National Exams May 2016

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: (20 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 when moist air is in contact with surfaces with temperature above its dew point.		
3	The SHGC of window is not only influenced by the properties of glazing but also the configuration of window frame.		
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	The principal function of a vapour barrier is to stop or, more accurately, to retard the passage of moisture as it diffuses through the assembly of materials in a wall, so the vapor barrier must be continuous.		
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 air leakage through a building enclosure and a generally downward movement of air within a building in cold weather.		

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.		
16	For hygroscopic materials, their vapour permeability changes with the change of ambient relative humidity. Typically the vapour permeability increases with the decrease of relative humidity.		
17	Lack of movement joints often results in cracks in brick veneer walls, especially at corners.		
18	An air barrier can also function as water resistive barrier, vapour retarder, thermal insulation.		
19	By filling the double IGU with Argon gas can significantly increase its thermal resistance.		
20	When the water content level of brick is under its critical degree of saturation, S_{crit}, frost damage won't occur regardless of the number of freeze/thaw cycles the brick is exposed to.		

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 R40 (RSI 7.0) 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 (16 marks)

Five meter wide, dark gray, precast concrete spandrel panels are to be used on a building with allowance made for lateral expansion and contraction. The panels are anchored at the middle point, as shown in Figure 1. This building is located in Montreal.

1) What is the maximum movement this concrete panel experiences? Assume the design winter temperature is -25°C and the maximum cladding temperature is 65°C. The coefficient of linear thermal expansion and contraction of concrete is 11.7 $\times 10^{-6}/°C$.
2) What would be the minimum vertical joint width if a sealant with a movement capacity of ±25% is applied at the annual mean temperature.
3) What would be the minimum vertical joint width is a sealant with a movement capacity of ±25% is applied at 5°C.

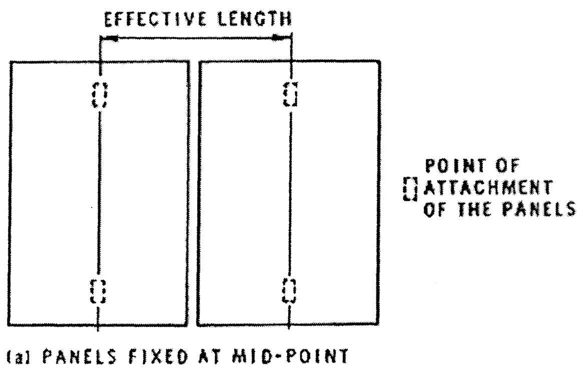
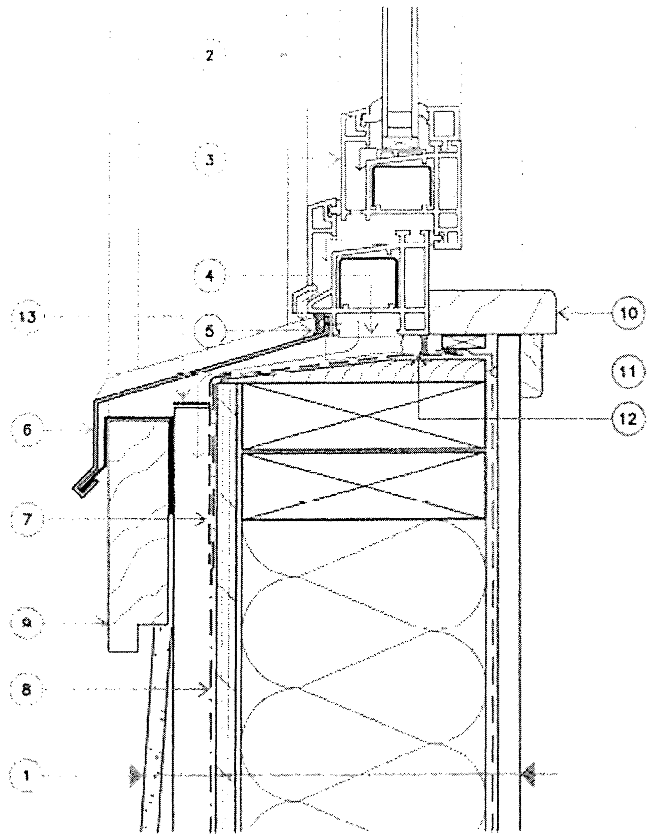


Figure 1

4) Sketch the vertical joint and label all components and comment on the requirements of the relative dimensions of this joint.
5) Explain what sealant failures it would result if the joint is too wide or too deep
6) 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)

Figure below shows a typical window/wall connection detail. Explain how the rainwater is managed in this design.



