Version RC/4

EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 19 April 2016 2 to 3.30

Module 3D8

BUILDING PHYSICS AND ENVIRONMENTAL GEOTECHNICS

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3D8 Building Physics and Env. Geotechnics Data Book (15 pages)
Supplementary page: one extra copy of Fig.1 (Question 1)
Engineering Data Book

10 minutes reading time is allowed for this paper.

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) Explain the terms thermal conductivity, volumetric heat capacity and thermal diffusivity with respect to heat flow in granular media. [15%]

(b) How is heat flow in a dry soil different to that in a fully saturated soil? [10%]

(c) A twin-tunnel is to be constructed next to a hill slope in Switzerland as shown in Fig.1. The outer walls are all 1 m thick but the central supporting wall is 0.5 m thick. The tunnel is made from concrete with a unit weight of 24 kN m^{-3}. Rainfall on the hill slope raises the ground water level to the top of the tunnel. The soil slope is formed from a silty sand with a hydraulic conductivity of 4.2×10^{-4} m s^{-1} underlain by a deep clay layer.

(i) Draw a 'flow net' at steady state seepage of the problem on the extra copy of Fig.1 provided. Highlight any limitations of the flow net you have constructed. You must submit this copy with your script. [25%]

(ii) Determine the quantity of leakage due to seepage through the silty sand in units of litres per day if the tunnel is 100 m long. Sketch the pore water pressure distribution along the left hand face of the tunnel and the tunnel base. [25%]

(iii) The effective stresses in the soil create a horizontal thrust of 80 kN m^{-1} on the left hand face of the tunnel. Calculate the factor of safety against sliding of the whole tunnel. The friction angle between the concrete and silty sand is 26°. [15%]

(iv) Give any measures that you may take to improve the factor of safety against sliding of this tunnel. [10%]

(cont.

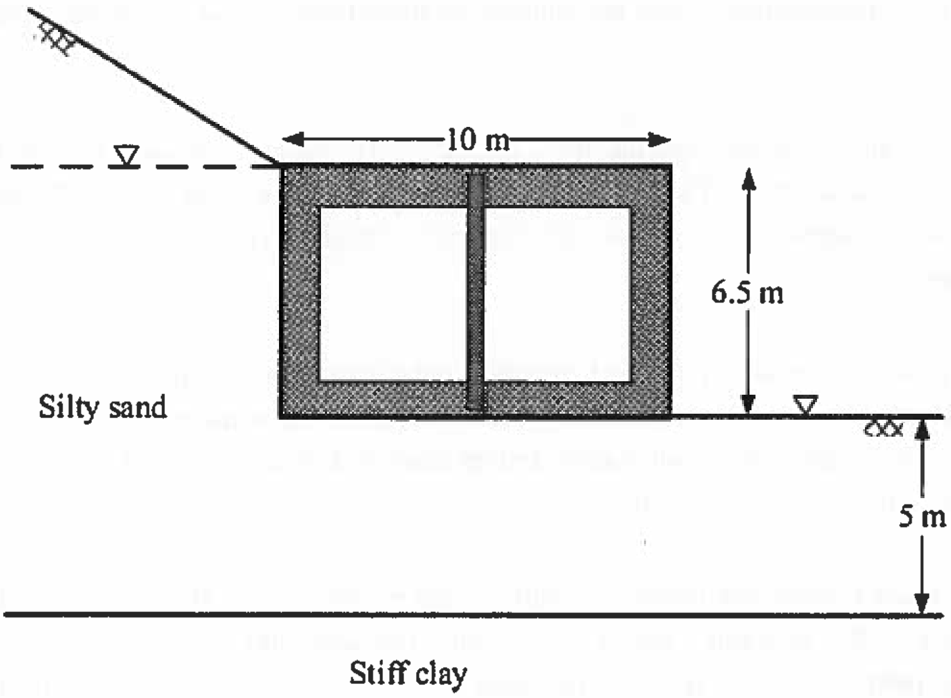

Fig. 1

2 (a) Explain briefly how horizontally stratified layers of soil are formed in nature. [10%]

(b) At a site it was observed that three distinct, horizontal layers of soils with thickness of L_1, L_2, and L_3 exist. The hydraulic conductivities of these strata are K_1, K_2, and K_3 respectively. Derive an expression for the overall vertical hydraulic conductivity of these soil layers. [20%]

(c) Derive a relationship for the hydraulic conductivity, K, of a soil sample in terms of the cross-sectional area a of the falling head tube, the cross-sectional area A of the soil sample, the length L of the soil sample, and the measured potential heads h_1 and h_2 at two different times t_1 and t_2 respectively. [25%]

(d) A soil sample was tested in a falling head permeameter. The soil sample had a diameter of 76.2 mm and a length of 98.4 mm. The area ratio between the soil sample and the falling head tube is 6000. The head of water above the base of the soil sample was recorded at different times as shown in the table below.

h (m)	1.00	0.94	0.90	0.88	0.80	0.75	0.66	0.46	0.35	0.25	0.20	0.15	0.10
t (hrs)	0.00	0.6	1.2	2.4	7.6	10.6	17.8	36.6	51	69	73.6	97	120

Calculate the hydraulic conductivity of the soil sample in m s^{-1}. [25%]

(e) The soil sample tested in Part (d) was found to have a 'rogue' silty clay layer that is 10 mm thick sandwiched between two layers of silty sand that has a hydraulic conductivity of 3.3×10^{-6} m s^{-1}. Calculate the hydraulic conductivity of the 'rogue' silty clay layer. Comment on the location of this 'rogue' layer within the soil sample. [20%]

3 (a) List three factors that are important when considering heat exchange by radiation between two surfaces. [15%]

