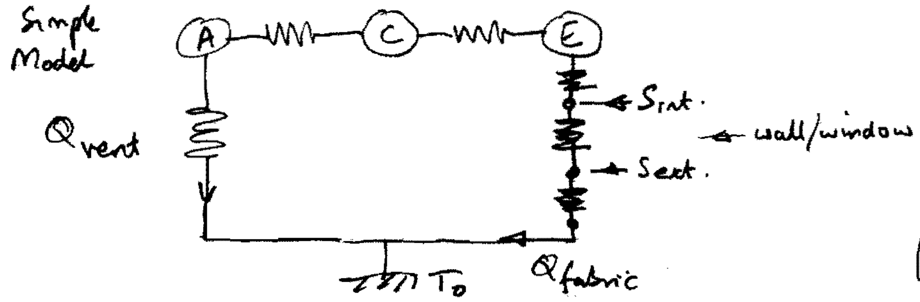
ENGINEERING TRIPOS PART IIB 2012
4D11 BUILDING PHYSICS **Dr M Overend**

1(a). CIBSE Simple Model



[20]

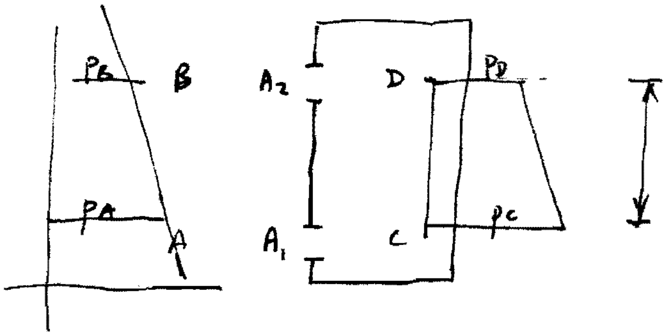
(A) = air node = representative of temperature of air inside room
(C) = operative node → "c" for comfort, and it is representative of an occupant in the room, and how warm they feel, as some split of radiative and air temperature.

(E) = environmental node ~ representative of a point just off the surface of the walls ~~where~~ (eg edge of ~~contact~~ convective boundary layer) where convective and radiation heat transfer are assumed to occur.

Sint and Sext are the nodes at the surface (interior and exterior) of the wall, and there are resistances (surface resistances) between them and the adjacent air.

4D11 1(b).

$$\Delta p = \tfrac{1}{2}\rho v^2 C \quad \text{for flow through orifice}$$



$$p_B = p_A - \rho_o g H$$

$$p_D = p_C - \rho_i g H.$$

Continuity of pressure round closed path $\quad \Delta p_{AB} = \Delta p_{AC} + \Delta p_{CD} + \Delta p_{DB}$

so pressure drop thru orifices

$$= \Delta p_{AC} + \Delta p_{DB} = \Delta p_{AB} - \Delta p_{CD}$$

$$= \rho_o g H - \rho_i g H$$

$$= (\rho_o - \rho_i) g H.$$

Now $\rho \propto \frac{1}{T}$ so $\frac{\rho}{\rho_{273}} = \frac{273}{T}$

$$\text{so } (\rho_o - \rho_i) g H = \rho_{273}\left(\frac{273}{T_o} - \frac{273}{T_i}\right) g H$$

and equate to pressure drop thru orifices

$$\tfrac{1}{2}\rho V_{AC}^2 C + \tfrac{1}{2}\rho V_{DB}^2 C = \rho_{273}\left(\frac{273}{T_o} - \frac{273}{T_i}\right) g H$$

But $V_{AC} = \frac{Q}{A_1}$ $\quad V_{DB} = \frac{Q}{A_2}$ $\quad$ can cancel all ρ's

$$Q^2 \, \frac{1}{2}\left(\frac{1}{A_1^2} + \frac{1}{A_2^2}\right) C = \left(\frac{273}{T_o} - \frac{273}{T_i}\right) g H$$

$$Q = A^* \sqrt{\frac{2gH}{C}} \sqrt{\frac{273}{T_o} - \frac{273}{T_i}}$$

$$\text{with } A^* = \frac{A_1 A_2}{\sqrt{A_1^2 + A_2^2}}$$

[5]

