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Exposure to Pollutants in Enclosed "Living Spaces"

THEODOR D. STERLING AND DIANA M. KOBAYASHI

Faculty of Interdisciplinary Studies, Simon Fraser University, Burnaby, B.C., Canada

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INTRODUCTION

Pollution of domestic premises, public buildings, and transport vehicles, is linked by problems peculiar to enclosures. Enclosures afford protection from toxic substances. On the other hand, they may entrap pollutants inside that have seeped in from the outside or have been generated inside, as enclosed spaces almost always contain sources of pollution of their own.

Studies on enclosed environments are grouped for our purposes into four categories. Each category will be discussed separately: pollutants in artificially-sealed environments, pollutants in domestic premises, pollutants in public buildings, and pollutants in transportation related enclosures. Pollution levels reported by different studies are summarized in a series of appended tables.

The information available about pollution in enclosed spaces is sparse but sufficient to indicate the magnitude of possible exposure to inhabitants. Evaluation of existing studies leads inevitably to one conclusion: *A building does not protect its inhabitants from pollution. To the contrary. The body burden of toxic vapors and dusts in the "inside" may very well exceed the burden of pollution in the "outside."*

POLLUTION IN ARTIFICIALLY- SEALED (SUBMARINE) ENVIRONMENTS

Studies of sealed environments, especially of submarines, are an important source of information about pollutants in enclosed spaces. 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 carbon dioxide 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 buildup 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 aging of paints (Schulte, 1961, 1964). These results are confirmed by Ebersole (1960) in his report on an early record-breaking 60-day dive of the *USS Seawolf* in 1958, and by Hine (1964). Although average CO concentrations of around 50 ppm are reported in studies conducted by Hine, Ebersole, and Schulte, a report by Alvis (1952) of

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can be surmised from urban–rural, indoor–outdoor pollution differences. Godin *et al.* (1972) studied CO levels. At a semirural farm, outdoor CO values were 1.0 ± 0.8 ppm. Values were double at a suburban home (outdoors: 2.0 ± 1.4 ppm; indoors: 1.9 ± 1.3 ppm). Schaefer *et al.* (1972) correlated particulate fallout in homes with their geographic locations. Homes in cities showed the highest amounts of sedimentation, and those in rural areas showed the lowest amounts. Although there were differences from room to room, kitchens, in general, were shown to have the highest amounts of particulate matter. Jacobs *et al.* (1962) similarly found that indoor particulate concentrations were similar to outdoor concentrations, although more submicron particles were found indoors than outdoors.

SOURCES OF INDOOR POLLUTION

Pollutants may be indoor-generated or they may originate from the outside. Furthermore, once present they may build up over time. As part of Yocom's study CO levels were monitored in an unoccupied house. CO levels increased more slowly inside than out, but, once built up, indoor levels remained higher for a longer period than did outdoor levels. Thus, domestic premises have a tendency to entrap gaseous pollutants. Garages attached to homes may also entrap pollutants, allowing them to seep into the home. In one of the homes tested by Yocom *et al.* (1971a) the attached garage proved to be a greater source of CO than even the gas stove.

Cracks in structures, in addition to doors and windows, permit this entrance of pollutants and the possible subsequent entrapment of pollutants. Although applied to an unusual case, the possible prolonged penetration of pollutants was strikingly demonstrated by Megaw (1962). In October 1957, a cloud of nuclear fission products was accidentally released near Windscale, England, permitting a test of the amount of ^{131}I found within contaminated houses. Although ^{131}I levels indoors were found to be much lower than ^{131}I levels outdoors, deposits on roofs and in crevices suggested that seepage over time was likely to occur. Megaw concluded that over time, amounts of ^{131}I trapped on roofs and in crevices could constitute a health hazard.

Further information regarding the sources of indoor-generated CO comes from a number of surveys. Goldsmith (1970) estimates the number of persons suffering from household exposure to CO in the United States to be 100,000 per year. While the exact number of persons exposed is not known, Goldsmith's conclusions, nonetheless, highlight the fact that exposure to elevated amounts of CO may be affecting a large portion of the U.S. population. The extent of indoor CO pollution may be assessed also from Kahn *et al.* (1974) who found that the COHb content of blood donors increased during winter months, despite reduction in the ambient CO level. Kahn points out that there is reduced traffic in the winter months and concludes that indoor emissions were the largest contributing factor to increased COHb levels during these winter periods. One recent study by the National Association for Sanitarians included investigations of the homes of 300 cases of suspected CO poisoning. Over 90% of the homes were positive for CO (Amiro, 1969). While there was no tabulation of overall average levels given, emissions of

variety of pollutants and toxic substances which are generated from many sources inside the structure or which penetrate from the outside. All pollutants, generated inside the building or penetrating from the outside, become part of the internal environment. The escape of all pollutants from the building depends on the type of existing ventilation.

There are some major differences between household dwellings and public buildings. Public buildings very often are situated in industrialized, more polluted areas. Larger buildings are also better sealed. This is true especially of the new, modern, air-conditioned and completely enclosed office buildings. However, even in older structures, the very size of the building will decrease the amount of ventilation per unit of space. As a consequence, not only must air be brought into the building but active filtration and ventilation are much more important in public buildings than in homes. Various pollution elimination devices or built-in filtration plants must be provided. Filters may be effective in reducing particulate concentrations but do little in regard to gases such as CO, CO_2, NO, NO_2, and others. SO_2 may be a lesser problem since it is usually absorbed by building materials regardless of filtration. Finally, many pollutants are generated by the activities of man and machinery inside public buildings just as in submarines. (For a discussion of current work on building pollution-reducing systems see Holcombe *et al.* (1971).)

The contribution of indoor- and outdoor-generated pollution is much more difficult to determine in large buildings than in households. However, both sources have been clearly identified.

A great deal of attention has always been paid to adequate ventilation in public schools. Much of the concern in the past was with odor problems. Korenevskaya *et al.* (1965) observe that upper floors in school buildings get pollution from kitchens, gyms, boiler rooms, and other structures that are located below them. They noticed a very definite increase in smell, dust, and CO levels. Grusha *et al.* (1964) measured changes in relative humidity and CO_2 as an index of metabolic by-products of school children. They found that relative humidities in schools rose to one and a half times the accepted level by the end of the first class period (values given were 78 to 80%). Temperatures also increased rapidly. The investigators observed that while CO_2 levels were normal at the beginning of a class period, they were double by its end.

Although the function of ventilation and air-conditioning units is to renew and purify internal building atmospheres, they may do just the reverse. Banaszak *et al.* (1970, 1974); and Fink *et al.* (1971) report air-conditioning and heating units contaminated with thermophilic fungi. The systems, in turn, pollute indoor spaces with the fungi. Another source of pollution arises from the current building practice of designing ceiling spaces as return air plenums. Air is allowed to circulate through these areas which have been sprayed with asbestos. The asbestos is gradually eroded and circulated throughout the building (Castleman and Fritsch, 1973).

For most public and office buildings the relation of outdoor to indoor pollution is exceedingly important. Studies have compared outdoor to indoor dust, SO_2, CO, and hydrocarbons (for buildings with and without filtration).

DeRouane (1971) found that indoor (total particulate) concentrations varied to

some extent, depending on whether the building was old or new, but were generally around 80% of outside values. However, SO_2 was much reduced due to surface absorption (approximately 25% of outdoor levels).

The Japan Air Cleaning Association (in 1968) examined indoor and outdoor sources of various pollutants: SO_2, CO, hydrocarbons, and dusts, in rooms with and without filtration. As in the DeRouane study, SO_2 was found to be one-fifth of the outdoor concentration. Carbon filters were found to be effective in reducing dust. However, there was no appreciable decrease in CO and hydrocarbon concentrations with the carbon filters in operation.