(b) The general form of net radiation heat exchange I between two black body surfaces i and j, both of emissivity 1, and at temperature T_i and T_j respectively is:

$$I_{i,j} = A_i F_{i,j} \sigma (T_i^4 - T_j^4)$$

where A_i is the area of surface i, $F_{i,j}$ is the view factor, and σ is the Stefan-Boltzmann constant. Since the temperature span in building physics applications is small, it is common practice to simplify the above equation and express it as a function of the mean temperature $\bar{T}$. The radiation heat exchange across the two surfaces of a wall cavity is thus:

$$I_{i,j} = A_i F_{i,j} 4\sigma (\bar{T}^3)(T_i - T_j)$$

(i) For $T_i > T_j$, show that the percentage error due to this simplification is:

$$\left(\frac{\triangle}{\bar{T}}\right)^2 \times 100\%$$

where $\triangle = (T_i - T_j)/2$. [35%]

(ii) Calculate the error introduced by the above simplification for the case when temperature difference of the wall surfaces across the cavity is 15 °C, and the mean temperature of the cavity is 0 °C. [15%]

(c) Under steady state assumptions, calculate the effect on radiant heat flux of locating bright aluminium foil, having an emissivity of 0.05, in the centre of a cavity wall. The two surfaces of the cavity are at temperatures 15 °C and 5 °C respectively, each having an emissivity of 0.9. Assume the surface temperature of the foil to be the average temperature across the two surfaces of the cavity. Comment on the results. [25%]

(d) Explain the difference between emissivity and Solar Heat Gain Coefficient as two properties of glass. [10%]

4 (a) Briefly explain the stack-effect in the context of building ventilation. [10%]

(b) The volumetric airflow Q in a warm room with upper and lower openings may be estimated by:

$$Q = A^* C_{orif} \sqrt{2gH \left(\frac{273}{T_o} - \frac{273}{T_i} \right)}$$

where C_{orif} is the dimensionless discharge coefficient, A^* is the effective area of the openings, H is the height separating the upper and lower opening, g is the gravitational constant, and T_o and T_i are the external and internal temperatures, respectively.
Derive the above equation for a stack with two openings, one at the top and one at the bottom, knowing that the pressure difference Δp for airflow through openings is expressed as:

$$\Delta p = \frac{1}{C_{orif}^2} \left(\frac{1}{2} \rho v^2 \right)$$

where ρ is the density of air and v is the air velocity. Support the derivation with a diagram roughly indicating the pressure gradients and the airflow. [40%]

(c) A five-storey office building of area 25×18 m^2 has floor to ceiling heights of 3 m. During the summer months, the office must be cooled. As an energy saving measure, a stack with two openings is proposed for structurally cooling the building at night through natural ventilation from 1800 hours to 0800 hours. A total of 42 air changes are required over this period. Calculate the following for indoor temperature of 25 °C and outdoor temperature of 15 °C. Use $C_{orif} = 0.61$, density of air $\rho = 1.2$ kg m^{-3}, and specific heat capacity of air $c = 1.0$ kJ kg^{-1} K^{-1}.

(i) Calculate the rate of free cooling in kW from naturally ventilating the building at night. [15%]

(ii) Determine the free area of the upper opening if the lower opening has an area of 4.0 m^2. Assume that the two openings are separated by 12 m. [15%]

(d) On a summer day, fresh air introduced into a building from outdoors is at 30 °C dry bulb temperature and 55% relative humidity. The air is cooled down to 15 °C. How much moisture will have condensed out due to cooling? [20%]

END OF PAPER

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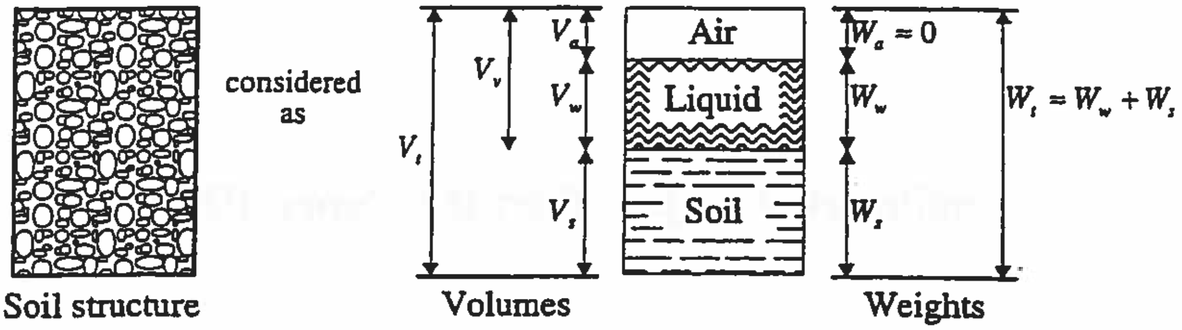
Engineering Tripos Part IIA Paper 3D8

BUILDING PHYSICS
&
ENVIRONMENTAL GEOTECHNICS

DATA BOOK

3 Groundwater

Soil: general definitions



Specific gravity of solid	G_s
Voids ratio	$e = V_v/V_s = n/(1-n)$
Specific volume	$v = V_t/V_s = 1+e$
Porosity	$n = V_v/V_t = e/(1+e)$
Water content	$w = W_w/W_s$
Degree of saturation	$S_r = V_w/V_v = wG_s/e$
Unit weight of water	$\gamma_w = 9.81\ \text{kN/m}^3$
Unit weight of soil	$\gamma = W_t/V_t = \left(\dfrac{G_s + S_r e}{1 + e}\right)\gamma_w$
Buoyant unit weight	$\gamma' = \gamma - \gamma_w = \left(\dfrac{G_s - 1}{1 + e}\right)\gamma_w$ (soil saturated)
Unit weight of dry soil	$\gamma_d = W_s/V_t = \left(\dfrac{G_s}{1 + e}\right)\gamma_w$

