

The EuroLifeNet Study: How Different Microenvironments Influence Personal Exposure to PM_{2.5} among High-School Students in Milan

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Abstract

Background: Epidemiological studies show that long-term exposure to PM is associated with an increased risk of cancer. The EuroLifeNet study measured the personal exposure to PM_{2.5} in 90 pupils attending three schools in Milan, using a portable nephelometer, over a three-week period spanning November and December 2006. Background levels explained 40% of the variability of the exposure. **Methods:** As a second part of that study we analyzed the role of different microenvironments as determinants of personal exposure to PM_{2.5}. **Results:** Exposure was influenced by the time of day, zone of the city and different microenvironments. Exposure was higher indoors than out, and indoors it was higher in the kitchen, particularly during cooking. In outdoor environments exposure was higher at bus stops where road traffic was heavy. **Conclusions:** Even though background concentration can be a good predictor of personal exposure to PM, students' personal exposure is strongly influenced by different microenvironments and should be considered in population studies. The EuroLifeNet experience gives a contribution to personal exposure measure methodology.

Keywords

Personal Exposure, Air Pollution, Fine Particles, Students, Schools, Indoor/Outdoor, Microenvironments

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1. Introduction

Many epidemiological studies show that air pollution and long-term exposure to atmospheric particulate matter (PM) are associated with an increased risk of specific cancers [1]-[3].

Studies on school-age children show an association between PM and adverse effects on respiratory function [4]-[7]. In epidemiological studies population's exposure to PM is generally estimated from fixed monitoring stations which afford standardized measurements of atmospheric pollutant outdoor concentrations on a daily or hourly basis. Although pollutant levels measured by monitoring stations in a general way reflect the exposure of individuals to pollutants in the area, they cannot accurately estimate the individual exposure, which has been shown to be profoundly affected by individual behavior.

Personal exposure levels to air pollution and in particular to fine particles (PM_{2.5}) are influenced by mode of transports, route and type of vehicle [8]-[10] and indoor emission sources (smoking and cooking). Some studies found that exposure to the particulate matter was higher in bus stops [11] and cars than during walking or cycling [12].

Some recent studies report that in children travelling by bus or car in slow-moving rush-hour traffic exposure may be significantly raised [13]-[17]. In this paper we present the results of personal exposure monitoring campaign conducted in the context of EuroLifeNet project.

The EuroLifeNet program was designed by the Research Centre on Information Technologies and Participatory Democracy (CITIDEP) with the support of the Institute for Environment and Sustainability (IES) of the Joint Research Centre (JRC) of the European Commission (website <http://www.citidep.pt/eurolifenet/>, accessed on 30 June 2014). Its aims are to measure personal exposure to particulate matter (PM₁₀ and PM_{2.5}) and raise awareness, particularly among school students, of the hazards of air pollution. In the first pilot project of EuroLifeNet, carried out in Portugal and Italy, school students gathered data on personal exposure to PM_{2.5} using portable nephelometers.

2. Methods

2.1. Nephelometer

Personal exposure was monitored using SidePak (TSI Inc., Model AM510, Shoreview, MN, USA) portable nephelometers (see material and methods of EuroLifeNet first published paper [18]). During the study, the instruments were calibrated each weekend by the Institute for Environment Sustainability (IES) of the Joint Research Centre (JRC), Ispra, Italy (see EuroLifeNet 1 [18]). Moreover, at the beginning of the study a zero filter was attached to each instrument inlet for the zeroing process.

2.2. Data Collection

Ninety pupils from three Milan schools (Feltrinelli, Cremona, Rinascita) were involved in the project, which lasted 3 weeks during November and December 2006; ninety students were involved, 57 males and 33 females; age ranged from 12 to 18 years old. Six nephelometers were available for the study; each was used by a different pupil each day. Six different students (two for each school) were involved every day, each one having a nephelometer for a 24-hour period. This way we had six simultaneous measurements in six different places, representing estimations of personal exposure and not of background level.

Teachers and pupils were instructed on correct instrument use. The instrument was placed in the classroom at the beginning of each run period (at about 12.00 a.m.) close to the pupil entrusted with it for that day. When pupils moved, in particular when they went home, they took the instrument with them carrying it in a bag mounted on the belt, with the inlet tube placed in the breathing zone, so that the inlet was always exposed. When pupils were at home they were instructed to keep the instrument in the room they mainly occupied, and to place it in their bedroom overnight [19]. The following morning the instrument was carried to school and remained in the classroom with the pupil during the first hour (until about 9.00 a.m.). So the total monitoring period for each pupil was about 21 h.

Each pupil was also educated by the teachers to complete a Time Activity Diary (TAD), when carrying the nephelometer, reporting his/her location and activity [20] [21]. The TAD recorded each pupil's personal information and time-activity patterns, including home location, traffic-related information and proximity to possible outdoor and indoor emission sources, e.g. when road traffic was heaviest (outdoor emission) or during cooking (indoor emission). Hour by hour students filled the TAD indicating every useful information.

In this second part of the study we made a detailed analysis of personal exposure of PM_{2.5} in relation to the TAD circumstances, *i.e.* the means of transports used to and from school, and information on indoor exposure sources. Moreover, it was possible to consider active or passive smoking confounder because students reported if they were smoking or there was someone smoking near them.

To calculate PM_{2.5} exposure in each microenvironment we compared each nephelometer's data (which reported day and time joined with the measurement of the instrument) and the indication reported hour by hour by the students in their TAD.

