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INDOOR CARBON MONOXIDE POLLUTION IN THE NETHERLANDS

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Most houses in the Netherlands are equipped with gas-fired heaters and cooking appliances, since large amounts of natural gas are available within the country since the mid-1960's. Carbon monoxide poisoning due to coal fires has virtually ceased to exist when coal-fired heaters were replaced by gas heaters. However, such poisonings still occur, although to a lesser extent, due to the use of instantaneous water heaters (geisers) that are gas fired. An investigation was carried out to establish the CO production potential of geisers under normal conditions of use. The study involved 254 houses; the results indicated that 17% of the geisers produced a CO level of more than 50 μL/L in the kitchens where they were located, after 15 min of operation. Presence of a flue, burner type, and maintenance system proved to be the main controlling factors.

Introduction

Indoor carbon monoxide pollution is probably as old as the discovery of fire. Studies in primitive dwellings with inadequate removal of combustion products of cooking and heating fires show extremely high levels of indoor pollutants including CO (Sofoluwe, 1968; Anderson, 1979). Town gas has long been, and in some areas continues to be, an important source of CO in houses, since CO is usually a constituent of the gas. Also, the burning of coal was seen to cause sometimes fatal levels of CO indoors under stagnant atmospheric conditions that caused insufficient removal of flue gases. This phenomenon has led to the suggestion that at least part of the increased mortality during the air pollution episodes that occurred before the mid-1960's in Western Europe was in fact caused by indoor CO poisoning (Biersteker and De Graaf, 1967).

In 1940 it was estimated that as many as 25,000 people died annually in the United States from CO poisoning, partly due to these sources (Beck *et al.*, 1940). A more recent figure by Schaplowski *et al.* (1974) estimates 1400 accidental deaths each year, mostly from automobiles (68%) and home heating equipment (26%). In the United Kingdom, several hundred fatalities due to CO were seen each year before the use of town gas was abandoned about 10 years ago. Since then the numbers have dropped, but recently a rise has been seen that is probably caused by restricted ventilation, lack of money for proper installment and maintenance of gas appliances, etc. (Anonymous, 1981a).

In the Netherlands, town gas was replaced in the mid-1960's by natural gas. This led to the rapid decrease of coal as a home heating fuel. Statistics on CO poisoning from 1961 to 1975 reflect these changes (Table 1). CO poisoning decreased dramatically due to the abandoning of coal, but at the same time a new source emerged, the geiser. A geiser is an instantaneous water heater that is usually located in the kitchen, often connected to the shower and usually not directly vented to the outside. At present, they are in use in 70% of Dutch homes. Most geisers have primary aerated burners that

Table 1. Registered fatal CO poisonings in the Netherlands, 1961–1975. Indoor CO survey Arnhem/Enschede, 1980.

	1961–1965	1966–1970	1971–1975
Coal-related	333	423	17
Direct poisoning, town gas	80	10	–
Geiser-related	21	34[1]	60[1]
Gas heater-related	3	12[1]	7[1]

Sources: Douze, 1971; VEG Gasinstituut, 1976; Central Bureau of Statistics.
[1]Number of accidents in which one or more people died; number of deaths approximately twice as high.

easily collect dust on the inside, thus restricting the air supply. This eventually leads to incomplete combustion and hence the formation of CO. Due to differences in combustion characteristics between town gas and natural gas, geisers that used town gas were all equipped with diffusion burners that use only secondary air, and for that reason they do not collect dust on the inside. Only one brand of natural gas geiser is equipped with a diffusion burner.

The Dutch gas industry has realized from the beginning that the natural gas geiser has a high potential for CO production. The solution for this problem has mainly been sought in encouragement of regular maintenance and the implementation and enforcement of an installation code which details the ventilation requirements for geisers. It also requires that geisers which are connected to a shower must be equipped with a safety provision that turns the geiser off automatically when a CO_2 concentration of more than ~1% is reached (Buyserd, 1968, 1976; Van Heijningen, 1969; Lensink, 1969; De Vries and Bartholomeus, 1973; Bartholomeus and Kayser, 1976; NNI, 1977; Vermünicht *et al.*, 1979; Anonymous, 1981b).

