THE IMPACT OF AIR POLLUTION ON RESIDENTIAL DESIGN

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ABSTRACT

Recent investigations, have found dangerously high levels of pollution inside contemporary dwellings. At the same time proposals for saving in fuel consumption include a reduction of ventilation by up to 50%. However, such reduction in ventilation would subject residents to possible dangerous chronic exposures to known pollution hazards. This paper first reviews what is known about sources and levels of pollutants in dwellings. Next a number of design guidelines are specified that would reduce the body burden of pollution without substantially increasing energy consumption for ventilating.

Houses do not protect their inhabitants from the effects of air pollution. Indoor as well as outdoor sources contribute to the level of household pollution. If ventilation is adequate, then ambient indoor levels of pollution will be no worse than those outdoors. If ventilation is hindered or, if an air conditioning system substitutes recirculated for fresh air, pollutants may become entrapped and concentrated indoors.

Air pollution present inside contemporary homes then may reach levels dangerous to the health and well being of occupants. An extreme example of the effect of inadequate ventilation on health recently was noted by Kelley and Gregory (1978). They found 12 suspected cases of carbon monoxide (CO) poisoning, of which 3 resulted in death possibly caused by over-insulation of homes in response to the recent fuel crises.

In addition to CO poisoning various diseases have been linked to many pollutants commonly found in households: heart disease to CO, lung disease to oxides of nitrogen (NO), increase in general morbidity to sulphur dioxide (SO_2). Cancer has been linked to soot, asbestos and other particulates as well as to benzopyrenes and SO_2. In addition to their effect on human health many of these same pollutants are potentially harmful to building materials and ornamental plants. (Gauri 1978, Guderian 1977, Mudd and Koslowski 1975.)

A previous paper reviewed present knowledge about levels of pollution in large public structures and suggested design responses (Sterling 1978). Here the available information about levels and sources of pollution affecting homes is reviewed and guidelines suggested for design that will help minimize the body burden of pollution on a home's occupants.

Indoor Sources of Air Pollution

Much of the information concerning sources of indoor pollution comes from studies conducted in sealed environments such as submarines and space vessels. (Alvis 1952; Anderson et al, 1976; Ebersole 1957, 1960; Gorban et al, 1964; Hine 1964; Kitzes 1958; Schulte 1974; Siegel 1961.) As contaminants generated outside do not penetrate the isolated structure, the types and amounts of pollutants generated within the sealed environments can thus be determined with accuracy and their sources established. Cooking and heating are major sources of CO, hydrocarbons, aerosols, oxides of nitrogen, ozone, and of course soot. Other major sources of CO determined in sealed environments are oxidation of oils, lubricants, smoking, aging of paints, mechanical equipments and gas appliances. Other sources of hydrocarbons are aging of paints, varnishes, lacquers, paint thinners, solvents, cleaning fluid, plastic, linoleum, asphalt tiles, rubber and plastic cement, and bonding compounds. Sparks from electric appliances are sources of oxides of nitrogen and ozone. Freon, a common refrigerant, is changed into chlorine, florine, hydrogen chloride, hydrogen floride, and even phosgene if it leaks into the ambient air. Polish, insect spray, lighter fluid, shaving soap, hair tonic and human metabolic activity all are sources of contamination.

A number of studies have measured levels of various substances found in the air inside houses. These studies are summarized in Table 1. Column 1 lists the author and year of the study, Column 2 indicates the type of pollutant being measured. The next two columns contain the average level of contamination which occurred over the period of measurement and the range of levels recorded. Note that the units of measurement are not always immediately comparable. International adoption of a standardized system of measuring atmospheric contaminants would be helpful. The last column comments on the significance of the study.

As shown in Table 1, in many cases indoor levels of many pollutants either equal or exceed outdoor levels. As in sealed environments, heating units and gas appliances such as stoves are responsible for most household CO. Gas stoves produce more CO during cooking when a pan is placed over the flame. Wood fires and attached garages are also household sources of CO. Coal heating can be a source of SO_2 as well as CO. More SO_2 is found indoors in coal heated homes than outdoors. Kitchens and bathrooms are major sources of oxide of nitrogen. Aerosols and solvents are sources of halogenated hydrocarbons.