2.3. Statistical Methods

On the basis of the TAD we considered eight microenvironments, four classified as indoor (classroom, kitchen, bedroom, living room) and four as outdoor (private cars, public bus, bus stop, on street). Indoor PM_{2.5} exposure was calculated aggregating any indoor environment. Sub-analyses were performed on three groups: bedroom and living room together, kitchen, classroom. Outdoor PM_{2.5} exposure was examined in a similar fashion. We first aggregated all outdoor measures and then we focused on the means of transports (private cars, public bus) and bus stop joined to street.

Background exposure to PM_{2.5} was calculated including in the analysis correction for the day, time of day (morning, afternoon, evening, night), zone of the city (where the school was located) and pupils (considered the sample unit). Differences between micro-environmental PM_{2.5} exposures and background were then calculated and considered as an estimate of the exposure completely attributable to the different microenvironments.

Descriptive statistics of PM_{2.5} exposure for each microenvironment used the mean, median, quartiles and standard deviation over the overall observation period. To highlight skewness in PM_{2.5} exposures the data were graphically reported by microenvironment using frequency histograms. A generalized linear model was applied to detect differences between microenvironment PM_{2.5} exposures and background. Multiple comparisons between microenvironments were done using the Bonferroni correction and reported using least squares (LS) means and 95% confidence limits (CIs). To investigate the relation between PM_{2.5} exposures and time and to highlight PM_{2.5} exposure peaks, the relation between PM_{2.5} exposure and time was graphically reported for each microenvironment. All statistical analysis was done using SAS software package vers. 9.1.3. [22].

3. Ethical Issues

All the participants were volunteers, and preliminary meetings to present the project were held at each school to explain and clarify all aspects. All procedures were performed in compliance with relevant laws and institutional guidelines. Informed consent of the students and their parents was obtained while compiling Time Activity Diaries. Data processing and storage were kept confidential and during the analysis personal identification data were separated from the nephelometer and TAD information.

4. Results

Descriptive statistics and histogram plots of PM_{2.5} exposure over the whole observation period showed that exposure was skewed for every microenvironment under analysis (Figure 1, Figure 2 and Table 1). Descriptive statistics (Table 1) indicated that PM_{2.5} exposure was generally higher in indoor microenvironments than outdoors. In addition, exposure on public buses seemed higher than in private cars. Exposure was also high at bus stops and in the kitchen.

Background PM_{2.5} exposure was calculated considering the sampling day, time of day, zone of the city and pupils. All these factors introduced in a nested generalized linear model resulted in an R² of 0.61 which corresponds to an explained variance of about 60%, the remainder being explained by other sources of variability such as micro environmental exposure or other random factors.

The statistical comparison among microenvironments (Table 2) showed that PM_{2.5} exposure was significantly different for some microenvironments.

Among these microenvironments PM_{2.5} exposure was high at bus stops and in the kitchen where the excesses were respectively 12.82 (95% CI, 2.2 - 23.4) and 29.38 (95% CI, 25.5 - 33.6) µg·m⁻³. Among means of transport, PM_{2.5} exposure appeared higher for public buses than private cars: the difference was 9.9 µg·m⁻³ (95% CI, 2.1 - 17.7).