Yocom *et al.* (1971a,b) also found little relation between indoor and outdoor concentrations of SO_2 (again because of the absorption in internal structures). Particulate concentrations were highest in buildings near roadways but generally were found to be lower indoors than outdoors. However, the organic fraction of particulate matter was consistently higher inside than outside in all public buildings. At times more than twice the organic contamination was found inside than outside. (In contrast, lead enrichment of particulate matter was about the same indoors as outdoors.) The soiling index in all buildings was about 80 to 90% of outdoor levels (except in a library where, during winter, it was only 50%). CO levels indoors showed a direct correlation with the structures' proximity to roadways, but CO was spread fairly evenly throughout the buildings. Filtration was not effective in reducing CO levels indoors and mean indoor CO levels were higher than mean outdoor CO levels. At the same time, the semi sealed buildings prevented the escape of CO. CO levels rose sharply, beginning around 7:00 AM in response to the buildup of outdoor CO due to traffic. But, after traffic reached its peak, indoor CO levels remained extremely high for long periods, while outside levels decreased. Yocom's findings are replicated in part in a study by Godin *et al.* (1972). In a building in which indoor CO values averaged 2.2 ± 1.3 ppm on the first floor and 2.8 ± 1.5 ppm on the second floor, fluctuations were similar to those found by Yocom *et al.* With the windows and doors shut, indoor concentrations fell less rapidly than outdoor concentrations.

A number of studies have been conducted on particulate matter. Jacobs *et al.* (1962) found that indoor dust contained more small particulate matter. Jacobs *et al.* (1962) found that indoor dust contained more small particles than outdoor dust (1 μm or less). Jacobs also supplied a number of measures for amounts of particulates found inside buildings, ranging between 4.0 and 53.4 mp/ft^3 of particulate matter. Lead as a component of indoor dust, in addition to other components, was reported by Hunt and Cadoff (1971) and McNesby *et al.* (1972). Both studies found lead to be a consistent trace element, along with ammonium sulfate, in both indoor and outdoor dust.

Few studies exist that measure air pollutants in public places of assembly as opposed to public-office-type buildings. One important study was conducted by Matsumoto and Kitamura (1971), who measured CO_2 and dust concentrations in the underground market streets of Osaka—in tea rooms, bowling alleys, movie theaters, and basements of department stores. CO_2 was found to be higher in all areas than in the outside air with the exception of the street itself. Dust underground was found to be double that above ground, with peaks of ten times the

outside concentration. In department stores, dust was found to be "severe" in the underground floor. Unfortunately, there was no analysis on the organic content of this dust.

One other study (Johnson *et al.*, 1975a) measured CO in a public place of assembly. Ice resurfacing machines operating in indoor rinks were found to be a source of CO levels of up to 304 ppm on the average.

TOBACCO-INDUCED POLLUTION IN PUBLIC BUILDINGS

Measurements have been made of smoke constituents of room air under *natural* and *experimental* conditions. Also measured have been blood levels of COHb and nicotine contents of urines.

Bridge and Corn (1972) measured CO during two experimental "parties." In one 5120 ft^3 room containing 50 people, 25 people consumed 50 cigarettes and seven cigars in 1 ½ hours. With a room air exchange rate of seven times per hour, CO averaged 7 ppm during the course of the party. During the second experiment in a 3750 ft^3 room containing 73 people, 36 smokers consumed 63 cigarettes and 10 cigars in 1 ½ hours and the average CO content was 9 ppm. These values actually coincided with values predicted using Turk's (1963) equation (6.5 and 8 ppm, respectively).

In order to determine mainstream to sidestream smoke ratios produced by cigarettes, Hoegg (1972) measured CO and total particulate matter from varying numbers of cigarettes. In a sealed 25 m^3 chamber, CO levels increased with the number of cigarettes smoked. Concentrations ranged from ~ 10 ppm for 4 cigarettes to 69.8 ppm for 24 cigarettes. For total particulate matter, initial or peak values ranged from ~2.5 mg/m^3 for 4 cigarettes to 16.65 mg/m^3 for 24 cigarettes. Utilizing these experimentally obtained values, Hoegg modified Turk's equation with the addition of a decay function for cigarette-produced particulate matter.

A study by Anderson and Dalhamn (1973) determined, in addition to CO, nicotine and smoke density produced by cigarettes in a medium-sized meeting room (80m^3). Fifty cigarettes were smoked in 120 minutes. With six air changes/hour, initial levels were 2 ppm and average peaks during smoking were around 6 ppm. Smoke density prior to testing was 0.02 mg/m^3. Highest concentrations were found at the beginning of the experiment but they rapidly dissipated. Nicotine content of the air increased from zero to 0.377 mg/m^3 during the course of the experiment, but it rapidly decreased also. The seven smokers and five non-smokers in the experiment were tested for their COHb levels. Changes in non-smoker COHb were not significant.

Harke conducted several experiments with cigarettes in enclosed office rooms under conditions of "severe" and "realistic" smoking. Twenty-one persons smoking two cigarettes each within 16 to 18 minutes in a room 57 m^3 produced 0.5 mg/m^3 nicotine and 49 ppm CO. Ventilating the room decreased these concentrations by 80%. In the case of one person smoking 11 cigarettes in 5 hours in a room 30 m^3, nicotine reached 0.04 mg/m^3 and CO was still under 10 ppm. With the window closed, nicotine was 0.06 to 0.09 mg/m^3 and CO was still under 10 ppm. (Background pollutants, however, were not mentioned (Harke, 1970).) In a number of experiments in 1972, Harke measured pollutants in large and small

rooms under extreme conditions. In the first experiment, a smoking machine consumed 30, 15, 10, and 5 cigarettes in 13 minutes in a small room (38.2m^3). After 30 cigarettes had been smoked, 0.52 mg/m^3 nicotine was found in the room air. In 21 minutes, 0.46 mg acrolein/m^3 was reached. Acetaldehyde/m^3 attained a level of 6.5 mg in the same time period. The highest concentration of CO, 64 ppm, was reached immediately after smoking. With 5 cigarettes smoked in 13 minutes and without ventilation, CO was 11.5 ppm at the end of smoking; nicotine was 0.06 mg/m^3; acrolein reached 0.07 mg/m^3; and acetaldehyde was 1.3 mg/m^3.

In a considerably larger (170m^3) second test room, after the machine had smoked 150 cigarettes in 60 minutes, CO was 53 ppm; nicotine reached 0.69 mg/m^3; acrolein 0.38 mg/m^3; and acetaldehyde 4.2 mg/m^3. Ventilation reduced all levels by a factor of 2 to 5. In every test situation, with or without ventilation, all constituents fell rapidly with time after smoking, nicotine being the most rapid.

Harke (1974d) measured particulate matter produced by 30 cigarettes in a 38 m^3 office room. In eight determinations, average concentrations ranged from 20.8 mg/m^3 in 11 to 31 minutes to 16.2 mg/m^3 in 41 to 61 minutes. Particulate concentrations rapidly diminished with time at the end of the smoking phase.

Russell *et al.* (1973) studied room contamination and subject COHb levels of 21 volunteers who spent 1 hour in a 15 × 12 × 8 ft unventilated room. Before the test, 30 cigarettes were left to burn in ashtrays. An additional 32 cigarettes and two cigars were smoked, and 18 cigarettes were left smoldering. After 18 minutes, CO reached 37 and 32.5 ppm (two samples). After 53 minutes, CO reached 41.8 and 41.3 ppm. the mean level CO was 38.2 for the entire experiment. The nonsmokers' mean COHb levels were 1.6% before and 2.6% after the experiments.

Some very preliminary results of cigarette-produced CO pollution were reported by Lawther and Commins (1970). In a 15 m^3 exposure chamber, CO rose to 20 ppm after seven cigarettes were smoked in 1 hour. Particulate matter reached 3 mg/m^3. The ventilation rate was one room change per hour. Further details, however, were not specified.

Harmsen and Effenberger (1957) reported results from an experiment conducted in an unventilated 98 m^3 room where a number (unspecified) of persons smoked a large (62) number of "nicotine-rich" cigarettes in 30 minutes. CO reached 0.008% by volume or 80 ppm, and nicotine was 5.2 mg/m^3. (These high values, however, have never been replicated by any other investigator.)

