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Impact of kerosene space heaters on indoor air quality

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HIGHLIGHTS

- Kerosene space heaters are sources of indoor air contaminants.
- Their impact on IAQ is higher than any other source.
- NO_2 and CO_2 levels exceed the guideline values during operation.
- Average CO_2 and NO_x levels are correlated with the duration of use.
- Kerosene heaters also produce ultrafine particles and VOCs.

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ABSTRACT

In recent years, the use of kerosene space heaters as additional or principal heat source has been increasing, because these heaters allow a continuous control on the energy cost. These devices are unvented, and all combustion products are released into the room where the heaters are operated. The indoor air quality of seven private homes using wick-type or electronic injection-type kerosene space heaters was investigated. Concentrations of CO, CO_2, NO_x, formaldehyde and particulate matter (0.02–10 μm) were measured, using time-resolved instruments when available. All heaters tested are significant sources of submicron particles, NO_x and CO_2. The average NO_2 and CO_2 concentrations are determined by the duration of use of the kerosene heaters. These results stress the need to regulate the use of unvented combustion appliances to decrease the exposure of people to air contaminants.

1. Introduction

Kerosene space heaters are combustion devices relying on liquid fuel. They are cheap (100–200 €, with some models up to ~1000 €), unvented, lightweight, small-size heaters, providing a fast heat. Wick-type kerosene heaters do not require an electrical outlet, whereas injection type heaters have to be plugged to such an outlet, or can run on batteries. Kerosene heaters can be installed in any location, and be easily moved, so as to provide an additional or temporary heat source where the user needs it. They are therefore particularly suited to heat places which are not connected to a central heating system, such as outhouses, garages or workshops. They are also increasingly found, in Northern France or Belgium, in shops and restaurants during wintertime. However, the main reason why kerosene heaters are used (Carteret, 2012; Salthammer, 2013) is linked to fuel poverty, because they are much cheaper than a standard central heating system, and provide heat only where it is needed. In addition, their fuel tanks capacity is limited to a few liters, and the users have to refill them regularly and have therefore real-time feedback over the actual cost of heating.

Because kerosene heaters are unvented appliances, the combustion products build up in the room during their use, in case of insufficient ventilation. As fuel poverty is usually associated with poorly thermally insulated dwellings, people tend to close all vents so as to retain the heat. This results in increased dampness of the dwelling, possibly leading to damages to the structure of the building. For this reason, kerosene heaters are usually forbidden in many French places such as university dorms or low income housing, though their use in such locations is often reported. It is therefore quite difficult to ascertain to what extent kerosene heaters are used, as people do not voluntarily admit to using such a device. It is estimated, based on cases reported by social workers and in two field studies of indoor pollution in Northern France (Schadkowski, 2003; Chambon and Schadkowski, 2004), that kerosene space heaters are used in ~10% of French households. These

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studies also reported that the daily average duration of use is 9 h, with a maximum of 22 h, well above the recommended duration ($2\ h\ d^{-1}$). They also put in evidence that the use of kerosene heaters is linked with elevated CO concentrations, possibly resulting in chronic CO poisoning.

Few studies have investigated the emissions induced by kerosene space heaters, and their impact on indoor air quality. Nitrogen oxides NO and NO_2, sulfur dioxide SO_2, and carbon oxides CO and CO_2 were identified in the emissions from kerosene heaters (Yamanaka et al., 1979; Leaderer, 1982; Tu and Hinchliffe, 1983; Lionel et al., 1986; Zhou and Cheng, 2000), as well as many organic compounds, such as carbonyl compounds (Traynor et al., 1983), aliphatic alkanes and mono- and poly-aromatic compounds, including nitro-PAHs (Mumford et al., 1991; Bozzelli et al., 1995). Particulate matter is also emitted (White et al., 1987; Traynor et al., 1990), with some mutagenic species, especially nitropyrene derivatives (Tokiwa et al., 1987; Kinouchi et al., 1988). In addition to the continuous emissions during use of the heater, a transient emission of air toxics is reported when the heater is turned on or off (Woodring et al., 1985). In particular, there is a spike in ultrafine particles (<100 nm aerodynamic diameter) that progressively coagulate into coarser particles during the continuous operation of the heater (Carteret et al., 2010).

Gaseous pollutants emission factors were recently determined in laboratory experiments, using the different heater types and fuels currently available in Northern France (Carteret et al., 2012). This study confirmed that NO_x, CO_2 and CO are the main gaseous pollutants emitted by kerosene space heaters. SO_2 emissions were found to be negligible. Carbonyl compounds (formaldehyde, acetaldehyde, acetone) were identified, as well as ~50 other VOCs, six of which presenting a risk for human health (1,3-butadiene, benzene, ethylene, propene, isobutene and acetylene). This study also put in evidence the accumulation of soot on wick heaters after a few hours of operation, concomitant with increasing CO emissions, which might explain the reported chronic and acute CO poisonings.