LEGEND

1. Wall Assembly
   - Cladding (cementitious siding)
   - 19mm (¾") wood strapping (p.t.)
   - Vapour permeable sheathing membrane
   - Sheathing
   - Wood framing 38x140mm (2x6) with batt insulation
   - Polyethylene
   - Gypsum board
2. Sealant beyond
3. Window assembly
4. Intermittent shim
5. Sealant
6. Pre-finished metal flashing with end dam
7. Foil-face membrane
8. Vapour permeable sheathing membrane
9. Exterior wood trim
10. Interior window trim
11. Sloped blocking
12. Sealant & backer rod
13. Insect screen

Question 4 (20 marks)

Design a low-slope, exposed membrane roofing assembly for a warehouse building located in Toronto. The primary membrane is to be Modified Bitumen (SBS). This warehouse has a brick veneer steel stud wall assembly.

1) Sketch the roof/wall junction and label the main components for both the roof and the wall;

2) List the potential failures of a low-slope roof with Modified Bitumen membrane and elaborate on how to prevent these failures.

Question 5 (20 marks):

1. (**10 marks**) The deteriorated brick shown in photo A was found under the coping in photo B. The cross section of the coping is shown in photo C.

   a) Explain the cause and mechanism which led to this deterioration of the brick,

   b) Outline the deficiencies of the design detail of this coping, and

   c) Draw the cross section of an effective coping and parapet.

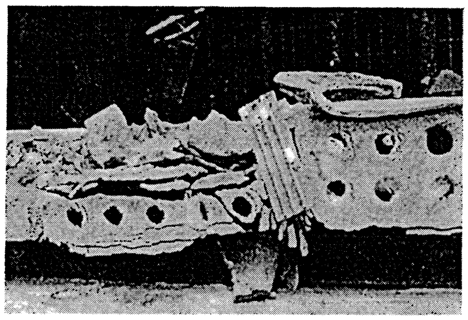


Photo A

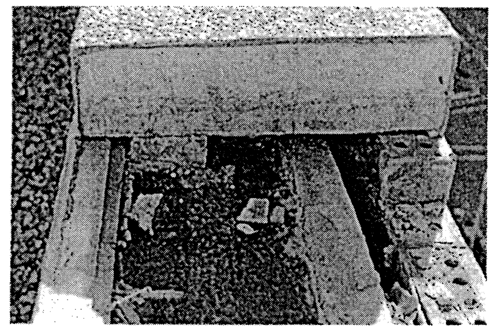


Photo C

Photo B

2) (**5 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.

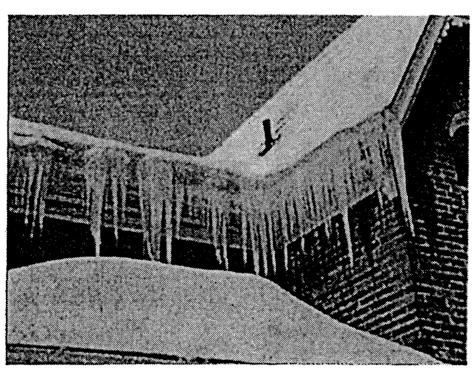


Photo 2

3. (**5 marks**). As shown in the photo below, cracks and spalling of bricks are noted at the corner of this brick veneer wall. Explain what has potentially contributed to this failure and what should have been done to avoid such a failure.

Photo 3

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.

The Brick Is Falling

Courtesy the author

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

By David H. Nicastro

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 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.

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^2·Pa), $M = \frac{\overline{\mu}}{l}$

θ = time during which flow occurs, s

l = thickness, m

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

A = cross-section area of the flow path, m^2

$(p_1 - p_2)$ = 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^2

U = overall coefficient of heat transmission, W/(m^2·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)

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

Table 4 Typical Thermal Properties of Common Building and Insulating Materials: Design Values[a] (*Continued*)

