IMPACT OF REDUCED INFILTRATION AND VENTILATION ON INDOOR AIR QUALITY IN RESIDENTIAL BUILDINGS

Hollowell, Craig D.

1978-11-01

To be presented at the ASHRAE Symposium on
Air Infiltration, Philadelphia, January 1979.

LBL-8470 c.2
EEB-Vent 78-6

Energy and Environment Division

Impact of Reduced Infiltration and Ventilation on Indoor Air Quality in Residential Buildings

Craig D. Hollowell, James V. Berk,
and Gregory W. Traynor

November 1978

Lawrence Berkeley Laboratory University of California/Berkeley

Prepared for the U.S. Department of Energy under Contract No. W-7405-ENG-48

For Presentation at: ASHRAE Symposium on Air Infiltration,
Philadelphia, January, 1979

LBL-8470
EEB-Vent 78-6

IMPACT OF REDUCED INFILTRATION AND VENTILATION ON INDOOR AIR QUALITY IN RESIDENTIAL BUILDINGS*

Craig D. Hollowell, James V. Berk,
and Gregory W. Traynor

Energy Efficient Buildings Program
Energy and Environment Division
Lawrence Berkeley Laboratory
Berkeley, California 94720

November, 1978

Abstract

The levels of air contaminants inside buildings are often higher than ambient outdoor levels. Interest in conserving energy has been motivating home-owners and builders to reduce infiltration rates in residential buildings and builders to reduce ventilation rates in institutional and commercial buildings. However, the resulting decrease of indoor/outdoor air exchange will tend to increase the concentration of many indoor air pollutants. Three indoor contaminants - nitrogen dioxide from gas stoves, formaldehyde from particleboard and urea-formaldehyde foam insulation, and radon from various building materials - are currently receiving considerable attention in the context of the potential health risks that are associated with reduced infiltration and ventilation rates. It is likely that some increased health risk will accompany an increase in indoor contaminant exposure; hence, it is desirable not to allow these concentrations to rise above human tolerance levels. There are several possible ways of circumventing increased health risks without compromising energy conservation considerations.

* The work described in this report is funded by the Department of Energy, Office of Assistant Secretary for Conservation and Solar Applications, Division of Buildings and Community Systems and the Office of Assistant Secretary for Environment, Division of Biomedical and Environmental Research.

INTRODUCTION

Reduced infiltration and ventilation rates in buildings, proposed as important energy conservation measures, can lead to elevated levels of indoor-generated air contaminants. Chemical and biological contaminants released into indoor environments are undesirable but often unavoidable byproducts of human activity and from the use of building materials and furnishings within closed spaces. Typical indoor contaminants include gaseous and particulate pollutants from indoor combustion processes (such as cooking, heating, tobacco smoking), toxic chemicals and odors from cooking and cleaning activities, odors and viable microorganisms from humans, odor-masking chemicals used in several activities, and a wide assortment of chemicals released from indoor construction materials and furnishings. Table 1 lists some of the major indoor air pollutants and their sources in residential buildings.

When these contaminants are generated in indoor environments in excessive concentrations, they may impair the health, safety, or comfort of the occupants. The random introduction of outdoor air by infiltration (through cracks in the building envelope), or its regulated introduction by natural ventilation (opening doors and windows) or mechanical ventilation (fan and duct systems of varying complexity), is the usual way in which building occupants are protected from the accumulation of undesirable indoor air contaminants. The primary engineering control for the maintenance of indoor air quality is ventilation, i.e., the use of controlled flows of air to lower the levels of air contaminants by 1) dilution with fresh outside air; 2) the use of recirculation systems incorporating chemical and physical contaminant control devices; or 3) a combination system employing both dilution and recirculation.

Ventilation with outside air or recirculated air serves a variety of purposes. Among these are:

1) Establishment of a satisfactory balance between the metabolic gases (oxygen and carbon dioxide) in the occupied environment.

2) Dilution of contaminating toxic chemical and biological species from indoor sources.

3) Dilution of human and nonhuman odors to levels below an acceptable olfactory threshold.

4) Removal of heat and moisture generated by internal sources.

In recent years, there have been several reasons for a closer analysis of the use of ventilation in buildings. Studies of outdoor air pollution, indicating that under certain circumstances "fresh" outdoor air may be more contaminated than indoor air, has motivated an examination of the quality and use of outside air for building ventilation. Outside air may be unpleasant or even dangerous; and for this reason, exclusion, reduction, or treatment of outside

---

Craig D. Hollowell, James V. Berk and Gregory W. Traynor are Staff Research Scientists with the Ventilation Program, Energy and Environment Division, Lawrence Berkeley Laboratory, Berkeley, California.

air are options which must sometimes be considered. Another important factor which has directed our attention to ventilation is energy conservation. When indoor air is heated or cooled, simply exhausting this air for ventilation purposes represents a major energy loss, suggesting that reduced ventilation rates could provide considerable energy savings.