Dublin (1972) burned two standard-brand unfiltered cigarettes. The room was medium-sized, 18 × 30 × 9 ft. Compared to background levels of 1 ppm of CO, a transient peak immediately after lighting a cigarette and in the immediate vicinity of the smoker was between 20.5 and 32.5 ppm (simultaneous samples). Further away, the levels were 13 and 17 ppm. Five minutes after smoking, the room reached equilibrium at 2 ppm of CO. The high initial concentration was the direct result of lighting up.

A number of investigations report on cigarette-produced pollution under *natural* conditions. CO was monitored for 18 days by Harke (1974a) in two office buildings, one air-conditioned, the other not. No significant overall increase in CO was found after employees started to smoke. The CO curve instead correlated well

with outdoor CO pollution. In individual rooms, increases of 1 to 2 ppm were found.

At a conference of the Academy of Allergy, cigarette-produced CO pollution was measured in the room and in the alveolar air of 11 persons attending (Slavin and Hertz, 1975). During the course of the meeting a ban on smoking was passed (unexpectedly). Two sets of conditions were thus examined, free smoking and non smoking. Initial concentrations in the meeting room during both days were 1 to 2 ppm. In the larger conference room, 8 ppm was registered by mid morning, and in the smaller room, 10 ppm was reached during the free smoking periods. After the smoking ban was enacted, CO concentrations remained about 1 to 2 ppm. Alveolar air CO content average 7 ppm in eight nonsmokers during free smoking and between 2 to 3 ppm in all individuals during nonsmoking.

In a study by Godin *et al.* (1972) higher values of CO were reported in a theater foyer, where smoking was permitted, than in the auditorium, where smoking was not permitted. Differences were small (3.4 ± 0.08 ppm vs 1.4 ± 0.8 ppm, respectively).

Further tests of tobacco smoke were conducted by Russell and Feyerabend (1975). They report on an experiment in which 80 cigarettes and two cigars were burned or smoked in an unventilated room, resulting in 38 ppm of CO. Individuals exposed in the experiment were then compared with two additional groups, 14 members of Russell's research group and 31 staff members of a nearby hospital. Blood and urinary nicotine levels were measured. For exposed nonsmokers, plasma nicotine increased from 0.73 to 0.90 ng/ml. Urinary nicotine after smoking was 80 ng/ml. Two other groups of non smokers (not exposed to the smoky room air) had 12.4 and 8.9 ng/ml of urinary nicotine. However, it is unclear what the exposure to tobacco smoke was for the comparison individuals. Horning *et al.* (1973) studied lab room air for nicotine content. They also investigated, as did Russell, physiological conditions of smokers' and nonsmokers' urine. Nicotine was detected in the air, but not in the water of the lab. (No precise levels were reported.) Nicotine was found in nonsmokers to be 5% of the level found in smokers. (But actual levels were not given.)

A few additional values for nicotine in public places were reported on by Hinds and First (1975). Samples were obtained for a restaurant, a cocktail lounge, and a student lounge with a hand-carried pump and filter. (However, this method tends to underestimate nicotine values [Harke, 1974d].) The restaurant was found to contain 5.2 $\mu g/m^3$ nicotine, while the cocktail lounge had 10.3 $\mu g/m^3$. The student lounge held 2.8 $\mu g/m^3$ of nicotine. These results were based on only a few samples taken and conditions were not detailed in each case (e.g., number of persons, room dimensions, number of smokers, etc.) On the basis of average amounts of nicotine/cigarette, cigarette equivalencies/hour were calculated to be 0.004 for the restaurant, and 0.009 and 0.002 for the cocktail and the student lounges, respectively. These latter results are more speculative than quantitative, however.

Smoking during 19 public gatherings in three arenas was the subject of an investigation by Elliott and Rowe (1975). The three arenas differed in size, ventilation, and smoking restrictions. Average CO was 14.3 ppm, particulates 367

$\mu g/m^3$, and BaP 12.5 ng/m^3 compared to background levels of 3 ppm, 68 $\mu g/m^3$, and 0.69 ng/m^3. Data insufficiencies prohibit reliable cross comparisons of the three arenas. However, differences in pollutant levels within one arena correlate well with crowd size. Smoking and poor ventilation are reported as contributing causes of these pollutant levels; however, no measures were taken.

Galuskinova (1964) reports on indoor benzo(a)pyrene air pollution in a Prague restaurant. Values found in the restaurant were compared with those for the city as a whole in both winter and summer. These values differed little in the summer but differed significantly in the winter (0.28 to 4.6/100 m^3 in the city and 2.83 to 14.4/100 m^3 in the restaurant). Galuskinova attributes the increase indoors to smoking. From what is known about entrapment and generation of pollutants, especially from cooking in a restaurant, such an inference would not be reasonable.

POLLUTANTS IN TRANSPORTATION-RELATED ENCLOSURES

Automobiles, buses, garages, tunnels, subways, underground streets, and platforms provide some form of enclosure (similar to that of households and office buildings) which may allow toxic substances to build up. The enclosure may be relatively well sealed, as in the cases of some automobiles, thus increasing the concentrating potential.

Automobiles

In a study by Brice and Roesler (1966), CO and hydrocarbons were measured in six major cities. Samples were taken so as to simulate the exposure to the driver. In warm weather, samples were taken with windows open, and in the winter with windows closed and heater/blowers on. In-car concentrations were shown to be consistently and considerably greater than (CAMP) values found in the cities Continuous Air Monitoring Programs. Average CO values in automobiles were 31.3 ppm, while outside values averaged 14.2 ppm. Average in-car hydrocarbons measured 6.4 ppm, while in-city values measured 3.5 ppm.

CO, monitored in cars in Paris (Chovin, 1967), showed mean concentrations of 24.3 ppm and 24.6 ppm in 1965 and 1966 studies. COHb levels of 1670 drivers involved in accidents were higher than those obtained from 3818 workers exposed to CO and 1530 individual cases of CO poisoning.

Haagen-Smit (1966) continuously recorded CO by means of a glass tube inserted in the windshield of a car driven through downtown Los Angeles. The mean CO level was 37 ppm in normal traffic and 54 ppm in heavy traffic. However, there were peaks as high as 220 ppm.

A number of CO samples within moving cars were obtained by Godin *et al.* (1972). Samples were taken both with heater fan on and off. Windows were closed at all times. CO remained at parking levels until the blower was activated. Street-level CO was reached in 30 to 60 seconds. Fluctuations during driving occurred with street-level changes, congested and "walled-in" areas having the highest levels of CO. Peak mean concentrations for heavy traffic were 78.8 ± 58.0 ppm.

CO may also leak into the car from emissions of its own engine. Amiro (1969) reported that of 19 automobiles tested in 1967, 9 were found to have CO emissions of up to 400 ppm leaking into the car. In a test for CO on a random sample of 60 cars, 30 were found to leak emission products (measured by CO) in varying

amounts. Internal emission is a considerable hazard since many automobiles are very nearly air tight with their windows and vents closed. Oxygen depletion is a problem often found in sealed environments and may be adding to the effects of other pollutants. At the same time, when a car is well sealed, emissions from the engine may remain entrapped within the automobile.

Buses

Fifty-two percent of 190 empty buses, tested for CO while the motor was running, were found to contain 25 to 800 ppm inside the bus. The highest concentration usually occurred at the rear of the bus, or at the front near the gear box (Amiro, 1969).

Johnson *et al.* (1975b) also tested CO in the passenger compartments of school buses. Ninety-seven tests were made. The mean range with the motor running was 10 to 25 ppm, although 8 buses were found to contain levels from 35 to 100 ppm of CO.

