Pollution in public buildings

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Much recent research has indicated that dangerously high levels of pollution may be present in public buildings. At the same time proposals for a reduction in fuel consumption include a reduction of ventilation by up to 33 per cent. This paper reviews the literature on sources and levels of pollutants in buildings and looks at the possible effects of a reduction in ventilation rates on the health and comfort of building occupants.

Current standards for ventilating buildings are based on comfort level control, primarily on the sensitivity of occupants to odours.[1] Much of the experimental work on which most present-day standards were established was carried out some time ago.[2] But recently a large body of information has accumulated which indicates that dangerously high levels of air pollution may be present inside public buildings. Unfortunately the implication of this information is not widely understood. With the price of fuel on the rise it is the desire of most segments of the building industry to reduce the fuel consumption of buildings. In an attempt to address the problem of energy conservation ASHRAE Standard 90-75 *Energy Conservation in New Building Design* proposes a reduction of ventilation rates by up to 33 per cent. (See also the recent symposium of *Effects of Energy Conservation Practices in New Buildings, Bureau of Standards, 1977*). This paper reviews the currently available information about levels and sources of pollutants in buildings in order to help ascertain the consequences that a policy of reducing ventilation rates may have on the health and well-being (including comfort) of building occupants.

The focus is on public buildings: offices, libraries, schools, public halls of assembly such as theatres, restaurants and areas where individuals gather in large numbers. These buildings are usually situated in areas where the ambient outside air is polluted. Newer buildings are tightly sealed and attempts are made to control all incoming air. As we shall see this does little to reduce internal pollution.

POLLUTION LEVELS IN PUBLIC BUILDINGS

Table I summarizes studies undertaken to measure dust (particulates, sulphur dioxide (SO_2), carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbons. These are comprehensive indices of the toxic content of air. The table is organized into five columns. Column one refers to the source of the information, column two the type of pollutant measured, column three the mean value, column four the range of contamination levels measured, and column five contains pertinent observations. The meaning of some levels of pollutants may be evaluated against threshold limit values (TLVs) used as industry standards. TLVs are defined as 'the values for air borne toxic materials which are to be used as guides in the control of health hazards and represent time weighted concentrations to which nearly all workers may be exposed eight hours per day over extended periods of times without adverse effects.' (Committee on Industrial Ventilation, 1968). Sample values of such limits are for CO—50 ppm, for CO_2—5000 ppm, and for SO_2—5 ppm.

A larger proportion of small particulates has been found indoors than out. The popular practice of recirculating filtered air may be considered the cause of this. Particulates smaller than the filter grid become trapped inside the building and may have little chance of escape. The organic fraction of particulates (benz[a]pyrene is considered cancer causing) was found to be greater indoors than out.[3] Traces of lead were also found in indoor dust. (Auto exhaust is almost the only source of atmospheric lead.)

One important study by Matsumoto measured dust and CO_2 concentrations in the underground market streets of Osaka.[4] Matsumuto found the particulate content of the ambient air in tea rooms, bowling alleys, movie theatres and department store basements to be from twice to ten times that found outdoors. CO_2 concentration was also found to be higher in all underground areas than outdoors with the exception of the street. A severe amount of dust was found in the basements of department stores.

The CO content in buildings has been found to be directly related to the structure's proximity to the street. Once inside, externally generated CO is spread evenly throughout the building by the ventilation system.

Large, semi-sealed, mechanically ventilated buildings prevent CO from escaping naturally and filtration is an ineffective way of removing it. For instance, Yocum found that CO levels indoors rose sharply around 7am in response to the build-up of outdoor traffic. After peak traffic, outdoor levels decreased while indoor levels remained extremely high. Godin noticed a similar occurrence in non-mechanically ventilated buildings when the windows and doors were closed.

A large amount of CO is generated within the building itself. The finding that one ice resurfacing machine can produce over 100 times the concentration of CO indoors as out may be a unique example. But one needs to consider the implications this has on the current trend toward compact multi-use structures that combine parking garages and restaurants with offices and residence. Indoor sources of CO are numerous—kitchens, heating plants, garages. Wherever combustion takes place, CO is generated.

