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SCIENCE DIRECT
Environmental Research 102 (2006) 1–8
Environmental Research
www.elsevier.com/locate/envres

Housing characteristics and indoor concentrations of nitrogen dioxide and formaldehyde in Quebec City, Canada ☆

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Received 12 September 2005; received in revised form 7 February 2006; accepted 17 February 2006
Available online 18 April 2006

Abstract

Concentrations of nitrogen dioxide and formaldehyde were determined in a study of 96 homes in Quebec City, Canada, between January and April 2005. In addition, relative humidity, temperature, and air change rates were measured in homes, and housing characteristics were documented through a questionnaire to occupants. Half of the homes had ventilation rates below 7.5 L/s person. Nitrogen dioxide (NO_2) and formaldehyde concentrations ranged from 3.3 to 29.1 $\mu g/m^3$ (geometric mean 8.3 $\mu g/m^3$) and from 9.6 to 90.0 $\mu g/m^3$ (geometric mean of 29.5 $\mu g/m^3$), respectively. The housing characteristics documented in the study explained approximately half of the variance of NO_2 and formaldehyde. NO_2 concentrations in homes were positively correlated with air change rates (indicating a significant contribution of outdoor sources to indoor levels) and were significantly elevated in homes equipped with gas stoves and, to a lesser extent, in homes with gas heating systems. Formaldehyde concentrations were negatively correlated with air change rates and were significantly elevated in homes heated by electrical systems, in those with new wooden or melamine furniture purchased in the previous 12 months, and in those where painting or varnishing had been done in the sampled room in the previous 12 months. Results did not indicate any significant contribution of indoor combustion sources, including wood-burning appliances, to indoor levels of formaldehyde. These results suggest that formaldehyde concentrations in Quebec City homes are caused primarily by off-gassing, and that increasing air change rates in homes could reduce exposure to this compound. More generally, our findings confirm the influence of housing characteristics on indoor concentrations of NO_2 and formaldehyde.

Keywords: Indoor air quality; Formaldehyde; Nitrogen dioxide; Air change rate; Housing

1. Introduction

Although residential environments historically have received less attention than outdoor air and workplaces, they may be major sources of exposure to certain air pollutants. This may be particularly true for Canadians, who spend, on average, two-thirds of their time inside their homes (Leech et al., 2001).

Indoor air pollution in residences arises from the infiltration of ambient air pollution and from indoor sources. Concentrations of pollutants with indoor sources are typically higher in indoor air than in ambient air.

Nitrogen dioxide (NO_2) is emitted by the combustion of fossil fuels such as gasoline, diesel, and natural gas (WHO, 1997). Concentrations of NO_2 are lower indoors than outdoors in the absence of indoor sources, but can be higher indoors than outdoors in the presence of unvented combustion appliances such as gas stoves (Levy et al.,

☆Information on study participants was collected and protected in accordance with privacy laws. The protocol of this study was reviewed and approved by Health Canada's Research Ethics Board.

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doi:10.1016/j.envres.2006.02.007

1998). NO_2 is an airway irritant. Exposure to NO_2 increases bronchial responsiveness in both asthmatic and healthy individuals and enhances response to inhaled allergens in asthmatics (WHO, 1997).

Human exposure to formaldehyde is primarily associated with indoor sources. Formaldehyde is emitted by off-gassing from wood-based products assembled with urea–formaldehyde and phenol–formaldehyde resins (Brown, 1999; Kelly et al., 1999) and by some paints (Chang et al., 1999, 2002) and varnishes (Howard et al., 1998; McCrillis et al., 1999). Formaldehyde is also present in wood smoke (Lipari et al., 1984; Ramdahl et al., 1982) and in cigarette smoke (IARC, 1986). Short-term exposure to formaldehyde causes irritation of the airways and the eyes, and chronic exposure is associated with an increased risk of nasopharyngeal and sinonasal cancer (Health Canada, 2005).

In Canada, residential indoor air quality guidelines were issued in the 1980s (Health and Welfare Canada, 1989). These include exposure limits for nitrogen dioxide, formaldehyde, ozone, and particulate matter, among others. A revision of these guidelines was initiated in 2001; a revised guideline has been proposed for formaldehyde (Health Canada, 2005), and reassessments are underway for other substances. A major knowledge gap identified in the re-assessment process was the lack of current data on levels and sources of indoor air pollution in residential indoor air.

The objectives of this study were, therefore, to determine indoor air concentrations of nitrogen dioxide and formaldehyde in a sample of houses of varying characteristics and to identify the factors associated with the presence of high levels of these pollutants in Canadian homes.

2. Methods

2.1. Selection and recruitment of participants

In 2002, 68% of dwellings in the province of Quebec were heated mainly by electrical systems, while 17% were heated by oil, 9% by wood-burning appliances, and only 6% by natural gas (Government of Quebec, 2004). In order to ensure approximately equal representation of electrical and combustion heating systems, participants were selected in three areas of Quebec City, with a greater proportion of combustion systems chosen.

