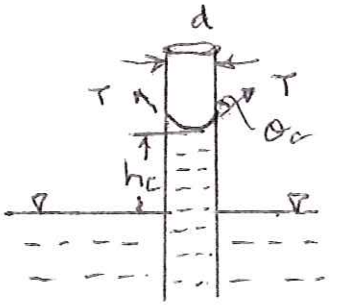
3D8 Environmental Geotechnics & Building Physics

May 2015

Q2 a) Rocks can be subjected to erosion and weathering. Thermal cycles, frost damage, abarasion (rock-rock, rock-ice, rock-soil) and chemical actions can lead to break up of rocks into soil particles. Soil particles thus formed are transported by wind and water leading aeolian formations or sedementary deposits. During this process soil particles undergo more breakdown, rounding of sharp particles and striations. Deposition of soil particles occurs depending on the particle size, current and levels in the river. Different flow rates in different seasons can lead to varved deposits. [10%]

2b) Consider a capillary tube of diametre 'd'.



Let the height of capillary rise be h_c

weight of water in the tube

$$W = \frac{\pi}{4} d^2 \gamma_w h_c \rightarrow ①$$

This is balanced by surface tension T

vertical force due to surface tension T = $T \cos\theta_c \, \pi d \rightarrow ②$

Equating ① and ② : $h_c \frac{\pi}{4} d^2 \gamma_w = T \cos\theta_c \, \pi d$

$$\Rightarrow h_c = \frac{4 T \cos\theta_c}{d \gamma_w}$$ [20 %]

2c) Estimate the capillary rise in the soil!

$T = 7 \times 10^{-5}$ kN/m $\quad \theta_c = 30°$

$\gamma_w = 9.81 \times 1000$ N/m³ $= 9.81$ kN/m³.

Typical pore size in the soil is given by $\underline{\underline{D_{10}}} = 0.01$ mm

$$\therefore h_c = \frac{4 \times 7 \times 10^{-5} \times \cos 30°}{0.01 \times 10^{-3} \times 9.81} \quad \frac{\text{kN/m}}{\text{m kN/m}^3} \text{ (m)}$$

$= 2.47$ m $\simeq \underline{\underline{2.5 \text{ m}}}$

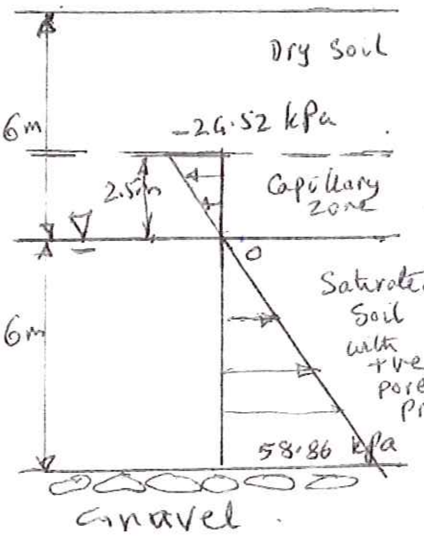
2c) contd. Calculate unit weights of the soil.

$$\gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e} \qquad G_s = 2.65 \ \& \ e = 0.65$$

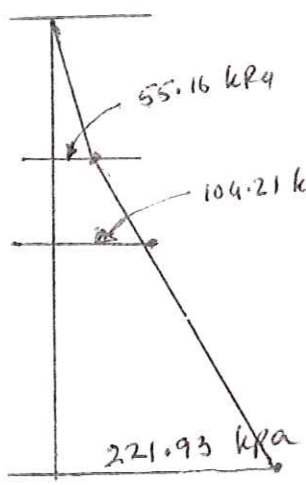
$$\therefore \gamma_{sat} = \frac{(2.65 + 0.65)}{1.65} 9.81 = 19.62 \ kN/m^3.$$

$$\gamma_{dry} = \frac{G\gamma_w}{1+e} = \frac{2.65}{1.65} \times 9.81 = 15.76 \ kN/m^3.$$