With respect to particulates, the minerals asbestos, baryllium, talc, and quartz are released into the air by home repair using spackling, patching, and taping compounds (Rohl et al, 1945). Talcum powder is also a source of talc. Home furnishing, carpets and drapes may contribute fibres to the air (Jacobs et al, 1962; Lefcoe and Inculet 1971, 1975). Heating and air conditioning ducts are sources of dust, asbestos, and thermophilic fungi (often the cause of allergic reactions). Special equipment sometimes used in the home can also contribute to air contamination. If, for instance mimeographing equipment is used, it is a source of methyl alcohol which oxidizes into formaldehyde.

Smoking is also thought to be an important source of pollution in the home. However most studies of the contribution of tobacco smoke to indoor pollution have been conducted in industrial or office buildings. Other published studies, listed in Table 2, were either conducted in chambers without ventilation, or under extreme conditions, (12 to 35 cigarettes smoked simultaneously or in close succession). Elevated levels of CO and particulates measured in these studies cannot be used to judge the effects of smoking on indoor air quality under normal conditions. It is safe to assume that smoking is a source of CO in the home but only one of many (Sterling, 1977).

Outdoor Sources Contributing to Indoor Air Pollution

In homes, indoor and outdoor air quality is closely linked. Residential areas may have special pollution problems if they are located near a polluting industry. Pollutants generated outdoors slowly infiltrate the building skin and become trapped indoors, increasing the indoor pollution burden overtime. For example, the only source for the lead in air is from automobile exhaust so that its presence in a home's atmosphere is a significant sign of penetration and entrapment of outdoor pollution. Penetration and entrapment of pollutants was also strikingly demonstrated by Megaw, 1962 when, in 1957, a cloud of nuclear fision products was accidentally released near Winscale, England. Radioactive iodine, ^{131}I, was deposited on roofs and in crevices, generating an enduring pollution of homes. CO is released into the atmosphere by the internal combustion engine, industrial furnaces, residential heating units, and incinerators. If sulphur contaminated coal, gas, or petroleum products are used as fuel, then large amounts of SO_2 and soot are also added to the atmosphere as well as CO. Industrial and residential coal burning is also a major source of benzopyrenes. Toxic materials may be introduced into the home on the clothing, hair and skin of industrial employees. This is not a trivial source of pollution. Industrial diseases are not uncommon among family members of industrial workers (Brodeur, 1974).

HOUSE DESIGN FOR HEALTH AND COMFORT

Every building has unique air quality and tempering requirements which the designer should be aware of from the initial selection of a site to the choice of building materials. Dependence on mechanical air conditioning, filtering, and ventilation equipment should be minimized in the future because of inceasing energy costs. Recirculated air should not be substituted for fresh air. It has the potential to cause a build up of pollution enriched air indoors. To depend upon filtering systems to remove gases such as CO and particulates under 1 micron in size from air intended for recirculation is an unreasonable demand. The most desirable means of reducing the concentration of air pollution indoors at the designer's disposal is by providing for adjustable natural ventilation.

Site Selection

Frequently homes must be located in areas where the outdoor air is already heavily polluted. When limited to such a location a preferred site should be upwind of the most predominant or hazardous source of pollution. The prevailing wind should be sufficiently strong to disperse pollution quickly and to provide ventilation for the building.

Landscape

Vegetation, if it does not inhibit air movement, can improve air quality by removing particulates and various gases from the atmosphere. Vegetation also serves as a visible indicator of air quality. Most plants are susceptible to the same pollutants as are men. Deformation and spotting of leaves and flowers, and conspicuous absence of certain species from the site may indicate that a serious pollution problem exists.

Air Movement

Organization of the various functional areas of the house for easy ventilation should be considered in the design phase.