Table I Table of pollutants in public buildings (extracted from Sterling, 1977)

Source (See Bibliography)	Pollutant	Mean value	Range	Comments
DeRouane, 1971	Particulates	38μg/m³ & 45μg/m³	up to 300 μg/m³	77.5% to 84.9% of outdoor level
Jacobs, 1962	Particulates	not given	4 to 53.4 mg/ft³	smaller particles indoors
Japan Air Cleaning Assoc., 1968	Particulates	not given	not given	filters reduce particles 'significantly'
Hunt & Cadoff, 1971	Particulates	not given	not given	lower levels indoors
Matsumoto, 1971*	Particulates	not given	.22 mg/m³ to 2.04 mg/m³	double indoor values 'severe' dust
Yocom, 1971	Particulates	not given	23 to 107 μg/m³	lower levels indoors
Godin, 1972 (small)	Carbon monoxide	1st floor 2.2 ± 1.3 ppm	not given	outdoor = 2.7 ± 1.5 ppm
		2nd floor 2.8 ± 1.5 ppm	not given	
(tall)		1st floor 4.6 ppm	not given	outdoor = 6.4 ppm
		54th floor 2.4 ppm	not given	
Japan Air Cleaning Society, 1969	Carbon monoxide	not given	not given	CO same as outdoors
Johnson, 1975 ice rink	Carbon monoxide	304 ppm (mean peak)	157-304 range of means	
Yocom, 1971 buildings (N=4)	Carbon monoxide	3.14 ppm	.76 to 6.02 ppm	indoor/outdoor ratio = 100% and over
Hunt & Cadoff, 1971	Ammonium	not given	not given	detected
McNesby, 1972	Sulfate	not given	not given	detected
Megaw, 1962	^{131}I	2.7 × (10⁻³) μc/m³	not given	entrapment indoors
Yocom, 1971	Hydrocarbons	not given	5 to 24.6 μg/m³	more benzene indoors
Hunt & Cadoff, 1971	Lead	not given	not given	detected
McNesby, 1972	Lead	not given	not given	detected
Yocom, 1971	Lead	not given	.18 to 2.04 μg/m³	slightly greater indoors
DeRouane, 1971	Sulfer dioxide	95 μg/m³ & 59 μg/m³	up to 300 μg/m³	25% of outdoor levels
Japan Air Cleaning Assoc., 1968	Sulfer dioxide	not given	not given	1/5 or outdoor levels
Yocom, 1971	Sulfer dioxide	not given	not given	little relation between indoor and outdoor
Matsumoto, 1971	Carbon dioxide	not given	not given	higher levels indoors
Castleman, 1973	Minerals	not given	not given	asbestos—found in fire-proofing of buildings

Table I cont'd

Source (See Bibliography)	Pollutant	Mean value	Range	Comments
Chovin, 1967, garages	Carbon monoxide	mean range 80 to 100 ppm	200 ppm (peaks	
Ramsey, 1967 garages	Carbon monoxide	58.9 ppm	7 to 240 ppm	
Trompeo, 1964 garages	Carbon monoxide	100 ppm	10 to 300 ppm	
Banaszak, 1970, 1974	Thermophilic fungi	not given	not given	heaters & air conditioners
Fink, 1971	Thermophilic fungi	not given	not given	heaters & air conditioners

The ventilation and air conditioning units themselves can be sources of contamination. One instance is as a source of asbestos fibres. This occurs when suspended ceiling spaces are used as return air ducts. These spaces are commonly sprayed with asbestos. The asbestos is then gradually eroded and circulated throughout the building. Another instance is as a source of thermophilic fungi and other organisms. These organisms may cause allergic reactions in building occupants and may contaminate food and water.

SPECIAL SOURCES OF POLLUTANTS

Today's public and office buildings are partially sealed and mechanically regulated environments. The amount of fresh air allowed to enter is carefully regulated and recirculation of large amounts of used air is common practice. Special filters as well as chemical cleaning and perfuming techniques are used to keep inside air 'clean'. This 'clean' air may no longer smell foul but it still contains large amounts of harmful contaminants. Not all of these contaminants are introduced from the external ambient air. Studies of completely sealed environments, especially of submarines, are an important source of information about pollutants in enclosed spaces. In submarines contaminants generated outside do not penetrate the isolating structure. The types and amounts of pollutants generated within the enclosed environment can be determined with good accuracy and their source can be established. At the same time, studies of these artificially-sealed environments have to contend with unique variables: oxygen must be provided and CO_2 must be removed or reconverted into oxygen; a pollutant-removal system usually is installed; ample machinery is usually present in addition to the equipment required to maintain a breathable atmosphere; and the structures are usually pressurized.