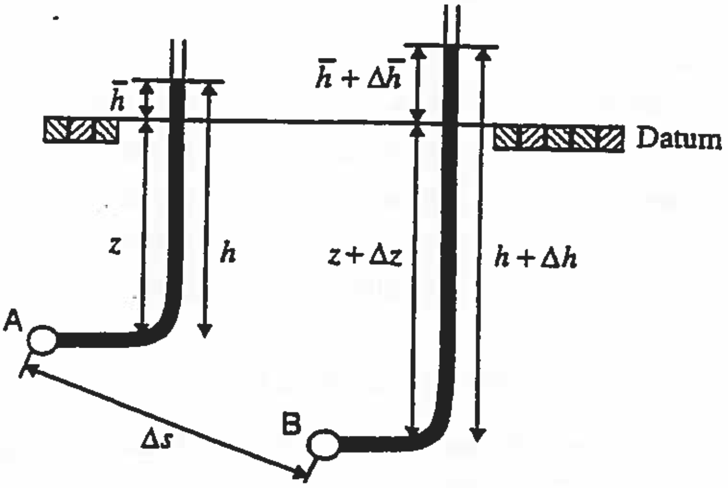
Classification of particle sizes

Boulders	larger than			200 mm
Cobbles	between	200 mm	and	60 mm
Gravel	between	60 mm	and	2 mm
Sand	between	2 mm	and	0.06 mm
Silt	between	0.06 mm	and	0.002 mm
Clay	smaller than	0.002 mm (two microns)		

D	equivalent diameter of soil particle
D_{10}, D_{60} etc.	particle size such that 10% (or 60% etc.) by weight of a soil sample is composed of finer grains.
C_U	uniformity coefficient D_{60}/D_{10}

Seepage

Excess pore water pressure



Total gauge pore water pressure at A: $p=\gamma_w h=\gamma_w(\bar{h}+z)$

B: $p+\Delta p=\gamma_w(h+\Delta h)=\gamma_w(\bar{h}+z+\Delta\bar{h}+\Delta z)$

Excess pore water pressure at A: $\bar{p}=\gamma_w\bar{h}$

B: $\bar{p}+\Delta\bar{p}=\gamma_w(\bar{h}+\Delta\bar{h})$

Hydraulic gradient A B $$i=-\frac{\Delta\bar{h}}{\Delta s}=-\frac{1}{\gamma_w}\frac{\Delta\bar{p}}{\Delta s}$$

Darcy's law $v = Ki$

v = superficial seepage velocity

K = coefficient of permeability or hydraulic conductivity

Typical hydraulic conductivities

$D_{10} > 10$ mm : non-laminar flow

10 mm $> D_{10} >$ 1µm : $K \cong 0.01\,(D_{10}$ in mm$)^2$ m/s

clays : $K \cong 10^{-9}$ to 10^{-11} m/s

Contaminant transport

Darcy's law

$$v_f = -\frac{k}{\mu n}\nabla(p+\rho g z)$$

where: v_f : pore fluid velocity $= \frac{v}{n}$

v : Darcy superficial velocity or specific discharge

n : porosity

k : intrinsic permeability $= \frac{K\mu}{\rho g}$

K : Darcy permeability or hydraulic conductivity

μ : dynamic viscosity of pore fluid

ρ : density of pore fluid

p : fluid pressure

Governing equation for one-dimensional transport in homogeneous media

$$\frac{\partial c}{\partial t} = D_l \frac{\partial^2 c}{\partial x^2} - v_f \frac{\partial c}{\partial x} \pm \frac{\Phi}{n}$$

where: c : mass of pollutant per unit volume of pore fluid (concentration)

D_l : coefficient of hydrodynamic dispersion $= D_d^* + D$

D_d^* : effective diffusion coefficient for pollutant in soil $= D_d \tau$

D_d : diffusion coefficient for pollutant in solution

τ : tortuosity of medium

D : coefficient of mechanical dispersion $= \alpha_l v_f$

α_l : dispersivity of the medium

Φ : chemical reactions

Error function tables

Relationships:

$$\mathrm{erf}(\beta)=\frac{2}{\sqrt{\pi}}\int_0^{\beta}\exp\left(-t^2\right)dt$$

$$\mathrm{erfc}(\beta)=1-\mathrm{erf}(\beta)$$

$$\mathrm{erf}(-\beta)=-\mathrm{erf}(\beta)$$

$$\mathrm{erfc}(-\beta)=1+\mathrm{erf}(\beta)$$

Tables (to four significant figures)

β	$\mathrm{erf}(\beta)$	$\mathrm{erfc}(\beta)$
0.00	0.0000	1.0000
0.05	0.0564	0.9436
0.10	0.1125	0.8875
0.15	0.1680	0.8320
0.20	0.2227	0.7773
0.25	0.2763	0.7237
0.30	0.3286	0.6714
0.35	0.3794	0.6206
0.40	0.4284	0.5716
0.45	0.4755	0.5245
0.50	0.5205	0.4795
0.55	0.5633	0.4367
0.60	0.6039	0.3961
0.65	0.6420	0.3580
0.70	0.6778	0.3222
0.75	0.7112	0.2888
0.80	0.7421	0.2579
0.85	0.7707	0.2293
0.90	0.7969	0.2031
0.95	0.8209	0.1791
1.00	0.8427	0.1573
1.10	0.8802	0.1198
1.20	0.9103	0.0897
1.30	0.9340	0.0660
1.40	0.9523	0.0477
1.50	0.9661	0.0339
1.60	0.9763	0.0237
1.70	0.9838	0.0162
1.80	0.9891	0.0109
1.90	0.9928	0.0072
2.00	0.9953	0.0047
2.20	0.9981	0.0019
2.40	0.9993	0.0007
2.60	0.9998	0.0002
2.80	0.9999	0.0001
3.00	1.0000	0.0000

