4D11 2009 Dr Overend

Building Physics **Environmental Data**

1. Lighting

(a) Definitions

		units
Luminous flux – rate of flow of light energy	–	lumens (1m)
Illuminance – density of light flux reaching a surface	–	lumens/m^2 or lux (1x)
Luminous intensity – light flux per unit solid angle from a point source, i.e. power to emit in a particular direction	–	candela (cd) (1 cd $\equiv 4\pi$ 1m)

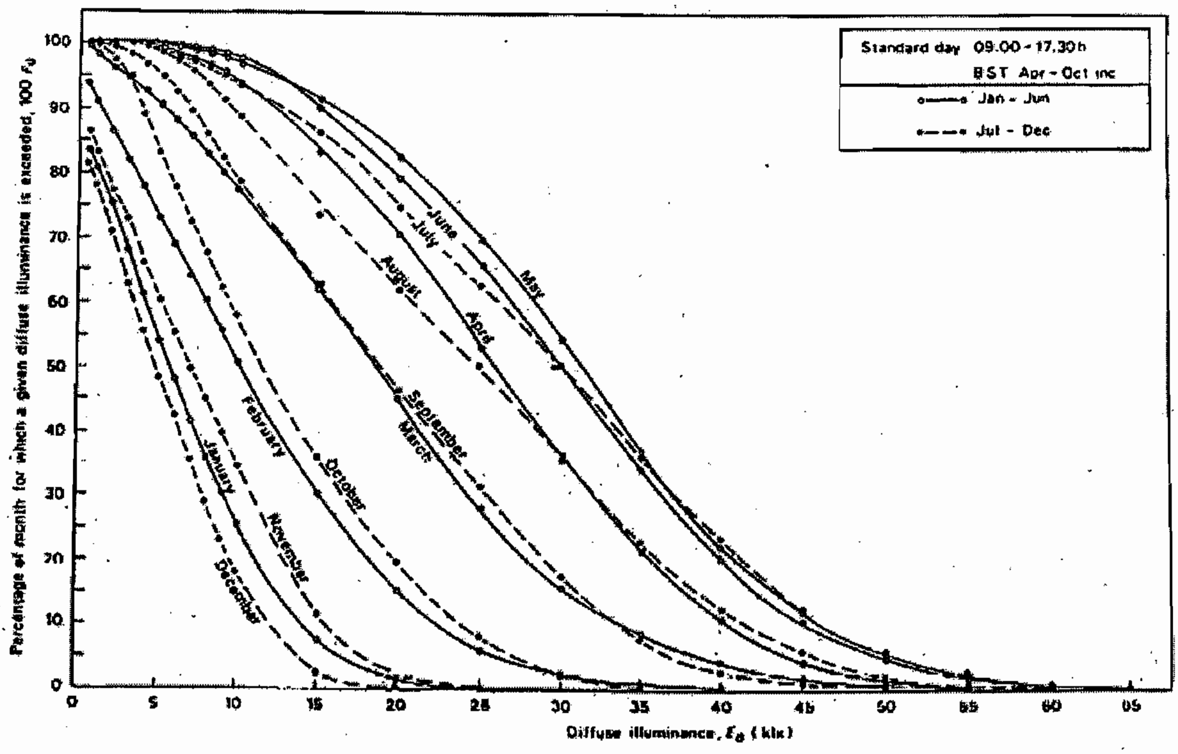
(b) Artificial light

Recommended illuminances, on horizontal working plane, vary from 150 lux for storage areas, through 500 lux for general offices, to 1500 lux for precision bench work.
"Utilisation factor" is the proportion of light emitted by the luminaires which actually reaches the working plane.
Typical luminous efficacies (lumens/Watt): tungsten filament (GLS) 12, tubular florescent 60, low pressure sodium 180, daylight 115.

(c) Daylight

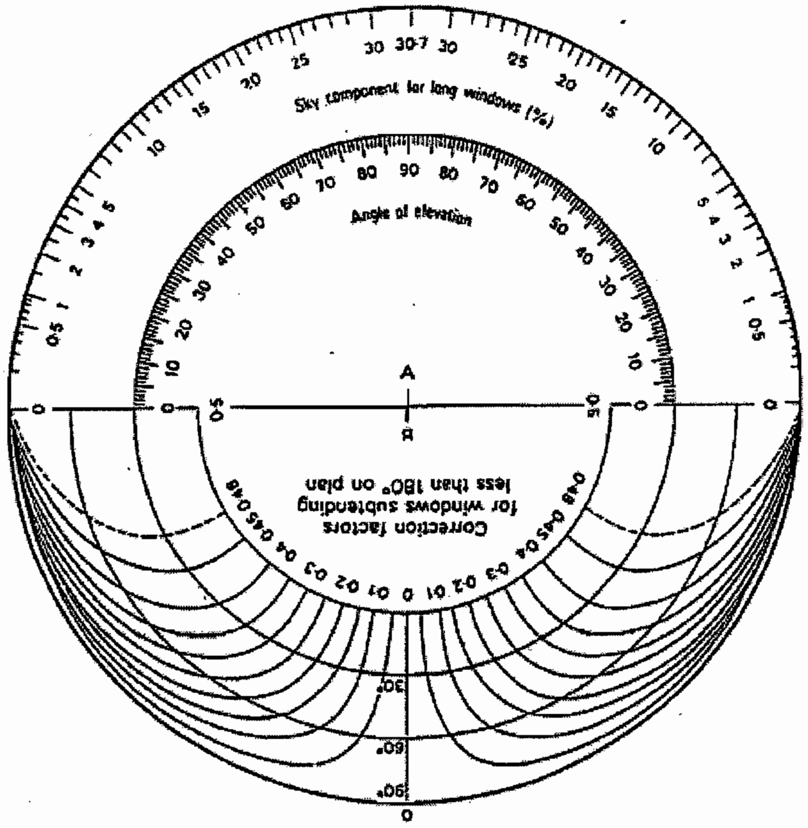
Sky as a diffuse source: sky luminance B_θ from elevation θ above horizon, where B_Z is luminance at the zenith: $B_\theta \approx B_Z(1+2\sin\theta)/3$ "CIE sky"

Example of monthly daylight availability curves for Bracknell; Percentage of working time exceeded vs diffuse illuminance level in *klx*.

