National Exams May 2011

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 approved calculator is permitted.

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)

A four-storey wood-frame residential building in Vancouver was built with a face-seal stucco wall. The wall assembly is made up of the following components:

- 19mm acrylic stucco
- 3-ply (2mm) semi-rigid asphalt breather board
- one layer of Tyvek water barrier membrane, 0.2mm
- 12.5 mm plywood sheathing
- 100mm glass fiber insulation
- 4mil (0.1mm) polyethylene film
- 12.5mm gypsum board.

For a cold winter day: outdoor at -5°C, 80%rh and indoor at 21°C, 35%rh

1) Is there any condensation within this wall assembly? If so, where does the condensation occur and what is the condensation rate? Support your answer with calculation.
2) If an amount of $6.7\times10^{-4} m^3/s\cdot m^2$ air exfiltration occurs at the top floor due to stack effect, would there be any condensation within the wall assembly? If so, where does it occur and what is the maximum condensation rate?
3) The owner had to rehabilitate the building envelope because of moisture damage caused by rain penetration. A rainscreen stucco wall is proposed with a 19mm air cavity added behind the stucco. To improve the thermal performance, a 2" expanded polystyrene board is added outboard of the plywood sheathing. The air exfiltration amount through the top floor wall assembly is reduced to $4\times10^{-4} m^3/s\cdot m^2$. Would there be any condensation caused by air exfiltration within the new wall assembly? If so, where does it occur and what is the maximum condensation rate. Support your answer with calculation.

Use the material properties listed in Table 1 for calculation.

Question 2 (20 marks):

A curtain wall office building built in early 80's used clear double-glazed units as vision panel. A ceiling mounted air diffuser, located in the middle of the room, provides heating, cooling and ventilation to the offices in the perimeter zone. During a cold spell, the outdoor temperature dropped to -18°C for a few days. The temperature at the edge-of-glass (the perimeter of the windows, refer to Figure. a) dropped to about 1°C. The distribution of temperatures on the interior surface of the window is shown in Figure b.

The office conditions were maintained at 21°C and 35%rh.

1) Was there any condensation on the windows? If so, mark the areas with condensation on Figure b and explain with the aid of the psychrometric chart.
2) To avoid any condensation to occur, what would you suggest to do?
3) To improve the energy performance, the owner decided to retrofit the vision panels with low-e coating and Argon filled Insulated Glazing Unit (IGU). The old IGUs have a U-value of $2.8 W/m^{2}{}^{o}C$ and Solar Heat Gain Coefficients (SHGC) of 0.7. The new IGUs have a U-value of $1.6 W/m^{2}{}^{o}C$ and SHGC of 0.5. Assume the average solar radiation is $1000 Wh/m^2/day$ and the daily average outdoor temperature is -15°C during this cold spell. What is the net improvement in term of heat loss achieved by retrofitting the existing IGUs during this cold spell?

4) Sketch a vertical section of glass/aluminum curtain wall showing the junction between vision and spandrel panel and explain how the curtain wall controls heat transfer, air leakage, and vapor diffusion, and rain penetration.

