INDOOR AIR POLLUTION

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Summary; Introduction; Factors in quality of indoor air; Sources of indoor air pollution; Some major pollutants; Concluding remarks; References.

SUMMARY

Research on communal air pollution has focused mainly on the outdoor environment, although far more time is spent indoors than outdoors. Indoor air pollution may have a great impact on assessment of the effect of air pollution on human health, on design of epidemiological studies and on energy-conservation strategies that may restrict indoor-outdoor exchange of air. The influence of the various sources on home environment is reviewed, e.g. outdoor air, gas-fired appliances, tobacco smoking and building materials. The pollutants carbon monoxide, nitrogen dioxide, particles and radon are discussed in more detail. Available data show that outdoor standards for air quality are often exceeded indoors. However, conclusions on exposure and health effects cannot be drawn until more data are available from random or stratified samples of houses.

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Introduction

Until recently, research on communal air pollution has focused mainly on the outdoor environment, though most people in Western society spend far more time indoors. Table I, a summary of a study in the Netherlands, indicates that people spend 73% of their time in their homes (50). Studies in other industrial societies (17,83) present the same pattern. An increasing amount of evidence shows that concentrations of some pollutants indoors frequently exceed those outdoors, though earlier studies (8) assumed that concentrations of pollutants indoors in general reflected those outdoors at a lower level. Such studies dealt mainly with sulphur dioxide, ozone or total suspended particulate matter. Little work had been done on compounds such as oxides of nitrogen, carbon monoxide, organics and

TABLE I

Average activity pattern of the Dutch population (≥12 years of age) (50)

	Time fraction	
	hours/day	*(%)*
— At home, indoors (e.g. sleeping, eating, housekeeping, television, newspaper)	17.6	73
— Mainly indoors, not at home (e.g. work, study, sports, shopping)	5.4	23
— Outdoors (e.g. recreation, gardening)	0.5	2
— Various	0.5	2
— Total	24	100

the respirable fraction of particulate matter, which can also be generated indoors.

Indoor air pollution is relevant for: interpretation of past epidemiological studies and design of future studies on effects on health of air pollution; and energy conservation strategies that might restrict indoor-outdoor air exchanges.

This last issue has generated increased interest in indoor air pollution. In 1979, the World Health Organization convened a working group to discuss the health aspects of indoor air quality (91). In December 1980, the United States Federal Interagency Research Group on Indoor Air Quality organized a National Indoor Air Quality Workshop to develop a research strategy.

In this article, concentrations of indoor air pollutants, the factors in those concentrations, and epidemiological studies are presented that support the importance of the indoor environment. Conclusions are drawn on gaps in our knowledge and policy consequences. Emphasis is on indoor air pollution in private homes.

Factors in Quality of Indoor Air

The concentration of an air pollutant indoors (C_i) depends on several factors:

— volume of air in the indoor space (V)
— rate of production, or release of the pollutant (P)
— rate of elimination of the pollutant (decay rate) through reaction, filtration or settling (D)
— rate of air exchange (γ)
— concentration of the pollutant outdoors (C_o).

The relationship between these factors is described in the following equation (61):

$$V\frac{dC_i}{dt} = P - D + \gamma V (C_o - C_i)$$

The equation resembles expressions governing pollutant concentrations in outdoor air, the main difference being scale. Because of the much larger volume of the outdoor atmosphere, the pollutants of primary concern outdoors are mainly those released in large amounts. In the indoor environment, even small amounts of a pollutant can produce high concentrations.

To solve the equation, we must know rate of production and elimination, outdoor concentration, filter efficiency and rate of air exchange for certain time intervals for each compound. Decay rate is probably reasonably constant for each compound. Production might be almost constant for some compounds (formaldehyde from chipboard, radon from building materials); for others (oxides of nitrogen, carbon monoxide, particulate matter) production closely depends on pattern of activity, smoking habits, and on cooking and heating habits. Air exchange depends mainly on the perviousness of the building, difference between inside and outside temperature, wind speed and direction, presence of forced ventilation systems and on the ventilation habits of the occupants. With so many variables, one can hardly predict exposure of a population to air pollutants in homes without detailed data from real life conditions. In studies on health effects in large populations, data must be simplified, for example by classifying the houses into two or more categories. Dockerey *et al.*[1] provides an approach on the basis of measurements of personal, indoor, and outdoor exposure of nine families to NO_2. They found that 77% of the variance of personal exposures could be explained by outdoor NO_2 and type of stove. We must, however, solve the equations to provide practical recommendations for tolerable production of indoor pollutants and ventilation requirements.

Sources of Indoor Air Pollution

The air we breath in homes can be contaminated in many ways. Major sources are outdoor air, gas-fired appliances, tobacco smoke and building materials. Also, such items as clothing, furnishing, grooming products and hobbies can influence indoor pollution.