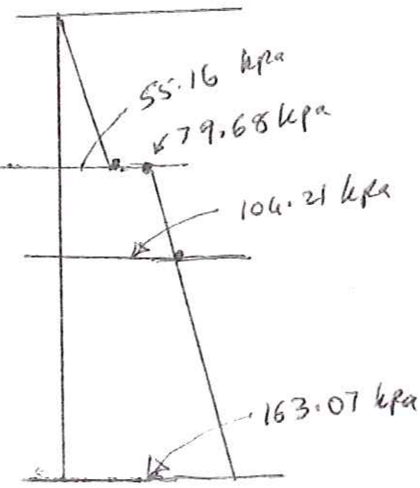
Consider the silty sand layer:



Pore pressure Distribution



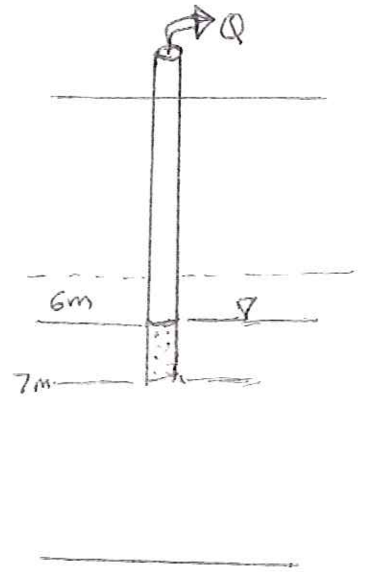
Total Stress



Effective stress profile.

[25%

2d)



Calculate hydraulic conductivity first.

$$K = \frac{k\gamma_w}{\mu}$$

$$= \frac{\frac{2 \times 10^{-6}}{1000^2} \times 9.81 \times 10^3}{1.307 \times 10^{-3}} \qquad \frac{m^2 \times N/m^3}{N\,s/m^2}$$

$$= 1.501 \times 10^{-5} \ m/s.$$

2d) Contd:-

$$Q = K i A = 2\pi r b K \frac{d\bar{h}}{dr}.$$

$$\text{Draw down} = \bar{h}_\infty - \bar{h}_w = \frac{Q}{2\pi b K} \ln \frac{R}{r_w} = 1.0\,m$$

$$Q = 50 \text{ gallons/hour} = 50 \times 4.5 \times 10^{-3}/3600 \ m^3/s$$
$$= 6.25 \times 10^{-5} \ m^3/s$$

$$K = 1.501 \times 10^{-5} \ m/s.$$

Thickness $b = 9m - 7m = 2m$; radius of well $r_w = 50\,mm = 0.05\,m$.

$$\therefore \quad 1 = \frac{6.25 \times 10^{-5}}{2\pi \times 2 \times 1.501 \times 10^{-5}} \ln\left[\frac{R}{r_w}\right]$$

$$\ln \frac{R}{r_w} = 3.0179$$

$$\frac{R}{r_w} = 20.449$$

Radius of influence $\therefore R = 20.449 \times 0.05 = \underline{1.022\,m}$ or 1022 mm [30%]

2e) Sorption is a mechanism by which chemical contaminants can attach themselves to the soil particles. Heavy metals can get sorbed onto soil particles selectively and displace other ions. Chemical contaminants that get sorbed onto soil particles are hard to dislodge. Pumping out of water may not remove the ~~co~~ soil contamination in this instance. Chemical treatment that can desorb the metal ions may have to be undertaken. [15%]

Q2. Examiner's Comment:

Almost all could derive the capillarity equation in 2b) and apply it in 2c), although not all could subsequently obtain the correct effective stresses. Part d) – to calculate the radius of influence of a pumped borehole - proved problematic for the candidates and the marker. Plausible attempts were rewarded, although the marker had reservations about the validity of the theory that was supposed to be applied. Only one candidate obtained the intended “correct” answer of “1022mm”. That candidate commented that the answer was “clearly wrong”, and they were awarded full marks.
Many candidates found difficulty with the fact that the pumping rate was specified in “gallons per hour”. Some found a conversion factor in the general Data Book (there is no conversion factor in the 3D8 datasheet), and then specified whether they were assuming Imperial or US gallons (which differ by around 20%). Others made assumptions, along the lines of “I shall assume 1 gallon = 1 litre” and even “Assume 1 gallon = 1m3”. One candidate wrote “I have no idea what a gallon is. Why would you ask that?” Students were not penalised for failing to make the conversion correctly, and plausible attempts to approach the question were given due credit.

