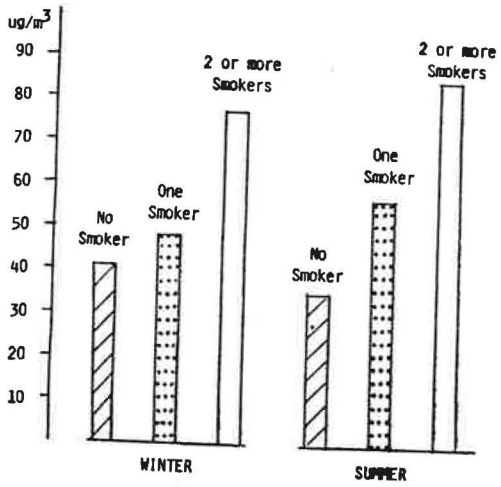
FIGURE 3

RESPIRABLE SUSPENDED PARTICULATE LEVELS
AS A FUNCTION OF SMOKING



NITROGEN DIOXIDE LEVELS IN RESIDENCES -
EFFECTS OF SOURCE TYPES

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This study was conducted to determine NO_2 contamination characteristics of residences which utilize a variety of combustion and noncombustion space heating systems, as well as those which use gas cooking. Residences were classified as gas cooking, gas furnace/electric cooking, wood-burning stoves/electric cooking, kerosene heat/electric cooking, noncooking steam heat, and all electric. Sampling was conducted by collecting NO_2 on Palmes diffusion tubes during several heating seasons. Highest NO_2 levels were measured in residences which used gas for cooking or kerosene heaters for supplemental space heating. Significantly lower NO_2 concentrations were measured in residences heated by gas furnaces/electric cooking, wood-burning stoves/electric cooking, steam-heated dormitory rooms, and all-electric residences. NO_2 levels in each of these four residence types were similar. In residences with wood-burning stoves, NO_2 could not be related to heating degree days, a measure of the 24 hr. average outdoor temperature. Multiple concurrent measurements in the upstairs and basement levels of a gas-heated residence indicated significantly higher levels upstairs even though the gas furnace was located in the basement. These results suggest that the source of NO_2 contamination in such residences, and possibly in those heated by wood, steam or electricity, is primarily external to the residences.

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Introduction

Nitrogen dioxide (NO_2) is a common contaminant of both ambient and indoor air. Because of its toxicity and its community-wide occurrence in ambient air, it is regulated under the National Ambient Air Quality Standards provision of the Clean Air Act. The contamination of indoor air by NO_2 may have considerable health significance because of longer average exposure durations (1) and the presence of sources indoors which can produce elevated NO_2 levels. Such sources may include gas ranges (2), kerosene heaters (3,4), wood-burning stoves (5), gas water heaters (6), gas/oil furnaces, tobacco smoking and infiltration of ambient air. This study was designed to expand the knowledge on indoor NO_2 contamination, particularly as it relates to a range of potential NO_2 sources and residence categories.

Methods

Study residences were selected and classified as to their primary source of space heating, and whether or not a gas range was used for cooking. Although most residences were single family dwellings, the study also included a population of steam-heated dormitory units. Studies of NO_2 levels associated with unvented kerosene heaters also included several multi-family condominium units. An attempt was made to monitor 10 residences in the following categories: gas furnace/electric range, wood-burning stove/electric range, gas range, dormitory steam heat, electric heat/electric range, and kerosene heater/electric range. This was achieved with the exception of the kerosene heater category (8 residences). However, residences classified as gas range or gas cooking were heated by either a gas furnace or electricity.

All NO_2 measurements were made by suspending Palmes diffusion tubes (7) approximately four feet above the floor surface in each residence monitored. A single Palmes tube was exposed near the middle of each residence in four of the residence/source categories. However, in residences heated by wood stoves and those with kerosene heaters, two samplers were used, one approximately 10 feet from the combustion source and a second in a bedroom distant from the potential source of NO_2. The results of these two measurements were averaged so that they could be compared to other residence/source categories. All Palmes diffusion tubes were exposed for an approximate 7-day sampling period and all results were therefore expressed as a 7-day average concentration. No attempt was made to sample all residences concurrently, rather measurements were made on a random basis in respect to time during several heating seasons.

The Palmes method is based on the passive collection of NO_2 on ethanolamine coated stainless steel screen discs mounted at the end of a 9.5 mm I.D. x 71 mm long acrylic plastic cylinder. The NO_2 collected during sampling is analyzed colorimetrically by reacting the NO2 - ethanolamine sorption complex with a combined reagent of phosphoric acid, sulfanilimide and N-1-naphthylenediamine hydrochloride. The method has a precision of $\pm$ 6% in the sample concentration range of 0.13 - 8.5 μg (8). The minimum detection level was 2 ppb for the sampling duration given.