Outdoor air

Doors, windows, ventilation openings and cracks in structures permit entry of pollutants. More pollution can enter if the air-exchange rate

[1] *Dockerey, D.W. et al.*: Relationships among personal indoor and outdoor NO_2 measurements. Presented at: 73rd Annual APCA meeting, Montreal, 1980.

increases. Some air pollutants differ in stability between outdoors and indoors, because a variety of surfaces are found indoors, on which reactive compounds absorb and decompose. Ozone (O_3) is decomposed especially quickly indoors. To a lesser extent, this is also true for sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) (61, 82, 88). Carbon monoxide (CO) and nitric oxide (NO) are less reactive (61). Benson *et al.* (8) reviewed the literature up to 1972 on indoor-outdoor relations. They concluded that the best available estimate for indoor concentrations of particulates and CO was obtained by presuming them equal to outdoor concentrations. However, concentration of SO_2 was usually less indoors than outdoors, the ratio going down to about 0.2 for high outdoor concentrations, as confirmed by later data (2, 78, 85). For CO, more attention has recently been paid to indoor sources. For particulates, more data are now available about components and the behaviour of the various size-classes (1, 2, 7, 19, 24, 54, 85). Indoor concentrations of suspended particulates of outdoor origin are lower than outdoors, the ratio depending on particle size. Cohen and Cohen (19) found an average 'protection factor' of about 4.5 for large particles and 2.2 for particles smaller than 1μ m. Consequently, the ratio indoors/outdoors is lower for elements such as iron, that occur mainly in larger particles, than for elements such as lead which occur mainly in the smaller particles.

Gas-Fired Appliances

Combustion in gas-fired appliances always generates harmful products, e.g. CO and NO_2. Since the mid-1960s, CO has not been a constituent of the gas distributed in the Netherlands, but it is formed by incomplete combustion. A special problem in the Netherlands is the widespread use of unvented flow-through water-heaters in kitchens. Such appliances are often poorly aerated as a result of maladjustment or dirty burners. Burners of gas cookers and furnaces usually produce lower concentrations of CO (11,16,66,80)[2,3].

[2] *Dewerth, D.W.*: Pollutant emissions from domestic gas-fired appliances. Paper 3rd conf. on natural gas research and technology, 1974.

[3] *Hollowell, C.D.; Budnitz, R.J.* and *Traynor, G.W.*: Combustion generated indoor air pollution; in *Kasuga* Proc. Int. Clear Air Congress, 4th Tokyo, 1977. pp. 684-687.

Combustion of gas at high temperatures always generates oxides of nitrogen (NO_x) from nitrogen and oxygen in the air. The amount generated depends on burner construction (11). The ratio in which NO and NO_2 are formed varies with burner construction and condition (23,61). The literature contains many examples of high concentrations from gas appliances (23,56,57)[2,3,4].

In the Netherlands and elsewhere, installation codes exist for gas appliances (62). Dutch codes are aimed only at prevention of too high a concentration of CO and CO_2; NO_x has not been considered. Many gas installations in Dutch homes probably do not meet the codes. In a country-wide investigation in 1973, 13% of the unvented water-heaters had too high a production of CO. Ventilation requirements were not met in 73% of the homes[5].

Tobacco Smoke

Smokers inhale many toxic substances leading to increased risk of lung cancer and other diseases. When these substances are released indoors, non-smokers are also exposed. More than 1200 gaseous compounds have been identified in cigarette smoke (22). Carbon monoxide, oxides of nitrogen, ammonia and acrolein are held responsible for some adverse health effects (such as coronary diseases and emphysema). Nicotine and several polycyclic aromatic hydrocarbons have been identified in particles. The increased incidence of lung cancer in smokers is partly attributed to benz (a)-pyrene, one of the polycyclic hydrocarbons.

Estimates have been made for pollutants released directly into the surrounding air (sidestream smoke) and pollutants exhaled after inhalation. Production of CO per cigarette is about 100 mg, particulate matter about 30-40 mg and benz(a)/pyrene about 10% 0-200 ng

[4] *Belles, F.E. et al.:* Measurement and reduction of NO_x emissions from natural gas-fired appliances. Paper 75.09.1 of the 68th Annual Meeting of the Air Pollution Control Ass., Boston 1975.

[5] *Bartholomeus, P.H.J. et al.:* Investigation of the condition of domestic gas installations by means of random tests in the Netherlands. Presented at: 13th World Gas Conference, London 1976.

(12,22,26,37,41,67,70,74). These figures, however, are changing as new types of cigarettes are being developed.

Building Materials

A well-known example of indoor pollution from building materials is formaldehyde from urea formaldehyde foam insulation and chipboard (3,4,34,42,61,22)[6]. Chipboard seems to be a greater source than foam, according to the relative number of complaints recorded in the Netherlands[7].

