National Exams May 2019

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. An approved Casio or sharp calculator is 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)

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	The function of brick tie is to transfer the lateral load on the brick veneer to the back-up wall.		
8	The risk for mold growth in wood-based materials depends not only on relative humidity and temperature but also on the duration of favorite conditions.		
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	In a typical metal/glass curtain wall system, the coldest spot is at the bottom edge of glass.		
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	By filling the double IGU with Argon gas can significantly increase its thermal resistance.		

Question 2 (20 marks)

Complete the following statements. Provide your answers directly on this question sheet.

1) (3 marks) Main factors contributing to frost heave are: limit your answers to the space below.

a. ....b. .... c. ....

2) (3 marks) Single ply EPDM roofing membrane can be secured to the substrate typically by three methods including:

a. .... b. .... c. ....

3) (2 marks) The vertical movement in brick veneer steel stud wall is accommodated by:

a...... .... b..

4) (2 marks) The two primary functions of shelf angle are:

a. ....

b. ....

5) (2 marks) The required slope in a conventional low-sloped roof can be achieved using

a. .... b. ....

6) (1.5 marks) The main components of a low-sloped roof include:

a. .... b. .... c. ....

7) (3 marks) List the three main failure modes of a built-up roof membrane:

a. .... b. .... c. ....

8) (1.5 marks) List three commonly used water resistive membrane (WRB)

a. .... b. .... c. ....

9) (2 marks) List four forces that can cause rain penetration through building envelopes.

a. .... b. .... c. .... d. ....

Question 3 (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 4 (20 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.

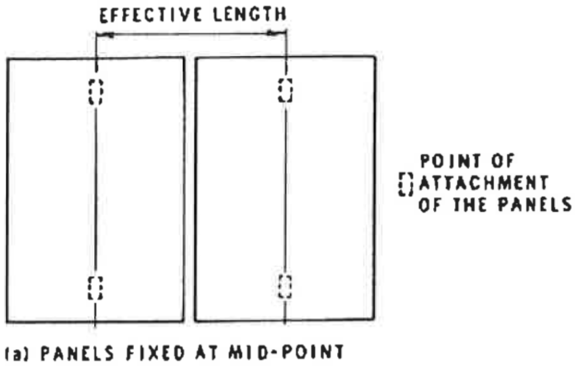


Figure 1

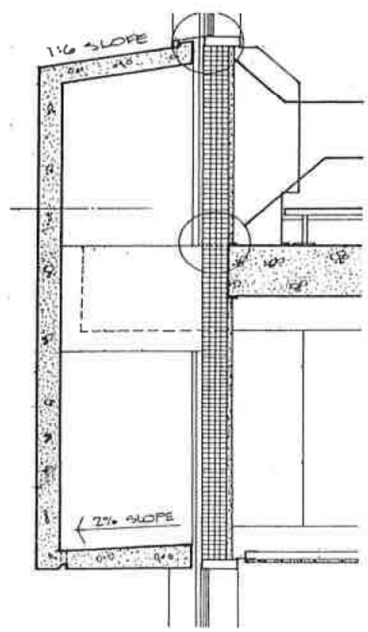
4) Sketch the vertical joint and label all components and comment on the requirements of the relative dimensions of this joint.

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.

Question 5 (20 marks):

1) **(5 marks)** The following observations were made of falling concrete pieces at a high-rise office building: cracks with mineral deposits observed in several locations; and loose pieces removed to reduce safety risk. An image of the failure is shown and one of the details of the precast concrete panel envelope is also shown in Figure below. Explain the failure mechanism and how to avoid this problem.



2) **(5 marks)** In photo shown below, note that icicles are formed at the eaves of a sloped roof. With the aid of sketch to explain what has caused it and how to avoid such a problem.

Photo 2

3) **(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.

