Science of the Total Environment xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Ozone exposure assessment for children in Greece - Results from the RESPOZE study

Georgios Grivas [a,*], Konstantina Dimakopoulou [b], Evangelia Samoli [b], Despina Papakosta [c], Anna Karakatsani [d], Klea Katsouyanni [b,e], Archontoula Chaloulakou [a]

[a] School of Chemical Engineering, National Technical University of Athens, GR 15780, Greece
[b] Department of Hygiene, Epidemiology and Medical Statistics, National and Kapodistrian University of Athens, School of Medicine, 75, Mikras Asias Street, 115 27 Athens, Greece
[c] Pulmonary Department, G. Papanikolaou Hospital, School of Medicine, Aristotle University of Thessaloniki, Thessaloniki, Greece
[d] 2nd Pulmonary Department, "ATTIKON" University Hospital, School of Medicine, National and Kapodistrian University of Athens, Athens, Greece
[e] Department of Primary Care & Public Health Sciences and MRC-PHE Centre for Environment and Health, King's College London, London, UK

HIGHLIGHTS

- Personal O_3 exposure of children was assessed using wearable filter-based samplers.
- Personal-ambient associations explored by community-outdoor and regulatory measurement.
- Ambient levels are key for personal exposure despite limited outdoor activity.
- Ventilation and residential factors affect spatiotemporal variation of personal O_3.
- Community outdoor sampling in health studies may improve personal-ambient correlations.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 18 October 2016
Received in revised form 23 December 2016
Accepted 23 December 2016
Available online xxxx

Editor: Dr. P Elena Paoletti

Keywords:
O_3
Personal exposure
Passive sampling
Panel study
Athens
Thessaloniki

ABSTRACT

Ozone exposure of 179 children in Athens and Thessaloniki, Greece was assessed during 2013–2014, by repeated weekly personal measurements, using passive samplers. O_3 was also monitored at school locations of participants to characterize community-level ambient exposure. Average personal concentrations in the two cities (5.0 and 2.8 ppb in Athens and Thessaloniki, respectively) were considerably lower than ambient concentrations (with mean personal/ambient ratios of 0.13–0.15). The temporal variation of personal concentrations followed the -typical for low-latitude areas- pattern of cold-warm seasons. However, differences were detected between temporal distributions of personal and ambient concentrations, since personal exposures were affected by additional factors which present seasonal variability, such as outdoor activity and house ventilation. Significant spatial contrasts were observed between urban and suburban areas, for personal concentrations in Athens, with higher exposure for children residing in the N-NE part of the area. In Thessaloniki, spatial variations in personal concentrations were less pronounced, echoing the spatial pattern of ambient concentrations, a result of complex local meteorology and the smaller geographical expansion of the study area. Ambient concentration was identified as the most important factor influencing personal exposures (correlation coefficients between 0.36 and 0.67). Associations appeared to be stronger with ambient concentrations measured at school locations of children, than to those reported by the nearest site of the air quality monitoring network, indicating the importance of community-representative outdoor monitoring for characterization of personal-ambient relationships. Time

* Corresponding author.
E-mail address: ggrivas@mail.ntua.gr (G. Grivas).

http://dx.doi.org/10.1016/j.scitotenv.2016.12.159

spent outdoors by children was limited (>90% of the time they remained indoors), but -due to the lack of indoor sources- it was found to exert significant influence on personal concentrations, affecting inter-subject and spatio-temporal variability. Additional parameters that were identified as relevant for the determination of personal concentrations were indoor ventilation conditions (specifically indoor times with windows open) and the use of wood-burning in open fireplaces for heating as an ozone sink.

1. Introduction

The solid body of epidemiological, toxicological and human controlled exposure research, amassed over decades, has provided conclusive evidence on harmful health effects of human exposure to ground-level ozone. The most pronounced causal relationship appears to exist between short-term O_3 exposure and respiratory health outcomes (Berhane et al., 2011; Katsouyanni et al., 2009), while adverse respiratory effects are likely to be linked with long-term exposure as well (Akinbami et al., 2010; Zanobetti and Schwartz, 2011). The presence of ozone, a highly reactive oxidant, in the respiratory tract, leads to formation of secondary oxidative products, which initiate a broad spectrum of responses in the respiratory system (Mudway and Kelly, 2000), resulting at pulmonary function decrements, airway inflammation, bronchial reactivity, modification of lung host defenses and aggravation of existing lung disease.

Children comprise a sizable population group on which these biological mechanisms impose intrinsically increased risks, due to their not fully developed respiratory system and the higher dose per body weight that they receive when exposed (Bennett et al., 2008; Sarangapani et al., 2003). They are also susceptible due to additional non-biological factors, such as the increased time and intensity of their outdoor activity (Klepeis et al., 2001), which lead to larger ozone uptakes. Aiming to improve the protection of children and other vulnerable groups (older adults, asthmatics and outdoor workers), in the United States, EPA has recently moved to strengthen the air quality standard for O_3 to 70 ppb (EPA, 2015). Abatement of ground-level ozone levels lies at the core of future EU air policy objectives as well, as laid out in the Clean Air Programme for Europe (EC, 2013).