4D11 c) $A_1 = 5\ m^2$ $A_2 = 2\ m^2$

$$A^* = \frac{10}{\sqrt{25+4}} = \frac{10}{\sqrt{29}} = 1.86\ m^2.$$

$C = \frac{1}{0.61^2}$

$$\sqrt{\frac{2gH}{C}} = \sqrt{\frac{2(9.81)(20)}{2.7}} = \cancel{14.1}\ 12.06\ ms^{-1} \quad \frac{ms^{-2}m}{-}$$

$$\sqrt{\frac{273}{T_o} - \frac{273}{T_i}} = \sqrt{\frac{273}{273+2} - \frac{273}{273+25}}$$

$$= \sqrt{0.9927 - 0.9161}$$

$$= 0.2768 \quad \text{dimensionless.}$$

$$\therefore \quad Q = 1.86 \times \cancel{14.1}\ 12.06 \times 0.2768$$

$$= \cancel{7}\ m^3/s \qquad 6.2\ m^3/s$$

$V_{window} = 3.5\ m/s$!

$V_{door} = 1.4\ m/s.$

$$\text{Heat lost} = (1\ kJ\ m^{-3}K^{-1})(\cancel{7}\ 6.2\ m^3/s)(23\ K)$$

$$= \cancel{161}\ kJ/s^{-1} = \cancel{161}\ kW \quad !$$

142 kW

High.

~~Maybe adjust equation~~

[30]

2 a) ADVANTAGES OF MAXIMISING DAYLIGHT:

- REDUCES HIGH ENERGY COST OF ARTIFICIAL LIGHTING
- POSITIVE PSYCHOLOGICAL EFFECT ON OCCUPANTS
- PROMOTES NATURAL RYTHM
- EXCELLENT COLOUR DEFINITION / AETHETIC ASPECTS

DISADVANTAGES OF MAXIMISING DAYLIGHT:

- LARGE WINDOW AREAS MAY LEAD TO UNWANTED SOLAR HEAT GAIN / HEAT LOSS ⇒ HIGHER ENERGY DEMAND
- GLARE LEADING TO VISUAL DISCOMFORT
- SPACE PLANNING LIMITATIONS IMPOSED BY NEED TO LOCATE WORK SPACES NEXT TO WINDOWS.

[15]

b) DAYLIGHT FACTOR IS THE RATIO OF DAYLIGHT ILLUMINANCE (LUMENS/m^2) ON A HORIZONTAL WORKING SURFACE AT A STANDARD HEIGHT TO THE ILLUMINANCE ON AN UNOBSTRUCTED HORIZONTAL SURFACE IN THE OPEN AIR ON AN OVERCAST DAY.

THE DAYLIGHT FACTOR IS COMPOSED OF:

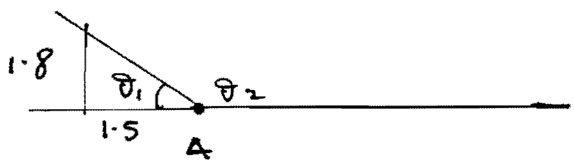
1. SKY COMPONENT – DEPENDS ON AREA OF SKY 'SEEN' THROUGH THE WINDOWS AND ITS ILLUMINANCE.

2. EXTERNALLY REFLECTED COMPONENT – LIGHT COMING TO THE POINT OF INTEREST AFTER REFLECTION FROM AN EXTERNAL OBJECT.

3. INTERNALLY REFLECTED COMPONENT – DEPENDS ON THE MULTIPLE REFLECTIONS FROM SURFACE WITHIN THE ROOM.

[15]

c) S.C. (A)



$\theta_1 = \tan^{-1} 1.8/1.5 = 50.2°$

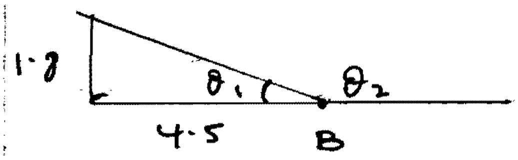
$\theta_2 = 0$ (NO VISIBLE SUN)

V. LONG OFFICE ∴ CORRECTION ANGLE:

FROM PROTRACTOR SC = 12%

∴ CORRECTED SC(A) = 12% × 0·7 = 8·4%

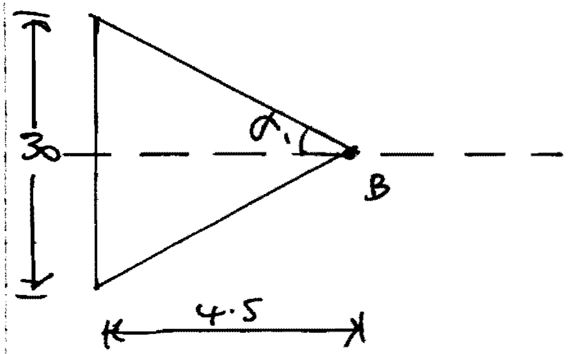
S.C. (B)