Some building materials have a certain amount of natural radioactivity leading to an elevated background radiation indoors (47). In a survey of 30,000 homes, radiation was 2-62% higher than the local natural background radiation from the soil (51). One of the decay products from the natural decay of uranium-238 is the noble gas radon-222. The direct precursor of radon-222 is radium-226, a natural constituent of many soils and building materials, e.g. concrete, brick and stone. The daughter elements of radon tend to stick to airborne particles; these may then be inhaled and contribute to the dose of alpha-radiation of lung tissue (14).

Because of its good insulating and fire-resistant properties, asbestos has been used in a variety of products. In some applications, release may continue to the indoor air (73).

Various Sources

A large source of compounds is found in consumer products. Products such as cosmetics, hair sprays, deodorants, cleaning agents, and nail polish and remover contain many volatiles and particulates; many of these use an aerosol propellant. Cleaning agents and surface-maintenace products, such as waxes, polishes, bleaching agents and detergents usually have organic constituents that

[6] *Berk, J.V. et al.:* The impact of reduced ventilation on indoor air quality in residential buildings. Presented at: 73rd Annual Meeting of the Air Pollution Control Ass., Montreal 1980.

[7] Report of the Interdepartmental Committee on Formaldehyde Problems, Ministry of Health and Environmental Protection, Geidschendam, 27th January 1978.

evaporate. Other products are biocides and air fresheners (91). Particles from clothing and furnishings can also contaminate air.

In addition to formaldehyde and radon, many compounds are emanated indoors (45,46). Molhave (60) found organic gases and vapours, of which 50% were alkylbenzenes, and the remainder alkanes (20%), terpenes (9%) and others (21%).

Pollutants known to be harmful at work can also be present at home as the same materials are used for hobbies (55). The number of occupants must also be taken into account as producers of CO_2, H_2O, CO, NH_3, organics and odours. Dutch ventilation requirements for dwellings, for example, are based on the combined production of CO_2 and odours by occupants. These requirements originate from the early work of Yaglou in the 1930s (92,93). Odour concentrations are assumed to stay within acceptable limits as long as the volume fraction of CO_2 does not exceed 0.10-0.15%.

Some Major Pollutants

Carbon Monoxide

Table II presents the results of studies on CO in homes. The great range in the results, particularly of experimental studies with gas cookers and furnaces in Category A, is striking. The concentrations varied from tens (66) to hundreds (76) of mg/m³. The studies in the United States in Categories B and C, under normal living conditions, all showed peak concentrations of only tens of mg/m³. Only in one Canadian study (80) were concentrations of 32-137 mg/m³ found.

In the Netherlands, attention has been paid mainly to CO release from flow-through water-heaters. Many unvented water-heaters, under standard conditions, can produce very high concentrations in kitchens (11). In a recent survey, concentrations were substantially lower (Table III). Burner type, presence of a flue, and maintenance were the main factors in CO concentration.

TABLE II

CO concentrations in homes[a]

Ref.	*Category**	*Conc. (mg/m³)*	*Remarks*
76 US**	A	20	mean, pilot-light, badly ventilated kitchen of 27 m³, 0.24 air changes per h;
		290	oven (same kitchen and ventilation) after 2 h burning, peak.
66 GB**	A	28	level reached after 1 h from 16 burners, 4 grills and 4 ovens in moderately ventilated room of 107 m³.
80 CA**	A	45	level reached after 30 min from 4 pan-covered burners in moderately ventilated kitchen, volume unknown.
80 CA	B	32-137	range in kitchens after 20 min cooking under normal conditions.
11 NL**	A/C	> 280	in 16.4% of the sample; from 237 unvented water-heaters, after 30 min burning, moderate to poor ventilation.
3) US	B	5	mean of 5 kitchens, pilot-light only;
		9	mean of 5 kitchens, during cooking;
		38	peak during cooking;
		1	simultaneous outdoor concentration.
87 US	B	4-9	mean in 4 kitchens;
		13	peak in 1 kitchen;
		1-2	simultaneous outdoor concentration in different seasons.
61 US	B	2-6	mean in 17 homes (av. for 1 h);
		22	highest conc (av. for 1 h);
		1-3	simultaneous outdoor concentration.

[a] *Elkins, R.H. et al.:* A study to CO and NO_x levels in the indoor environment. Presented at: 67th Annual Meeting Air Pollution Control Ass., Denver 1974.

TABLE II, cont.

Ref	Category*	Conc. (mg/m³)	Remarks
8) US	C	8	mean max. concentration (av. for 1 h) during cooking in 57 homes;
		> 25	in 2 of the 57 homes.
12 US	C	8-10	from smoking during parties.
74	A	20-80	from smoking in experiments.
self NL	A/B	70-150	after 30 min from water-heater in small kitchen;
		up to 50	during cooking under normal circumstances (See also Fig. 1).

