VENTILATION FOR CONTROL OF INDOOR AIR QUALITY

William J. Fisk
Building Ventilation and Indoor Air Quality Program
University of California, Lawrence Berkeley Laboratory
Berkeley, California, U.S.A.

Abstract

Ventilation is widely used to help maintain acceptable indoor pollutant concentrations. In this paper, the relationships between ventilation rate and indoor concentration are examined by the use of mass balance models and measured data. It is shown that the pollutant source strength and pollutant removal by processes other than ventilation can have a large impact on the indoor concentration and that maintenance of a typical ventilation rate does not ensure an acceptable indoor concentration. The importance of avoiding unusually low ventilation rates and of minimizing pollutant source strengths is emphasized.

Introduction

Factors that affect indoor pollutant concentrations include: the strength of indoor pollutant sources, the outdoor concentration, ventilation rate, and the rate of pollutant removal by processes other than ventilation. The purpose of this paper is to describe and examine the relationships between ventilation rate and indoor pollutant concentrations and to discuss the implications of these relationships.

Mass Balance Models

Two equations that relate indoor pollutant concentrations and ventilation rate are presented below. They are based on a number of simplifying assumptions including: steady-state conditions, perfectly mixed indoor air, and, except where noted otherwise, no coupling between the ventilation rate and the pollutant source strength. Despite these simplifications, the equations can yield valuable information on the utilization of ventilation to control indoor pollutant concentrations.

The equations, based on a mass balance, must account for all significant pollutant sources and removal mechanisms. Equating the source terms to the removal terms yields an expression for the indoor concentration

$$C_i = (S + a P C_o) / (a + K + \lambda + R) \qquad (1)$$

where:

- S = pollutant source strength per unit volume indoor air,
- a = air exchange rate (i.e., air flow rate/indoor volume),
- P = fraction of outdoor pollutant that penetrates the building envelope or ventilation system,
- C_o = outdoor pollutant concentration,
- K = pollutant removal rate by plate-out on surfaces and chemical reaction per unit volume indoor air,
- λ = pollutant removal rate by radioactive decay, and
- R = pollutant removal rate by air cleaning per unit volume indoor air.

Only limited data are available for the various parameters in Equation 1. Based on experimental data the most significant cause of the wide ranges observed in indoor concentrations appears to be variation in pollutant source strengths. This fact is exemplified in Figures 1 and 2 from references (5) and (12), respectively. For nonreactive gases such as radon, carbon dioxide, and carbon monoxide, the reaction constant K and penetration factor P are essentially zero and unity, respectively. Measured values for nitrogen dioxide, formaldehyde, and particulates are tabulated below.

Table 1. Values for the Reaction Constant and Penetration Factor.

Pollutant	Reaction Constant ± Standard Deviation (h^{-1})	Penetration Factor	Literature Source
nitrogen dioxide	0.18, 0.29		13
nitrogen dioxide	0.20 ± 0.13		12
nitrogen dioxide	1.29 ± 0.67		10
nitrogen dioxide	1.39		2
nitrogen dioxide	0.16 to 0.5		7
nitrogen dioxide	0.83		14
formaldehyde	0.4 ± 0.24	1.0	11
particulates	0.48 ± 0.21 *	0.4	11
particulates	0.03 to 0.35 **		6

* particle diameter < 0.5 um ** function of particle size

Pollutant removal by reaction and plate-out is poorly understood. These removal processes may depend on the nature and quantity of indoor surfaces, the degree of indoor air movement, and the indoor concentration, thus, considerable uncertainty exists regarding the average and range of reaction constants in buildings.

The relationship between ventilation rate and the concentration of radon's short-lived radioactive decay products (radon progeny) is unique. The ventilation rate clearly affects the source strength for radon progeny through its impact on indoor radon concentrations. Also, the total concentration of radon progeny is generally expressed by the potential alpha energy concentration (PAEC) in units of working levels. The PAEC indicates the potential emission of alpha energy from all radon progeny in the air. A mass balance yields the expression, similar to that in (8), for the PAEC

$$PAEC = S_R \lambda_A/[(\lambda_R + a)(\lambda_A + a + K_A)] \times \qquad (2)$$

$$[0.00103 + (\lambda_B/(\lambda_B + a + K_B))(0.00507 + 0.00373 (\lambda_C/(\lambda_C + a + K_C)))]$$

where S_R is the radon source strength in pCi/ ℓ-h), and subscripts R, A, B, and C refer to radon, and radon progeny A, B, and C, respectively (λ_R=0.00758 h^{-1}, λ_A=13.7 h^{-1}, λ_B=1.55 h^{-1}, λ_C=2.11 h^{-1}). The plate-out constants K_A, K_B, and K_C depend highly on the fraction of radon progeny that are attached to airborne particulates which is a function of the indoor particle concentration. Offermann et al (6) give values of K_A=7.8 h^{-1}, K_B=1.8 h^{-1}, and K_C=0.5 h^{-1} for a low indoor particle concentration of 3000 particles/cc and K_A=1.4 h^{-1}, K_B=0.4 h^{-1} and K_C=0 for a high indoor particle concentration of 30,000 particles/cc. A factor not accounted for in Equation 2 is that the indoor particle concentration and, thus, the plate-out constants for radon progeny will generally depend on the ventilation rate.