$\theta_1 = \tan^{-1} 1.8/4.5 = 21.8°$

$\theta_2 = 0$ (NO VISIBLE SKY)

SC = 1.5 %



CORRECTION FACTOR FOR WINDOW WIDTH:

MEAN ANGLE OF ELEVATION = 10.9°

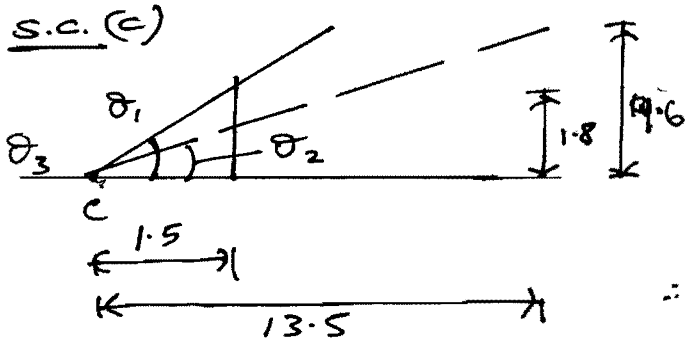
$\alpha_1 = \tan^{-1} \frac{15}{4.5}$ ∴ $\alpha_1 = 73.3°$

∴ CORRECTION ANGLE FROM PROTRACTOR = 0.49

∴ FOR 2α = 0.98

∴ CORRECTED SC(B) = 1.5% × 0.98 × 0.7 = **1.03%**

S.C. (C)



$\theta_1 = \tan^{-1} \frac{1.8}{1.5} = 50.2°$

$\theta_2 = \tan^{-1} \frac{9.6}{13.5} = 35.4°$

∴ SC = 12% − 4% = 8%

VERY LONG OFFICE ∴ CORRECTION ANGLE = 0

∴ CORRECTED SC(C) = 8% × 0.7 = **5.6%**

ERC (A)

$\theta_2 = \tan^{-1} 1.8/7.5 = 13.5°$

ERC = 0.6% × 0.5 = 0.3%

CORRECTION ANGLE FOR WINDOW WIDTH: $\alpha_1 = \tan^{-1} 15/7.5 = 63.4$

MEAN ANGLE OF ELEVATION = 7.75°

CORRECTION ANGLE FROM PROTRACTOR = 0.48 = 0.96 FOR 2α

∴ CORRECTED ERC = 0.3% × 0.96 × 0.7 = **0.20%**

ERC (B)

$\theta_2 = 21.8°$ ⇒ ERC = 0.5(SC)

∴ CORRECTED ERC (B) = 0.5 × 1.03% = 0.52%

ERC (C)

$\theta_2 = 50.2\%$ ⇒ ERC (C) = 0.5 × 4% = 2%

∴ CORRECTED ERC (C) = 0.7 × 2.% = 1.4%

IRC AT (A), (B) AND (C)

WINDOW SURFACE AREA = 2 × 30 × 1.8 = 108 m²
TOTAL ROOM SURFACE AREA (EXCLUDING END WALLS)
= (2 × 9 × 30) + (3 − 1.8) × 2 × 30 = 612 m²

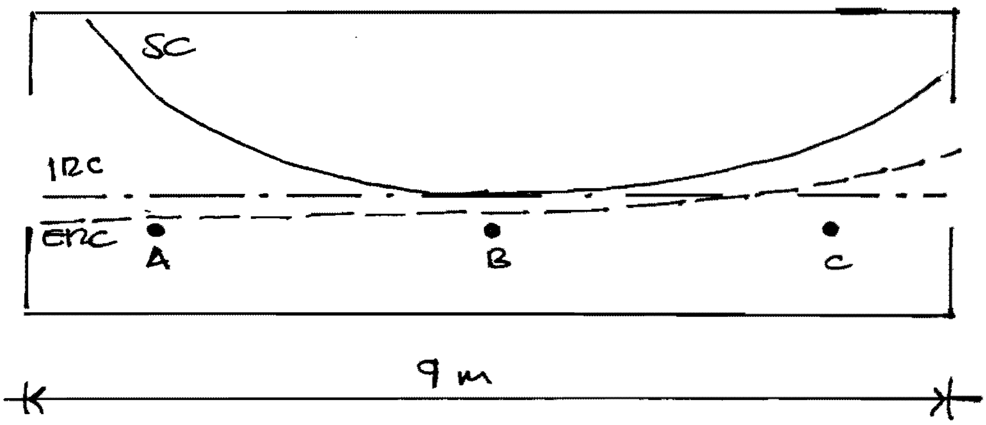
∴ RATIO = 0.18

USING NOMOGRAM LINE FROM 0.18 ON SCALE A TO 30% ON SCALE C GIVES 1.3% ON SCALE C.

