Children exposure to $PM_{2.5}$ in kindergarten classrooms equipped with air purifiers – a pilot study

Anna Gayer[1,*], *Dominika* Mucha[2], *Łukasz* Adamkiewicz[2,3], *Artur* Badyda[2]

[1]The Main School of Fire Services, Faculty of Fire Safety Engineering, 52/54 Slowackiego St., 01-629 Warsaw, Poland
[2]Warsaw University of Technology, Faculty of Building Services, Hydro- and Environmental Engineering, 20 Nowowiejska St., 00-653 Warsaw, Poland
[3]European Clean Air Center, 10/6 Felicjanek St., 33-332 Cracow, Poland

Abstract. Children exposure to $PM_{2.5}$ is associated with several negative health effects. Particulate air pollution in the ambient and indoor air could lead to exacerbation of respiratory diseases and even influence cognitive function in children. One of the methods to improve indoor air quality is to use electronic air purifiers. Such an equipment is still not commonly used in Polish kindergartens and homes. The aim of the study was to assess changes in children exposure to particulate air pollution in kindergarten classrooms due to the occurrence of air purifier. Automatic $PM_{2.5}$ concentration monitors were used to assess the air quality changes in the indoor and ambient air. As it was a pilot study, four kindergartens in Warsaw has been chosen as research fields. Concentration measurements were conducted in cold season. In each kindergarten measurements of the $PM_{2.5}$ concentration were made in two classrooms – one with air purifier switched on and the other one without air purification. Changes in air quality were observed due to opening windows and the presence of the children. Air quality in classrooms with air purification was on average almost 40%-50% better than in those without any procedures to decrease air pollutants concentration.

1 Introduction

Children exposure to $PM_{2.5}$ is associated with several negative health effects. As a specific group, children are sensitive to airborne particulate matter. Particulate air pollution in ambient and indoor air, arising from various sources of emission, could lead to exacerbation of respiratory diseases and even influence children's cognitive functions.

Australian researchers have studied the impact of early childhood traffic-related air pollution (TRAP) exposure on the development of asthma and allergies. This systematic review and meta-analyses of articles in MEDLINE, EMBASE and ISI Web of Science databases showed increased longitudinal childhood exposure to $PM_{2.5}$ and black carbon was

* Corresponding author: anna.gayer@gmail.com

associated with increasing risk of subsequent asthma in childhood ($PM_{2.5}$: OR 1.14, 95%CI 1.00 to 1.30 per 2 μg/m^3 and black carbon: OR 1.20, 95%CI 1.05 to 1.38 per 1x10^{-5} m^{-1}). Also, early childhood exposure to TRAP was associated with the development of asthma across children up to 12 years of age. The magnitude of these associations increased with age, and the pattern was prominent for $PM_{2.5}$ [1].

Other review have examined the impact of air pollution on children's brain development and the clinical, cognitive, brain structural and metabolic consequences. Researchers stated that children's optimal health and brain development requires clean air. Diffuse neuroinflammation, damage to the neuro-vascular unit, and the production of autoantibodies to neural and tight-junction proteins are worrisome findings in children chronically exposed to concentrations above the current standards for ozone and fine particulate matter ($PM_{2.5}$), and may constitute significant risk factors for the development of Alzheimer's disease later in life. Early cognitive deficits are associated with prenatal and early postnatal air pollutant exposures, and brain structural, volumetric and metabolic changes have been described in adolescence and early adulthood with significant cognitive deficits that have negative impacts on the academic, job-related and social performances of affected individuals [2].

