University of Waterloo
Department of Civil Engineering

CE507 Building Science and Technology

PHYSICS QUIZ #1 SOLUTIONS

Question 1: Buildings **[10]**

i) Provide a short but completely general definition of the functions of a building [2]

ii) List the three major building enclosure functions and the one building function that has the most impact on building enclosure design.

Support, Control, Finish

Distribute [3]

iii) List five important categories of control-related functions of the building enclosure [5]

Heat, Air, Moisture, Fire Sound Insects Access

Question 2: Definitions **[16]**

Define and/or explain the following, with aid of sketches if useful [2 marks each]:

i) Surface film
ii) Night-sky cooling
iii) Greenhouse effect
iv) Absolute zero
v) Spectrally selective coating
vi) What is a black body?
vii) What is Kirchoff's law?
viii) Condensation

See textbook for answers.

Question 3: Basic Laws **[18]**

Write one form of Fourier's Law. Define in words what each variable is: q, Q, A, k, l, C, R, U, t (or T), and provide the proper S.I. units for each.

$$Q = A \cdot k / l \cdot (T_1 - T_2) \qquad \text{(Eq. 5.3)}$$

q	Heat flux	W/m^2
Q	Heat flow	W = J/s
A	Area	m^2

k	Thermal conductivity	W/m·K
l	Length of flow path/thickness	m
C	Thermal conductance	$W/m^2 \cdot K$
R	Thermal resistance	$m^2 \cdot K/W$
U	Heat transfer/transmission coefficient (through layers)	$W/m^2 \cdot K$
t (or T)	Temperature	° C or ° K

Question 4: Radiation **[10]**

A campfire has burned out and is now a 600 mm diameter pancake of glowing embers at about 600° C while the air temperature has dropped to 10° C. How much heat is being radiated in all directions from the fire? *[4]*

Using the Stefan-Boltzmann equation:

$$q = Q/A = \varepsilon \cdot \sigma \cdot T^4$$

where: T is the surface temperature (K),
A is the enclosure surface area (m^2).

It is safe to assume that the emissivity (ε) of the embers is about 0.9:

$$q = \varepsilon \cdot \sigma \cdot T^4 = 0.9 \cdot 5.67 \times 10^{-8} \cdot (273+600)^4$$

$$=29{,}640 \text{ W/m}^2$$

This gives the heat flux (q, heat flow per unit area); to find heat flow (Q):

$$q = Q/A$$
$$Q = q \cdot A = 29{,}640 \cdot \pi \cdot (0.3)^2 = \mathbf{8380\ W = 8.4\ kW}$$

Many of you used the equation assuming heat loss from the fire to the sky (at 10° C):

$$q = Q/A = \varepsilon \cdot \sigma \cdot (T_s^4 - T_a^4)$$

However, the question is worded looking for the total heat radiated from the fire, not the net amount of heat.

Two large 3x3 m parallel plates of rusty iron (solar absorptance (α) = 60%, thermal emittance (ε) = 90%), face each other across a 75 mm air space. If the temperature of *one plate is 70º C, and temperature of the second plate is at 40º C, what is the **net** transfer of heat across the air gap by radiation?* [6]

To find this, we will need the following equations: net radiation exchange between two non-blackbody plane surfaces of equal areas, and the emissivity factor (F_E). Both plates have emittances (ε) of 0.90 in the thermal range.

$$F_E = \frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1} = \frac{1}{\frac{1}{0.9}+\frac{1}{0.9}-1} = 0.82$$ Emissivity factor equation