3D8 Building Physics Databook

Ruchi Choudhary

Symbol	Meaning	Units
a	thermal diffusivity	$a = \lambda/\rho c$
c	Specific heat capacity	$\mathrm{J/(kg \cdot K)}$
d	Thickness	m
b	thermal effusivity	$\mathrm{W\sqrt{s}/m^2k}$
d_p	Penetration depth	m
h_c	Convective surface heat transfer coefficient	$\mathrm{W/m^2K}$
h_r	Radiative surface heat transfer coefficient	$\mathrm{W/m^2K}$
h_{c+cd}	Combined convective and conductive coefficient	$\mathrm{W/m^2K}$
Ψ	linear thermal transmittance	W/mK
χ	local thermal conductance	W/K
f_{Rsi}	Surface temperature factor	
g	Density of moisture flow rate	$\mathrm{kg/m^2s}$
q	Density of heat flow rate	$\mathrm{W/m^2}$
q_b	Power emitted per unit area	$\mathrm{W/m^2}$
n	Air exchange rate	$\mathrm{s^{-1}}$ or $\mathrm{h^{-1}}$
v	Velocity	m/s
v	Water vapour content or humidity by volume	$\mathrm{kg/m^3}$
v_s	Saturation	$\mathrm{kg/m^3}$
A	Area	$\mathrm{m^2}$
C_p	Dynamic pressure	Pa
D_w	Diffusivity of water vapour in air	$\mathrm{m^2/s}$
E	Total radiative power	$\mathrm{W/m^2}$
F	View factor	-
G	Moisture flow rate	kg/s
K	Thermal conductance	W/K
p	pressure	Pa
Q	Total heat flow	W
R	Thermal Resistance	K/W or $\mathrm{m^2K/W}$
R_a	Air flow rate	$\mathrm{m^3/s}$
T	Temperature	K or °C
T_e	External temperature	K or °C
T_{en}	Environmental temperature	°C
T_i	Inside temperature	°C
U	Thermal transmittance	$\mathrm{W/m^2K}$
V	Volume	$\mathrm{m^3}$
Z_v	Water vapour resistance	s/m
Z_{vi}	Surface vapour resistance interior wall	s/m
Z_{ve}	Surface vapour resistance exterior wall	s/m

Symbol	Meaning	Unit
α	Absorptivity	-
β	Moisture transfer coefficient	m/s
δ_v	Vapour permeability	$\mathrm{m^2/s}$
χ	Local thermal conductance	W/mK
ϵ	Emissivity	-
λ	Thermal conductivity	W/mK
λ	Wavelength	m
μ	Dynamic viscosity	kg/ms
ν	Frequency	Hz
ρ	Density	$\mathrm{kg/m^3}$
ρ	Reflectivity	-
ψ	Linear thermal transmittance	W/mK
σ	Stefan-Boltzmann constant	$\mathrm{W/m^2K^4}$
τ	Transmittance to radiation	-

Some useful values

σ	Stefan-Boltzmann constant	$5.67 \times 10^{-8}\ \mathrm{Wm^{-2}K^{4}}$
ρ_{air}	Density of air	$1.2\ \mathrm{kg/m^3}$
c_{air}	Specific heat capacity of air	1000 J/Kg K
ν_{air}	Kinematic viscosity of air	$15 \times 10^{-6}\ \mathrm{m^2/s}$
μ_{air}	Dynamic viscosity of air	18×10^{-6} kg/ms
λ_{air}	Thermal conductivity of air	0.024 W/mK
g	Acceleration due to gravity	$9.8\ \mathrm{m/s^2}$

1. STEADY STATE CONDUCTION

U-value with bridges: $U = \frac{U_0}{A} + \frac{\Sigma_{i=1}^{n}(\Psi L_i) + \Sigma_{j=1}^{m}\chi_j}{A}$

For conductance through pipes: $K_{pipe} = \frac{2\pi\lambda H}{\ln(r2/r1)}$

U-value of basements: $U_b = \frac{A_b U_{bf} + h_b P_{bf} U_{bw}}{A_b + h_b P_{bf}}$

2. RADIATION

Longwave radiation exchange:

(a) between 2 surfaces in an enclosure: $Q_{12} = h_r \cdot A_1 \cdot (T_1 - T_2)$

where $h_r = \frac{4\sigma T_{1,2}^3}{\frac{1-\epsilon_1}{\epsilon_1} + \frac{1}{F_{12}} + \frac{1-\epsilon_2}{\epsilon_2}\frac{A_1}{A_2}}$

and $T_{1,2} = \frac{T_1 + T_2}{2}$

(b) in air cavity: $h_r = 4\epsilon_{12}\sigma T_{1,2}^3$

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

(c) in an attic: $h_r = \frac{4\sigma T_{1,2}^3}{\frac{1}{\epsilon_1} + \frac{1-\epsilon_1}{\epsilon_2} . \cos x}$

Solar heat gain through transparent media: $Q_{sol} = I_{sol}^0 . \text{SHGC} . A$

Solar heat gain through opaque media: $Q_{sol} = \Sigma(UA) \times dT_e, \quad dT_e = \alpha . I_{sol}^0 . R_{se}$

3. VENTILATION

Heat Loss due to ventilation: $Q_{vent} = (T_i - T_e) \cdot \rho_a c_{Pa} \cdot Q$

Airflow through window: $Q = C_{orif} A_w (2\Delta p_w / \rho)^{0.5}$

Stack driven flow: $Q = \frac{A_1 A_2}{\sqrt{A_1^2 + A_2^2}} C_{\text{orif}} \sqrt{\frac{2\Delta p_s}{\rho}}$