A study in Jinan, China aimed to examine the effect of short-term changes in the concentration of $PM_{2.5}$ and PM_{10} on pediatric hospital admissions for pneumonia. Data was collected from the database of Jinan Qilu Hospital. An increment of 10 μg/m^3 in $PM_{2.5}$ and PM_{10} were correlated with a 6% (95% CI 1.02-1.10) and 4% (95% CI 1.00-1.08) increase in a number of admissions for pneumonia, respectively. In two pollutant models, $PM_{2.5}$ and PM_{10} remained significant after inclusion of sulfur dioxide or nitrogen dioxide but not carbon monoxide. This study demonstrated that short-term exposure to atmospheric particulate matter ($PM_{2.5}$/PM_{10}) may be an important determinant of pediatric hospital admissions for pneumonia in Jinan, China [3].

The Californian researcher has investigated the association of improved air quality with lung development in children. As part of the Children's Health Study they measured lung function annually in 2,120 children from three separate cohorts. Mean ages of the children within each cohort were 11 years at the beginning of the period and 15 years at the end. Linear regression models were used to examine the relationship between declining pollution levels over time and lung-function development from 11 to 15 years of age, measured as the increases in forced expiratory volume in first second of expiration (FEV_1) and forced vital capacity (FVC) during that period (referred to as 4-year growth in FEV_1 and FVC). Over the 13 years spanned by the three cohorts, improvements in 4-year growth of both FEV_1 and FVC were associated with declining levels of nitrogen dioxide ($p<0.001$ for FEV_1 and FVC) and of particulate matter with an aerodynamic diameter of less than 2.5 μm ($p=0.008$ for FEV_1 and $p<0.001$ for FVC) and less than 10 μm ($p<0.001$ for FEV_1 and FVC). These associations persisted after adjustment for several potential confounders. Significant improvements in lung-function development were observed in both boys and girls and in children with asthma and children without asthma. The proportions of children with clinically low FEV_1 (defined as <80% of the predicted value) at 15 years of age declined significantly, from 7.9% (cohort C) to 6.3% (cohort D) and only to 3.6% (cohort E) across the three periods, as the air quality improved ($p=0.001$). Long-term improvements in air quality were associated with statistically and clinically significant positive effects on lung-function growth in children [4].

Due to the fact that children are one of the particularly vulnerable groups to air pollution and the consequences of the exposure that could affect their adult life keeping good air quality in places they are spending time in is essential. One of the measures to improve indoor air quality is to use electronic air purifiers. Some of the educational facilities (e.g. kindergartens) are equipped with such devices. There is still not much evidence whether the air purification methods used in popular devices provide the high effectiveness of air pollutants reduction. The aim of the study was to assess changes of children exposure to particulate air pollution in kindergarten classrooms due to the occurrence of air purifier.

2 Materials and Methods

The efficiency of purification of various models and brands of devices was tested in four selected kindergartens in Warsaw, Poland. In each of the selected pre-school institutions in one of the rooms where routine work was performed (spending time with children, serving meals, cleaning, etc.) the air purifier was turned on for 24 hours 7 days a week, and in the other room (similar in terms of number, age of children etc.) the air purifier was turned off. Kindergartens localizations were representing areas in which air quality depends on various types of emitters (the municipal and living sector or the presence of roads with high traffic volume). In order to maintain the anonymity of institutions that participated in the study specific localization and number of kindergartens will not be presented. The assessment of the effectiveness of air purification was carried out in the natural, real conditions of children's stay and during their routine activities (serving in meals, physical activity, entering and leaving the rooms, etc.) In order to maintain these conditions, no instructions were given regarding ventilation such as keeping windows closed, in which the measurement was carried out. Kindergarten staff was asked to fill in the dailies to document in which rooms, where the research was conducted, the windows were opened or closed.

In each of the facilities selected for the research, the measurement of $PM_{2.5}$ concentration was carried out in two rooms - in the room #1 - with the air purifier switched on 24 hours a day and in room #0 - with the air purifier turned off for the duration of measurements. Measurements of $PM_{2.5}$ concentration where conducted during 5 days a week (3 working days and weekend) with use of SidePak 510 Aerosol Monitor by TSI. The study was conducted from 7th of March until 1st of April 2018 in one of the four selected kindergartens at a week time. As children spent time in the kindergartens during day time observations of the $PM_{2.5}$ concentrations were made from 6 PM until 6 AM.