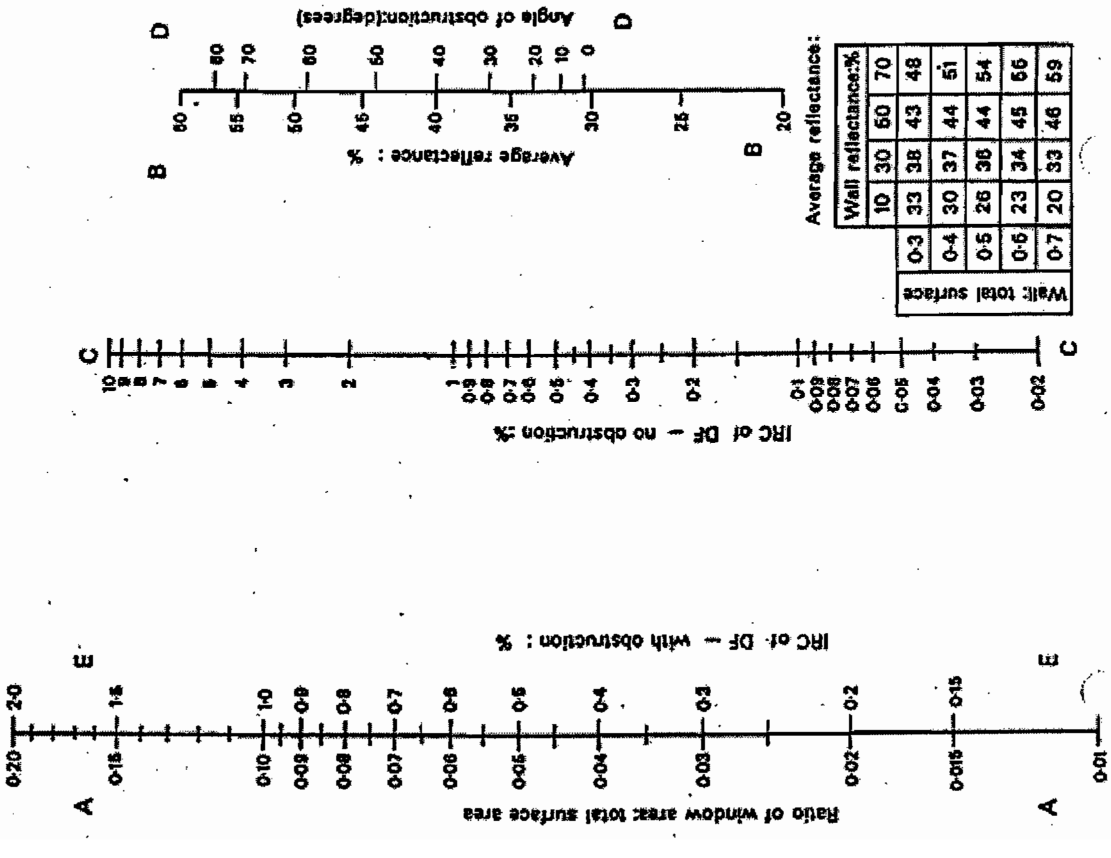


Average daylight factor (%) in a room is approx. TWMd/A(1 – ρ^2) where T is glazing transmittance; W is net window area; M is 'maintenance factor' (i.e. cleaning); d (degrees) is the angle at the window centre in the vertical plane between the vertical and the highest external building obstruction; A is the total area of all internal surfaces; and ρ is the weighted mean reflectance of the internal surfaces.

BRE Sky Component protractor: single clear vertical glazing, CIE overcast sky, illuminance on a horizontal surface indoors. Externally reflected component is SC with a further correction factor of 0.2.

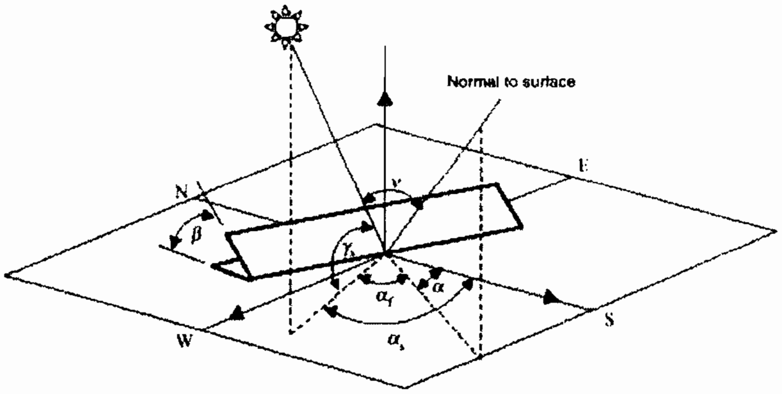


Typical nomogram for internally-reflected component:
(ground reflectance 0.1 in this case)



Wall: total surface	Average reflectance: Wall reflectance:% 10	30	50	70
0·3	33	38	43	48
0·4	30	37	44	51
0·5	26	36	44	54
0·6	23	34	45	56
0·7	20	33	46	59

(d) Solar irradiation



Typical mean daily irradiation on South facing panel in Southern Europe (kWh/m^2)

Angle	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
0	2.25	2.92	3.88	4.98	5.66	6.38	6.67	5.75	4.20	3.18	2.23	1.70	4.15
5	2.56	3.19	4.08	5.09	5.69	6.36	6.68	5.84	4.46	3.42	2.49	1.93	4.32
10	2.86	3.44	4.26	5.18	5.70	6.32	6.66	5.90	4.61	3.64	2.74	2.16	4.46
15	3.14	3.67	4.42	5.25	5.67	6.25	6.61	5.94	4.73	3.84	2.98	2.37	4.57
20	3.40	3.87	4.55	5.28	5.62	6.15	6.52	5.94	4.82	4.03	3.19	2.57	4.66
25	3.65	4.05	4.66	5.29	5.54	6.03	6.41	5.91	4.89	4.18	3.39	2.75	4.73
30	3.86	4.21	4.73	5.26	5.44	5.88	6.26	5.85	4.93	4.31	3.57	2.92	4.77
35	4.05	4.34	4.78	5.21	5.31	5.70	6.08	5.75	4.94	4.42	3.72	3.07	4.78
40	4.22	4.45	4.81	5.13	5.15	5.49	5.88	5.63	4.93	4.50	3.85	3.19	4.77
45	4.36	4.53	4.80	5.03	4.97	5.26	5.65	5.48	4.88	4.55	3.96	3.30	4.73
50	4.47	4.58	4.77	4.89	4.77	5.01	5.39	5.29	4.81	4.57	4.04	3.39	4.66
55	4.55	4.60	4.71	4.73	4.55	4.74	5.11	5.09	4.71	4.57	4.09	3.45	4.57
60	4.60	4.59	4.62	4.55	4.30	4.45	4.80	4.85	4.58	4.53	4.12	3.49	4.46
65	4.62	4.55	4.50	4.34	4.04	4.14	4.48	4.59	4.42	4.47	4.12	3.51	4.32
70	4.61	4.49	4.36	4.11	3.77	3.83	4.15	4.31	4.25	4.38	4.10	3.51	4.15
75	4.57	4.39	4.19	3.86	3.48	3.50	3.80	4.02	4.05	4.27	4.04	3.48	3.97
80	4.50	4.27	4.00	3.59	3.18	3.17	3.44	3.70	3.82	4.13	3.97	3.43	3.77
85	4.40	4.13	3.79	3.31	2.88	2.84	3.08	3.37	3.58	3.96	3.87	3.36	3.55
90	4.27	3.95	3.55	3.02	2.57	2.51	1.86	3.04	3.32	3.78	3.74	3.27	3.24

2. Thermal matters

(a) Temperatures

Air temperature in shade T_a – the 'dry bulb' temperature, usually in degrees C db.

'Wet bulb' temperature, C wb, in a small damp sponge in air current (taken with T_a indicates humidity).

'Mean radiant temperature' T_r – the uniform surface temperature of a surrounding black enclosure delivering the same radiant heat to the point in question as arrives in the actual non-uniform space (in practical rooms, approx. the mean surface temperature T_m of all the enclosing surfaces).

Radiant heat flow is roughly $Q_r = A\,\varepsilon\,\sigma\,(T_b^4 - T_r^4)$ where A and T_b (K) are the surface area and temperature of the radiating body, ε is emissivity (usually 0.95, but 1.0 for a 'black' body), and σ is $5.67 \times 10^{-8}\ \mathrm{W/m^2K^4}$.

'Globe temperature' (measured inside a small black sphere) is roughly the 'operational temperature', the mean of T_a and T_r.

'Environmental temperature' T_e in a room is $(T_a + 2T_m)/3$.

'Corrected effective temperature' CET depends on globe and wet-bulb temperatures, and air velocity – the wind-chill effect – and is obtained from charts.

'Neutral temperature' (CET in C at which most people feel comfortable) is
$T_n = 11.9 + 0.564\ T_o$ +/- 2.5 (Humphreys) for a sedentary occupation, where T_o is the mean outdoor temperature for the month in question.

(b) Thermal Comfort

Comfort will depend on many factors, not just the temperature but also such things as the humidity, the freshness of the air, and the amount of clothing being worn (0.1 clo for shorts only, 1.0 clo for a business suit, 2.5 clo for a heavy overcoat).

Also important will be the metabolic rate M (ranging from 70 W when sleeping, through 150 W when typing, 300 W for fast walking, to 650 W for hard sustained work); the rate W watts at which work is being done; and the rate H watts of loss of heat, which will depend on radiation, convection, and evaporation from the skin, as well as heat and water-vapour losses in breathing.

Fanger introduced the Predicted Mean Vote (PMV) for people's sensation of comfort on a scale of – 3 to + 3 (very cold to very hot). His equation has over 15 terms, based on metabolic rate, work being done, temperature etc, with empirical constants and factors based on surveys of large numbers of people – and with some subsequent dispute whether the equation is correct in all circumstances.

Fanger also investigated the 'Predicted Percentage Dissatisfied' at a given PMV, suggesting the relation $\mathrm{PPD} = 100 - 95\ \exp\{-(0.04\ \mathrm{PMV}^4 + 0.22\ \mathrm{PMV}^2)\}$.

(c) Heat loss and gain calculations for buildings

Total 'specific heat loss' $Q = Q_c + Q_v$ in watts per degree difference between environmental temperature inside and air temperature outside.