In 1969 an investigation was carried out in the city of Enschede in 237 residences that were equipped with geisers (Borst, 1972). In 16% of the kitchens, the CO level was higher than 250 μL/L after 30 min of operation under standardized conditions. The results of this survey prompted the implementation of a strict maintenance system in this particular city. The system includes off-site ultrasonic cleaning of geiser burners once every year.

This concentrated effort of the Dutch gas industry to fight acute CO poisoning has always been accompanied by a remarkable lack of interest for the possible health consequences of lower but still elevated levels of CO that might occur indoors. The Dutch installation code for gas appliances for example mentions an indoor CO standard of 50 μL/L without specifying an averaging time. This means that the occurrence of carboxyhemoglobin (COHb) levels of more than 2.5%–3% — the target level specified by most outdoor CO standards (NAS, 1977; WHO, 1979; Dutch Department of Public Health, 1975) — cannot be excluded under unfavourable conditions. Apart from the aforementioned study by Borst, there has been no effort to measure CO in Dutch houses other than in the flue gases of geisers and other gas appliances, for which the installation code specifies a maximum CO to CO_2 ratio of 0.01. This is roughly equivalent to a CO content of 600-700 μL/L in flue gases of geisers; most local gas companies in practice use 300 μL/L as an "action level" above which maintenance is required.

Recent indoor CO research in other countries has centered on gas-fired cooking appliances mostly, because geisers are uncommon in countries such as the United States, Canada, the United Kingdom, and Denmark, from which the bulk of indoor pollution literature originates. CO from cooking does not reach very high concentrations; peak levels of a few tens of μL/L are typical (Parry, 1979; Hollowell *et al.*, 1977; Wade *et al.*, 1975; Elkins *et al.*, 1974) although in one study levels up to more than 100 μL/L have been found (Sterling and Sterling, 1979). A different picture might arise when cooking appliances are put to use as supplementary heating equipment (Sterling and Kobayashi, 1981).

Since so little data are available on actual levels of CO in Dutch homes, the present study was established to gather information on the indoor CO pollution potential of geisers. The cities of Enschede and Arnhem were selected as study areas. Both cities are located in the eastern part of the Netherlands, and both have about 150,000 inhabitants. Enschede was selected because of the presence of a special maintenance system, mentioned earlier, which services about 80% of the geisers. Arnhem is considered to be more or less typical for the Dutch situation with regard to maintenance of gas appliances.

Materials and Methods

The survey was carried out in November and December 1980. The investigation covered 254 houses that came from a random sample of 815 (537 in Arnhem, 278 in Enschede), out of all houses that "most probably" were equipped with a geiser. People were informed in advance about the survey but not about the exact date of visit. The investigators did not attempt to make appointments; rather, they performed the measurements immediately after consent was obtained. Thus, many houses in which people were frequently not at home during office hours were not visited. The study sample was not different from the original sample with respect to the categories (apartments, row houses, etc.) into which the houses could be divided. Information on other parameters was not available.

In each house the air pollution potential of the geiser was assessed by operating the appliance continuously for 15 min. The CO concentration in flue gases was measured after 1 and 15 min of operation, the CO concentration at breathing height (1.5 m) was measured before and after the 15-min period. Also, the CO_2 concentration at breathing height was measured after 15 min. All measurements were taken with windows and doors closed. Permanent ventilation ducts, however, were left open. The installation code requires that gas appliances function properly under these circumstances.

The CO measurements were performed with Ecolyzer 2000 monitors with a dual range (0–100 and 0–600 μL/L). The instruments were field calibrated twice a day. The monitors exhibit little zero or span drift when operated under stable conditions, but show greater variations in response with temperature changes. As temperature changes cannot be eliminated in a field study such as this one, the overall coefficient of variation of the measurements is estimated to be ±10%. CO_2 was measured with Dräger colorimetric detection tubes, that are accurate to within 20%.

In addition to the measurements, a number of items were recorded by the investigators including: make, age and burner type of the geiser, presence of a flue, ventilation circumstances, number and type of other gas appliances, presence of a vent hood above the stove. The occupant that mostly operated the gas appliances in the house (usually the housewife) was interviewed on ventilation habits and appliance usage and on family characteristics.