Due to the measurement dates (end of the heating period, when levels of air pollutant are relatively high due to intensive household emission) it was possible to capture the differences in the $PM_{2,5}$ concentration in the outdoor air and compare the amount of particulates present in the rooms under different environmental conditions. In order to illustrate the quality of ambient air in urban background automatic measurements of $PM_{2.5}$ of the Regional Inspectorate of Environmental Protection (WIOŚ) in Warsaw were taken into consideration. The concentration of measurement results come from 2 fixed monitoring stations located in Ursynów and Targówek districts of Warsaw.

For each day of measurements effectiveness of air purification as a difference between $PM_{2.5}$ concentration in room #0 and room #1 was calculated.

3 Results and discussion

Diagrams below present time series of $PM_{2.5}$ concentration measured indoor – in rooms with (#1) and without (#0) air purifier in selected kindergartens and outdoor – ambient air quality measurements of fixed site urban background monitoring stations.

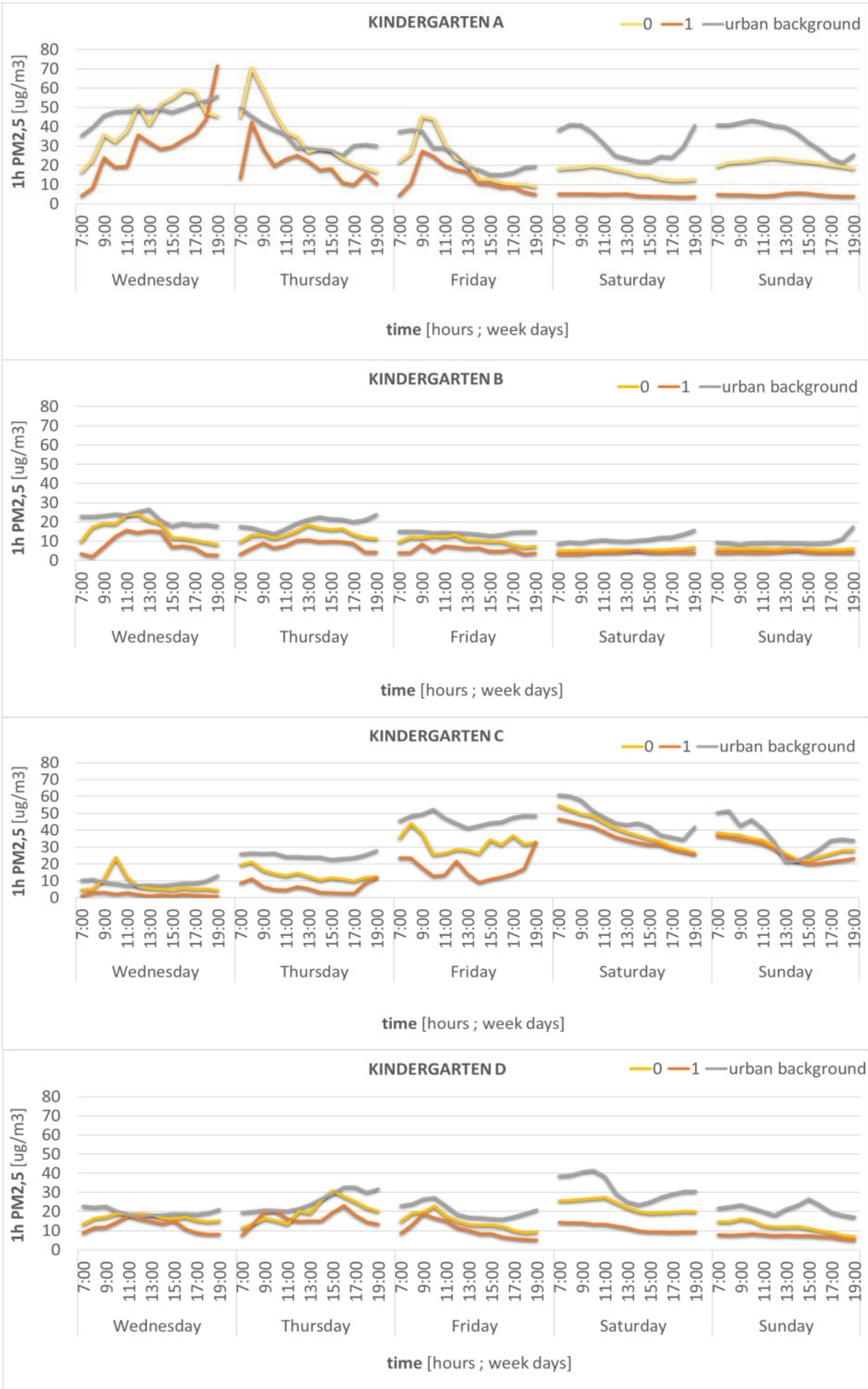

Fig. 1. $PM_{2.5}$ concentration measured indoor – in rooms with (#1) and without (#0) air purifier in selected kindergartens and outdoor in urban background monitoring station.

As it is shown on the diagrams in Fig.1. air quality indoors depends on the concentration of $PM_{2.5}$ in urban background. When the urban background concentration of $PM_{2.5}$ was relatively high (eg. in Kindergarten A on Wednesday and in Kindergarten C on Friday) concentration indoor was also high. Results