Developments during the past several years concerning the limited quantity and availability of conventional energy resources have necessitated an examination of energy consumption and ways of reducing it. It is clear that the United States has entered a period in which increasing attention will be devoted to discovering new methods of conserving energy. Because of this increased energy conservation awareness, measures are being taken to make buildings more energy efficient. These include "tightening up" the building envelope to reduce exfiltration and infiltration, improving insulation, and reducing ventilation. As these measures are implemented and less fresh air is introduced into buildings, the quality of the indoor air may decrease.

Unfortunately, the level of fresh air required for the health, safety, and comfort of building occupants is not widely agreed upon. Ventilation standards currently employed in the United States may vary by as much as a factor of five for the same type of space, depending on local code and building use. Ventilation standards for buildings with different functional uses have been in existence for over half a century. They are generally conservative and, since they have been established by a variety of groups, they frequently vary for the same application. A comprehensive effort is now underway in several laboratories in the United States and Europe to establish a scientific basis for all such existing standards, to measure the actual levels of indoor air contaminants in several classes of buildings, and to provide a consistent set of recommendations for the establishment of energy efficient ventilation standards in residential, institutional and commercial buildings.

The ultimate objective is to reduce energy consumption as much as possible without impairing the health and comfort of the occupants. At the present time, there are major gaps in the understanding of what positive steps must be taken to assure good air quality in buildings. These gaps are due in large measure to the complex biological, chemical, and physical nature of air pollution. In particular, the complex mix of indoor air pollutants has only very recently been recognized. Most studies of indoor air pollution have largely assumed that indoor pollution arises from and is directly related to outdoor sources. Such studies have been concerned mainly with SO_2, O_3, CO, and total suspended particulate matter. They have found in general that the concentrations of these species in indoor air are lower than in outdoor air. Surprisingly little work has been concerned with other potentially important indoor air pollutant species, such as NO, NO_2, organics, and the respirable fraction of the particulate matter. Furthermore, a number of air contaminant sources exist within buildings which can be traced to the built environment itself. These sources and their emissions have, until quite recently, been neglected in most indoor air pollution studies.

The following discussion highlights three indoor-generated contaminants of particular concern in residential buildings: nitrogen dioxide (NO_2), formaldehyde (HCHO), and radon (Rn). The health risks posed by exposure to these contaminants in conventional residential buildings, as well as the added risks engendered by pursuing various strategies of reduced infiltration and ventilation is discussed.

DISCUSSION

Gas Stove Emissions: Nitrogen Dioxide and Carbon Monoxide

Several recent field and laboratory studies at various laboratories have focused on combustion-generated indoor air pollution, namely air contaminants from gas stoves and heating systems in residential buildings. Field studies have shown that levels of carbon monoxide (CO) and nitrogen dioxide (NO_2) approach or exceed existing U.S. ambient outside air quality standards in some residential buildings with gas appliances.[1] Nitrogen dioxide levels in kitchens of houses with gas stoves were observed to be as high as 0.5 ppm with one top burner operating for less than 30 minutes and as high as 0.8 ppm with the oven operating for 20 minutes. Concentrations of NO_2 were observed to be as high as 0.6 ppm for 8 hours in the bedroom of a house with a forced-air gas-fired heating system operating under normal conditions. These NO_2 concentrations can be compared with the short-term U.S. and foreign NO_2 ambient outside air quality standards shown in Table 2 ($\sim$0.2 ppm for 1 hour).[2-5]

Studies using an experimental room with a volume of 800 ft^3 (27 m^3) have characterized the emissions from a new gas stove operating in the room with air exchange rates from 1/4 to 10 air changes per hour (ach).[6] These laboratory studies have shown that gas stoves generate extremely high emissions of such species as CO, NO, NO_2, and respirable aerosols (size <2.5 μm), and that the concentrations of these species become significant when the air exchange rate is controlled to less than 1 ach. Figures 1 and 2 illustrate the levels of CO and NO_2 observed in the experimental room at various ventilation rates ranging from 0.24 to 7.0 ach. These experiments were conducted with the oven of the gas stove operated at 350°F (~180°C) for one hour. It can be seen that the CO concentration exceeds the 1-hour ambient outside air quality standard only under "tight" conditions; but the NO_2 concentration exceeds the recommended 1-hour standard, even with an air exchange rate as high as 2.5 ach. Table 3 gives the one-hour average NO_2 concentrations in the experimental room. The ASHRAE ventilation requirements[7] for residential buildings are given in Table 4. Particularly noteworthy is the observation that a kitchen ventilation rate of 50 cfm (the upper limit of the recommended column of ASHRAE Standard 62-73) results in an NO_2 concentration of 0.4 ppm/hour or higher, a value considerably higher than the promulgated standards. Lower ventilation rates result in even higher NO_2 concentrations.

