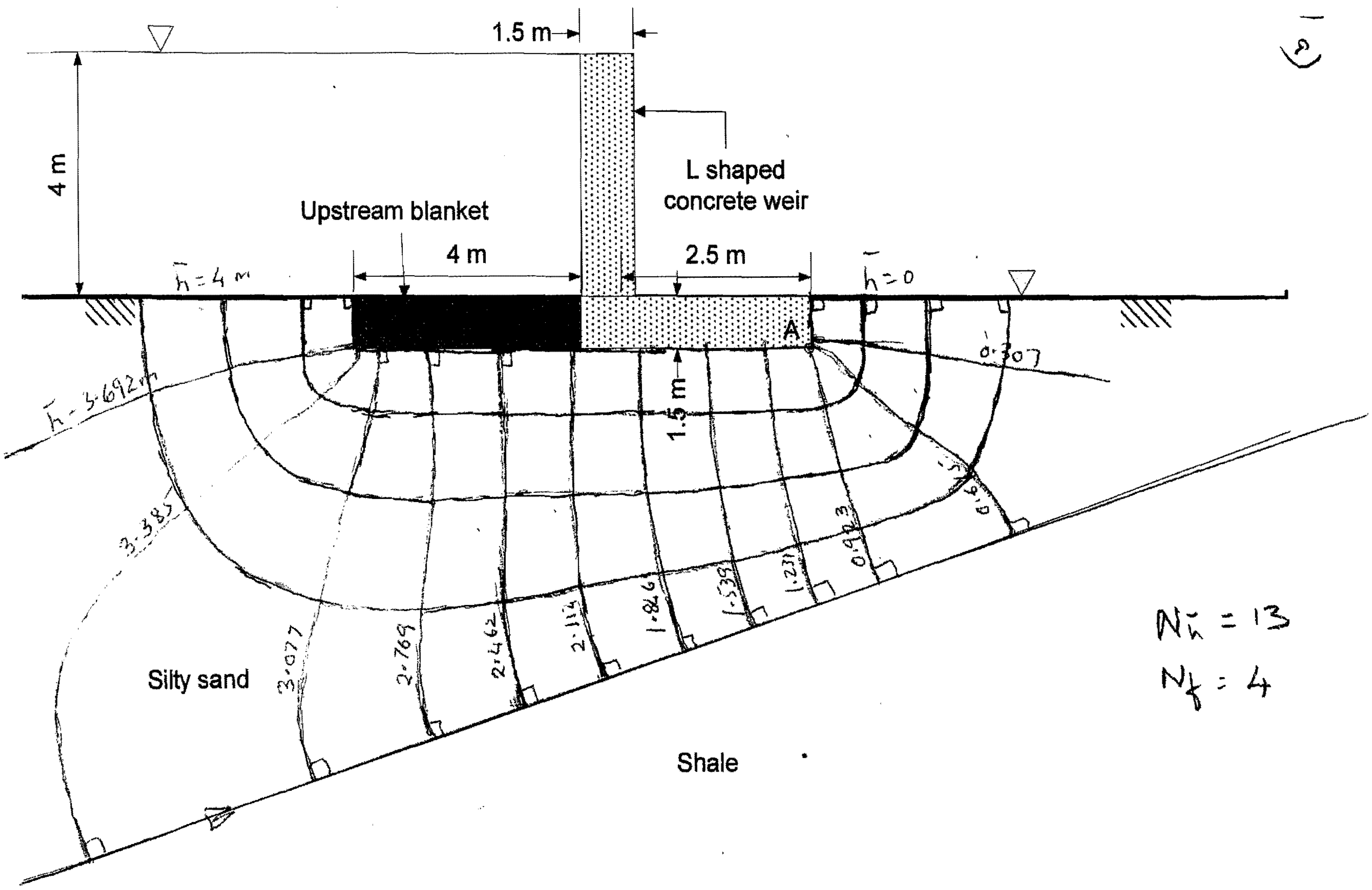
Q1 a)



$N_h = 13$

$N_f = 4$

Flow net

[20%]

2013 3D8 Choudhary

Q 1b) Hydraulic Conductivity K of the Silty Sand layer

$= 2.3 \times 10^{-3}$ m/s.