The need for indoor heating and cooking poses an additional ventilation problem. Ventilation reduces the heat storage capacity of an enclosed space in direct proportion to the rate of air change. It may be sometimes necessary to sacrifice some fuel economy in order to maintain a healthy and comfortable indoor environment.

An additional problem is created by cold drafts during periods of heating. Occupants cannot be expected to open windows and doors for ventilation when the outdoor air is too cold for comfort. Also ventilating air ought to be warmed before entering the living zone. Most ideally, ventilation devices should be included in the design of the building which will allow passive, draft free, ventilation during all seasons. For example, heating and cooling registers can also function as fresh air inlets (Sutcliffe, 1899).

The ventilation rate required to purify indoor air can be reduced if the furnace and all gas, oil, and coal burning appliances are carefully placed within the house so that their contribution to the household pollution can be directly vented to the outdoors. Careful placement of the exhaust for this air should minimize the danger of reintroducing it into the house by infiltration or through a fresh air inlet.

A great deal is known already about the natural properties of air movement in and around buildings (Givoni, 1969; Oakley, 1961; Olgyay, 1963: Saini, 1973). A number of guidelines useful for design, can be derived from these properties.

1. Climatic and wind patterns affecting the site should be assessed to determine how ventilation can best be generated (either by taking advantage of prevailing winds or by using the stack or venturi affects).

2. Inlets should be placed on the windward or high pressure side of the building, outlets on the leeward or low pressure side.

3. Kitchens, heating units, and other sources of pollution should be placed on the leeward side. Exhaust from these sources should not be easily reintroduced into the building.

4. Every room must have both an inlet and an outlet in order to produce air movement. The inlet should be smaller than the outlet. Since wind direction is variable, wind ventilated rooms should have an adjustable ventilation pattern.

5. Landscaping materials and windbreaks can be used to direct the flow of air into the house. Vegetation can be used to filter particulates from the incoming air. Shading devices should be ventilated to avoid trapping stale, warm, polluted air.

Building Materials

Some materials have the capacity to remove certain pollutants from the air. For instance, masonry is known to absorb SO_2 from air (Gauri, 1978). More knowledge is needed of the capacities of different building materials to absorb pollutants. As previously noted in the discussion of sealed environments and Table 1, better documentation is available regarding materials as pollution sources. In general, materials should be chosen for their chemical stability over time and under adverse conditions of heat and humidity. Materials requiring frequent use of paints, lacquers, waxes, or cleaning compounds and solvents should be avoided.

The use of minerals such as asbestos, which are known health hazards, should be curtailed. Materials which do not severely affect the health of the occupants should be substituted where possible.

If synthetic materials (plastics) are used in the construction or equipment of buildings the following of the World Health Organization recommendations should determine choice (Goromosov, 1968).

"1. They should have the maximum possible chemical stability, so that no harmful substances will be liberated into the environment. This is particularly important since people spend the major part of their lives in their homes or in public buildings, making it practically impossible to isolate them from any unfavourable effects of plastics used in construction.

2. They should be appropriate to the climate where they are used; special attention must be given to the possible decomposition of such materials due to the effect of high temperature, bright sunlight, and other climatic factors.

6. They must have adequate mechanical strength and durability, must not produce dust when the floors and walls are cleaned, and must be easy to clean.

7. They must fulfill the same physical and hygienic requirements as conventional materials. Since most plastics have low thermal stability, care must be taken to insure that materials situated near heating or lighting installations are sufficiently stable at elevated temperatures.

8. Since certain plastics (particularly polyethylene pipes) may favour the growth of bacterial flora, microbiological control will sometimes be required when they are used."

CONCLUSION

It is the architect's added responsibility to design homes so that they enhance health and comfort as well as fulfill all other aesthetic and practical needs. This responsibility is too often delegated to the mechanical engineer charged with provision of energy intensive mechanical air supply and filtering systems. A future shift to dirtier fuels, such as sulphur contaminated coal, fuel oil, and gas may be expected to increase outdoor and indoor levels of pollution.

