POLLUTION CONCENTRATIONS IN BUILDINGS

E.M. Sterling, Theodor D. Sterling Limited, #70 - 1507 West 12th Ave.
Vancouver, B.C., V6J 2E2
and
T.D. Sterling, Faculty of Interdisciplinary Studies, Simon Fraser
University, Burnaby, B.C., V5A 1S6

Abstract

Pollutants in a substantial number of buildings have now been investigated by public and private agencies. The archive of data on indoor pollutant levels observed in office buildings under conditions of normal operation and occupancy are reviewed using a computer based Building Performance Database.© Representative values of 153 pollutants as well as detailed frequency distributions of commonly measured pollutants and of temperature and humidity are presented. These distributions may offer architects and engineers a means to predict pollutant patterns to be expected in new buildings as well as provide a standard against which pollution patterns in individual buildings can be evaluated.

Introduction

Levels of concentrations of many pollutants inside working buildings have been summarized in the literature[1,2,3,4]. However, typical or representative values such as means or medians which usually are given, only provide limited information of the range and distribution of concentrations that may be encountered indoors. Building location, configuration, materials, type of HVAC system, lighting characteristics, equipment, furnishings, work population and uses, all combine to determine a particular mix and level of pollutants contained in the ambient air of specific buildings. Thus, for a working building, a typical pollutant mix exists that differs to some extent from that of other buildings. In that mix, some pollutants may occur at higher and some at lower concentrations. Where complaints of "Tight Building Syndrome" occur, very often the question is not so much if some concentrations exceed some typical value but more if a particular pollutant concentration falls within the range of concentrations commonly observed in other similar buildings. That need is especially urgent when comfort and/or health complaints among occupants have been confirmed.

Environmental conditions existing in a substantial number of buildings now have been investigated by public and private agencies. Investigations were conducted by certified industrial hygienists, physicians, epidemiologists, physicists, engineers and architects. Detailed reports of investigations are available for these studies. Their combined results form a valuable archive of data about indoor pollutant levels as they have been observed in office buildings under conditions of normal operation and occupancy. Findings of these investigations were reviewed using a computer-based information system designed to store, organize, describe, retrieve, manipulate and analyze building performance data[5]. The Building Performance Database© (BPD) includes data regarding the architecture and engineering of the buildings; the ventilation and thermal environmental characteristics; materials and machinery used; information about occupants; other uses of the building as well as levels of gaseous and particulate pollutants measured.

It is our purpose to provide architects and engineers with bench mark data on the distribution of some frequently reported environment measures available from 143 studies of working office buildings now included in our Building Performance Database©.

Method and Results

One hundred and forty-three reports of studies of working office buildings conducted between 1974 and 1983 were reviewed. Concentrations of a total of 153 different pollutants were reported. These pollutants are listed in Table 1 along with the number of studies in which they were measured and the median concentrations reported for them. For a few pollutants that had been measured only a single time, the observed value is reported. In addition to temperature and humidity, twenty pollutants were measured often enough to construct graphs of frequency distributions.

Figures 1-10 present frequency distributions in the form of bar graphs of values for temperature, relative humidity and of some key pollutants noted in Table 1. (Frequency distribution of pollutants listed in Table 1 but not presented here can be made available on request.) The height of the bars indicates the number of studies in which a particular concentration or value was measured. For example, in Figure 1, temperature frequencies are arranged in intervals of 2 F. The range of 24 reported temperatures was between 70 F to 82 F. Most temperatures were centered in a narrow interval between 70 F to 76 F. Figure 2 reports the observed distribution of Relative Humidity from 29 reports. Humidities are evenly distributed between the values of 10% RH to 70% RH.

Carbon dioxide is often considered to be an indicator of ventilation adequacy or efficiency [6,7,8,9]. Figure 3 shows that the CO_2 level measured in the majority of buildings was below atmospheric levels (300 ppm). Further, the CO_2 level in most buildings was well below that at which the health or comfort of even sensitive individuals is impaired[10]. However, the CO_2 level exceeded 600 ppm in seven buildings and in two reached peaks as high as 1500 ppm. Six hundred ppm has recently been suggested as the level at which occupants begin feeling discomfort and appears to be linked to increasing complaints of Tight Building Syndrome[11].