obtained from the measurements made in week days (Wed -Fri) show stronger correlation (indoor-urban background $PM_{2.5}$ concentration)- R^2 =0.64 for kindergarten A, R^2 = 0.53 for B, R^2 =0.8 for C, R^2 =0.58 for D than those from weekends (Sat- Sun). Kindergartens which were selected for the study are open only from Mondays to Fridays. As they have inefficient ventilation systems during the presence of children windows in classrooms remains open. Occurrence of peaks of particulate matter concentrations (Wed-Fri) indoor is highly correlated with opening the windows. Physical activity of the children present in classrooms causes resuspension of the particulate matter indoors, what also can be observed during week days (Wed -Fri). In table 1 average air purification calculation results are presented.

Table 1. Average $PM_{2.5}$ concentration and average air purification efficiency measured in selected kindergartens.

			Average $PM_{2.5}$ concentration [μg/m³]		**Average air purification efficiency**	
Dates	Kindergarten	Room	week days**	weekend ***	week days**	weekend ***
7 March – 11 March	A*	0	33.0	18.6	36%	75%
		1	20.9	4.6		
		urban background	35.5	33.1		
14 March – 18 March	B*	0	13.3	5.7	46%	26%
		1	7.3	4.2		
		urban background	18.6	10.6		
21 March – 25 March	C*	0	17.8	31.5	58%	11%
		1	8.4	35.0		
		urban background	26.9	41.1		
28 March – 1 April	D*	0	17.1	17.3	24%	43%
		1	13.0	9.4		
		urban background	21.9	26.8		

*anonymous names of kindergartens
** average $PM_{2.5}$ concentration from 7AM to 7AM on Wednesdays, Thursdays and Fridays
*** average $PM_{2.5}$ concentration from 7AM to 7AM on Saturdays and Sundays