Subways

Contaminants inside subways have been tested. One study, conducted by Godin *et al.* (1972), has reported on CO values obtained during subway travel. Allowing for high (0.08 to 0.18%) CO_2 levels, CO concentrations were found to reach 3.4 ± 2.6 ppm on open sections of track. In tunnels, however, CO averaged as high as 5.5 ± 3.2 ppm. As smoking is not permitted on subways, these levels were thought to be due to street-level air intakes. Another study conducted in Osaka by Matsumoto and Kitamura (1971) found that on the average, levels of dust on platforms exceeded above-ground concentrations by one and a half times. Values for dust inside trains of subways ranged from 0.43 to 2.42 mg/m^3 with a mean concentration of 1.20 mg/m^3.

Tunnels

Tunnels are basically closed systems because of their structural design (and two-way traffic flow.) As closed systems, they trap pollutants inside. Conlee *et al.* (1967) compared values taken from the Sumner Tunnel in Boston when it was used as a one-way tube and when it was used as a two-way system. Pollutant levels decreased when the tunnel was used for one-way traffic only.

Larsen and Konopinski (1962) conducted a thorough study of pollutants in the Sumner Tunnel. CO peaked at 250 ppm (at this concentration warning signals caused new vents to be opened.) Many weekday peaks ranged from 120 to 150 ppm. The soiling index inside the tunnel was found to be five times that outside. Particulate matter was 100 μg/m^3 outside and 600 μg/m^3 inside. Organic particulate matter was found to be 11 times the outside amount, which indicates considerable enrichment inside the tunnel. Lead inside the tunnel was found to be 45 times the outside levels. Benzo(a)pyrene was as much as 200 times more concentrated inside the tunnel than outside. Findings similar to Konopinski's were reported by Chovin (1967) in a Paris auto-exhaust study. Chovin also found that the concentration of pollutants within a tunnel depended on its length. Ayres *et al.* (1973), reporting for New York tunnels, found that CO averages were 63 ppm for the 30-day testing period with peaks of 217 ppm. Lead averaged 30.9 μg/m^3 with peaks up to 98 μg/m^3, as determined by high-volume sampling. Hydrocarbons

average 7.9 ppm with peaks at 29.6 ppm. Similar findings were reported by Wilkins (1956) of CO levels in Blackwell Tunnel in London. Levels ranged from 150 to 590 ppm, in 1954, and from 235 to 470 ppm in 1955. A later investigation of the same tunnel, and of Rotherhithe Tunnel, was conducted by Waller *et al.* (1961). Again, values for all pollutants were extremely high. Particulates ranged from 93 to 235 $\mu g/100\ m^3$. CO on the average was over 100 ppm, with a maximum peak at 500 ppm. Oxides of nitrogen ranged from 1 to 8 ppm.

Garages

Parking garages may have pollutant-concentrating abilities similar to those of tunnels. Ramsey (1967) found garage air to contain from 7 ppm to 240 ppm of CO. The mean concentration was 58.9 ppm. In all employees, COHb levels were found to increase significantly from 2.4% in the morning to 8.4% in the evening. Trompeo *et al.* (1964) reported similar findings for garages in Turin. CO levels were found to reach 100 ppm, on the average, ranging from 10 to 300 ppm. Chovin (1967) measured 80 to 100 ppm of CO on the average, with frequent peaks of 200 ppm lasting for as long as 20 minutes, in ventilated Paris garages. Goldsmith (1970) reported that traffic jams in parking garages during mass exits could raise levels of pollutants to extreme concentrations. While no measurements have been taken of pollutants such as benzo(a)pyrene, soiling particulates, or lead, the findings on CO would indicate that these pollutant levels are also probably very high.

Airplanes

Unlike submarines, fresh air enters the aircraft during flight, and little if any machinery within the passenger cabin contributes to the pollution load. A study by the U.S. Department of Transportation (1971) tested the air during a large number of flights for CO, hydrocarbons, ammonia, particulates, ozone, relative humidity, and temperature. Sampling was undertaken in four locations throughout each aircraft. Pollutant concentrations were, on the whole, low. CO for the majority of flights was less than 5 ppm and averaged 2 ppm. No hydrocarbon contamination was detected. Particulates were higher, measuring 120 $\mu g/m^3$. Some benzo(a)pyrene contamination was found with particulates but only in five samples. Ammonia and ozone levels were negligible.

TOBACCO-INDUCED POLLUTION IN TRANSPORTATION-RELATED ENCLOSURES

As with domestic premises, tobacco smoke data for transportation-related enclosures such as cars, garages, buses, and trains, is spares. However, there are a few useful studies available.

Automobiles

In 1974, Harke *et al.* conducted two sets of experiments with cigarette-produced CO. In the first of these tests (1974b), a car was placed in a wind tunnel with four passengers, three of whom smoked cigarettes. Time spent smoking was varied, as was wind speed and ventilation. At 0 km/hour, with full ventilation, CO averaged 8 to 10 ppm when six cigarettes were smoked intermittently. At 50 km/hour with no ventilation, and nine cigarettes smoked intermittently, CO reached 30 ppm. When cigarettes were smoked continuously, one after the other, final CO levels were registered at 80 ppm with no wind or ventilation factor. With

wind and ventilation, however, CO remained at 5 to 6 ppm, with no increases observed. In all cases CO levels returned to base levels even with no ventilation, within a few minutes after smoking stopped.

In the second set of tests (Harke, 1974a), cars of different makes were driven in Hamburg streets while being tested for CO. Cigarettes were smoked continuously by two of the four passengers. Each car made two runs per day with and without ventilation. At no ventilation, 21.4 ppm CO was registered on the average. With the air jets open, CO averaged 15.7 ppm, and with the blower also on, CO averaged 12.0 ppm. Speed was also an important factor. At 80 km/hour and with ventilation off, CO averaged 12.1 ppm, while at 35 km/hour CO reached 24.3 ppm. Unfortunately, Harke does not report background CO levels.

Srch (1967) measured CO concentrations produced by cigarettes in a closed automobile with no ventilation present in or outside. The test car was parked in an unventilated garage while two smokers consumed five cigarettes each in 1 hour. CO levels reach 90 ppm in that time. COHb in smokers rose from 5 to 10%, and in the two non smokers present, from 2 to 5%.

Buses

The U. S. Department of Transportation in 1973 conducted a study of cigarette-caused pollution on intercity buses. Inside a stationary Greyhound bus with the engine off, vents open, and blower on, cigarettes were allowed to burn in the ashtrays. Test conditions ranged from the "worst" case, where it was assumed that all 43 passengers smoked half the time, to the "realistic" case, where only the last 20% of the seats were allotted to smokers. After 30 minutes in the worst case, CO stabilized at 33 ppm, and in the realistic case, CO stabilized at 18 ppm, after 43 minutes, with the outside level 13 ppm.

Additional values obtained under normal operating conditions were provided by Hinds and First (1975). Nicotine concentration was found to be 6.3 $\mu g/m^3$ on a commuter bus and 1.0 $\mu g/m^3$ in a bus station waiting room. These values, however, represent only a single case. Hinds and First also reported that passengers ignored smoking and nonsmoking zones indicated on the bus. As some suggestions have been made to segregate smokers and nonsmokers on buses, Hinds and First's observations raise the problem of how such segregations would be enforced. Also, as Amiro (1967) had found CO values to be higher at the rear of the bus, a question is raised of how to distribute smokers and nonsmokers equitably.

Trains

Harmsen and Effenberger (1957) studied "dust" in nonsmoker and smoker cars. Dust values in smoker cars ranged from 100 to 200 particles/cm^3 of air, and from 21 to 63 particles/cm^3 in nonsmoker cars. The numbers of cigarettes were not specified. Unfortunately it was not reported whether the numbers of passengers were different in the two types of car. CO and nicotine were then surveyed on the same trains. CO ranged from 0 in nonsmoker cars, up to 40 ppm in heavily smoked cars. Nicotine ranged from 0.7 mg/1000 liters with light smoking to 3.1 mg/1000 liters with heavy smoking. The method of CO measurement (Draeger tube) used in this study, however, is not a very accurate one, and has a wide margin of error (±25%). This applies to the nicotine assay method (wet method) as well.