An assessment of the potential health impact of gas stove emissions under low ventilation rates is now in progress at the Lawrence Berkeley Laboratory. A recent study in England[8] has reported that 2554 children living in homes in which natural gas was used for cooking had a greater incidence of respiratory illness than did 3204 children from homes in which electric stoves were used. In this study, the analysis of collected data took into account age, social class, local meteorology, population density, family size, crowding in the home, outdoor levels of smoke and sulfur dioxide, and the home heating fuel type. Smoking habits of parents were not considered in the analysis, but known relationships between smoking and social class were believed by the authors to negate at least some of the potential bias from this source. The prevalence of bronchitis in homes using gas stoves was 5.7 and 4.7 percent for boys and girls respectively. The prevalence in homes with electric stoves was 3.1 and 2.0 percent respectively. Smaller but still statistically significant increases in "day or night cough," "morning cough," and "colds going to chest" were found for both boys and girls living in homes with gas stoves. The investigators concluded that elevated levels of nitrogen dioxide from gas stoves might have caused the increased levels of respiratory illness.

The field and laboratory measurements carried out thus far certainly indicate a potential impact of combustion-generated indoor air pollution on human health; and if borne out by further work, they may ultimately have a large impact on energy conservation strategies for buildings and on the need for more stringent control of air pollution from indoor combustion sources.

Formaldehyde

Formaldehyde (HCHO) is an inexpensive, high volume chemical which is used throughout the world in a variety of products, mainly in urea, phenolic, melamine and acetal resins. These resins are used in large quantities in building materials such as insulation, particleboard, plywood, textiles, adhesives, etc.

Formaldehyde has a pungent and characteristic odor which can be detected at levels well below 1 ppm by most humans. Formaldehyde toxicity is evidenced on contact with the skin and the mucous membranes of the eyes, nose and throat. Exposure to formaldehyde may cause burning of the eyes, weeping, and irritation of the upper respiratory passages. High concentrations (>few ppm) may produce coughing, constriction in the chest, and a sense of pressure in the head. Several studies reported in the literature indicate that swelling of the mucous membranes begins in the range of 0.05 and 0.1 ppm, depending on individual sensitivity and environmental conditions (temperature, humidity, etc.). Reviews of the disease effects of formaldehyde are given in a recent EPA report,[9] work reported in Denmark,[10] and recent studies carried out in Sweden.[11,12] Various recommended and promulgated formaldehyde air quality standards are given in Table 5. European countries are moving rapidly to establish formaldehyde standards. In July, 1978, the Netherlands established a standard of 0.1 ppm (120 μg/m^3) as the maximum permissible concentration.[14] Denmark, Sweden, and West Germany are all considering establishing a standard at approximately the same value (0.1 ppm).

Indoor sources of formaldehyde include combustion processes (cooking, tobacco smoking) and various building materials. Particleboard and urea-formaldehyde foam insulation have recently received the most attention, although many other building materials contain HCHO through the use of phenolic- and urea-formaldehyde resins.

Particleboard is a commonly used construction material made of woodshavings held together with a urea-formaldehyde resin. Particleboard continuously emits formaldehyde for a long period of time, and in dwellings where it is used for furniture, partition walls, etc., the emission may reach significant levels and even exceed the Threshold Limit Value (TLV - see

Table 5).* The emission rate varies as a function of several parameters, such as the original manufacturing process, quality control of fabrication, porosity, humidity, cutting of the board for final use, etc. as well as the rate of infiltration and ventilation.

Considerable concern has recently been raised regarding the use of urea-formaldehyde (UF) based foam insulation materials because of the high emanation rate of formaldehyde gas. There are no well documented studies in the United States on formaldehyde emissions from UF foam;[20] however, problems with UF foam in the Netherlands initially led to the promulgation of the current standard of 0.1 ppm.[14]

In the case of formaldehyde emissions from particleboard, limited measurements in Denmark,[16] Sweden,[11,12,21] West Germany[15,22,23] and the U.S.A.[24] have shown that indoor concentrations often exceed the recommended ambient and indoor standards of 0.1 ppm and in several cases even exceed the TLV standards for workroom air. In twenty-three Danish houses, the average formaldehyde concentration was 0.5 ppm (0.62 mg/m^3) and the range was 0.07-1.9 ppm (0.08-2.24 mg/m^3).[16] Formaldehyde measurements in more than 200 mobile homes in the U.S. ranging from 0.03 to 2.4 ppm have been reported in cases where occupants have complained about indoor air quality.[24]

For comparison, ambient outdoor formaldehyde measurements have been reported in a number of studies. Average formaldehyde concentrations in Los Angeles have been observed to be approximately 0.04 ppm in one study[25] and somewhat lower in another study.[26] The peak one-hour formaldehyde concentrations in Los Angeles have been observed to be as high as 0.16 ppm[25] while the maximum concentrations at four sites in New Jersey are reported to be in the range of from 0.014 to 0.020 ppm.[27]

Field tests and a mathematical model indicate the half life for formaldehyde found in particleboard typically used in Scandinavian home construction is about two years with a ventilation rate of 0.3 air changes per hour (ach).[21] The formaldehyde problem cannot be solved by use of mechanical ventilation during a short period. However, it has been shown that the level of HCHO can be reduced to half of the original value by chemical treatment or coating with a formaldehyde absorbent paint.