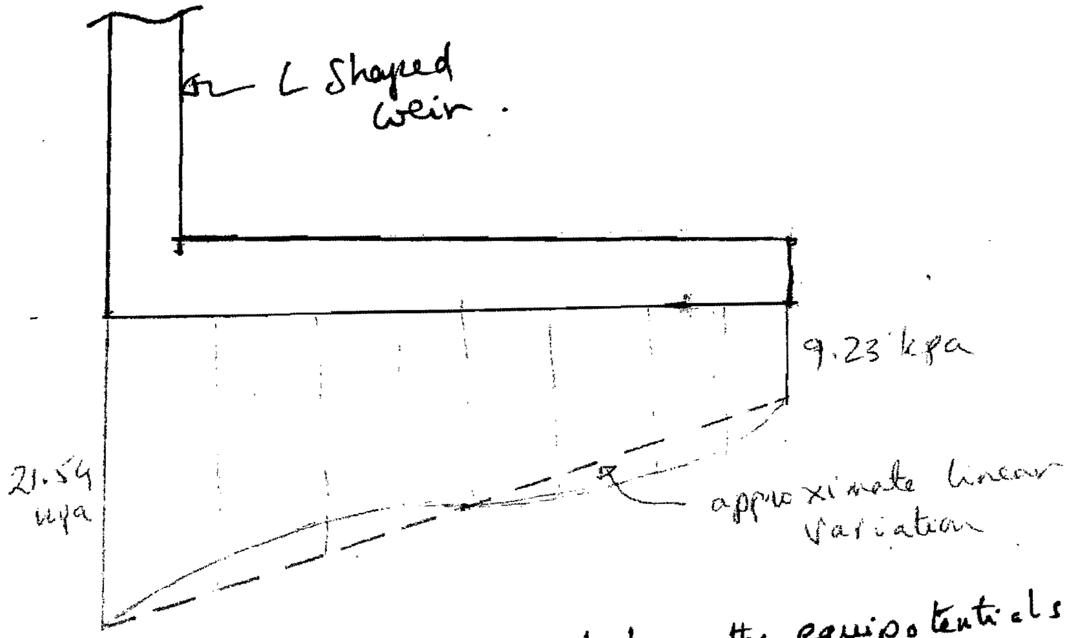
Leakage below weir $q = K \, \Delta h \, \frac{N_f}{N_h}$

$= 2.3 \times 10^{-3} \times 4 \times \frac{4}{13}$

$= 2.831 \times 10^{-3}$ m³/s / m width

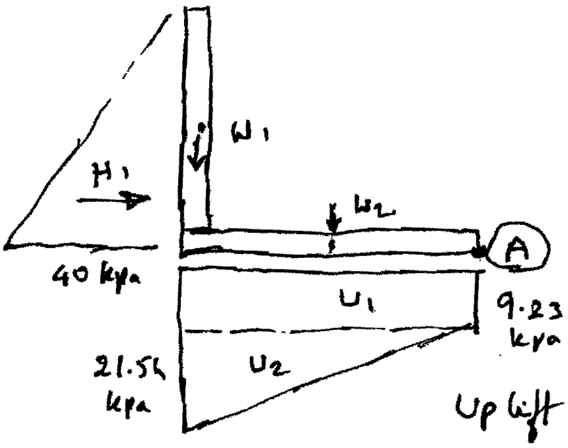
or 89271.14 litres/year. [10%]

1c)



The uplift pressures can be obtained from the equipotentials on the flow net. Due to upstream blanket, the uplift pressure drops to 21.54 kpa at left edge. This drops further to 9.23 kpa on the right edge. The actual variation will be non linear due to the sloping shale bed. An approximate linear variation can be used to calculate uplift force. [10%]

Q 1 d)



Vertical part of weir

$W_1 = 24 \times 4 \times 1.5 \times 1 = 144$ kN/m

Horizontal part of weir

$W_2 = 24 \times 4 \times 1.5 \times 1 = 144$ kN/m

Horizontal thrust due to water

$H_1 = \frac{1}{2} \times 40 \times 4 \times 1 = 80$ kN/m.