By conduction $Q_c = \Sigma\, U\, A$ W/K , where A is area of wall, roof, windows etc, each with their individual 'U-value'. For layered construction, the U-value in W/m^{2}K is given by

$$1/U = R_i + \Sigma\, r\, t + R_c + R_e$$

where R_i and R_e are thermal resistances at internal and external surfaces (depending on radiative and convective heat transfer), R_c is for any cavity, and r and t are respectively reciprocal of conductivity, and thickness, of the various layer materials (typical conductivities being given in tables of data).

By ventilation Q_v depends on room volume, number of air changes per unit time, and the appropriate coefficient for air (ρc_p, approx 1200 J/m^{3}K at 20 C).

'Degree days', presented in statistics for each month for a locality, are the integral over time of the shortfall of the outside air temperature below a chosen internal design temperature, often 18 C.

'Mean internal environmental temperature' , over a long period say 24 hours, can be calculated, as an increment above the mean outside air temperature, from the mean internal casual heat gains (people, lights, computers etc) plus the mean solar gains (window area, gain in W/m^2 depending on aspect and time of year, and a Solar Gain Factor) – giving total mean heat gains (in W) – and the specific heat loss Q in W/K .

Typical solar gains in June for a South-facing window are 700 W/m^2 .

Swings in internal environmental temperature (mean to peak) can be estimated, for the time of day when the peak is likely to occur, from;

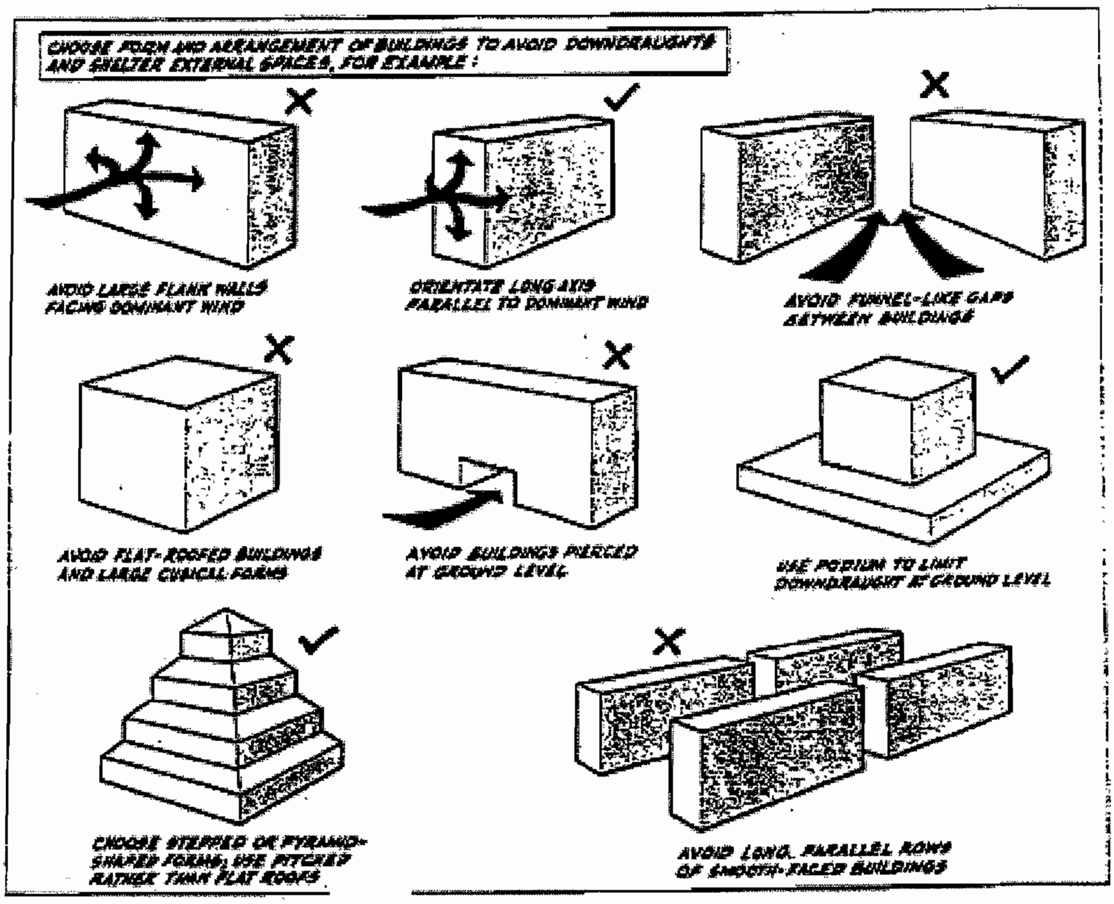
(i) the swing in solar gain (W) using the window area, the difference between peak and mean gains (W/m^2) and an Alternating Solar Gain Factor;
(ii) any simultaneous swing in casual gain (W) from its mean; and
(iii) any departure of the outdoor air temperature at the peak time from its mean, multiplied by a new 'specific heat loss factor' Q (now from window area and U-value for glazing, plus ventilation)

to give a total apparent swing of heat gain in W.

This total is divided by another specific heat loss factor – now ventilation Q_v plus the sum of wall areas times Y-values ('admittances' in W/m^{2}K) – to give the swing in environmental temperature from the mean. Y-values for the various materials are available from tables of data.

3. Ventilation

(a) Reducing the wind sensitivity of buildings (from Building Research Establishment, Digest 350)



Wind pressure coefficients (tabulated) ; $C_P = \dfrac{p - p_{ref}}{\frac{1}{2}\rho U_{ref}^2}$;

where $U_{ref} = U_{ambient}$ is typically taken as wind velocity 10 m above ground level.

(b) Orifice flow

$$\Delta p = K\frac{1}{2}\rho U^2 \text{ , with } K \approx 1$$

whence $$U = \sqrt{\frac{2\Delta p}{\rho}}$$

Q (volume flow rate) = $C_D \times U \times Area$
C_D = discharge coefficient due to streamline contraction.

(c) Momentum jets

$$R \quad \alpha \quad x$$

$$U \,\alpha\, \left(\frac{M_o}{\rho}\right)^{\frac{1}{2}} x^{-1}\ ; M_o = source\ momentum\ flux = \rho\, Q_o U_o$$

(d) Buoyancy effects

Stack effect; $U \approx \sqrt{g\frac{\Delta\rho}{\rho}H}$ for two equal area vents, depending on discharge C_D etc.

Empirical equations used in practice:

nominal pressure difference $\Delta p = 0.043\ h\ (T_i - T_o)$ Pa , where h (m) is the height between inlet and outlet of the stack and T_i and T_o are average internal and air outside temperatures.

then volume flow is $Q = 0.827\ A\ (\Delta p)^{1/2}$ m^3/s , where A (m^2) is given for inlet area A_1 and outlet area A_2 by $A = A_1 A_2/(A_1^2 + A_2^2)^{1/2}$.

Exchange flows Q (one fluid) = $\begin{pmatrix} 0.25\ horizontal \\ 0.05\ vertical \end{pmatrix} \sqrt{g\frac{\Delta\rho}{\rho}d}$ (Area)

Gravity currents $U = (\sim 1.0)\sqrt{g\frac{\Delta\rho}{\rho}h}$

Buoyant plumes

$$R = 0.12\ z$$

$$U = 2.55\ F_o^{\frac{1}{3}}\ z^{-\frac{1}{3}}$$

$$g\left(\frac{\Delta\rho}{\rho}\right) = 8.66\ F_o^{\frac{2}{3}}\ z^{-\frac{5}{3}}$$

$$F_o = Q_o g \frac{\Delta\rho_o}{\rho} = \frac{\dot{Q}_g}{\rho T C_p}$$

Consistent with assumptions in derivation we have $\rho \approx \rho_a$ and use ρ_a and T_a as reference conditions whenever necessary.

