Indoor Air and Air Exchange Rates

The air exchange rate (sometimes referred to as the number of air changes per hour “ach”) is a first order rate constant \( k_e \) for the ventilation of indoor air. It is related to the indoor air residence time \( \tau_e \) as \( k_e = \frac{1}{\tau_e} \).

Taking into account air exchange processes only (i.e., no chemical loss mechanisms);

\[
\text{Rate of infiltration of an outdoor contaminant} = \frac{d[X]}{dt} = k_e [X]_{\text{outside}}
\]

\[
\text{Rate of ventilation of an indoor contaminant} = \frac{d[X]}{dt} = -k_e [X]_{\text{inside}}
\]

Taking into account both infiltration from outdoor sources and ventilation of indoor sources, the net rate of accumulation of a contaminant inside is given by;

\[
\text{Rate} = \frac{d[X]}{dt} = k_e [X]_{\text{outside}} - k_e [X]_{\text{inside}}
\]

The integrated form of the rate equation is given by;

\[
\ln ([X]_o - [X]_i) = -k_e t + \text{Constant}
\]

At steady state, \( \text{Rate in} = \text{Rate out} \)

\[
\text{Rate in} = k_e [X]_{\text{outside}} + \text{Rate of emission from an internal source}
\]

and, assuming no chemical loss;

\[
\text{Rate out} = k_e [X]_{\text{inside}}
\]

Hence, at steady state;

\[
k_e [X]_{\text{inside}} = k_e [X]_{\text{outside}} + \text{Rate of emission from an internal source}
\]
1. An open fire in a well ventilated home produces VOCs at a rate of 30 mg m\(^{-3}\) h\(^{-1}\). A complete exchange of air takes place every 5 minutes. The ambient outdoor air concentration of VOCs is 75 µg m\(^{-3}\). Calculate the steady state indoor concentration of VOCs from this source assuming no chemical loss mechanisms.

\[ \text{Answer} = 2.6 \text{ mg m}^{-3} \]
2. In some rural communities, heating and cooking are often done with open fires. If the rate of emission of PAHs from indoor combustion is 3.5 ng m\(^{-3}\) h\(^{-1}\) and the outdoor concentration of PAHs is 0.60 ng m\(^{-3}\), estimate the steady state indoor air concentration of PAH compounds if the air exchange rate is 2 h\(^{-1}\). Assume that the only loss mechanism is by air exchange.

\[ \text{Answer} = 2.4 \text{ ng m}^{-3} \]
3. A one compartment home of volume 330 m$^3$ has an infiltration rate of 0.25 ach with doors and windows closed. During an episode of photochemical smog, the outdoor concentration of PAN is 85 ppbv. If the family remains indoors and the initial concentration of PAN inside is 18 ppbv, how long will it take before the PAN concentration inside rises to 45 ppbv.

[Answer = 2.0 hr]
4. A mobile home has a volume of 100 m$^3$ and a ventilation rate of 0.28 ach. If the concentration of formaldehyde in the home has reached a steady state concentration of 11 ppmv, what is the rate of emission of formaldehyde from the materials in the home in mg per hour?

$[Answer = 38 \text{ mg h}^{-1}]$