R a) Fourier's law states that rate of heat transfer through a body is proportional to the negative gradient of temperature and the cross-sectional area normal to flow.

Heat flux $H \propto -A \frac{\partial T}{\partial x}$

$$H = -\lambda A \frac{\partial T}{\partial x}$$

where λ is the thermal conductivity of the soil. (W/m K)

In the case of saturated soil the thermal conductivity depends on both the solid soil particles and the pore fluid between the particles. Heat can flow by conduction between the solid particles and through convection in the pore fluid. The relative proportions of those depends on the soil particle sizes.

Examples of heat flow in ground problems include;

a) GSHP schemes (Ground Source Heat pumps)
b) Underground tanks holding hot fluids.
c) Pipe lines carrying fluids at high temperature etc (underground) [15%]
d) Energy walls. etc

R b) Advection is a contaminant transport mechanism by which the dissolved contaminant moves through porous medium along with the ground water flow.

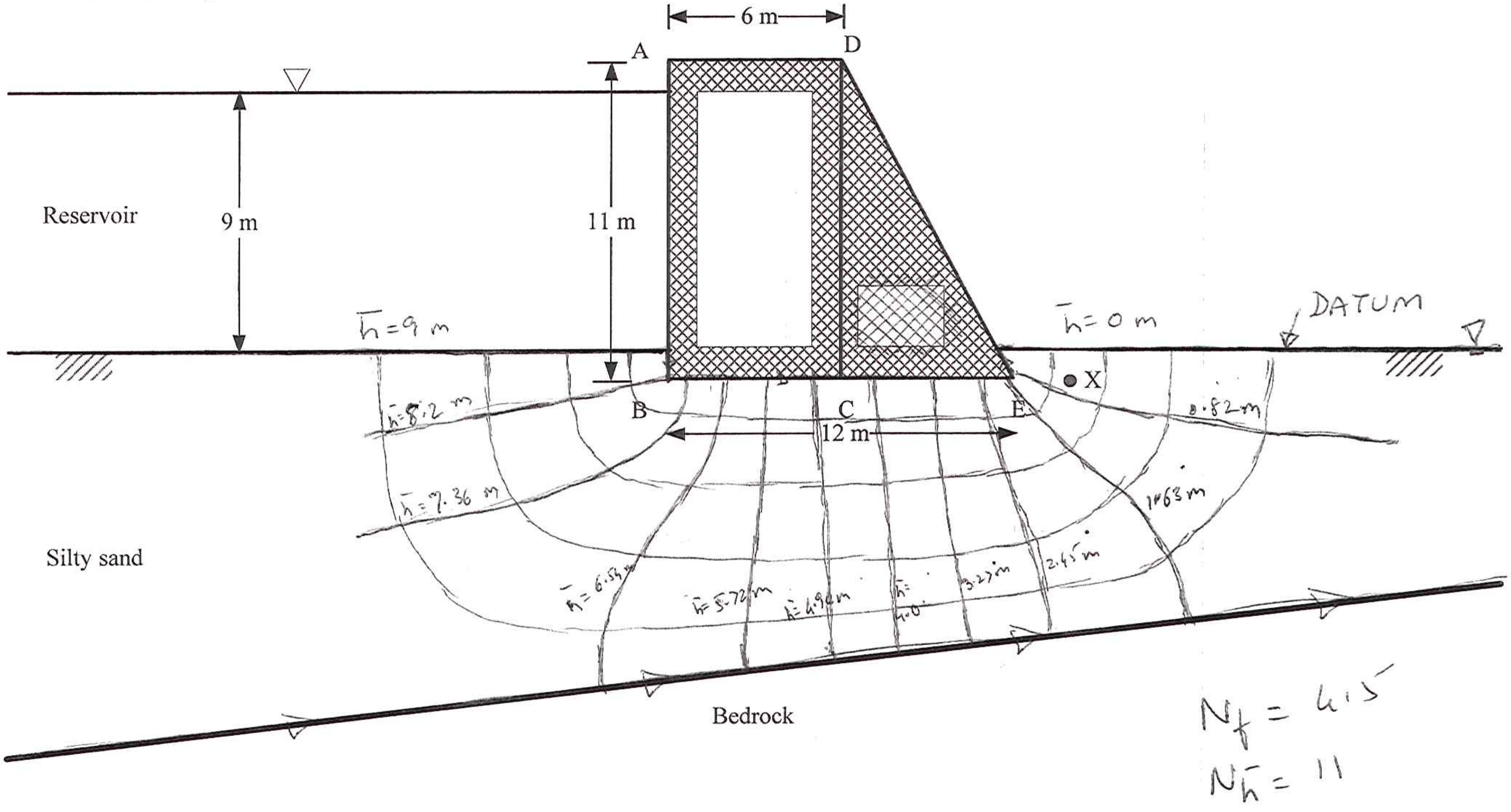
Diffusion on the other hand occurs when there is no ground water flow and is solely due to concentration gradients. Diffusion obeys Fick's law which is similar to Fourier's law and states mass flux $m \propto \frac{\partial c}{\partial x}$. Therefore we can say that diffusion of contaminants and heat are similar. Heat can transfer can also occur due to ground water moveme[nt] and this is analogous to advective contaminant transport.