The range of levels measured for the gaseous combustion byproducts carbon monoxide, nitrogen oxide and nitrogen dioxide, are shown in Figures 4-6. The levels of these combustion byproducts measured inside working buildings appear to be extremely low. Carbon monoxide occurred below 4 ppm in 41 out of 61 studies. Nitrogen oxide occured below 20 ppb in 23 out of 31 studies, and nitrogen dioxide was found at or below 20 ppb in 9 out of 13 studies.

Sulphur dioxide is a byproduct of combustion of dirty or "sulphur contaminated" fuel. Combustion of such fuel primarily occurs outdoors. Figure 7 shows that SO_2 was measured at or below .003 ppm in the majority of studies.

Special concern has lately focused on particulate concentration due to numerous studies of passive exposure to environmental tobacco smoke[3,12,13,14,15]. Figure 8 shows that from the available studies, the level of particulates measured inside working buildings is almost exclusively below .06 mg/m^3 (in 19 out of 22 reports). This level is well below the U.S. Occupational Safety and Health Administration standard of 15 mg/m^3 for 8 hour (time weighted average) exposure in the occupational environment and is even below the U.S. Environmental Protection Agency National Ambient air quality standard of .075 mg/m^3 for outdoor air[16].

The American Society of Heating, Refrigerating and Air Conditioning Engineers[17] recommends that formaldehyde concentrations inside residential, commercial and industrial buildings not exceed 120 ug/m^3. In Figure 9 the level of formaldehyde measured in 40 out of 44 working office buildings is less than half the ASHRAE recommended level.

Indoor concentrations of ozone, shown in Figure 10, are of particular interest. Even with the increasing multitude of indoor sources such as duct work, electrical systems, photo copiers and other electronic office equipment, ozone has been measured at extremely low levels, below .003 ppm or not detected at all.

Rules restricting or eliminating the smoking of tobacco products are often implemented in office buildings to control indoor air quality. Smoking was restricted or not allowed at all in many of the buildings studied. Also, many of the buildings contained designated nonsmoking areas. Figures 11 and 12 are frequency distributions of concentrations of carbon monoxide and carbon dioxide measured in buildings with and without smoking restrictions. The graphs are constructed similarly to those in Figures 1-10 except that shaded bars represent measurements in smoking restricted locations and solid bars represent measures taken in areas where smoking was allowed. The distributions of contaminant levels overlap for both types of premises, those that allow and those that restrict smoking. *

Discussion

Many pollutants have been consistently and repeatedly measured in a significant number of office buildings. A summary of what has been measured in recent building diagnostic field studies serves as the first step to obtain an armamentorium of field data as an aid to architects and engineers to evaluate the great multitude of contaminants and complex system effects in order to identify specific causes of Tight Building Syndrome occurring in office buildings. Once the causes have been identified design solutions can be developed.

---

* Similar overlapping distributions exist for other pollutants for which adequate numbers of observations are in the Database.

References

1. National Adademy of Science, National Research Council (NAS/NRC) 1981. Indoor Pollutants. Washington, DC: National Academy Press.

2. Sterling, T.D., and Kobayashi, D. 1977. "Exposure to pollutants in enclosed living spaces." Env. Res. 13:1-25.

3. Sterling, T.D., Dimich, H., and Kobayashi, D. 1982. "Indoor byproduct levels of tobacco smoke: A critical review of the literature." JAPCA 32:250-259.

4. Yocum, J.E. 1982. "Indoor-outdoor air quality relationships." JAPCA 32: No. 5.

5. Theodor D. Sterling Ltd., 1984. The Building Performance Database User's Guide. Available on request from Theodor D. Sterling Ltd., 1507 West 12th Avenue, Vancouver, B.C., V6J 2E2.

6. Janssen, J.E., Hill, T.J., Woods, J.E., and Maldonado, E.A.B. 1982. "Ventilation for control of indoor air quality: A case study." Env. Int. 8:487-496.

7. Sodergren, D. 1982. "CO_2 controlled ventilation system." Env. Int. 8:483-486.

8. Turiel, I. and Rudy, J. 1980. "Occupant generated CO_2 as an indicator of ventilation rate." Building Ventilation and Indoor Air Quality Program, Energy and Environment Division, Lawrence Berkeley Laboratory, University of California, Berkeley. LBL-10496.

