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Association of carbon dioxide with indoor air pollutants and exceedance of health guideline values

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ABSTRACT

This study aims to test if CO_2 concentration could be used as a proxy for indoor air quality. It focuses on the observed correlations between concentrations of carbon dioxide (CO_2) and indoor air pollutants within two measurement campaigns in France (567 dwellings and 310 nurseries, kindergartens and elementary schools). In dwellings, the weekly averaged concentration of CO_2 was positively and significantly correlated with formaldehyde, acetaldehyde, acrolein, benzene and particulate matter ($PM_{2.5}$ and PM_{10} fractions). In schools, similar significant correlations were observed between CO_2 and both formaldehyde and benzene. With high concentration of CO_2 in dwellings and schools, the probability to exceed the pollutant health guideline values for long term exposure increased. CO_2 concentration was used as a diagnosis test to predict the probability to exceed a guideline value. The real gain in exceedance detection probability was at best +33% for acetaldehyde (guideline value of 9 $\mu g/m^3$) in dwellings and +23% for formaldehyde (guideline value of 10 $\mu g/m^3$) in schools. The optimum CO_2 concentration threshold that maximizes exceedance detection probability ranges from 660 ppm to 890 ppm depending on the pollutant. However, limiting CO_2 concentration is not enough to prevent exceedances to occur. CO_2 as a tracer of some pollution sources cannot be considered as a unique indoor air quality indicator. CO_2 is also often considered as a surrogate of ventilation rate. Hence, this study confirms that even with good ventilation conditions (i.e. low CO_2 level), the reduction of pollutant sources remains necessary to achieve a satisfactory indoor air quality.

1. Introduction

Several studies and reviews have reported associations between CO_2 indoor air concentration and health symptoms [1–6] or human performance [7,8] in different environments. These associations were observed at CO_2 concentrations around or above 1000 parts per million (ppm), far below known CO_2 toxicity values which are above 10,000 ppm [9]. These relationships are usually explained by the presence and influence of other hazardous indoor pollutants and not as a direct effect of CO_2. However, the conclusions of the studies on performance according to CO_2 level suggest that the latter assumption should be revised. Many studies have also reported high CO_2 concentrations especially in schools [10–12]. For dwellings, CO_2 may also achieve high levels in bedrooms during the night [13]. But in new energy-efficient houses, CO_2 concentrations below 1000 ppm are generally observed [14,15]. A guideline value

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for CO_2 is provided in French regulation, i.e. 1000 ppm with a tolerance of 1300 ppm in non-smoking and non-residential buildings [16]. However, this guideline is not health-based. Similarly, an air stuffiness index called ICONE (*Indice de CONfinement d'air dans les Ecoles*) has been introduced in the French regulation regarding monitoring of indoor air quality in nurseries, kindergartens and schools [17,18]. ICONE was developed by Ribéron et al., in 2011 as an easy to understand way to communicate on air stuffiness [19]. The air stuffiness index is based on the frequency and intensity of CO_2 levels around defined threshold values of 1000 and 1700 ppm, and taking exclusively into account children occupancy periods. These thresholds were not defined on a health-based point of view. This study is part of a larger French study looking at the opportunity to recommend a health-based guideline value for CO_2 in indoor air [20]. It aims to test if CO_2 concentration could be used as a proxy for indoor air quality, and focuses on the observed correlations between concentrations of CO_2 and selected air pollutants in French dwellings and schools (including nurseries and kindergartens), namely formaldehyde, acetaldehyde, acrolein, benzene and particulate matter. In particular, the probability that these pollutants exceed health guideline values was calculated according to CO_2 concentration classes.

2. Materials and methods

2.1. Data sets

The pollutants considered in this study were previously defined as high priority pollutants in indoor air according to a health-based ranking method by the French Observatory for indoor air quality (OQAI) and the French Agency for Food, Environmental and Occupational Health & Safety (ANSES) [21,22]. The ranking resulted in 15 high priority pollutants in dwellings, schools and offices, including formaldehyde, benzene, acrolein, acetaldehyde, PM_{10} and $PM_{2.5}$ mass fractions which were selected in this study.

Two sets of data were used to study the statistical relations between CO_2 and the selected indoor air pollutant concentrations, i.e. one in dwellings and the other in schools.