[15%]

Candidate No:

DRAWN TO SCALE

Q 7c) i)



Extra copy of Fig. 1

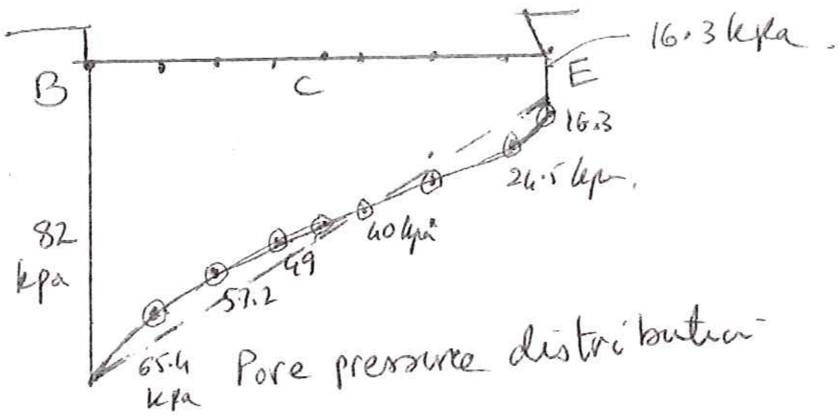
1 c) ii)

$$Q = K \Delta \bar{h} \frac{N_f}{N_h}$$

$$= 1.75 \times 10^{-5} \times 9 \times \frac{4.5}{11}$$

$$= 6.443 \times 10^{-5} \ m^3/s/m$$

$$= \underline{\underline{2.032}} \text{ million litres / year}$$



Pore pressure distribution

Clearly the pore pressure distribution is <u>non-linear</u>.

Point 'x' is 1m below ground level. ; i_{crit} 0.8 ~ 1.0

$$\bar{h}_x = \frac{1}{4} \times 0.82 = 0.205$$

$$i = \frac{d\bar{h}}{ds} = \frac{0.205 - 0}{1.0} = \underline{0.205} < i_{crit} \text{ so safe } \checkmark \text{OK}$$

So the barrage structure <u>should</u> be safe from d/s erosion

[20%]

iii) Weight of barrage $= (6 \times 11 - 4 \times 9)\ 24 + \frac{1}{2} \times 6 \times 11 \times 24$

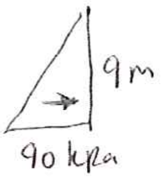
$W = 720 + 792 = 1512$ kN/m width

Uplift due to pore pressure $= \frac{1}{2}(82 + 16.3) \times 12 = 589.8$ kN/m width

Net weight $W' = W - U = 922.2$ kN/m

1 c iii) Contd

Horizontal Force = H = $\frac{1}{2} \times 90 \times 9 = 405$ kN/m width.



$\phi = 28^\circ$ for Sand/Concrete interface

$W' \tan\phi = 922.2 \tan 28^\circ$

$= 490.34$ kN.