Infiltration losses: $Q_{\text{infilt}} = (T_i - T_e) \cdot \rho_a c_{Pa} \cdot R_{\text{std-pressure}}$

where, $R_{\text{std-pressure}} = R_a / 20$ and, $R_a = \text{ACH} \cdot V / 3600$

Air leakage through gaps: $R_a = \frac{1}{2 \cdot S_e'} \cdot (\sqrt{S_g^2 + 4 \cdot \Delta P \cdot S_e'} - S_g)$

where, $S_e' = \frac{1.8 \cdot \rho_a}{2 \cdot A^2}$ and, $S_g = \frac{12\mu \cdot L}{b^2 \cdot A}$

4. MOISTURE

Moisture flow through wall by diffusion: $Z_{v,tot} = \Sigma_{i=1}^{N} \frac{d_i}{\delta_v, i} + Z_{si} + Z_{so}$

Moisture flow through wall by convection: $v_i(t) = v_e + \frac{G}{nV} \cdot (1 - e^{-nt})$

where, $G = R_a \cdot (v_{in} - v_{out})$

Table 1: Typical thermal conductivities (λ)

Material	Thermal Conductivity W/mK
Aluminium	160
Plywood	0.14
Expanded polystyrene	0.03
Brick	0.84
Concrete block	0.22
Dense plaster	0.50
Vermiculite	0.03
Concrete slab	1.00
Roofing felt	0.20
Plasterboard	0.16
Wood wool slab	0.10
Clay soil - water content 0.2	1.18
Clay soil - water content 0.4	1.58
Glass (density 2500kg/m^3)	1.05
Rock: Marble (2500kg/m^3)	2.0
Rock: Slate (2700kg/m^3)	2.0
Sheep's wool	0.045
Thatch (straw)	0.07
Mineral fibreboard	0.035

Table 2: Approximate Thermal Diffusivity at Room Temperature

Material	λ (W/mK)	ρc (J/m^3K)	a (m^2/s)
Wood	0.14	0.75×10^6	0.19×10^{-6}
Lt.-wt. Concrete	0.14	0.50×10^6	0.28×10^{-6}
Mineral Wool	0.04	0.12×10^6	0.30×10^{-6}
Brick	0.60	1.35×10^6	0.44×10^{-6}
Concrete	1.70	1.80×10^6	1.00×10^{-6}
Granite	3.5	2.20×10^6	1.60×10^{-6}
Iron	84	3.60×10^6	23.0×10^{-6}

Table 3: Internal Surface Resistances

Surface	Direction of heat flow	Resistance [m^2 K/W]
Walls	Horizontal	0.13
Floors or Ceilings	Upward	0.10
Floors or Ceilings	Downward	0.17
Roofs (flat or sloping)	Upward	0.10

Table 4: External Surface Resistances

Surface	Direction of heat flow	Resistance [m^2 K/W]		
		Sheltered	Normal	Exposed
Walls	Horizontal	0.06	0.04	0.02
Floors	Downward	0.06	0.04	0.02
Roofs	Upward	0.06	0.04	0.02

Table 5: Default values of Ψ for different types of junctions

Junction detail	Ψ W/mK
Lintels	1.00
Sill	0.08
Jamb	0.10
Grd. Flr., Flr above garage or unheated space	0.32
Intermediate floor within a dwelling	0.14
Eaves (insulation at ceiling level)	0.12
Gables (insulation at rafter level)	0.48
Corner	0.18
Party wall between dwellings	0.12

Table 6: Typical solar gain factors (τ or SHGC) for windows

Glazing Type	Instantaneous	Alternating	
		Lightweight	Heavyweght
Clear 6mm	0.76	0.64	0.47
Clear surface tinted 6mm	0.60	0.53	0.41
Clear reflective film 6mm	0.32	0.29	0.23
Clear reflective tinted film 6mm	0.28	0.26	0.23
Double clear 6 mm	0.64	0.56	0.42
Double reflecting	0.28	0.25	0.21
Triple clear 6 mm	0.55	0.50	0.39
Triple clear 6 mm w/ mid shade	0.28	0.26	0.24
Double clear 6 mm w/ int. shade	0.26	0.25	0.21
Double clear 6 mm w/ ext. shade	0.13	0.09	0.07

Ratio, p_b / A_b (/ m^{-1})	U-value of basement floor, U_{bf} (/ W·m^{-2}·K^{-1}), for stated basement depth, h_b (/ m)				
	0.5	1.0	1.5	2.0	2.5
0.1	0.20	0.19	0.18	0.17	0.16
0.2	0.34	0.31	0.29	0.27	0.26
0.3	0.44	0.41	0.38	0.35	0.33
0.4	0.53	0.48	0.44	0.41	0.38
0.5	0.61	0.55	0.50	0.46	0.43
0.6	0.68	0.61	0.55	0.50	0.46
0.7	0.74	0.65	0.59	0.53	0.49
0.8	0.79	0.70	0.62	0.56	0.51
0.9	0.84	0.73	0.65	0.58	0.53
1.0	0.89	0.77	0.68	0.60	0.54

Figure 1: U-value for un-insulated basement floors, CIBSE Guide A

Thermal resistance of basement walls, R_{bw} (/ m^2.K.W^{-1})	U-value of basement walls, U_{bw} (/ W·m^{-2}·K^{-1}), for stated basement depth, h_b (/ m)				
	0.5	1.0	1.5	2.0	2.5
0.2	1.55	1.16	0.95	0.81	0.71
0.5	0.98	0.78	0.66	0.58	0.52
1.0	0.61	0.51	0.45	0.40	0.37
2.0	0.35	0.30	0.27	0.25	0.24
2.5	0.28	0.25	0.23	0.21	0.20