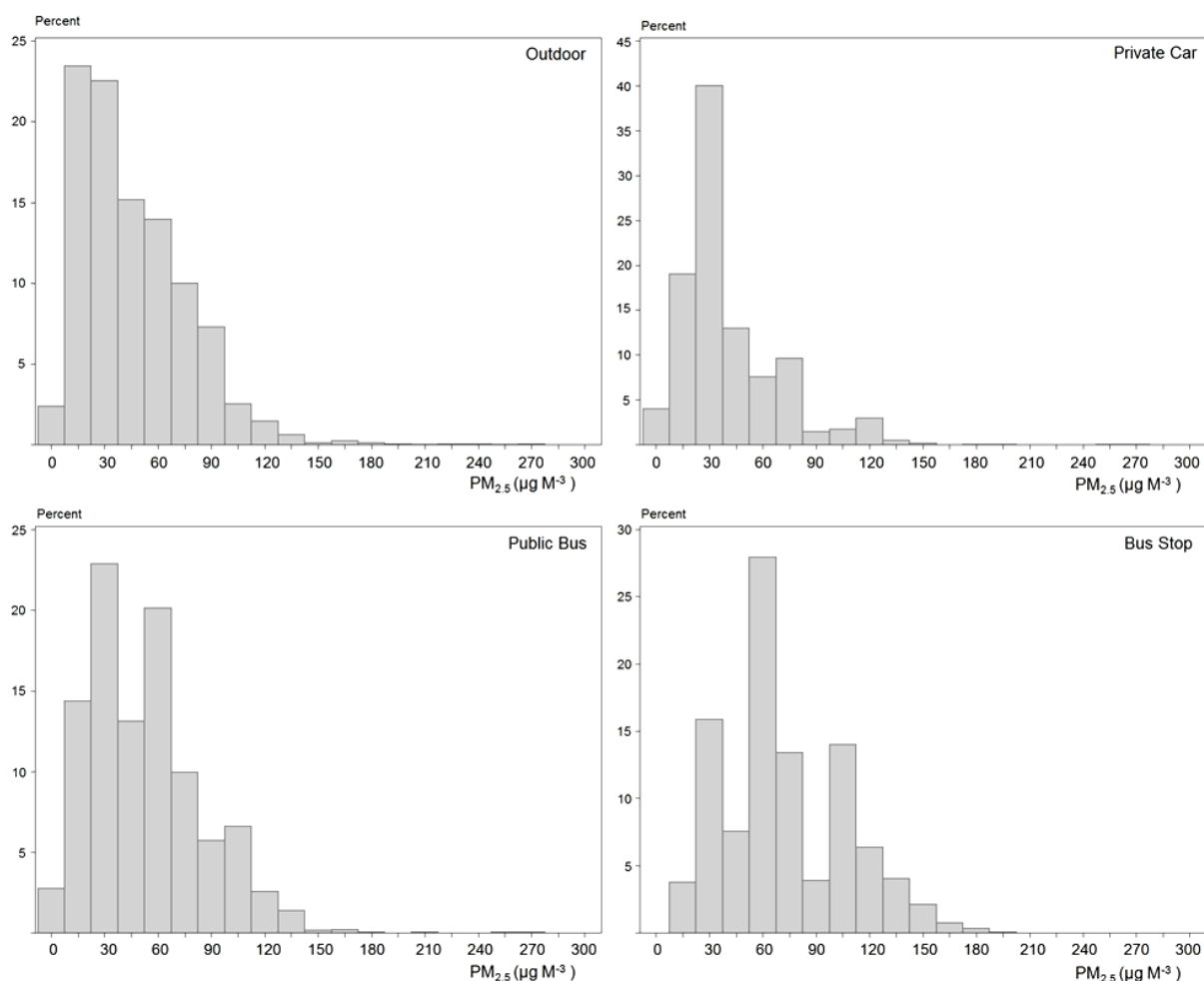


Figure 1. Histograms of $PM_{2.5}$ exposure by microenvironment (outdoor).

Table 1. Descriptive statistics by microenvironment.

Microenvironment	Mean	Median	First Quartile	Third Quartile	Standard Deviation
Outdoor	46.0	38.5	22.0	65.0	30.2
Inside private car	40.6	33.5	23.3	50.9	27.2
Inside public bus	52.9	48.5	29.5	69.0	31.4
On street/at bus stop	71.3	63.8	50.8	101.0	34.9
Indoors	53.6	42.5	28.8	66.7	35.2
Kitchen	69.3	62.3	49	76.3	35.7
In the classroom	39.4	30.3	19.8	55.5	27.2
Bedroom and living room	35.1	24.5	13.8	48.5	31.0

The scatter plot of $PM_{2.5}$ exposure over time showed that exposure was closely influenced by time (**Figure 3**). As expected, kitchen $PM_{2.5}$ exposure was higher between 12.00 - 14.00 p.m. and 18.00 - 21.00 p.m., corresponding to lunch and dinner cooking periods; this effect was glaring for all indoor microenvironments (**Figure 3**—indoor panel). $PM_{2.5}$ exposure at bus stops was higher during the period 13.00 - 15.00 p.m. and 17.00 - 19.00 p.m. and in the early morning (07.00 a.m.) when car traffic in the city was highest (**Figure 3**—bus stop panel).