Radon

Radon-222 is an inert, radioactive, naturally occurring gas which is part of the uranium-238 decay chain. Any substance that contains radium-226, the precursor of radon, is a potential emanation source. Since radium-226 is a trace element in most rock and soil, indoor radon sources include concrete, brick, and other building materials. Radium-226 has a half life of 1602 years, so its presence in building materials results in a continuous source of radon for the life of the building. Another potentially significant source of radon in buildings is the soil beneath the foundation and tap water, especially if the water is taken from certain wells or underground springs.

The alpha decay of radium-226 produces a chemically inert, recoiling radon-222 atom which has a 3.8 day half-life. If the atom ends its recoil in an interstitial space of the solid source material, it may migrate to the surface and enter the air. Radon gas has four short-lived daughters which rapidly attach themselves by chemical or physical means to airborne particulates, generally less than a micron in size. These particulates, when inhaled, may be retained in the lung bronchii where the subsequent decays to lead-210 result in a radiation dose to the lung. The primary hazard is due to the alpha emissions of polonium-218 and polonium-214. Since alpha particles have a very short range (a few tens of microns), essentially all of the energy is deposited near the surface of the lung tissue.

Although the inert radon is not the principal health hazard in the decay chain, its concentration is a good indicator of exposure to the biologically important daughters. In the literature there are numerous examples of radon measurements showing higher indoor than outdoor concentrations. Recent measurements in the New York City area showed annual mean radon concentrations in 21 typical homes ranging from 0.2 to 3 nCi/m^3, with a geometric mean of 0.8 nCi/m^3.[28] For the same locations, outdoor concentrations were 0.1 to 0.2 nCi/m^3. Levels in Swedish homes of various construction were found to range from 1 to 12 nCi/m^3.[29] However, Swedish homes, with air exchange rates of about 0.2 to 0.8 ach,[29,30] are tighter than typical U.S. homes where air

---

*A Threshold Limit Value refers to an airborne concentration of a substance and represents a level under which it is believed that nearly all workers may be repeatedly exposed day after day without adverse effect.[18]

exchange rates are on the order of 0.5 to 1.5 ach.[31]

The concentration of radon in indoor air depends on the emanation rate from the parent material and on the mechanisms for removal, including ventilation. Most single-family homes in the United States are ventilated by infiltration through cracks in the building envelope: between walls and floors, around windows, doors, plumbing, vents, electrical wiring, etc. Commercial (non-residential) buildings are usually mechanically ventilated, with fresh air supplied at about 10 cubic feet per minute (cfm) per occupant. A calculation based on the emanating surface per volume and the air exchange rate shows that the concentrations of outgassing pollutants are comparable in typical commercial and residential buildings. Due to the fact that the vast majority of the population spends most of its time indoors, the total exposure of the general public to radon daughters will be largely determined by the elevated indoor concentrations.

A simple populations-at-risk model based on a "linear hypothesis" that risk is directly proportional to dose suggests an added annual risk of 20 to 200 cases of lung cancer per million based on an average concentration of 1 nCi/m^3 of indoor radon.[32] In the United States, the 45-64 year age group is at highest risk to lung cancer. Annual incidence rates during 1969-1971 for this age group were 1200 cases per million for white males and 300 cases per million for white females.[33] Although precise quantification is difficult, tobacco smoking is generally thought to be causally associated with 80% or more of the male cases. Presumably, the same relationship holds for females. Based on the above estimates of risk due to exposure to 1 nCi/m^3, life-time exposure to a few nCi/m^3, which might be the case with low air exchange rates (<0.5 ach), could yield increased lung cancer incidence (∿300 cases per million for exposure to 3 nCi/m^3) equal to the observed rate for non-smokers.

Since we do not yet know enough about the actual dose-response characteristics of low-level radiation exposure, we cannot say with certainty whether there is any added risk from a lifetime exposure to a few nCi/m^3. However, use of a linear hypothesis model is considered prudent for radiation protection purposes until we do have a better understanding of the dose-response characteristics of radiation exposure.

