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INDOOR AIR POLLUTION IN ROTTERDAM HOMES

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Abstract—800 paired samples of indoor and outdoor smoke and SO_2 concentrations of 60 Rotterdam homes were studied in an effort to throw more light on the role that indoor air pollution may play in epidemiology. It was found that smoking increased the amount of smoke found in living rooms and the data suggest that newer houses tend to have less SO_2 in the living rooms than older houses. On the average living rooms contained approximately 80 per cent of the smoke and 20 per cent of the SO_2 measured simultaneously outdoors during 24 hr periods. The probability of having more SO_2 in the living room than outdoors is estimated at less than 2 per cent of the days by the authors, but the finding of constant high SO_2 in one living room in this small sample may mean, in the view of the authors, that faulty chimneys and heaters may play a bigger role in air pollution mortality during fogs than so far has been suspected.

1. INTRODUCTION

ONE of the intriguing questions in air pollution epidemiology is how air pollution precipitates the deaths of weakened persons during smogs. SO_2 and smoke concentrations measured in the outdoor air during such episodes stay well below the concentrations encountered in many industrial occupations. Also, weakened persons in general will not venture outdoors during smogs and the general belief is that the indoor atmosphere during such episodes is safer than the outdoor atmosphere. Little has been published, however, on air pollution levels inside and outside normal homes. SHEPHARD *et al.* (1960) made a study of pulmonary function of cardiorespiratory cripples and domestic pollution in Cincinnati, Ohio, U.S.A. The highest indoor concentration of SO_2 (6 hr averages) was 0·075 ppm. KRUGLIKOWA and EFIMOWA (1958) earlier published findings in Moscow. Their maximal short-term indoor concentrations were 900 $\mu g\ SO_2/m^3$ (approx. 0·3 ppm). Our impression from these papers was that Russian homes tended to have far more SO_2 indoors than American homes, possibly as a result of differences in heating methods amongst other factors. As for Dutch homes, we could only guess.

2. METHODOLOGY

Air was sampled in the living rooms of 60 Rotterdam homes and simultaneously outside by a second apparatus located in the same house with the daily volumetric smoke and SO_2 samplers that have been in use in Rotterdam for several years. Approximately 2 litres of air per minute are drawn first through a glass fibre filter (Whatman GF/C), then through a Drechsel bottle containing a solution of hydrogen peroxide in water and finally through a calibrated gasmeter. Smoke was measured with an EEL reflectometer and smoke scale. SO_2 was determined by titration of the total acidity. Filters and bottles were changed every morning, except during weekends.

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4. DISCUSSION

The epidemiological meaning of our data is hard to understand. The home of the modern inhabitant of Rotterdam, who spends on the average only a few hours a day

TABLE 5. REGRESSION ANALYSIS OF SO_2 CONCENTRATION IN HOMES OF DIFFERENT AGE

Year of construction	SO_2 indoors (as perc. of outdoors)	
–1919	30·0	
1920–1939	17·7	
1940–1959	16·8	
1960+	5·9	$r = -0·33$

$P<0·05$

TABLE 6. REGRESSION ANALYSIS OF SMOKE AND SO_2 CONCENTRATIONS IN HOMES WITH DIFFERENT HEATING SYSTEMS

Heating system	Smoke and	SO_2 indoors (as perc. of outdoors)
Central heating	81	12
oil heaters	91	17
coal heaters	82	20
gas heaters	77	33
n.s.	$r=-0·09$	$r= -0·16.$

TABLE 7. INDOOR AND OUTDOOR SO_2 CONCENTRATIONS IN HOME 21, 30 YEARS OLD, MODERN ANTHRACITE HEATER

Date	SO_2 inside ($\mu g^2/m^3$)	SO_2 outside ($\mu g^2/m^3$)
Feb. 12	1250	200
Feb. 13	782	197
Feb. 14	985	513
Feb. 17	776	195
Feb. 18	904	117
Feb. 19	623	190

in the outdoor air, provides good protection against SO_2 but little protection against smoke.