$\therefore$ FoS against sliding $= \frac{490.34}{405} = \underline{\underline{1.21}}$ $> \underline{\underline{1.2}}$ OK [15%]

c iv) If the construction joint fails, then water can escape at location 'C'. This drops the seepage length to 'BC' which is only 6m. As a result the upword hydraulic gradient at 'C' can be excessive causing destabilisation of the block ABCD and can cause failure of the whole structure. [10%]

Q1. Examiner's Comment:

This was a popular and straightforward question that was attempted by almost all, with good results. The final part – about the crack – tripped up many who somehow concluded that the uplift pressure under BC increased, even after having drawn a diagram showing the opposite.

3 (a) (+ve) Low values of SHGC means "less" solar radiation is transmitted & absorbed by a window. Therefore it helps in reducing solar gains in summer, when they are undesirable.

(−ve) Low SHGC in winter means less "useful" solar heat gains. Also, it also tends to reduce visible transmittance (∴ less light)

~~3~~(b) The lines of constant enthalpy slope down to the right, approximately parallel to the lines of constant wet-bulb temperature.

They signify the process of evaporative cooling — i.e. by adding moisture and passing air over it. The moisture evaporates which results in lowering the temperature.

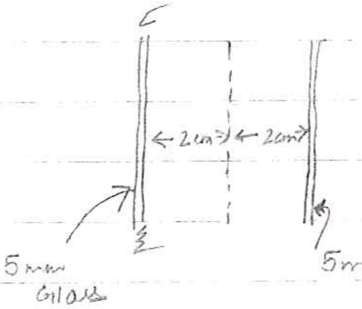
3 (b) Volume $= 30\,m^3$ $\quad T_{ext} = -5°C \quad RH_{ext} = 90\%$

$N = 2 \quad T_{int} = 20°C$

$A_{wall} = 25\,m^2 \quad U_{wall} = 0.2\ W/m^2 K$

$A_{window} = 5\,m^2$

(ii) Calculate U-Value of double-glazed window



$\lambda_{glass} = 1.0\ W/mK$

$d_{glass} = 0.005\,m$

$d_{gap} = 0.02\,m$

$\lambda_{air} = 0.024\ W/mK$ (from data book)

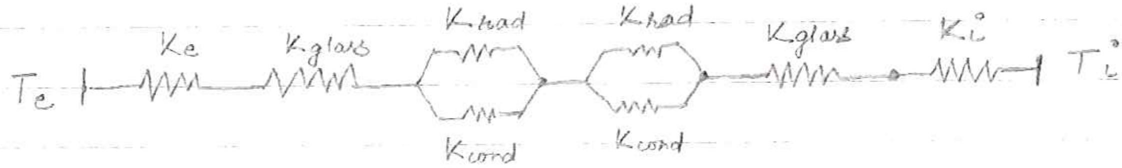
$\epsilon = 0.9 = \epsilon_1 = \epsilon_2$

→ $$T_{12} = \frac{T_1 + T_2}{2} = \frac{(273 + 0 + 273 + 15)}{2}\ K$$

$$= \underline{280.5\ K}$$

$$\frac{1}{\epsilon_{12}} = \frac{1}{0.9} + \frac{1}{0.9} - 1 = 1.22$$

→ $\epsilon_{12} = \underline{0.81}$



$$K_i = A_{window} \cdot h_i = A \times \underbrace{\left(1/_{0.13}\right)}_{\text{from data book}} = A \times 7.69$$

$$K_{glass} = A_{window} \cdot U_{win} = A \times \frac{\lambda_{glass}}{d_{glass}} = A \times \left(\frac{1.0}{0.005}\right) = 200$$

$$K_{rad} = A \cdot \underbrace{4\sigma\,\epsilon_{12}\,T_{12}^3}_{\text{data book}} = 4 \times \underbrace{5.7 \times 10^{-8}}_{\text{data book}} \times 0.81 \times (280.5)^3$$

$$= 4.12 \cdot A$$

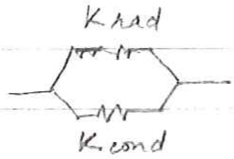
3(b) (ii)
contd :

$$K_{cond} = A \times \frac{\lambda_{air}}{d_{glass}} = A \times \frac{0.024}{0.02} = 1.2 \times A_{win}$$

databook

$$K_{int} = A \times h_i = A \times \left(\frac{1}{0.04}\right) = 25 \times A_{window}$$

data book



$$K' = K_{rad} + K_{cond}$$

$$K' = (4.12 + 1.2) \times A_{win}$$

$$= 5.32 \times A_{win} \quad W/K$$

Total K

$$\frac{1}{K_{Total}} = \frac{1}{K_{int}} + 2 \times \left(\frac{1}{K_{glass}}\right) + 2 \times \frac{1}{K'} + \frac{1}{K_{ext}}$$