CONCLUSIONS AND RECOMMENDATIONS

Because of increased energy prices, there are financial incentives to reduce air exchange rates and the resulting heat losses. Nevertheless, measures presently under consideration that would reduce infiltration and ventilation rates could significantly increase exposure to indoor contaminants and perhaps increase disease rates.

The possible increase in indoor contaminant levels requires considerable attention. Two regulatory approaches are possible for limiting exposure to indoor contaminants. One is to specify a maximum permissible level and to accept the disease incidence, if any, that may be associated with increases in contaminant levels to this limit. There is a precedent for selecting such a level in the setting of occupational exposure standards* and standards for the general public are sometimes selected by comparison with occupational standards. The other approach is to set standards based on an explicit comparison of the disease incidence that may be caused by increased indoor contaminant concentrations with the cost of preventing these increases. Such a comparison would be made considering the financial benefit to be gained from reduced energy usage, balanced with the adverse effects of increased indoor pollutant levels. A decision on this matter must be preceded by substantial work on characterizing both the sources of indoor contaminants and the impact of various building designs on indoor concentrations.

Indoor contaminant emanation rates for the same material vary widely due to differences in fabrication and its use in buildings. Indoor pollution levels are strongly affected by human activities in a building and by the manner in which materials are incorporated into a building, as well as other aspects of the building design, particularly the infiltration or ventilation rate. There are several design features that might be adopted specifically to limit increases:

1) Mechanical ventilation could be coupled with an air-to-air heat exchanger to transfer heat (and not contaminated air) from the exhaust air to the fresh air stream in winter and vice versa in summer. Already in use in larger buildings, small heat exchangers (50-500 cfm) are now being marketed for homes in Europe and Japan. These could be

---

*"Threshold Limit Values" (TLV) have been established for several chemicals and physical agents encountered in the occupational environment.[18]

used to maintain constant air exchange rates (and, therefore, contaminant concentrations) at an acceptable level, while reducing heat losses from air exchange.

2) Indoor air could be circulated through contaminant control devices (e.g., electrostatic precipitators, particle filters, chemical adsorbents) substantially reducing the concentration of particulate and gaseous contaminants.

3) Measures could be incorporated to seal or eliminate certain contaminants at the source. For example, radon from the soil could be reduced by crawl space ventilation. Walls or floors could be sealed with polymers. Building materials could be selected for low emanation rates.

The effectiveness and advisability of such measures depend on various circumstances, such as the type of building and the geographical location. At this time, however, insufficient information exists to provide a basis for a considered regulatory decision. The effects of elevated indoor contaminant levels are highly uncertain, and the impact of building energy conservation measures is not yet known in detail.

Until all these relationships are known, it would be premature for the regulatory authorities to formulate basic energy conservation policy decisions affecting the built environment.

A relatively simple interim approach to the indoor air pollution question alone would be to avoid substantially altering indoor air pollution levels. This may be accomplished in some cases by using the heat exchangers noted above to maintain air exchange rates around their current levels of 1 ach. In some circumstances other measures may be more appropriate, but in any case, measures to conserve energy in buildings need not necessarily be compromised. For the long term, a comprehensive approach which balances factors such as the adverse impact of pollutants and the need for energy conservation is required. However, such an approach demands substantial work to delineate more precisely the sources of indoor pollutants, the effects of conservation measures on indoor pollutant levels, and the disease effects of such changes.

REFERENCES

1. Hollowell, C.D., Budnitz, R.J., and Traynor, G.W., "Combustion-Generated Indoor Air Pollution," in Proceedings of The Fourth International Clean Air Congress, Tokyo, Japan, May 16-20, 1977, pp. 684-7, The Japanese Union of Air Pollution Prevention Associations, Tokyo, Japan (1977).

2. Kiyoura, R., International Comparison and Critical Analysis of Nitrogen Dioxide Air Quality Standards. Paper No. 76-17.03, presented at the 69th Annual Meeting of the Air Pollution Control Association, Portland, Oregon (June 27-July 1, 1976).

3. World Health Organization, "WHO Environmental Health Criteria for Oxides of Nitrogen," Ambio, 6, 290 (1977).

4. "Short-Term NO_2 Standard in Preparation," NO_x Control Review, 3, No. 3, 14 (Summer, 1978).

5. Cullison, A.E., "Rigid Air Pollution Standard for NO_x Modified in Japan," World Environment Report, 4, 1 (August 14, 1978).

6. Hollowell, C.D., Traynor, G.W., "Combustion-Generated Indoor Air Pollution," LBL 7832, Presented at the 13th International Colloquium on Polluted Atmospheres, Paris, France, April 25-28, 1978.

7. The American Society of Heating, Refrigerating, and Air Conditioning Engineers, Inc., "Standards for Natural and Mechanical Ventilation, 62-73" (1973).