Uplift force $U_1 = 9.23 \times 4 \times 1 = 36.92$ kN/m

Uplift force $U_2 = \frac{1}{2}[21.54 - 9.23] \times 4 \times 1$

$= 24.62$ kN/m

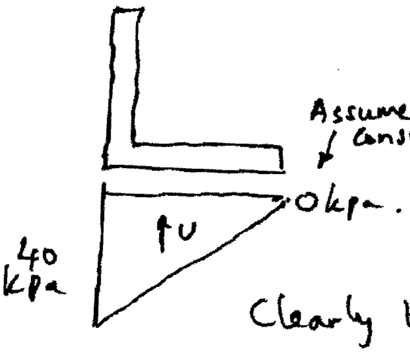
Effective weight of weir $= W' = W_1 + W_2 - (U_1 + U_2) = 226.46$ kN/m

FoS against sliding $= \frac{W' \tan\delta}{H_1} = \frac{226.46 \tan 25^\circ}{80} = \underline{\underline{1.32}}$

FoS against rotation about A $= \frac{\text{Resisting moments}}{\text{Disturbing moments}} = \frac{144 \times 3.25 + 144 \times 2}{80 \times 2.8\dot{3} + 36.92 \times 2 + 24.62 \times 2.6}$

$= \underline{\underline{2.0657}}$ [30%]

1e) Major risk for this L-shaped weir is 'if it settles differentially' ~~to~~ with respect to the upstream blanket. This can cause a crack to form ~~be~~ vertically between the concrete weir & the upstream blanket. If this happens then the efficacy of the blanket is lost and the uplift pressure change as shown below.



Assume conservatively.

The new uplift pressure U will be

$\therefore U = \frac{1}{2} \times 40 \times 4 \times 1 = 80$ kN/m.

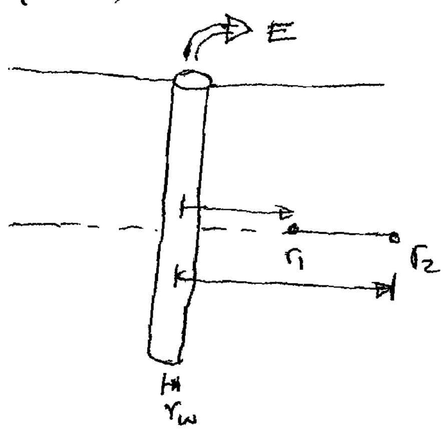
Recalculate FoS against sliding.

$FoS = \frac{(144 \times 2 - 80) \tan 25^\circ}{80} = \underline{\underline{1.21}}$

Clearly the factor of safety has dropped.

[30%]

Q2 a)



According to Fourier's law, heat flux H.

$$H \propto \frac{dT}{dr}.$$

$$H = -\lambda \frac{dT}{dr}$$

$$H = \frac{E}{2\pi r B} = -\lambda \frac{dT}{dr}$$

Rearranging $\quad \frac{E}{2\pi B} \frac{dr}{r} = -\lambda \, dT$

Integrating $\quad \frac{E}{2\pi B} \int_{r_1}^{r_2} \frac{dr}{r} = -\lambda \int_{T_1}^{T_2} dT.$

$$\frac{E}{2\pi B} \ln \frac{r_2}{r_1} = \lambda (T_2 - T_1)$$ (as temp gradient is +ve in this case)

or $\quad \lambda = \dfrac{\frac{E}{2\pi B} \ln(r_2/r_1)}{(T_2 - T_1)}$ [20%]

2b)

$$T_2 - T_1 = \frac{E}{2\pi B} \frac{\ln r_2/r_1}{\lambda}$$

$$T_2 - T_1 = \frac{1500}{2\pi 100} \times \frac{\ln\left[\frac{5+0.25}{2+0.25}\right]}{2.8}$$ [allow for radius of the borewell]

$$T_2 - 3^\circ c = 0.7224^\circ c$$

$$\therefore T_2 = \underline{\underline{3.72}}^\circ c.$$

[20%]

2 c) Radius of influence :

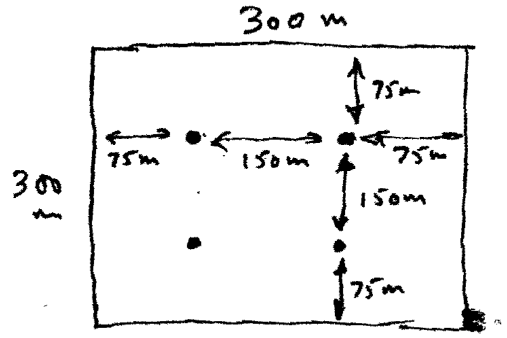
$$T_2 - T_1 = \frac{E}{2\pi B} \frac{\ln[r_2/r_1]}{\lambda}$$

Ambient temperature of ground is 6°C.

$$\therefore 6-3 = \frac{1500}{2\pi 100} \times \frac{\ln[R/2.25]}{2.8}$$

$$3 = 0.8526 \times \ln\left[\frac{R}{2.25}\right]$$

$\Rightarrow R = 75.91$ m. from the centre of the bore well.