2.1.1. Dwelling survey

The first set was a national survey carried out between 2003 and 2005 on 567 representative French dwellings [23–26]. The measurements were performed in the main bedroom during 7 days either during heating or non-heating season. The heating season was defined when a heating system was turned on during the week of measurement. Among all the measured pollutants, the following parameters were selected in this study: CO_2, formaldehyde, acetaldehyde, acrolein, benzene, and particulate matter fractions $PM_{2.5}$ and PM_{10}. The measurement methods are described in Table 1.

The Q-Trak instrument was checked and calibrated before each investigation. After sampling, the passive samplers were stored at temperature below 4°C and analyzed within two weeks. The modelled sampling rate for benzene suggested by Pennequin et al. [31] was used in this study. $PM_{2.5}$ and PM_{10} were measured in the living room by programmed active sampling on evenings and nights from 5 pm to 8 am during working days and all time during week-end. Pre-weighted 37 mm diameter PTFE membranes (2 μm porosity, Gelman Sciences) were used to collect particulate matter and then returned to the laboratory conducting the gravimetric measurement using a 1 μm sensitive electronic scale. Blank filters were left in the field to provide effective detection limit of the method. The limit of detection (LD) and limit of quantification (LQ) for all pollutants are provided in Table 2 along with extended uncertainties associated with the measurements. Additional information on data quality assurance and control can be found in Ref. [23]. Data below LD were replaced by LD/2 and data below LQ were replaced by LQ/2.

2.1.2. School survey

The second set of data comes from a national survey conducted on 310 French nurseries (children aged 0–3 years), kindergartens (children aged 3–5 years) and elementary schools (children aged 6–10 years) carried out between September 2009 and July 2011 [32,33]. Corsica and overseas departments of Réunion Island and Martinique were also included in the survey. The measurements were performed during 4.5 days from Monday morning to Friday evening during both heating and non-heating seasons, in a total of 896 rooms. The heating season was defined as beginning on 1st November and ending on 31st March. Formaldehyde and benzene were measured in the air of classrooms or playrooms by diffusive sampling using the same methods as described previously. CO_2 was monitored every 10 min using an instrument developed by Ribéron et al. [19] based on a non-dispersive infrared sensor. The monitoring of CO_2 took place in both seasons, except during the non-heating season in 2010. Formaldehyde and benzene measured during this particular season were discarded from the present study. LD and LQ calculated from field blank measurements (one per school) are provided in Table 2.

2.2. Guideline values

The long-term health-based guideline values for inhalation of benzene (for an excess individual lifetime cancer risk of 10^{-5}), formaldehyde and acrolein were defined by the French Agency for Food, Environmental and Occupational Health & Safety (ANSES), respectively as 2 μg/m^3, 10 μg/m^3 and 0.8 μg/m^3 [21,34]. For

Table 1
Description of the measurement methods (more information available in Ref. [23]).

Pollutant	Sampling technique	Method	Duration	Ref
CO_2	Non-dispersive infrared sensor (Q-Trak IAQ model 8550, TSI Inc.)	Continuous monitoring	7 days (per 10 min)	[27]
Formaldehyde Acetaldehyde Acrolein	Radial passive sampler with 2,4-DNPH coated Florisil® (Radiello® cartridge code 165)	Diffusive sampling Solvent extraction (acetonitrile) HPLC/UV	7 days (integrated)	[28]
Benzene	Radial passive sampler with carbograph 4 adsorbent (Radiello® cartridge code 145)	Diffusive sampling Thermodesorption, GC/FID-MS	7 days (integrated)	[29]
PM_{10} $PM_{2.5}$	PEMS impactor at 1.8 L/min with Chempass model 3400 2100 Minipartisol air sampler (Rupprecht & Patachnick Co, Inc.)	Programmed active sampling collection on pre-weighted PTFE filter	7 days (occupancy periods)	[30]

Note: DNPH: dinitrophenyl hydrazine, HPLC: high performance liquid chromatography, UV: ultraviolet, GC: gas chromatography, FID: flame ionization detector, MS: mass spectrometry, PEMS: Personal environmental monitors, single stage impactors, PTFE: polytetrafluoroethylene.