Ventilation Rate Versus Pollutant Source Strength

The source strengths of radon, formaldehyde, and perhaps other pollutants can be coupled to the ventilation rate, however, the equations presented above do not account for this coupling.

The primary source of radon in buildings with elevated radon concentrations is thought to generally be radon emanating from the soil that is transported into the building through cracks and other openings by pressure driven flow (4). The rates of radon entry and infiltration may both increase with the indoor-outdoor temperature difference since an increased temperature difference causes a greater driving force for infiltration and also a greater depressurization of lower regions within the structure adjacent to openings where radon is likely to enter. Depressurization caused by mechanical exhaust ventilation may have a similar effect on radon source strength although no data are directly available. An example (3) of positive coupling between air infiltration rate and radon source strength is shown in Figure 3.

Coupling between the ventilation rate and the formaldehyde source strength may result from two mechanisms. Ventilation tends to reduce the indoor formaldehyde concentration and it has been shown (1) that the emission rate of formaldehyde from building materials increases significantly as the surrounding formaldehyde concentration is reduced. Ventilation can also affect the indoor humidity and decreased humidity substantially reduces the formaldehyde emission rate (1).

Discussion

Examination of the mass balance models and consideration of the potential coupling between ventilation rate and pollutant source strength indicates that the relationship between ventilation rate and indoor concentration is often complex. Figure 4, generated from the models, illustrates that the rate of pollutant removal by processes other than ventilation (e.g. plate-out) can substantially affect the indoor concentration when ventilation rates are low. At high ventilation rates, however, these removal processes have a small effect on indoor concentration.

The relationships between a change in ventilation rate and a change in indoor concentration are better illustrated in Figure 5. The sensitivity of indoor concentration to air exchange rate is decreased as the rate of removal by processes other than ventilation increases. The PAEC is highly sensitive to the ventilation rate for the case shown of a constant radon source strength. The plate-out rates of radon progeny do not have a great impact on the relationship between a change in concentration and a change in air exchange rate, although, as shown in Figure 4 they may substantially affect the absolute concentration. Included in Figure 5, is a possible relationship (9) between ventilation rate and formaldehyde concentration based on assumptions of a linear increase in formaldehyde source strength with a decrease in the indoor concentration, a constant indoor humidity, and no removal of formaldehyde by chemical reaction. The coupling between formaldehyde source strength and indoor concentration reduces the impact of ventilation.

While the theoretically derived relationships differ substantially, in all cases the indoor concentration increases rapidly as air exchange rates become low. Avoiding unusually low air exchange rates is, therefore, an important component of strategies for maintaining acceptable indoor air quality. Because of the large range in pollutant source strengths, however, maintaining a typical ventilation rate does not ensure low indoor pollutant concentrations. In addition, the energy requirements associated with ventilation make it generally impractical to increase the ventilation rate by more than about one air change per hour and an increase of this magnitude will only have a large impact on indoor concentration when the initial air exchange rate is low. Thus, the strategy of avoiding unusually low ventilation rates should be combined with explicit efforts to minimize pollutant source strengths and, in some instances, attention to pollutant removal processes other than ventilation. Only through attention to each factor that significantly affects indoor concentrations can acceptable indoor air quality be maintained in the most efficient manner.

Acknowledgements

This work was supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

References

(1) Matthews, T.G., et. al. Formaldehyde release from pressed wood products. Proceedings of the 17th International Washington State Univ. Particleboard/Composite Materials Symposium. Pullman, WA., 1983.

(2) Mochandreas, D.J., and Stark, J.W.C. The Geomet indoor-outdoor air pollution model. U.S. Envir. Prot. Agency, EPA-60017-78-106, 1978.

(3) Nazaroff, W.W., Boegel, M.L. and Nero, A.V. Measuring radon source magnitude in residential buildings. University of California, Lawrence Berkeley Laboratory LBL-12484, 1981.

(4) Nazaroff, W.W., and Nero A.V. Transport of radon from soil into residences. To be published in proceedings of the 3rd International Conference on Indoor Air Quality and Climate, Stockholm, Sweden, 1984.

(5) Nero, A.V. et. al. Radon concentrations and infiltration rates measured in conventional and energy-efficient houses. Health Physics, 1983, 45(2), 401-405.

(6) Offermann, F.J., et. al. Control of respirable particles and radon progeny with portable air cleaners. University of California, Lawrence Berkeley Laboratory LBL-12484, 1984.

(7) Ozkaynak, H., et. al. Indoor air quality modeling: compartmental approach with reactive chemistry. Environ. Internat. 1982, 8, 461-472.