Results

Flue gases

Table 2 shows the frequency distribution of CO levels in flue gases. The main parameter determining CO concentrations in flue gases was the type of burner. Of all the primary aerated (bunsen) burners, 32% reached CO concentrations higher than 300 μL/L. In case of secondary aerated (diffusion) burners this was only 3% ($\chi^2 = 22.85$; $p < 0.001$). For the group of geisers with a primary aerated burner, the maintenance system appeared to be an important factor to prevent high CO concentrations in flue gases ($\chi^2 = 10.54$; $p < 0.025$).

There was no significant difference between Arnhem and Enschede; the Arnhem sample contained more diffusion burners, but Enschede had a better maintenance system.

CO levels at breathing height

Table 3 shows the frequency distribution of CO concentrations at breathing height in the kitchens. As many variables related to CO levels at breathing height were also related to each other, linear logit models were used to analyze the data, with CO concentration as the dependent variable. Table 4 presents the distribution of cases on four parameters used in a linear logit model.

Table 2. Frequency distribution of CO concentrations in flue gases of geisers. Indoor CO survey Arnhem/Enschede, 1980.

CO Concentration, μL/L (ppm)	n	%
≤ 100	119	53
101–300	46	20
301–600	20	9
> 600	41	18
Missing values	28	
	254	100

Table 3. Frequency distribution of CO concentrations at breathing height. Indoor CO survey Arnhem/Enschede, 1980.

CO Concentration, μL/L (ppm)	n	%
≤ 10	154	63
11–50	50	20
51–100	25	10
> 100	17	7
Missing values	8	
	254	100

In 17% of cases a level of 50 μL/L, the installation code standard, was exceeded. In some cases a level of more than 600 μL/L was observed. Presence of a vent and, again, type of burner both had an effect on CO levels at breathing height. In 3% of the cases, water heaters with a flue produced CO concentrations higher than 25 μL/L, while in 50% of the houses in which unvented geisers with a primary aerated burner were located, CO levels exceeded 25 μL/L.

A second-order interaction appeared between city, type of burner, and CO level at breathing height. In Arnhem a higher percentage of unvented geisers with primary aerated burners produced CO levels above 25 μL/L than in Enschede. This again is probably due to the maintenance system, mentioned above. No other factors were found to be statistically related to both CO level and city. Too few observations per cell remained to permit a more detailed analysis.

Discussion

In 27% of the investigated houses, CO concentrations in flue gases exceeded requirements of the local gas companies (300 μL/L). The presence of a secondary aerated burner proved to be the most important factor in preventing high CO concentrations in flue gases. This type of burner and the presence of a vent were the most important factors in reducing CO concentrations at breathing level. In addition, the type of maintenance system proved to be important. Since our measurements were carried out under standard conditions (15 min, doors and window closed) no exposure estimate can be derived from the data. The period of 15 min we used in our measurements is in accordance with the usage pattern of gas appliances established in a small survey (Dijkhof and Ogink, 1978).

The Dutch Health Council uses an outdoor standard of 35 μL/L CO (1-h average) not to be exceeded more than once a week. In the United States the same stan-

Table 4. Distribution of cases according to CO level at breathing height, burner type, city, presence of a flue. Indoor CO survey Arnhem/Enschede, 1980.

	Bunsen Burner				Diffusion Burner			
	Flue		No Flue		Flue		No Flue	
	Arnhem	Enschede	Arnhem	Enschede	Arnhem	Enschede	Arnhem	Enschede
CO ≤ 25 μL/L	37	40	45	14	9	4	22	1
CO > 25 μL/L	3	0	49	10	0	0	2	1
Missing values 17								

dard is used, not to be exceeded more than once a year. In 1980 the EPA proposed to lower the 1-h standard to 25 μL/L (Anonymous, 1980).

A high risk is associated with prolonged periods of continuous use under low ventilation conditions. No information as yet is available on the frequency of these coincidences. Although no 1-h measurements were made, the frequency in which a level of 50 μL/L was exceeded was high enough to warrant the conclusion that existing outdoor standards for CO could very well be violated regularly in a significant number of kitchens in the sample.

At this moment it is not possible to define the consequences in terms of ill health. Continuous measurement of CO in homes will be undertaken in the next few years. In addition, measurement of CO in exhaled breath, as an estimate of COHb, in residents under different circumstances of gas appliance usage and ventilation, is planned for the near future.

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