Initial studies focused on NO_2 contamination of residences associated with the use of wood stoves for space heating. An attempt was made to relate indoor NO_2 concentrations to heating-degree days, a measure of the 24-hour average outdoor temperature. Ten wood-burning stove residences were sampled an average of three times over the course of the heating season. The relationship was evaluated by the application of simple linear regression analysis.

Concurrent measurements of NO_2 levels in the upstairs and basement areas of a single family residence heated by a gas furnace located in the basement were made in 7 different one-week sampling periods. Results of these measurements were analyzed by a paired t-test. A paired t-test was also employed to determine whether there were significant differences in NO_2 levels in wood-burning stove residences in terms of sampler position relative to the source of combustion.

Differences in NO_2 concentrations measured in the residence/source categories defined in this study were evaluated by a Completely Randomized Design Analysis of Variance and Duncans Multiple Range Test. A probability value of 0.05 was accepted as significant in all statistical analyses.

Results

Results of indoor NO_2 concentrations ($\pm$ 2 standard errors of the mean) associated with different residence/source categories are summarized in Figure 1. No significant differences were observed among these residence/source categories: wood-burning stove/electric cooking, dormitory steam heat/no cooking, gas furnace/electric cooking and electric heat. Significantly higher concentrations were observed in residences utilizing a gas range and those using a kerosene heater for supplemental space heat. Differences in NO_2 concentrations between the last 2 categories were not significantly different.

An analysis of wood-burning stove data (paired t-test) relative to position of samples with respect to distance from the combustion source revealed no significant differences. Similar data for kerosene heater residences could not be analyzed since a portion of the samplers inadvertently had not been labeled as to position. Heating degree days, a measure of the 24 hr. average temperature, and NO_2 concentrations in wood-burning houses were not found to be significantly related.

A significant difference ($P = .001$) was observed in the basement and upstairs levels of NO_2 in a residence heated by a gas furnace (electric cooking) located in the basement. Basement levels had an average concentration measured over 7 separate 7-day periods of 4.2 ppb; upstairs levels were 7 ppb.

Discussion

Significant contamination of indoor residences by NO_2 was only observed under conditions where unvented gas or kerosene appliances were utilized. By comparison, in residences utilizing wood stoves or gas furnaces for space heat, NO_2 levels were not significantly different from those (dormitory/steam heat and all electric) which utilized no combustion appliances. Average NO_2 concentrations in residences using gas cooking appliances were similar to those reported by Palmes *et al* (2). However, concentrations of NO_2 reported here for non-gas stove residences were

higher (11-15 ppb vs 8 ppb) than those reported by Palmes. They were also higher than average values of 4 ppb reported by Leaderer et al (9) for similar residences.

Traynor et al (5) have reported that residences with wood-burning stoves and furnaces show elevated levels of NO and NO_2 which they suggest result from slow leakage from these devices rather than episodal release during stoking and reloading. Their observations, however, are not supported by the studies reported here which indicate no statistically significant differences in NO_2 levels in wood-burning residences and those which do not have a major source of combustion. The lack of any differences in NO_2 levels associated with distance from wood-burning stoves supports these observations that wood-burning stoves, at least those involved in this study, are not a significant source of NO_2 emissions into indoor air. The lack of a correlation between wood-burning and indoor NO_2 levels has also been reported by Moschandreas et al (10).

Nitrogen dioxide levels in residences heated by gas furnaces were not significantly different from those heated by electricity or steam suggesting that normally-operating gas furnaces are not a major source of NO_2 contamination. The comparative study of NO_2 levels in the basement level and the upstairs level of a residence in which the gas furnace was located in the basement also indicates that gas furnaces normally are not a significant source of indoor NO_2 contamination. Studies by Fortman et al (11) indicate fugitive emissions from gas furnaces are very low.

Concentrations (11-15 ppb) of NO_2 reported here for non-gas stove and non-kerosene heater residences appear to be significantly higher than those reported by Palmes et al (2) and Leaderer et al (9). These results suggest a source of NO_2 in Central Indiana residences which has not been accounted for by a consideration of the presence or absence of combustion appliances. Other sources may include cigarette smoking, infiltration of ambient air, and intrusion of motor vehicle emissions from attached garages. Measurement of outdoor concentrations of NO_2 were not included in this study. However, data available from continuous ambient monitoring in a portion of the study area (Indianapolis) indicate average ambient levels of 20 ppb. The infiltration of ambient air and intrusion of motor vehicle emissions is suggested from observed differences in NO_2 levels in the upstairs and basement areas of the multiply sampled gas furnace-heated residence.

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