Arrange the GSHP's at 75m from edge and with 150 m spacing between themselves.

Note there will be a small overlap between radius of influences ie about 0.91m but this is << 75.0 m

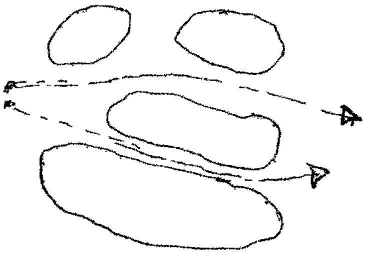
[20%]

2 d) Contaminant transport mechanisms:

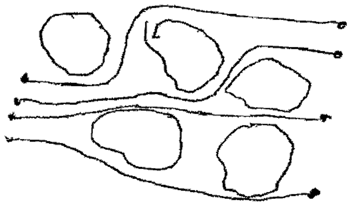
i) Diffusion: Movement of contaminant from one place to another in a soil layer due to a concentration gradient is called diffusion. This is governed by Fick's law which states that the rate of diffusion is proportional to the concentration gradient. This mechanism is important at very low flow velocities of ground water.

ii) Mechanical dispersion: Spreading of contaminant within the porous soil medium by virtue of moving in the soil pore space can be termed as mechanical dispersion. This occurs due to following reasons.

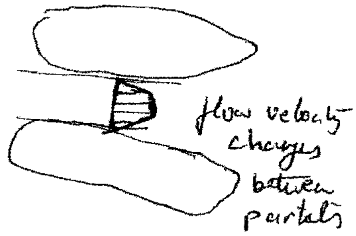
Different pore sizes



Different paths taken



Boundary layer effects



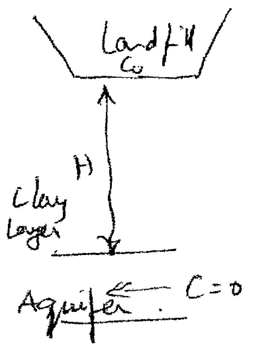
iii) Advection: Contaminant simply moves with ground water flow. This is important when ground water flow velocity is high.

iv) Sorption: This involves certain contaminants getting adsorbed to the clay minerals due to their ionic charges (eg Ca^{++}, Ba^{+} etc). This may slow down the contaminant transport especially in the case of heavy metals. Can create difficulties when attempting clean up of contaminated sites.

[15%]

2 e) Consider

$$\frac{\partial c}{\partial t} = D_L \frac{\partial^2 c}{\partial z^2} - \vartheta_b \frac{\partial c}{\partial z}$$



Under steady state conditions $\Rightarrow \frac{\partial c}{\partial t} = 0$.

$$\Rightarrow \quad \frac{D_L}{\vartheta_b}\frac{\partial^2 c}{\partial z^2} = +\frac{\partial c}{\partial z}.$$

Integrate once

$$\frac{D_L}{\vartheta_b}\frac{\partial c}{\partial z} = C - P \quad \text{where 'P' is a constant.}$$

Integrate again. $\ln(C-P) = \frac{\vartheta_b}{D_L} z + \ln Q$ (Q is constant of integration)

$$\Rightarrow \quad C = P + Q \exp\left(\frac{\vartheta_b z}{D_L}\right)$$

Applying BC's at $z=0$ $C=C_0$. $\Rightarrow P + Q = C_0$
at $z=H$ $C=0$ $\Rightarrow C = P + Q\exp\left(\frac{\vartheta_b H}{D_L}\right)$.