There were no days with steep rises of the outdoor SO_2 and smoke levels during the period of investigation, the highest concentrations stayed below 700 $\mu g/m^3$. This means that our data do not throw light on the conditions during smog disasters when air pollutants reached 3 or more times these concentrations. MARTIN and BRADLEY (1960)

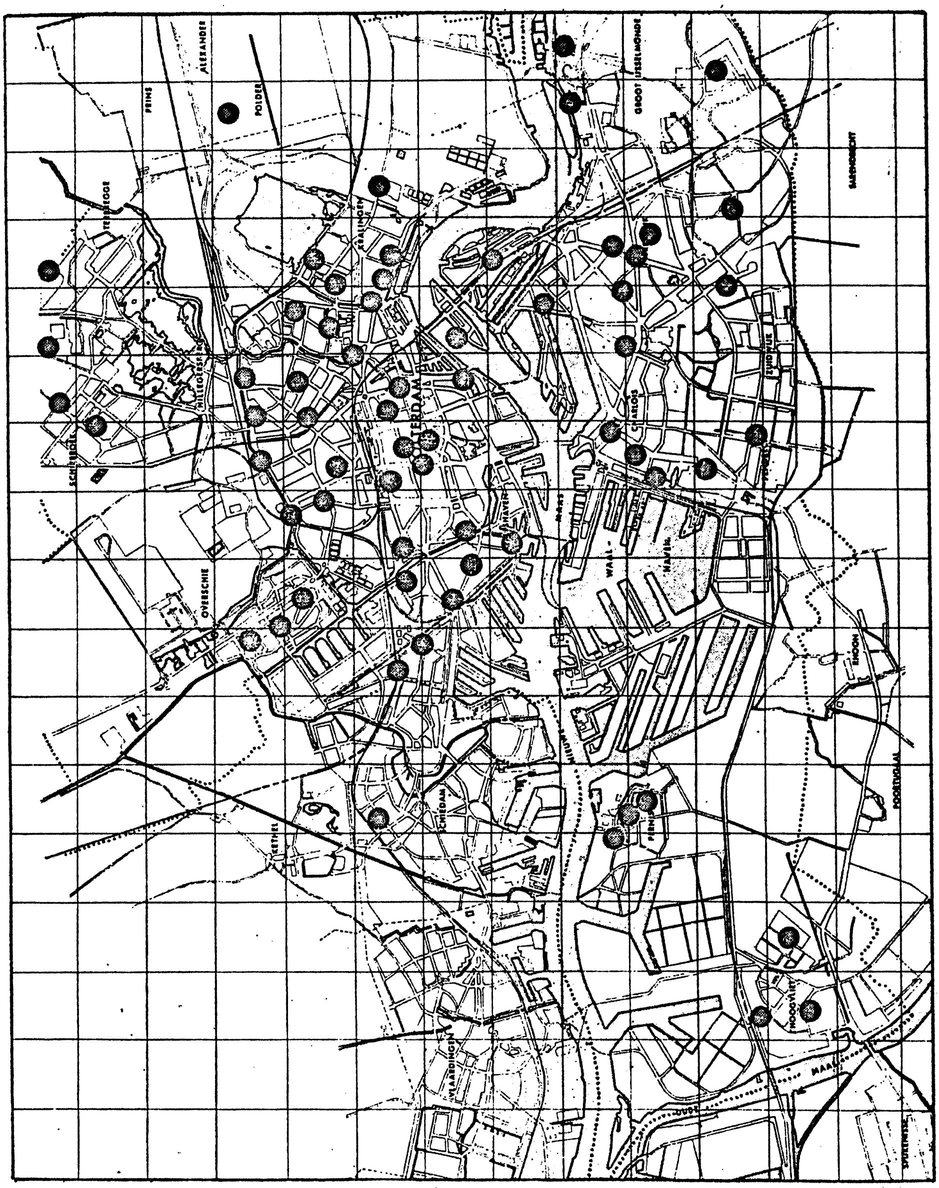

FIGURE 1. Location of the homes that were studied (one square represents 1 km^2).

As air pollution levels outside were known to show a weekly cycle, simultaneous measurements were continued for at least 7 successive days at each location, to make sure the weekend was included. Much longer periods did not prove practicable because of the annoyance caused by the noise of the pumps. As can be seen in TABLE 1, the actual sampling periods ranged from 7 to 11 days with a mean of 8 days.

Though we started with the hope of obtaining a random sample of the upwards of 200,000 Rotterdam homes, there were too many refusals to cooperate for this. We, therefore, asked the Municipal Housing Department to suggest 70 addresses that were scattered evenly over the city and represented the types of homes in use in Rotterdam. The homes that were suggested included bungalows, flats, multi-storied houses and high apartments. A social worker of the Municipal Health Department then tried to obtain the cooperation of these occupiers or selected a similar home in the neighbourhood with occupiers she knew to be willing to cooperate. Only 3 families, who had heard of the investigation, volunteered to cooperate and were accepted.