Description	Density, kg/m³	Conductivity[b] k, W/(m·K)	Resistance R, (m²·K)/W	Specific Heat, kJ/(kg·K)	Reference[e]
Finish Flooring Materials					
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)
Linoleum/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)
Terrazzo.. 25 mm	—	—	0.014	0.80	
Insulating Materials					
Blanket and batt[c,d]					
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)
Board and slabs					
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 tile[g]..	290	0.050	—	0.80	
....	335	0.053	—	—	
wet-molded, acoustical tile[g]..................................	370	0.061	—	0.59	
Perlite board...	160	0.052	—	—	Kumaran (1996)
Polyisocyanurate, aged					
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)
Loose fill					
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)
Mineral fiber (rock, slag, or glass)[d]........................					
...................................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	—	
Vermiculite, exfoliated...	110 to 130	0.068	—	1.34	Sabine et al. (1975)
....	64 to 96	0.063	—	—	(Manufacturer)
Spray-applied					
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)
Polyurethane foam (low density)..............................	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	—	3.60	—	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) 10%	30%	50%	70%	90%	Water Absorption Coefficient, $(kg\cdot s^{1/2})/m^2$	Mean Air Permeability, kg/(Pa·s·m)	References/ Comments
Building Board and Siding								
Asbestos cement board, 3 mm thickness	←	0.66 to 1.37	→	← N/A	→			Dry cup[a]
with oil-base finishes	←	0.05 to 0.09	→	← N/A	→			
Cement board, 13 mm, 1130 kg/m³	7.4	7.4	9.3	12	16	0.013	3×10^{-8}	Kumaran (2002)
Fiber cement board, 8 mm, 1380 kg/m³	0.21	0.58	1.6	4.7	14.8	0.025	3×10^{-12}	Kumaran (2002)
Gypsum board		21		23	30			Kumaran (1996)/NRC
asphalt impregnated	←		0.038		→			
Gypsum wall board, 13 mm, 625 kg/m³	23.4	27.2	31.9	37.6	44.7	0.0019[c]	4.2×10^{-9}	Kumaran (2002)
with one coat primer	6.83	14.9	22.0	28.9	35.9	N/A	2.2×10^{-8}	Kumaran (2002)
with one coat primer/two coats latex paint	1.1	2.1	4.0	8.0	16.5	N/A	2.5×10^{-9}	Kumaran (2002)
Hardboard siding, 11 mm, 740 kg/m³	3.92	4.28	4.67	5.10	5.58	0.00072	4.5×10^{-9}	Kumaran (2002)
Oriented strand board (OSB), 9.5 mm, 660 kg/m³	0.0064	0.177	0.487	1.35	3.83	0.0016	1×10^{-9}	Kumaran (2002)
11.1 mm	0.026	0.60	1.23	2.30	4.08	0.0022	2×10^{-9}	Kumaran (2002)
12.7 mm	0.044	0.344	0.90	1.70	2.75	0.0016	1×10^{-9}	Kumaran (2002)
Particleboard		4.4	6.0	10.2	15.2			Kumaran (1996)
Douglas fir plywood, 12 mm, 470 kg/m³	0.19	0.59	1.46	3.19	6.50	0.0042[d]	4×10^{-11}	Kumaran (2002)
15 mm, 550 kg/m³	0.15	0.41	1.09	2.91	7.99	0.0031	1×10^{-9}	Kumaran (2002)
Canadian softwood plywood, 18 mm, 445 kg/m³	0.06	0.57	2.28	6.12	13.30	0.0037	2×10^{-11}	Kumaran (2002)
Plywood (exterior-grade), 12 mm, 580 kg/m³	0.21	0.36		0.80	8.62			Burch et al.
Wood fiber board, 11 mm, 320 kg/m³	12.4	13.6	15.0	16.4	18.1	0.00094	2.5×10^{-7}	Kumaran (2002)
25 mm, 300 kg/m³	71.5	58.4		86.7	77.2			Burch and Desjarlais (1995)
Masonry Materials								
Aerated concrete, 460 kg/m³	11.2	15.9	22.9	33.4	50	0.036	5×10^{-9}	Kumaran (2002)
600 kg/m³	18	21.6	22	42	63			Kumaran (1996)
Cement mortar, 1600 kg/m³	13.6	16.5	20.1	24.5	30.2	0.02	1.5×10^{-9}	Kumaran (2002)
Clay brick, 100 by 100 by 200 mm, 1980 kg/m³	4.14	4.44	4.77	5.12	5.50	0.17	2 to 5×10^{-10}	Kumaran (2002)
Concrete, 2200 kg/m³		1.26	1.4	2.5	6.5			Kumaran (1996)
Concrete block (cored, limestone aggregate), 200 mm	←		27.4		→			
Lightweight concrete, 1100 kg/m³		12.3		11.4	18.7			Kumaran (1996)
Limestone, 2500 kg/m³	0.26	0.26	0.26	0.26	0.26	0.00033	negligible	Kumaran (2002)
Perlite board		28		33	82			Kumaran (1996)
Plaster, on metal lath, 19 mm	←		16.3		→			
on wood lath	←		12.0		→			
on plain gypsum lath (with studs)	←		21.7		→			
Polystyrene concrete, 530 kg/m³		0.88		1.1	2.7			Kumaran (1996)
Portland stucco mix, 1985 kg/m³	0.81	1.15	1.63	2.31	3.26	0.012	1×10^{-11}	Kumaran (2002)
Tile masonry, glazed, 100 mm	←		0.69		→			
Woods								
Eastern white cedar, 20 mm, 360 kg/m³ (transverse)	0.013	0.078	0.48	3.05	20.9	0.0016	negligible	Kumaran (2002)
Eastern white pine, 19 mm, 460 kg/m³ (transverse)	0.47	0.17	0.67	2.58	10.2	0.0066	1×10^{-12}	Kumaran (2002)
Pine	0.35	0.51	1.1	3.1	6.3			Kumaran (1996)
Southern yellow pine, 20 mm, 350 kg/m³ (transverse)	0.12	0.404	1.37	4.7	16.9	0.0014	3×10^{-11}	Kumaran (2002)
Spruce (longitudinal)	53	74	84	86	87			Kumaran (1996)
20 mm, 400 kg/m³ (transverse)	0.37	1.08	3.13	9.27	29.5	0.002	5×10^{-11}	Kumaran (2002)
Western red cedar, 18 mm, 350 kg/m³ (transverse)	0.106	0.228	0.491	1.06	2.29	0.001	$<1 \times 10^{-12}$	Kumaran (2002)
Insulation								
Air (still)	←		174		→			
Cellular glass	←		0.0		→			
Cellulose insulation, dry blown, 30 kg/m³	112	140	156	168	178	0.1	2.9×10^{-4}	Kumaran (2002)
Corkboard		3.0 to 3.8		14				
Glass fiber batt, 11.5 kg/m³	172	172	172	172	172	N/A	2.5×10^{-4}	Kumaran (2002)
Glass-fiber insulation board, 24 mm, 120 kg/m³		238			152			Burch et al.
facer, 1.6 mm, 880 kg/m³	0.004	0.00251		0.0184	0.0389			Burch et al.
Mineral fiber insulation, 30 to 190 kg/m³		70		88	250			Kumaran (1996)
Mineral wool (unprotected)	←		245		→			

