PART IIB 2010 4D11: BUILDING PHYSICS DR M OVEREND

4D11, 2010.

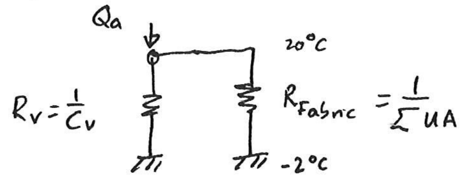
Q1. a) In series

Internal surface	R_i		$= 0.12\ m^2K/W$
Plaster	R_p	$0.015m / 0.56\ W/mK$	$= 0.027\ m^2K/W$
Conc. block	R_c	$0.1m / 0.20\ W/mK$	$= 0.5\ m^2K/W$
Wool	R_w	$0.075m / 0.04\ W/mK$	$= 1.875\ m^2K/W$
Brick	R_b	$0.102m / 0.84\ W/mK$	$= 0.121\ m^2K/W$
Ext. surf.	R_e		$= 0.06\ m^2K/W$

$$\Sigma R = 2.703\ m^2K/W$$

$$U = \frac{1}{\Sigma R} = \underline{0.37\ W/m^2K}$$

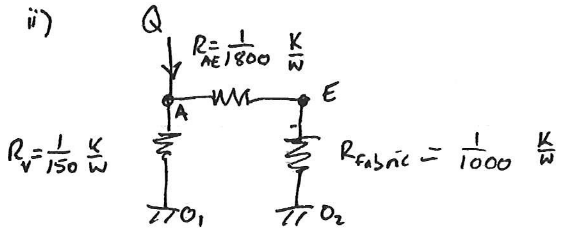
b) i) $\Sigma UA = 600 + 300 + 100 = 1000\ W/K$ in parallel.



(4)

$$Q = (\Sigma UA + C_v)\Delta T = (1000 + 150)\frac{W}{K}(22K) = \underline{25.3\ kW}$$

ii)

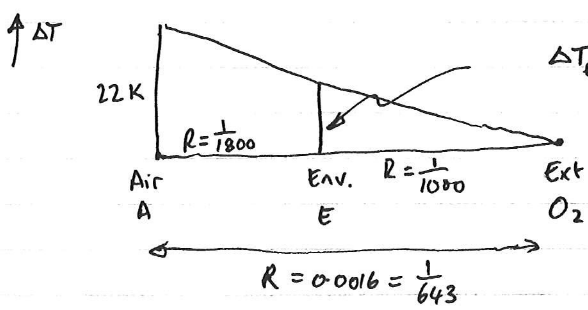


$$R_{AO_2} = \frac{1}{1800} + \frac{1}{1000} = 0.0016\ \frac{K}{W}$$

$$C_{AO_2} = \frac{1}{R_{AO_2}} = 643\ W/K$$

(3)

$$\Delta T = 22K \rightarrow Q = (643 + 150)\frac{W}{K}(22K) = \underline{17.4\ kW}$$



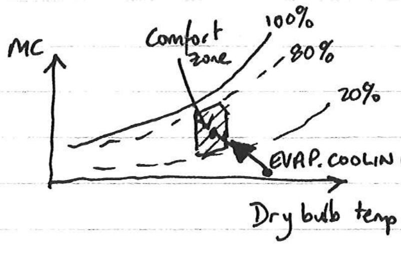
$$\Delta T_{Env} = \left(\frac{22}{(1/643)}\right)\left[\frac{1}{1000}\right] = 14.1\ K$$

3

$$\therefore\ T_{env} = 14.1° - 2° = \underline{12.1°C}$$

c) Marks will be gained evaporative cooling gives no net energy change (such that specific enthalpy stays constant), and how the required latent heat of evap. is provided by a corresponding decrease in sensible heat.