Hinds and First (1975) reported nicotine concentrations of a much lower level.

Their measurements on a commuter train averaged 4.9 $\mu g/m^3$. This was calculated as a smoking equivalent of 0.004 cigarettes/hour.

Ferryboat

There is one report of tobacco-induced pollution on a ferryboat. Both smoking and nonsmoking sections were tested for CO concentrations by Godin *et al.* (1972). Carbon monoxide averaged 18.4 ± 8.7 ppm in the smoking compartment and 3.0 ± 2.4 ppm in the nonsmoking section. (Unfortunately important information was not included as, for example, proximity to the engine room. It is difficult in this case to determine emission sources precisely.)

Airplanes

In response to public inquiry into tobacco smoke pollution in aircraft, the U.S. Department of Transportation in conjunction with the Federal Aviation Administration and NIOSH undertook a study of military and domestic flights. All smoke constituents were found to be extremely low due to ventilation. CO averaged 2 ppm while aldehydes and volatile hydrocarbons could not be detected. Particulates ranged up to 120 $\mu g/m^3$.

In addition to testing for nicotine concentrations aboard aircraft, Hinds and First (1975) tested an airplane waiting room for nicotine and found 3.1 $\mu g/m^3$ and a cigarette equivalent of 0.003/hour.

DISCUSSION AND SUMMARY

It has been assumed, somewhat naively, that exposure to toxic pollutants is limited largely to the air outside buildings and inside industrial shops. However, in the few studies in which pollutants were studied inside homes, schools, public buildings, and public places of assembly, the findings showed persisting higher levels of some pollutants inside these structures than outside. Even in transportation vehicles, pollution tends to be higher inside than outside. We have summarized our findings in a number of tables for the different types of enclosed spaces for different communities in different studies and for different pollutants (*see the Appendix*). The results of all these studies consistently and dramatically point to an increase of exposure in the enclosed space.

As we tend to spend most of our time either at home or in some public building, or traveling between one building or another, we are constantly exposed to levels of toxic materials which exceed the same levels measured on the outside. The reason is not hard to find. An enclosed space tends to entrap pollutants seeping in from outside. Additional pollutants are produced (and concentrated) in the enclosed space by crowding, by a large number of machines (some of which are designed to remove pollutants), by the activity of people, and by materials present and their decay over time.

In artificially closed spaces the air is constantly cleaned by a number of anti pollution devices. Concentrations reported are of pollutant levels that exist during the operation of these air-cleaning devices. Without constant air cleaning, it would not be possible for man to survive in sealed spaces. On the other hand, most domestic enclosures, office buildings, and public places of assembly do not have the complex filtering and screening procedures to eliminate pollutants that enter from outdoors and, much less, to remove all the various pollutants generated

indoors. Ventilation through doors, windows, cracks, and crevices is the sole avenue for the elimination of toxic contaminants. It is not surprising, therefore, to find that the air in homes and other areas of human habitation sometimes exceeds exposure levels to toxic materials found in submarines and space craft. It has yet to be recognized that the dangers of contaminants in sealed environments also apply to partially sealed domestic premises and especially to the modern office-building type of structure. This is especially true because the many sources of pollution isolated in artificially sealed environments are present in the home and in public buildings.

Significant, too, is the enrichment of particles in the house. Particles such as soot and fibers offer surfaces to which may adhere any number of chemicals. Many of these chemicals may be toxic. One frequent source of such toxic materials is the industrially employed adult who may carry home dusts containing harmful substances such as beryllium and asbestos on his clothing, hair, or skin. (For instances of familial disease see Lieben and Williams (1969) and Anderson (1976).) There are many other sources, generated both within and without a building. Many of the pollutants result from the combustion of coal and petroleum. Much of this benzene-soluble organic matter that adheres to and is found in heightened concentrations on particles breathed in the home is basically carcinogenic. The longer the particles remain in a home, the more they may become *concentrators* of toxic matter. *When such particles become lodged in the lungs, they may be much more harmful than particles found in the outside air.* In fact, the incidence of so-called familial occupational disease may be related to this process of particle enrichment.

High levels of CO resulting from cooking should be of considerable concern. Apparently CO levels of 200 to 300 ppm are not unlikely to occur in poorly ventilated homes, and the extremely high levels of CO (as found in Nigerian and New Guinea homes) may very likely occur also in homes in North America. This is especially so in the homes of the poor, where good ventilation is not likely to be found.

Great concern has been expressed recently that tobacco smoke is a major source of pollution in the home and in public buildings (Schmeltz *et al.* (1975) and Rylander (1974), for instance.) Our review of data has therefore taken special notice of studies that have measured levels of tobacco-related pollutants. Unfortunately, many of the studies measuring dust or CO in the smoker's environment innocently assume zero levels of these contaminants in the absence of smoke so that the addition of smoking to the overall pollution can be assessed only approximately. Fortunately, it has now been shown that CO values in buildings and the associated COHb levels and the contributions of smoking to these levels can be estimated with great accuracy. Where conditions of ventilation and other parameters are known, contributions of cigarette emissions to CO and COHb levels were predicted with good accuracy by Jones and Fagan (1974, 1975). This was accomplished by applying to the by now well-tested equation developed by Turk and another equation for COHb levels by Pace (1946), data from Anderson and Dalhamn (1973), Lefcoe and Inculet (1971), and the Department of Transportation surveys of aircraft (1971) and buses (1973). With poor ventilation, it appears that

smoking adds to the body burden, but not extensively. For instance, CO values in average-sized public rooms and under average conditions of ventilation appear to be increased by 7 to 9 ppm when smoking is permitted in them (Bridge and Corn, 1972). Similarly, the amount of nicotine found in the air of public places ranges between 0.001 and 0.011 filter-cigarette equivalents per hour (Hinds and First, 1975). It is clear that while smoking adds to overall pollutant levels, it is only one other, and a relatively minor, source of pollution.

SOME UNPLEASANT CONCLUSIONS ABOUT POLLUTANT BURDENS IN PUBLIC BUILDINGS

As with domestic structures, many sources of indoor contamination found in submarines are also likely to be found in public buildings. Yet, the increasing use of steel and glass structures suggests a number of serious problems. As in all sealed structures, the escape rate of contaminants is seriously impeded and pollutants may easily build up inside. It may be possible that many of the undesirable features of completely enclosed structures, such as submarines, actually are amplified by the characteristics of public buildings. Also, the special antipollution devices which submarines carry are conspicuously absent in office and public buildings. In general, public buildings have no way of removing CO, CO_2, hydrocarbons, lead, ammonia, oxides of nitrogen, oxidants, and other pollutants present in the outer air and likely found indoors as well. The more airtight a structure is, the longer it can trap contaminants inside. As Schulte (1964) points out, pollutant concentrations in submarines rise very rapidly when the CO burners, CO_2 scrubbers, electrostatic precipitators, inert filters, activated beds, etc., are not operating. Usually there are no similar air-cleansing mechanisms in public structures.

Present studies appear to show that indoor pollution in public office buildings is of greater potential harm than outdoor pollution. Air-conditioned and modern enclosed buildings are penetrable, sometimes highly penetrable, by nearly all forms of outdoor pollution. Even with filtration and pollutant-removal devices, there is a great possibility that pollutants will be trapped inside and will lead to continuous exposure at high levels. With a significant increase in outside pollution to be expected in cities as we turn increasingly toward cheaper fuels, these exposures may constitute a real threat to the health of a large part of the urban population.[1]

[1] This threat may be infinitely aggravated during energy crises, when the action of ventilation equipment and antipollution devices will be curtailed, according to recent suggestions by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (1975).

