Today, we will:

- ***Note***: Skip **Sec. 5.11**
- Discuss **Mean Age and Ventilation Effectiveness** in **Section 5.12**
- Discuss **Make-up Air Operating Costs** in **Section 5.13**
- Do an example problem – Make-up air operating costs
- ~~If time, begin to discuss **Tunnel Ventilation** in **Section 5.14**~~ (NO TIME)
- Do Candy Questions for Candy Friday

SEC 5.12 Mean Age & Ventilation Effectiveness

[Useful concepts in the HVAC industry]

Define (A LOCAL PARAMETER)

$$e \equiv \text{effectiveness coefficient} = \frac{t_N}{t_{age,P}}$$

P = some point (location in the room)

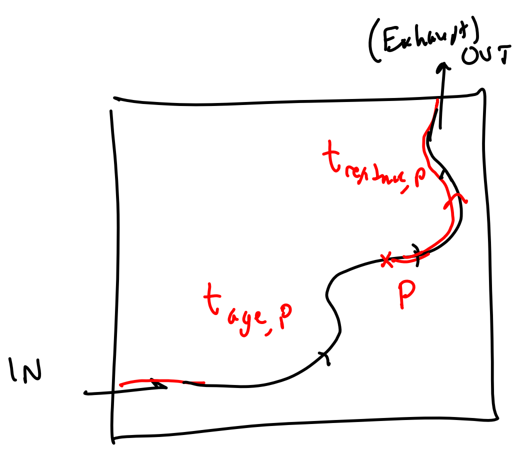
(avg. over room) t_N = avg. residence time in the room of a fluid particle

N = # room air changes

$N = Q/\forall$

$$t_N = \frac{1}{N} = \frac{\forall}{Q}$$

(local @ one pt) $t_{age,P}$ = local mean age ≡ time for a fluid particle entering the room to reach point P



$t_{residence,P}$ = time to go from P to the exhaust

Typically we helium soap bubbles to measure these times

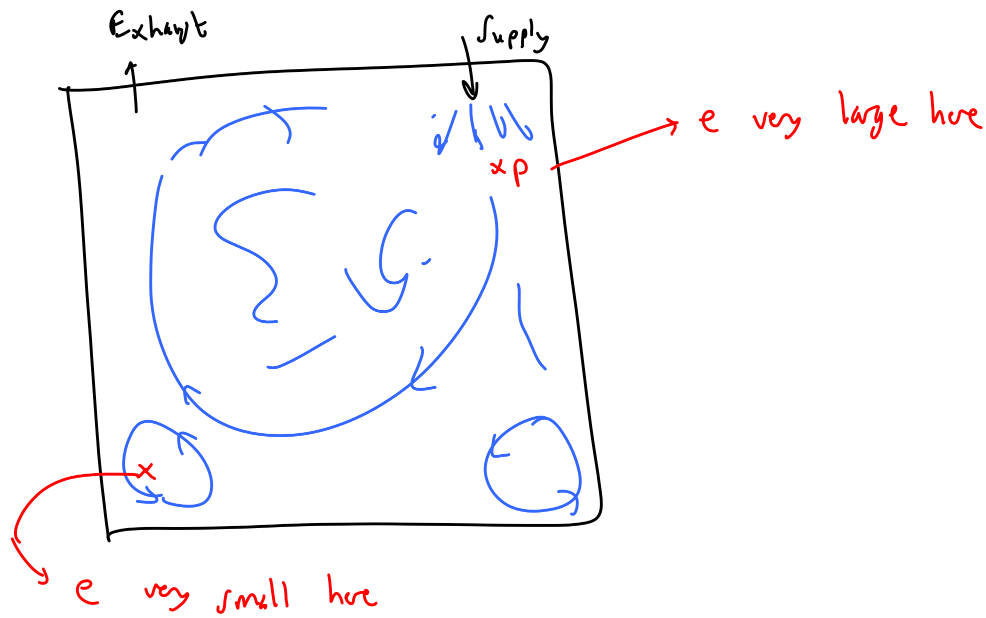
e tells us how well the air is mixed or "changed" @ a point

If $e = 1$ $(t_{age,p} = t_N)$ → Mixing at that point is the same as what it would be for a perfectly well-mixed room.

If $e < 1$ $(t_{age,p} > t_N)$ → slower response time
→ poor mixing at that point

If $e > 1$ → fast response time
→ good or vigorous mixing at that point

E.g.

