Today, we will:

- *Briefly* discuss **Partially Mixed Conditions** in **Section 5.7** – (Skim)
- Discuss **The Well-Mixed Model as an Experimental Tool** in **Section 5.8**
- Discuss **Clean Rooms** in **Section 5.9**
- Do an example problem – Clean rooms (Example 5.10 in text)
- Discuss **Infiltration** in **Section 5.10**
- Do an example problem – The Professor's office (Example 5.11 in text)

Arch Engrs introduce m = mixing factor

→ An attempt to account for rooms that are not well mixed

Use well-mixed analysis, but throw in m as a "fudge factor"

$0 < m < 1$ $m = 1$ → well-mixed

$m = 0$ → not mixed at all

SEC 5.8 Well-mixed model as an experimental tool

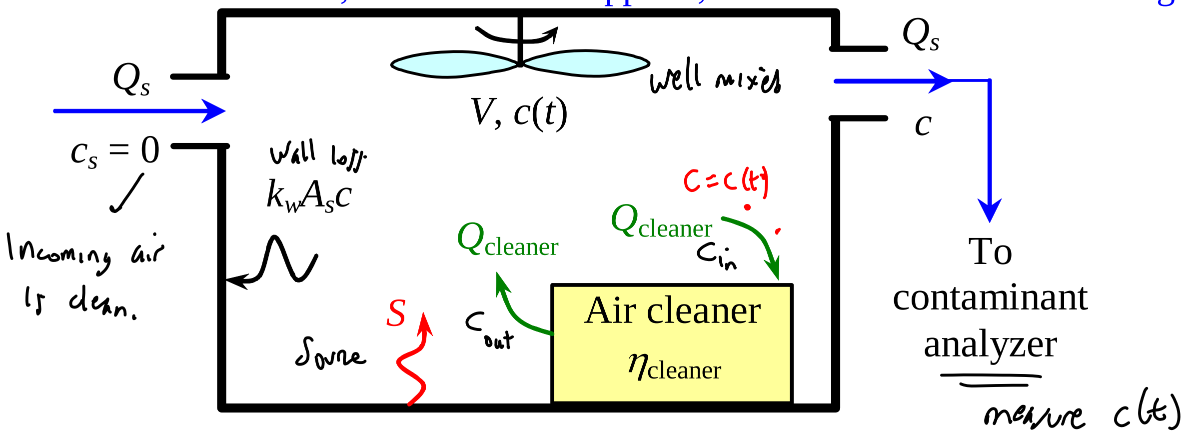
Use it to measure parameters:

- Wall loss coefficient k_w (we already discussed this)
- Source strength S (technique to measure S has already been discussed – CH. 4 flux chamber)
- Efficiency of air cleaners $\eta_{cleaner}$

→ Let's discuss this one, for room air cleaners

Example

Given: The room shown, with clean air supplied, and a room air cleaner running.



To do: Derive an expression for the efficiency of the air cleaner.

Solution:

Cons. of mass of contaminant:

$$V \frac{dc}{dt} = Q_s c_s + S - k_w A_s c - Q_s c - Q_{cleaner} c_{in} + Q_{cleaner} c_{out}$$

($c_s = 0$; $c_{in} = c$; $c_{out} = c(1 - \eta_{cleaner})$)

regroup → all terms w/o c → B
& all terms w/ c → A } write in standard form

$$\frac{dc}{dt} = \frac{S}{V} - \frac{Q_s + k_w A_s + Q_{cleaner}\eta_{cleaner}}{V} c$$

($B = \frac{S}{V}$, $A = \frac{Q_s + k_w A_s + Q_{cleaner}\eta_{cleaner}}{V}$)

$$\frac{dc}{dt} = B - Ac$$

Run until steady-state conditions reached.