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

Material	Permeability at Various Relative Humidities, ng/(Pa·s·m) 10%	30%	50%	70%	90%	Water Absorption Coefficient, $(kg \cdot s^{1/2})/m^2$	Mean Air Permeability, kg/(Pa·s·m)	References/ Comments
Phenolic foam (covering removed)	←		38		→			
Polystyrene								
expanded, 14.8 kg/m^3	2.85	3.36	3.96	4.66	5.50	N/A	1.1×10^{-8}	Kumaran (2002)
extruded, 28.6 kg/m^3	1.22	1.22	1.22	1.22	1.22	N/A		Kumaran (2002)
Polyurethane								
expanded board stock [(R = 1.94 $W/(m^2 \cdot K)$]		0.58 to 2.3						
sprayed foam, 39.0 kg/m^3	2.34	2.54	2.75	2.97	3.22	N/A	1×10^{-11}	Kumaran (2002)
6.5 to 8.5 kg/m^3	87.5	87.5	87.5	87.5	87.5	N/A	4.2×10^{-9}	Kumaran (2002)
Polyisocyanurate insulation, 26.5 kg/m^3	4.04	4.56	5.14	5.80	6.55	N/A		Kumaran (2002)
Polyisocyanurate glass-mat facer, 0.8 mm, 430 kg/m^3	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						
Foil, Felt, Paper								
Bituminous paper (#15 felt), 0.72 mm, 515 g/m^2 (transverse)	0.29	0.29	0.29	0.40	1.17	0.0005	2.5×10^{-6}	Kumaran (2002)
Asphalt-impregnated paper								
10 min rating, 0.2 mm, 170 g/m^2 (transverse)	0.24	0.43	0.78	1.48	3.06	0.001	1.1×10^{-6}	Kumaran (2002)
30 min rating, 0.22 mm, 200 g/m^2 (transverse)	0.44	0.74	1.28	2.31	4.67	0.093	6.6×10^{-6}	Kumaran (2002)
60 min rating, 0.34 mm, 280 g/m^2 (transverse)	1.51	1.91	2.44	3.18	4.24	0.0011	7.1×10^{-6}	Kumaran (2002)
Spun bonded polyolefin (SBPO)								
0.14 to 0.15 mm, 65 g/m^2 (transverse)	4.37	4.37	4.37	4.37	4.37	0.00031	4.6×10^{-7}	Kumaran (2002)
with crinkled surface, 0.1 to 0.11 mm, 67 g/m^2 (transverse)	3.17	3.17	3.17	3.17	3.17	0.00024	3×10^{-7}	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^2 (transverse)	0.08	0.14	0.21	0.32	0.46	0.00025	5×10^{-9}	Kumaran (2002)
Other Construction Materials								
Built-up roofing (hot-mopped)	←		0.0		→			
Exterior insulated finish system (EIFS), 4.4 mm acrylic, 1140 kg/m^3	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 reference available N/A – Not applicable