4. Acoustics

(a) Fundamentals and definitions

Velocity of sound in air at 20 °C : $c \approx 344 m/s$ when air density $\rho \approx 1.2 kg/m^3$

Consider root mean square pressure fluctuation $\bar{p}$ Pa and standard reference level $p_o = 2.0 \times 10^{-5}$ Pa at 1000Hz. Sound pressure level (SPL) defined as $20 \log_{10} (\bar{p}/p_o)$ decibels.
Sound intensity (rate of energy transmission across given surface):

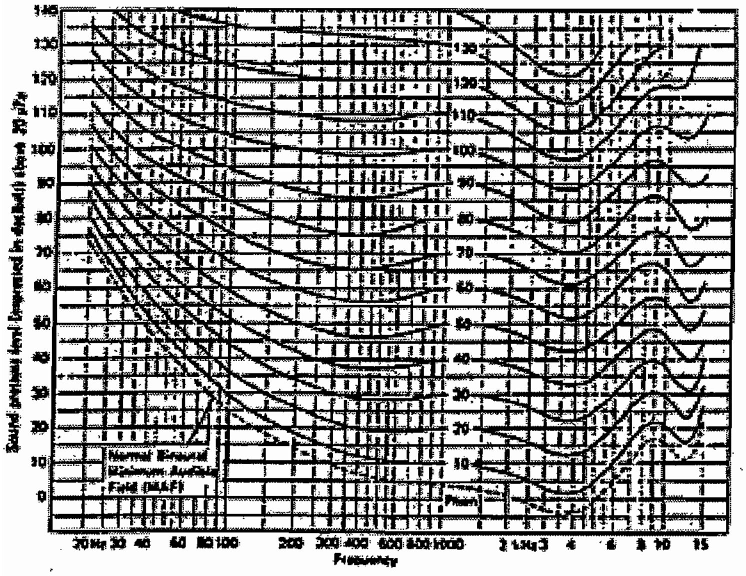
$$I = \frac{\bar{p}^2}{\rho c} : \quad IL = SPL = 10 \log (I/I_o) : \quad I_o = \frac{p_o^2}{\rho c} \approx 10^{-12}$$

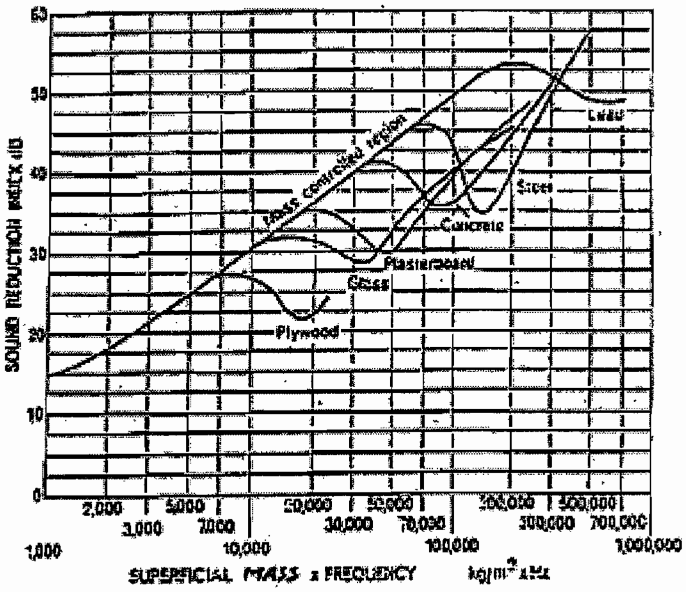
Sound energy density (energy per unit volume):

$$D = \frac{\bar{p}^2}{\rho c^2} : \quad SPL = 10 \log (D/D_o) : \quad D_o = \frac{p_o^2}{\rho c^2}$$

Source power W watts : SWL = $10 \log (W/10^{-12})$

Human ear: curves of equal perceived loudness (men) on left below: sound pressure level in dB versus frequency in Hz.





So adjusted curves (e.g. dBA from 40 phon line) to allow for ear characteristics varying with frequency.

Addition and comparison of incoherent sound: add mean square pressures to find overall mean square and hence SPL (or L_{eq} using average over time for varying sound levels).

(b) Acoustics of room-like enclosures (volume V, total surface S)

From uniform omnidirectional source W, at radius r (m) :
direct SPL = SWL – $10 \log 4\pi$ - $20 \log r$

(from practical sources, intensity varies with direction). Reverberant sound due to reflections from walls: energy density D tends to 4W/Ac where A is the total absorption of the enclosure surface i.e. total of areas times absorption coefficients α, or $A = S\overline{\alpha}$ where $\overline{\alpha}$ is the mean absorption coefficient. Intensity in enclosure is Dc/4.

So reverberant SPL = SWL + 10 log 4 – 10 log A.

"Room radius" is the distance from the source at which direct and reverberant sound levels are equal.

On switching off source, energy density D decays exponentially, with time constant 4V/Ac related to the "reverberation time" T (Sabine's Law). Eyring's modification: use
A = - S ln (1- $\overline{a}$). Preferred values for T: speech 1.0 secs, orchestral music 1.8 to 2.2 secs.

(c) Noise control

Barriers and screens: if uninterrupted wave travels distance *d* and diffracted wave *a*+*b*, wavelength λ, "insertion loss" on introducing an infinitely long barrier across the path is 10 log (3 + 20N) dB where $N = 2(a+b-d)/\lambda$.

Partitions: 'transmission coefficient' τ = transmitted/ incident intensity, and 'sound reduction index' $R = 10 \log (1/\tau)$. For source and receiver rooms separated by area S of partition,

difference in SPL's = R – 10 log (S / A) dB

where A is absorption in receiving room. For compound partitions, use transmission coefficient τ weighted by areas.

Mass law: plane wave incident at θ to normal of single leaf wall

$$R = 10 \log \left[1 + \left(\frac{\pi M f \cos\theta}{\rho c} \right)^2 \right]$$

where *f* is sound frequency and *M* is wall mass per unit area. For high frequencies and diffuse sound field $R = 20 \log (Mf) - 47$ dB.

Problems with mass Law: resonance effect at frequencies proportional to $\sqrt{B/M}$ and dependent on panel span, where *B* is bending stiffness per unit width; "coincidence effect", when speed of bending waves in panel equals speed of sound in air, at frequency proportional to $\sqrt{M/B}$ and independent of panel span. See curves of *R* for different materials, on right above, storing R in dB versus superficial mass x frequency in kgHz/m^2.

Double wall mass-air-mass resonance: frequency f_d

$$f_d = \frac{1}{2\pi} \sqrt{\frac{\gamma P_o}{d} \cdot \frac{(M_1 + M_2)}{M_1 M_2}}$$

where γ is 1.4 for air, P_o is atmospheric pressure, d is cavity width, and *M* is wall mass per unit area.

5. Whole-life costing

(a) Discounted cash flow table

Capital repayment period/years[1]	Real discount rate /%						
	0	**2**	**5**	**8**	**10**	**12**	**15**
5	200	212	231	250	264	277	298
10	100	111	130	149	163	177	199
15	67	78	96	117	131	147	171
20	50	61	80	102	117	134	160
25	40	51	71	94	110	127	155
30	33	45	65	89	106	124	152
40	25	37	58	84	102	121	151
50	20	32	55	82	101	120	150
60	17	29	53	81	100	120	150

[1] This is not necessarily equal to the total physical lifetime of the project.

1.

a) Internal Surf. $R_i =$ $0.13\ m^2K/W$

Plasterboard $R_1 = \frac{L}{k} = \frac{0.01\ m}{0.16\ W/mK}$ $= 0.063\ m^2K/W$

Concrete slab $R_2 = \frac{L}{k} = \frac{0.10\ m}{1.00\ W/mK}$ $= 0.10\ m^2K/W$

External Surf $R_o =$ $= 0.04\ m^2K/W$

$\Sigma = 0.333\ m^2K/W$

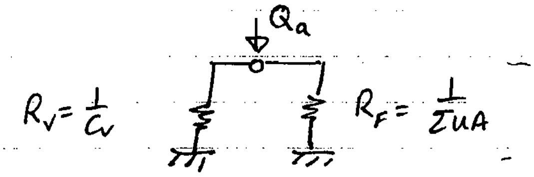
⑥

$$U\ value = \frac{1}{\Sigma R} = 3.00\ \frac{W}{m^2K}.$$

b) Fabric Conductance $\Sigma UA = 800\ W/K$.
Vent Conductance $C_v = 150\ W/K$.