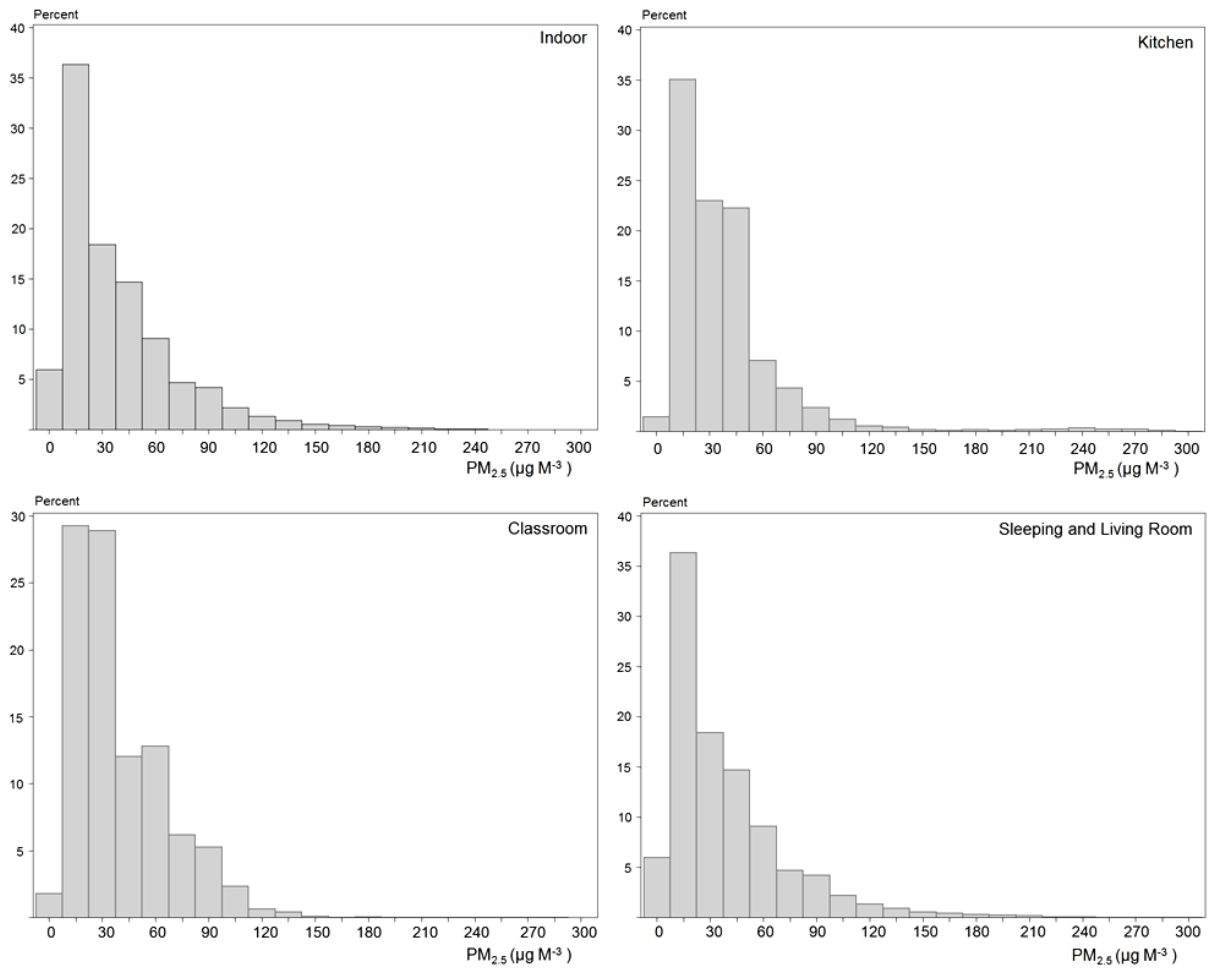


Figure 2. Histograms of PM_{2.5} exposure by microenvironment (indoor).

Table 2. PM_{2.5} exposure differences between microenvironment.

	Private Cars	Public Bus	Bus Stop	Kitchen	Classroom	Sleeping & Living Room	Outdoor	Indoor
Private cars	0.53 [-7.0; 8.0]							
Public bus	9.9* [2.1; 17.7]	10.5** [3.2; 17.6]						
Bus stop	12.2** [4.0; 16.2]	2.3 [-5.8; 10.4]	12.8* [2.2; 23.4]					
Kitchen	28.8** [22.9; 34.7]	18.2** [10.4; 26.0]	16.6** [7.1; 26.10]	29.4** [25.2; 33.6]				
Classroom	0.41 [-6.1; 6.9]	10.4** [3.9; 16.9]	12.3** [4.5; 20.1]	28.9** [21.7; 36.1]	0.12 [-3.4; 3.6]			
Sleeping & living room	7.8* [1.1; 14.5]	2.1 [-4.7; 8.9]	4.5 [-2.0; 11.0]	21.1** [14.3; 27.9]	8.2* [1.6; 14.8]	8.3 [-1.7; 18.2]		
Outdoor	1.3 [-4.6; 7.2]	9.2** [3.4; 15]	10.0** [3.2; 16.8]	28.1** [19.9; 36.3]	1.1 [-4.8; 7.0]	7.0* [0.2; 13.8]	1.8 [-3.7; 7.3]	
Indoor	21.1 [13.6; 28.6]	2.1 [-4.1; 8.3]	0.2 [-5.7; 5.9]	8.3** [2.4; 14.1]	12.4** [6.1; 18.7]	4.3 [-2.1; 10.7]	19.3** [13.1; 25.5]	12.6** [7.1; 18.1]

*P ≤ 0.01; **P ≤ 0.001. The comparison between microenvironments and background PM_{2.5} exposure was reported on the diagonal.

