4D11 Solutions

1. (a) U in W/m^2K 25°C temperature drop

roof $9 \times 25 \times 0.6 = 135$ W

floor $9 \times 25 \times 0.2 = 45$

walls $36 \times 25 \times 0.3 = 270$

450 W

for total heat loss to be less than 600 W, the window can allow 150 W at max.

resistances : glass 0.12 $K/(W/m^2)$

0.08

$0.2 \times 2 = 0.4$ K per W/m^2

so for 25 K temp. drop, double glazing loses

$25/0.4 = 62.5\ W/m^2$

walls already lose $25 \times 0.3 = 7.5\ W/m^2$

so excess loss due to the window is $55\ W/m^2$

[30%] ∴ max. area is $\frac{150}{55} = 2.73\ m^2$

(b) window area is actually $1.5\ m^2$, so loss for 25° drop is $450 + 1.5 \times 55 = 532.5$ W

so gain for 5° temp. drop is $\frac{1}{5} \times 532.5 = 106.5$ W

∴ total gain by electrical equipment, minus fabric losses to outside is $500 - 106.5 = 393.5$ W

which must be removed by ventilation.

Room full of air, volume $27\ m^3$, $\rho c_p = 1200\ J/m^3K$

So energy per air change, 5° temp. change is $1200 \times 5 \times 27 = 162$ kJ

which is equivalent to $\frac{162 \times 10^3}{3600} n$ W where n is the number of air changes per hour.

$$\therefore \quad 393.5 = \frac{162}{3.6} n \quad \Rightarrow \quad n = 8.74$$

Discussion: T_{ei} is the "environmental temperature", dependent on the air temperature T_{ai} and the mean radiant temperature (dependent on radiation from nearby surfaces). Often $T_{ei} = \frac{2}{3} T_{ai} + \frac{1}{3} T_r$. Might differ in summer due to radiation from sun — but ventilation effect depends on T_{ai}, even though comfort

[35%] more related to T_{ei}.

(c) In winter: need to take account of electrical gains, caused, to reduce required added heat: but also, losses due to opening doors etc.

In summer: reduce solar gain by window blinds (preferably external): possibly attempt to improve ventilation by stack effect (but small height of room

[20%] makes this unlikely).

(b) Other factors: generation of moisture in room (winter condensation), noxious gases etc (CO_2): similar calc. using

[15%] quality of incoming air, select which rate governs.

2. (a) wind pressure $C_p = \dfrac{p - p_{ref}}{\frac{1}{2}\rho U^2}$

so if pressure inside room is p_i

flow through opening A_1 :

$$Q = C_d A_1 \sqrt{\frac{2}{\rho}\left\{C_{p1}\cdot\tfrac{1}{2}\rho U^2 + p_{ref} - p_i\right\}}$$

through A_2 must be the same Q

$$Q = C_d A_2 \sqrt{\frac{2}{\rho}\left\{p_i - C_{p2}\cdot\tfrac{1}{2}\rho U^2 - p_{ref}\right\}}$$

$$\therefore\ A_1^2\left\{C_{p1}\cdot\tfrac{1}{2}\rho U^2 + p_{ref} - p_i\right\} = A_2^2\left\{p_i - C_{p2}\cdot\tfrac{1}{2}\rho U^2 - p_{ref}\right\}$$

$$\therefore\ A_1^2\cdot C_{p1}\cdot\tfrac{1}{2}\rho U^2 + A_2^2\cdot C_{p2}\times\tfrac{1}{2}\rho U^2 = (p_i - p_{ref})(A_2^2 + A_1^2)$$

$$\therefore\ p_i - p_{ref} = \frac{\rho U^2}{2}\cdot\left[\frac{A_1^2 C_{p1} + A_2^2 C_{p2}}{A_1^2 + A_2^2}\right]$$

$$\therefore\ Q = \frac{C_d A_1\sqrt{2}}{\sqrt{\rho}}\sqrt{C_{p1}\cdot\tfrac{1}{2}\rho U^2 - \frac{\rho U^2}{2}\left\{\frac{A_1^2 C_{p1} + A_2^2 C_{p2}}{A_1^2 + A_2^2}\right\}}$$

$$= C_d U\sqrt{A_1^2\left\{C_{p1} - \frac{(A_1^2 C_{p1} + A_2^2 C_{p2})}{A_1^2 + A_2^2}\right\}}$$

$$= C_d U A_w\sqrt{C_{p1} - C_{p2}} \quad \text{where } A_w^2 = \frac{A_1^2 A_2^2}{(A_1^2 + A_2^2)}$$

[40%]

Q.E.D.