A target sample size of 100 had been established based on resource considerations. Only families living in single-family dwellings, duplexes, or triplexes and owning their homes were eligible to participate. Participation was restricted to families owing their homes to avoid having to seek owner's authorization in addition to occupants' consent. A total of 418 potential participants identified in phone directories were sent letters inviting them to participate in the study, and were then contacted by telephone. Among these, 358, or 86%, were successfully reached. Residents who agreed to take part in the study ($n = 177$, 42%) were asked to complete a screening questionnaire to determine eligibility for the study and identify the heating systems of the homes. Then a final selection was made to ensure a sufficient number of homes with nonelectrical systems: 93 dwellings were selected. Since only one of these had a gas stove, public health staff members who lived in Quebec City, had gas stoves, and met all other eligibility criteria were invited to join the study; three additional dwellings were recruited in this way.

2.2. Data collection

Data collection, including questionnaire administration and indoor air quality measurements, was carried out between January and April 2005, i.e., in winter and early spring, when people in Quebec City usually keep their windows closed.

During the first visit, an initial questionnaire was administered to an adult occupant to document house characteristics, e.g., type, year built, dimensions, heating and cooking systems, other equipment, recent addition of furniture, recent painting or varnishing, and presence of smokers. During this visit, monitoring/sampling devices for nitrogen dioxide, formaldehyde, relative humidity, temperature, and air change rates were installed in the living room.

A second visit took place 24 h after the first one. Formaldehyde samplers were removed, and a second questionnaire dealing with potential air pollution sources (heating and cooking, smoking, new furnishing, painting and varnishing) during the previous 24 h was administered.

A final visit took place 7 days after the first one. Relative humidity and temperature monitors, NO_2 samplers, and equipment used to determine air change rates were removed, and a third questionnaire was administered to document air pollution sources during the previous 6 days (i.e., since the second visit).

All measurements were taken in the living room, regardless of the floor where it was located. Temperature and relative humidity were recorded every 10 min over 7 days by means of two ACR SmartReader data loggers (ACR Systems, Inc.).

Nitrogen dioxide was sampled for 7 days by means of two-sided Ogawa passive monitors with triethanolamine-impregnated filters (Ogawa & Co., Pompano Beach, USA). Each monitor had two independent filters and therefore yielded duplicate results. Every second week, two samplers were removed from their bags, and immediately resealed, and sent to the laboratory, along with exposed samplers, in order to serve as field blanks (total 14 blanks). Samples were analyzed by ion chromatography. The amount of nitrite measured in each sampler was corrected for possible contamination by subtracting the mean amount found in field blanks. The method detection limit was 0.08 μg nitrite per sample which, assuming a 1-wk sampling duration, a temperature of 20 °C, and 32% relative humidity, corresponds to a concentration of 1.0 $\mu g/m^3$.

Formaldehyde was sampled for 24 h using Umex 100 passive monitors, with 2,4-dinitrophenylhydrazine (DNPH) as the reagent. Samples were collected between Monday and Friday. In eight homes, two monitors were placed side by side for duplicate sampling. Every second week, two samplers were removed from their bags, and immediately resealed, and sent to the laboratory along with exposed samplers in order to serve as field blanks (total 14 blanks). Formaldehyde was analyzed using high performance liquid chromatography (HPLC). The amount of formaldehyde measured in each sampler was corrected for possible contamination by subtracting the mean amount found in field blanks. The minimum reporting limit (MRL) of the method was 40 ng formaldehyde per sample which, assuming a 0.0286 L/min sampling rate and a 24-h sampling, corresponds to a concentration of 1.0 $\mu g/m^3$.

Rates of air infiltration in the homes (in m^3/h) were determined by the perfluorocarbon tracer (PFT) technique (Dietz and Cote, 1982). Three PFT sources in each home were considered to be a sufficient distributed quantity to attain a uniform tagging level. They were generally placed in the kitchen, the living room, and the masters' room. In most homes, one capillary adsorption tube sampler (CATS) was centrally located for a seven-day sampling duration; in four homes, three CATS samplers were placed side by side for a QA check on sampling and analysis. The thermal desorption of the CATS, followed by electron capture detection in a calibrated gas chromatograph, provided the quantity of tracer (nl) and the duration of exposure allowed the determination of the passive volume (m^3) of air collected; dividing this concentration (nl/m^3) into the temperature-corrected PFT source rate (nl/h) gave the m^3/h infiltration rates (Dietz and Cote, 1982). Air change rates (in h^{-1}) were calculated by dividing infiltration rates by estimated house volumes; ventilation rates (in L/s person) were obtained by dividing infiltration rates by 3.6 (3600 s/h over 1000 L/m^3) and then by number of occupants.