TABLE 1

PARTICULATES

Source	Location	Mean value	Range	Comments
Biersteker *et al.*, 1965	Domestic premises (N = 60)	157.72 $\mu g/m^3$[a]	52–309 $\mu g/m^3$	Indoor = 80% of outdoor
Cleary and Blackburn, 1968	Domestic premises	666 $\mu g/m^3$	Peak = 4862 $\mu g/m^3$	
Jacobs *et al.*, 1962	Domestic premises	Not given	1.7–34.9 mp/ft^3	More fibers found indoors
Lefcoe and Inculet, 1971, 1975	Domestic premises	(1022.79)·(10^3/ft^3) (filter off)[a]	(139.3–1584.28)·(10^3/ft^3)	
		(406.66)·(10^3/ft^3) (filter on)[a]		Outdoor higher than indoor
Schaefer *et al.*, 1972	Domestic premises (N = 100)	Not given	4.5–9 mg (mass/foil) residential areas 9 to >18 mg (mass/foil) cities	
Yocom, 1971a,b	Domestic premises (N = 2)	Not given	32–76 $\mu g/m^3$	Indoor level less than outdoor
DeRouane, 1971	Buildings	38 and 45 $\mu g/m^3$	Up to 300 $\mu g/m^3$	77.5–84.9% of outdoor level
Jacobs *et al.*, 1962	Buildings	Not given	4–53.4 mg/ft^3	Smaller particles indoors
Japan Air Cleaning Assoc., 1968	Buildings	Not given	Not given	Filters reduce particles "significantly"
Hunt and Cadoff, 1971	Buildings	Not given	Not given	Lower levels indoors
Matsumoto and Kitamura, 1971[b]	Buildings	Not given	0.22–2.04 mg/m^3	Double outdoor values "severe" dust
Yocom, 1971a,b	Buildings	Not given	22–107 $\mu g/m^3$	Lower levels indoors
Ayres *et al.*, 1973	Tunnels	200 $\mu g/m^3$	Not given	
Larsen and Konopinski, 1962	Tunnels	600 $\mu g/m^3$	Not given	Six times outside levels
Waller *et al.*, 1961	Tunnels	Not given	93–235 $\mu g/100m^3$	
Matsumoto and Kitamura, 1971	Subways	1.28 mg/m^3	0.43–2.43 mg/m^3	1½ times outside levels

[a] Derived from tables.

[b] Department stores, cinema, tearoom, bowling alley.

TABLE 2
SOILING INDEX

Source	Location	Mean value	Range	Comments
Yocom, 1971a,b	Domestic premises	Not given	0.22–0.52 Cohs/1000 ft	
Yocom, 1971a,b	Buildings	Not given	0.19–0.61 Cohs/1000 ft	
Larsen and Konopinski, 1962	Tunnels	4.25 Cohs/1000 ft	Not given	0.53 Cohs/1000 ft (outdoors)

TABLE 3
CARBON MONOXIDE

Source	Location	Mean value (ppm)	Range (ppm)	Comments
Amiro, 1969	Domestic premises (N = 300)	Not given	200–300 (selected cases)	90% of homes tested, CO positive
Cleary and Blackburn, 1968		21.3	150 (peak)	
Godin *et al.*, 1972	Farm house			
	Outdoor	0.8 ± 0.6	Not given	
	Indoor	1.0 ± 0.8	Not given	
	Suburban home			
	Outdoor	2.0 ± 1.4	Not given	
	Indoor	1.9 ± 1.3	Not given	
Goldsmith, 1970	Domestic	Not given	Not given	100,000 persons exposed/yr in U.S.
Kahn *et al.*, 1974	Domestic	Not given	Not given	Winter indoor CO higher than outdoor
Sofoluwe, 1968	Domestic (N = 98)	940.2	100–3000	
Tanaka *et al.*, 1971	Domestic (gas stove)	Not given	up to 290	
Wade *et al.*, 1975	Domestic (kitchen)	Not given	4190–9070[a]	Peaks occurred coincidental to operation of gas appliances
Yates, 1967	(Gas stove)	Not given	10–2500+	Referrals tested, 100% CO positive
Yocom, 1971a,b		Not given	1–5 ppm	random sample tested, 33% CO positive
Godin *et al.*, 1972	Buildings			
	Small	1st floor, 2.2 ± 1.3	Not given	Outdoor = 2.7 ± 1.5 ppm
		2nd floor, 2.8 ± 1.5	Not given	
	Tall	1st floor, 4.6	Not given	Outdoor = 6.4 ppm
		54th floor, 2.4	Not given	

Japan Air Cleaning Society, 1969	Buildings	Not given	Not given	CO same as outdoors
Johnson *et al.*, 1975	Ice rink	304 (mean peak)	157–304 range of means	
Yocom, 1971a; 1971b	Buildings (N = 4)	3.14	0.76–6.02	Indoor/outdoor ratio = 100% and over
Amiro, 1969	Cars (N = 21)	400 (mean peak)	Range 0–1000	In one car driver's seat contained 200 ppm in 60 seconds
Brice and Roesler, 1966	Cars	Chicago, 37	20–59	
		Cincinnati, 21	8–50	
		Denver, 40	22–72	
		St. Louis, 36	11–77	
		Washington, 25	7–43	
Chovin, 1967	Cars	24.3 (1965)	Not given	
		24.6 (1966)	Not given	
Godin *et al.*, 1972	Cars	78.8 ± 58.0 (mean peak for heavy traffic)	Not given	
			Not given	
Haagen-Smit, 1966	Cars	37 (normal traffic)	220 (peak)	
		54 (heavy traffic)		
Ayres *et al.*, 1973	Tunnels	63	Up to 217	
Larsen and Konopinski, 1962	Tunnels	Mean range 120–150	250 (peak)	
Waller *et al.*, 1961	Tunnels	100	Up to 500	
Wilkins, 1956	Tunnels	Not given	150–590 (1954)	
			235–470 (1955)	
Chovin, 1967	Garages	Mean range 80–100	200 (peak)	
Ramsey, 1967	Garages	58.9	7–240	
Trompeo *et al.*, 1964	Garages	100	10–300	
Amiro, 1969	Bus (N = 191)	Not given	25–800	52% tested, CO positive
Johnson *et al.*, 1975	Bus	15–25	0–100	

[a] $\mu g/m^3$.

TABLE 4
OXIDES OF NITROGEN

Source	Location	Mean value	Range	
DeRouane and Verduyn, 1974	Kitchen	600 $\mu g/m^3$ (water heater) 250 $\mu g/m^3$ (gas range)	Not given	NO_2 = one-third of total NO_x during operation of appliances
	Bathroom	Not given	Up to 2000 $\mu g/m^3$	
Lefcoe and Inculet, 1975 (NO_2)	Domestic premises	<0.1 pphm[a]	0.5–1.5 pphm	No significant difference in indoor and outdoor
Sofoluwe, 1968	Domestic premises	8.6 ppm	0.5–50 ppm	
Wade *et al.*, 1975 (NO_2)	Domestic (kitchen)	Not given	Range of means: 53–213 $\mu g/m^3$	Peaks coincidental to operation of gas appliances
(NO)	Domestic (kitchen)	Not given	53–305 $\mu g/m^3$	
Ayres *et al.*, 1973	Tunnels	1.38 ppm	Up to 6.13 ppm	
Larsen and Konopinski, 1962	Tunnels	25.5 $\mu g/m^3$	Not given	
Waller *et al.*, 1961	Tunnels	Not given	1–8 ppm	

[a] Derived from tables.