Considering the effect on air quality of the widespread use of low grade fuels and the possible unavailability of even those fuels at times of greatest demand, the prudent architect should rely on energy intensive mechanical air supply, tempering, and filtering technology only after taking full advantage of local climatic factors and the natural properties of air movement to satisfy human health and comfort requirements.

The author acknowledges his appreciation for help and criticism received from Drs. Ray Cole, Diane Kobayashi, and Theodor Sterling.

TABLE 1

TABLE OF POLLUTANTS IN DOMESTIC PREMISES (EXTRACTED FROM STERLING AND KOBAYASHI, 1977)

Source	Pollutant	Mean Value	Range	Comments
Biersteker et al, 1965	Particulates	157.72 $\mu g/m^3$	52-309 $\mu g/m^3$	Indoor - 80% of outdoor
Cleary & Blackburn, 1968	"	666 $\mu g/m^3$	Peak = 4862 $\mu g/m^3$	
Jacobs et al, 1962	"	Not given	1.7-34.9 mp/ft^3	More fibers found indoors
Lefcoe & Inculet, 1971, 1975	"	(1022.79).(103/ft^3) (Filter off) (406.66).(103/ft^3) (Filter on)	(139.3-1584.28). (103/ft^3)	Outdoor higher then indoor
Schaefer et al, 1972	"	Not given	4.5-9 mg (mass/foil) Residential areas 9 to > 18 mg (mass/foil) Cities	
Yocom, 1971a, b	"	Not given	32-76 $\mu g/m^3$	Indoor level less than outdoor
Yocom, 1971a, b	Soiling Index	Not given	0.22-0.52 Cohs/1000 ft	
Amiro, 1969	Carbon Monoxide	Not given	200-300 (selected cases)	90% of homes tested CO positive
Cleary & Blackburn, 1968	" "	21.3	150 (peak)	
Godin et al, 1972	" "	Farm house outdoor 0.8 $\pm$ 0.6 Farm house indoor 1.0 $\pm$ 0.8 Suburban Home Outdoor 2.0 $\pm$ 1.4 Indoor 1.9 $\pm$ 1.3	Not given Not given Not given Not given	

TABLE 1 (Cont'd)

Source	Pollutant	Mean Value	Range	Comments
Goldsmith, 1970	Carbon Monoxide	Not given	Not given	100,000 persons exposed/yr in U.S.
Kahn et al, 1974	" "	Not given	Not given	Winter indoor CO higher than outdoor
Sofoluwe, 1968	" "	940.2	100-3000	
Tanaka et al, 1971	" "	(Gas stove) Not given	up to 290	
Wade et al, 1975	" "	(Kitchen) Not given	4190-9070[a]	Peaks occurred coincidental to operation of gas appliances
Yates, 1967	" "	Not given	10-2500+	Referrals tested, 100% CO positive, random sample tested, 33% CO positive
Yocom, 1971a, b	" "	Not given	1-5 ppm	
DeRouane & Verduyn, 1974	Oxides of Nitrogen (Kitchen)	600 $\mu g/m^3$ (Water heater) 250 $\mu g/m^3$ (gas range)	Not given	NO_2=one third of total NO during operation of kitchen appliances
	(Bathroom)	Not given	up to 2000 $\mu g/m^3$	Bathroom
Lefcoe & Inculet, 1975 (NO_2)	" " "	< 0.1 pphm	0.5-15 pphm	No significant difference in indoor and outdoor
Sofoluwe, 1968	" " "	8.6 ppm	0.5-50 ppm	
Wade et al, 1975 (NO_2)	" " "	(Kitchen) Not given	Range of means: 53-213 $\mu g/m^3$	Peaks coincidental to operation of gas appliances
" " " (NO)	" " "	(Kitchen) Not given	53-305 $\mu g/m^3$	

TABLE I (Cont'd)

