National Exams December 2010

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.
   A 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 2x6 wood-frame brick veneer wall is made up of the following components:
- 100mm exterior brick
- 25mm air space
- one layer of Tyvek weather-barrier membrane, 0.2mm
- 12.5 mm plywood sheathing
- 140mm glass fiber insulation
- 12.5mm gypsum board.

Part A (10 marks):

For a cold winter day: outdoor at -15°C, 80% rh and indoor at 21°C, 40% rh

1) Calculate and plot the temperature gradient through the insulation space of this wall;
2) Calculate and plot the vapour pressure gradient through the insulation space of this wall;
3) Is there any condensation within this wall assembly? If so, where does the condensation occur and what is the condensation rate?
4) What would you do to prevent the condensation due to vapour diffusion? Provide the calculated results to support your solution.

Part B (10 marks):

Suppose this brick veneer wall is located at the top floor of a 20-storey high-rise building and the height of the building is 60m. For the same cold winter day:

1) Calculate the pressure differential across the brick veneer wall induced by the stack effect;
2) What is the maximum possible condensation rate within the brick wall at the top floor caused by an air exfiltration amount of 6.7x10^-4 m^3/s·m^2?
3) Compare the condensation rate calculated in Part A 1) to the condensation rate due to air exfiltration in Part B 2) to comment on the importance of controlling air leakage.

Question 2 (20 marks):

For the same brick veneer wall described in Question 1, the brick veneer is wet after a rain event in a hot and humid July summer day and then the sun comes out. Assume this is a south facing wall and the solar radiation received by this wall is 420 W/m². The outdoor temperature is 30°C and 60% rh and indoor conditions are maintained at 22°C and 50% rh.

1) calculate the expected wall surface temperature;
2) would there be any condensation within the wall assembly if a 6mil (0.15mm) polyethylene vapour barrier is placed between the interior gypsum board and the glass fiber insulation? If so, where does the condensation occur and what is the condensation rate?
3) What if the brick veneer is ventilated by having openings both at the bottom and top of the air space? Would there be any condensation within the wall assembly? In this situation, assume the conditions within the air cavity is the same as outdoor.
Material properties required for the calculation are provided in the appendix.

**Question 3 (20 marks)**

**Part A (4 marks):**
List the requirements for an air barrier system.

**Part B (8 marks):**
List the three conditions required for rainwater penetrating through a cladding to occur. List the design strategies commonly used to prevent rain penetration through building envelopes?

**Part C (8 marks):**
Single choice questions. 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 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. In cold climates, a vapour barrier is placed:
   A. anywhere in the wall assembly, as long as it is continuous
   B. on the warm side of the thermal insulation
   C. on the cold side of the thermal insulation
   D. anywhere in the wall assembly as long as it is the same as the air barrier

3. The vapour permeability of materials is normally measured using dry-cup, or wet-cup or both methods in accredited laboratories. 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

4. 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

5. Wind-driven rain that can penetrate behind the cladding through cracks and joints is a result of the action of:
   A. kinetic forces
   B. gravity
   C. pressure gradient across the cladding
   D. surface tension

6. Expanded polystyrene cannot be considered as an air barrier
   A. True   B. False
7. 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

8. In cold climate, what would be the most beneficial position to apply low-e coating to a glazing surface of an air-filled double-glazed unit (Figure 1)?
   A. Surface 3
   B. Surface 2
   C. There is no difference

Question 4 (20 marks)

Part A (7 marks):
Ten meter wide, light 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. What would be the minimum vertical joint width if a sealant having a movement capacity of ±25% was proposed. The coefficient of linear thermal expansion and contraction of concrete is $11.7 \times 10^{-6}/^\circ C$. The maximum temperature experienced by the concrete is 70°C in the summer and -20°C in the winter.

Part B (4 marks):
Make a sketch of the horizontal joint and label all components and comment on the requirements of the relative dimensions of this joint.

Part C (4 marks):
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 D (5 marks):
Explain the difference between an expansion joint and a control joint: with the help of sketches.

Question 5 (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.
Part B (5 marks):
Figure b) shows the exterior surface of a brick veneer apartment building. The section shown is at the floor/wall joints. Please comment on the white deposition, what is it and what could have possibly caused it and how to correct the problem?

Part C (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.
Question 6 (20 marks):

Part A (10 marks):
Figure below shows a vertical cross-section of a brick veneer cavity wall with steel stud.

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.