There were in total 65 homes in which air pollution indoors and outdoors was measured simultaneously. Only 60 of these are included in our statistical analysis.

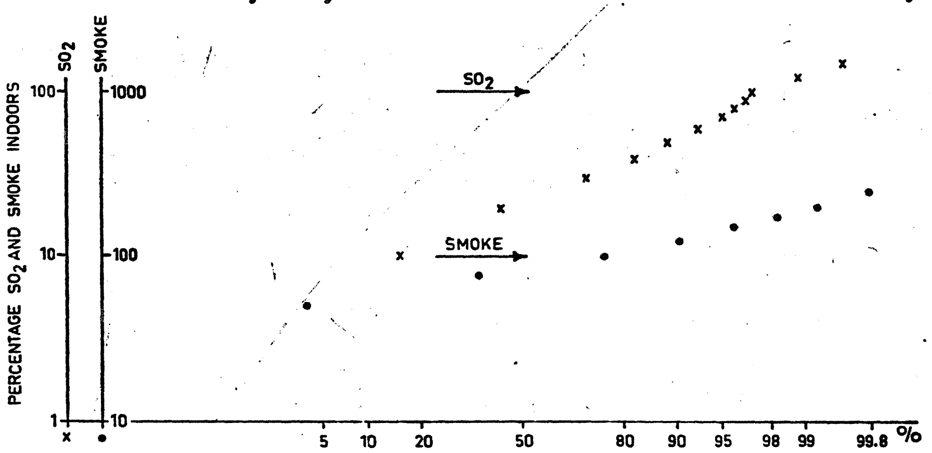

FIGURE 2. Cumulative frequency of smoke and SO_2 concentrations in Rotterdam living rooms as percentages of the concentrations found outdoors.

In the other 5 homes, 2 showed almost constantly higher SO_2 concentrations indoors than outdoors (1 of these belonged to a volunteer), in 1 case samples were taken in a tobacco shop instead of in the living room, and in 2 cases occupiers stopped the meters at night or changed their location.

The distribution of the total sample of 65 homes over the city is given in FIG. 1. We feel that there is no reason to assume that the cumulative frequency distribution of the indoor pollution as percentages of the outdoor pollution, as shown in FIG. 2, is far from normal. We assumed that the percentages behaved as random variates in the multiple regression analysis that was carried out on year of building, type of heating, smoking habits and outdoor concentration.

The winter season was selected to guarantee sufficient pollution outdoors plus presence of indoor sources of air pollution. The sampling started on January 17 and ended on March 26, 1964. People continued their normal habits of heating and ventilating the living rooms during the study. A total of somewhat more than 800 paired samples became available for statistical analysis, approximately 1600 data in total.

TABLE 1. MEAN INDOOR AND OUTDOOR SMOKE AND SO_2 CONCENTRATIONS OF 60 ROTTERDAM HOMES, YEAR OF CONSTRUCTION, TYPE OF HEATING AND SMOKING HABITS OF INHABITANTS