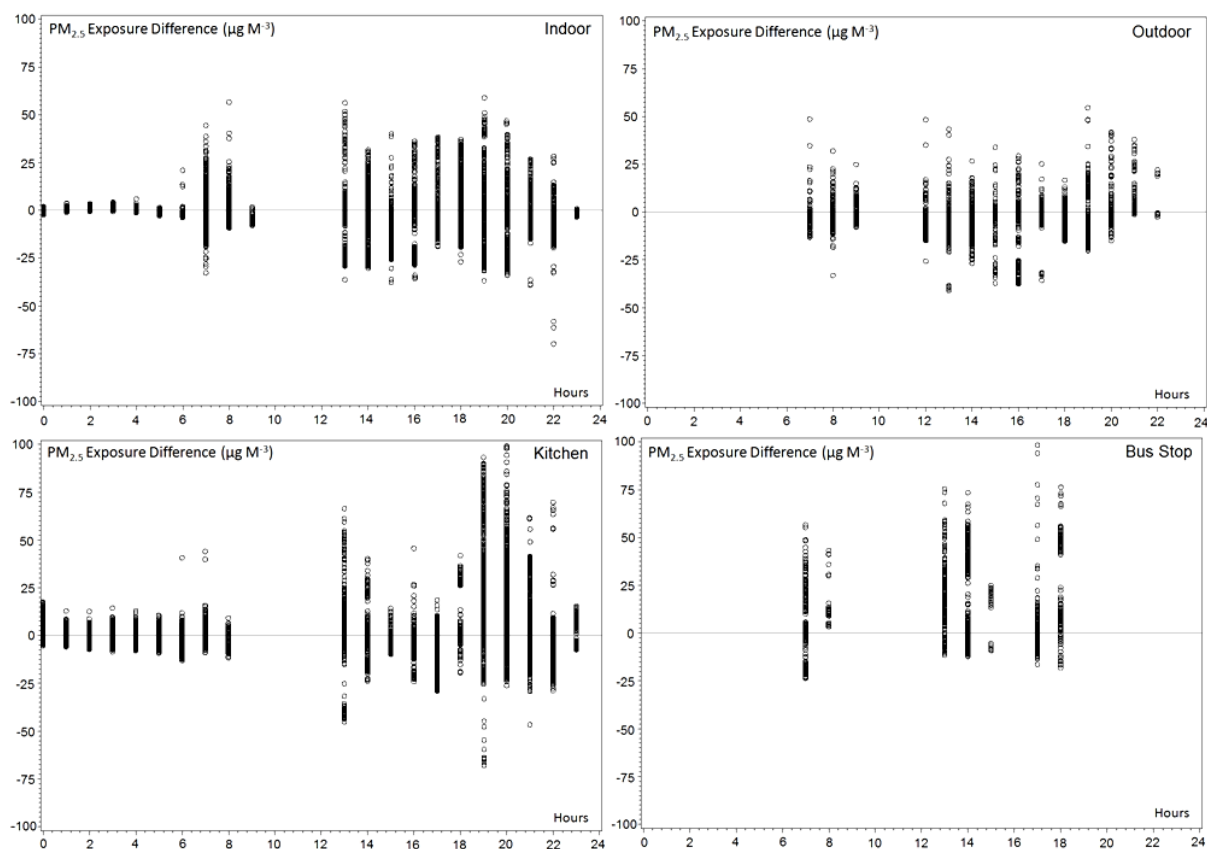


Figure 3. Histograms of PM_{2.5} exposure by microenvironment (outdoor).

5. Discussion

Children's exposure could be described and simplified as due to air pollution concentrations in three microenvironments: home, school and transport. In the period considered outdoor activities, e.g. sports or walking were rare (in winter time students are more often at school or at home). The strong positive skewness was mostly due to some PM_{2.5} exposure peaks observed during the sampling period. This feature was common to all the microenvironments considered, particularly indoor microenvironments such as the kitchen [23], or outdoor microenvironments such as bus stop and others [24]. This difference is presumably due to indoor sources of exposure like cooking at home or science laboratories at school. Indoor PM_{2.5} is affected by ambient concentrations, air exchange rates, penetration factors, as well as deposition and resuspension [25].

In different articles comparing indoor and outdoor exposure, PM concentrations were generally higher indoors [26], as also reported in studies such as the European Project EXPOLIS [27]-[31]. Cooking, cleaning and particularly smoking result in the formation of PM_{2.5} and others contaminants in indoor air [32]-[34].

Although children spend less time in transport than at home or school, the data suggest that travel could be an important source of exposure; in fact, as reported in the study by Yip *et al.* [35], we too found high PM_{2.5} concentrations in the outdoor microenvironments, and this was related to the time children spent near main roads with heavy traffic, at bus stops or in moving buses [36].

Children's exposure to air pollution according to different transport modes and microenvironments has been considered in many studies [37]-[40] but it is still hard to quantify exactly the differences in air pollution exposure in relation to children's behaviour. The most plausible reason is that most studies compare measurements taken in different means of transport, but in different moments of the day and not simultaneously, so they are influenced by variations in background level.

In EuroLifeNet study children's exposure is measured close to the breathing zone to give a good estimate of the inhaled concentration. The breathing zone is much closer to the main emission sources of motor vehicles than city background fixed-site monitors. Fine particulate matter levels in different microenvironments are largely

determined by outdoor and indoor emission sources. However, concentrations in enclosed locations from indoor sources can be higher and even children's behaviour can significantly influence exposure levels.

The principle limitations of this study are the limited period of data collection (only three weeks in autumn time, it would have been surely better to have more campaigns in different seasons) and the fact that student's movements and locations were ascertained only on the basis of what they reported on the TAD, because for this study was not possible to equip the students also with a GPS instrument, in order to report their movements on a map.

6. Conclusion

EuroLifeNet study was designed to measure personal exposure, indoor and outdoor levels of PM_{2.5} concentrations of pupils of three high schools in Milan. The first analysis showed a good correlation between daily PM_{2.5} background concentrations and personal exposure measured by the nephelometers. This second part of the study evidenced that students' personal exposure was influenced by the microenvironment in which they spent their time. In summary, we found that the daily variability of personal exposure could be well estimated by the daily variability of background concentrations (the indicator mostly used in epidemiological studies on health effects of PM exposure), but the real extent of the exposure, attainable only using portable instruments such as the nephelometers, was generally higher in terms of concentrations levels.

Competing Interests

The authors declare that they have no competing interests.