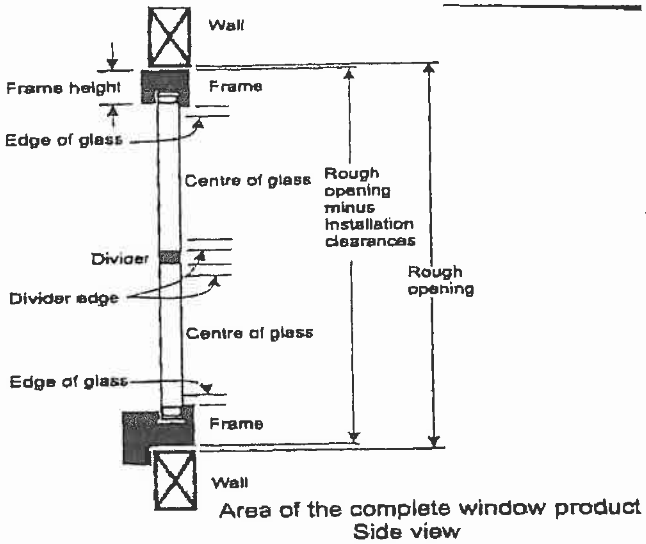


Fig. a: window components

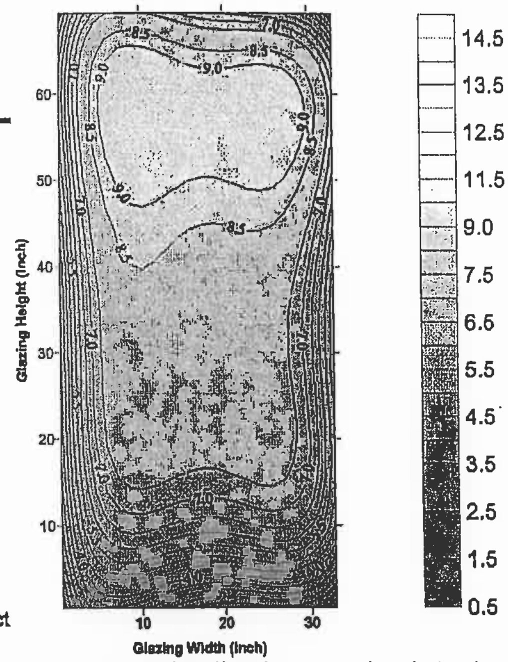


Fig. b: Temperature distribution on the interior surface of a clear double glazed unit when outdoor temperature is -18°C and indoor at 21°C.

Question 3 (20marks)

Part A (12 marks):

Ten meter wide, dark gray, precast concrete spandrel panels are to be used on a building with allowance made for lateral expansion and contraction at one of the two structural connections. This building is located in Toronto.

1) What is the maximum temperature experienced by the concrete panel? Assume the wall receives 800W/m^2 solar radiation in a summer day with outdoor temperature of 29°C. The soar absorptance of the dark gray surface is 0.8 and the outdoor heat transfer coefficient is 20W/m^{2o}C for a clam day.

2) What is the maximum movement this concrete panel experiences? Assume the design winter temperature is -20°C. The coefficient of linear thermal expansion and contraction of concrete is 11.7 x10^{-6}/°C.

3) What would be the minimum vertical joint width if a sealant having a movement capacity of ±25% is proposed.

Part B (8 marks):

1) Make a sketch of the vertical joint and label all components and comment on the requirements of the relative dimensions of this joint.

2) Explain the difference between an expansion joint and a control joint with the help of sketches.

Question 4 (20 marks)

Part A (5 marks):

In the photo shown below (Figure a), note that icicles are formed at the eaves of a sloped roof. Please explain what has caused it and how to avoid such a problem.

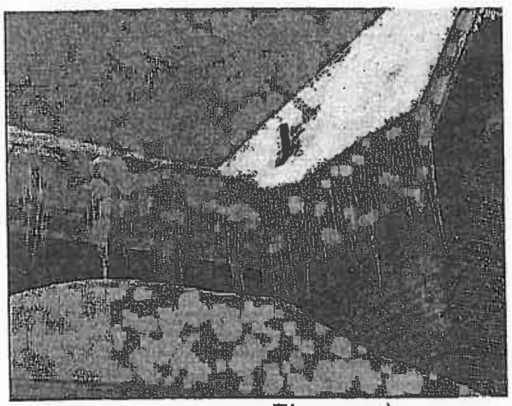


Figure a)