A — studies in experimental or normal houses under controlled circumstances.
B — detailed studies in a restricted number of houses under normal conditions.
C — general surveys in many houses.
** US, United States; GB, Great Britain; CA, Canada; NL, the Netherlands.

TABLE III

CO concentrations at breathing height in 246 Dutch kitchens in 1980, after operating a gas-fired water-heater for 15 min with doors and windows closed

*Conc. (ppm)**	*Number*	*Relative number (%)*	*Cumulative rel. number (%)*
⩽10	154	63	63
11-50	50	20	83
51-100	25	10	93
>100	17	7	100

* 1 ppm = 1.1 mg/m³; 1 atm. 25°C

Detailed measurements were conducted in a flat in which the kitchen had an open connection with the hall. A typical concentration pattern during preparation of a meal is given in Fig. 1.

Concentrations from smoking do not generally exceed 10 mg/m³ (12). Under experimental conditions, concentrations up to 80 mg/m³ were observed (74). However, such concentrations would be unlikely in homes, as smoking also produces irritating agents that would stimulate the occupants to ventilate as soon as the increase in concentration was more than 3-5 mg/m³ (29,36).

For outdoors the Dutch Health Council has proposed the following standard: a one-hour average concentration of 40 mg/m³, not to be exceeded more than once a week, and an 8-hour concentration of 10 mg/m³, not to be exceeded more than once a month (32).

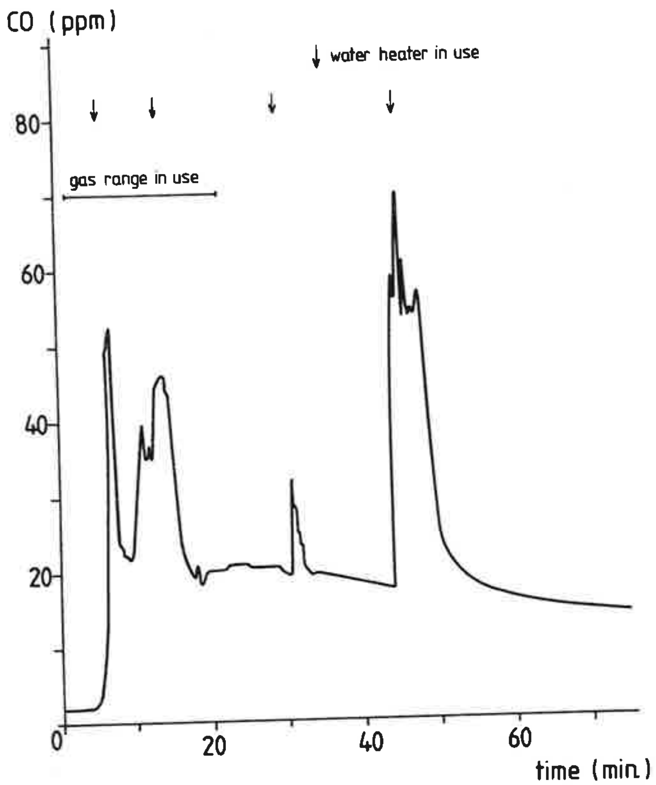
According to the United States primary air-quality standard, the same concentrations are not to be exceeded more than once per year (28). Recently the U.S. Environmental Protection Agency has proposed a reduction of the one-hour value to 28 mg/m³ (52). The critical factor is the carboxyhaemoglobin concentration in blood (COHb). The objective of the proposed Dutch standard is to prevent it from exceeding 3%; a value higher than this can harm health in high-risk groups, e.g. persons with seriously disturbed cardiovascular, pulmonary or central nervous function. These groups form together an estimated 5-15% of the population (32).

The standards are based on estimates of COHb after exposure to selected concentrations of CO for specified durations (18,68). These estimates apply to persons at rest. A complicating factor indoors is gas appliances, which also produce CO_2, that can accelerate breathing and enhance CO uptake into blood (16,25). A concentration of CO_2 of only 1% is sufficient. In other words, the outdoor standard may be too lenient for use indoors.

Tables II and III indicate that concentrations from water-heaters occasionally exceed outdoor standards in the Netherlands. Outdoor standards are probably approached during normal cooking, but will not be exceeded unless ventilation is greatly reduced or the gas appliances are used atypically, for instance for heating or clothes drying (79).

