Indoor NO_2 pollution and personal exposure to NO_2 in two areas with different outdoor NO_2 pollution

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Abstract

Indoor NO_2 concentrations were measured in the kitchen, the living room and bedroom of 612 houses in two different areas in the Netherlands. In a sub-sample personal exposure of the housewives to NO_2 was measured. NO_2 concentrations indoors depended on the presence or absence of (un)vented gas appliances. Personal NO_2 exposure was only different between the two areas in the group with the lowest indoor concentrations. It was concluded that with respect to NO_2 exposure it is impossible to categorize groups without accounting for gas appliances inside the house.

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Introduction

Several studies on the occurence of nitrogen dioxide inside homes have indicated that fossil fuel combustion is the main indoor NO_2 source (Melia et al., 1977; Melia et al., 1979; Florey et al., 1979; Keller et al., 1979a,b; Speizer et al., 1980; Hasselblad et al., 1981; Dodge, 1982; Berwick et al., 1984; Leaderer et al., 1984a,b, Noy et al., 1984; Yanagisawa et al., 1984). A well-known source is the gas-stove, which is mostly unvented and therefore emitting NO_2 directly into the kitchen and from there into the rest of the house.

In the Netherlands a special type of gas fired water-heater, a so-called geiser, is commonly used. In 64% of the houses such a geiser is present and in approximately 75% of these houses it is located in the kitchen. 50% Of the "kitchengeisers" are unvented. The geisers supply hot-water for dishwashing and showering.

Field studies have shown that for the Dutch situation the geiser is a major source of NO_2 production (Lebret et al., 1983; Noy et al., 1984; Remijn et al., 1985). It has been shown that personal exposures to nitrogen dioxide were highly determined by indoor NO_2 concentrations while outdoor concentrations were of minor importance for personal exposures (Spengler et al., 1984). Because of this, and because indoor NO_2 concentrations can be very high, several studies have been initiated to assess the health-effects of indoor NO_2 pollution (Hoek et al., 1984; Remijn et al., 1985). In these studies special attention is paid to the integrated personal NO_2 exposure by measuring the actual exposure or by calculating exposure estimates by the use of models.

The present study deals with the exposure characteristics of NO_2 in a field study concerning the relationship between indoor exposure to NO_2 and tobacco smoke and pulmonary function of housewives (Brunekreef et al., 1985, Fischer et al., 1985, Remijn et al., 1985). For the purpose of this study houses were visited of housewives who already participated in a longitudinal field study on the natural history and determinants of chronic non specific lung diseases (Lende van der, 1969; Lende van der et al., 1981). In the latter study two populations were selected from a non-polluted rural area in the north-eastern part and from an urban area near the harbor of Rotterdam. Typical for the study is that the cohorts in both areas of residence are studied at intervals of 3 years. Outdoor NO_2, SO_2 and standard smoke concentrations are consequently higher in the urban area, a.o. due to the presence of a number of oil refineries situated near the harbor of Rotterdam.

Methods

In the winter of 1982-1983 164 houses were visited in the rural area; in the winter of 1983-1984 an additional sample of 149 houses was visited in the rural area and a sample of 299 houses was visited in the winter of 1984-1985 in the urban area.
During the visits weekly average NO_2 concentrations were measured in the kitchen, living room and bedroom with diffusion tubes (Palmes et al., 1976). The tubes were placed in the kitchen as far away as possible from NO_2 sources like the geiser and gas stove, and at central points in the living room and bedroom between 1.50m and 2m height.
In the last two winters the women were asked to carry a personal Palmes' diffusion sampler during the week in which NO_2 was measured inside their homes. During the same week the women kept a small diary on their activity pattern. They were asked to fill out for every hour of the day where they had spent most of their time. The six possible categories indicated were kitchen, living room, bedroom, job, outdoors and other indoor environments. Personal exposure then was estimated by calculating time weighted exposure from measured NO_2 levels and activity pattern. Furthermore a questionnaire on house characteristics and personal data was completed. Outdoor NO_2 concentrations during the measurement period were measured at stationary points by the National Institute of Public Health and Environmental Hygiene.

Results

Arithmetric mean NO_2 concentrations are summarized in Table 1 for the subsequent measurement periods. It can be seen from the table that kitchen concentrations are higher than living- and bedroom concentrations. Bedroom concentrations are the lowest, representing the absence of a NO_2 source, dilution and decay in the rest of the house.