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References

- [1] Raaschou-Nielsen, O., Andersen, Z.J., Beelen, R., Samoli, E., Stafoggia, M., Weinmayr, G., Hoffmann, B., Fischer, P., Nieuwenhuijsen, M.J., Brunekreef, B., Xun, W.W., Katsouyanni, K., Dimakopoulou, K., Sommar, J., Forsberg, B., Modig, L., Oudin, A., Oftedal, B., Schwarze, P.E., Nafstad, P., De Faire, U., Pedersen, N.L., Ostenson, C.G., Fratiglioni, L., Penell, J., Korek, M., Pershagen, G., Eriksen, K.T., Sørensen, M., Tjønneland, A., Ellermann, T., Eeftens, M., Peeters, P.H., Meliefste, K., Wang, M., Bueno-de-Mesquita, B., Key, T.J., de Hoogh, K., Concin, H., Nagel, G., Vilier, A., Grioni, S., Krogh, V., Tsai, M.Y., Ricceri, F., Sacerdote, C., Galassi, C., Migliore, E., Ranzi, A., Cesaroni, G., Badaloni, C., Forastiere, F., Tamayo, I., Amiano, P., Dorronsoro, M., Trichopoulou, A., Bamia, C., Vineis, P. and Hoek, G. (2013) Air Pollution and Lung Cancer Incidence in 17 European Cohorts: Prospective Analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). *The Lancet Oncology*, **14**, 813-822. [http://dx.doi.org/10.1016/S1470-2045\(13\)70279-1](http://dx.doi.org/10.1016/S1470-2045(13)70279-1)
- [2] Beelen, R., Raaschou-Nielsen, O., Stafoggia, M., Andersen, Z.J., Weinmayr, G., Hoffmann, B., Wolf, K., Samoli, E., Fischer, P., Nieuwenhuijsen, M., Vineis, P., Xun, W.W., Katsouyanni, K., Dimakopoulou, K., Oudin, A., Forsberg, B., Modig, L., Havulinna, A.S., Lanki, T., Turunen, A., Oftedal, B., Nystad, W., Nafstad, P., De Faire, U., Pedersen, N.L., Östenson, C.G., Fratiglioni, L., Penell, J., Korek, M., Pershagen, G., Eriksen, K.T., Overvad, K., Ellermann, T., Eeftens, M., Peeters, P.H., Meliefste, K., Wang, M., Bueno-de-Mesquita, B., Sugiri, D., Krämer, U., Heinrich, J., de Hoogh, K., Key, T., Peters, A., Hampel, R., Concin, H., Nagel, G., Ineichen, A., Schaffner, E., Probst-Hensch, N., Künzli, N., Schindler, C., Schikowski, T., Adam, M., Phuleria, H., Vilier, A., Clavel-Chapelon, F., Declercq, C., Grioni, S., Krogh, V., Tsai, M.Y., Ricceri, F., Sacerdote, C., Galassi, C., Migliore, E., Ranzi, A., Cesaroni, G., Badaloni, C., Forastiere, F., Tamayo, I., Amiano, P., Dorronsoro, M., Katsoulis, M., Trichopoulou, A., Brunekreef, B. and Hoek, G. (2014) Effects of Long-Term Exposure to Air Pollution on Natural Cause Mortality: An Analysis of 22 European Cohorts within the Multicenter ESCAPE Project. *The Lancet*, **383**, 785-795. [http://dx.doi.org/10.1016/S0140-6736\(13\)62158-3](http://dx.doi.org/10.1016/S0140-6736(13)62158-3)
- [3] IARC (International Agency for Research on Cancer) (2012) A Review of Human Carcinogens: Chemical Agents and Related Occupations. *IARC Monographs on the Evaluation of Carcinogenic Risks to Humans*, **100F**, 1-599.