Int. airtemp $= 22°C$, Ext $= -5°C$.

i)



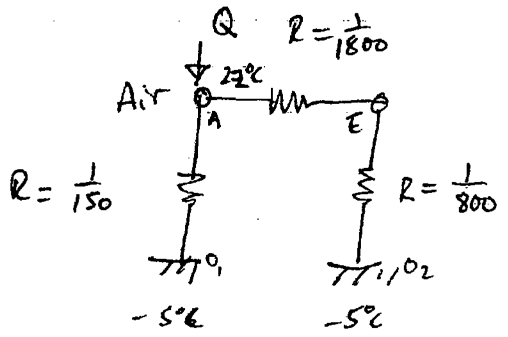
$$Q = (\Sigma UA + C_v)\,\Delta T$$

$$= (800 + 150)\frac{W}{K} \times (27\ K)$$

④

$$= \underline{\underline{25.65\ kW}}$$

ii)



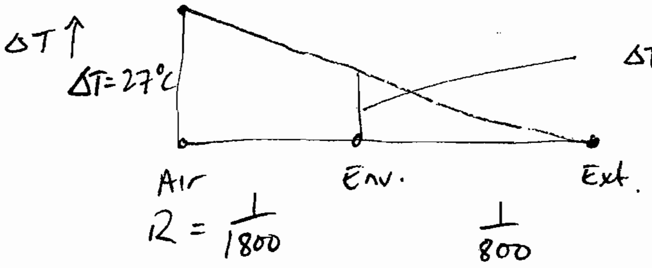
$R_{AEO_2} = \frac{1}{1800} + \frac{1}{800} = 0.0018$

$C_{AEO} = \frac{1}{R_{AEO}} = 554\ W/K$

Q1 b) ii) Cont'd $\Delta T = 27°C$

$$\Rightarrow \quad Q = (554 + 150)\frac{W}{K} \times 27K$$

(4) $$= \underline{\underline{19\ kW}}$$



$$\Delta T_{Env} = \left(\frac{27}{0.0018}\right) \times \left(\frac{1}{800}\right) = 18.75$$

$$\therefore \quad T_{env} = 18.75°C - 5°C.$$

(2) $$= \underline{\underline{13.75°C}}.$$

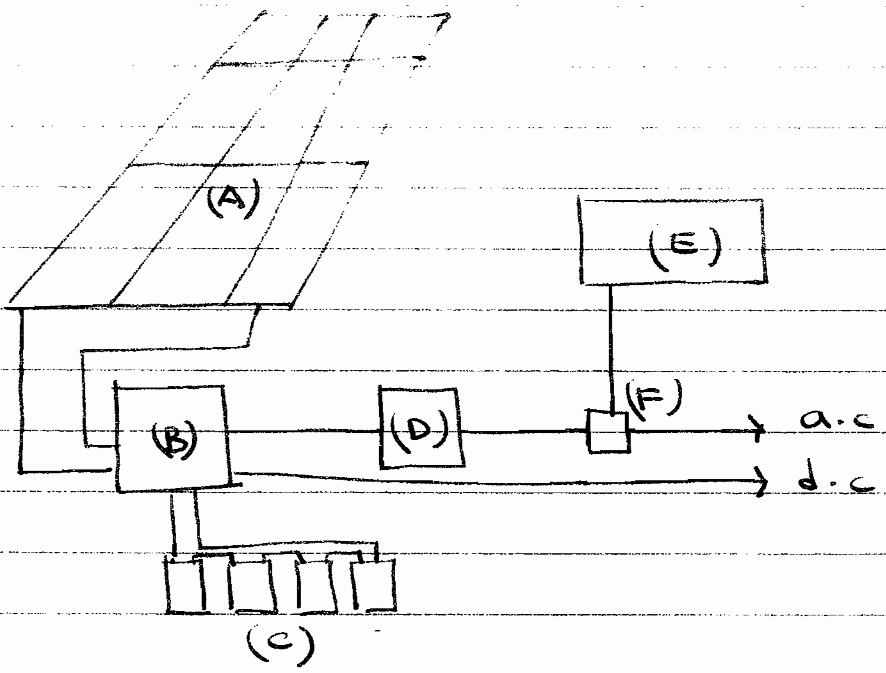
c) Admittance Method considers cyclic heat flows and temperature differences over a daily cycle. It can therefore take some account of thermal mass effects, which can be used to "knock the peaks off" the daily fluctuations.

Glass fronted office towers can overheat during the afternoon summer sun, and may need substantial cooling plant. The Admittance Method allows one to (crudely) analyse these diurnal ranges and so size the required plant, (and perhaps also identify whether thermal mass can be used to advantage – (or sun-shades etc.)).

(4)

2.(a) OFF GRID PV SYSTEM

⑤



(A) - PV PANELS

(B) - CHARGE CONTROLLER FOR REGULATING POWER INTO / OUT OF THE BATTERY STORAGE BANK

(C) - POWER STORAGE SYSTEM GENERALLY COMPRISING OF A NUMBER OF BATTERIES.

(D) - INVERTER TO CONVERT ~~PV PANEL OUTPUT~~ BATTERY d.c. OUTPUT TO a.c.

(E) - BACK-UP POWER SUPPLY SUCH AS DIESEL GENERATOR

(F) - SWITCH GEAR

(b) OPTIMUM INCLINATION

THIS IS AN OFF-GRID SYSTEM THEREFORE OPTIMUM ANGLE SHOULD BE DETERMINED FROM IRRADIANCE IN 'WORST' MONTH.

FROM IRRADIATION CHART WORST MONTH IS DECEMBER AND ~~BEST~~ OPTIMUM ORIENTATION θ = 65°-70° TO THE HORIZONTAL

NO. OF PV PANELS REQUIRED:

IRRADIANCE FOR OPTIMUM ANGLE IN DECEMBER = 3.51 kWh/m²

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

∴ PEAK SOLAR HOURS (PSH) = $3.51/1$ = 3.51 h

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

$$= \frac{600 + 4500 \text{ Wh/day}}{3.51 \text{ h}}$$

$$= 1452 \text{ W}$$

∴ No. OF PANELS $= \frac{1452 \text{ W}}{200 \text{ W/PANEL}} = 7.26$

⑤ ∴ SPECIFY 8 IN NO. 200 W (P_{MAX}) PV PANELS.

(c) A GRID CONNECTED SYSTEM WOULD CONSIST OF: PV PANELS; INVERTER TO CONVERT d.c. OUTPUT TO a.c. COMPATIBLE WITH THE UTILITY GRID AND LOAD IN HOTEL; ~~SWITCHGEAR~~ SAFETY DISCONNECTS. THEREFORE (B), (C) AND (E) SHOWN IN THE SKETCH ARE NOT REQUIRED.

OPTIMUM ORIENTATION FOR GRID-CONNECTED SYSTEM IS DETERMINED FROM MAXIMUM ANNUAL IRRADIATION

③ ∴ FROM CHART θ = 35° TO HORIZONTAL (COMPARE TO θ = 65-70° FOR OFF-GRID SYSTEM).

7011 / [illegible] / 2,3

AVERAGE ANNUAL IRRADIANCE FOR OPTIMUM ANGLE = 4.78 kWh/m²

∴ NOMINAL POWER OF PANEL = $\frac{600 + 4500}{4.78\,h}$

= 1067 W

∴ NO. OF 200W PANELS = 1067/200

= 5.33

(2) ∴ 6 IN NO. 200W (P_{MAX}) PV PANELS – (COMPARE TO 7 IN NO. FOR OFF-GRID SYSTEM)

(d) CAPITAL COST = £7,000 (OFF-GRID) / £6000 (GRID-CONNECTED)
SERVICE LIFE = 25 YEARS / 25 YEARS.
O&M COST = – –
~~OUTPUT = 4.24~~
OUTPUT FOR OFF-GRID IS LIMITED TO ENERGY LOAD = (600 + 4500 Wh/day) x 365

= 1861500 Wh
= 1861.5 kWh p.a.

OUTPUT FOR GRID CONNECTED IS A TOTAL SOLAR ENERGY CONVERTED

= (4.78 h x 6 x 200 W) x 365
= 2093 kWh p.a.

4D11/2009/2/4

	OFF-GRID	GRID-CONNECTED
ANNUITISED COST OF CAPITAL SPREAD OVER SERVICE LIFE (DISCOUNT RATE - 8%)	$£94 \times \frac{£8,000}{£1,000}$ $= £752$ p.a.	$£94 \times \frac{£6000}{£1000}$ $= £564$ p.a.
O&M	–	–
TOTAL	£752 p.a.	£564 p.a.
COST OF ELECTRICITY . . . =	$\frac{75200\ p\ p.a.}{1861.5\ kWh\ p.a.}$ $= 40.4\ p/kWh$	$\frac{56400\ p\ p.a.}{2093\ kWh\ p.a.}$ $26.9\ p/kWh$

⑤

3(a) A MULTI PURPOSE HALL WITH THESE DIMENSIONS IS NOT LIKELY TO BE USED AS A SERIOUS MUSIC VENUE FOR UNAMPLIFIED MUSIC. IT IS HOWEVER LIKELY TO BE USED FOR FUNCTIONS SPEECH INTELLIGIBILITY IS IMPORTANT (E.G. LECTURES, PRESENTATIONS ETC.).