In the present paper we investigate the impact of kerosene space heaters emissions on indoor air quality in 7 private homes in the Lille (Northern France) area, where these heaters are used as the primary or supplemental source of heating.

2. Materials and methods

The measurements were carried out in six individual dwellings, five in France and one in Belgium. They were selected on a voluntary basis of the occupants, and cannot therefore be considered representative of the French house panel (Kirchner et al., 2008). The heaters used in these households cannot also be considered representative of the heaters available in France. However, only few models are available, and it was shown (Carteret et al., 2012) that the emission factors of wick- and injection-type heaters are comparable. Additional measurements were carried out in one semi-detached private house (dwelling #7), with the kerosene heaters and fuels previously used in the laboratory experiments (Carteret et al., 2012). These dwellings were located in urban or suburban areas, away from high traffic or industrial emissions. The characteristics of the dwellings and heaters are summarized in Table 1. The reported room volume is approximate, because of unclear boundaries in the case of open space living rooms, or when the room opens on a staircase. The ventilation rates, of $0.5–0.6\ h^{-1}$, estimated from the CO_2 decay curves after extinction of the kerosene heaters, are typical for French dwellings (Kirchner et al., 2008).

Environmental parameters (T, RH) and carbon dioxide (CO_2) concentration were measured with a HD37B17D probe (ATC Mesures, France), with a 1-min time resolution. Carbon monoxide (CO) was measured with a 1-min time resolution using a Dräger Pack III probe (Drägerwerk AG & Co., Allemagne).

In the first six dwellings, NO_2 and NO_x were sampled with passive samplers (Ogawa & Co, USA), which were analyzed by visible spectrophotometry at 545 nm, after reaction with a color producing reagent (sulfanilamide and N-(1-Naphthyl)-ethylenediamine dihydrochloride). The estimated accuracy is ~10%. In dwelling #7, three NO_2 sensors were used (Cairpol, France, 0–250 ppb and 0–1000 ppb range, estimated limit of quantification of 4 ppb, possible interferences with ozone and other oxidant species), as well as an online NO_x analyzer (Thermo Scientific model 42i). VOCs were sampled in dwellings 1–6 using passive diffusive GABIE samplers (TECORA, France), that were chemically desorbed with CS_2 and analyzed by gas chromatography with mass spectrometer and flame ionization detection. The estimated accuracy is ~10%. Formaldehyde was sampled in dwellings 1–6 using passive UME^x 100 samplers (Tecora, France) (four days in dwelling #5), and analyzed with the standard HPLC method with UV detection at 365 nm (OSHA Method 1007). The estimated accuracy is ~20%. In dwelling #7, online CO and SO_2 analyzers (Thermo Scientific, models 48i and 43i) were also employed, as well as a handheld particle counter (Lighthouse HH3016IAQ, size range 0.3–10 μm) and a submicron particle counter (TSI P-Trak, 0.02–1 μm).

Only one kerosene space heater was used during experiments in each dwelling. Whenever possible, all the measuring instruments were in the same room as the kerosene heater, a few meters from the heater, and away from any other potential pollution source, about 1 m above the ground. In that way, the measured concentrations can be directly related to the exposure of a sitting person or a standing child. In dwelling #1, the room adjacent to the one with the heater was also instrumented, so as to check for dispersion of the pollutants throughout the house. In dwelling #2, the heater was located in a hallway, but the instruments were installed in the living room.

All the activities possibly influencing the air quality during the measurements were documented with questionnaires filled in by the occupants of the dwellings, and with open enquiries after the measurement period.

3. Results and discussion

Average daily duration of use of the heaters, calculated from the activity statement questionnaire, ranged from 2 to over 10 h. This covers widely different usage patterns, with some users leaving the heater on for long periods of time, even in their absence, in spite of the safety advice from the kerosene heaters manufacturers. Oppositely, some people only use their heater for short periods of time (less than ½ h each time). It is to be noticed than though kerosene heaters are intended as auxiliary heat sources, in two dwellings (#4 and #5) they are reported as the main source of heat. Moreover, in dwellings #1 and #2, the average daily duration of use of the kerosene heater is longer than the duration of use of the self-reported main heat source (coal stove and wood stove respectively).

The environmental parameters (CO_2, T and RH) in each dwelling are presented in Table 2. Time dependent CO_2, CO and H_2O data in one of the dwellings are presented in Fig. 1. Also presented on the graphs are the specific activities which could influence the CO, CO_2, and H_2O concentrations (cooking, window opening, use of open wood-burning fireplace, smoking). The data for the other dwellings are available in supplementary figures.

There is a strong agreement between the observed CO_2 concentrations and the questionnaires reporting the use of the heater and the other activities. This validates that the questionnaires were