National Exams May 2017

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, charts, 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 diffused 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 at temperature above its dew point.		
3	The SHGC of window is not only influenced by the properties of glazing but also the configuration of the window frame.		
4	Moisture induced dimensional change is the greatest along the longitudinal direction in wood.		
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	A low-sloped roof must have a minimum slope of 5%		
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 may be placed anywhere in the building envelope as long as it is structurally supported and does not need to be continuous.		
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	The optimum glazing cavity thickness is ½" (12.5mm) for both Argon and Krypton gas filling in a double IGU.		
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	Blisters in built-up roof are more frequently *interfacial* than *interply*.		
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 2x6 wood-frame brick veneer wall 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)
- 12.5mm gypsum board (RSI 0.08)

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 framing factor of 25% can be assumed in the calculation.
2) Is there any condensation due to vapour diffusion? If so, where would the condensation occur? Calculate the condensation rate.
3) To avoid vapour diffusion induced condensation within the wall assembly, what is the required minimum vapour resistance of the vapour retarder?

In your calculation, you can assume a RSI 0.12 for the interior surface film thermal resistance, a RSI 0.03 for the exterior surface film thermal resistance. The indoor conditions are kept at 22°C dry-bulb and 40% rh and the outdoor temperature is at -10°C and 80%rh. Material properties and water vapour saturation pressures are provided in the appendix.

Question 3 (20 marks)

Design a low-slope, exposed membrane roofing assembly for a warehouse building located in Toronto. The primary membrane is Modified Bitumen (SBS). This warehouse has a brick veneer steel stud wall assembly with concrete roof deck and concrete floor slab.

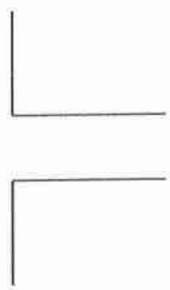
1) Sketch the roof/wall junction and label the main components for both the roof and the wall;

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

Question 4 (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 (8 marks)

1) List four forces that can cause rain penetration through building envelopes and explain how to counter these forces in the design with the help of sketches.
2) Name three commonly used water resistive barrier (WRB) materials, three insulation materials, and three vapour retarder materials.
3) List the requirements for an air barrier system.

Question 5 (20 marks):

Part A (10 marks)

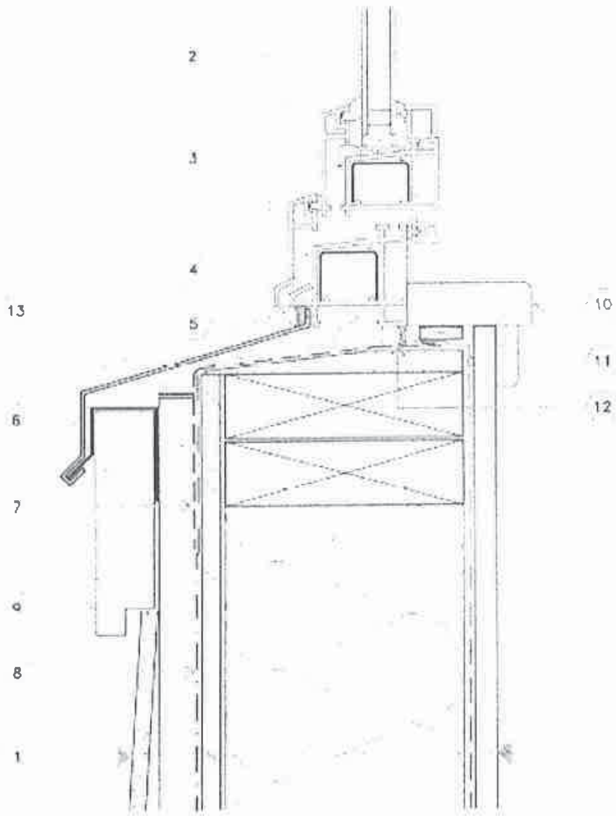
Windows with a temperature index of 50 are installed in a house located in Toronto and the indoor conditions are kept at 21°C and 40%rh. The temperature index of these windows is determined under standard test conditions of -18°C outdoor and 21°C indoor. Will there be any condensation on the window surfaces under the Mean January temperature of -12°C? If yes, how to solve the problem?