CARBON MONOXIDE

Because of the rapid build-up of carbon monoxide, burners (actually non-specific incinerators) must be utilized at all times. Even so, CO averages 50 ppm during periods of submergence. There are numerous sources of CO production, including heating, cooking, oxidation of oils and lubricants, smoking and ageing of paints.[5] At one time, cigarette smoke was thought to be a major source of CO.[6] Schulte[7] however, points out that when additional CO detection equipment was installed in newer submarines, inaccessible reactor compartments contained the highest concentrations of carbon monoxide. Further measures were made of areas housing equipment. It was determined that most CO production was caused by the oxidation of oils, lubricants, and paints—especially on steam pipes. Living areas, the only areas where smoking was allowed, contained much less CO than other areas of the ship (by a factor of 3 in comparison to the reactor room).[8]

HYDROCARBONS

Extremely high concentrations (500 ppm) of aromatic hydrocarbons have been reported by Schulte coincidental to cooking episodes.[9] Hine also lists cooking as a major source of hydrocarbon production.[10] Besides cooking, aromatic hydrocarbon sources are: paints, varnishes, lacquers, paint thinners, solvents, cleaning fluids, artificial leather, linoleum, asphalt tiles, rubber and plastic cement, and bonding compounds.[11] Many substances give off hydrocarbons for many months at a slow rate.[12] Although water-base paints are used whenever possible, Seigel has found that a 72-hour limit of painting must still be imposed before submergence.[13]

MISCELLANEOUS CONTAMINANTS

Cooking is responsible for most of the aerosol production.[14] Oxides of nitrogen are formed on submarines by electric arcing of armatures and by short circuits.[15] Sources of ozone are the same as oxides of nitrogen.[16] SO_2 and hydrogen sulphide are produced by the bacterial action of sanitary tanks.[17] Some forms of freon are converted under heat (often in CO burners) to chlorine, fluorine, hydrogen chloride, hydrogen fluoride, and phosgene. There is not a good means of removing this gas once it has leaked from cooling and refrigeration systems.[18] Halogens are produced when freon is oxidized in CO burners.[19] Mercury vapour comes from meters and gauges.[20] Methyl alcohol comes from mimeograph equipment.[21] Tri-aryl phosphate comes from hydraulic fluids.[22] Formaldehyde is a product of oxidation of methyl alcohol.[23] Among

Table II Studies on indoor tobacco smoke: CO measured under natural and simulated conditions (Extracted from Sterling, 1977)

Study (See Bibliography)	Location	Dimensions of premises	Ventilation	Amount of tobacco smoked	Number of persons present	Time	CO Levels Smoking (ppm)	Non-smoking controls
Anderson et al. 1973	conference room	80 m^3	6/hr	50 cigarettes	7 smokers 5 non-smokers	120 min.	4.5 ppm 6 ppm (peak)	2 ppm
Bridge & Corn 1972	party # 1	5120 ft^3	7 changes/hr	50 cigarettes, 17 cigars	25 smokers 25 non-smokers	1½ hrs.	7 ppm	no controls
	party # 2	3570 ft^3	10.6/hr	63 cigarettes, 10 Cigars	37 smokers 36 non-smokers	1½ hrs.	9 ppm	no controls
Elliott, 1975	arenas	not given	not given	not given	11,000 to 14,000	not given	14.3 ppm	3 ppm
Godin, 1972	theatre	not given	not given	not given	not given	not given	3.4 ± .08 (foyer)	1.4 ± .8 ppm (auditorium)
Harke, 1970	office	30 m^3	open window	11 cigarettes	1 person	5 hrs.	under 10	none
	office	30 m^3	closed—no ventilation	11 cigarettes	1 person	5 hrs.	under 10	none
Harke, 1974a	office	21 storeys	not given	40 cig/day in large room	not given	18 days	2-11 ppm	2-11 ppm
	office	12 storeys	not given	70 cig/day in large room	not given	18 days	2-11 ppm	2-11 ppm
	(individual rooms)		not given	varied	not given	not given	1-2 mean increase	2-11 ppm
Slavin, 1975	conference room	not given	8/hr.	not given	not given	1 day	8	1-2 ppm
	conference room	not given	6/hr.	not given	not given	1 day	10	1-2 ppm

other sources of pollutants mentioned by Hine are shoe polish, insect sprays, lighter fluids, shaving soap, and hair tonics.[24] Kitzes expands the list of pollutants present in cabin type environments by adding a few more sources found in aircraft, including anti-icing fluids, fire extinguishants, cargo, fuels, oils, and silenium in rectifiers.[25] The air contains also by-products of metabolic activity.