FIGURE 1

Typical concentration pattern of CO at breathing height in a kitchen during preparation of a meal.
(1 ppm ≌ 1.15 mg/m^3; 1 atm., 25°C)



Little work has been done on the health effects of CO in homes, even though serious gas accidents have been registered in the Netherlands[9]. Between 1966 and 1975, 136 deaths associated with gas were reported, 90 being poisoning due to unvented water-heaters. As for poisoning by intermittent repeated exposure to moderate concentrations, one can only guess, as the diagnosis is easily missed.

Oxides of Nitrogen

Table IV gives the results of studies on indoor NO_x pollution. Moderate to high NO_x concentrations can occur, particularly when unvented gas-fired appliances are used. A typical example of the simultaneous concentration pattern in three different rooms in a flat is given in Fig. 2. The corresponding outdoor concentrations averaged about 40 μ g/m^3 for NO_2 and 20 μ g/m^3 for NO. Striking is the contribution of the pilot-light of the water-heater to the concentration levels in the kitchen during night, presumably as a result of low windspeed and air exchange.

We also performed a large survey in kitchens and living-rooms in Enschede and Arnhem (Table V). Palmes *et al.* (65) reported concentrations up to 410 μ g/m^3 (av. for 1 week), when unvented gas space-heaters were used.

For outdoors the Dutch Health Council has proposed a standard for NO_2 (33) which reads as follows: 135 μ g/m^3 (av. for 1 h) not to be exceeded during 98% of time, 300 μ g/m^3 not to be exceeded more than once a year; 120 μ g/m^3 (av. for 24 h) not to be exceeded during 98% of the year, 150 μ g/m^3 not to be exceeded more than once a year. These values are in line with the international tendency to regulate especially short term exposures[3,6]. Short term exposures to high levels of NO_2 decrease the resistance to airway infections and cause irritation of the mucus membranes of the respiratory system. The non-continuous use of unvented gas-appliances produces high peak concentrations during use. Peak-to-mean ratios of 5 to 10 have been reported (5). From Tables IV and V it is obvious that existing out-

Gasongeoallen in Nederland, VEG Gasinstituut, September 1976.

TABLE IV

NO_x concentrations in homes

Ref.	*Category**	*Conc. ($\mu g/m^3$)*	*Remarks*
42	A	2300	NO_2 (av. for 1 h), oven on during
US**			1 h in 27 m^3 kitchen, 0.24 air changes per h:
		760	2.5 air changes per h;
		60	simultaneous outdoor conc.
87	B	47-140 (95-229)***	NO_2 (NO) mean in 4 kitchens (av. for 24 h);
US		1450 (2030)	peak conc. in 1 kitchen;
		32-50 (19-65)	simultaneous outdoor conc. in different seasons.
3	B	60 (70)	NO_2 (NO) mean 5 kitchens, pilot-light only;
US		160 (490)	during cooking;
		1030 (2530)	maximum during cooking;
		30 (20)	simultaneous outdoor conc.
8	C	140	NO_2, mean in 'gas' kitchens (av. for 24 h):
US		300	maximum;
		75	mean in 'electric' kitchens;
		65	simultaneous outdoor conc.
35	C	210	NO_2, mean in 428 'gas' kitchens (av. for 1 week):
GB**		10-600	range;
		34	mean in 87 'electric' kitchens;
		11-360	range.
48	C	95 (130)	NO_2 (NO) mean in 93 'gas' homes (av. for 24 h):
US		210 (510)	maximum;
		40 (90)	mean in 50 'electric' homes;
		114 (425)	maximum;
		57 (59)	simultaneous outdoor conc;
		95 (275)	maximum
77	C	54, 116	NO_2, geom. mean (54) and 95-percentile (116) in living-rooms of gas homes in a polluted area (av. for 24 h);
US		15, 39	in a clean area;
		5, 16	average difference between means and 95-percentiles and simultaneous out door conc. in 5 cities with various pollution levels.
64	B	92	NO_2, mean in 10 'gas' kitchens (av. for 1 week):
US		38-164	range;
		47	mean non-kitchen;
		24-131	range;
		16	mean in 9 'electric' kitchens;
		13	mean non-kitchen.
self	B	300 (450)	NO_2 (NO) peak in kitchen (see also Fig. 2):
NL**	C	118	mean in 289 kitchens (av for 1 seek);
		58	in 294 living rooms (see also Table 5).

* For explanation see Table II
** See Table II
***NO concentrations in parentheses).