FROM INSIDE TO OUTSIDE
- Gypsum board
- Polyethylene sheet, 6 mil.
- Steel stud, 92 mm @ 400 mm c/c and batt insulation
- Exterior grade gypsum board
- Rigid insulation non wind-sensitive type
- Air space, 40 mm (25 mm min.)
- Masonry veneer and ties
  @ 800 mm c/c, horizontally and vertically.

Brick Veneer Steel Stud Wall
Part B (10 marks):
Sketch a vertical section of glass/aluminum curtain wall showing the junction between vision and spandrel panel;
   a. Explain how the curtain wall controls heat transfer, air leakage, and vapor diffusion, and rain penetration.
   b. Explain the principle of the pressure equalization rainscreen by stating the components and their functions, and explain how the pressure equalization rainscreen design is implemented in the curtain wall design.

Question 7 (20 marks)

Part A (5 marks):
What are the two types of roof systems with which you are most familiar? Sketch and label a representative section of an example of each.

Part B (5 marks):
Which of the following contributes to uplift forces on a roof?
   i) mechanical ventilation
   ii) stack (buoyancy) effect
   iii) wind
   iv) gravity roof loads
   Explain how to avoid roof uplift.

Part C (5 marks):
What are the likely consequences of a roofing membrane being exposed to direct sunlight?

Part D (5 marks):
Are the suction pressures on the roof more severe:
   a. when the wind is blowing perpendicular to the face of the building or
   b. when the wind is blowing toward the corner of the building.
   Explain with the aid of diagram.
Appendix: equations

- Vapor flow equation:
  \[ W = MA \theta (p_1 - p_2) \]  
  where:
  \( W \) = total mass of vapor transmitted, ng
  \( M \) = permeance coefficient, ng/(s·m²·Pa), \( M = \frac{\mu}{l} \)
  \( \theta \) = time during which flow occurs, s
  \( l \) = thickness, m
  \( \mu \) = average permeability, ng/(s·m·Pa)
  \( A \) = cross-section area of the flow path, m²
  \( (p_1 - p_2) \) = vapor pressure difference applied across the specimen, Pa.

- Conductive heat transmission equation
  \[ \frac{q}{A} = U(t_i - t_o) \]  
  where
  \( q/A \) = heat-flow rate, W/m²
  \( U \) = overall coefficient of heat transmission, W/(m²·K)
  \( t_i, t_o \) = inside and outside temperature, K

- Thermal resistance of composite section
  \[ R = \frac{1}{U} = R_1 + R_2 + R_3 \]  

- Air flow rate through an incremental area of the exterior wall
  \[ \frac{dQ}{dA} = C(\Delta p)^n \]  
  where:
  \( dQ \) = leakage rate through an area \( dA \) of the exterior wall, m³/s
  \( dA \) = incremental area, m²
  \( C \) = flow coefficient, m³/(s·m²·Pa^n)
  \( n \) = flow exponent for wall openings

- Pressure differential induced by stack effect
  \[ \Delta P = 3465 \times h \times \left( \frac{1}{T_o} - \frac{1}{T_i} \right) \]  
  where,
  \( \Delta P \) = pressure in Pa;
  \( h \) = height in m,
  \( T_o \) = outdoor temperature in °K;
  \( T_i \) = indoor temperature in °K

- Solar air temperature on vertical surfaces
  \[ t_o = t_{so} + \frac{\alpha I}{h_o} \]  
  where,
  \( t_o \) = solar air temperature, in °C
\[ t_o = \text{outdoor air temperature, in } ^\circ\text{C} \]
\[ \varepsilon, \text{ solar absorptance, 0.7 for red brick;} \]
\[ I, \text{ solar radiation intensity, in } \text{W/m}^2; \]
\[ h_e, \text{ the exterior surface heat transfer coefficient, } \text{W/m}^2\text{C} \]

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<tr>
<th>Table 1</th>
<th>Material properties</th>
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<td>Element</td>
<td>( k ) (W/m(^2\cdot\text{C})) or ( C ) (W/m(^2\cdot^\circ\text{C}))</td>
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<td>Exterior surface transfer coefficient</td>
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Table 2:
Water-Vapour Pressures at Saturation at Various Temperatures over Plane Surfaces of Pure Water and Pure Ice

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<th>Temp., °C</th>
<th>Pressure, Pa Over ice</th>
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Fig. 1 ASHRAE Psychrometric Chart No. 1