9. Woods, J.E., Winakor, G., Maldonado, E., and Kipp, S. 1982. "Subjective and objective evaluation of a CO_2-controlled variable ventilation system." ASHRAE Transactions 82 pt. 1.

10. Sterling, E.M., Arundel, A., Mintzes, B., Kobayashi-Hartel, D., Sterling, D.A., Sterling, T.D., and McIntyre, E.D. 1984. Criteria for Residential Exposure to Carbon Dioxide. Environmental Health Directorate, Health and Welfare Canada. Contract #1032.

11. Rajhans, G.S., 1983. "Indoor air quality and CO_2 levels." Occupational Health in Ontario 4(4):160-167.

12. Cain, W.S., Leaderer, B.P., Isseroff, R., Berglund, L.G., Huey, R.J., Lipsitt, E.D., and Perlman, D. 1983. "Ventilation requirements in buildings--I. Control of occupancy odor and tobacco smoke odor." Atmospheric Environment, 17:6, pp. 1183-1197, 1983.

13. Repace, J.L., and Lowrey, A.H. 1980. "Indoor air pollution, tobacco smoke and public health." Science 208:464.

14. Spengler, J.D., and Sexton, K. 1983. "Indoor air pollution: A public health perspective." Science 221(4605):9-17.

15. Weber, A., and Fischer, T. 1980. "Passive smoking at work." Int. Arch. Occup. Env. Health 47:209.

16. U.S. Environmental Protection Agency, National Primary and Secondary Ambient Air Quality Standards, Code of Federal Regulations, Title 40 Part 50 (40CFR 50).

17. ASHRAE Standard 62-1981. "Ventilation for acceptable indoor air quality." 1981. Atlanta: ASHRAE.

Table 1

POLLUTANT	MEDIAN	NO. OF REPORTS
Acetone	ND*	5
Acids	ND	14
Acetic Acid	Trace	7
Formic Acid	ND	3
Hydrochloric Acid	0.025 mg/m³	2
Hydrocyanic Acid	ND	1
Nitric Acid	ND	1
Acryonitrile	ND	3
Alcohols**	ND	11
Ethanol	ND	3
Isopropyl Alcohol	90.4 mg/m³	2
Methyl Alcohol	473. mg/m³	3
Nitro Gylcol	ND	1
Aldehydes	ND	8
Acetaldehyde	ND	4
Acrolein	0.052 mg/m³	1
Aliphatic Aldehydes	0.009 mg/m³	1
Alkylchloroformiates	ND	2
Allethrin	ND	1
Amines	ND	10
Aromatic Amines	0.001 mg/m³	1
Analine	ND	3
N.N. Dimethyl Amine	0.004 mg/m³	1
Triethyl Amine	ND	2
Ammonia	ND	9
Aromatic Hydrocarbons	TRACE	58
E-Pinene	0.36 mg/m³	1
Alkene	0.004 mg/m³	1
Benzene	TRACE	9
Benzo (A) Pyrene	ND	1
Chrysene	ND	1
Ethyl Benzene	ND	4
Flouranthene	ND	1
Pyrene	ND	1
Styrene	ND	2
Toluene	0.015 mg/m³	23
Xylene	TRACE	10
Arsine	ND	3
Butyl Methyacrylate	0.19 mg/m³	1
Carbon Black	ND	1
Carbon Dioxide**	400 ppm	26
Carbon Disulphide	ND	1
Carbon Monoxide**	2.54 ppm	61
Carbon Tetrachloride	ND	5
Cellusolve Acetate	TRACE	1
Cellulose	TRACE	1
Chlorine	ND	4
Chloroform	0.11 mg/m³	2
Chloroformiates	ND	1
Chloroprene	ND	3
Cyanogen Chloride	ND	3
Diazinon	ND	1
Diethyl Ether	ND	3
Dimethyl Acetamide	TRACE	6
Dimethyl Formamide	ND	3
Dimethyl Sulfate	ND	1
Dimethyl Sulfide	ND	3
Enflurane	1.44 mg/m³	1
Epichlorohydrin	ND	3
Ethrane	25.2 mg/m³	4
Ethyl Acetate	ND	4
Ethylene	ND	3

Table 1 (cont'd)