$q = F_E \cdot \sigma \cdot (T_1^4 - T_2^4)$ Net radiation exchange equation

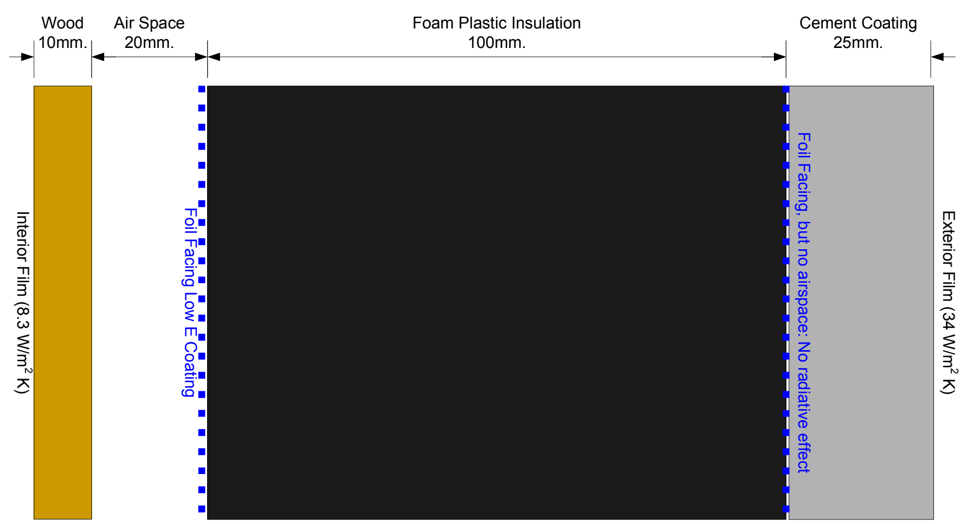
$q = 0.82 \cdot 5.67 \times 10^{-8} \cdot (273+70)^4 - (273+40)^4 = 196.9\ W/m^2$

Thus giving the heat flux (i.e., normalized by area). To determine total heat flow Q, we need to multiply by the area (9 m^2)

$Q = q \cdot A = 196.9\ W/m^2 \cdot 9\ m^2 =$ **1772 W.**

Question 5: Heat flow across enclosures **[12]**

i) What is the total thermal resistance of a composite enclosure wall panel made of a 10 mm thick sheet of wood (k=0.1), a 20 mm air gap, a 100 mm of foam plastic insulation (k=0.030) with a reflective aluminum foil on both surface, and a 25 mm layer of cement coating (k=2.0). Include appropriate surface films (see table below). *[6]*



First, we want to simplify the surface films and air spaces using information from the table below; these values combine conduction, convection, and radiation effects into an equivalent conductance that can be used in a Fourier heat flow equation.

- Interior film conductance (h_{int}) is 8.3 W/m^2·K (vertical surface, horizontal heat flow, still air, ε=0.9), which gives a resistance of 0.12 m^2·K/W.

- Exterior film conductance (h_{ext}) is 34 W/m^2·K (winter conditions), which gives a resistance of 0.029 m^2·K/W.

- A 20 mm air gap with foil on one side: unfortunately, Table 5.4 (Equivalent conductances for plane airspaces) was not provided. If it were, we would use the 20 mm spacing, an F_E of 0.05, horizontal flow, and a mean temperature of 32° C, for a value of 1.75 W/m^2·K, which gives a resistance of 0.57 m^2·K/W.

  However, given that this table was not available, we will accept an answer of 3.4 W/m^2·K (the closest reasonable estimate from Table 5.3), which gives a resistance of 0.29 m^2·K/W.

Given these values, we can obtain the total thermal resistance of the assembly:

Layer material	Conductivity (W/m·K)	Thickness (m)	Conductance (W/m^2·K)	Resistance RSI (m^2·K/W)
Interior film	n/a	n/a	8.3	0.12
Wood Panel	0.1	0.01	10	0.10
Air space	n/a	0.02	3.4	0.29
Plastic Insulation	0.03	0.1	0.3	3.33
Cement Coating	2	0.025	80	0.01
Exterior film	n/a	n/a	34	0.03
			RSI total	**3.89**
			Overall co-efficient of heat transfer (U value)	**0.26**

Total thermal resistance is 3.89 m^2·K/W; if it were done with the value from Table 5.4, it would be 4.17 m^2·K/W.

ii) If the interior air temperature (on the wood panel inside) was 20° C and the outdoor temperature (on the cement coating side) was –20° C, how much heat would flow through the system during a cold windy winter night? What would the temperature be at the interface between the insulation and the cement coating? *[6]*

Given the overall U-value (0.26 W/m^2·K), the temperature difference (ΔT = 40° C), we can find the heat flow:

$$q = U \cdot \Delta T = 0.26 \text{ W/m}^2\cdot\text{K} \cdot 40 \text{ C} = 10.3 \text{ W/m}^2$$

To find the interface temperature, the short cut is to find the total R-value inboard of the location we're interested in (between the insulation and cement coating), divide it by the total R-value, then apportion the temperature difference to the temperature difference (ΔT).

