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Modeling indoor air pollution of outdoor origin in homes of SAPALDIA subjects in Switzerland☆,☆☆

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ABSTRACT

Given the shrinking spatial contrasts in outdoor air pollution in Switzerland and the trends toward tightly insulated buildings, the Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults (SAPALDIA) needs to understand to what extent outdoor air pollution remains a determinant for residential indoor exposure. The objectives of this paper are to identify determining factors for indoor air pollution concentrations of particulate matter (PM), ultrafine particles in the size range from 15 to 300 nm, black smoke measured as light absorbance of PM ($PM_{absorbance}$) and nitrogen dioxide (NO_2) and to develop predictive indoor models for SAPALDIA. Multivariable regression models were developed based on indoor and outdoor measurements among homes of selected SAPALDIA participants in three urban (Basel, Geneva, Lugano) and one rural region (Wald ZH) in Switzerland, various home characteristics and reported indoor sources such as cooking. Outdoor levels of air pollutants were important predictors for indoor air pollutants, except for the coarse particle fraction. The fractions of outdoor concentrations infiltrating indoors were between 30% and 66%, the highest one was observed for $PM_{absorbance}$. A modifying effect of open windows was found for NO_2 and the ultrafine particle number concentration. Cooking was associated with increased particle and NO_2 levels. This study shows that outdoor air pollution remains an important determinant of residential indoor air pollution in Switzerland.

1. Introduction

We spend a majority of our time in indoor environments (Schweizer et al., 2007). As newly constructed or retrofitted building infrastructure is increasingly air tight to save energy (Chan et al., 2003), epidemiologic studies, such as the Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults (SAPALDIA), need to understand the extent to which outdoor levels of air pollutants remain a determinant of exposure and, therefore, of health in the indoor environment. Exposure assessment to air pollutants of outdoor origin is crucial, because they have been linked to various adverse health effects (Brook et al., 2010; WHO, 2013). Pollutants from indoor sources, often related to cooking and heating, may influence associations with health but it is not known if they cause similar adverse effects — apart from indoor combustion of solid fuels which is mainly a problem in low and middle income countries (WHO, 2014). Parallel indoor and outdoor measurements of particulate air pollutants and NO_2 revealed a high variability of indoor/outdoor ratios between selected homes of SAPALDIA participants (Meier et al., 2015). This suggests that home characteristics and indoor sources have a large influence on indoor levels. However, outdoor levels remain an important factor for indoor levels despite this variability (Chen et al., 2012a,b). The objectives of this paper are to identify the determining factors for indoor air pollution in SAPALDIA homes, to evaluate the role of ambient air pollution indoors and to develop predictive indoor models for SAPALDIA. We analyzed a data set of indoor and outdoor air pollution measurements (Meier et al., 2015) in the context

Abbreviations: LOOCV, leave one out cross validation; LOAOCV, leave one area out cross validation; NO_2, nitrogen dioxide; $PM_{2.5}$, mass concentration of particles less than 2.5 µm in size; PM_{10}, mass concentration of particles less than 10 µm in size; $PM_{absorbance}$, measurement of the blackness of $PM_{2.5}$ filters — a proxy for elemental carbon, which is the dominant light absorbing substance; PM_{coarse}, mass concentration of particles between 2.5 µm and 10 µm in size; PNC, particle number concentration; SAPALDIA, Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults.

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of home characteristics, indoor sources and prevailing meteorological conditions during the measurement periods. Findings were used to develop multivariable regression models for estimating indoor concentrations of the particle number concentration (PNC) of particles in the size range of ~15–300 nm, particulates smaller than 2.5 μm ($PM_{2.5}$) and smaller than 10 μm (PM_{10}), the coarse particle fraction (PM_{10}–$PM_{2.5}$), light absorbance of $PM_{2.5}$ ($PM_{absorbance}$) and nitrogen dioxide (NO_2). Exposure estimates based on models can be used for a refined exposure classification of SAPALDIA subjects with the aim to get more precise risk estimates for outdoor air pollution related health effects.

2. Methods

2.1. Study design

The evaluated data set was collected during repeated indoor and outdoor measurements at non-smoking homes of selected SAPALDIA participants in three urban areas (Basel, Geneva, Lugano) and one rural area (Wald ZH, hereafter referred to as Wald). All study participants gave written informed consent. Two-week long measurements during three seasons (spring, summer, winter) from a total of 48 (PNC), 64 (PM metrics) and 66 (NO_2) homes were included for the development of indoor models. Whenever possible, indoor air pollution measurements were conducted in less frequented rooms to capture indoor pollutants of outdoor origin rather than air pollutants mainly influenced by indoor sources. Outdoor measurements were conducted in nearby gardens or on balconies, thus, reflecting the prevailing air quality around the house. A more detailed description of the study design and measurement setup is provided elsewhere (Meier et al., 2015). Average indoor and outdoor air pollutant concentrations were combined with information about indoor sources, home characteristics and meteorological conditions to develop multivariable regression models for estimating indoor concentrations based on a stepwise modeling procedure to identify determining factors for indoor concentrations.