SPEECH INTELLIGIBILITY IS AN ISSUE OF SIGNAL TO NOISE AND REVERBERATING SOUNDS FROM PREVIOUS UTTERANCES INCREASE THE NOISE LEVEL AND THEREFORE DECREASE THE SIGNAL/NOISE RATIO AND HENCE REDUCE INTELLIGIBILITY.

A ROOM WITH A VERY LOW REVERBERATION TIME (< 0.8s) IS EXPENSIVE TO PRODUCE AND LEADS TO A LACK OF RESPONSE FROM THE ROOM WHEN SPEAKING.

⑥ IN BB93 THE RECOMMENDED REVERBERATION TIME FOR A MULTIPURPOSE HALL IS BETWEEN 0.8s AND 1.2s. 1.0s IS A HAPPY MEDIUM.

(b) A SUITABLE AREA OF ACOUSTIC ABSORPTION SHOULD BE ADDED.

VOLUME $= 17.8 \times 11.4 \times 6.1$

$= 1237.8 \text{ m}^3$

SABINE EQ $T = 0.16\, V/A$

EXISTING CONDITION $A = 0.16\, V/T$

$= 0.16 \times 1237.8 / 2.8$

$= 70.7 \text{ m}^2$

REQUIRED CONDITION $A = 0.16 \times 1237.8 / 1.0$

$= 198 \text{ m}^2$

REQUIRED ADDITIONAL ACOUSTIC ABSORPTION = 198 − 70·7

= 127·3 m²

(4)

IF THE CHOSEN SUITABLE MATERIAL HAS AN ABSORPTION COEFFICIENT AT MID FREQUENCY OF 0·9, THEN THE REQUIRED AREA OF ABSORPTION WOULD BE:

(4)

$$S = A/\alpha$$
$$= 127{\cdot}3/0{\cdot}9 = 141{\cdot}5\,m^2$$

i.e. APPROX. 49 STANDARD SHEETS (1·2 × 2·4m)

(c) THE ACOUSTIC ABSORBER SHEETS WOULD BE DISTRIBUTED ON EACH OF THE FOUR WALLS AND SOME ON THE CEILING IN ORDER TO MAINTAIN A DIFFUSE SOUND FIELD AND MAXIMISE THE EFFECT OF ABSORPTION.

THE NEGATIVE IMPACT OF THIS INTERVENTION IS THE SETTING UP OF FLUTTER ECHOES IN THE LISTENING ZONE. THIS CAN BE MITIGATED BY ENSURING THAT IN THE AREA 0·8m FROM THE FLOOR TO 2·0m FROM THE FLOOR, AROUND THE PERIMETER OF THE HALL, THERE ARE NO SECTIONS OF PARALLEL WALLS WITHOUT ABSORPTION ON AT LEAST ONE FACE. (6)

(c) ALTERNATIVE ANSWER.

1·0S REVERBERATION TIME IS UNSUITABLE FOR UNAMPLIFIED MUSIC. THIS CAN BE MITIGATED BY USING DEPLOYABLE ACOUSTIC ABSORBERS THEREBY ALLOWING THE REVERBERATION TIME TO BE MODIFIED TO SUIT THE USE. EXAMPLES OF DEPLOYABLE ABSORBERS ARE CURTAINS, SLIDING ACOUSTIC PANELS ETC.

4(a) $L_{Aeq,5mins}$ 92 dB : THE EQUIVALENT CONTINUOUS NOISE LEVEL MEASURED OVER A 5 MINUTE PERIOD USING THE A WEIGHTING NETWORK IS 92 dBA. THIS IS A MEASURE OF THE AVERAGE NOISE LEVEL.

$L_{A90,5mins}$ 40 dB : THE LEVEL MEASURED USING THE A WEIGHTING NETWORK WHICH IS EXCEEDED FOR 90% OF THE 5 MINUTE PERIOD MEASURED. THIS IS A LEVEL OF THE LOWEST NOISE LEVEL ABOVE WHICH INDIVIDUAL NOISE EVENTS CAN BE HEARD.

THE A WEIGHTING NETWORK SIMULATES THE FREQUENCY RESPONSE OF THE EAR BY FILTERING OUT THE LOW FREQUENCY COMPONENTS IN A PRESCRIBED WAY.

(b) $D = R - 10\log_{10} S + 14 + 20\log_{10} r$

$92 - 40 - 10 = R - 10\log_{10} 240 + 14 + 20\log_{10} 8$

$\therefore \underline{\underline{R = 54\,dB}}$

(c) $R = 10 + 14.5\log_{10} m$

$\underline{\underline{M = 1030\,kg/m^2}}$

(d) SURFACE DENSITY = DENSITY × THICKNESS

$\therefore$ THICKNESS = $1030/2000$

= 516 mm

THIS IS FAR TOO THICK A WALL FOR PRACTICAL APPLICATION.

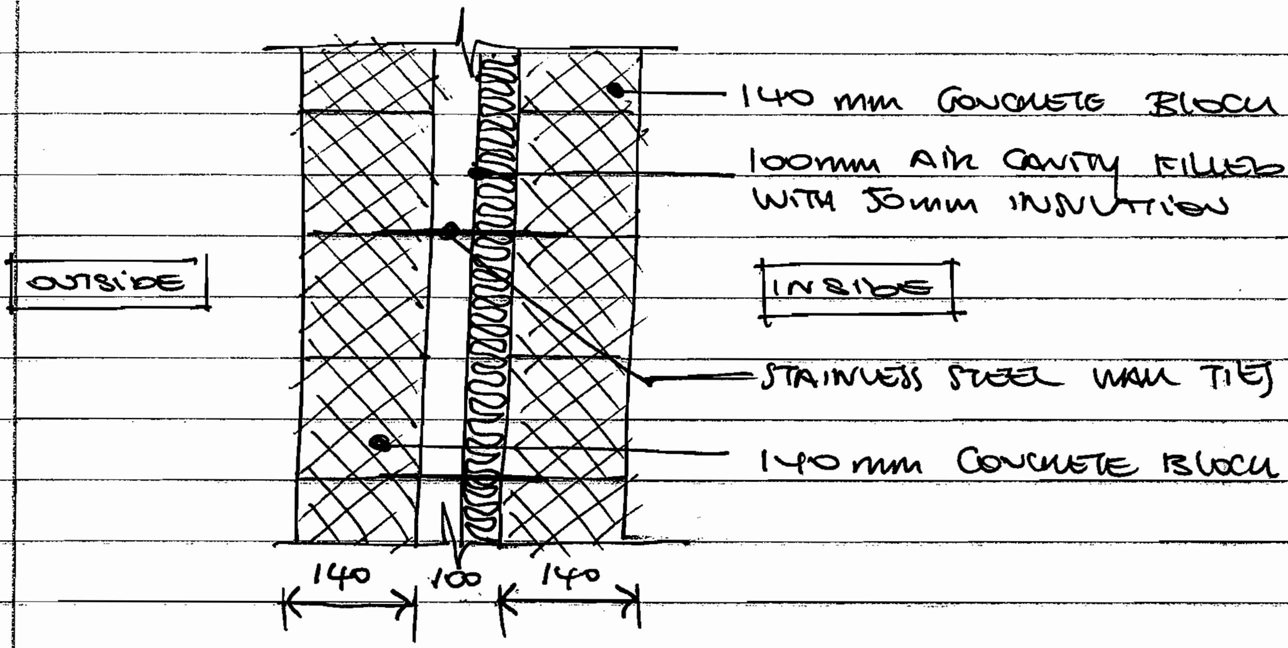
(e) 140mm CONCRETE BLOCKS HAVE A SURFACE DENSITY OF 280 kg/m².