8. Melia, R.J.W., Florey, C. duV., Altman, D.G., and Swan, A.V., "Association Between Gas Cooking and Respiratory Disease in Children," Brit. Med. J., 2 (1977) 149.

9. Kitchens, J.F., Casner, R.E., Harward, III, W.E., Macri, B.J., Edward, G.S., "Investigations of Selected Potential Environmental Contaminants: Formaldehyde," Environmental Protection Agency Report EPA-560/2-76-009 (August, 1976).

10. Andersen, I., "Formaldehyde in the Indoor Environment - Health Implications and the Setting of Standards," Presented at the International Indoor Climate Symposium, Copenhagen, Denmark (August 30-September 2, 1978).

11. Private Communication, Jan Sundell, Statens Planverk, Stockholm, Sweden (July, 1978).

12. Private Communication, Thomas Lindvall, Karolinska Institute, Stockholm, Sweden (August, 1978).

13. American Industrial Hygiene Association, "Community Air Quality Guides, Aldehydes," Am. Ind. Hyg. Assoc. J. 29, 404 (1968).

14. Baars, R., "The Formal Aspects of the Formaldehyde Problem in the Netherlands," presented at "International Indoor Climate Symposium," Copenhagen, Denmark (August 30-Sept. 1, 1978)

15. Private Communication, Dr. Bernd Seifert, Institut für Wasser-, Boden- und Lufthygiene des Bundesgesundheitsamtes, Berlin, Germany (May, 1978).

16. Andersen, I., Lundgvist, G.R., and MØlhave, L., "Indoor Air Pollution Due to Chipboard Used as a Construction Material," Atmos. Environ. 9, 1121 (1975).

17. Occupational Safety and Health Administration, Federal Register 40, 23072 (May 28, 1975).

18. "TLVs - Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1977," American Conference of Governmental Industrial Hygienists, P.O. Box 1937, Cincinnati, Ohio 45201 (1978).

19. National Institute for Occupational Safety and Health, "Criteria for a Recommended Standard....Occupational Exposure to Formaldehyde," NIOSH Publication No. 77-126 (December, 1976).

20. Rossiter, W.J., Mathey, R.B., Burch, D.M. and Pierce, E.T., "Urea-Formaldehyde Based Foam Insulators: An Assessment of Their Properties and Performance," NBS Technical Note 946 (July, 1977).

21. "Formaldehyde Offgassing From Building Materials," Symposium held with KemaNobel in conjunction with Casco, Dyno and the Swedish Chipboard Union, Nacha, Sweden (November 15, 1977).

22. Deimel, M., "Erjahrungen uber Formaldehyde - Rawnluft - Konzentrationen in Schulneubausen," Vortragstagung - Organische Verunreinigungen in der Innen-und Aussenfuft, Berlin (1976).

23. Weber-Tschopp, A., Fischer, T., and Grandjean, E., "Reizwirkungen des Formaldehyds auf den Menschen," Int. Arch. Occup. Environ. Health, 39, 207 (1977).

24. Private Communication, Dr. Peter A. Breysse, University of Washington, Seattle, WA (August, 1978).

25. Altshuller, A.P., and McPherson, S.P., "Spectrophotometric Analysis of Aldehydes in the Los Angeles Atmosphere," J. Air Pollut. Control Assoc. 13, 109 (1963).

26. Scott Research Laboratories, Inc., NTIS Publication No. PB-194059 (1969).

27. Cleveland, W.S., Graedel, T.E., and Klema, B., "Urban Formaldehyde: Observed Conelation with Source Emission and Photochemistry," Atmos. Environ. 11, 357 (1977).

28. George, A.C. and Breslin, A.J., "The Distribution of Ambient Radon and Radon Daughters in Residential Buildings in the New Jersey and New York Area," Presented at the Symposium on the National Radiation Environment III, Houston, TX, April 23-28, 1978.

29. Swedjemark, G.A., "Radon in Dwellings in Sweden," Presented at the Symposium on the National Radiation Environment III, Houston, TX, April 23-28, 1978.

30. Olsson, F.A., "Ventilation and the Draught-Proofing of Windows in Old Blocks of Flats," Lund Institute of Technology, Department of Building Science Report (1977).

31. Handley, T.H. and Barton, C.J., "Home Ventilation Rates: A Literature Survey," Oak Ridge National Laboratory Report No. ORNL-TM-4318 (1973).

32. Budnitz, R.J., Berk, J.V., Hollowell, C.D., Nazaroff, W.W., Nero, A.V., and Rosenfeld, A.H., "Human Disease from Radon Exposures: The Impact of Energy Conservation in Buildings," LBL 7809, EEB-Vent 78-5 (August 8, 1978).

33. Cutler, S.J. and Young, J.L., Jr., (Eds.) "3rd National Cancer Survey: Incidence Data," Monograph 41, DHEW Publication No. {NIH} 75-787. U.S. Department of Health, Education & Welfare, National Institutes of Health (1975).