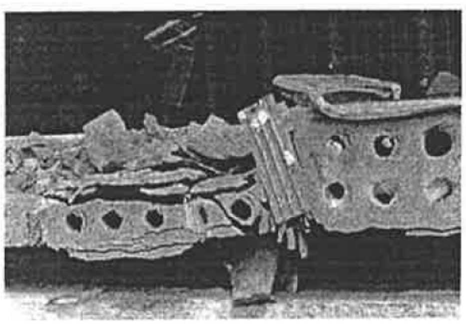


Photo A

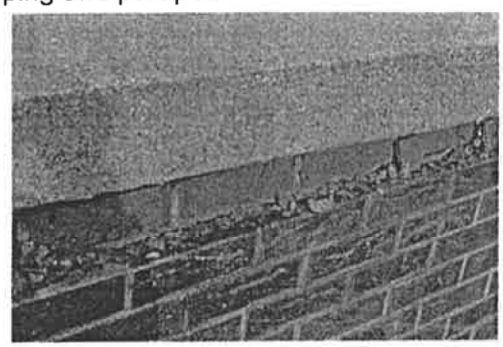


Photo B

Photo C

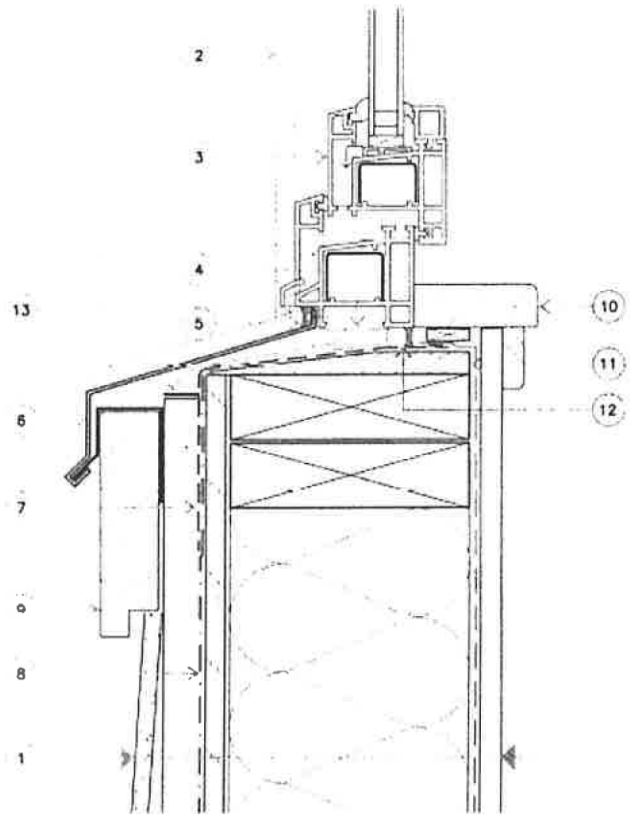
Question 6 (20 marks)

Part A (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 buyond
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

Part B (10 marks)

Review the case study "flashing failure". 1) Explain the failure mechanism of this case with the aid of sketch. 2) Propose the remedy solution with the aid of sketch to show proper detailing.

Flashing Failure

Courtesy the author

At first glance, this photo of a brick masonry wall excavation might appear to reveal satisfactory construction details. So why does this building leak like a sieve?

Leak-Free Design and Construction

The wall is an example of a cavity wall: the exterior brick masonry is a veneer over a back-up wall (composed of concrete masonry or steel studs at various places in this building). Like the "rain-screen principle" in modern curtain walls, a cavity wall does not require the outermost components to be absolutely weathertight because there is a back-up system.

Water can run under flashing that does not extend past the wall.

By David H. Nicastro

The Brick Institute of America (BIA) recommends a minimum 50 mm (2 in.) wide cavity to prevent mortar droppings from clogging the cavity, creating mortar bridges between the veneer and back-up wall and blocking the weep holes. Although the cavity in the photo is narrower and substantial mortar droppings were found, the droppings cannot be the cause of the pervasive leaking observed.

Masons almost always completely fill the bed joints but often only partially fill the head joints with mortar. This allows more water to penetrate the veneer, but that is only a difference of degrees—some water is expected to penetrate and drain down the inside face of the veneer.

In the photo, the joints are reasonably well filled. They are also tooled concave, which is the best mortar joint profile for shedding water off the face of the wall, and there is not an excessive amount (i.e., more than 15 percent) of joint separations (shrinkage cracks).

Weep holes are on 610 mm (24 in.) centers, as BIA recommends. They are fully open head joints, which drain better than weep tubes, and are baffled to prevent insects from nesting inside them.

Faulty Design

In the photo, the flashing, which directs water from the cavity to the exterior through the weep holes, is still elastic. Unreinforced PVC flashings are notorious for developing holes, embrittling, and shrinking.[1] The flashing in the photo is in good condition because of the product type, and the seams are well lapped.

The top edge of the flashing does not terminate in a reglet, as would be preferred, but it is still well adhered to the back-up wall with mastic.

However, the flashing has a fundamental design error.

Notice that the front edge of the flashing terminates 13 mm (½ in.) inside the wall, which was required by the specifications and drawings but is discouraged by BIA. It can allow water to curl around the toe of the flashing and run back inside under it.

On this building, we performed systematic water testing and demonstrated conclusively that the source of the leakage is simply because the flashing does not extend past the face of the wall.