Figure 2: U-value for basement walls, CIBSE Guide A

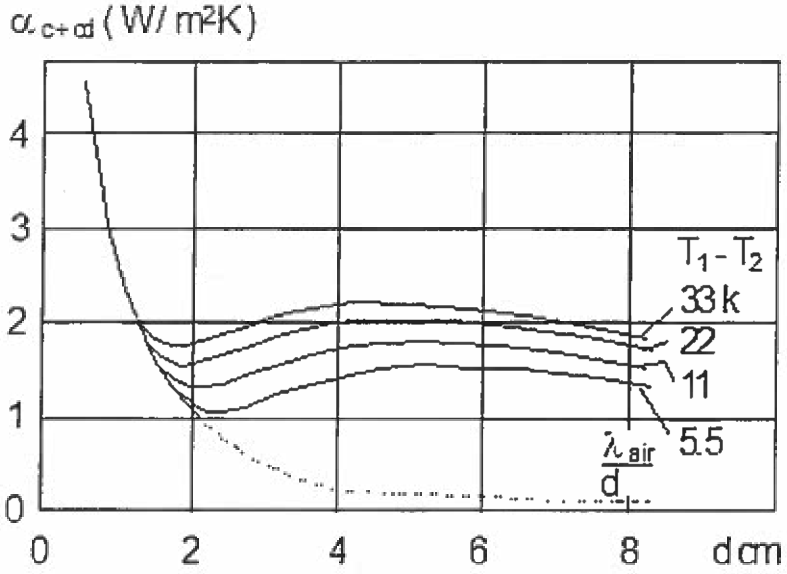


Figure 3: Combined convective and conduction heat transfer coefficient in vertical non-ventilated airgaps

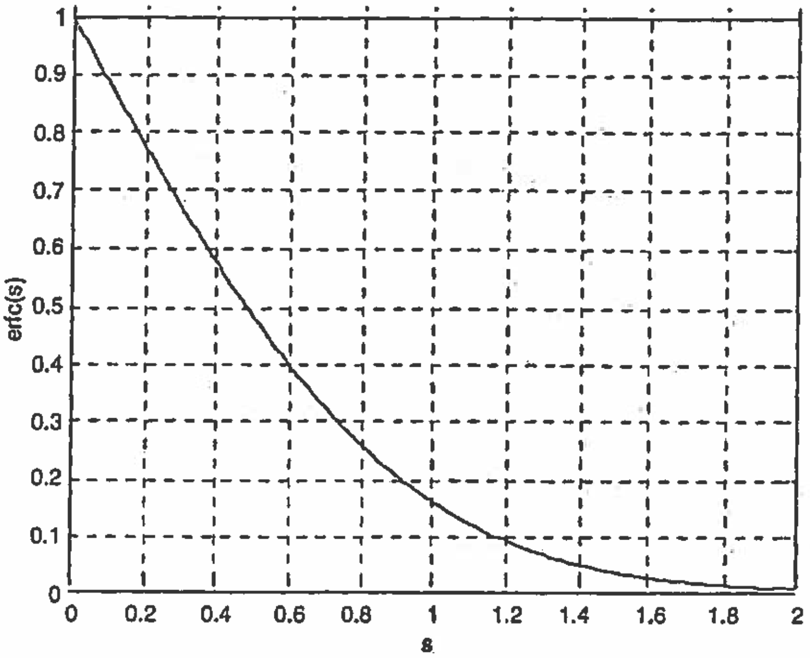


Figure 4: The complementary error function, erfc(s)