All concentrations measured in the urban area were higher than in the rural area. The conclusion that can be drawn from this table is that people living in an urban area are more exposed to NO_2 than people living in a rural area. The difference in outdoor NO_2 concentrations might be an explanation. However, the distribution of the major NO_2 source in Dutch homes, the geiser, differed substantially between the two areas. This is shown in Table 2. In 61% of the houses in the urban area an unvented geiser was present in the kitchen, while this was the case in only 24% of the rural kitchens. Therefore it might be illustrative to compare indoor NO_2 concentrations and personal exposure in the two areas by presence of a geiser in the kitchen and presence of a venting duct. The results are given in Table 3.
Indoor NO_2 concentrations in all locations and personal exposures were higher when an unvented geiser was present in the kitchen. Kitchen concentrations were even higher in the rural area when an unvented geiser was present. Bedroom concentrations were higher in the urban area, independent of the venting situation of the geiser probably due to the higher outdoor concentrations. Personal exposure seems to differ only for people living in houses without a geiser. This difference, among other differences was investigated with multiple regression analysis. The effects of the geiser class were incorporated in the model through the use of dummy (0,1) variables: D1 = 1 if a vented geiser was present in the kitchen and D2=1 if an unvented geiser was present in the kitchen.
The regression coefficient associated with D1 is the difference in NO_2 level between the group with a vented geiser and the group without a geiser. Similarly the regression coefficient associated with D2 is the difference between the group with an unvented geiser and the group without a geiser. Furthermore the effect of place (0=rural, 1=urban), cooking fuel (electricity=0, gas=1) and presence of a hood on the stove (yes=0, no=1) were incorporated in the model. Tables 4a-d summarize the results.
For the whole group, table 4a, all the concentrations were significantly related to the geiser class. Cooking fuel has an effect on the concentrations as well, but it has to be pointed out that in only 5% (N=15) of the houses electricity was used for cooking and therefore the magnitude of the effect has to be interpreted with care. Place of residence did not have an effect on the kitchen concentrations in the whole group. When, however,

regression analyses were performed for the different geiser classes the results became somewhat different (table 4b-d).
In the group "no geiser present" place and cooking fuel affected all concentrations. In the group "vented geiser in the kitchen" place of residence only had an effect on living- and bedroom concentrations, but not on kitchen concentrations and personal exposure. In the highest exposure group (unvented geiser in the kitchen) place of residence was of borderline significance for the kitchen concentrations (with the higher concentrations in the area with the lowest outdoor NO_2 concentrations) and only bedroom concentrations differed statistically significant between the two places in the expected direction. Living room concentrations and personal exposure however did not differ. The conclusions we can draw from the tables are that personal NO_2 exposure was different between the two places in the group with the lowest indoor concentrations. Bedroom NO_2 concentrations differed consistently between the two places for all categories, while only in the lowest exposure class all concentrations differed between the two places.
The most important conclusion we can draw is that for this population with respect to NO_2 exposure it is impossible to categorize groups without considering the presence of gas appliances inside the house.
That this conclusion is only true for the underlying population is shown in table 5, which gives the time distribution for the women living in the two areas. In the rural area relatively more time is spent in the kitchen and less time in the living room. Since kitchen concentrations are the highest, differences in personal exposure as they would exist when the time distribution of the two populations was the same, will be diminished. On the other hand, in the urban area more time is spent outdoors which will enlarge differences in personal exposure. Because of the differences in time distribution it is not possible to generalize the results quantitatively to other populations.

Discussion

In this study it appeared that NO_2 levels in houses depended on the presence of (un)vented gas appliances. Personal exposure measurements showed the same pattern and were not related to

outdoor concentrations alone. In the groups with a relatively high indoor NO_2 pollution there was no significant difference between the personal exposures in the two areas. Therefore we concluded that for this population it is impossible to categorize groups on the basis of outdoor NO_2 concentrations.
It has to be pointed out, however, that our population consisted of women who spend relatively much time inside their own home (82% - 86%). For other pollutants outdoor concentrations might be a good determinant for differences in personal exposure (SO_2, O_3) when no indoor source is present. Due to the large fraction of time spent inside the home, however, personal exposure differences will be lower than differences as they exist in the outdoor-air.
We did not check if the personal sampler was worn correctly, nor did we check if the time activity diary was filled out correctly. Estimated personal exposure, calculated with the NO_2 concentrations and the time spent in the different locations, correlated well with measured personal exposures. Therefore we believe that measured personal exposure is a good indicator of the true personal exposure.
If this study had been performed in two populations with the same time distribution, differences in outdoor concentrations might have been more important as explanation of differences in personal exposure than we found in this study. Nevertheless, within each population the presence of (un)vented gas appliances will be the most important determinant of personal exposure.
For a long time it was believed that personal exposure to air pollution was a matter of outdoor pollution. Now it becomes clear that for NO_2 indoor pollution is a major determinant of personal exposure. The consequence of this knowledge for studies performed in the past to assess the effects of air pollution on human health is not yet clear. Refinement of exposure measurements and estimates is a necessity in any air pollution health effect study to be performed in the future.