Number	Days sampled	Smoke		SO_2		Year of Construction	Heating (X_b)	Smoking habits
		Indoor ($\mu g/m^3$)	Outdoor ($\mu g/m^3(X_d)$)	Indoor ($\mu g/m^3$)	Outdoor ($\mu g/m^3(X_d)$)	(X_a)		(X_c)
1	7	292	267	100	319	2	3	3
2	11	284	301	67	372	1	2	2
3	8	223	284	13	158	1	2	3
4	8	175	225	29	325	1	2	2
6	8	241	272	148	384	1	2	3
7	8	126	181	72	215	1	3	3
9	8	62	77	7	263	1	3	3
11	8	69	94	22	155	3	2	3
12	7	136	130	246	242	1	3	3
13	8	117	119	0	166	2	1	1
14	8	95	79	1	133	1	3	1
15	8	81	118	12	198	4	4	2
16	8	87	135	25	168	3	4	3
17	8	115	180	30	211	3	2	3
18	8	156	223	2	276	2	2	2
19	8	183	216	119	275	1	1	2
20	8	173	189	44	169	2	3	1
22	9	153	220	14	238	3	3	3
23	8	160	147	2	164	4	4	1
24	8	167	144	61	128	3	2	1
25	11	198	225	26	191	3	4	2
26	7	138	185	0	144	3	2	1
27	8	144	195	105	293	2	2	3
28	8	168	179	22	207	3	4	3
29	8	151	232	72	265	2	2	3
30	7	123	198	25	152	3	3	2
31	7	225	229	158	281	2	2	2
32	7	176	235	95	247	2	1	1
33	8	254	225	0	211	4	4	3
34	8	180	240	62	226	2	3	2
35	8	142	173	13	178	3	2	2
36	8	122	125	7	139	4	4	1
37	7	108	174	16	129	3	4	3
38	8	88	129	33	111	2	4	3
39	8	105	186	25	145	2	2	3
40	8	120	176	43	191	3	1	3
41	8	119	145	21	148	4	2	2
42	8	208	183	84	256	3	2	2
43	8	121	150	51	151	4	3	1
45	9	81	99	0	73	4	4	1
46	8	137	181	0	240	1	3	3
47	8	124	123	0	137	4	2	2
48	9	52	115	21	124	3	4	3
49	8	301	364	33	226	3	2	2
50	8	249	262	39	196	2	2	2
51	8	281	228	0	301	4	2	2
52	9	160	244	51	167	3	2	3

(*cont. at top of p.* 347)

TABLE 1 (Cont.)

53	8	196	191	0	152	2	2	1
54	8	184	281	43	247	1	2	2
55	8	158	261	45	260	1	1	3
56	8	309	353	122	339	1	2	3
57	8	144	202	9	207	2	2	2
58	8	151	163	0	89	4	2	1
59	8	115	162	3	129	3	2	3
60	8	113	146	9	125	2	2	3
61	7	93	83	78	104	2	2	3
62	8	112	104	7	80	2	2	1
63	7	91	82	0	83	2	2	2
64	7	64	93	38	105	2	2	3
65	7	83	117	10	118	3	4	1

Year of construction—
1: older than 1919
2: 1920–1939
3: 1940–1959
4: 1960+.

Heating—
1: gas heater
2: coal heater, closed
3: oil heater, closed
4: central heating.

Smoking habits—
1: heavy smokers
2: moderate smokers
3: occasional smokers

3. RESULTS

TABLE 1 summarizes the mean smoke and SO_2 concentrations found indoors and outdoors at the 60 locations and provides in addition information regarding the year of construction of each house, the type of heating used, and the smoking habits of the inhabitants.

TABLE 2 shows that the recorded smoke concentration measured in living rooms was on average more than 80 per cent of the smoke concentration measured outside. There was little or no change of this percentage with increasing smoke concentrations outdoors.

TABLE 2. SMOKE AND SO_2 CONCENTRATIONS IN LIVING ROOMS AS PERCENTAGES OF CONCENTRATIONS OUTSIDE AT DIFFERENT AIR POLLUTION LEVELS OUTSIDE

Range outdoors ($\mu g/m^3$)	Smoke indoors	SO_2 indoors
0–99	104	19
100–199	88	17
200–299	81	23
300–399	87	21
400+	85	22

A multiple regression analysis was performed to discover possible independent effects of year of construction, heating methods, smoking habits and outdoor pollution levels and the results are given in TABLE 3. The effect of smoking on indoor smoke concentrations was statistically highly significant but no other independent influences could be discovered.

As for SO_2, much lower percentages of the outdoor concentrations were found to exist in the living rooms, the average room containing not more than approximately 20 per cent of the concentration that was found outside. In this case too there was little or no change of this percentage with increasing SO_2 concentrations outdoors, as shown by TABLE 2.

The multiple regression analysis of percentage indoor SO_2 concentration, shown in TABLE 4, reveals a very significant joint influence of the four factors studied, but due to the large scatter and relatively few results, an independent influence is not statistically proven for any of them. The year of construction is according to TABLE 4 the most suspected factor and the single regression analysis with percentage SO_2, shown in TABLE 5, gives a significant result, suggesting that the newer houses have lower indoor concentrations of SO_2. Penetrating SO_2 from outside must somehow be absorbed and

TABLE 3. MULTIPLE REGRESSION ANALYSIS FOR INDOOR SMOKE PERCENTAGES

Characteristic	S. S.	D.F.	var.	F	signif.
(*a*) Year of construction	313·3	1		1·26	n.s.
(*b*) Type of heating	103·5	1		0·42	n.s.
(*c*) Smoking habits	3136·7	1		12·60	$P<0{\cdot}001$
(*d*) Outdoor smoke	227·8	1		0·92	n.s.
Residual	13694·8	55	249·0		
multiple correlation	R: 0·46		$P<0{\cdot}001$		

S.S.: sum of squares
D.F.: degrees of freedom
var.: variance.