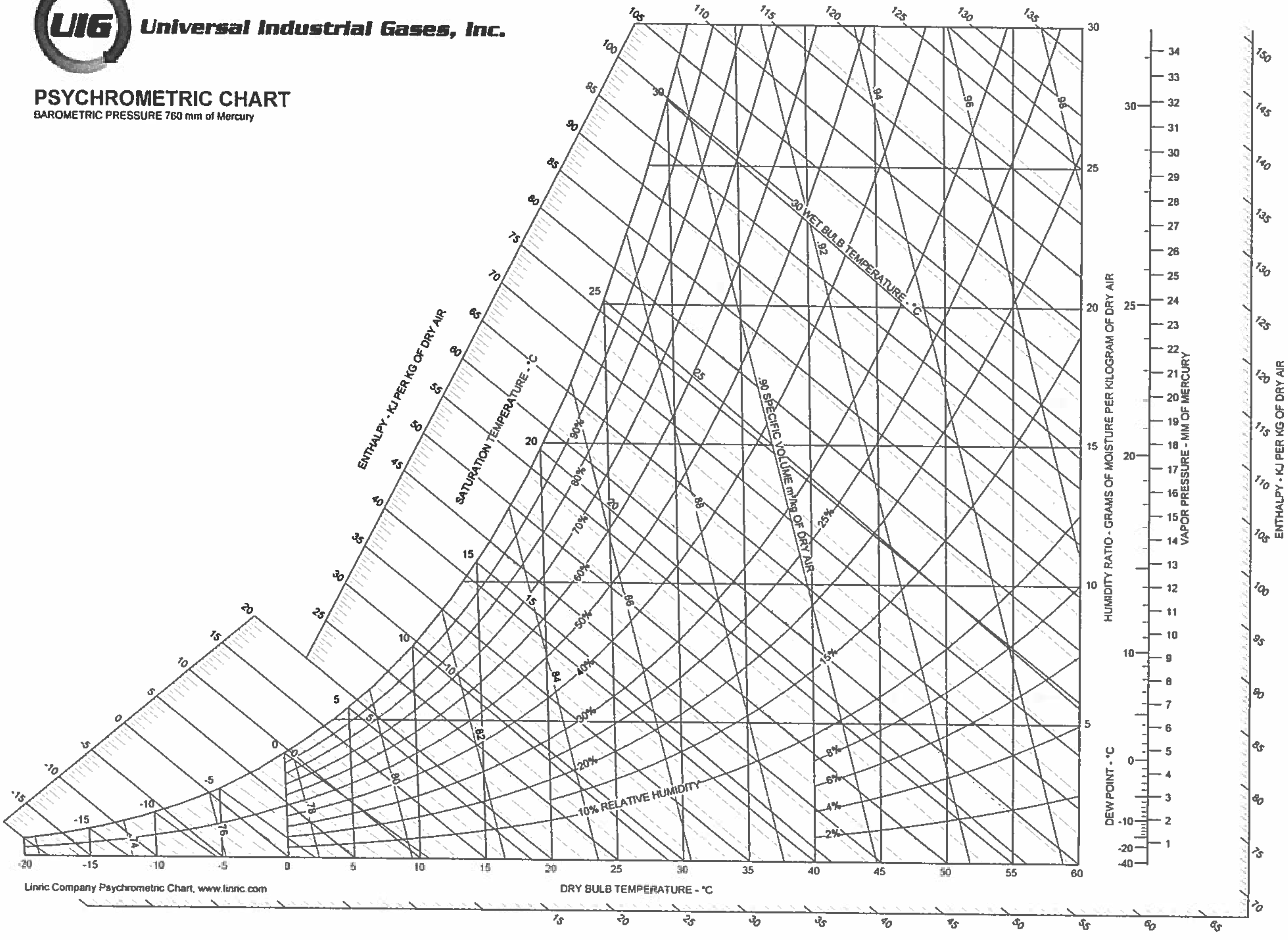
T (°C)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
-20	0.89	0.88	0.87	0.86	0.85	0.85	0.84	0.83	0.82	0.82
-19	0.97	0.96	0.95	0.94	0.94	0.93	0.92	0.91	0.90	0.89
-18	1.06	1.05	1.04	1.03	1.02	1.02	1.01	1.00	0.99	0.98
-17	1.16	1.15	1.14	1.13	1.12	1.11	1.10	1.09	1.08	1.07
-16	1.27	1.26	1.25	1.24	1.23	1.22	1.20	1.19	1.18	1.17
-15	1.39	1.38	1.36	1.35	1.34	1.33	1.32	1.31	1.29	1.28
-14	1.52	1.50	1.49	1.48	1.46	1.45	1.44	1.43	1.41	1.40
-13	1.65	1.64	1.63	1.61	1.60	1.58	1.57	1.56	1.54	1.53
-12	1.80	1.79	1.77	1.76	1.74	1.73	1.71	1.70	1.68	1.67
-11	1.97	1.95	1.93	1.92	1.90	1.88	1.87	1.85	1.84	1.82
-10	2.14	2.12	2.10	2.09	2.07	2.05	2.03	2.02	2.00	1.98
-9	2.33	2.31	2.29	2.27	2.25	2.23	2.21	2.20	2.18	2.16
-8	2.53	2.51	2.49	2.47	2.45	2.43	2.41	2.39	2.37	2.35
-7	2.75	2.73	2.71	2.69	2.66	2.64	2.62	2.60	2.58	2.55
-6	2.99	2.97	2.94	2.92	2.89	2.87	2.85	2.82	2.80	2.78
-5	3.25	3.22	3.20	3.17	3.14	3.12	3.09	3.07	3.04	3.02
-4	3.52	3.50	3.47	3.44	3.41	3.38	3.36	3.33	3.30	3.27
-3	3.82	3.79	3.76	3.73	3.70	3.67	3.64	3.61	3.58	3.55
-2	4.14	4.11	4.08	4.04	4.01	3.98	3.95	3.92	3.88	3.85
-1	4.49	4.45	4.42	4.38	4.35	4.31	4.28	4.24	4.21	4.18
-0	4.85	4.82	4.78	4.74	4.71	4.67	4.63	4.60	4.56	4.52
0	4.85	4.88	4.92	4.95	4.98	5.02	5.05	5.09	5.12	5.16
1	5.19	5.23	5.27	5.30	5.34	5.38	5.41	5.45	5.49	5.52
2	5.56	5.60	5.64	5.68	5.72	5.75	5.79	5.83	5.87	5.91
3	5.95	5.99	6.03	6.07	6.12	6.16	6.20	6.24	6.28	6.32
4	6.37	6.41	6.45	6.50	6.54	6.58	6.63	6.67	6.71	6.76
5	6.80	6.85	6.90	6.94	6.99	7.03	7.08	7.13	7.17	7.22
6	7.27	7.32	7.36	7.41	7.46	7.51	7.56	7.61	7.66	7.71
7	7.76	7.81	7.86	7.91	7.96	8.02	8.07	8.12	8.17	8.23
8	8.28	8.33	8.39	8.44	8.50	8.55	8.61	8.66	8.72	8.77
9	8.83	8.89	8.94	9.00	9.06	9.11	9.17	9.23	9.29	9.35
10	9.41	9.47	9.53	9.59	9.65	9.71	9.77	9.83	9.90	9.96
11	10.02	10.09	10.15	10.21	10.28	10.34	10.41	10.47	10.54	10.60
12	10.67	10.74	10.80	10.87	10.94	11.01	11.08	11.14	11.21	11.28
13	11.35	11.42	11.49	11.57	11.64	11.71	11.78	11.85	11.93	12.00
14	12.07	12.15	12.22	12.30	12.37	12.45	12.53	12.60	12.68	12.76
15	12.83	12.91	12.99	13.07	13.15	13.23	13.31	13.39	13.47	13.55
16	13.63	13.72	13.80	13.88	13.97	14.05	14.14	14.22	14.31	14.39
17	14.48	14.57	14.65	14.74	14.83	14.92	15.01	15.10	15.19	15.28
18	15.37	15.46	15.55	15.64	15.74	15.83	15.92	16.02	16.11	16.21
19	16.30	16.40	16.50	16.59	16.69	16.79	16.89	16.99	17.09	17.19
20	17.28	17.39	17.49	17.59	17.69	17.80	17.90	18.01	18.11	18.22
21	18.32	18.43	18.53	18.64	18.75	18.86	18.97	19.08	19.19	19.30
22	19.41	19.52	19.63	19.75	19.86	19.97	20.09	20.20	20.32	20.44
23	20.55	20.67	20.79	20.91	21.03	21.15	21.27	21.39	21.51	21.63
24	21.75	21.88	22.00	22.13	22.25	22.38	22.50	22.63	22.76	22.89
25	23.02	23.14	23.28	23.41	23.54	23.67	23.80	23.94	24.07	24.20
26	24.34	24.48	24.61	24.75	24.89	25.03	25.16	25.30	25.45	25.59
27	25.73	25.87	26.01	26.16	26.30	26.45	26.59	26.74	26.89	27.04
28	27.19	27.33	27.49	27.64	27.79	27.94	28.09	28.25	28.40	28.56
29	28.71	28.87	29.03	29.19	29.34	29.50	29.66	29.83	29.99	30.15
30	30.31	30.48	30.64	30.81	30.98	31.14	31.31	31.48	31.65	31.82