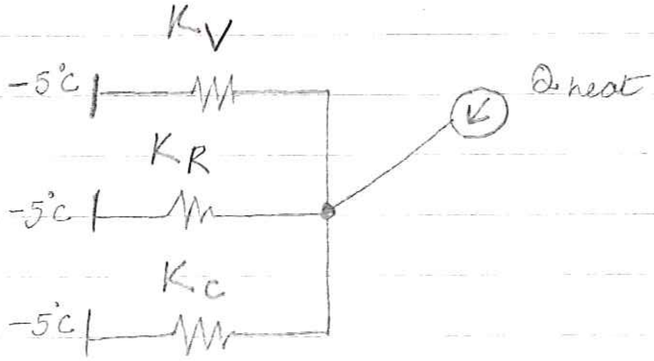
$$= 0.55$$

$$K_{Total} = 1.8 \cdot A_{window}$$

$$K = U \cdot A_{window}$$

$\therefore$ $\boxed{U\text{-Value} = 1.8 \ W/m^2K}$

3(b)
(iii)



3(b)

(iii) $\underline{K_{vent}} = N \times Volume \times \rho_{air} \times Cp_{air} \quad W/K$

$$= \frac{2}{3600} \times 30 \times 1.2 \times 1000 = 20 \ W/K$$

$\underline{K_{wall}} = A_{wall} \times U_{wall}$

$$= 25 \times 0.2 = 5 \ W/K$$

$K_{window} = A_{win} \times U_{wind}$

$$= 5 \times 1.8 = 8.99 \ W/K$$

$K_{total} = K_{vent} + K_{wall} + K_{window} = 33.99$

$$T_i = 20 = \frac{K_{total} \times T_e + Q_{heat}}{K_{total}}$$

$$\Rightarrow \underline{Q_{heat}} = (20 \times K_{total}) - (K_{total} \times T_e)$$

$$= 849.75 \text{ Watts}$$

3(b)

(iv) $G = 0.75 \ Kg/h$

$V_{i1} = 3.5 \times 10^{-3} \ kg/m^3$

RH of ext air

$V_{i2}(0) = 3.25 \times 10^{-3} \ kg/m^3 \times 0.9$ (table in fig. 5 data book) $V_S(-5)$

$= 0.0029 \ kg/m^3$

$$V_i(t) = \underbrace{V_e}_{V_{i1} + V_{i2}} + \frac{G}{nV} \times (1 - e^{-nt})$$

$t = 10$ minutes $\approx \frac{10}{60}$ hr

$$= V_i(t) = (\cancel{4.36}\ 2.9 + 3.5) \times 10^{-3} + \frac{0.75}{2 \times 30}\left[1 - e^{-2 \times \frac{10}{60}}\right]$$

$$V_i(10\,min) = 0.011 \ kg/m^3$$

$$V_{sat}(20) = 17.28 \times 10^{-3} \ kg/m^3$$

$$RH = \frac{V_i(10\,min)}{V_{sat}(20)} \times 100 = 57.69\ \%$$

Contd: →

3(b)

(iv) contd: Time for condensation

$U_{wind} = 1.8\ W/m^2K$ — calculated in 2(i)

$R_{si} = 0.13\ m^2K/W$ — data book

$T_{surface} = T_i - R_{si} \cdot U_{win} \cdot \Delta T = 15.3\ ^\circ C$

$V_i^{max} = 13.07 \times 10^{-3}\ kg/m^3$ (from table $V_i(15.3)$)

$$13.07 \times 10^{-3} = (0.0029 + 0.0035) + \frac{0.75}{2 \times 30}\left[1 - e^{-2 \times t}\right]$$

$$\left[1 - e^{-2 \times t}\right] = 0.53$$

$$2t = -\ln(1 - 0.53)$$

$$= 0.758$$

$$t = 0.38\ hr$$

$$= 22.75\ \text{minutes}$$

Q3. Examiner's Comment:

A popular question, with most scoring full marks on the early parts. Marks were lost in the U-value calculation, often for omitting the surface resistances. Few scored well on the relative humidity and condensation part of the question. There was potential ambiguity in the question regarding the initial moisture conditions and the meaning of initial “moisture supply”, but most candidates ignored the effects of ventilation completely and were unaffected by this. Plausible attempts were duly rewarded.