Although buildings, unlike submarines, do not have to rely on a static amount of atmosphere which must be cleaned and recirculated constantly to produce a habitable environment, the tendency has been to minimize the amount of fresh air entering the building's skin. With the use of large percentages of recirculated air comes the problems of contaminants witnessed in submarines. Most sources of pollutants identified in submarine studies are found in modern public and office buildings. While they differ from completely sealed enclosures, these buildings are partially sealed and mechanically regulated environments. Monitoring of actual levels of pollutants inside public buildings may well become a requirement in the future. There have been documented cases where pollutants in buildings have been suspected of causing disease. One notable recent example has been the so-called Legionaires Disease in Philadelphia. Ahmed has suggested that Freon 11 leaking from the cooling system of the Stratford Bellvue Hotel was oxidized into phosgene gas (commonly known as mustard gas and used as a weapon in World War 1) which causes symptoms much like those of the Philadelphia victims.[26] While Ahmed's suggestion may be considered unproven, there are other instances that call for caution such as the reaction of hypersensitive lungs to heating and air duct contaminants.[27]

TOBACCO RELATED POLLUTANTS

Smoking is of particular interest because of the special attention tobacco induced pollution has been receiving in recent years. Most studies of tobacco generated pollution have been limited to measuring CO as a major index. Table II summarizes major studies measuring the build-up of CO under normal conditions of smoking in the atmosphere of public indoor places. A contribution to CO in buildings due to smoking, varying from 0 to 32.5 ppm has been recorded with an average of approximately 5 ppm. Contrary to many claims, smoking does not appear a major source of a building's pollution under normal conditions.

CONCLUSION

Indoor air pollution levels may become dangerously high due to both outdoor and indoor produced contaminants. Buildings tend to trap pollutants. This is a dangerous situation at a time when outdoor pollution is expected to rise with the burning of cheaper fuels.

An extreme example of a building trapping dangerous pollutants occurred when fission products 131_I were accidentally released and became lodged in a building.[28] Existing ventilation standards for buildings other than hospitals are primarily concerned with maintaining comfort levels rather than controlling pollution levels.

In the long run, the goal of designing a well-tempered building may well have to be to achieve at best the same quality air inside as out. A number of important parameters appear to restrict or determine possible design responses in public buildings.

1. The relation of outdoor to indoor pollution
   a. the existing pollution level of the ambient outdoor air
   b. the acceptable indoor levels of pollutants of the building either existing or being considered.
2. The type of building
   a. large halls
      *usually windowless
      *need acoustic separation
      *dense peak occupancy
   b. office buildings
      *require lighted workspace
      (do office workers prefer windows to artificial light?)
      *proportion of corridor to work space
      (space is an important economic concern)
3. Characteristics of the building's users
   a. spend prolonged periods of time.
      *older and/or sick people
      *office workers
      *industrial workers
   b. meet only for short periods.

The design alterations are not obvious. But we can begin to define the necessary criteria with natural ventilation and cooling in mind. (A historical survey of ventilation techniques could be helpful to review ideas that 'worked'. Banham's survey of the *Architecture of the Well Tempered Environment* is an important step.[29])

A partial list of possible lines of action would include:

1. Floorplans should be limited to depths which can be economically ventilated and lit.
2. Control of ventilation and lights should be manual, for example, operable windows and light switches.
3. Free movement of air is advantageous to equalize air quality inside and out. This would employ natural ventilation methods such as cross ventilation and 'stack' effects.
4. Kitchens, parking garages, heating units and other sources of internally generated pollution should be separated or carefully vented from offices, residences, and indoor public places.
5. Materials that are sources of harmful contaminants should be identified and eliminated from enclosed environments.
6. Materials that absorb toxic compounds from the air should be identified and specifically required.
7. Heating, cooling, and ventilation equipment should be specially treated to inhibit the growth of organic substances.

This is not an exhaustive list. Rather it is an attempt to identify requirements for designing a healthy living environment.

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