- [4] Horak, F., Studnicka, M., Gartner, C., Spengler, J.D., Tauber, E., Urbanek, R., Veiter, A. and Frischer, T. (2002) Particulate Matter and Lung Function Growth in Children: a 3-Yr Follow-Up Study in Austrian Schoolchildren. *European Respiratory Journal*, **19**, 838-845. <http://dx.doi.org/10.1183/09031936.02.00512001>
- [5] Peacock, J.L., Symonds, P., Jackson, P., Bremner, S.A., Scarlett, J.F., Strachan, D.P. and Anderson, H.R. (2003) Acute Effects of Winter Air Pollution on Respiratory Function in Schoolchildren in Southern England. *Occupational and Environmental Medicine*, **60**, 82-89. <http://dx.doi.org/10.1136/oem.60.2.82>
- [6] Ward, D.J. and Ayres, J.G. (2004) Particulate Air Pollution and Panel Studies in Children: A Systematic Review. *Occupational and Environmental Medicine*, **61**, 1-12. <http://dx.doi.org/10.1136/oem.2003.007088>
- [7] Moon, J.S., Kim, Y.S., Kim, J.H., Son, B.S., Kim, D.S. and Yang, W. (2009) Respiratory Health Effects among School Children and Their Relationship to Air Pollutants in Korea. *International Journal of Environmental Health Research*, **19**, 31-48. <http://dx.doi.org/10.1080/09603120802272201>
- [8] Kaur, S., Nieuwenhuijsen, M. and Colvile, R. (2005) Personal Exposure of Street Canyon Intersection Users to PM_{2.5}, Ultrafine Particle Counts and Carbon Monoxide in Central London, UK. *Atmospheric Environment*, **39**, 3629-3641. <http://dx.doi.org/10.1016/j.atmosenv.2005.02.046>
- [9] Chen, H., Namdeo, A. and Bell, M. (2008) Classification of Road Traffic and Roadside Pollution Concentrations for Assessment of Personal Exposure. *Environmental Modelling & Software*, **23**, 282-287. <http://dx.doi.org/10.1016/j.envsoft.2007.04.006>
- [10] Rim, D. and Novoselac, A. (2009) Transport of Particulate and Gaseous Pollutants in the Vicinity of a Human Body. *Building and Environment*, **44**, 1840-1849. <http://dx.doi.org/10.1016/j.buildenv.2008.12.009>
- [11] Hess, D.B., Ray, P.D., Stinson, A.E. and Park, J.Y. (2010) Determinants of Exposure to Fine Particulate Matter (PM_{2.5}) for Waiting Passengers at Bus Stop. *Atmospheric Environment*, **44**, 5174-5182. <http://dx.doi.org/10.1016/j.atmosenv.2010.08.046>
- [12] Kaur, S., Nieuwenhuijsen, M.J. and Colvile, R.N. (2007) Fine Particulate Matter and Carbon Monoxide Exposure Concentrations in Urban Street Transport Microenvironments. *Atmospheric Environment*, **41**, 4781-4810. <http://dx.doi.org/10.1016/j.atmosenv.2007.02.002>
- [13] Richmond-Bryant, J., Saganich, C., Bukiewicz, L. and Kalin, R. (2009) Associations of PM_{2.5} and Black Carbon Concentrations with Traffic, Idling, Background Pollution, and Meteorology during School Dismissals. *Science of the Total Environment*, **407**, 3357-3364. <http://dx.doi.org/10.1016/j.scitotenv.2009.01.046>
- [14] Massey, D., Masih, J., Kulshrestha, A., Habil, M. and Taneja, A. (2009) Indoor/Outdoor Relationship of Fine Particles Less than 2.5 mm (PM_{2.5}) in Residential Homes Locations in Central Indian Region. *Building and Environment*, **44**, 2037-2045. <http://dx.doi.org/10.1016/j.buildenv.2009.02.010>
- [15] Raut, J.C., Chazette, P. and Fortain, A. (2009) Link between Aerosol Optical, Microphysical and Chemical Measurements in an Underground Railway Station in Paris. *Atmospheric Environment*, **43**, 860-868. <http://dx.doi.org/10.1016/j.atmosenv.2008.10.038>
- [16] Zhou, Y. and Levy, J.I. (2008) The Impact of Urban Street Canyons on Population Exposure to Traffic-Related Primary Pollutants. *Atmospheric Environment*, **42**, 3087-3098. <http://dx.doi.org/10.1016/j.atmosenv.2007.12.037>
- [17] Kim, S.R., Dominici, F. and Buckley, T.J. (2007) Concentrations of Vehicle-Related Air Pollutants in an Urban Parking Garage. *Environmental Research*, **105**, 291-299. <http://dx.doi.org/10.1016/j.envres.2007.05.019>
- [18] Borgini, A., Tittarelli, A., Ricci, C., De Saeger, E., Bertoldi, M. and Crosignani, P. (2011) Personal Exposure to PM_{2.5} among High-School Students in Milan and Background Measurements: The EuroLifeNet Study. *Atmospheric Environment*, **45**, 4147-4151. <http://dx.doi.org/10.1016/j.atmosenv.2011.05.026>
- [19] Sorensen, M., Steffen, L., Andersen, V.H., Raaschou-Nielsen, O., Skovgaard, L.T., Knudsen, L.E., Nielsen, I.V. and Hertel, O. (2005) Personal Exposure to PM_{2.5}, Black Smoke and NO₂ in Copenhagen: Relationship to Bedroom and Outdoor Concentrations Covering Seasonal Variation. *Journal of Exposure Analysis and Environmental Epidemiology*, **15**, 413-422. <http://dx.doi.org/10.1038/sj.jea.7500419>
- [20] Fondelli, M.C., Chellini, E., Yli-Tuomi, T., Cenni, I., Gasparrini, A., Nava, S., Garcia-Orellana, I., Lupi, A., Grechi, D., Mallone, S. and Jantunen, M. (2008) Fine Particle Concentrations in Buses and Taxis in Florence, Italy. *Atmospheric Environment*, **42**, 8185-8193. <http://dx.doi.org/10.1016/j.atmosenv.2008.07.054>
- [21] Du, X., Kong, Q., Ge, W., Zhang, S. and Fu, L. (2010) Characterization of Personal Exposure Concentration of Fine Particles for Adults and Children Exposed to High Ambient Concentrations in Beijing, China. *Journal of Environmental Sciences*, **22**, 1757-1764. [http://dx.doi.org/10.1016/S1001-0742\(09\)60316-8](http://dx.doi.org/10.1016/S1001-0742(09)60316-8)
- [22] SAS Institute Inc. (1989) SAS/STAT User's Guide, Version 8e. SAS Institute Inc., Cary.
- [23] Begum, B.A., Paul, S.K., Hossain, D.M., Biswas, S.K. and Hopke, P.K. (2009) Indoor Air Pollution from Particulate Matter Emissions in Different Households in Rural Areas of Bangladesh. *Building and Environment*, **44**, 898-903. <http://dx.doi.org/10.1016/j.buildenv.2008.06.005>