4(a) (i) Analysis of thermal mass or any kind of heat storage media in buildings

(ii) Quantification of long term energy demand

(iii) Analysis of solar heat gains that vary throughout

(iv) Design of ventilation systems

(v) Analysis of time varying occupancy patterns influencing energy

4(b) (i) $T(x,t) = T_0 + (T_1 - T_0)\left[\frac{2}{\pi}\int_{s=\frac{x}{\sqrt{4at}}}^{\infty} e^{-s^2}\,ds\right]$ — (1)

$$q(x,t) = -\lambda \frac{\partial T}{\partial x} \quad \text{—— (2)}$$

Insert $T(x,t)$ (1) in (2)

$$q(x,t) = -\lambda\left[\frac{-2(T_1 - T_0)}{2\sqrt{at}}\, e^{-x^2/4at}\right]$$

$$Q(x,t) = \frac{A\cdot\lambda(T_1 - T_0)}{\sqrt{\pi at}}\, e^{-x^2/4at} \quad \text{—— (3)}$$

4(b) (ii) Thermal Diffusivity a : Measure of how fast temperature change spreads through a material. $a = \lambda/\rho c_p$ in m^2/s

It is a measure of 'thermal inertia'

Thermal Effusivity b : $b = \lambda/\sqrt{a} = \sqrt{\lambda\rho c}$

Measure of heat storage. materials w/ high value give large heat absorption & large release when surface temperature changes.

4 (b) (iii)

From equation (3) in 4(b)(i)

$$Q(x, t) = \frac{A \cdot \lambda (T_1 - T_0)}{\sqrt{\pi a t}} e^{-x^2/4at}$$

$$Q(0, t) = \frac{A \cdot b (T_1 - T_0)}{\sqrt{\pi t}}$$

where $b = \frac{\lambda}{\sqrt{a}}$

For 2 materials in contact & $T_1 > T_2$, the heat flow rate at interface is:

Material 1 : $Q_{s1} = (T_1 - T_c) \frac{A b_1}{\sqrt{\pi t}}$ —— (4)

Material 2 : $Q_{s2} = (T_c - T_2) \frac{A b_2}{\sqrt{\pi t}}$ —— (5)

where T_c is contact temperature.

Both heat flow rates must be equal so

(4) = (5)

$$(T_1 - T_c) \frac{A b_1}{\sqrt{\pi t}} = (T_c - T_2) \frac{A b_2}{\sqrt{\pi t}}$$

$$\Rightarrow \quad T_c = \frac{b_1 T_1 + b_2 T_2}{b_1 + b_2}$$

4(b) (iv)

$$T_{12} = \frac{b_1 T_1 + b_2 T_2}{b_1 + b_2}$$

$$b = \frac{\lambda}{\sqrt{a}}$$

	λ (W/mk)	a (m^2/s)	
Granite	3.5	1.6×10^{-6}	from databook
Concrete	1.7	1.0×10^{-6}	

Concrete $b_1 = \frac{1.7}{\sqrt{1.0 \times 10^{-6}}} = 1700 \frac{W\sqrt{s}}{m^2 K}$

Granite $b_2 = \frac{3.5}{\sqrt{1.6 \times 10^{-6}}} = 2767 \frac{W\sqrt{s}}{m^2 K}$

$T_1 = ?$

$T_2 = -10°C$

$T_c = 0°C$

$$T_1 = \frac{T_c(b_1 + b_2) - b_2 T_2}{b_1}$$

$$= +16.3°C$$

Q4. Examiner's Comment:

It would appear that this question was only attempted by those few candidates who were confident of scoring highly, since there was a high proportion of near-perfect answers. Marks that were lost were largely the result of incomplete answers, as there were very few actual errors.