POLLUTANT	MEDIAN	NO. OF REPORTS
Ethyl Gylcol Acetate	ND	3
Ethylene Gylcol	0.05 mg/m³	1
Ethylene Oxide	ND	6
Fluoride	ND	1
Formaldehyde**	0.02 ppm	44
Freon	TRACE	1
Gasoline Vapour	96 ppm	2
Halothane	5.2 mg/m³	5
Hydrazine	ND	6
Hydrogen Chloride	ND	1
Hydrogen Cyanide	ND	3
Hydrogen Fluoride	ND	3
Hydrogen Sulfide	ND	9
Hydrocarbons	TRACE	77
Alkanes	0.032 mg/m³	7
Alklcyclohexane	0.005 mg/m³	1
Cyclohexane	ND	3
Dimethylcyclohexane	0.003 mg/m³	2
Hexane	ND	5
Hexanone	TRACE	1
Methane	ND	1
Methylalkylcyclohexane	0.003 mg/m³	1
Methylcyclohexane	0.003 mg/m³	2
Methyl Hexane	0.008 mg/m³	1
n-Heptane	0.003 mg/m³	2
n-Nonane	0.029 mg/m³	1
n-Pentane	0.17 mg/m³	2
Organic Hydrocarbons	TRACE	11
P-Dioxane	0.08 mg/m³	1
Diborane	ND	3
Trimethylcyclohexane	0.019 mg/m³	1
2.4-Dimethyl, 1-3 Ethylpentane	0.006 mg/m³	1
2-Methylnonanes	0.033 mg/m³	1
Hydroquinone	ND	2
Mercaptan	ND	3
Metals	TRACE	8
Methacryonitrile	ND	3
Methylacrylate	ND	3
Methyl Bromide	ND	3
Methylene Chloride	ND	5
Methyl Ethyl Ketone	0.9 mg/m³	2
Methyl Methacrylate	ND	4
Monostyrene	ND	2
Naptha	7.3 mg/m³	5
Natural Gas	ND	1
Nickel Tetracarbonyl	ND	1
Nitric Oxide	0.002 mg/m³	2
Nitrogen Oxides**	ND	31
Nitrogen Dioxide**	ND	13
Nitrosamines	ND	1
Nitrosodimethylamine	0.051 ng/L	2
Nitrous Fumes	ND	1
Nitrous Oxide	67.5 ppm	5
Olefin	ND	1
Ozone**	ND	27
P.C.B.'s	ND	1
Particulates**	0.029 mg/m³	22
Perchloroethane	0.03 ppm	1
Perchloroethylene	TRACE	6
Phenol	ND	1
Phosgene	ND	4
Phosphates	ND	1
Phosphine	ND	3
Phthalic Anhydride	0.015 mg/m³	1

Table 1 (cont'd)

POLLUTANT	MEDIAN	NO. OF REPORTS
Propylene Glycol	0.015 mg/m³	1
Pyrethin	ND	1
Solvent	ND	2
Sulphate	0.004 mg/m³	2
Sulphur	0.004 mg/m³	2
Sulphur Dioxide**	ND	20
Systox	ND	1
Tetrahydrofuran	0.33 mg/m³	1
Tetrahydrothiophene	ND	1
Toluene Diisocyanate	TRACE	1
Trichloroethane	0.1 ppm	8
Trichloroethylene	0.017 ppm	8
Tetrachloroethylene	0.019 mg/m³	1
Trinitrofluorene	0.001 mg/m³	1
Vinyl Chloride	ND	1
OTHER MATERIALS		
Asbestos	TRACE	7
Bacteria	DETECTED	8
Fibres	DETECTED	16
Fungi	DETECTED	4
Illumination	54 fc	10
Noise	72 dba	2
Oxygen	20.7%	4
Radio Frequency Radiation	ND	4
Relative Humidity**	38.5%	29
Temperature**	72°F	26
Ultraviolet Radiation	0.24 mw/cm²	4
X-Ray Radiation	ND	4