The association of ambient O_3 concentrations -regulated by air quality standards- with actual exposures that result in health effects is not straightforward. Many epidemiological studies relied on the hypothesis that ambient concentration can represent the personal exposure of inhabitants in a certain area. However this assumption is weakened when considering obvious factors like indoor ozone exposure, different activity patterns and the significant spatial and inter-subject variability for a pollutant as reactive as ozone (Delfino et al., 1996).

The importance of personal exposure monitoring has been recognized early on, but given the instability of O_3 it was difficult to develop an artefact-free method for micro-environmental sampling. The nitrate-coated filter method for passive ozone sampling (Koutrakis et al., 1993) resolved the majority of such issues. It has been extensively used since and is still being applied for measurement of personal and ambient ozone concentrations (Kerckhoffs et al., 2015; Wan et al., 2014; Williams et al., 2012). Most of the research on personal ozone exposure assessment has been conducted in North America and has revealed, inter alia, that personal O_3 concentrations, measured over short-term periods (hours to days), are lower than respective ambient levels, and that they cannot be effectively modelled only on outdoor concentration data (Lee et al., 2004; Xue et al., 2005). Results from European cities have been sparse (Bernard et al., 1999; Cattaneo et al., 2010; Liard et al., 1999), since the severity of ozone pollution in Europe is considerable mainly in the Mediterranean region, due to intense photochemical activity and circulation of air masses of various origins (Gerasopoulos et al., 2006).

Specifically in Greece, in the two major urban centers of Athens and Thessaloniki, the existence of the ozone pollution problem has been well documented over the years (Chaloulakou et al., 1999; Gusten et al., 1997) and does not appear to improve (Dimitriou and Kassomenos, 2014; Moussiopoulos et al., 2009), as limit value exceedances in violation of EU standards are still being observed in the majority of monitoring locations. In fact, due to the continuing economic crisis in the country and the resulting rapid decline of ozone-titrating primary emissions, O_3 concentrations have been observed to increase over Greece since 2008 (Vrekoussis et al., 2013). As a result, ozone - along with particulate matter - remain the priority pollutants in consideration for the protection of the Greek population (Kassomenos et al., 2013).

The RESPOZE-children panel study (RESPiratory effects of Ozone Exposure in children) was undertaken in order to investigate associations between ozone exposure and numerous outcomes of respiratory health (Samoli et al., 2016), including lung and nasal function indicators, inflammation markers and respiratory symptoms.

In the present study we present results from repeated ozone concentration measurements, using passive samplers, focused on the determination of weekly personal exposure of 179 schoolchildren in Athens and Thessaloniki, over the school season of 2013–14. O_3 levels were also monitored at respective school locations to characterize community-scale outdoor exposure. The results are analyzed in combination with time-activity and questionnaire data for location and indoor housing parameters, in order to identify factors driving the variability of personal exposure levels. In Greece, until recently, measurements for personal O_3 concentrations have only been reported by Karakatsani et al., (2010), for one-day exposures of 41 outdoor workers in Athens. To our knowledge this study is the first in Southern Europe to address personal ozone exposure and to explore inter-subject, temporal and spatial variation patterns in a large panel of participants, over an extended period.

The study aims to provide data for personal exposure to O_3 and its controlling factors in Southern Europe and to investigate whether stationary ambient ozone measurements can provide representative exposure data in comparison with personal measurements.

2. Methodology

2.1. Study area

The study was carried out in the greater areas of Athens and Thessaloniki, the two largest Greek conurbations, amassing a combined population of approximately 4 million (3.09 and 0.79 mi. respectively, as of 2011). An overview of the two study areas is provided in Fig. 1. High ozone levels have been documented in both areas over the years, with all non-traffic air quality monitoring stations consistently recording annual average concentrations exceeding 25 ppb and with 10 out of 15 state-operated stations in both cities violating the O_3 quality standard - as laid out in EU directive 2008/50/EC - for the period 2012–2014.

In the greater area of Athens and specifically in the central Athens basin, ozone pollution is most pronounced in the Northern and Eastern parts, as a result of photochemical transformation processes involving precursor substances excessively produced in the densely populated city center and in the port area of Piraeus, the transport of which is being aided by the frequent prevalence of southeasterly sea-breeze mesoscale circulations (Grivas et al., 2008).

In Thessaloniki, the geographical extension of the metropolitan area is smaller in comparison with Athens, with a proportionally larger

Please cite this article as: Grivas, G., et al., Ozone exposure assessment for children in Greece - Results from the RESPOZE study, Sci Total Environ (2016), http://dx.doi.org/10.1016/j.scitotenv.2016.12.159