ACKNOWLEDGEMENT

The work described in this report is funded by the Department of Energy, Office of Assistant Secretary for Conservation and Solar Applications, Division of Buildings and Community Systems and the Office of Assistant Secretary for Environment, Division of Biomedical and Environmental Research.

The assistance of the Lawrence Berkeley Laboratory Ventilation Program staff in the preparation of this report, based in part on research in progress at LBL, is greatly appreciated.

TABLE 1

Indoor Air Pollution in Residential Buildings

SOURCES	POLLUTANT TYPES
OUTDOOR	
Ambient Air	SO_2 NO, NO_2, O_3, Hydrocarbons, CO, Particulates
Motor Vehicles	CO, Pb
INDOOR	
Building Construction Materials	
Concrete, stone	Radon
Particleboard	Formaldehyde
Insulation	Formaldehyde, Sulfates
Adhesives	Organics
Paint	Mercury, Organics
Building Contents	
Heating and cooking combustion appliances	CO, SO_2, NO, NO_2, Particulates
Furnishings	Organics, Odors
Water service; natural gas	Radon
Human Occupants	
Metabolic activity	CO_2, NH_3, Organics, Odors
Human Activities	
Tobacco smoke	CO, NO_2, HCN, Organics, Odors
Aerosol spray devices	Fluorocarbons, Vinyl Chloride
Cleaning and cooking products	Hydrocarbons, Odors, NH_3
Hobbies and crafts	Organics

TABLE 2

Recommended and Promulgated Short-Term NO_2 Air Quality Standards[2-5]

Country	Short-term NO_2 air quality standard ($0.1\ ppm \approx 190\ \mu g/m^3$)	Status
Canada	0.2 ppm/1 hr	promulgated
(Ontario)	0.1 ppm/24 hr	promulgated
Japan	0.04-0.06 ppm/24 hr	promulgated
U.S.A.	0.25-0.50 ppm/hr	recommended
West Germany	0.15 ppm/short-term exposure	promulgated
WHO/UNEP	0.10-0.17 ppm/hr	recommended

TABLE 3

Nitrogen Dioxide Concentrations in a Test Kitchen

AIR EXCHANGE RATE IN KITCHEN	NO_2 IN KITCHEN*
.24 ach (No stove vent)	1.2 ppm
1.0 ach (With hood vent above stove)	0.80 ppm
2.5 ach (Stove hood vent with fan at 50 CFM)	0.40 ppm
7.0 ach (Stove hood vent with fan at 140 CFM)	0.10 ppm
Outside during test	0.03 ppm

*(1-hour average concentrations in kitchen with a gas oven on for 1 hour at 350° F)

Typical ambient outside NO_2 concentrations	0.02 ppm (clean) - 0.30 ppm (heavy pollution)
Promulgated and recommended 1-hour NO_2 standards	0.20 - 0.40 ppm
ASHRAE ventilation requirements for kitchens in single family residential houses	Recommended: 30 - 50 CFM (ASHRAE 62-73) Minimum: 20 CFM (ASHRAE 90 - 75)

TABLE 4

ASHRAE Ventilation Requirements[7]

Building Classifications	Ventilation Requirements (cubic feet per minute per human occupant)	
	Minimum	Recommended
<u>Single Family Residential</u>		
General Living Areas, Bedrooms	5	7-10
Kitchens	20	30-50
Baths, Toilet Rooms	20	30-50
Basements, Utility Rooms	5	5
<u>Multiple Family Residential</u>		
General Living Areas, Bedrooms	5	7-10
Kitchens	20	30-50
Baths, Toilet Rooms	20	30-50
Basements, Utility Rooms	5	7-10
<u>Mobile Homes</u>	5	7-10