FIGURE 2

Typical concentration pattern of NO and NO_2 during one day in an apartment/flat.
(1 ppb NO_2 ≚ 1.88 µ g/m³, 1 ppb NO ≚ 1.23 µ g/m³; 1 atm., 25°C)

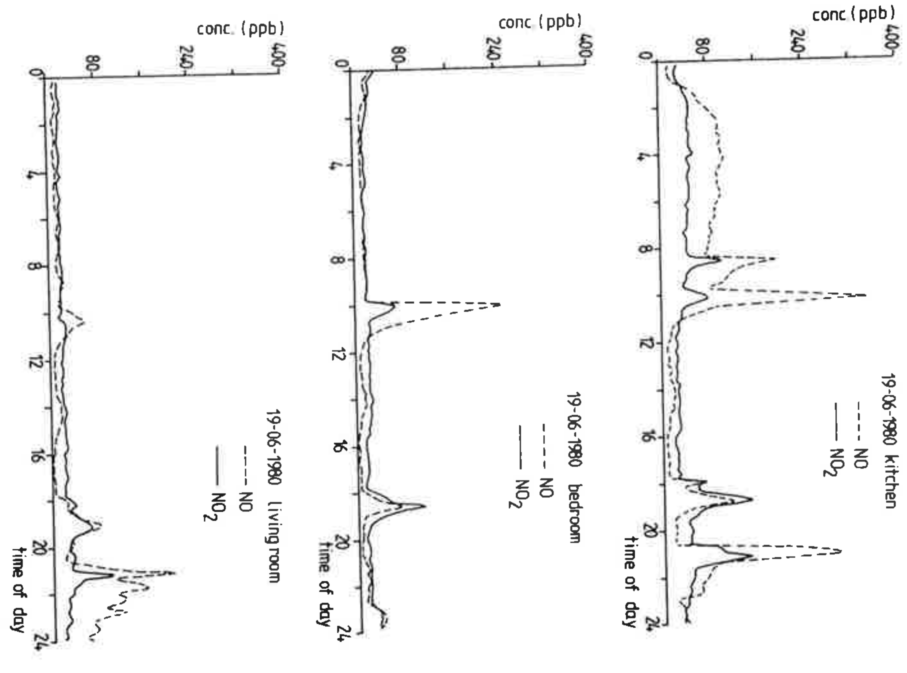


TABLE V

NO_2 concentrations (av. for week) in 289 kitchens and 294 living-rooms during November and December, 1980, using Palmes tubes (63)

Conc. (µ g/m³	*kitchen*			*living room*		
	number	*relative number (%)*	*cumulative rel. number (%)*	*number*	*relative number (%)*	*cumulative rel. number (%)*
0-40	29	10	10	104	35	35
41- 80	78	27	37	122	41	76
81-120	56	19	56	45	15	91
121-160	41	14	70	11	4	95
161-200	37	13	83	4	2	97
201-240	22	8	91	—	—	—
241-280	9	3	94	2	1	98
281-320	3	1	95	2	1	99
320	14	5	100	4	2	101

door standards will regularly be exceeded by indoor concentrations.

Epidemiological studies have been conducted on the effects of indoor NO_2 on the occurrence of respiratory illness. Florey *et al.* (31), and others (35,58,59) investigated 1,810 children living in 'electric' homes. Allowance was made for smoking habits of the occupants and other relevant factors. They found that children from homes where gas was used for cooking had a higher prevalence of respiratory symptoms. The relative risk, however, varied considerably between age-groups, and between girls and boys. It was not possible to directly correlate respiratory symptoms to NO_2 concentrations. Firmer evidence is provided by Speizer *et al.* (77) who found more respiratory diseases and lower pulmonary functions in children from households with gas stoves, in a study of approximately 8,000 children from 6 to 10 years of age. The findings were not explained by differences in social class or by parental smoking habits. These studies contrast with that of Keller *et al.* (48), which showed no difference in respiratory symptoms among children up to 12 years of age, living in 'gas' or 'electric' homes. However, the number of children investigated was small (approximately 600) and most of them came from a relatively high socioeconomic class.

Most studies investigated children of primary school age, which are less often at home than younger children (0-4 years) and thus less frequently exposed to indoor pollution. Younger children are also more sensitive to respiratory diseases. Both factors suggest that future studies should deal with younger children. Such studies have so far been conducted only for the influence of parental smoking on respiratory symptoms (see under Particles).

Particles

Table VI gives the results of studies on indoor suspended particles mainly from smoking. The concentrations can be compared with, for example, United States primary air-quality standard (28), although these are based on total suspended particulates by high-volume sampling and measured gravimetrically. The standard reads: maximum annual geometric mean 75 $\mu g/m^3$ (av. for 24 h) and 260 $\mu g/m^3$ not to be exceeded more than once a year. Annual mean con-