- [24] Branis, M., Safranek, J. and Hytychova, A. (2008) Exposure of Children to Airborne Particulate Matter of Different Size Fractions during Indoor Physical Education at School. *Building and Environment*, **44**, 1246-1252. <http://dx.doi.org/10.1016/j.buildenv.2008.09.010>
- [25] Fromme, H., Twardella, D., Dietrich, S., Heitmann, D., Schierl, R., Liebl, B. and Ruden, H. (2007) Particulate Matter in the Indoor Air of Classrooms-Exploratory Results from Munich and Surrounding Area. *Atmospheric Environment*, **41**, 854-866. <http://dx.doi.org/10.1016/j.atmosenv.2006.08.053>
- [26] Quintana, P.J.E., Valenzia, J.R., Delfino, R.J. and Liu, L.J.S. (2001) Monitoring of 1 Min Personal Particulate Matter Exposures in Relation to Voice Recorded Time Activity Data. *Environmental Research Section A*, **87**, 199-213. <http://dx.doi.org/10.1006/enrs.2001.4304>
- [27] Lai, H.K., Bayer-Oglesby, L., Colville, R., Gotschi, T., Jantunen, M.J., Kunzli, N., Kulinskaya, E., Schweizer, C. and Nieuwenhuijsen, M.J. (2006) Determinants of Indoor Air Concentrations of PM_{2.5}, Black Smoke and NO₂ in Six European Cities (EXPOLIS Study). *Atmospheric Environment*, **40**, 1299-1313. <http://dx.doi.org/10.1016/j.atmosenv.2005.10.030>
- [28] Kousa, A., Oglesby, L., Koistinen, K., Kunzli, N. and Jantunen, M. (2002) Exposure Chain of Urban Air PM_{2.5}—Associations between Ambient Fixed Site, Residential Outdoor, Indoor, Workplace and Personal Exposures in Four European Cities in the EXPOLIS-Study. *Atmospheric Environment*, **36**, 3031-3039. [http://dx.doi.org/10.1016/S1352-2310\(02\)00232-7](http://dx.doi.org/10.1016/S1352-2310(02)00232-7)
- [29] Janssen, N.A., Hoek, G., Harssema, H. and Brunekreef, B. (1997) Childhood Exposure to PM₁₀: Relation between Personal, Classroom, and Outdoor Concentrations. *Occupational and Environmental Medicine*, **54**, 888-894. <http://dx.doi.org/10.1136/oem.54.12.888>
- [30] Janssen, N.A.H., Hoek, G., Harssema, H. and Brunekreef, B. (1999) Personal Exposure to Fine Particles in Children Correlates Closely with the Ambient Fine Particles. *Archives of Environmental Health*, **54**, 95-101. <http://dx.doi.org/10.1080/00039899909602242>
- [31] Janssen, N., van Vliet, P.H.N., Aarts, F., Harssema, H. and Brunekreef, B. (2001) Assessment of Exposure to Traffic Related Air Pollution of Children Attending Schools near Motorways. *Atmospheric Environment*, **35**, 3875-3884. [http://dx.doi.org/10.1016/S1352-2310\(01\)00144-3](http://dx.doi.org/10.1016/S1352-2310(01)00144-3)
- [32] Liu, W., Zhang, J., Zhang, L., Turpin, B.J., Weisel, C.P., Morandi, M.T., Stock, T.H., Colome, S. and Korn, L.R. (2006) Estimating Contributions of Indoor and Outdoor Sources to Indoor Carbonyl Concentrations in Three Urban Areas of the United States. *Atmospheric Environment*, **40**, 2202-2214. <http://dx.doi.org/10.1016/j.atmosenv.2005.12.005>
- [33] Polidori, A., Turpin, B., Yumeng, Q., Lee, J.H., Weisel, C., Morandi, M., Colome, S., Stock, T., Winer, A., Zhang, J., Kwon, J., Okhtari, S., Shendell, D., Jones, J., Farrar, C. and Maberti, S. (2006) Fine Organic Particulate Matter Dominates Indoor-Generated PM_{2.5} in RIOPA Homes. *Journal of Exposure Science and Environmental Epidemiology*, **16**, 321-331. <http://dx.doi.org/10.1038/sj.jes.7500476>
- [34] Meng, Y.Q., Turpin, B.J., Korn, L., Weisel, C.P., Morandi, M., Colome, S., Zhang, J.J., Stock, T., Spektor, D., Winer, A., Zhang, L., Lee, J.H., Giovanetti, R., Cui, W., Kwon, J., Alimokhtari, S., Shendell, D., Jones, J., Farrar, C. and Maberti, S. (2005) Influence of Ambient (Outdoor) Sources on Residential Indoor and Personal PM_{2.5} Concentrations: Analyses of RIOPA Data. *Journal of Exposure Science and Environmental Epidemiology*, **15**, 17-28. <http://dx.doi.org/10.1038/sj.jea.7500378>
- [35] Yip, F.Y., Keeler, G.J., Dvonch, J.T., Robins, T.G., Parker, E.A., Israel, B.A. and Brakefield-Caldwell, W. (2004) Personal Exposures to Particulate Matter among Children with Asthma in Detroit, Michigan. *Atmospheric Environment*, **38**, 5227-5236. <http://dx.doi.org/10.1016/j.atmosenv.2004.06.006>
- [36] Zuurbier, M., Hoek, G., Oldenwening, M., Lenters, V., Meliefste, K., van de Hazel, P. and Brunekreef, B. (2010) Commuters' Exposure to Particulate Matter Air Pollution Is Affected by Mode of Transport, Fuel Type, and Route. *Environmental Health Perspectives*, **118**, 783-788. <http://dx.doi.org/10.1289/ehp.0901622>
- [37] Ashmore, M.R. and Dimitroulopoulou, C. (2009) Personal Exposure of Children to Air Pollution. *Atmospheric Environment*, **43**, 128-141. <http://dx.doi.org/10.1016/j.atmosenv.2008.09.024>
- [38] Adams, H.S., Nieuwenhuijsen, M.J. and Colville, R.N. (2001) Determinants of Fine Particle (PM_{2.5}) Personal Exposure Levels in Transport Microenvironments, London, UK. *Atmospheric Environment*, **35**, 4557-4566. [http://dx.doi.org/10.1016/S1352-2310\(01\)00194-7](http://dx.doi.org/10.1016/S1352-2310(01)00194-7)
- [39] Brinkman, G.L., Milford, J.B., Schauer, J.J., Shafer, M.M. and Hannigan, M.P. (2009) Source Identification of Personal Exposure to Fine Particulate Matter Using Organic Tracers. *Atmospheric Environment*, **43**, 1972-1981. <http://dx.doi.org/10.1016/j.atmosenv.2009.01.023>
- [40] Hänninen, O., Zauli-Sajani, S., De Maria, R., Lauriola, P. and Jantunen, M. (2009) Integrated Ambient and Microenvironment Model for Estimation of PM₁₀ Exposures of Children in Annual and Episode Settings. *Environ Model Assess*, **14**, 419-429. <http://dx.doi.org/10.1007/s10666-008-9141-y>

Abbreviations

CI: Confidence Interval; IES: Institute for Environment Sustainability; JRC: Joint Research Centre; PM_{2.5}: Particulate matter of aerodynamic diameter $\leq 2.5 \mu\text{m}$; TAD: Time Activity Diary.