(b) total temp drop across roof + inside surface is 10°C : with given U and surface resistance this gives a surface temperature of 18°C. So we must keep the wet bulb temperature below 18°C inside room

From psychrometric chart:

outside db 10 wb 8 ∴ moisture 0.0058 kg/kg

inside db 20 wb 18 ∴ 0.0122 -/-

max. permitted increase in moisture is .0064 kg/kg

if moisture added at rate 1.0×10^{-4} kg/s

need air flow rate 0.0156 kg/s

i.e. 0.013 m^3/s

Now substitute into wind-velocity formula:

$A_w = 0.1\ m^2$, $C_{p1} = 0.8$ $C_{p2} = -0.1$

$C_d = 0.6$

$$\therefore \quad U = \frac{Q}{C_d A_w \sqrt{C_{p1} - C_{p2}}} = \frac{0.013}{0.6 \times 0.1 \times \sqrt{0.9}} = 0.23 \text{ m/s}$$

[40%]

(c) Of course, one cannot rely on such a wind at all times — so some other form of ventilation may well be necessary. Could try some stack effect using temperature of warm air to drive flow — but not likely to be reliable. Can we reduce moisture input? — unlikely. Can we go to some form of forced ventilation — by fan? Probably necessary, and above calculations give some idea of what might be needed. 0.013 m^3/s in say 20 m^3 bathroom is

[20%] 2.3 air changes/hour — not very many.

3. This is an exercise on Sabine's Law – not actually given on the Data Sheet, but so crucial in room acoustics that the students are expected to remember it: reverberation time $RT = 0.16 \frac{V}{A}$ in secs, where V (m^3) is room volume, A is area (m^2) of acoustic absorption (surface S times absorption coefficient).

(a) Hall volume $3000\ m^3$; "cupboards" 10 m high, 1 m wide – pretty tall, for microdesign. Dimensions should not be related by small integers to avoid standing wave reinforcement: 10 m high by 20 m by 15 m ruled out, say <u>11 m high by 21 m by 13 m</u> ($= 3003\ m^3$). Twelve cupboards on each side would fit – but probably need some along back.

Empty $3.0 = 0.16 \times \frac{3000}{A} \Rightarrow A = 160\ m^2$, doors closed

[20%] (ceiling and floor absorbing at say 0.4, seems OK).

(b) With doors open, more <u>added</u> absorption $24 \times 10 \times 1 = 240$

so $A = 400 \Rightarrow RT = 0.16 \times \frac{3000}{400} = \underline{\underline{1.2 s}}$

Thickness of the cupboards reduces V a little, but not significantly. Door absorption in front of wall likely to be small (heavy panels), but open doors might mask absorption by obscured wall – still, walls prob. fairly hard anyway.

[20%]

(c) Drama rehearsal : speech, so 1.0s OK. All doors open $T = 0.16 \times 3000 / 410 = 1.17$ s — a bit high but probably OK. This is the best we can do.

Drama performance : ideal $T = 1.0$s. $\Rightarrow A = 480\ m^2$ so cupboards must provide $480 - 160 - 160 = 80\ m^2$, i.e. 1/3 of doors open, ideal.

Orchestra rehearsal : ideal about 2s. $A = 240\ m^2$, just achieved with all doors closed. ⟨so orchestra should be OK in another hall, properly organised⟩

Orchestra performance : again need $240\ m^2$, but here at least $400\ m^2$, $T = 1.2$ s — a rather dry situation

[40%] — so hall not good for actual concerts.

(d) Diffusing effect of curvature on door fronts is to reduce the chance of "room modes" of vibration at particular frequencies, and the chance of "flutter echoes" giving different response to musical notes. (Note, also need to reduce vertical flutter, by angles

[10%] on ceiling etc.)

(e) Closed doors are meant not to absorb — but light panels would be absorbent at low frequencies. Heavy panels do not absorb much across entire range.

[10%]

4. This question gives scope for discussion of acoustic specifications and the reasons for them — all mainly bookwork, covered in the lectures.

(a) Reverberation time in seconds — time taken for sound pressure level to drop by 60 dB after source of incoherent sound ceases. Long T in office would assist sound transfer and hence reduce privacy. Is is ideal for a lecture theatre — gives support to orator, but reflected waves do not interfere with intelligibility.

Noise Rating curves for background noise: lowest of a set of dB curves across frequencies 63 Hz to 8 kHz, below which all background noise falls — defined by value at 1 kHz. High background noise assists privacy, but low NR improves intelligibility. Too high is disturbing, too low is expensive.

Ceiling: office absorption helps to reduce RT and improve privacy. In lecture theatre, we do not want so much absorption, to keep ideal RT — but absorption in rear third reduces unwanted echoes from back, whose long travel time interferes with intelligibility.

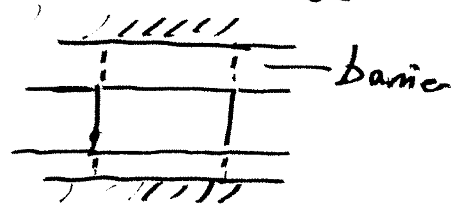
Doors: R, sound reduction index, ten times log of transmission coefficient, ratio of transmitted to incident sound. 25 dB door is simple, no seals: 40 dB is heavy and has complex seals. Intrusive noise is masked by the background noise level in an office — that would be disturbing in a LT.

dBA : sound pressure level as measured by a meter with an A weighting filter, simulating frequency response of human ear. Both max levels high, and disturbing

[70%] — but audio-visual shows in LT could easily reach 90dB and would not be harmful, whereas 85 dBA would bring office work to a halt.