Figure 5: Humidity by volume in g/m^3 at saturation as a function of temperature.

Universal Industrial Gases, Inc.

PSYCHROMETRIC CHART

BAROMETRIC PRESSURE 760 mm of Mercury

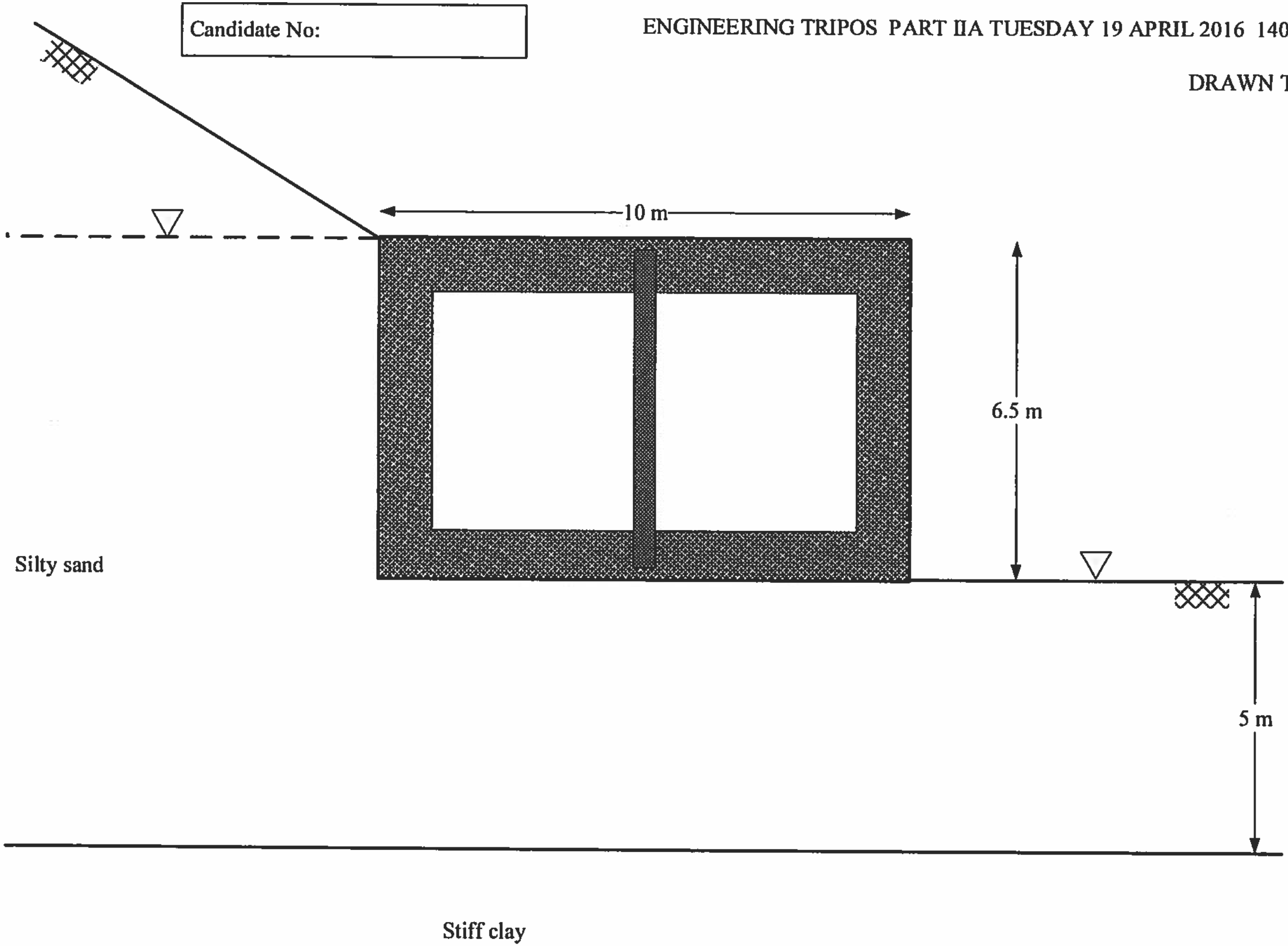


Linric Company Psychrometric Chart, www.linric.com

Candidate No:

ENGINEERING TRIPOS PART IIA TUESDAY 19 APRIL 2016 1400 TO 1530

DRAWN TO SCALE



Extra copy of Fig. 1