TWO WALLS OF 140mm BLOCKS SEPARATED BY

4611/2009/4/2

A CAVITY (SAY 100mm) IS QUITE LIKELY TO ACHIEVE THE REQUIRED SOUND INSULATION OF 54dB. EACH LEAF WOULD HAVE AN INDIVIDUAL SOUND REDUCTION INDEX OF 45dB. IF THE TWO LEAVES WERE PERFECTLY ACOUSTICALLY ISOLATED THE SOUND REDUCTION INDEX OF THE COMBINATION WOULD BE 90dB. IF THE TWO WALLS WERE JOINED WITHOUT A CAVITY THE COMBINATION WOULD BE 50dB.

THE CAVITY MAKES THE WALL BUILDABLE AND WILL ADD AT LEAST THE NECESSARY 4dB OF SOUND INSULATION, BY OVERCOMING THE MASS LAW USING ADDED ISOLATION. WALL TIES WOULD NOT PRESENT A PROBLEM AND THE CAVITY COULD USEFULLY BE FILLED WITH 50mm OF THERMAL INSULATION.



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5 (a) DAYLIGHT FACTOR IS THE <u>RATIO</u> OF DAYLIGHT ILLUMINANCE (LUMENS/m^2) ON A HORIZONTAL WORKING SURFACE AT STANDARD HEIGHT WITHIN A ROOM ON AN OVERCAST DAY TO THE ILLUMINANCE ON AN UNOBSTRUCTED HORIZONTAL SURFACE IN THE OPEN AIR.

IT INCLUDES THE "SKY COMPONENT" THE "EXTERNALLY REFLECTED COMPONENT" AND THE "INTERNALLY REFLECTED COMPONENT".

SKY COMPONENT — DEPENDS ON AREA OF SKY SEEN THROUGH THE WINDOWS AND ITS LUMINANCE (DEPENDING ON ANGLES IN VERTICAL PLANE. DETERMINED BY USING *SPECIAL* PROTRACTOR FOR LONG WINDOWS, CORRECTION REQUIRED FOR SHORTER WINDOWS.

EXTERNALLY REFLECTED COMPONENT - LIGHT COMING TO ROOM IN QUESTION AFTER REFLECTION FROM AN EXTERNAL OBJECT (E.G. ANOTHER BUILDING). DETERMINED IN SIMILAR WAY TO SKY COMPONENT, BUT WITH A REFLECTANCE FACTOR FOR EXTERNAL SURFACES.

INTERNALLY REFLECTED COMPONENT - DEPENDS ON THE MULTIPLE REFLECTIONS FROM SURFACES WITHIN THE ROOM IN QUESTION. THE SIMPLEST METHOD FOR DETERMINING THIS ~~BY~~ IS BY USING A NOMOGRAM.

(4)

(b) ADVANTAGES:

- POSITIVE PSYCHOLOGICAL EFFECT AND WELL-BEING OF WORKERS
- PROMOTES A NATURAL RHYTHM BY CHANGING DAYLIGHT PATTERNS.

- AESTHETIC ASPECTS OF NATURAL LIGHT
- EXCELLENT COLOUR DEFINITION OF NATURAL LIGHT
- REDUCES THE HIGH ENERGY COST OF ARTIFICIAL LIGHTING IN BUILDINGS.

DISADVANTAGES:

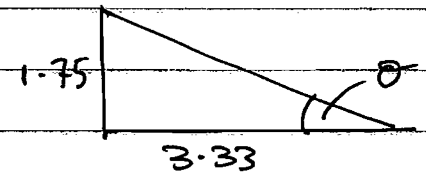
- REQUIRES SHALLOW BUILDINGS WHERE OFFICE SPACES ARE LOCATED CLOSE TO WINDOWS (i.e. SPACE PLANNING LIMITATIONS).
- GIVES RISE TO GLARE PROBLEMS LEADING TO VISUAL DISCOMFORT
- ④ LARGE WINDOW AREAS REQUIRED FOR MAXIMUM DAYLIGHT PENETRATION MAY LEAD TO EXCESSIVE SOLAR HEAT GAIN AND HEAT LOSS WHICH IMPACTS ON ENERGY EFFICIENCY.

(C) i) TWO POINTS:

POINT A - 3.3m FROM OPEN COUNTRY WINDOW
POINT B - 3.3m FROM COURTYARD WINDOW

CONSIDER POINT A:

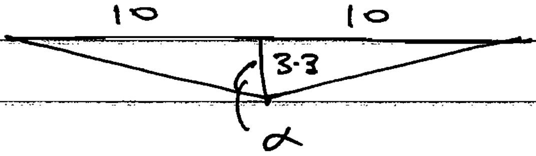
SC



$\theta = \tan^{-1}\frac{1.75}{3.3} = 27.7°$

$\therefore SC = 3\%$ (PROTRACTOR)

CORRECTION FACTOR FOR WINDOW LENGTH:



$\alpha = \tan^{-1}\frac{10}{3.3} = 71.6°$

$\therefore$ CORRECTION FACTOR (PROTRACTOR) $\approx 0.45 \times 2 = 0.9$

$\therefore SC = 0{\cdot}9 \times 3\%$

$= \underline{2{\cdot}7\%}$

IRC

CONSIDER NO OBSTRUCTION:

WINDOW AREA $= 20 \times 1{\cdot}75$

$= 35\,m^2$ (ONE WINDOW)

TOTAL INTERNAL SURFACE AREA (FOR HALF OFFICE) $= (3{\cdot}5 \times 20) + (5 \times 20 \times 2) + (5 \times 3{\cdot}5 \times 2)$

$= 305\,m^2$

$\therefore$ RATIO $= 0{\cdot}115$

USING NOMOGRAM STRAIGHT LINE FROM 0·115 ON SCALE A TO 35% ON SCALE B GIVES 1·5% ON SCALE C.

CONSIDER OBSTRUCTION AT BOTH ENDS:

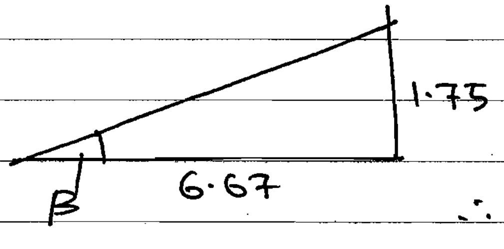
ANGLE OF OBSTRUCTION $= \tan^{-1}\dfrac{10{\cdot}5}{15} = 35^\circ$

STRAIGHT LINE FROM 35° ON SCALE D THROUGH 1·5% ON SCALE C GIVES 0·87% ON SCALE E.

OBSTRUCTION ONLY ONE END

$\therefore$ AVERAGE IRC $= \underline{1{\cdot}2\%}$

ERC



$\beta = \tan^{-1}\dfrac{1{\cdot}75}{6{\cdot}67} = 14{\cdot}7^\circ$

$\therefore$ ERC $= 0{\cdot}7\%$ (PROTRACTOR)

BUT WALL REFLECTANCE $= 70\%$

$\therefore \underline{ERC = 0{\cdot}49\%}$

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WINDOW TRANSPARENCY ↓

$\therefore$ TOTAL DF AT A $= (SC + IRC + ERC) \times 0.75$

$= (2.7 + 1.2 + 0.49) \times 0.75$

③ $= \underline{\underline{3.3\ \%}}$

NOW CONSIDER POINT B :