Source	Pollutant	Mean Value	Range	Comments
Megaw, 1962	^{131}I	1.54 x (10-4)	Not given	
Bridbord et al, 1975	Hydrocarbons	Not given	Not given	Sources of halogenated hydrocarbons aerosols and solvents
Sofoluwe, 1968	"	85.6	20-200	
Yocom, 1971a, b	"	Not given	5.3-25.6b	More benzene indoors
Yocom, 1971 a, b	Lead	Not given	0.47-1.75	Slightly greater indoors
Biersteker et al, 1965	Sulfer Dioxide	35.43 ug/m3a	0-246 ug/m3	20% of outdoor levels
Lefcoe & Inculet, 1975	" "	0.06 pphm[a]	0- < 0.1	Little difference in out-door - indoor
Sofoluwe, 1968	" "	37.8 ppm	5-100 ppm	
Yocom, 1971a, b	" "	Not given	up to 0.8 ppm	Coal-heated homes more SO_2 indoors
Tanaka et al, 1971	Carbon Dioxide	Not given	Not given	Rise in CO_2, 0 depleted
Lieben & Williams, 1969	Minerals	Not given	Not given	Beryllium detected
Rohl et al, 1975	"	9.38 fibers/ml[a]	0.5 to 59.0	Asbestos, quartz, and talc detected
Selikoff et al, 1972	"	Not given	Not given	Asbestos, higher in work-men's homes than outdoors
Castleman & Fritsch, 1973	"	Not given	Not given	Asbestos, found in fire proofing of buildings
Cleary & Blackburn, 1968	Aldehydes	1.08 ppm	3.8 ppm peak	
Banaszak et al 1970, 1974	Thermophilic fungi detected	Not given	Not given	Heaters and air conditioners
Fink et al, 1971	" "	Not given	Not given	Heaters and air conditioners

TABLE II

STUDIES ON INDOOR TOBACCO SMOKE

CO AND PARTICULATES MEASURED UNDER NATURAL AND SIMULATED CONDITIONS

(EXTRACTED FROM STERLING AND KOBAYASHI, 1977)

Study	Location	Dimensions of Premises	Ventilation	Amount of Tobacco Smoked	Number of Persons Present	Time	CO Levels (ppm) Smoking (X)	CO Levels Nonsmoking Controls
DeRouane & Verduyn, 1974	Domestic	50 m^3	Closed	3 cig.	0	34 min.	7.5 ppm	4 ppm
							Particulates Smoking (X)	**Particulates Nonsmoking Controls**
DeRouane & Verduyn, 1974	Domestic	50	Closed	3 cig.	0	24 min.	1000 $\mu g/m^3$	Not given
McNall, 1975	Domestic	425	0.35 m^3/sec. recirculation	12 cig.	0	1 hr.	1100 $\mu g/m^3$	60 $\mu g/m$
	Domestic		0.06 m^3/sec. infiltration	35 cig.	0	1 hr.	2700 $\mu g/m^3$	60 $\mu g/m$

REFERENCES

1. Alvis, H.J. (1952). CO Toxicity in Submarine Medicine, Naval Research Laboratory, Report No. 208, NM 002, 015.03, June 25.

2. Amiro, A.G. (1969). CO presents public health problems, J. Environ. Health 32, 83-88.

3. Anderson, H.A., Lilis, R., Daum, S.M., Fischbein, A.S., and Selikoff, I.J. (1976). Household contact asbestos neoplastic risk, Ann. N.Y. Acad. Sci., 311-323.

4. Anderson, W.L., and Saunders, R.A. (1964). Evolution of materials in the closed system, in "Symposium on Toxicity in the Closed Ecological System" (Honma and Crosby, eds.), Material Sciences Lab., Lockheed Missile and Space Co., Palo Alto, Calif., April.

5. Banaszak, E.F., Barboriak, J., Fink, J., Scanlon, G., Schlueter, D.P., Sosman, A., Thiede, W., and Unger, G. (1974). Epidemiologic studies relating thermophilic fungi and hypersensitivity lung syndromes, Amer. Rev. Resp. Dis. 110, 585-591.