(4)

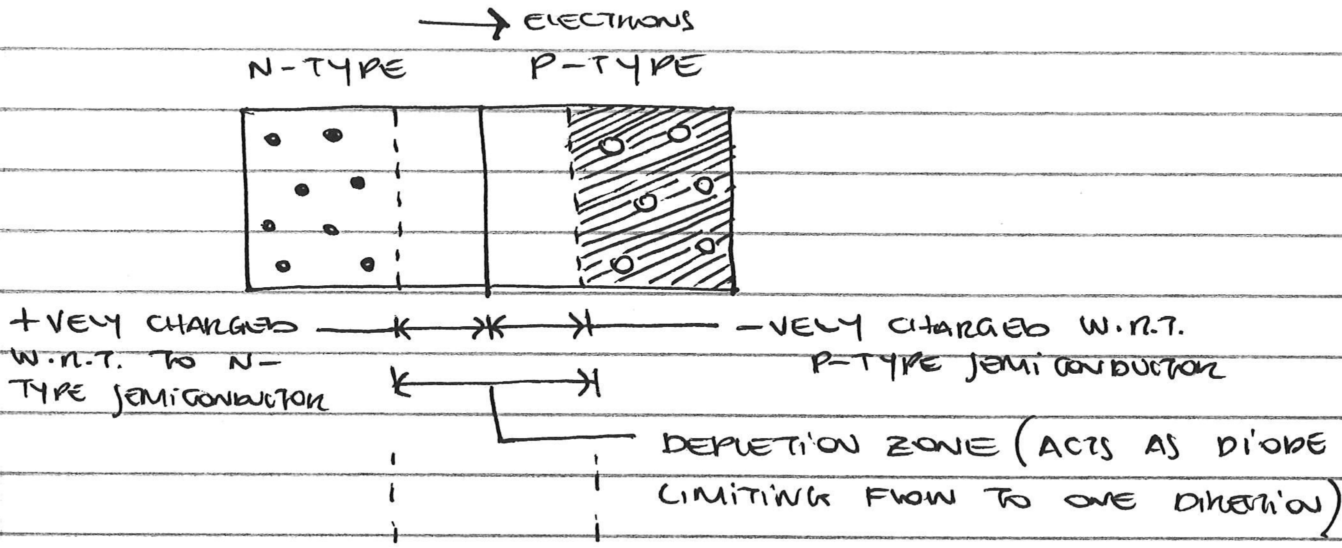


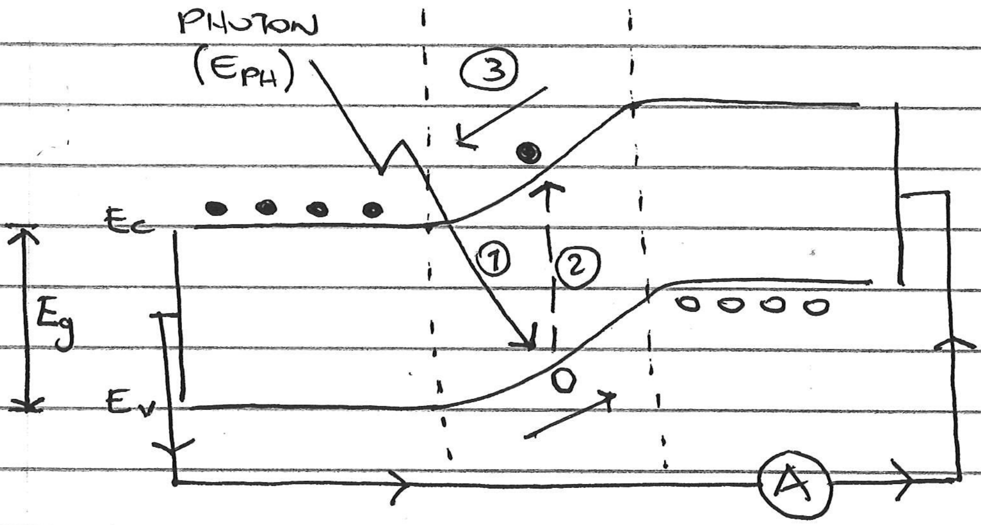
Assessor's comment Q1:

This was the most popular question (attempted by all candidates) and very well answered. Most candidates were able to calculate the U-value required in part (a) and the heat input required in part (b)(i). The few marks that were lost were in the calculation of the temperature of the environmental node in part (b)(ii) and in the descriptive parts related to the use of evaporative cooling devices in part (c).