(b) Need sound barrier in the void below the raised floor, beneath the partitions, and in the void above suspended ceiling — to reduce airborne comm. Cut down structure-borne noise by heavy walls (mass law) — and also by stopping up any holes. So need mastic seals round doors, round barrier, round any

[30%] connection for services etc. Also cross-talk attenuator in the air distribution system.



---

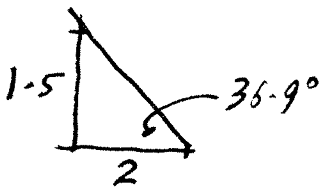
5 (a) Bookwork : "sky component" — coming directly into windows from the unobstructed (overcast) sky ; "externally reflected" component, coming directly into the windows after one external reflection, e.g. from an adjacent

building; "internally reflected component" arriving at the point in question after multiple internal reflections from internal surfaces. Optimise SC by high windows (to capture more light from high in sky) and shallow rooms — SC cannot easily reach well well away from window. Optimise ERC by not having adjacent buildings, or making them reflective. If need be have "light shelves" to direct light into building, reflecting from ceiling. Increase IRC by increasing reflectance

[25%] of internal surfaces (white paint etc).

(b) Best to start with "open country" end. No ERC.

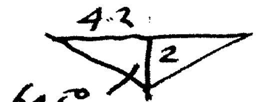
Long window: if 100% transparency:



∴ SC (protractor) = 6%

mean angle 18°

Window length: $\frac{0.4 \times 9 \times 3.5}{1.5} = 8.4\,m$ angle



correction factor about $0.48 \times 2 = 0.96$

∴ $\underline{SC = 5.8\%}$

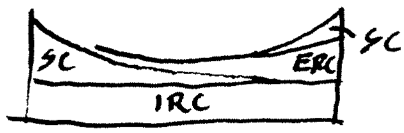
<u>Then, IRC</u>: if both ends on to open country

window area $= 0.4 \times 9 \times 3.5\ m^2$ each end
total surface area (half room) $= 5 \times 25 + 9 \times 3.5$ } ratio 0.08

straight line: scale A to 45% scale B, gives 1.9% on scale C

Suppose half comes from each window. If obstruction at both ends, angle $\tan^{-1} \frac{7 \text{(say)}}{12} = 30.2°$, scale D → C →

gives 1·3 % on scale E.



But obstruction only at one end : average 1·6%
Now consider effect of atrium window : clearly no SC.
ERC has angle $\tan^{-1} \frac{1.5}{8} = 11°$ ∴ ERC max 0·4%
times atrium transparency 0·85, times reflectance 0·75
(but factor 0·2 on Data Sheet) – say 0·2%

∴ total 5·8 + 0·2 + 1·6 = 7·6

window transparency 72% ⇒ 5·5%

At inner end near atrium : IRC again 1·6%
SC from far window 0·4%, SC from atrium 6%–4%
for long window × 0·96 ≈ 2·0%, times 0·85 = 1·7%
ERC is 4% × 0·85 × 0·75 (but factor 0·2 in Data Sheet)
say 1·7% (mean)

∴ total 1·7 + 0·4 + 1·7 + 1·6 ⇒ 5·4

window transparency 72% so 3·9%

[50%]

(c) Probably have 3 zones, say 2·5 m deep near each window, central zone 5m. Say central zone has 2·5% DF. Then lights on when external lux below 12 klux. From daylight availability curves, lights on e.g. in Sept. for 30% of office hours : work out energy use/m² to give 300 lux artificial, hence energy demand per m².

[20%]

6. (a) This question gives scope for display of knowledge about lighting requirements, and implementation

- natural light – likely to be more important for classroom (welfare of children, good colour rendering) than on a frenetically busy dealing floor
- design specifications – in terms of recommended Lux values at working height, but also discuss glare, use of computer screens in dealing room etc
- choice of lamps and fittings – diffuse overhead light versus subdued workstation lights (which more appropriate in a school – children probably not to control their lighting)
- energy efficiency : could save by utilising natural light, especially in classroom, and a control system. Savings less likely in dealing room, where natural light unlikely (deep plan, no distraction)
- other factors they can think of – recall lecture material.

[60%]

(b) Suppose we require 500 lux

32 W tube gives $85 \times 32 \times 0.7$ lumens = 1904 lumens

so for 500 lux, need 1 tube every 4 m^2

over the room 90 m^2 so need say 22 fittings, might get away with 20, in 4 rows of 5.

[20%]

(c) For dealing-room floor, no natural light, requirement in power is 32 W every 4 m²
i.e. about 8 W/m², continuous throughout working day.

For school classroom, say 300 lux — so need similar max. power levels — but there would be substantial savings over a year, utilizing natural light (say 2% daylight factor), and a proper control system.

[20%] Can be worked out using daylight availability curves