TABLE 5
AMMONIUM SULFATE

Source	Location	Mean value	Range	Comments
Hunt and Cadoff, 1971	Buildings	Not given	Not given	Detected
McNesby *et al.*, 1972	Building	Not given	Not given	Detected

TABLE 6
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Source	Location	Mean values ($\mu c/m^3$)	Range
Megaw, 1962	Domestic premises	$1.54 \times (10^{-4})$	Not given
Megaw, 1962	Buildings	$2.7 \times (10^{-3})$	Not given

TABLE 7
HYDROCARBONS

Source	Location	Mean value (ppm)	Range (ppm)	Comments
Bridbord *et al.*, 1975	Domestic premises	Not given	Not given	Sources of halogenated hydrocarbons aerosols and solvents
Sofoluwe, 1968	Domestic premises	85.6	25–200	
Yocom, 1971a,b	Domestic premises	Not given	5.3–25.6[b]	More benzene indoors
Yocom, 1971a,b	Buildings	Not given	5–24.6[b]	More benzene indoors
Brice and Roesler, 1966	Cars			
	Chicago,	4.8	2.4–8.4	
	Cincinnati,	5.7	3.6–11.6	
	Denver,	9.6	4.6–19.0	
	St. Louis,	9.3	4.4–19.0	
	Washington, D.C.	6.2	2.0–23.0	
Ayres *et al.*, 1973	Tunnels	7.9	Up to 29.6	
Larsen and Konopinski, 1962	Tunnels	690[a]	Not given	$\bar{x}$ = 2.6 ng/m^3 (outside)

[a] ng/m^3.
[b] μg/m^3.

TABLE 8
LEAD

Source	Location	Mean value ($\mu g/m^3$)	Range ($\mu g/m^3$)	Comments
Yocom, 1971a,b	Domestic premises	Not given	0.47–1.75	Slightly greater indoors
Hunt and Cadoff, 1971	Buildings	Not given	Not given	Detected
McNesby *et al.*, 1972	Buildings	Not given	Not given	Detected
Yocom, 1971a,b	Buildings	Not given	0.18–2.04	Slightly greater indoors
Ayres *et al.*, 1973	Tunnel	30.9	Up to 98	
Larsen and Konopski, 1962	Tunnel	45	Not given	1 $\mu g/m^3$ = outdoor $\bar{x}$

TABLE 9
SULFUR DIOXIDE

Source	Location	Mean value	Range	Comments
Biersteker *et al.*, 1976	Domestic premises (N = 60)	35.43 $\mu g/m^3$[a]	0–246 $\mu g/m^3$	20% of outdoor levels
Lefcoe and Inculet, 1975	Domestic premises	<0.06 pphm[a]	0–<0.1	Little difference in outdoor–indoor
Sofoluwe, 1968	Domestic premises	37.8 ppm	5–100 ppm	
Yocom, 1971a,b	Domestic premises	Not given	Up to 0.8 ppm	Coal-heated homes, more SO_2 indoors
DeRouane, 1971	Buildings	95 and 59 $\mu g/m^3$	Up to 300 $\mu g/m^3$	25% of outdoor levels
Japan Air Cleaning Assoc. 1968	Buildings	Not given	Not given	20% of outdoor levels
Yocom, 1971a,b	Buildings	Not given	Not given	Little relation between indoor and outdoor

[a] Derived from tables.

TABLE 10
CARBON DIOXIDE

Source	Location	Mean value	Range	Comments
Tanaka *et al.*, 1971	Domestic premises	Not given	Not given	Rise in CO_2, 0 depleted
Grusha and Leshchinskii, 1964	School	Not given	Not given	Double by end of class
Matsumoto and Kitamura, 1971	Buildings	Not given	Not given	Higher levels indoors
Srch, 1967	Cars	3% in 60 minutes	Not given	0 depleted

TABLE 11
MINERALS

Source	Location	Mean value	Range	
Lieben and Williams, 1969	Domestic premises	Not given	Not given	Beryllium detected
Rohl *et al.*, 1975	Domestic premises	9.38 fibers/ml[a]	0.5 to 59.0	Asbestos, quartz, and talc detected
Selikoff *et al.*, 1972	Domestic premises	Not given	Not given	Asbestos, higher in workman's home than outdoors
Castleman and Fritsch, 1973	Buildings	Not given	Not given	Asbestos, found in fire-proofing of buildings

[a] Derived from tables.

TABLE 12
MISCELLANEOUS

Source	Location	Mean value	Range	
Cleary and Blackburn, 1968	Domestic premises	1.08 ppm	3.8 ppm peak	Aldehydes
Banaszak *et al.*, 1970, 1974	Heaters and air conditioners	Not given	Not given	Thermophilic fungi detected
Fink *et al.*, 1971	Heaters and air conditioners	Not given	Not given	Thermophilic fungi detected

TABLE 13

STUDIES ON INDOOR TOBACCO SMOKE CO MEASURED UNDER EXPERIMENTAL CONDITIONS

Study	Location	Dimensions of premises	Ventilation	Amount of tobacco smoked	Number of persons present	Time	CO levels (ppm) smoking ($\bar{x}$)	CO levels (ppm) Nonsmoking controls
DeRouane and Verduyn, 1974	Domestic premises	50 m^3	Closed	3 cig.	0	34 min	7.5 ppm	~4 ppm
Anderson and Dalhamn, 1973	Conference room	80 m^3	6/hr	50 cig.	7 smokers & 5 nonsmokers	120 min	4.5 ppm 6 ppm (peak)	2 ppm
Bridge and Corn, 1972	Party No. 1	5120 ft^3	7 changes/hr	50 cig. 17 cigars	25 nonsmokers 25 smokers	1.5 hr	7 ppm	No controls
	Party No. 2	3570 ft^3	10.6/hr	63 cig. 10 cigars	37 smokers 36 nonsmokers	1.5 hr	9 ppm	No controls
Dublin, 1972	Conference room	4860 ft^3	12/hr	2 cig.	1 person	Initial value	20.5–32.5	1 ppm
	Conference room	4860 ft^3	12/hr	2 cig.	1 person	5 min	2	1 ppm
Harke, 1970	Office	30 m^3	Open window	11 cig.	1 person	5 hr	Under 10	None
	Office	30 m^3	Closed, no vent	11 cig.	1 person	5 hr	Under 10	None
	Office[a]	57 m^3	Closed no vent	42 cig.	21 persons	16–18 min	48 ppm	None
Harke *et al.*, 1972	Office[a]	170 m^3	Closed, no vent	150 cig.	0	30 min	53 ppm	None
	Office[a]	38.2 m^3	Closed, no vent	5 cig.	0	13 min	11.5	None
	Office[a]	38.2 m^3	Closed no vent	30 cig.	0	13 min	64	None

Harmsen and Effenberger, 1957	Office[a]	98 m³	Closed, no vent	62 cig., "nicotine-rich"	Not given	2 hr	80	None
	Office	98 m³	Closed, no vent	26 cig.	Not given	1 hr	40	None
Hoegg, 1972	Office	25 m³	Closed,	24 cig.	1 person	200 min	69.8	Not given
	Office	25 m³	no vent	4 cig.	1 person	200 min	~10	Not given
Lawther and Commins, 1970	Office	15 m³	1 change/hr	7 cig.	Not given	1 hr	20	None
Russell *et al.*, 1973	Office[a]	1440 ft³	No vent.	80 cig., 2 cigars	21 persons	18 min	38.2	None
Harke *et al.*, 1974b	Car[a]	Not given	50 km/hr No vent.	9 cig.	4 persons	Simultaneous	30	None
	Car	Not given	No vent	6 cig.	4 persons	Simultaneous	10	None
	Car[a]	Not given	0 km/hr Vent. open	6 cig.	4 persons	Simultaneous	8–10	None
	Car	Not given	0 km/hr No vent.	9 cig.	4 persons	Simultaneous	110	None
	Car	Not given	59 km/hr No vent	6 cig.	4 persons	One by one	10–15	None
	Car	Not given	50 km/hr Vent. open	6 cig.	4 persons	One by one	5–6	None
	Car[a]	Not given	0 km/hr No vent	6 cig.	4 persons	One by one	80	None
Srch, 1967	Car[a]	Not given	Parked in garage, no vent	10 cig.	4 persons 2 smokers	1 hr	90	None
Dept. of Trans., 1973	Bus[a]	Not given	Not given	21 cig.	0	30 min	33	7 ppm ambient level
	Car	Not given	Not given	5 cig.	0	42 min	18	13 ppm ambient level

[a] Abnormally high smoking rates.