Multiple regression equation —
Percentage indoor smoke =
$119{\cdot}6-2{\cdot}56X_a-1{\cdot}58X_b-9{\cdot}49X_c-0{\cdot}03X_d$.

TABLE 4. MULTIPLE REGRESSION ANALYSIS FOR INDOOR SO_2 PERCENTAGES

Characteristic	S.S.	D.F.	var.	F	signif.
(*a*) Year of construction	590·8	1		1·72	n.s.
(*b*) Type of heating	55·9	1		0·16	n.s.
(*c*) Smoking habits	589·2	1		1·71	n.s.
(*d*) Outdoor SO_2	469·6	1		1·37	n.s.
Residual	18900·3	55	343·6		
multiple correlation	R: 0·41	$P<0{\cdot}001$			

S.S.: sum of squares
D.F.: degrees of freedom
var.: variance.

Multiple regression equation,—
Percentage indoor SO_2=
$13{\cdot}8-3{\cdot}78X_a-1{\cdot}14X_b+4{\cdot}12X_c+0{\cdot}04X_d$

is probably neutralized better by walls and ceilings in the newer homes. Old homes that have not been re-plastered gradually become saturated.

Town gas in Rotterdam contained at the time of investigation 100–250 mg S per m^3, so we expected the open gas heaters that were found in some of the living rooms to have a registerable effect on indoor SO_2 concentration. Since there were only 5 living rooms with gas heaters in our sample, our suspicion is not removed by the negative results of TABLES 4 and 6, the latter giving the single regressions of the percentages of smoke and SO_2 on the heating systems. As a matter of fact it is slightly increased by the fact that according to TABLE 6 the average percentage SO_2 indoors is by far the highest for gas heated living rooms.

showed, however, that in the winter season in London small mortality peaks coincided with relatively small air pollution peaks. They demonstrated that this effect occurred with outdoor SO_2 and smoke concentrations of only 700 $\mu g/m^3$. During a dense fog on 5 December 1962 we measured in Rotterdam concentrations of approximately 1000 μg SO_2 and 400 μg smoke per m^3 air. FIGURE 3 shows that there was a coincidence with a small rise in mortality of persons 60 years of age and older who died of cardio-respiratory diseases and tumors. If these rises in mortality are related to indoor pollution, it means that the victims may have been exposed in reality to still lower SO_2 concentrations than suggested by the outdoor samples taken during such episodes.

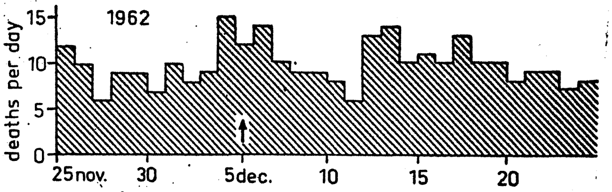

FIGURE 3. Daily mortality due to cardiorespiratory diseases and tumors of residents over 60 years old in Rotterdam during the fog of 5 December 1962.

In our series of 60 homes the probability of having more smoke indoors than outdoors was approximately 20 per 100 days and the probability of having more SO_2 indoors than outdoors was not more than 2 per 100 days, as illustrated by FIG. 2. We could have obtained a higher percentage of such days, if we had not left out two homes with in one case intermittent and in the other case continuous higher SO_2 concentrations indoors. TABLE 7 gives the indoor and outdoor SO_2 concentrations in the home with continuously higher indoor concentrations. This home was found by accident, not because the owners had volunteered because of complaints.

If 1 out of 100 houses has a failing chimney or a failing stove during smogs, one begins to wonder how far indoor concentrations of air pollutants play a role in causing premature death in persons with failing circulation and respiration and what role CO plays in this process.

Unfortunately our data are too sparse to give an answer to this important epidemiological question. However, as so little is understood of the mechanism which cause such persons to die, we thought justified in making these findings more widely known.

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