Inboard R-value: $0.12 + 0.10 + 0.29 + 3.33 = 3.85$ m^2·K/W

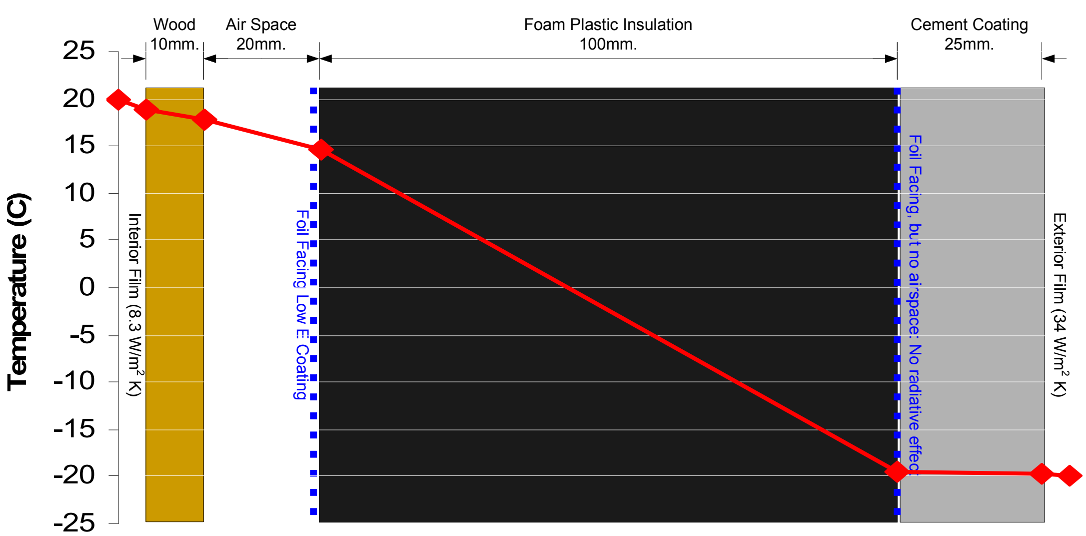
Inboard R-value / Total R-value = 3.85 / 3.89 = 0.989 (proportion R-value inside)

Proportion · ΔT = 0.989 · 40° C = 39.6° C (ΔT between interior & between 2 layers)

$T_{int} - \Delta T_{\text{to layer}} = 20 - 39.6 = -19.6$° C

The alternate methodology for the problem is to expand the table above, to show temperatures at the interfaces of materials, giving the same answer:

Layer material	**Conductivity (W/m·K)**	**Thickness (m)**	**Conductance (W/m²·K)**	**RSI (m²·K/W)**	**ΔT (°C)**	**T (°C)**
						20.0
Interior film	n/a	n/a	8.3	0.12	1.2	
						18.8
Wood Panel	0.1	0.01	10	0.10	1.0	
						17.7
Air space	n/a	0.02	3.4	0.29	3.0	
						14.7
Plastic Insulation	0.03	0.1	0.3	3.33	34.3	
						$\boxed{-19.6}$
Cement Coating	2	0.025	80	0.01	0.1	
						-19.7
Exterior film	n/a	n/a	34	0.03	0.3	
						-20.0
			RSI total	**3.89**	**40.00**	
			Overall co-efficient of heat transfer (U value)	**0.26**	**Checksum OK**	



We tried to grade this portion of the problem assuming the results you found in part i, so you would not be penalized for mistakes made there.

Using the Stefan-Boltzmann equation:

$$q = Q/A = \varepsilon \cdot \sigma \cdot (T_s^4 - T_a^4) \qquad \text{(Eq. 5.19)}$$

where: T_s is the surface temperature (K),
T_a is the outdoor surface temperature (K) usually assumed to be equal to the ambient air temperature, and
A is the enclosure surface area (m^2).

It is safe to assume that the emissivity (ε) of the embers is 0.9:

$$q = \varepsilon \cdot \sigma \cdot (T_s^4 - T_a^4) = 0.9 \cdot 5.67 \times 10^{-8} \cdot (273+600)^4 - (273+10)^4$$

$$=29{,}300 \text{ W/m}^2$$

This gives the heat flux (q, heat flow per unit area); to find heat flow (Q):

$$q = Q/A$$
$$Q = q \cdot A = 29{,}300 \cdot \pi \cdot (0.3)^2 = \mathbf{8290\ W = 8.3\ kW}$$

$(T1 - T2)^4 \neq T_1^4 - T_2^4$