2(a) A P-N JUNCTION IS FORMED BY JOINING A P-TYPE SEMICONDUCTOR (EG. SILICON DOPED WITH BORON) AND AN N-TYPE SEMICONDUCTOR (EG: SILICON DOPED WITH PHOSPHORUS). THE FORMER IS +VELY CHARGED (i.e. HAS LACK OF ELECTRONS IN VALENCE BAND) WHILE THE LATTER IS -VELY CHARGED (i.e. HAS SURPLUS ELECTRONS IN CONDUCTION BAND).

WHEN THE P-TYPE SEMICONDUCTOR AND THE N-TYPE SEMICONDUCTOR ARE BROUGHT INTO CONTACT THERE IS A FLOW OF ELECTRONS FROM THE N-TYPE TO THE P-TYPE CLOSE TO THE JUNCTION UNTIL EQUILIBRIUM IS REACHED. THIS REGION IS CALLED THE DEPLETION REGION.





E_c = ENERGY CONDUCTION BAND

E_v = ENERGY VALENCE BAND

E_g = ENERGY GAP

E_{PH} = ENERGY PHOTON

① - INCIDENT PHOTON

- $E_{PH} \geq E_g$ ⇒ ELECTRON PROMOTED ②
  $E_{PH} - E_g$ CONVERTED TO HEAT
- $E_{PH} < E_g$ ⇒ NO EFFECT

③ PROMOTED ELECTRON FLOWS TOWARDS N-TYPE SEMICONDUCTOR AND 'HOLE' FLOWS TOWARDS P-TYPE SEMICONDUCTOR. THEREBY CREATING AN ELECTRIC CURRENT IN THE CIRCUIT.

(3)

(b) <u>OFF-GRID SYSTEM:</u>

OPTIMUM INCLINATION BASED ON 'WORST' MONTH → 65°-70°

IRRADIANCE FOR 65°-70° IN DECEMBER = 3.51 kWh/m²

SOLAR IRRADIATION ON EARTH'S SURFACE = 1 kW/m²

∴ PEAK SOLAR HOURS (PSH) $= \frac{3.51}{1} = 3.51\ h$

NOMINAL POWER OF PANELS FOR DAILY DEMAND $P_o = \frac{\text{LOAD}}{\text{PSH}}$

$= \frac{1000 + 6500\ Wh}{3.51\ h}$

$= 2137\ W$

∴ NO. OF PV PANELS $= \frac{2137\ W}{200\ W/\text{PANEL}} = 10.68$

(3) ∴ PROVIDE 11 IN NO. 200 W PV PANELS @ 65°-70° TO HORIZONTAL PLANE

<u>GRID-CONNECTED SYSTEM:</u>

OPTIMUM INCLINATION BASED ON MEAN ANNUAL → 35°

IRRADIANCE FOR 35° (MEAN ANNUAL) = 4.78 kWh/m²

SOLAR IRRADIATION ON EARTH'S SURFACE = 1 kW/m²

∴ PEAK SOLAR HOURS (PSH) $= \frac{4.78}{1} = 4.78\,h$

NOMINAL POWER OF PANELS FOR DAILY DEMAND $P_0 = \frac{LOAD}{PSH}$

$$= \frac{1000 + 6500\ Wh}{4.78\ h}$$

$$= 1569\ W$$

∴ NO. OF PV PANELS $= \frac{1569\ W}{200\ W/PANEL} = 7.85$

(3) ∴ PROVIDE 8 IN NO. 200 W PV PANELS @ 35° TO HORIZONTAL PLANE

(c) GRID-CONNECTED SYSTEM

TOTAL CAPITAL COST = 8 × £1000 = £8000

SERVICE LIFE = 25 YEARS

O & M COST → ANNUAL BALANCE OF SUPPLYING / DRAWING ELECTRICITY FROM GRID DUE TO OVER / UNDER PRODUCTION

REQUIRED FROM GRID $= 8 \times 200\,W \times [(4.78 - 4.05) + (4.78 - 4.34) + (4.78 - 4.42) + (4.78 - 3.72) + (4.78 - 3.07)]$