2.2. Air pollution measurements

A detailed description of the air pollution measurements is provided elsewhere (Meier et al., 2015). Briefly, PNC of particles in the size-range from ~15–300 nm were measured in real-time with a miniature diffusion size classifier, miniDiSC (Fierz et al., 2011). Minute means were used to calculate averages of PNC over the one to two-week long measurements: we calculated the mean PNC and the median PNC and developed separate indoor models for both averages. Two week samples of PM_{10} and $PM_{2.5}$ were collected on 37 mm Teflon filters (Pall Corporation, Port Washington, NY, USA) using Harvard Impactors at an air flow rate of 4.0 l/min. One MEDO vacuum pump VP0125 (MEDO USA, Roselle, IL, USA) per site was operated on two separate timers, which sequentially routed flow to the $PM_{2.5}$ and PM_{10} inlet for 10 min each hour, thereby effectively sampling an air volume of 13.5 m^3 over 14 days for each size fraction. The coarse fraction (PM_{coarse}) was determined by subtracting the $PM_{2.5}$ from the PM_{10} concentration at each occasion where both were available. $PM_{absorbance}$, a measure of the blackness of PM and a surrogate for black smoke (Götschi et al., 2002), was measured as reflectance on $PM_{2.5}$ filters using a Smokestain Reflectometer (EEL Model 43D, Diffusion Systems Ltd., London, U.K.). Two week samples of NO_2 were collected using passive diffusion samplers (Passam AG, Männedorf, Switzerland) and analyzed in the Passam AG laboratory.

2.3. Home characteristics and meteorological information

Complementary information about building age, years since last renovation and heating energy was retrieved from the building registry of the Swiss Federal Statistical Office (FSO). Additional home characteristics were assessed by the SAPALDIA main questionnaire and an additional bi-weekly questionnaire with specific questions for each two week time period of the measurements. Specific information about the placement of the measurement devices was retrieved from the field log sheets. Meteorological data from area specific meteorological stations was provided by the Swiss Federal Office of Meteorology and Climatology (MeteoSwiss).

2.4. Evaluated predictor variables

Continuous covariates evaluated for indoor models included the time-matched average home outdoor concentration, meteorological factors (temperature, wind speed and precipitation; measured at the area specific meteorological station) and various variables which may be modifying factors for the indoor concentration. The age of the building structure (building age and the number of years since last renovation; retrieved from building registry) was evaluated as it may be a potential indicator for building tightness. Other home characteristics, assessed with questionnaires or retrieved from the building registry, were evaluated as categorical or binary variables. These included information about the building (type of house, number of rooms, single/double glazed windows), occupancy (number of inhabitants and pets), ventilation (frequency of open windows), frequency of cooking, energy used for cooking and heating. The variable describing the influence of cooking was derived from the reported cooking frequency: cooking frequency was considered null if the room in which the indoor measurements were conducted was separated from the kitchen. Separation, and therefore no direct influence of reported cooking, was assumed when there was no direct passage between the kitchen and the measurements (closed doors or on different floor). In addition, we also evaluated information about the room in which the indoor measurements were conducted: the floor, use of the room by the inhabitants and if the door to the room was open or closed. Predictor variables included in the final models are shown in Table 1; all other variables are shown in Supplementary Table A1.

Table 1
Descriptive statistics of predictor variables selected for indoor models. Number of observations for categorized variables is indicated in brackets. Information from total of 174 repeated measurements at 66 homes. Information about double glazed windows, type of cooking stove and use of room in which indoor measurements were conducted are based on 66 homes (same value for repeated measurements).

Continuous variables	p5	p25	Median	p75	p95	Data source
Outdoor concentration	Summary statistics in Table 2					Measurements
Outdoor temperature [°C]	−1.9	4.3	12.6	16.6	20.9	MeteoSwiss

Categorical variables	Category 1	Category 2	Category 3	Data source
Type of cooking stove	Electric (54)	Gas (12)		SAPALDIA questionnaire
Double glazed windows	No (5)	Yes (61)		SAPALDIA questionnaire
Use of room[a]	Not used (8)	Used (58)		Field notes
Cooking influence[b]	No (153)	Yes (21)		Derived variable
Open kitchen window	Never/few (62)	Sometimes (56)	Mostly (56)	Bi-weekly questionnaire
Open windows[c]	Never/few (108)	Sometimes (31)	Mostly (33)	Bi-weekly questionnaire

[a] Specific remark in field protocols on whether the room in which the indoor measurements were conducted was not used/used by inhabitants.
[b] No influence of cooking was attributed if either no cooking reported or no direct passage between kitchen and room in which indoor measurements were conducted (closed doors, different floor).
[c] Windows of the room in which indoor measurements were conducted; missing information for two measurements.