Solving

$$P = \frac{-C_0 \exp\left(\frac{\vartheta_b H}{D_L}\right)}{1-\exp\left(\frac{\vartheta_b H}{D_L}\right)} \quad \& \quad Q = \frac{C_0}{1-\exp\left(\frac{\vartheta_b H}{D_L}\right)}$$

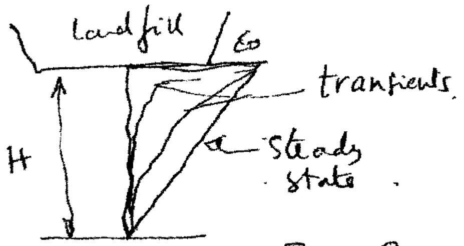
∴ For steady state distribution.

$$\frac{C}{C_0} = \frac{\exp\left(\frac{v_f Z}{D_L}\right) - \exp\left(\frac{v_f H}{D_L}\right)}{1 - \exp\left(\frac{v_f H}{D_L}\right)}$$

For small flow velocities (v_f is small), exponentials can be approximated to first few terms of a power series.

$$\frac{C}{C_0} = \frac{\left(1 + \frac{v_f Z}{D_L}\right) - \left(1 + \frac{v_f H}{D_L}\right)}{1 - \left(1 + \frac{v_f H}{D_L}\right)} = \frac{H - Z}{H} = \frac{H-Z}{H}.$$

i.e under steady state conditions, C/C_0 varies linearly with depth.



[25%]

3

(a)

Material	d (m)	(from data book) λ (W/mK)	R (m²K/W) d/λ
Ext. Surface			0.02*
Brick	0.12	0.84	0.14
Cavity / air Gap	0.08		0.23 **
Concrete	0.10	0.22	0.45
dense Plaster	0.01	0.5	0.02
Int. Surface			0.13*

$\Sigma R = 0.99 \approx 1.0$

Total U-Value $= 1.0$ W/m²K

* from data book

** $h_c = 0.5 \ W/m^2K$

$$h_{cd} = \frac{0.024}{0.08} \left(\frac{\lambda}{d}\right) = 0.3 \ W/m^2K$$

$$h_r = 4\epsilon_{12}\sigma T_{12}^3$$

$$= 4 \times 0.67 \times 5.67 \times 10^{-8} \times (285.5)^3$$

$$= 3.54 \ W/m^2K$$

$$\frac{1}{\epsilon_{12}} = \frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1$$

$$= \frac{1}{0.8} + \frac{1}{0.8} - 1$$

$$= 1.5$$

$$\epsilon_{12} = \frac{1}{1.5} = 0.67$$

$$h = h_c + h_{cd} + h_r$$

$$\Rightarrow 4.34 \ W/m^2K$$

$R_{airgap} = 0.23 \ m^2K/W$

$$T_{12} = \frac{T_1 + T_2}{2} \ K$$

$$\Rightarrow \frac{283 + 288}{2}$$

$$\Rightarrow 285.5 \ K$$

$\sigma = 5.67 \times 10^{-9} \ W/m^2K^4$ (data book)

(3)

(b) $U_{required} = 0.35 \ W/m^2K$

$$R_{required} = \frac{1}{0.35} = 2.85 \ m^2K/W$$

$$\Rightarrow \quad 2.85 = \Sigma R_{wall} - R_{airgap} + R_{insulation}$$

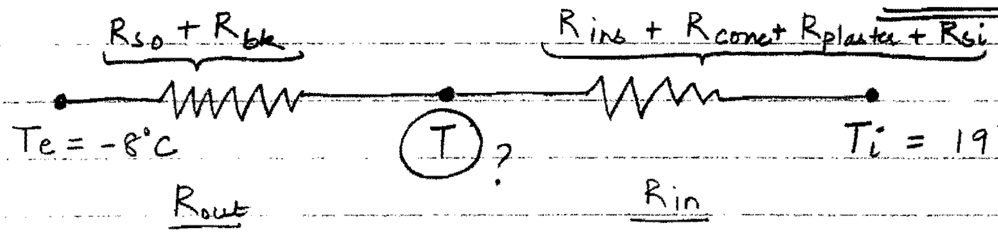
$$\Rightarrow \quad 2.85 = 1.0 - 0.23 + R_{insulation}$$

$$\Rightarrow \quad R_{insulation} = 2.09 \ m^2K/W$$

$$\lambda \text{ (thermal conductivity)}_{insulation} = \frac{d}{R} = \frac{0.08}{2.09} =$$

$$= \underline{\underline{0.038 \ W/mK}}$$

(c)