(8) Rudnick, S.N., et. al. Effect of plateout, air motion, and dust removal on radon decay product concentration in a simulated residence. Health Physics, 1983, 45(2), 463-470.

(9) Spencer, R.K. et. al. Indoor air quality mitigation strategies. University of California, Lawrence Berkeley Laboratory LBL-16493, 1984.

(10) Traynor, G.W., et. al. The effects of ventilation on residential air pollution due to emissions from a gas-fired range. Environ. Internat. 1982, 8, 447-452.

(11) Traynor, G.W., Anthon, D.W., and Hollowell, C.D. Technique for determining pollutant emissions from a gas-fired range. Atmos. Environ., 1982, 16, 2979-2988.

(12) Traynor, G.W., et. al. Indoor air pollution due to emissions from unvented gas-fired space heaters: a controlled field study. University of California, Lawrence Berkeley Laboratory LBL-15130, 1983.

(13) Traynor, G.W., Apte, M.G., Dillworth, J.F., and Grimsrud, D.T. Indoor air pollution from portable kerosene-fired space heaters. University of California, Lawrence Berkeley Laboratory LBL-15612, 1983.

(14) Wade III, W.A., Cote W.A., and Yocum, J.E. A study of indoor air quality. J. Air Pollution Control Association, 1975, 25, 933-939.

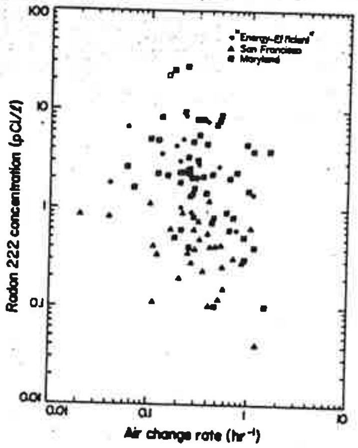

Figure 1. Scatter plot of radon concentration versus air exchange rate.

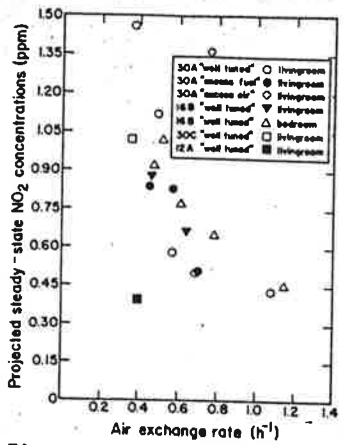

Figure 2. NO_2 concentration versus air exchange rate in a house with various unvented gas-fired heaters.

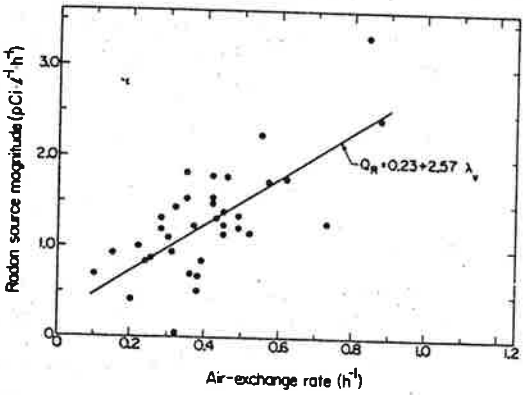

Figure 3. Example of coupling between radon source strength and infiltration rate.

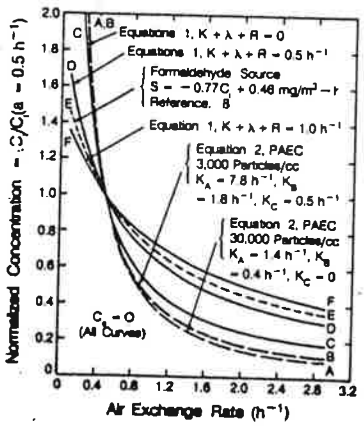

Figure 4. Relative concentration versus air exchange rate for variable pollutant removal by processes other than ventilation

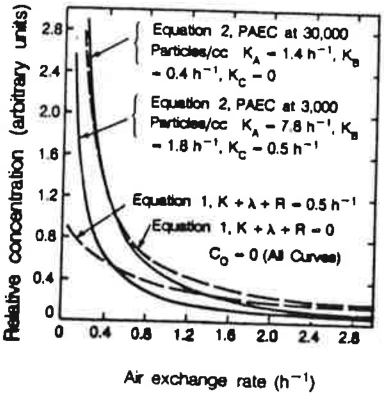

Figure 5. Relationship between a change in indoor concentration and a change in air exchange rate.

Indoc
less gas-f
ly and exp
the incom
depression
ration bec
with the a
gen depres
inversely
acteristic
tion requi
acteristic

There
combustion
of carbon
health eff
concentrat
on the cha
istics of
ression ar

In Ja
heaters bu
utilized.
utilized
are not ye
using port
gases, eve
or other c

Hygie
type are w
1900s (3).
lation to