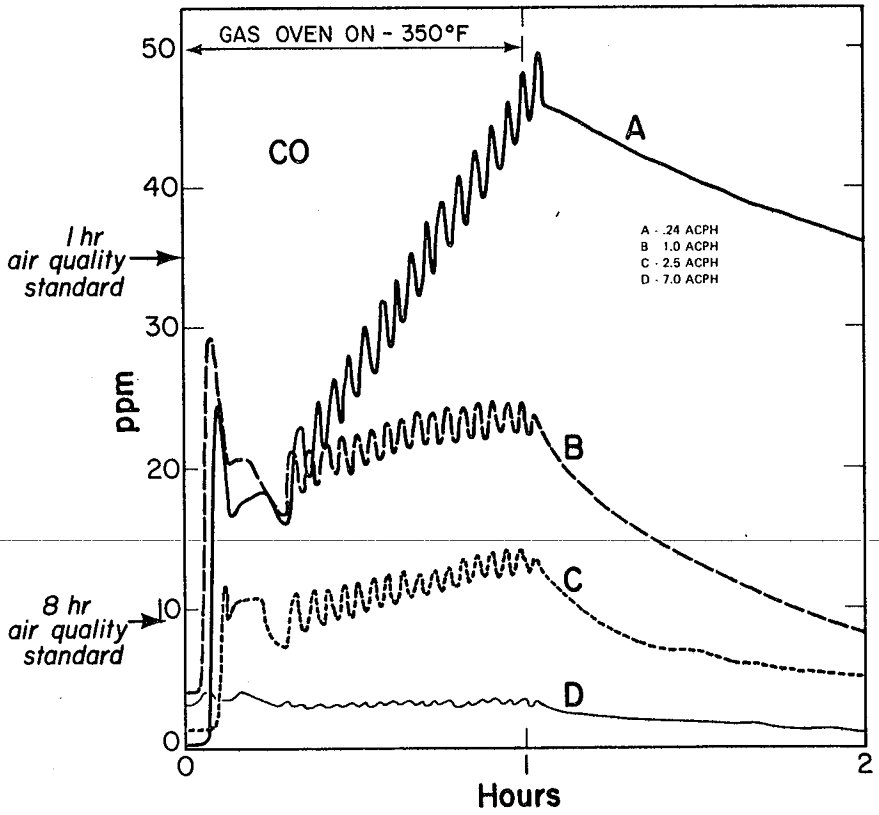
TABLE 5

Recommended and Promulgated Formaldehyde Air Quality Standards

Country	HCHO standard (0.1 ppm ≈ 120 $\mu g/m^3$)	Status
<u>AMBIENT AIR</u>		
U.S.A.	0.1 ppm maximum	recommended[13]
<u>INDOOR AIR</u>		
Denmark	0.12 ppm maximum	recommended [10]
The Netherlands	0.1 ppm maximum	promulgated [14]
Sweden	0.1-0.4 ppm maximum	recommended[11,12]
West Germany	0.1 ppm maximum	recommended[15]
<u>OCCUPATIONAL AIR</u>		
Denmark	1 ppm TLV*	promulgated [16]
U.S.A.	3 ppm TWA+	promulgated [17] (OSHA)
	2 ppm TLV*	promulgated [18] (ACGIH)
	1 ppm/30 min.	recommended [19] (NIOSH)
West Germany	1 ppm TLV*	promulgated [16]

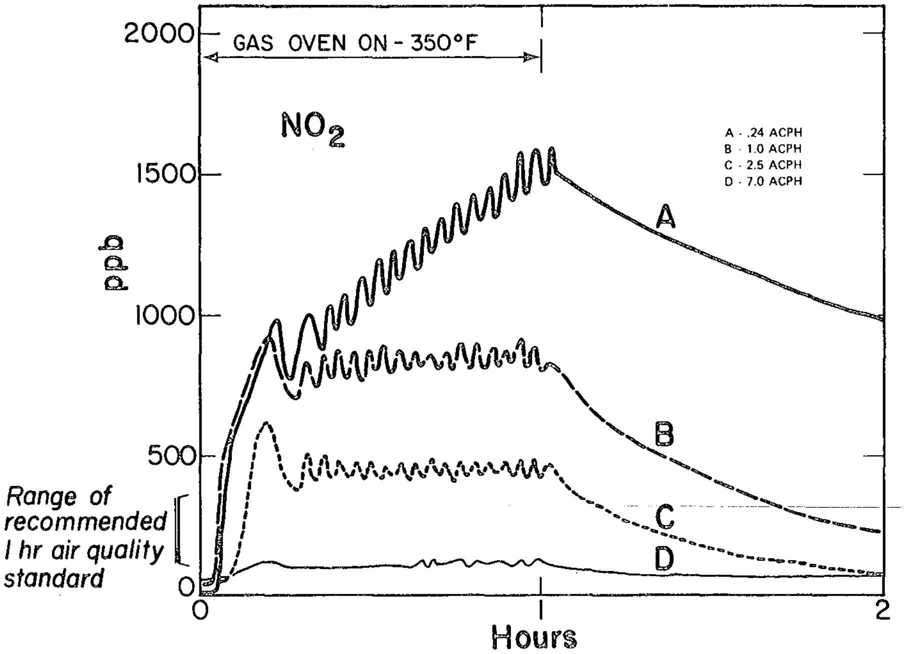
+TWA = 8 hr. Time Weighted Average

* TLV = Threshold Limit Value



XBL 772-304A

Figure 1 - Carbon Monoxide concentrations in a 27m^3 experimental room at various air exchange rates. Gas oven operated for 1-hour at 350°F (180°C).



XBL 772-306 A

Figure 2 - Nitrogen Dioxide concentrations in a $27m^3$ experimental room at varjous air exchange rates. Gas oven operated for 1-hour at 350°F (180°C).

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720