∴ DF (A) = 8.4 + 0.2 + 1.3 = 9.9%
DF (B) = 1.03 + 0.52 + 1.3 = 2.85%
DF (C) = 5.6 + 1.4 + 1.3 = 8.3%

[40]

c ii)



[15]

d) GLAZED ROOF WOULD HAVE SIGNIFICANT IMPACT ON ERC AND SC (C):

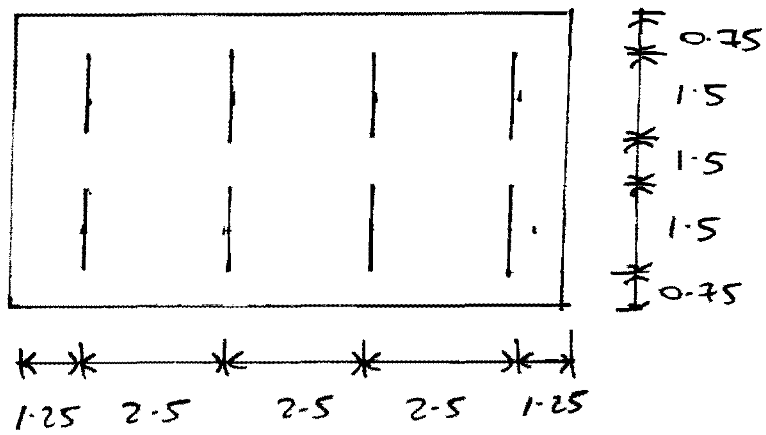
DF (A) = 8.4 + (0.2 × 0.75) + 1.3 = 9.85%
DF (B) = 1.03 + (0.52 × 0.75) + 1.3 = 2.3%
DF (C) = (5.6 × 0.75) + (1.4 × 0.75) + 1.3 = 6.55%.

[15]

3 a) USEFUL OUTPUT / LUMINAIRE = 63 W × 80 lm/W × 0·75
= 3780 lm

ILLUMINANCE = 500 lux ⇒ 500 × 10 m × 6 m
= 30,000 lm

∴ NO. OF LUMINAIRES REQD. = $\frac{30,000}{3780}$ = 7·94 , say 8



[15]

b) DAYLIGHT REQUIRED TO MEET 500 lux. = $\frac{500}{0\cdot5}$ = 10,000 lux.

FROM DAYLIGHT AVAILABILITY CURVES THIS IS EXCEEDED AS FOLLOWS :
DEC = 3% ; JAN = 8% ; NOV = 12% ; FEB = 30% ; OCT = 35% ;
SEPT = 62% ; MARCH = 62% ; AUGUST = 75% ; APRIL = 84% ;
JULY = 87% ; JUNE = 90% ; MAY = 92% .

MEAN = 640/12 = 53%

∴ ARTIFICIAL LIGHTING REQUIRED FOR 47% OF OFFICE HOURS.

[15]

c) i) TOTAL LOAD DEMAND =

LIGHTING = 63 W × 8 × 8·5 hrs = 4284 Wh/day
OTHER = 5000 Wh/day

TOTAL LOAD DEMAND = 9284 Wh/day.

PEAK SOLAR HOURS = 4·15
($\beta = 0°$; GRID-CONNECTED ∴ ANNUAL)

NOMINAL POWER REQUIRED = $9284/4{\cdot}15$ = 2237

∴ NO. OF PANELS REQUIRED = $\frac{2237}{200}$ = 11·2 , say 12

[15]

c)ii) CAPITAL COST = 12 × £900 = £10,800
O & M COST = 0
POWER OUTPUT p.a. = 2400 W × 365 × 4·15
= 3·63 MWh

ANNUALISED COST OVER 25 YEARS = $\frac{71}{1000}$ × 10,800 = £766·80

∴ COST OF ELECTRICITY GENERATED = £766·80 / $3{\cdot}36 \times 10^3$ kWh
= 22·8p / kWh [15]

c)iii) COST OF ELECTRICITY WITH GLAZED ROOF OPTION (i.e. NO PV)
= £0·15 / kWh.