1 $= 6880\ Wh/day$ FOR 5 MONTHS

∴ ANNUAL COST $= \frac{6880}{1000} kWh/day \times \frac{5}{12} \times 365 \times £0.15/kWh$

(4) $= £156.95$

SURPLUS SUPPLIED TO GRID $= 8 \times 200\,W \times [(5.21 - 4.78) + (5.31 - 4.78) + (5.7 - 4.78) + (6.08 - 4.78) + (5.75 - 4.78) + (4.94 - 4.78)]$

(2) $= 6896\ Wh/day$ FOR 6 MONTHS

∴ ANNUAL COST = $\frac{6896 \text{ kWh/day}}{1000} \times \frac{6}{12} \times 365 \times -£0.1/\text{kWh}$

= $-£125.85$

∴ NET COST (ANNUAL BALANCE) = £156.95 − £125.85
= £31.10

ANNUALISED COST OF CAPITAL SPREAD OVER SERVICE LIFE (@ 5%) = $71 \times \frac{8000}{1000}$ + £31.10

= £599.10 p.a.

(2)

∴ COST OF ELECTRICITY GENERATED = $\frac{599.10 \text{ p.a.}}{(8 \times 200 \text{ W} \times 4.78 \times 365)/1000}$ = 21.5p/kW

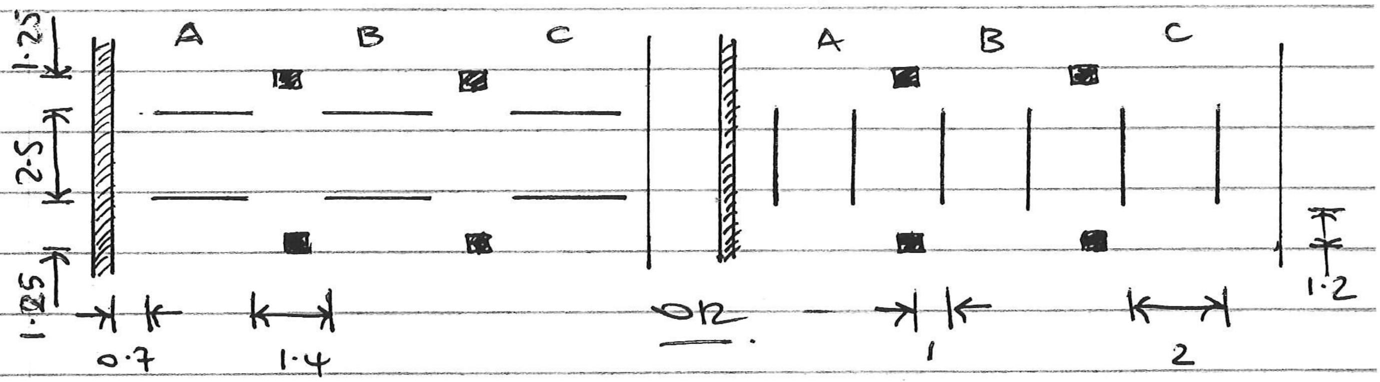
Assessor's comment Q2:

Most students were able to describe the components and operation of PV cells although some students described the entire PV system (i.e. PV panels, inverter, battery storage, etc.) rather than focusing on the PC cell itself. Most students determined the number of PV panels and the optimal inclinations for both the grid-connected and the off-grid systems. There were several errors in the calculation of the cost of the renewable energy required in part (c). Most of the marks lost in this section were due to the failure of some candidates to account for the monthly variations in incident (and therefore converted) solar energy.