TABLE VI

Suspended particles in homes

Ref.	*Category**	*Conc. ($\mu g/m^3$)*	*Remarks*
12 US**	C	2000—4500	calculated conc at parties on the basis of measured CO-concentrations
23 B**	A	1000	conc measured with light scattering in 50 m³ room after smoking of 3 cigarettes
37 BRD**	A	0.2	benz(a)pyrene conc in 38 m³ room after smoking of 30 cigarettes
41 US	A	1200—16600	observed total part. matter in various smoking experiments
39 US	C	40—400	calulated part. conc on the basis of measured nicotine-conc in smoky spaces
67 US	A	230—1980	calculated part. conc (av. for 16 h) in 36 m³ space from 20 cigarettes with different ventilation regimes
70 US	A	2000	steady-state conc of respirable dust in 113 m³ space with four heavy smokers;
	C	40	mean conc respirable dust in non-smoker homes;
	C	86—697	conc respirable dust from smoking in various spaces
24 NL**	C	120	mean conc in 101 homes (av. for 2 months)
		20—570	range
self NL	A	570	peak conc respirable dust in poorly ventilated 55 m³ room after smoking 1 small cigar

* For explanation see Table 2

** US, United States; B, Belgium; BRD, West-Germany; NL, the Netherlands.

centration measurements indoors have not been reported, and only some 24 hour data are available.

In an epidemiological study of lead-uptake by children around a secondary leadsmelter, we measured suspended particle concentrations (average for two months) in 101 houses (24). Later collected data on smoking habits in 26 participating houses suggest a relation between average concentration of suspended particles and number of smokers in the house (Table VII).

TABLE VII

Indoor concentration of suspended particles (av. for 2 months) in relation to number of smokers per house

number smokers	*number of houses*	*av. conc* ($\mu g/m^3$)	*range* ($\mu g/m^3$)
0	4	55	20— 85
1	7	125	60—240
2	14	150	70—265
3	1	335	

Calculations from Repace and Penkala (67,70) further indicate that many people are probably exposed, in smoke-filled rooms, to concentrations considerably higher than outdoor standards.

Experimental studies on the hazard for non-smokers have dealt mainly with acute effects, such as exercise-induced angina pectoris, rising COHb levels and irritation symptoms (29,36,75).

Epidemiological studies have dealt mainly with respiratory symptoms in children in relation to parental smoking habits (20,21,53,84). Increased respiratory diseases can, at least partly, be attributed to direct infection by smoking parents. Having more respiratory diseases in childhood might have consequences in adult life (49, 69). Recently it has been shown that non-smokers regularly exposed to tobacco smoke had lower forced mid-and end-expiratory flow rates than non-exposed non-smokers (90). The values of passive smokers

were not significantly different from those of light smokers and mokers who did not inhale. It is not yet clear to what extent passive smoking enhances lung cancer risk (15, 26, 38, 84). In one study in Japan, among 91,450 non-smoking wives aged 40 and above, wives of heavy smokers were found to have a higher risk of developing lung cancer (40).

TABLE VIII

Radon and decay-products

Ref.	*Category**	*Conc.* (nCi/m^3)	*Remarks*
86		0.1	outdoor conc. in continental air;
various		0.01	outdoor conc. in coastal areas;
countries		0.001	outdoor conc. above the sea;
14[10]	C	0.07—4.8	conc. indoors in various studies
14[11] US**	C	0.83 0.18	geom. mean in 21 homes New York/New Jersey; simultaneous outdoor conc.
14 A**	C	0.42 0.16	geom. mean in hundreds of homes in Salzburg; simultaneous outdoor conc.
30,43 US	C	4.0	indoor conc. in houses built on phosphate slags in Florida
43 US	A	0.7—15	indoor conc. in homes with 0.05-1.0 air changes per h
71 US	C	>10	in 6 of 22 unpaved crawl-spaces under houses in Argonne, Illinois
81 N**	C	1.0 1.3 2.0	mean in 36 houses with brick walls in Norway; in 42 houses with wooden walls; in 42 houses with concrete walls

* For explanation see Table II.
** US, United States; A, Austria; N, Norway

[10] *George, A.C.* and *Breslin, A.J.:* The distribution of ambient radon daughters in residential buildings in the New York-New Jersey area. Presented at: Symposium on Natural Radiation Environment, 3rd, Houston 1978.

[11] *Steinhauser, F. et al.:* Local and temporal distribution pattern of radon and daughters in an urban environment and determination of organ dose frequency distributions with demoscopical methods. Presented at: Symposium on Natural Radiation Environment 3rd, Houston 1978.

Radon

Table VIII gives the results of studies in which concentrations of radon and decay-products were measured. Concentrations are expressed in pCi/1 or nXi/m^3; one Ci(Curie) stands for the amount of radioactive material in which 3.7 x 10^{10} desintegrations per second occur (in the SIsystem, activity is expressed as Becquerels; 1 Ci = 3.7 x 10^{10} Bq). An annual exposure to 1 nCi/m^3, on the average, will lead to an estimated radiation load, of the basal cells of the bronchial epithelium, of 100-200 mrad/year (6); this corresponds to a biological effective dose of 500-4000 mrem/year, as mainly alpha radiation is involved (1 Rad = 0.01 Gy (Gray) and 1 Rem = 0.01 Sv (sievert)). The calculation of the radiation dose of lung tissue by exposure to the decay products of radon, has many uncertainties (89), which gives rise to a great range of estimated doses.