6. Banaszak, E.F., Thiede, W.H., and Fink, J.N. (1970). Hypersensitivity pneumonitis due to contamination of an air conditioner, N. Eng. J. Med. 283, 271-276.

7. Banham, R. (1969). The Architecture of the Well-Tempered Environment, The University of Chicago Press.

8. Biersteker, K., DeGraaf, H., and Hass, Ch. A.G. (1965). Indoor air pollution in Rotterdam homes, Int. J. Air Water Pollut. 9, 343-350.

9. Bridbord, K., Brubaker, P.E., Gay, B., and French, J.G. (1975). Exposure to halogenated hydrocarbons in the indoor environment, Environ. Health Persp. 11, 215-220.

10. Brodeur, P. (1974). The Expendable Americans, New York, Viking Press.

11. Castleman, B.I., and Fritsch, A.J. (1973). Asbestos and You, Center for Science in the Public Interest, Washington, D.C.

12. Cleary, G.J., and Blackburn, C.R.B. (1968). Air pollution in native huts in the highlands of New Guinea, Arch. Environ. Health 17, 785-794.

13. DeRouane, A. (1971). Indoor air pollution as related to outdoor pollution, Cent. Belg. Etud Doc. Eaux, 24(377), 553-560.

14. DeRouane, A., and Verduyn, G. (1974). Study of some factors affecting air pollution inside buildings, Trib. Cebedeau 27, 482-488.

15. Drysdale, J., and Hayward, J.N. (1872). Health and Comfort in House Building, E. and F.N. Spon, New York, N.Y.

16. Ebersole, J.H. (1957). Submarine medicine on the USS Nautilus and the USS Seawolf, Proc. Roy. Soc. Med. 51, 63-74.

17. Ebersole, J.H. (1960). The new dimensions of submarine medicine, N. Eng. J. Med. 262, 599-610.

18. Fink, J.N., Banaszak, E.F., Thiede, W.H., and Barboriak, J.J. (1971). Interstitial pneumonitis due to hypersensitivity to an organism contaminating a heating system, Ann. Intern. Med. 74, 80-83.

19. Gauri, K.L. (1978). The Preservation of Stone, Sci. Am. 238:16, 126-136.

20. Givoni, B. (1969). Man,Climate and Architecture, Elsevier, New York.

21. Godin, G., Wright, G., and Shephard, R.J. (1972). Urban exposure to carbon monoxide, Arch. Environ. Health 25, 305-313.

22. Goldsmith, J.R. (1970). Contribution of motor vehicle exhaust, industry, and cigarette smoking to community CO exposures, Ann. N.Y. Acad. Sci. 15, 122-134.

23. Gorban, C.M., and Kondratyeva, Poddubnaya (1964). Gaseous activity products excreted by man when in an air tight chamber, in "Problems of Space Biology" (Siskayan and Yazdovskiy, Eds.) Joint. Pub. Res. Service, Washington, D.C.

24. Goromosov, M.S. (1968). The Physiological Basis of Health Standards for Dwellings, World Health Organization, Public Health Papers No. 33.

25. Guderian, R. (1977). Air Pollution, Phytotoxicity of Acidic Gases and its Significance in Air Pollution Control, Springer-Verluz, Berlin.

26. Hine, C.A. (1964). Physiological effects and human tolerances. In "Symposium on Toxicity in a Closed System" (Honma and Crosby, Eds.), Material Sciences Lab., Lockheed Missile and Space Co. Research Lab., Palo Alto, Calif. April.

27. Jacobs, M.B., Monoharan, A., and Goldwater, L.J. (1962). Comparison of dust counts of indoor and outdoor air, Int. J. Air Water Pollut. 6, 205-213.

28. Kelley, J.S., Gregory, J.S. (1978). Retinal Hemorrhages in Subacute Carbon Monoxide Poisoning, Exposure in homes with blocked furnaces, J. Am. Med. Assoc., 236:15, 1515-1517.