3(a) USEFUL OUTPUT PER LUMINAIRE = 80 W x 96 lm/W x 0·75
= 5760 lumens.

REQUIRED ILLUMINANCE OF 500 lux OVER 3 TYPICAL BAYS
= 500 x (5x12)
= 30,000 lumens.

(4) ∴ NO. OF LUMINAIRES = $\frac{30\,000}{5760}$ = 5·2, say 6



(b) ADVANTAGES:
- POSITIVE PHYSIOLOGICAL AND PSYCHOLOGICAL EFFECT ON OCCUPANTS BY:
  - PROMOTING A NATURAL RHYTHM (CHANGING DAYLIGHT)
  - AESTHETIC QUALITIES OF NATURAL LIGHT
  - EXCELLENT COLOUR DEFINITION
- (1) REDUCES THE HIGH ENERGY COST OF ARTIFICIAL LIGHTING

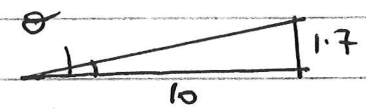
DISADVANTAGES:
- SPACE PLANNING LIMITATIONS AS REQUIRES 'SHALLOW' PLAN BUILDINGS.
- GIVES RISE TO VISUAL DISCOMFORT FROM GLARE.
- (2) LARGE WINDOWS MAY LEAD TO UNWANTED SOLAR GAINS AND HEAT LOSS.

(c) D.F. = SC + ERC + IRC

BUT ERC = 0 (OPEN COUNTRY).

POINT A

SC

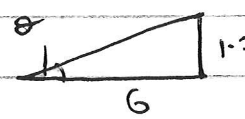


$\theta = \tan^{-1} \frac{1.7}{10} = 9.6°$

(2) SC = 0.3% (PROTRACTOR)

POINT b

SC

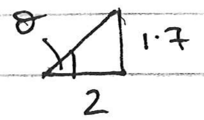


$\theta = \tan^{-1} \frac{1.7}{6} = 15.8°$

SC = 0.8% (PROTRACTOR)

POINT C

SC



$\theta = \tan^{-1} \frac{1.7}{2} = 40.4°$

SC = 7.5% (PROTRACTOR)

NO CORRECTION FACTOR REQUIRED AS WINDOW IS VERY LONG.

IRC

WINDOW SURFACE AREA FOR 3 TYPICAL BAYS

= 5 × 1.7 . . . = 8.5 m^2

TOTAL SURFACE AREA FOR 3 TYPICAL BAYS

= 5 × 2(12 + 4) = 160 m^2

∴ RATIO = 0.053

USING NOMOGRAM STRAIGHT LINE FROM 0.053 ON SCALE A TO 30% ON SCALE B GIVES 0.5% ON SCALE C

(2) DF AT A = 0.3 + 0.5 = **0.8%**

DF AT b = 0.8 + 0.5 = **1.3%**

DF AT C = 7.5 + 0.5 = **8 %**

DAYLIGHT REQUIRED FOR CORRECT ILLUMINANCE (A) $= \frac{500}{0.008} = 62,500$ lux

DAYLIGHT REQUIRED FOR CORRECT ILLUMINANCE (b) $= \frac{500}{0.013} = 38,462$ lux

DAYLIGHT REQUIRED FOR CORRECT ILLUMIN. (C) $= \frac{500}{0.08} = 6250$ lux

a	b	c
FROM DAYLIGHT AVAILABILITY CHART THIS IS NEVER EXCEEDED ∴ ARTIFICIAL LIGHT REQUIRED 100% OF THE TIME. AT POINT a	JAN 0% JULY 27% FEB 0% AUG 16% MAR 5% SEP 3% APR 15% OCT 0% MAY 27% NOV 0% JUN 25% DEC 0% Σ 121 ∴ EXCEEDED FOR $121/12 = 10.1\%$ ARTIFICIAL LIGHT REQUIRED 89.9% OF TIME AT POINT b	JAN 50% JULY 99% FEB 71% AUG 99% MAR 90% SEP 95% APR 99% OCT 80% MAY 100% NOV 57% JUN 100% DEC 43% Σ 983 ∴ EXCEEDED FOR $983/12 = 81.9\%$ ARTIFICIAL LIGHT REQUIRED 18.1% OF TIME AT POINT c

(d) LIGHTS IN BAYS 'A', 'B' AND 'C' SWITCHED INDEPENDANTLY OF EACH OTHER AND CONTROLLED BY LIGHT SENSORS.