$$C_{ss} = \frac{B}{A} = \frac{S}{Q_s + k_w A_s + Q_{cleaner}\eta_{cleaner}}$$

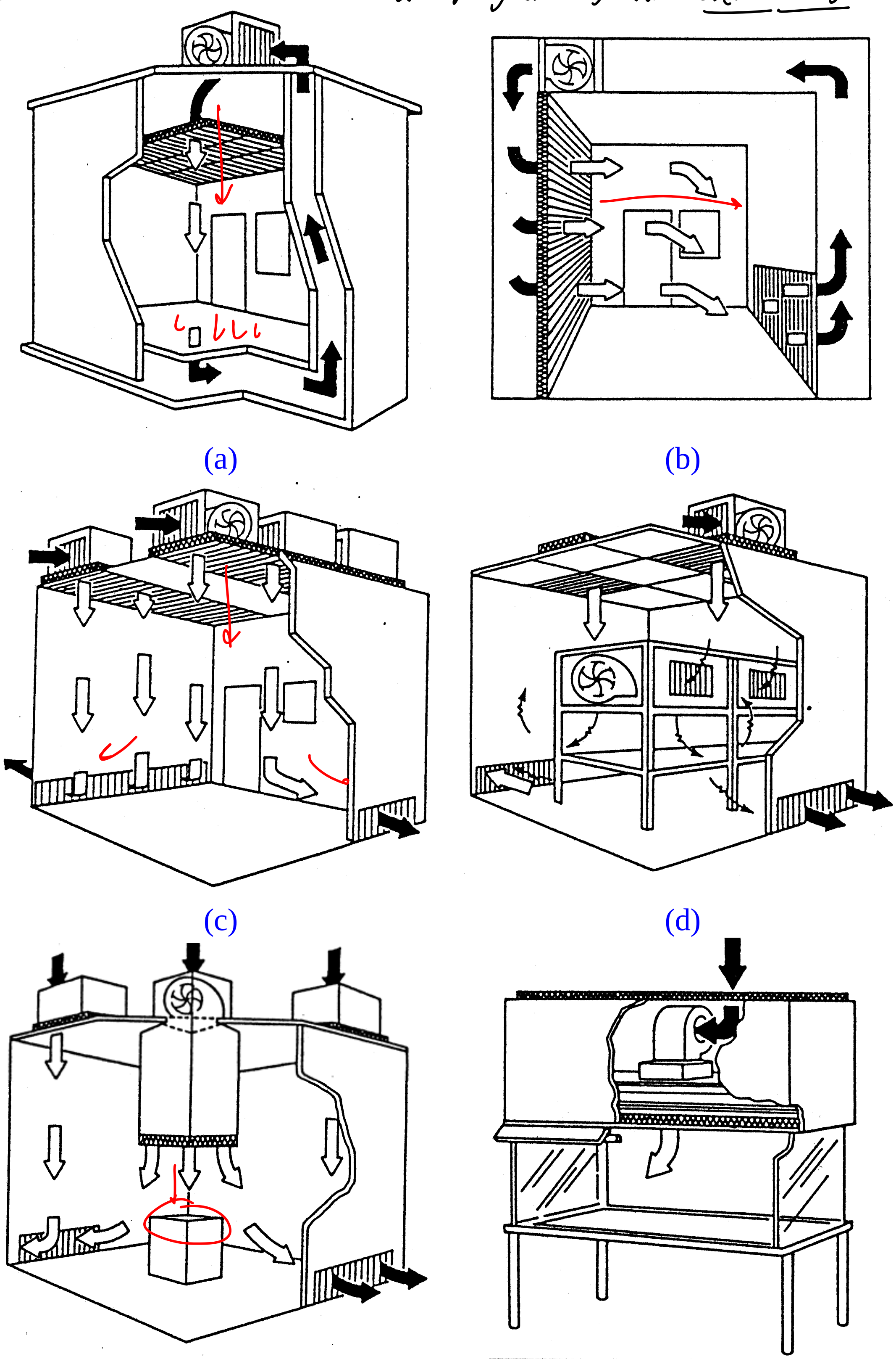
measure C_{ss}

Solve for

$$\eta_{cleaner} = \frac{\frac{S}{C_{ss}} - Q_s - k_w A_s}{Q_{cleaner}}$$

Assuming we know k_w, A_s, S, etc.

Various geometries for clean rooms



(a) (b) (c) (d) (e) (f)

Figure 5.11 Clean rooms: (a) vertical laminar-flow, (b) horizontal laminar-flow, (c) tunnel laminar-flow, (d) tabletop tunnel laminar-flow, (e) island laminar-flow, and (f) unitary work station (miniature) (from Canon Communications, 1987).

Table 5.2 Clean room class limits; maximum permissible c_{number} in English and SI units; **bold** c_{number} indicates number concentration on which the corresponding **bold** class name is based (abstracted from ASHRAE HVAC Applications Handbook, 1999.)

class name		$D_p \geq 0.1\ \mu m$		$D_p \geq 0.2\ \mu m$		$D_p \geq 0.5\ \mu m$		$D_p \geq 5\ \mu m$	
SI	English	$\#/m^3$	$\#/ft^3$	$\#/m^3$	$\#/ft^3$	$\#/m^3$	$\#/ft^3$	$\#/m^3$	$\#/ft^3$
M1		350	9.9	75.0	2.14	$\mathbf{10^1}$	0.283	-	-
M1.5	**1**	1240	35	265	7.5	35.3	**1**	-	-
M2		3500	99.1	757	21.4	$\mathbf{10^2}$	2.83	-	-
M2.5	**10**	12400	350	2650	75.0	353	**10**	-	-
M3		35000	991	7570	214	$\mathbf{10^3}$	28.3	-	-
M3.5	**100**	-	-	26500	750	3530	**100**	-	-
M4		-	-	75700	2140	$\mathbf{10^4}$	283	-	-
M4.5	**1000**	-	-	-	-	35300	**1000**	247	7.00
M5		-	-	-	-	$\mathbf{10^5}$	2830	618	17.5
M5.5	**10000**	-	-	-	-	353000	**10000**	2470	70.0
M6		-	-	-	-	$\mathbf{10^6}$	28300	6180	175
M6.5	**100000**	-	-	-	-	3530000	**100000**	24700	700
M7		-	-	-	-	$\mathbf{10^7}$	283000	61800	1750