29. Kitzes, G. (1958). Air Force problems in toxicology, Am. Med. Assoc. Arch. Ind. Health 17, 556-562.

30. Lefcoe, N., and Inculet, I. (1971). Particulates in domestic premises, Arch. Environ. Health 22, 230-238.

31. Lefcoe, N.M., and Inculet, I.I. (1975). Particulates in domestic premises. II. Ambient levels and indoor-outdoor relationships, Arch. Environ. Health 30, 565-570.

32. Lieben, J., and Williams, R.R. (1969). Respiratory disease associated with beryllium refining and alloy fabrication, J. Occup. Med. 11, 480-485.

33. McNall, P.E. (1975). Practical methods of reducing airborne contaminants in interior spaces, Arch. Environ. Health 30, 552-556.

34. Meadows, D.H., Meadows, D.L., Randers, J., Behrens, W.W. (1972). The Limits to Growth, Earth Island Ltd., London; A Report for the Club at Rome's Project on the Predicament of Mankind.

35. Megaw, W.J. (1962). The penetration of iodine into buildings, Int. J. Air Water Pollut. 6, 12-128.

36. Mudd and Koslowski (1975). Responses of Plants to Air Pollution, Academic Press, San Francisco.

37. Oakley, D. (1961). Tropical Houses, B.T. Batsford Ltd., London.

38. Olgyay, A. (1963). Design with Climate, Princeton University Press, Princeton, N.J.

39. Rohl, A.N., Langer, A.M., Selikoff, I.J., and Nicholson, W.J. (1945). Exposure to asbestos in the use of consumer spackling, patching, and taping compounds, Science 189, 551-553.

40. Saini, B., (1973). Building Environment, an Illustrated Analysis of Problems in Hot Dry Lands, Royal Australian Institute of Architects, Sydney, Australia.

41. Schulte, J.H. (1961). The medical aspects of closed cabin atmosphere control, Mil. Med., 40-48, January.

42. Schulte, J.H. (1974). Sealed environments in relation to health and disease, Arch. Environ. Health 8, 438-452.

43. Selikoff, J.H., Nicholson, W.J., and Langer, A.M. (1972). Asbestos air pollution, Arch. Environ. Health 25, 1-13.

44. Siegel, J. (1961). Operational toxicology in the Navy, Mil. Med. May, 340-346.

45. Sofoluwe, F. (1968). Smoke pollution in dwellings of infants with bronchopneumonia, Arch. Environ. Health 16, 670-672.

46. Stein, R.G. (1977). Architecture and Energy, Anchor Press.

47. Sterling, E.M. (1978). Pollution in Public Buildings, J. Archit. Res. 6:(2), 13-19.

48. Sterling, T.D. and Kobayashi, D. (1977). Exposure to Pollutants in Enclosed "Living" Spaces, Environmental Reseach, February, Vol. 13/1.

49. Sutcliffe, G.L. (1899). The Principles and Practice of Modern House Construction, London.

50. Tanaka, M., Kobayashi, Y., and Yoshizara, S. (1971). Indoor air pollution due to domestic gas range, Kuki Seijo (Tokyo) 9, 28-38.

51. Wade, W.A., Cote, W.A., and Yocom, J.E. (1975). A study of indoor air quality, J. Air Pollut. Contr. Assoc. 25, 933-939.

52. Yates, M.W. (1967). A preliminary study of CO gas in the home. J. Environ. Health 29, 413-420.

53. Yocom, J.E., Clink, W.L., and Cote, W.A. (1971a). Indoor/outdoor air quality relationships. J. Am. Poll. Cont. Assoc. 21, 251-259.

54. Yocom, J.E., and Cote, W.A. (1971b). Indoor/outdoor air pollutant relationships for air conditioned buildings, J. Amer. Soc. of Htg. Refrig. & Air Cond. Eng. 77, 61-71.