TRUE COST OF ELECTRICITY WITH PV OPTION:

$$= £0{\cdot}228/\text{kWh} - \underbrace{\left(\frac{2400-2237}{2400}\right) \cdot £0{\cdot}4}_{\text{DAILY SURPLUS FED TO GRID}} - \underbrace{\left(\frac{52+8}{365}\right) \cdot £0{\cdot}4}_{\text{WEEKEND AND HOLIDAY SURPLUS FED TO GRID}}$$

= £0·16 / kWh.

[20]

∴ GLAZED ROOF OPTION IS MARGINALLY MORE ECONOMICAL THAN PV OPTION.

d) ALTERNATIVE OPTION #1 : CLAD WHOLE ROOF WITH PV PANELS (60 PANELS TOTAL).

CAPITAL COST = £54,000

∴ COST OF ELEC. GENERATED $= \frac{71}{1000} \times \frac{54,000}{(200 \times 60 \times 10^{-3}) \times 365 \times 4.15}$

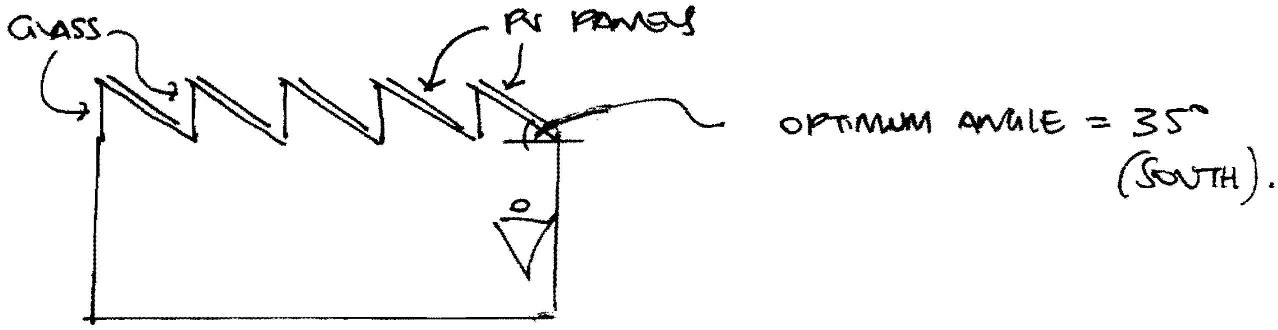
$= 21.1 p/kWh$

∴ TRUE COST OF ELEC.

$= 21.1 p/kWh - \left(\frac{12000 - 2237}{12000}\right) £0.4 - \left(\frac{52+8}{365}\right) . £0.4$

$= -18 p/kWh.$ ⇒ PROFIT.

ALTERNATIVE OPTION #2 : NORTH LIGHTS WITH PV PANELS.



OTHER CONSIDERATIONS :

1. SOLAR HEAT GAIN / HEAT LOSS FROM GLAZED ROOF
2. GLARE FROM GLAZED ROOF.
3. OCCUPANT WELL-BEING IN OPTIONS WITHOUT NATURAL LIGH

[20]

Question 4(i)

	abs coeff	Surface Area	SA
Floor	0.06	375	22.5
Wall	0.02	325	6.5
Window	0.1	75	7.5
Roof	0.25	375	93.75
sumSA			**130.25**

Volume 2652

RT **3.3** [35]

Question 4(ii)

	abs coeff	Surface Area	SA
Floor	0.06	25	1.5
Wall	0.02	325	6.5
Window	0.1	75	7.5
Roof	0.25	25	6.25
People	0.9	350	315
sumSA			336.75

Volume 2652

RT **1.3** [20]

A reverberation time of slightly less than 1 s is ideal for speech. Moreoever, the pupils at the back of the hall are unlikely to find speech intelligible as the source receiver distance of over 20 m is so great. Therefore a speech reinforcement system will be necessary.

Question 4(iii): A reverberation time of slightly less than 1 s is far too low for good acoustic conditions for orchestral music, for which 2 s is normally required. The flat floor means the sight lines from the back are very poor. 5%

4 (iv): The flat walls are likely to create flutter echoes across the width of the hall. There are likely to be late reflections back from the wall at the end of the hall. The wood wool ceiling does not provide a clear reflection to the back of the hall to aid speech intelligibility. 5%

4(v) The sight lines will be very bad, speech intelligibility at the back of the hall will be poor - implying a speech reinforcement system will be necessary (which for theatrical productions is usually complicated) and the actors will be disturbed by the reflection from the back of the hall. 5%