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Statistical analysis of parameters influencing the relationship between outdoor and indoor air quality in schools

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Abstract

Under the French national research program PRIMEQUAL, measurements of outdoor and indoor pollution have been performed in eight school buildings in La Rochelle (France) and its suburbs. The school buildings were either naturally ventilated by opening the windows or mechanically ventilated with minimum fresh air, and demonstrated various permeabilities. Ozone, nitrogen oxides (NO and NO_2), and particulate matter (PM) (15 size intervals ranging from 0.3 to 20 μm) concentrations were monitored continuously indoors and outdoors for two 2-week periods. The indoor relative humidity, temperature, CO_2 concentration (room occupancy), window openings and permeability of the building were also measured. Principal component analysis (PCA), a multivariate observation-based statistical method, was used to determine the parameters influencing the relationship between the outdoor and indoor concentration levels. After a brief description of the experimental data and methodology, the paper presents a detailed analysis of the PCA diagrams. This analysis leads to distinguish between positively correlated, negatively correlated and non-correlated variables. The main conclusions arising from the study are: (1) the influence of the room occupancy on the particle concentrations indoors changes with different particle sizes, (2) the building air-tightness and the outdoor concentration level greatly influence the indoor/outdoor (*I/O*) concentration ratios of ozone, and (3) indoor ozone and particles concentrations are negatively correlated, which may be the result of complex homogeneous and/or heterogeneous processes.

Keywords: Schools; Principal component analysis; *I/O* ratios; Particulate matter; Nitrogen dioxide; Nitric oxide; Ozone; Building permeability

1. Introduction

Contaminant transport in buildings involves a variety of more or less complex phenomena including advective transports, indoor sources, chemical reactions in the bulk air phase of the rooms, and heterogeneous processes at the air and solid interfaces. During the past 30 years, several studies have dealt with the influence of outdoor pollution on indoor air quality. Many of them were based on simultaneous measurements of outdoor and indoor contaminant concentrations in naturally ventilated or air-conditioned buildings (Phillips et al., 1993; Chao, 2001), and the results were often discussed in terms of "contaminants transport from outdoors to indoors" or "entering of atmospheric pollution indoors". However, such names may be confusing as they suggest that the phenomenon investigated only relates to advective transports while concentrations measured

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indoors include the effects of all the phenomena listed above. As the contribution of these phenomena may be very different from one building to another, measured indoor to outdoor concentration ratios (I/O) may vary significantly without any explanation regarding the discrepancies. The present paper aims to improve the knowledge on this topic by identifying the building and environmental parameters that influence the I/O ratios of contaminants initially found in the outdoor air. The study attempts to define if a dependable assessment of the indoor pollution level can be obtained by measuring the outdoor pollution level and other parameters. Particular emphasis is put on the role of the building air-tightness, which is of central importance to determine the ventilation airflow rate of the building (advective transports) and the residence time of the air inside the buildings. The latter represents the time available for homogeneous and heterogeneous processes to occur (Weschler and Shields, 2000).

In a previous paper (Blondeau et al., 2004), we have described the experimental protocol used to measure the indoor and outdoor pollution levels in various schools in La Rochelle, France. We have also presented a first analysis of the data based on computed mean concentration ratios. Further analysis of these data is proposed in the follow-up study: principal component analyses (PCA) were used to verify the trends observed and discussed in the first paper, and to determine the parameters influencing the concentration levels indoors. After briefly presenting the experimental data and the methodology, we discuss the correlation relationships observed in the PCA diagrams by referring to the likely underlying physical phenomena.

2. Materials and methods

Under the French national research program PRIMEQUAL (inter-ministry program for better air quality in urban environments), measurements of outdoor and indoor pollution have been carried out in eight schools of La Rochelle (France) and its suburbs. The buildings and experimental rooms were selected to ensure diversity regarding the outdoor environment, building construction, the ventilation system used, and the presumed air-tightness of the building envelope (Table 1). In all cases, the selected classrooms were cleaned each day after school; no information about the chemicals contained in the cleaning products used is available.

The outdoor and indoor concentrations of ozone (O_3), nitric oxide (NO), nitrogen dioxide ($NO_2 = NO_x$–NO), and particles were continuously monitored for two 2-week periods in each school, one during winter and the other during spring or summer. Nitrogen oxides and ozone concentrations were monitored with an $AC3_{1M}$ analyser (Environnement SA company, chemiluminescence, lower detectable limit: 0.35 ppb, repeatability: 1%), and a $O_{3\ 41M}$ analyser (Environnement SA company, UV absorption, lower detectable limit: 0.001 ppm, repeatability: 1%), respectively. Particle concentrations were monitored indoors and outdoors using two different GRIMM 1.108 analysers (continuous measurement of the particle numbers within 15 size intervals ranging from 0.3 to 15 μm). All analysers were calibrated before each 2-week set of measurements. As an illustration of the spatial and seasonal differences of the atmospheric pollution level in the region of La Rochelle, Table 2 shows the arithmetic

Table 1
Main features of the schools and rooms selected

School	Age	Area	Type of flooring	Ventilation	Windows	Permeability: airflow under 4 Pa ($m^3 h^{-1}$)
S1	19th	Urban, heavy traffic street nearby	Tiled floor	Window opening	PVC, new	0 (low)
S2 S2(R)	1960s	Residential	Linoleum	Window opening	Wood, damaged PVC, new	156 (medium) 3 (low)
S3	19th	Urban, heavy traffic street nearby	Parquet	Window opening	PVC, undamaged	4 (low)
S4	1930	Rural	Tiled floor	Mechanical[a]	PVC, undamaged	146 (medium)
S5	19th	Rural, seaside	Linoleum	Mechanical[a]	Metal, undamaged	156 (medium)
S6	1960s	Urban, seaside	Linoleum	Window opening	Metal, damaged	292 (high)
S7	19th	Urban, Industrial area nearby	Linoleum	Window opening	PVC, new	No measurement (assumed low)
S8	19th	Urban	Tiled floor	Window opening	Wood, undamaged	No measurement (assumed low)

[a]Extractor + air inlets–minimum air-change rate.