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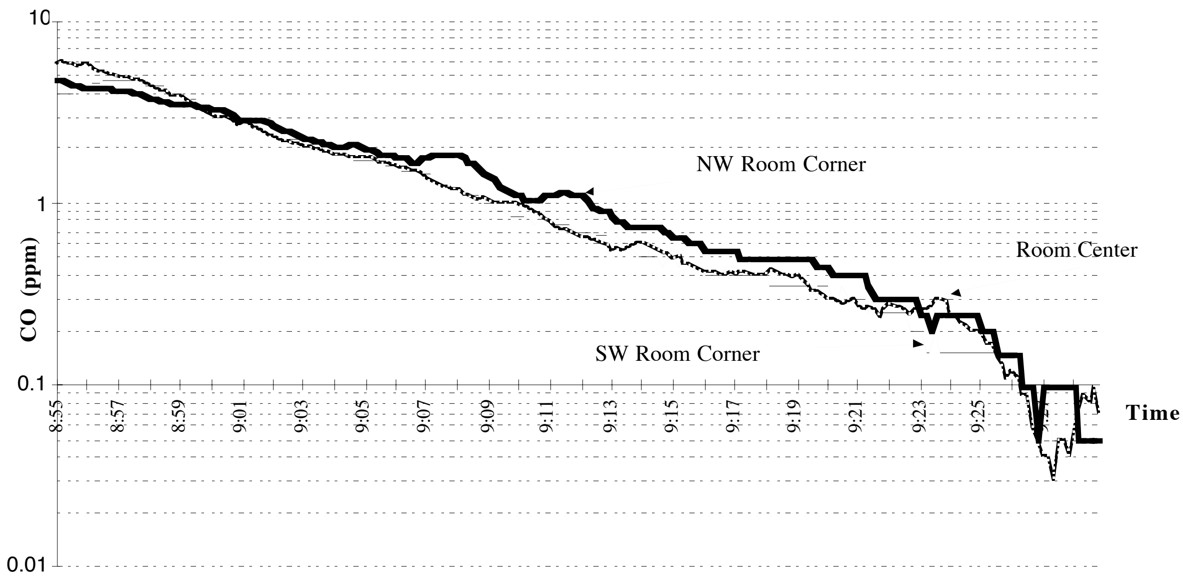
* Ott, Wayne; Switzer, Paul; Robinson, John (1996): "Particle Concentrations Inside a Tavern Before and After Prohibition of Smoking: Evaluating the Performance of an Indoor Air Quality Model". Journal of Air & Waste Management Association, Vol. 46: 1120-1134, December.



The decay of CO measured using Langan Measurers at three locations within the `Oasis', a drinking and eating establishment long known to Stanford people. These data show the volume of air equal to the entire tavern (521 cubic meters) was replaced every eight minutes, an air exchange rate of 7.5 air changes each hour (ach)..*

Ventilation Rates — From CO Measurements

Bear Facts -- #74

How frequently the air in a given space is replaced may often determine how healthy, or at least how fresh, the space can be maintained.
It has been complicated to measure this, until now.

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the DataBear

Keeping in Touch!

People who concern themselves about the ventilation of a given space, concern themselves about the 'air exchange rate' or 'air changes per hour' (ach), the time it takes for the total volume of air in a given space to be replaced. Some prefer to think of this as the period of retention or 'residence time' (1/ach). It is better to measure than to guess 'ach', an important factor in modeling the pollutant content of indoor space.

The mathematics below establish the rationale for calculating ach. It shows that, once a source of measurable material ceases to add concentation to a room or group of rooms-- any space-- the concentation of this source will decay exponentially over time. It is reduced to background levels, as the air is replaced. The rate of exponential decay is shown as a straight line on a natural logrithmic plot. Indeed, using a spreadsheet, one can refine the observation by calculating the least squares fit to this decay. The slope of this decay *is* ach!