* Not Detected
** Frequency distributions presented in bar graphs

Figure 1

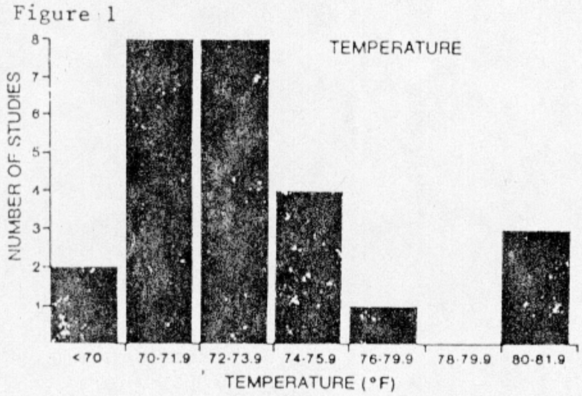

Figure 2

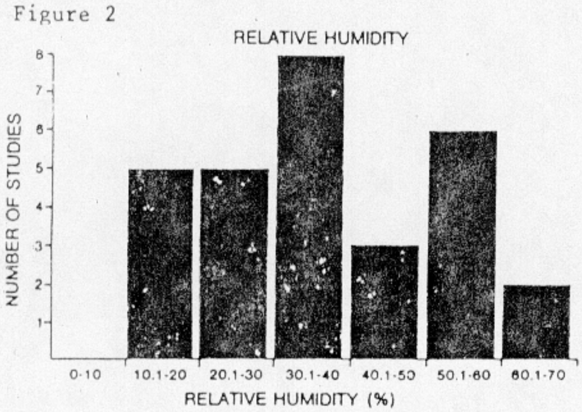

Figure 3

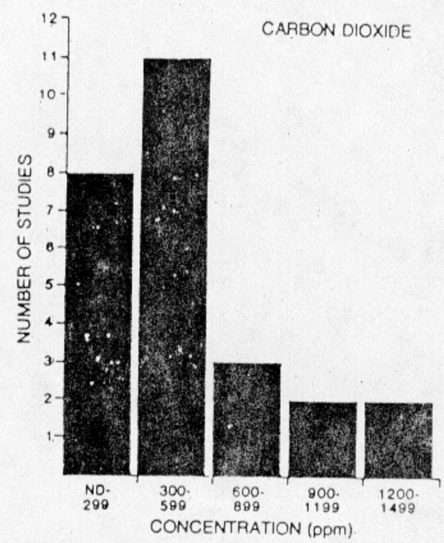

Figure 4

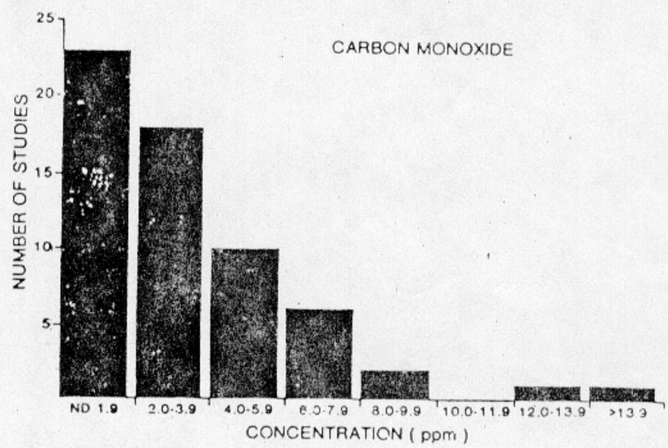

Figure 5

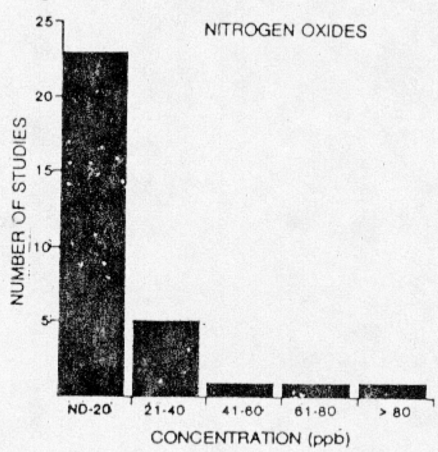

Figure 6

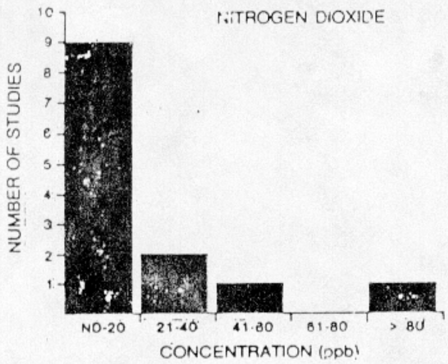

Figure 7.