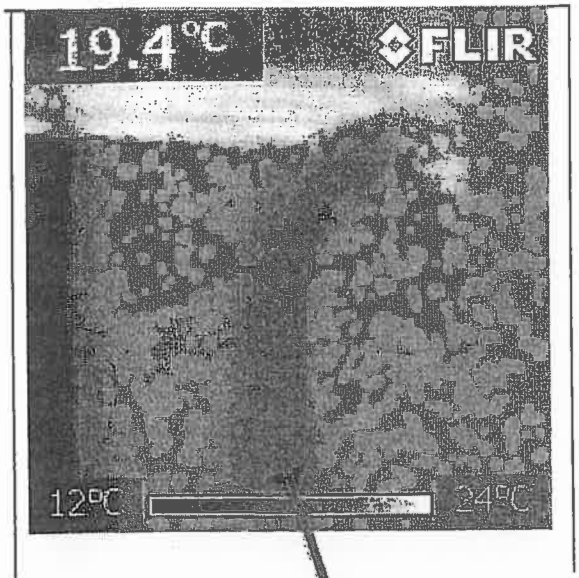
Figure b)

Part B (5 marks):

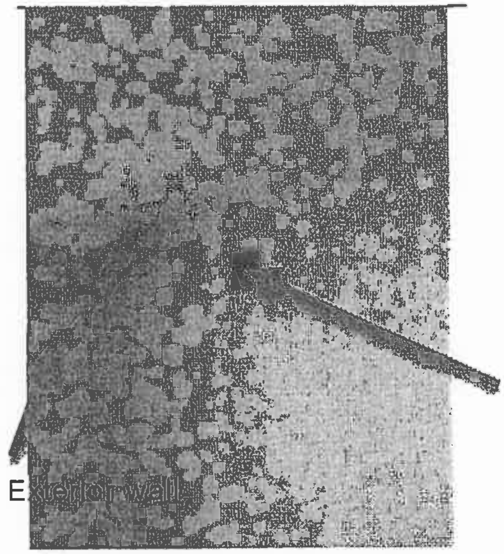
Figure b) shows the interior surface of a solid brick wall in a three-story single-family house. Please note the white deposition on the interior surface of brick, especially at the mortar. What is it and what could have possibly caused it and how to correct the problem?

Part C (5 marks):

Figure c1) shows the IR image of a room with a ceiling mounted radiant heating system in a two-story single-family house. Figure C2 shows the corresponding photo of the room. As shown in Figure C1, a cold area is identified on the IR image of the interior wall. The temperature of the colder area is about 19.4°C and the rest of the interior wall is at about 21°C. Please explain what has possibly caused the existence of a colder area on the IR image of the interior wall? How to solve the problem?



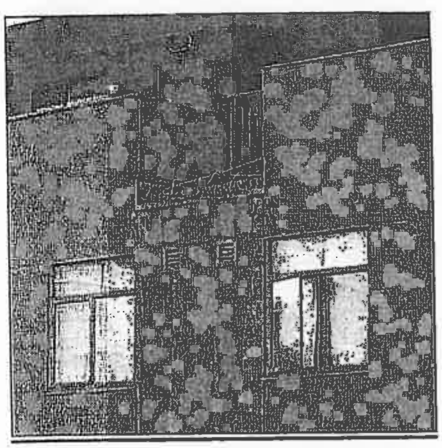
Cold area



Fresh air outlet on the interior wall

Figure C1. IR image of the interior surfaces. Figure C2. Photo of the room.

Part D (5 marks)
The photo below shows a 4-storey wood-frame building constructed with face-seal stucco walls. Note the rainwater runoff shown in the photo. Identify design defects, comment on the potential consequences of this rainwater runoff and how to solve the problem.



Question 5 (20 marks):

Part A (10 marks):
Sketch a vertical cross-section of a brick veneer cavity wall with steel stud including the roof and floor section.

1) Label all the components and explain the function of each component.
2) Mark the air barrier on the drawing and list the elements that form the air barrier system.
3) 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 (10 marks):

1) List all the three conditions required for rainwater penetrating through a cladding to occur.
2) List all the forces that can cause rain penetration through building envelopes and explain how to counter these forces in the design with the helps of sketches.
3) List the two commonly used strategies to prevent rain penetration. Explain how each strategy works and comment on their advantages and disadvantages.