Considerably higher concentrations of radon and daughters can be found inside dwellings rather than outdoors. Hollowell *et al.* (43) have estimated that at present,indoor exposure to radon daughters may account for as many as 10,000-20,000 lung cancer deaths each year in the United States. The many uncertainties make the absolute size of the numbers rather speculative. It seems probable, however, that inhalation of radon daughters in the indoor environment accounts for the biggest single 'background' radiation dose in many people.

Internationally, the problem of indoor radiation from radon and daughters is receiving increased attention. In Sweden a large-scale measurement program of radon and daughters in homes has started[12], while the US Environmental Protection Agency has insisted on changes in the energy conservation programs: reduction of indoor ventilation as a measure for energy conservation should be omitted in these programs until more is known about the health hazards[13]. In response to the 1977 UNSCEAR Report (86) the Dutch Health

[12] ES and T Currents. Environ. Si. Technol. *14*, 633 (1980).

[13] ES and T Currents. Environ. Sc: Technol. *14*, 497 (1980).

Council also stressed the importance of indoor radon for the radiation hygiene policy in the Netherlands[14].

Concluding Remarks

High concentrations of air pollutants can occur in homes. Indoor concentrations of some pollutants (NO_2, CO, particles, radon) often exceed outdoor concentrations. The many studies give no representative picture of exposure or of health hazards. Further studies are needed on the nature and rate of production of indoor contaminants, their rates of decay, ventilation patterns and resulting concentrations. The results can help in determining the best energy-conservation strategy needed for reducing ventilation without harming health.

In 1978 Geomet Inc. concluded that the average ventilation rate in American houses could be reduced from about 0.9 to 0.5 without harming health (61), but only two years later this conclusion seems to have been reversed by the work at Lawrence Berkeley Laboratory (42)[6]. The US Environmental Protection Agency also won an agreement from the Department of Energy in the United States to set an interim standard to control indoor air pollution in the residential conservation service program. The interim standard sets a minimum ventilation standard of one air change per hour, twice as high as previously envisioned for new homes (27).

Care must be taken with restrictions on infiltration and ventilation in energy-conservation programs, as additional measures are needed. These measures could include installation of air-to-air heat exchangers, electrostatic air filtration, installation of vents on gas appliances and banning of pilot-lights and smoking restrictions indoors. The control technology for indoor pollution, however, is still in its infancy. The cost effectiveness of control measures needs attention. Solutions that offer a direct financial benefit may be the most promising as they are likely to be widely applied.

In this review, outdoor standards as far as they are based on health criteria, were applied for evaluation of indoor situations, since hardly

[14] Gezondheidsraad: Advies inzake de betekenis van het UNSCEAR-rapport 1977 voor het stralingshygiëne beleid in Nederland.

any standards or criteria exist for indoor air quality (63). Theoretically, this seems justified, as outdoor standards are set for the protection of the population as a whole, including high-risk groups, e.g. the aged, children, pregnant women and patients. Legally, however, there are problems. The Dutch law on air pollution, for instance, is explicitly restricted to the outdoor environment in its definition of air pollution. Also, the US Environmental Protection Agency probably lacks legal authority to deal with indoor pollution, though the point is disputed. A clear mandate could come from an amendment to the Clean Air Act, an action urged on Congress by a General Accounting Office report (13). There will be many communication problems, since the Environmental Protection Agency, Department of Energy, Occupational Safety and Health Administration, Consumer Product Safety Commission, Department of Health and Human Services, and Department of Housing and Urban Development are all active in one way or another in United States indoor pollution.

The scientific data for most pollutants on which air quality standards are based come from epidemiological studies, which attempted to relate health effects with outdoor levels only. Indoor pollution, however, may have introduced distortions. A systematic bias, for example for NO_2, leading to an overestimate of health hazards, is possible in an epidemiological study in a city where stoves are predominantly gas fired and only outdoor levels are taken into account.

In the 1960s, Biersteker *et al.* (9,10) had already concluded that air pollution indoors might be a neglected variable in epidemiology and in standard setting. In future studies, total exposure must receive more attention by means of low cost and reliable monitoring systems for personal exposure.

The groups most exposed to air pollution indoors are younger children, housewives, aged and sick people. These groups also belong to the high risk groups for air pollution. Of these groups, only the younger children have been investigated. Recearch is also urgently needed on the health hazards of indoor air pollution to the other groups.

A general picture is not yet possible. Comprehensive statistically valid studies are needed. We are designing such a study and would appreciate advice, criticism and suggestions from readers.

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