Part B (10 marks)

The figure below shows a typical window/wall connection detail. The exterior air barrier approach is used, in which the sealed sheathing membrane functions as the air barrier.

1) Use color pen to highlight the air barrier, vapour barrier, water resistive barrier, and rainwater shedding layer on the drawing. For each critical layer, list the components.

2) Explain how the window manages rainwater.



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 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

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.

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

By David H. Nicastro

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. ◆

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Appendix: equations

- Vapor flow equation:

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

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

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

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

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

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

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

- Temperature index:

$$I_{\text{minimum}} = (\frac{T_s - T_e}{T_i - T_e}) \times 100$$

where, T_s-glass surface temperature, °C

T_e-outdoor temperature, °C

T_i-indoor temperature, °C

Table 1. Material properties

Materials	Vapour permeability (ng/m s Pa)	Vapour permeance (ng/m^2 s Pa)
Exterior brick	5.12	
Air space		6960
Tyvek	4.37	
Plywood sheathing	0.8	
Fiberglass insulation	172	
Gypsum board	21	

Table 2:

Water-Vapour Pressures at Saturation at Various Temperatures over Plane Surfaces of Pure Water and Pure Ice

Temp., °C	Pressure, Pa Over ice	Pressure, Pa Over water	Temp., °C	Pressure, Pa Over ice	Pressure, Pa Over water	Temp., °C	Press., kPa	Temp., °C	Press., kPa
−50	3.935	6.409	−22	85.02	105.4	5	0.8719	33	5.031
−49	4.449	7.124	−21	93.70	115.0	6	0.9347	34	5.320
−48	5.026	7.975	−20	103.2	125.4	7	1.001	35	5.624
−47	5.671	8.918	−19	113.5	136.6	8	1.072	36	5.942
−46	6.393	9.961	−18	124.8	148.8	9	1.147	37	6.276
−45	7.198	11.11	−17	137.1	161.9	10	1.227	38	6.626
−44	8.097	12.39	−16	150.6	176.0	11	1.312	39	6.993
−43	9.098	13.79	−15	165.2	191.2	12	1.402	40	7.378
−42	10.21	15.34	−14	181.1	207.6	13	1.497	41	7.780
−41	11.45	17.04	−13	198.4	225.2	14	1.598	42	8.202
−40	12.83	18.91	−12	217.2	244.1	15	1.704	43	8.642
−39	14.36	20.97	−11	237.6	264.4	16	1.817	44	9.103
−38	16.06	23.23	−10	259.7	286.3	17	1.937	45	9.586
−37	17.94	25.71	−9	283.7	309.7	18	2.063	46	10.09
−36	20.02	28.42	−8	309.7	334.8	19	2.196	47	10.62
−35	22.33	31.39	−7	337.9	361.8	20	2.337	48	11.17
−34	24.88	34.63	−6	368.5	390.6	21	2.486	49	11.74
−33	27.69	38.18	−5	401.5	421.5	22	2.643	50	12.33
−32	30.79	42.05	−4	437.2	454.5	23	2.809	51	12.96
−31	34.21	46.28	−3	475.7	489.8	24	2.983	52	13.61
−30	37.98	50.88	−2	517.3	527.5	25	3.167	53	14.29
−29	42.13	55.89	−1	562.3	567.8	26	3.361	54	15.00
−28	46.69	61.39	0	610.8	610.8	27	3.565	55	15.74
−27	51.70	67.27	+0.01	Triple point of water		28	3.780	56	16.51
−26	57.20	73.71	1	—	656.6	29	4.006	57	17.31
−25	63.23	80.70	2	—	705.5	30	4.243	58	19.15
−24	69.85	88.27	3	—	757.5	31	4.493	59	19.02
−23	77.09	96.49	4	—	812.9	32	4.755	60	19.92