Question 6 (20 marks)

Part A (10 marks):

Design and detail a pitched residential roof system for the house shown in the photo below. The house is located in the Greater Toronto Area. Ontario Building Code requires a roof assembly with a RSI 7.0. Attic ventilation is required.

1) Sketch the wall to roof detail and label the component of the roof sections.

2) Explain how the attic ventilation requirement can be met and indicate the ventilation flows.

Part B (10 marks):

Design a low-slope, perfect barrier roofing assembly for a warehouse building located in Toronto. The primary membrane is to be Modified Bitumen (SBS).

1) Sketch the roof section and label all components
2) Elaborate on how to avoid condensation risks in your design
3) Draw a roof plan and show the location of drainage and the detailing of drainage
4) List the potential failures of a low-slope perfect barrier roofing assembly and elaborate on how to prevent these failures.

Material properties can be found in the appendix.

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

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

- Air flow rate through an incremental area of the exterior wall

$$\frac{dQ}{dA} = C(\Delta p)^n \qquad (4)$$

where:

dQ = leakage rate through an area dA of the exterior wall, m^3/s

dA = incremental area, m^2

C = flow coefficient, m^3/(s·m^2·Pa^n)

n = flow exponent for wall openings

- Pressure differential induced by stack effect

$$\Delta P = 3465 \times h \times (\frac{1}{T_o} - \frac{1}{T_i}) \qquad (5)$$

where,

ΔP= pressure in Pa;

h= height in m,

T_o=outdoor temperature in ^{o}K;

T_i=indoor temperature in ^{o}K

- Solar air temperature on vertical surfaces

$$t_e = t_o + \frac{\alpha I}{h_o} \qquad (6)$$

where,

t_e=solar air temperature, in ^{o}C

t_o=outdoor air temperature, in °C

α, solar absorptance, 0.7 for red brick;

I, solar radiation intensity, in W/m^2;

h_o, the exterior surface heat transfer coefficient, W/m^2°C

- Humidity ratio

$$W = \frac{p_w}{p_a} \times 0.622 = \frac{0.622 p_w}{p_t - p_w} = \frac{0.622 \times RH\% \times p_{sat}}{p_t - RH\% \times p_{sat}} \qquad (7)$$

p_w=partial water vapour pressure, Pa

p_{sat}=saturated water vapour pressure at temperature °C, Pa

p_t=atmospheric pressure, 101325Pa at sea level;

- Density

$$\rho_a = \frac{p_a}{R_a T} \quad , R_a=287.1 \text{ J/(kg·K)} \qquad (8)$$

$$\rho_w = \frac{p_w}{R_w T} \quad , R_w=461.5 \text{ J/(kg·K)} \qquad (9)$$

- Conversion from volume flow to mass flow

$$m = \frac{L}{\upsilon}$$

where, L is volume flow, m^3/s;

υ is specific volume, kg/m^3.

Table 1 Material properties

Element	Conductivity k (W/m·°C) or Conductance C (W/m^2·°C)	Vapour permeability μ (ng/s·m·Pa) or permeance M(ng/s·m^2·Pa)
Exterior surface transfer coefficient	C=34	--
Fibreboard 12.5mm	k=0.055	M=2500
Plywood	k=0.115	M=40
Hardboard	k=0.105	M=290
Gypsum board 12.5 mm	C=12.5	M=2870
Expanded polystyrene	k=0.036	M=6
Fiberglass insulation	k=0.04	μ=170
Face brick (100mm)	k=1.32	M=46
Tyvek membrane	----	M=2000
Polyethylene	----	M=2
Air space (25mm)	C=4.8	M=7200
19mm acrylic stucco	C=18	M=120
semi-rigid asphalt breather board	C=16	M=350
interior surface heat transfer coefficient	C=8.3	--

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	27.09	38.18	−5	401.3	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