TABLE 14
STUDIES ON INDOOR TOBACCO SMOKE PARTICULATES MEASURED UNDER EXPERIMENTAL CONDITIONS[b]

Study	Location	Dimensions of premises	Ventilation	Amount of tobacco smoked	Number of persons present	Time	Particulates	
							Smoking ($\bar{x}$)	Nonsmoking controls
DeRouane and Verduyn, 1974	Domestic	50	Closed	3 cig.	0	24 min	1000 $\mu g/m^3$	Not given
McNall, 1975	Domestic[a]	425	0.35 m^3/sec recirculation	12 cig.	0	1 hr	~1100 $\mu g/m^3$	60 $\mu g/m$
	Domestic[a]		0.06 m^3/sec infiltration	35 cig.	0	1 hr	~2700 $\mu g/m^3$	60 $\mu g/m$
Anderson and Dalhamn, 1973	Conference room	80	6/hr	50 cig.	7 smokers 5 nonsmokers	120 min	0.02 mg/m^3	None
Harke, 1974d	Office[a]	38	No vent.	30 cig.	0	11–90 min	20.8–10.2 mg/m	None
Harmsen and Effenberger, 1957	Office[a]	98		62 cig.	Not given	2 hr	93 part/cm^3	None
	Office[a]	98	No vent.	26 cig.	Not given	1 hr	53 part/cm^3	None
Hoegg, 1972	Chamber	25	No vent.	24 cig.	1 person	200 min	16.65 mg/m^3	Not given
	Chamber	25	No vent.	4 cig.	1 person	200 min	~2.5 mg/m^3	
Lawther and Commins, 1970	Office[a]	15	1 chg/hr	7 cig.	1 person	1 hr	3 mg/m^3	Not given

[a] Abnormally high smoking rates.

[b] Note: At present, methods for determining levels of particulate matter generated by cigarettes are not entirely accurate. Harke (1974d) studied dust sampling on filters, light scattering, FID and IR-adsorption methods. All proved unsatisfactory in at least one main aspect.

TABLE 15

STUDIES ON INDOOR TOBACCO SMOKE ACROLEIN AND ACETALDEHYDE MEASURED UNDER EXPERIMENTAL CONDITIONS

Study	Location	Dimensions of premises (m^3)	Ventilation	Amount of tobacco smoked	Number of persons present	Time (min)	Acrolein (mg/m^3)	Acetaldehyde
Harke *et al.*, 1972	Office[a]	38.2	None	5 cig.	0	13	0.07	1.3
	Office[a]	38.2	None	30 cig.	0	13	0.38	4.2
	Office[a]	170	None	150 cig.	0	30	0.46	6.5

[a] Abnormally high smoking rates.

TABLE 16

STUDIES ON INDOOR TOBACCO SMOKE NICOTINE MEASURED UNDER EXPERIMENTAL CONDITIONS

Study	Location	Dimensions of premises	Ventilation	Amount of tobacco smoked	Number of persons present	Time	Nicotine	
							mg/m^3 smoking	Nonsmoking
Anderson and Dalhamn, 1973	Office	80	6/hr	50 cig.	7 smokers 5 nonsmokers	120 min (peak)	0.377	Not measured
Harke, 1970	Office	30	Not given	11 cig.	1 person	5 hr	0.04	Not measured
	Office	30	Window open	11 cig.	1 person	5 hr	0.06–0.09	Not measured
	Office[a]	57	Not given	42 cig.	21 persons	16–18 min	0.5	Not measured
Harke *et al.*, 1972	Office[a]	30.2	Not given	5 cig.	Not given	13 min	0.06	Not measured
	Office[a]	30.2	Not given	30 cig.	Not given	13 min	0.52	Not measured
	Office[a]	170	Not given	150 cig.	Not given	18 min	0.69	Not measured
Harmsen and Effenberger, 1957[b]	Office[a]	98	Not given	62 cig.	Not given	2 hr	~5.2	Not measured
	Office[a]	98	Window open	26 cig.	Not given	1 hr	~3.8	Not measured

[a] Abnormally high smoking rates.

[b] These results were determined with highly unspecific testing methods and have never again been obtained in any other study.

TABLE 17

STUDIES ON INDOOR TOBACCO SMOKE CO MEASURED UNDER NATURAL CONDITIONS

Study	Location	Dimensions of premises	Ventilation	Amount of tobacco smoked	Number of persons present	Time	CO Levels	
							Smoking (ppm)	ppm Nonsmoking
Elliott, 1975	Arenas	Not given	Not given	Not given	11,000 to 14,000	Not given	14.3	3
Godin, 1972	Theatre	Not given	Not given	Not given	Not given	Not given	3.4 ± 0.08 (foyer)	1.4 ± 0.8 (auditorium)
Harke, 1974a	Office	21 stories	Not given	40 cig./day in large room	Not given	18 days	2–11	2–11
	Office	12 stories	Not given	70 cig./day in large room	Not given	18 days	2–11	2–11
	(Individual rooms)		Not given	Varied	Not given	18 days	1–2 $\bar{x}$ increase	2–11
Slavin, 1975	Confce. rm	Not given	8/hr	Not given	Not given	1 day	8	1–2
		Not given	6/hr	Not given	Not given	1 day	10	1–2
Harke, 1974c	Cars	Not given	30 km/hr No vent	Freely	4 persons (3 smokers)	Not given	21.4 (increase) over outside)	11–15
		Not given	30 km/hr Vent open	Freely		Not given	10.7	11–15
		Not given	80 km/hr No vent	Freely		Not given	10–12	11–15
		Not given	80 km/hr Vent open	Freely		Not given	7–10	11–15
D.O.T., 1971	Aircraft	Not given	Not given	Not given	Not given	Not given	2	Not measured
Godin *et al.*, 1972	Ferryboat	Not given	Not given	Not given	Not given	Not given	18.4 ± 8.7	3.0 ± 2.4

TABLE 18

BENZO(A)PYRENE, NICOTINE, AND PARTICULATES MEASURED UNDER NATURAL CONDITIONS

Study	Location	Dimensions of premises	Ventilation	Amount of tobacco smoked	Number of persons present	Time	Smoking	Nonsmoking
							Particulates	
Elliott and Rowe, 1975	Arenas	Not given	Not given	Not given	11,000 - 14,000	Not given	367 $\mu g/m^3$	68$\mu g/m^3$
							BaP	
Galuskinova, 1964	Restaurant	Not given	Not given	Not given	Not given	Not given	12.5 ng/m^3 2.83–14.4/ 100 m^3	0.69 ng/m^3 0.28–4.6/ 100 m^3
							Particulates	
D.O.T., 1971	Aircraft	Not given	Not given	Not given	Not given	Not given	120 $\mu g/m^3$ (peak)	Not measured
							Nicotine	
Harmsen and Effenberger, 1957[a]	Trains	Not given	Not given	Not given	Not given	Not given	0.7–3.1 mg/m^3	Not measured
Hinds and First, 1975	Commuter trains	Not given	Not given	Not given	Not given	Not given	4.9 $\mu g/m^3$	Not measured
	Commuter bus	Not given	Not given	Not given	Not given	Not given	6.3 $\mu g/m^3$	Not measured
	Bus waiting room	Not given	Not given	Not given	Not given	Not given	1.0 $\mu g/m^3$	Not measured
	Airline waiting room	Not given	Not given	Not given	Not given	Not given	3.1 $\mu g/m^3$	Not measured
	Restaurant	Not given	Not given	Not given	Not given	Not given	5.2 $\mu g/m^3$	Not measured
	Cocktail lounge	Not given	Not given	Not given	Not given	Not given	10.3 $\mu g/m^3$	Not measured
	Student lounge	Not given	Not given	Not given	Not given	Not given	2.8 $\mu g/m^3$	Not measured

[a] Note: The accuracy of results in this study are highly questionable, as the method of nicotine assay is nonspecific.

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