The study results show that the efficiency of air purification differs between classrooms. Average air purification efficiency is 40% what can be seen also in other surveys. Korean researchers described the characterization of indoor air quality and efficiency of air purifier in childcare centers in Seoul in 2013[5]. The concentrations of particulate matter indoor in childcare centers were correlated with the corresponding outdoor locations, in residential areas (R^2 =0.64 for PM_{10} and 0.66 for $PM_{2.5}$), near roadways (R^2 =0.72 for PM_{10} and 0.76 for $PM_{2.5}$), and near construction areas (R^2=0.45 for PM_{10} and 0.62 for $PM_{2.5}$). The removal efficiency of particulate matter and bio-aerosols were 58-85% for $PM_{2.5}$, 49-86% for PM_{10}, 41-68% for airborne bacteria, and 40-58% for fungi [5]. The limitation of the presented study is that only particulate matter concentration was measured whereas Korean studies were also focused on microbiological air quality indoors. Also, only air purifiers with HEPA filters were considered in the presented study so that no other features of air purification method could be surveyed. Differences between two methods – filtering by HEPA filter and electrostatic cleaning were included in Norwegian studies. A double-blind crossover intervention study with air cleaners was conducted in an office and a kindergarten. Two different air cleaners were used: a cleaner with HEPA filter and a cleaner with an electrostatic unit. The HEPA filter reduced nearly all particle fractions, while the electrostatic filter reduced particles less than 5 μm. Health improvements were obtained by the air cleaners in the kindergarten [6].

Despite that air purification in households and kindergartens gained much popularity in Poland there are still not much evidence about the efficiency of these methods.

5 Conclusion

Results of the study show that the quality of indoor air in selected kindergartens varies due to differences in operating air purification devices and manual, by opening the windows, ventilation of the classrooms. In a room with the air purifier turned on, when the windows are closed, the $PM_{2.5}$ concentration is significantly lower, what can be observed during weekends. Closing the windows could increase the efficiency of air purification process but on the other hand, it could significantly affect other parameters, important from the point of view of the number of people and physical activity of children staying in the room. In many of the rooms opening the windows is the only method in the present infrastructural conditions to maintain adequate air quality in terms of thermal comfort of children, reduction of moisture and the amount of carbon dioxide, increased air movement or oxygen supply to the room.

Observed dependences allow, however, to state that the presence of the air purifier in a pre-school facility significantly affects the reduction of particulate matter pollution with a 2.5 μm aerodynamic diameter, however further research is needed.

Based on the conducted research, it is recommended to:

- the use of air purifiers to reduce dust pollution in kindergarten rooms, in particular during the heating season, when the concentrations of suspended particulate matter in the urban background remain high (the research does not result in recommendations for specific brands of purifiers);
- leaving the devices turned on in all rooms for 24 hours a day (especially in the period of high concentrations of pollutants in the ambient air);
- if necessary, also the modernization of the ventilation system in facilities where inefficient ventilation of rooms is found (which is crucial not only because of the limited efficiency of removing air pollutants from indoor rooms, but also maintaining appropriate air humidity conditions, and thus limiting microbial risk);

• modernization of air conditioning systems in facilities where the ventilation system does not allow for efficient air exchange in rooms where children are present.

References

1. G. Bowatte, C. Lodge, A.J. Lowe, B. Erbas, J. Perret, M.J. Abramson, M. Matheson, S.C. Dharmage, Allergy **70**, 245 (2015)
2. L. Calderon-Garciduenas, E. Leray, P. Heydarpour, R. Torres-Jardon, J. Reis, Rev. Neurol. **172**, 69 (2016)
3. C. Lv, X. Wang, N. Pang, L. Wang, Y. Wang, T. Xu, Y. Zhang, T. Zhou, W. Li, JA&WMA **67**, 669 (2017)
4. W.J. Gauderman, R. Urman, E. Avol, K. Berhane, R. McConnell, E. Rappaport, R. Chang, F. Lurmann, F. Gilliland, N. Engl. J. Med. **372;10**, 905 (2015)
5. H-J. Oh , I-S. Nam , H. Yun, J. Kim, J. Yang, J-R. Sohn, Build. Environ. **82**, 203 (2014)
6. K. Skulberg, B. Hellum, O. Sjøvold, *12th International Conference on Indoor Air Quality and Climate 2011*, **2**, 1643 (2011)