Today, we will:

- Do an example problem – heating degree days and estimate heating cost
- Begin to discuss **tunnel ventilation**

**Example: Heating cost for make-up air**

**Given:**
- My house \( V = 29000 \text{ ft}^3 \)
- Assume 1 air exchange per hour (natural infiltration)
- Electric heat @ \( \$0.08/\text{kWh} \)

**To do:** Estimate yearly cost \((\$)\) to heat due to make-up air

**Solution:**

\[
N = \frac{Q}{V} = \frac{1}{hr} \\
Q = N \cdot V = \left( \frac{1}{hr} \right) \left( 29000 \text{ ft}^3 \right) \left( \frac{1 \text{ hr}}{60 \text{ min}} \right)
\]

\[
Q = 333.33 \text{ CFM} \left[ \frac{\text{ft}^3}{\text{min}} \right] \text{ACFM}
\]

**DDh for a year in Stcht Calvys = 6000 °F day**

\[
24 \times 7 = 168 \frac{\text{hr}}{\text{week}}
\]

**Cost**

\[
\text{Cost} = 0.154 \times 6000 \times 8.6 = 7200 \text{ annual cost for make-up air only}
\]

I have geothermal heating \( \text{sys.} \rightarrow \text{COP} \approx 4 \) → My cost is actually \( \$300 \)
TUNNEL VENTILATION (Sec 5.14)

- Usually automobile tunnel only
- Concentrate on CO pollution from car exhaust - $S$ very large
- Drivers → not contained if CO level > PEL
  (not in the tunnel key)
- However → Concern for workers (OSHA) → CO level must < PEL
- Concern for traffic jam

$\text{collisions} + \text{fire} \rightarrow S \text{ very huge}$

There are emergency fan for this case

We will talk only about normal tunnel operation

(See video on website)

CLASSIFICATION OF TUNNELS

1) Natural ventilation - good for short tunnels only $L \leq 300 \text{ m}$

Consider one-way traffic only

$U(0) \leftarrow L \rightarrow U(L) = U(0)$

$U = \text{constant} \times x$

$U = U(0)$
2) **Local Make-up Air Ventilation**

Blow in additional air near tunnel entrance

Same as natural case except $U(t)$ is bigger

Good to $L \leq 600$ m
3) Uniform make-up air ventilation (also called no-exhaust ventilation)

Distribute extra air uniformly

\[ U(x=L) \gg U_0 \text{ at } x=0 \text{ (entrance)} \]

\[ U = u(x) \text{ not constant} \]

\[ \frac{C}{C_{max}} \]

Good to \( L \leq 1500 \text{ m} \)

\[ (\text{limit to avoid } U \text{ getting too big}) \]
4) Transverse Ventilation

Have distributed supply (make-up air) and exhaust air.

- Exhaust plenum
- Top in ceiling
- Supply plenum (typically in side walls)
- Supply fresh air

$Q_e = Q_m$

- No limit to $L$ for this kind of tunnel

Balanced Transverse Ventilation

For this case, $U = \text{constant} = U(0)$

You set a 1st-order ODE in $x$. 
ANALYSIS For Balanced case

\[ S = \text{one of } (EF)_c \rightarrow \frac{mg}{\text{Car-Km}} \]

EPA reg's \(ightarrow 1990\), for CO limit was \(9 \text{ gram CO/mile-car}\)

\((EF)_c \approx 5600 \text{ mg/car-km}\)

*Recent EPA reg's \(ightarrow 3.4 \text{ gram CO/mile-car}\)

\((EF)_c \approx 2100 \text{ mg/car-km}\)

\[ S = (EF)_c \cdot n_c \cdot V_c \cdot L \]

= Source Strength

\[ \left[ \frac{\text{mg}}{\text{hr}} \right] = \left[ \frac{9}{\text{car-km}} \right] \text{ traffic density} \cdot \text{avg car speed} \cdot \text{road length} \]

or \[ \left[ \frac{\text{mg}}{\text{hr}} \right] = \left[ \frac{\text{mg}}{\text{km}} \right] \]
Note: In a traffic jam, \( V_c = 0 \) (avg. car speed).

But \( S' \neq 0 \)!

\[ S' = (EF)_{c, \text{jam}} N_c L \]

must use a different \( EF \)

\[ \frac{g}{\text{Mile} \cdot \text{car}} = (EF)_{c, \text{jam}} \]

\[ \frac{g}{\text{hr} \cdot \text{car}} = (EF)_{c, \text{jam}} \]