 <sup>-11</sup>	Kumaran (2002)
6.5 to 8.5 kg/m <sup>3</sup>	87.5	87.5	87.5	87.5	87.5	N/A	4.2 × 10 <sup>-9</sup>	Kumaran (2002)
Polyisocyanurate insulation, 26.5 kg/m <sup>3</sup>	4.04	4.56	5.14	5.80	6.55	N/A		Kumaran (2002)
Polyisocyanurate glass-mat facer, 0.8 mm, 430 kg/m <sup>3</sup>	0.49	0.90		1.30	2.29			Burch et al.
Structural insulating board, sheathing quality	←————— 29 to 73 —————→							
interior, uncoated, 13 mm	←————— 37.2 to 67 —————→							
Unicellular synthetic flexible rubber foam	0.029							
<b>Foil, Felt, Paper</b>								
Bituminous paper (#15 felt), 0.72 mm, 515 g/m <sup>2</sup> (transverse)	0.29	0.29	0.29	0.40	1.17	0.0005	2.5 × 10 <sup>-6</sup>	Kumaran (2002)
Asphalt-impregnated paper								
10 min rating, 0.2 mm, 170 g/m <sup>2</sup> (transverse)	0.24	0.43	0.78	1.48	3.06	0.001	1.1 × 10 <sup>-6</sup>	Kumaran (2002)
30 min rating, 0.22 mm, 200 g/m <sup>2</sup> (transverse)	0.44	0.74	1.28	2.31	4.67	0.093	6.6 × 10 <sup>-6</sup>	Kumaran (2002)
60 min rating, 0.34 mm, 280 g/m <sup>2</sup> (transverse)	1.51	1.91	2.44	3.18	4.24	0.0011	7.1 × 10 <sup>-6</sup>	Kumaran (2002)
Spun bonded polyolefin (SBPO)								
0.14 to 0.15 mm, 65 g/m <sup>2</sup> (transverse)	4.37	4.37	4.37	4.37	4.37	0.00031	4.6 × 10 <sup>-7</sup>	Kumaran (2002)
with crinkled surface, 0.1 to 0.11 mm, 67 g/m <sup>2</sup> (transverse)	3.17	3.17	3.17	3.17	3.17	0.00024	3 × 10 <sup>-7</sup>	Kumaran (2002)
Wallpaper								
paper		0.12		1.2 to 1.7				Kumaran (1996)
textile		0.05		0.74 to 2.34				Kumaran (1996)
vinyl, 0.205 mm, 170 g/m <sup>2</sup> (transverse)	0.08	0.14	0.21	0.32	0.46	0.00025	5 × 10 <sup>-9</sup>	Kumaran (2002)
<b>Other Construction Materials</b>								
Built-up roofing (hot-mopped)	←————— 0.0 —————→							
Exterior insulated finish system (EIFS), 4.4 mm acrylic, 1140 kg/m <sup>3</sup>	0.09	0.09	0.09	0.09	0.09	0.00053	0	Kumaran (2002)
Glass fiber reinforced sheet, acrylic, 1.4 mm	←————— 0.01 —————→							
polyester, 1.2 mm	←————— 0.035 —————→							

\*Historical data, no references available

N/A – Not applicable