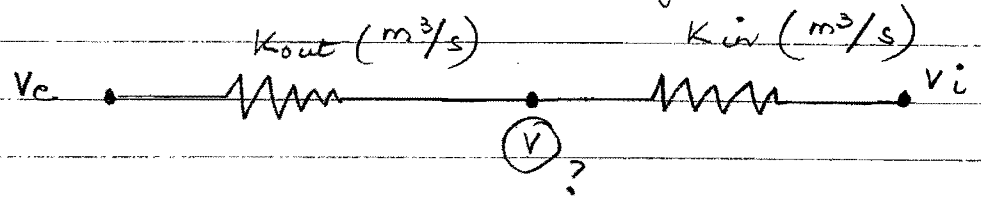
$$R_{out} = R_{so} + R_{bk} = 0.16 \ m^2K/W$$

$$R_{in} = R_{ins} + R_{conc} + R_{plaster} + R_{si} = 2.69 \ m^2K/W$$

$$T = \frac{R_{out}T_i + R_{in}T_e}{R_{out} + R_{in}} = \frac{(0.16 \times 19) + (2.69 \times -8)}{0.16 + 2.69}$$

$$\Rightarrow \quad \underline{\underline{-6.48^\circ C}}$$

(d) Humidity at saturation $V_s(-6.48^\circ C) = 2.87 g/m^3$
(from table in data book)



$$(m^3/s)\quad K_{out} = \frac{A}{d_{brick}/\delta_{brick}} = \frac{1}{0.12/5\times10^{-6}} = 4.16\times10^{-5}$$

$$(m^3/s)\quad K_{in} = \frac{A}{d_{ins}/\delta_{ins} + d_{conc}/\delta_{conc}} = \frac{1}{\frac{0.08}{20\times10^{-6}} + \frac{0.10}{10\times10^{-6}}} = 2.5\times10^{-4}$$

$$V = \frac{K_{out} V_e + K_{in} V_i}{K_{out} + K_{in}}$$

$$\Rightarrow \frac{(4.16\times10^{-5})\times3 + 2.5\times10^{-4}(7)}{2.92\times10^{-4}}$$

$$\Rightarrow 6.43 \ g/m^3$$

$6.43 > 2.87$ hence condensation

Install vapour barrier at the interface

(4)

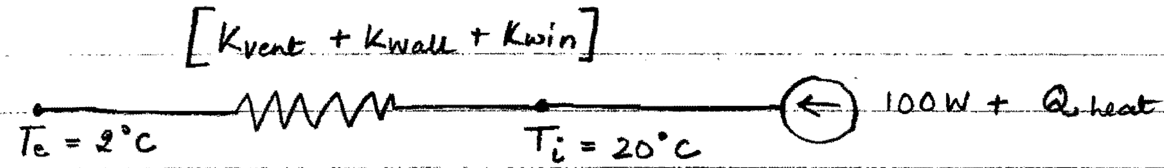
(a) Ventilation Rate for 40 students @ 5 l/s/person:

$$\underline{\underline{K_{vent}}} = \left(\frac{40 \times 5}{1000}\right) \times \rho_{air} \times C_{air}$$

$$= 0.2 \times 1.2 \times 1000 = 240 \text{ W/K}$$

$$\underline{\underline{K_{wall}}} = A_{wall} U_{wall} = 50 \times 0.35 = 17.5 \text{ W/K}$$

$$\underline{\underline{K_{win}}} = A_{win} U_{win} = 15 \times 1.5 = 22.5 \text{ W/K}$$



$$T_i = 20 = \frac{[K_{vent} + K_{wall} + K_{win}] \times 2 + 100 + Q_{heat}}{[K_{vent} + K_{wall} + K_{win}]}$$

$$\Rightarrow T_i = 20 = \frac{280 \times 2 + 100 + Q_{heat}}{280}$$

$$\Rightarrow 20 = 2 + 0.36 + \frac{Q_{heat}}{280}$$

$$\Rightarrow Q_{heat} = (20 - 2.36)\, 280$$

$$= \underline{\underline{4939 \text{ W}}}$$

4 (b)

- Thermal storage / mass
- time - varying heat gains
- non steady operation of heating/cooling
- cooling loads

4 (c) $q(x,t) = -\lambda \frac{\partial T}{\partial x}$ (Insert T in

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

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

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

Thermal Effusivity $b = \frac{\lambda}{\sqrt{a}} = \sqrt{\lambda \cdot \rho c}$

(in $W\sqrt{s}/m^2K$)

Materials w/ high b are good storage media. high value gives a large heat absorption and large release when surface temp. rises or drops.

~~Applications~~ Thermal mass for temp. storage of gains