CLASS 1 clean room | 1 particle/ft^3 @ $D_p \geq 0.5\ \mu m$ (English units)

Metric classes are based on exponent of 10^x

Major distinction of a clean room:

→ designed to protect a product

whereas general ventilation is designed to protect people

Clean room requirements are very strict:

- temperature
- humidity
- static electricity
- concentration of vapors & particles

Introduce terminology

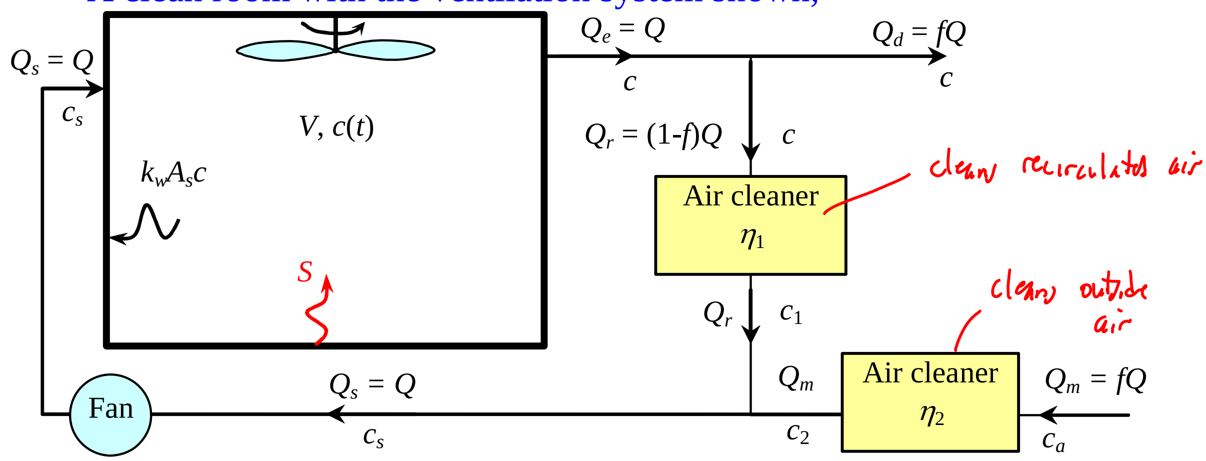
HEPA = "high efficiency particulate air" filter

ULPA = "ultra low penetration air" filter

(See text for definitions)

Example (Example 5.10 in text – Time to Achieve Clean Room Conditions)

Given: A clean room with the ventilation system shown,



and with the following specifications:

- η_1 = 98.%, η_2 = 98.% (air cleaner efficiencies)
- f = 0.050 (fresh make-up air fraction)
- c_a = 10^3 particles/m^3 (particle concentration in the ambient make-up air)
- → D_p = 1.0 µm (particle size of concern)
- Q_s = 20. m^3/min (supply ventilation rate into the clean room) HUGE
- S = 300 particles/min (particle emission rate within the clean room)
- V = 300 m^3 (volume of the clean room)
- A_s = 320 m^2 (total surface area of the clean room)
- k_w = 0.030 m/min (wall loss coefficient)
- $c(0)$ = 10^5 particles/m^3 (initial particle concentration within the clean room)

To do: Calculate how long it will take to achieve class 10,000, 1,000, 100, 10, and 1.

Solution:

Calc. C_{max} for 1 µm particles for each class
(interpolate from the above table)

Class	C_{max} particles/m^3 for D_p = 1.0 µm
10,000	74,000
1,000	7,400
100	740
10	74
X cannot achieve → 1	7.4 (Best we can do is 10.7)

} Max. allowable particle number concentration for each class of clean room

Eq. for the room ventilation:

$$\frac{dc}{dt} = B - Ac$$

Same as previous example

$$A = \frac{Q_s + k_w A_s + Q_s(1-f)(1-n_1)}{\forall} \qquad B = \frac{S + Q_s C_a f(1-n_2)}{\forall}$$

$$A = 0.0999 \ \frac{1}{\text{min}} \qquad B = 1.07 \ \frac{\text{particles}}{\text{min} \cdot m^3}$$

$$C_{ss} = \frac{B}{A} = \frac{1.07 \ \frac{\text{part.}}{\text{min}\ m^3}}{0.0999 \ \frac{1}{\text{min}}} = 10.7 \ \frac{\text{particles}}{m^3}$$

→ Best we can possibly do with these conditions ☆

Recall, for constant coefficients, 1st-order ODE

$$t = -\frac{1}{A} \ln\left[\frac{C_{ss} - C(t)}{C_{ss} - C(0)}\right]$$

Plug in the value from the table above (for $C(t)$)

Results:

class	time required (minutes)
10,000	3.0
1,000	26.
100	49.
10	74.
1	∞

Cannot achieve class 1

Note: we are actually using $C_{number} = \frac{\#\ \text{particles}}{\text{vol}}$ → number concentration instead of mass concentration

SEC. 5.12 – INFILTRATION

SEE EXAMPLE 5.11 → Professor's office

Great review problem for a dark, rainy night!