Another unusual detail is the use of a grout dam: the flashing is raised one course and rests on the mortar-filled collar joint. Use of the grout dam leaves one course of masonry around each entire floor with no cavity, flashing, or weep holes. No doubt this detail exacerbates the leakage. ◆

Note

1. Clayford T. Grimm, "The Hidden Flashing Fiasco," *The Construction Specifier*, June 1994.

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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 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

	Pressure, Pa			Pressure, Pa					
Temp., °C	Over ice	Over water	Temp., °C	Over ice	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

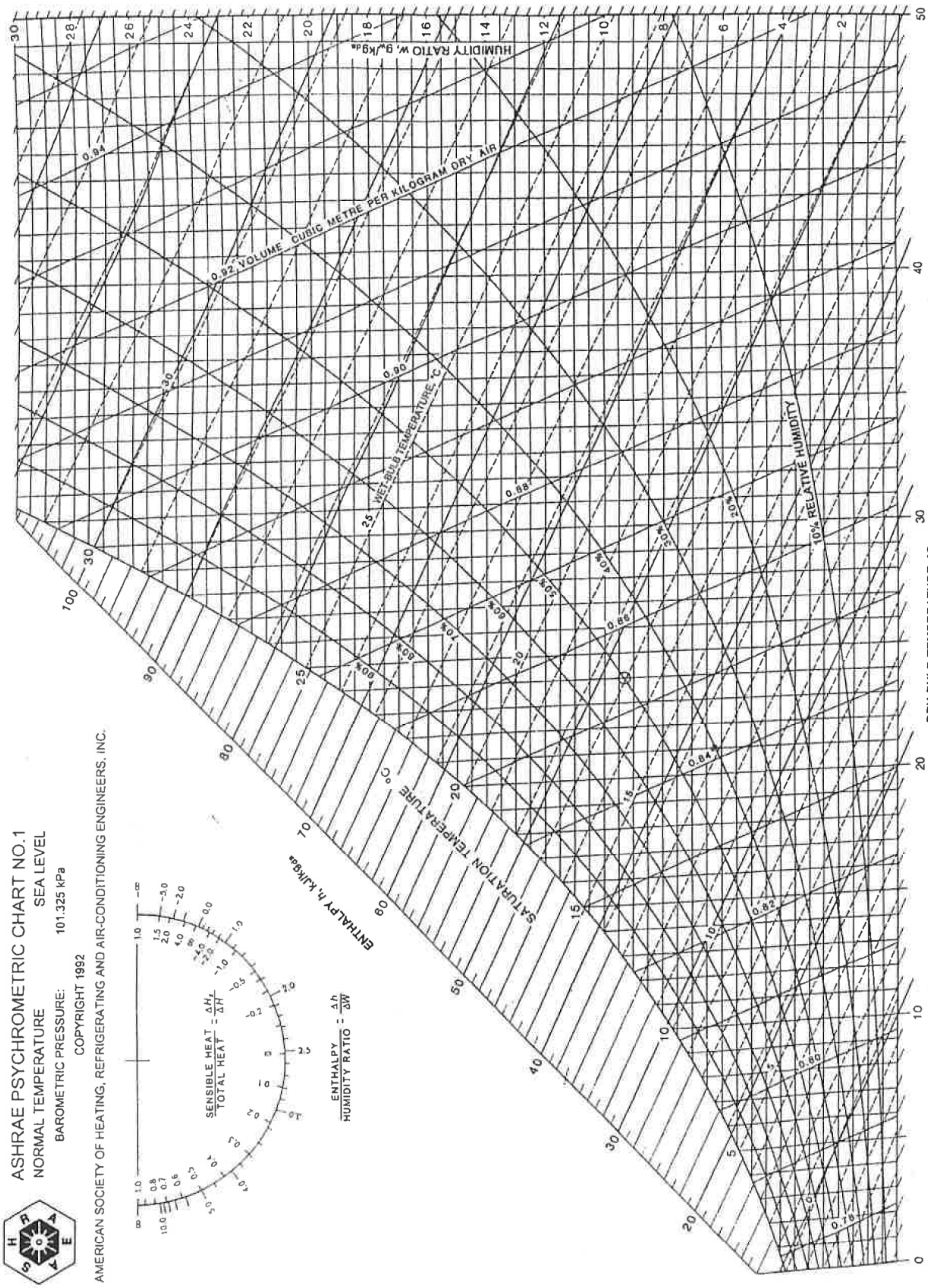

Fig. 1 ASHRAE Psychrometric Chart No. 1