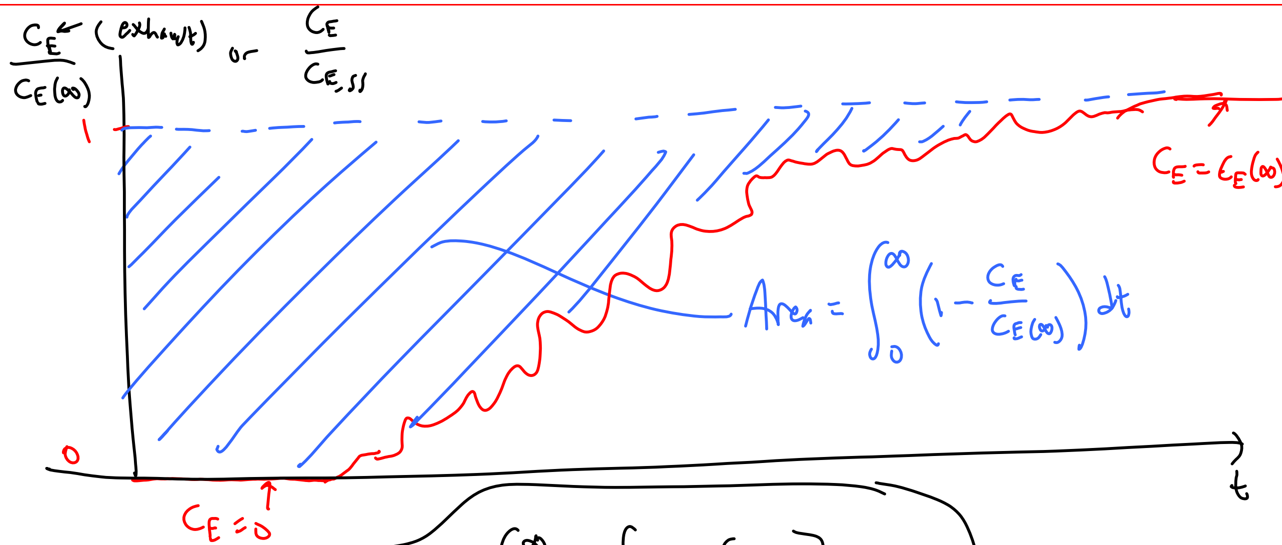


Room mean age $t_{room, avg}$

Use the exhaust location (E) as our point instead of P

$t_{room,age}$ = room-averaged over the whole room → it is a global property, not a local property

"Step-up Tracer Experiment"
- start with clean air @ $t=0$
- @ $t=0$ inject a tracer gas (usually SF_6) @ a steady rate into the supply air



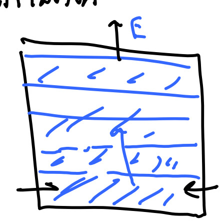
Define
$$t_{room,avg} = \frac{\int_0^\infty t\left[1 - \frac{C_E}{C_E(\infty)}\right]dt}{\int_0^\infty \left[1 - \frac{C_E}{C_E(\infty)}\right]dt}$$
= room mean age

Define:
$$e_{room} = \frac{t_N}{t_{room,avg}}$$
= room ventilation effectiveness coefficient ✪

A GLOBAL PARAMETER

$t_N = \frac{1}{N} = \frac{\forall}{Q}$

Example: Given: A room with ideal displacement ventilation



To do: calculate e_{room}

Sol'n:

$$t_{room,avg} = \frac{\int_0^\infty t\left[1 - \frac{C_E}{C_E(\infty)}\right]dt}{\int_0^\infty \left[1 - \frac{C_E}{C_E(\infty)}\right]dt} = \frac{t_N}{2}$$

$\frac{C_E}{C_E(\infty)}$ = 0 for $t < t_N$
= 1 $t > t_N$

$$\therefore e_{room} = \frac{t_N}{t_{room,avg}} = 2$$

It turns out that $\boxed{0 < e_{room} < 2}$

$e_{room} = 1$ for perfectly well-mixed ventilation (dilution vent.) — rapid mixing

$e_{room} = 2$ for ideal displacement ventilation (no mixing)

$1 < e_{room} < 2$ for performance between ideal disp. & dilution ventilation

So → e_{room} is kind of "efficiency" for the ventilation except for the factor of 2

See examples in book

SEC 5.13 Make-up Air Operating Cost

- Make-up air costs $! [needs to be heated or cooled]
  - high IAQ means large make-up air (Q_m)
  - high energy efficiency (low cost) means small Q_m

  } conflict

HVAC engineers & meteorologists use:

Heating Degree Days	DD_h
& Cooling Degree Days	DD_c

For a given city

For one day, calculate the avg. outdoor temperature

$\overline{T}_{outdoor}$ e.g. say 55° F

· Define T_{bal} = balance pt. temperature

↳ if $\overline{T_{outdoor}} > T_{bal}$ → need A/C

if $\overline{T_{outdoor}} < T_{bal}$ → need heat

Standard value of $T_{bal} = 65°F$

$$DD_h = (1\ day) \sum_{365\ days} \left(T_{bal} - \overline{T_{outdoor}} \right)^{+}$$

(+) counting only when positive

State College $DD_h \cong 6500$ °F-days

Heating season = July 1 to June 30 (one yr.)

Cooling season = Jan 1 to Dec 31 (one yr.)

DD_h or DD_c are published in newspapers each day

CDT → Oct 15 is the switch day

EXAMPLE: Given: · My house

· $\forall = 20{,}000\ ft^3$

· Assume 1 air change / hr

· Electric heat @ \$0.08 / kWh

To do: Estimate my yearly heating cost

Soln: $N = \frac{Q}{\forall} = \frac{1}{1\ hr} \rightarrow Q = Q_m = N \cdot \forall = 333.33$ CFM

Eq 5-70:

$$C_{ost}(\$) = 0.154 \frac{DD_h \; t_{operating} \; C_{fu} \; Q}{q_{fu}}$$

$DD_h \approx 6500$ °F·days

$t_{operating}$ = operating hours / week = 24×7 = 168

C_{fu} = unit fuel cost = \$0.08/kWhr

Q = 333.33 CFM

q_{fu} = available energy per unit of fuel

Table 5.6 → q_{fu} = 3415 Btu/kWh for elec. heat

C_{ost} = \$1,313 ≃ **\$1300**

[Actually, I have a geothermal heat pump with a coefficient of performance (COP) of about 3.]

So – I pay only about 1/3 of this amount to heat my house.