$\underline{IRC} = \underline{1.2}\ \%$

SC

OPEN COUNTRY $\theta = \tan^{-1} \dfrac{1.75}{6.67} = 14.7°$

$\therefore SC_1 = 0.8\%$

CORRECTION FOR WINDOW SIZE $\alpha = \tan^{-1} \dfrac{10}{6.67} = 56°$

$\therefore$ CORRECTION FACTOR $= 0.42 \times 2 = 0.84$

$\therefore SC_2 = 0.8\% \times 0.84$

$= \underline{0.67}\ \%$

COURTYARD $SC_2 = 0$ AT 3.33m

ERC

$\beta = \tan^{-1} 1.75/3.33 = 27.7°$

$\therefore$ ERC $= 3\%$ (PROTRACTOR) $\times$ 70% REFLECTANCE

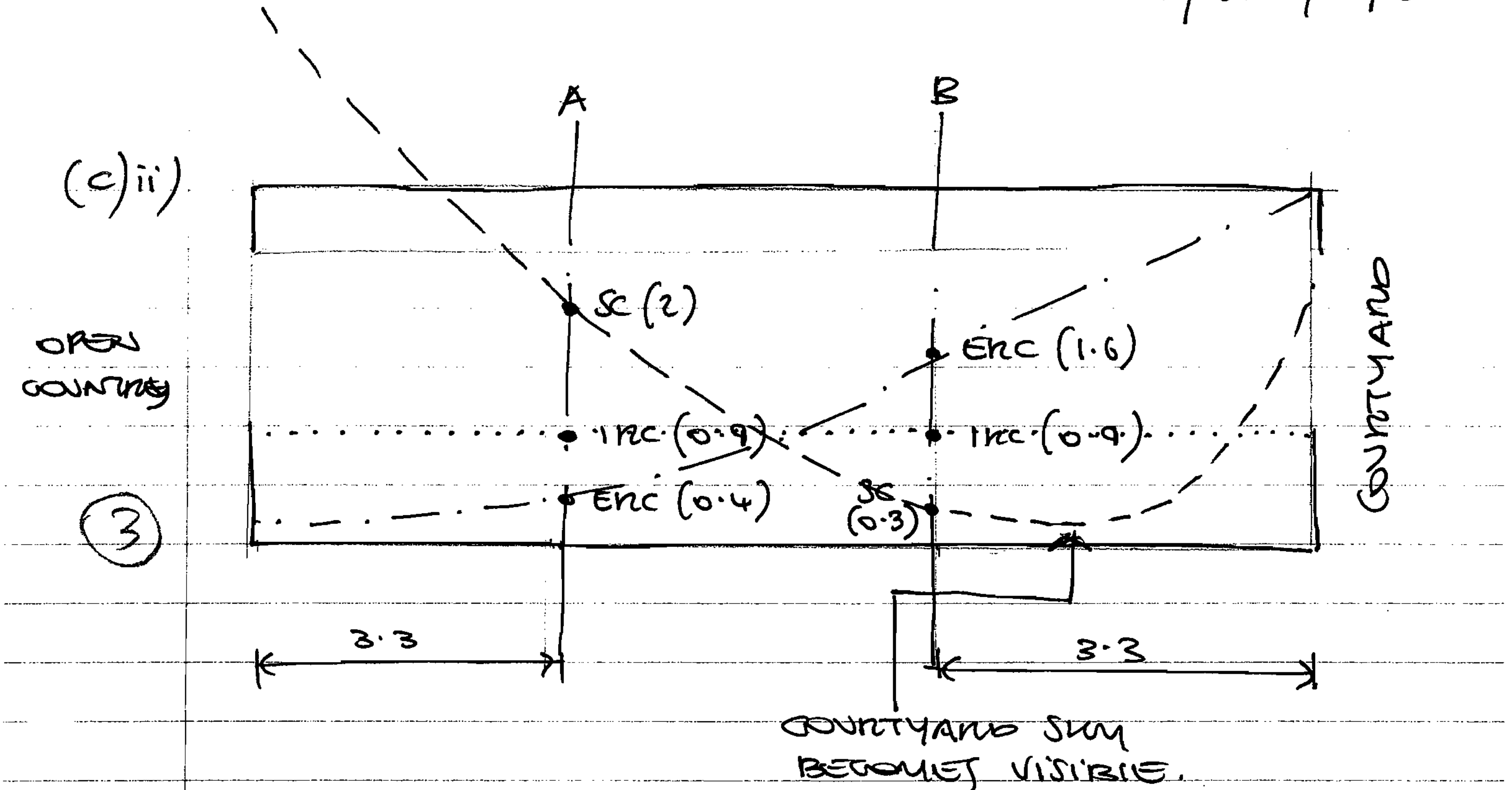
$= \underline{2.1\%}$

$\therefore$ TOTAL DF AT B $= (SC + IRC + ERC) \times 0.75$

$= (0.67 + 1.2 + 2.1) \times 0.75$

③ $= \underline{\underline{3\ \%}}$

(c)ii)



(3)

d) THE PROPOSED GLASS ROOF OVER THE COURTYARD WILL CLEARLY REDUCE THE DAYLIGHT FROM THE COURTYARD WINDOW. THIS MAY BE VERIFIED BY RE-CALCULATING A AND B:

$$\text{AT A} = \Big[\underset{SC}{2.7} + \underset{IRC}{\frac{1.5 \times (0.8 \times 0.87)}{2}} + \underset{ERC}{(0.49 \times 0.8)}\Big] \times 0.75$$

$$= (2.7 + 1.1 + 0.4)\, 0.75$$

$$= 3.15\%$$

$$\text{AT B} = \Big[\underset{SC}{0.67} + \underset{IRC}{1.1} + \underset{ERC}{(2.1 \times 0.8)}\Big]\, 0.75$$

$$= 2.6\%$$

(3)

THE SC FROM THE OPEN COUNTRY WINDOW IS UNAFFECTED, BUT THE ERC FROM THE COURTYARD AND THE SC FROM THE COURTYARD ARE DRAMATICALLY REDUCED – WITH REFERENCE TO SKETCH IN Cii THIS WILL RESULT IN A MUCH DARKER ROOM TOWARDS THE COURTYARD HALF.

THIS MAY BE MITIGATED BY:

- LIGHT SHELF ON OPEN-COUNTRY WINDOW TO INCREASE DF IN MIDDLE OF ROOM.
- INCREASE REFLECTANCE OF OPPOSITE BUILDING AND PERHAPS USE LIGHTER COLOURED FLOORING IN COURTYARD TO INCREASE ERC.
- INCREASE INTERNAL REFLECTANCE OF ROOM TO INCREASE DF LEVEL THROUGHOUT OFFICE.

4011/2009/6/1

6(a) USEFUL OUTPUT PER LUMINAIRE = 36 W x 80 lm/W x 0.75
= 2160 lumens

REQUIRED ILLUMINANCE OF 300 lux OVER 50m²
= 300 x 50
= 15,000 lumens

∴ No. OF LUMINAIRES = $\frac{15000}{2160}$ = 6.9, say 7

(2+2) HOWEVER THIS IS A SQUARE ROOM ∴ PROVIDE
8 LUMINAIRES (IN 4 ROWS x 2 COLS.)

(b) i) DAYLIGHT REQUIRED FOR CORRECT ILLUMINANCE:
= $\frac{300}{0.03}$ = 10,000 lux

∴ % OF TIME WHEN 300 lux IS EXCEEDED IN OFFICES
(FROM DAYLIGHT AVAILABILITY CURVES):

MONTH	% EXCEEDED	MONTH	% EXCEEDED
JAN	26	SEP	79
FEB	50	OCT	57
MAR	77	NOV	35
APR	94	DEC	18
MAY	96		
JUN	97		Σ 811
JULY	94		
AUG	88		

∴ DIFFUSE DAYLIGHT SUFFICIENT
FOR $811/_{12}$ = 68%

(6) ∴ ARTIFICIAL LIGHTING REQUIRED FOR 32% OF TIME

b ii) SWITCHING LIGHTS IN ROOM AUTOMATICALLY ACCORDING TO DAYLIGHT SENSOR OUTSIDE.

(c) WITH A DAYLIGHT FACTOR OF 1·8%, 300 LUX IN THE OFFICES WOULD REQUIRE:

$$\frac{300}{0{\cdot}18} = 16{,}667 \text{ lux.}$$

MONTH	% EXCEEDED	MONTH	% EXCEEDED
JAN	5	AUG	71
FEB	25	SEP	56
MAR	56	OCT	30
APR	79	NOV	7
MAY	89	DEC	1
JUN	86		
JUL	84	Σ =	576

∴ DIFFUSE DAYLIGHT SUFFICIENT FOR $576/12 = 48\%$ OF TIME

∴ ARTIFICIAL LIGHT REQUIRED FOR 52% OF TIME.

EXTERNALLY SHADED OPTION WOULD REQUIRE AN INCREASE OF $(52\% - 32\% = 20\%)$ IN USE OF ARTIFICIAL LIGHT.

∴ INCREASE IN LIGHTING ENERGY LOAD

$$= 8 \times 36\text{W} \times \Big[\underbrace{60 \times 60 \times 8{\cdot}5}_{\text{SECONDS IN WORKING DAY}} \times \underbrace{250}_{\text{DAYS OPEN FOR BUSINESS}}\Big] \times \underbrace{0{\cdot}2}_{20\%}$$

$= 440{\cdot}6 \text{ MJ / YEAR}$

$= 122{\cdot}4 \text{ kWh / YEAR}$

THIS IS THE MINIMUM ENERGY SAVING REQUIRED TO JUSTIFY THE USE OF SHADING DEVICES.