Carbon monoxide, because of its chemical stability and availability can be a useful species to measure a source and subsequent decay. The Langan High Resolution CO Measurer can record the concentration of CO. A source of CO may be an available combustion appliance, a canister of gas or even a cigar (as used for CO in figure on reverse side)! These are quite simple tools for making an accurate measure of ventilation.

The Mathematics of Ventilation Rates

Considering mass balance and given Q_{in}, the total amount of pollutant (mass) entering a room over time, and Q_{out}, the total amount of pollutant leaving a room over time, then the quantity of pollutant in a room, Q_{room}, is

1) $$Q_{in} - Q_{out} = Q_{room}$$

Assume the pollutant is equally distributed throughout the room. It is then equal to the concentration in the room (C_{room}) times the room's volume (V), where C_{room} will be everywhere the same, and

2) $$Q_{in} - Q_{out} = C_{room}V$$

Now, if W is the flow rate of air in volume per time (cubic meters per minute) over time, the integrals are

3,4) $$Q_{in} = \int_0^T C_{in}W\,dt \quad \text{and} \quad Q_{out} = \int_0^T C_{out}W\,dt$$

Substituting these values for Q_{in}, Q_{out} in Equation 2, and noting that $C_{room} = C_{out}$, because the concentration is evenly distributed within the room, we obtain

5) $$\int_0^T C_{in}W\,dt - \int_0^T C_{room}W\,dt = C_{room}V$$

Finally, taking derivatives of all terms, we obtain

6) $$C_{in}W - C_{room}W = \frac{dC_{room}}{dt}V$$

or $$\frac{dC_{room}}{dt}V + C_{room}W = C_{in}W$$

or 7) $$\frac{V}{W}\frac{dC_{room}}{dt} + C_{room} = C_{in}$$

If the input concentration entering the room (from outside or generated within) becomes zero, $C_{in} = 0$. Then multiplying Equation 7 by $\frac{dt}{C_{room}}$ we obtain

8) $$\frac{V}{W}\frac{dC_{room}}{C_{room}} = -dt$$

Then, integrating from the initial condition C_0 at $t = 0$ to concentration, C, at time, T, we obtain

9) $$\frac{V}{W}\int_{C_0}^{C}\frac{dC_{room}}{C_{room}} = -\int_0^T dt$$

By using look-up tables of integrals, and plugging in the limits, we obtain

10,11) $$\int_{C_0}^{C}\frac{dC_{room}}{C_{room}} = \ln C - \ln C_0 \quad \text{and} \quad -\int_0^T dt = -T$$

Thus,

12) $$\frac{V}{W}\ln\left(\frac{C}{C_0}\right) = -T$$

$\frac{W}{V}$ is 'normalized flow rate'. Let $\Phi = \frac{W}{V}$, the air exchange rate, by selecting units as 'volumes' of the measured space. From Equation 12, we get

13) $$\frac{1}{\Phi}\ln\left(\frac{C}{C_0}\right) = -T, \quad \text{because } \frac{V}{W} = \frac{1}{\Phi},$$

which gives an exponential relationship of the measured concentation with respect to time. If we plot the natural log of the concentration ratio, $\ln\left(\frac{C}{C_0}\right)$, vs. time, T, we get a straight line with slope, $-\Phi$.

14) $$\ln\left(\frac{C}{C_0}\right) = -\Phi T \quad \text{or} \quad \boxed{C = C_0 e^{-\Phi T}}$$

[ach derivation courtesy Dr. Wayne R. Ott. See (1995) Environmental Statistics and Data Analysis. Lewis Publishers. CRC Press, Boca Raton, ISBN 0-87371-848-8]

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**Langan CO Instruments provide a direct way to measure ambient air quality.
This Bear Facts shows a very inexpensive and practical way to measure the ventilation in a space of almost any size by monitoring the decay of CO within.
After a hockey game, when smokers leave or when the kitchen closes, a CO source stops!**