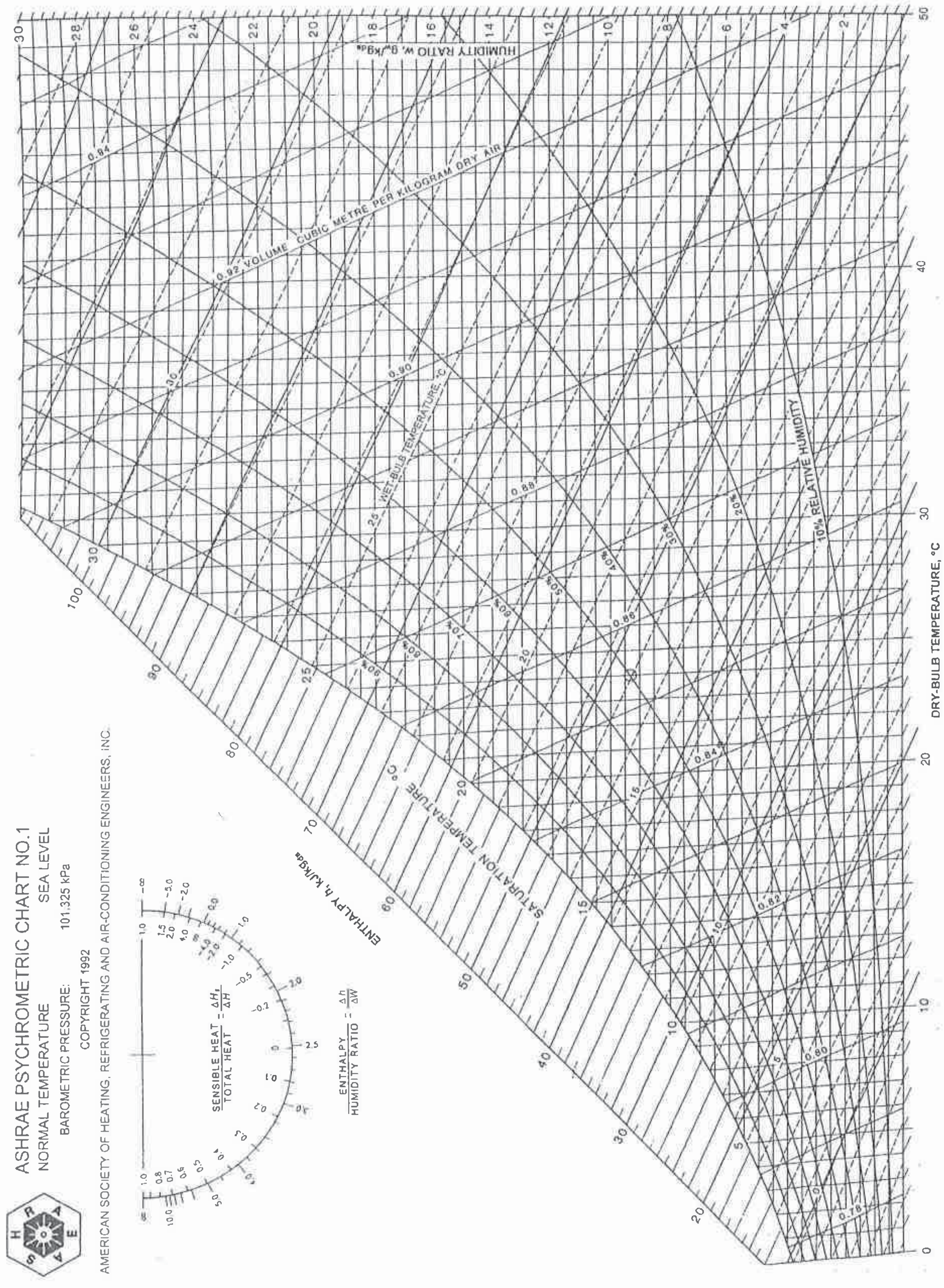

Fig. 1 ASHRAE Psychrometric Chart No. 1