WITHOUT INDEPENDANT SWITCHING:

$$\text{ENERGY REQUIRED} = 6 \times 80\,W \times [\underbrace{60 \times 60 \times 8.5}_{\text{SECONDS IN A WORKING DAY}} \times \underbrace{250}_{\text{DAYS OPEN FOR BUSINESS.}}] / 12 \times 5\,m^2$$

$= 61.2\ MJ/m^2/\text{YEAR}$

OR

$= 17\ kWh/m^2/\text{YEAR}.$

WITH INDEPENDANT SWITCHING:

$$\text{ENERGY REQUIRED} = \left(\frac{100\% + 89.9\% + 18.1\%}{3}\right) \times 17$$

$= 11.79\ kWh/m^2/\text{YEAR}$

∴ ENERGY SAVING $= 17 - 11.79 = 5.21\ kWh/m^2/\text{YEAR}.$

(3)

Assessor's comment Q3:

Parts (a) and (b) i.e. the number of luminaries required and the advantages and disadvantages of day lighting were well answered. The first steps of part (c) were also well executed in that most candidates were able to determine the daylight factors at the three points in the room. Some candidates however failed to account for the monthly variations in daylight when calculating the percentage of the year during which artificial light was required. Most candidates recognised that independent switching was required in part (d), but few were able to calculate the potential energy savings.

4) Volume of Gym before alterations = 22.5 x 16 x 7.4 = 2664 m3

Find total absorption of gym before alterations A = 0.16 x 2664 / 3.4 = 125.4 m2
(average wall absorption is low therefore ignore covering effect during calculations)

Volume of stage = 6 x 16 x 1.2 = 115.2 m3

Volume of seating = 10 x 3 x 16 / 2 = 240 m3

Volume of theatre with seats extended = 2664 – 115.2 – 240 = 2308.8 m3

Area of seating = (√(100 + 9) x 16) + 70 = 237.0 m2
Absorption of seating = 237 x 0.7 = 165.9 m2

Total absorption of theatre without additional = 165.9 + 125.4 = 291.3 m2

(a) Recommended Reverberation Time (Tr) of Theatre = 1 s (15%)

(b) In refurbished theatre additional absorption = (0.16 x 2308.8 / 1) – 291.3 = 78.1 m2

Additional area of absorption = 78.1 / 0.8 = 97.6 m2 (30%)

(c) Volume of theatre with seats retracted = 2308.8 + 120 = 2428.8 m3

Total absorption in this configuration = 125.4 + 78.1 = 203.5 m2

→ Tr = 0.16 x 2428.8 / 203.5 = 1.9 s (20%)

(d) Absorption should be placed on the back wall (approx 50 m2 allowing for seats) to prevent a reflection arriving late to the stage. The remainder is best placed on the side walls of the stage and flat seating area, at low level to prevent flutter echoes. The stage wall and ceiling should not have absorption as they reflect sound to the audience. (25%)

(e) With the seating retracted the reverberation time has been shown to be twice as long as is desirable for speech use, but music may be important in this configuration and the longer Tr would then be desirable. More worrying is the likelihood of flutter echoes across the width of the theatre where the seating once stood. Therefore some of the additional absorption should be placed in the triangle at the ends of the seating. (10%)

Assessor's comment Q4:

All candidates answered part (a) correctly. The majority of marks lost were in part (b) i.e. the calculation of the area of absorbing material. There were also some errors in the calculation of the reverberation time in part (c). The descriptive parts in part (d) and part (e) were well answered.