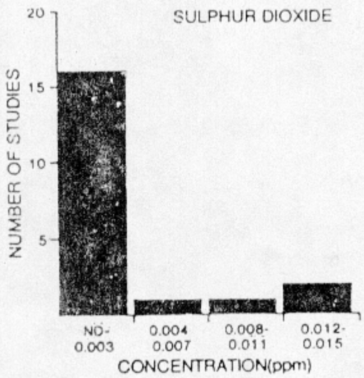

Figure 8

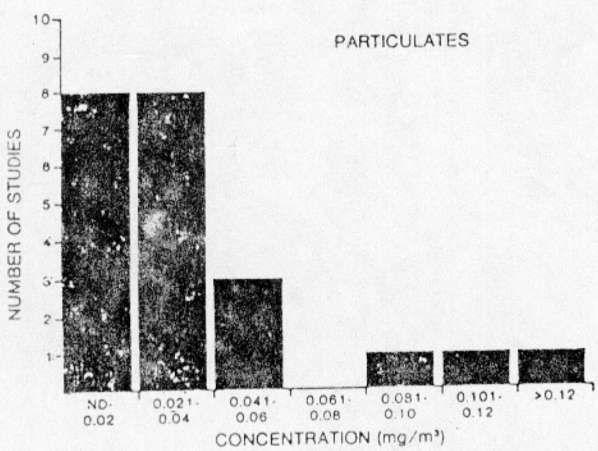

Figure 9

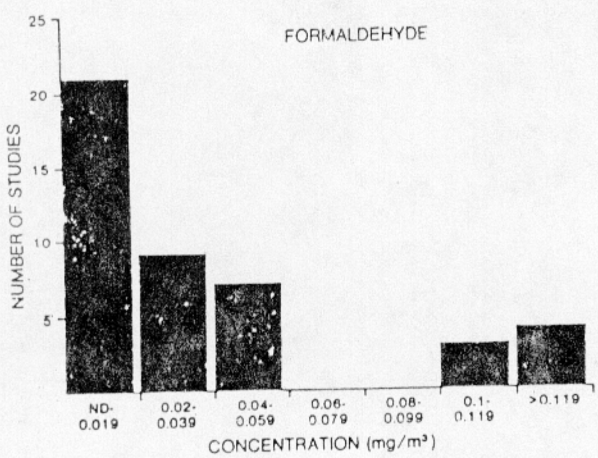

Figure 10

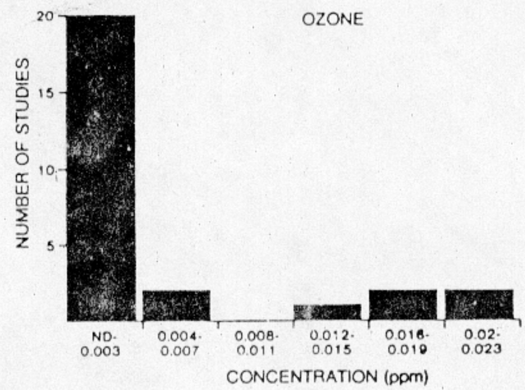

Figure 11

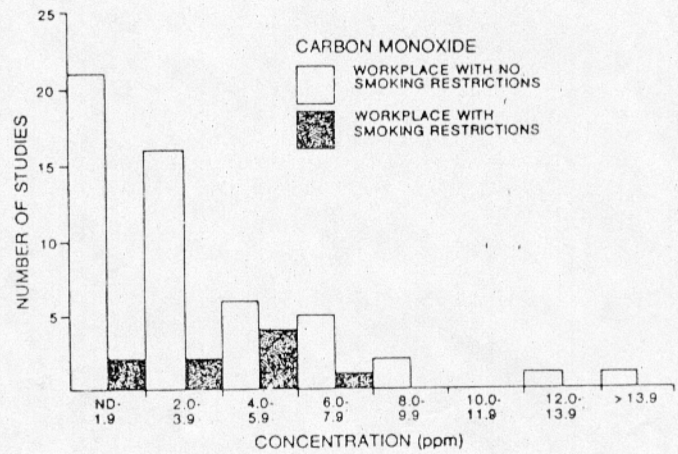

Figure 12