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Table 1. Weekly average NO_2 concentrations (AM±SD, $\mu g/m^3$) in the subsequent measurements periods

year	area	N	kitchen	livingroom	bedroom	personal*	outdoor
1982-1983	rural	164	75±62	36±28	17±7	--	22±9
1983-1984	rural	149	64±50	33±24	16±9	37±23	35±19
1984-1985	urban	299	96±59	47±25	35±18	51±22	62±12

* in the first period no personal measurements were performed; in the second period 10 personal measurements were lost and in the third period 3 personal measurements

Table 2. Distribution of geisers over the two areas investigated (%)

	urban	rural
presence of geiser	85	77
geiser in kitchen	77	57
unvented geiser in kitchen	61	24

Table 3. Weekly average NO_2 concentrations (AM±SD, $\mu g/m^3$) by presence of a geiser in the kitchen and presence of a venting duct

		urban	rural
unvented geiser	kitchen	120±55 (n=181)	143±60 (n=73)
	livingroom	55±24	51±30
	bedroom	39±17	23±11
	personal	58±21 (n=180)	55±17 (n=28)
vented geiser	kitchen	71±53 (n=48)	60±38 (n=105)
	livingroom	43±26	34±21
	bedroom	35±27	15±6
	personal	43±19 (n=48)	41±26 (n=45)
no geiser	kitchen	49±30 (n=44)	32±24 (n=34)
	livingroom	32±23	23±19
	bedroom	23±8	11±4
	personal	36±19 (n=42)	23±17 (n=31)

Table 4a. Regression coefficients of NO_2-concentrations ($\mu g/m^3$) and personal exposure ($\mu g/m^3$) on several predictor variables for all exposure groups

predictor variable	kitchen concentration	p	livingroom concentration	p	bedroom concentration	p	personal exposure	p
D1	19	<.01	9	<.01	7	<.01	12	<.01
D2	84	<.01	23	<.01	14	<.01	24	<.01
cooking fuel	34	<.01	14	.03	7	.08	17	<.01
hood	1	NS*	0	NS	0	NS	3	NS
place	-3	NS	7	<.01	17	<.01	6	.03
constant	12	NS	11	NS	3	NS	11	NS

*NS=not significant (p>.10)
D1=presence of vented geiser; 0=no, 1=yes
D2=presence of unvented geiser; 0=no, 1=yes
cooking fuel: 0=electricity, 1=gas
hood=presence of hood on the gas stove; 0=no, 1=yes
place: 0=rural, 1=urban

Table 4b. Regression coefficients of NO_2-concentrations ($\mu g/m^3$) and personal exposure ($\mu g/m^3$) on several predictor variables for the group: no water-heater present

predictor variable	kitchen concentration	p	livingroom concentration	p	bedroom concentration	p	personal exposure	p
cooking fuel	30	<.01	17	.04	7	<.01	17	.02
hood	5	NS	2	NS	1	NS	0	NS
place	16	.02	11	.04	11	<.01	13	<.01
constant	3	NS	5	NS	6	NS	8	NS

Table 4c. Regression coefficients of NO_2-concentrations ($\mu g/m^3$) and personal exposure ($\mu g/m^3$) on several predictor variables for the group: vented water-heater

predictor variable	kitchen concentration	p	livingroom concentration	p	bedroom concentration	p	personal exposure	p
cooking fuel	42	NS	14	NS	3	NS	27	.10
hood	19	.01	1	NS	-3	NS	3	NS
place	9	NS	9	.04	19	<.01	2	NS
constant	15	NS	20	NS	14	NS	14	NS

Table 4d. Regression coefficients of NO_2-concentrations ($\mu g/m^3$) and personal exposure ($\mu g/m^3$) on several predictor variables for the group: unvented water-heater

predictor variable	kitchen concentration	p	livingroom concentration	p	bedroom concentration	p	personal exposure	p
cooking fuel	44	.06	12	NS	6	NS	15	NS
hood	-7	NS	0	NS	2	NS	3	NS
place	-16	.09	4	NS	16	<.01	4	NS
constant	100	NS	39	NS	16	NS	39	NS

Table 5. Time distribution (%) in the two areas investigated, on the basis of hourly registration in a 7-day diary.

location	rural area	urban area
kitchen	24	11
living room	24	35
bedroom	36	38
job	3	2
outdoors	4	7
other house	9	8