# JOAQUIN - JOINT AIR QUALITY INITIATIVE

## Work Package 2 - Action 8

# Reducing public exposure to indoor air pollution: Assessing the effectiveness of air filtration systems on health-relevant pollutants in schools.

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Investing in Opportunities

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# 1. SUMMARY

In this study the application of high performance air filtration was tested in seven educational buildings in Northwestern Europe, mainly primary schools. This study shows that high performance air filtration can reduce exposure to traffic-related air pollution of school children at hot spot locations.Filtration is only effective, however, if filters are frequently replaced and the ventilation system properly maintained. We encountered a variety of maintenance related problems, which may result in air filtering posing health risks from inadequate ventilation. If a filter is applied and proper maintenance is guaranteed, F9 is the best choice. Siting schools away from busy roadways is always the preferred option, however.

# 2. INTRODUCTION

Measurements of air pollutants near roadways consistently show elevated levels based on proximity. A review of the scientific literature by the Health Effects Institute (HEI) found that proximity to busy roadways is associated with a variety of adverse health impacts, the strongest association being exacerbation of asthma, with others including asthma onset in children, impaired lung function and increased heart disease (HEI, 2010). Children appear to be particularly vulnerable to the adverse effects of traffic emissions.

In order to reduce exposure to traffic-related particulate air pollution of children attending school near busy roadways, the application of mechanical ventilation systems with air filtration might be an effective mitigation measure.

In addition to air filtration, a variety of other air cleaning devices is available on the market, based on different principles. An overview and evaluation of the available air cleaning methods can be found at websites of (among others) the US EPA and Californian EPA:
http://www2.epa.gov/indoor-air-quality-iaq/guide-air-cleaners-home
http://www.arb.ca.gov/research/indoor/acdsumm.pdf
http://epi.publichealth.nc.gov/oee/iaq/devices.html
From the information at the websites it can be concluded that ventilation systems with high efficiency particle filtration, if properly configured and maintained, may have the greatest potential to improve indoor air quality at schools.

The effectiveness of mechanical ventilation systems with air filtration to improve indoor air quality was investigated in seven educational buildings in proximity to busy roads. Among the educational buildings were a university (a Lecture Theatre of the University of Brighton, (UK) and six schools: one in Amsterdam (NL), one in The Hague (NL), two in Antwerp (BE) and two in the province of Limburg (BE).

## 3. METHODS

In each building, the effectiveness of high efficiency F9 filters to remove outdoor pollutants was compared to the baseline situation under otherwise equal ventilation conditions. Different baseline situations were studied depending on the existing filter: none (Amsterdam), G4 (Brighton), M5 (The Hague) or F7 (Belgium). The higher the filter number, the smaller the pore size of the filter and the higher the efficiency to remove 0.4 µm particles. Traffic emissions are predominantly in the submicron size range (Riddle *et al*., 2008). Table 1 shows characteristics of the seven educational buildings and the study period.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|
| Country | NL | NL | BE | BE | BE | BE | UK |
| City | Amsterdam | The Hague | Antwerp | Antwerp | Limburg | Limburg | Brighton |
| Region | urban | urban | urban | urban | suburban | rural | suburban |
| Type of education | high school | primary school | primary school | primary school | primary school | primary school | university |
| In use since | 1952 | Modular built | Newly built (2010) | Newly built (2010) | Newly built (2010) | New annex existing | 1960 |
| Traffic source | freeway | local road | local road | local road | local road | freeway | main road |
| Measurement period | 28th Oct 2013 – 31st Jan 2014 | 2ndFeb – 28th May 2014 | 2nd Jun – 19th Sep 2014 | 26th Sep – 21st Nov 2014 | 28th Nov 2014 – 30th Jan 2015 | 12th Jan – 13th Mar 2015 | 9th Oct – 31st Dec 2014 |
| Existing filter | F5 | F5 | F7 | F7 | F7 | F7 | F4 |
| New (test) filter | F8 | F9 | F9 | F9 | F9 | F9 | F9 |

Table1. Characteristics of the educational buildings

In Belgium, the study was part of a larger study on indoor air quality in energy-efficient buildings. Four newly built energy-efficient schools were selected for the Belgian part of the study (table 1), while two buildings were over 50 years old.

$PM_{2.5}$ and black carbon (BC) concentrations were measured inside the intervention classrooms and outside each educational building. For BC the same type of device (micro-aethalometer AE51) were used for the measurements in the three countries. The indoor/outdoor AE51's were co-located on a number of occasions to ensure results were comparable. In the Netherlands and the UK, $PM_{2.5}$ was measured continuously with a TEOM device and reported in 30-minute average concentrations. In Belgium, $PM_{2.5}$ was sampled on Teflon filters by a MS&T Harvard type impactor during school hours, resulting in only one $PM_{2.5}$ result per week. However, additional continuous $PM_{2.5}$ and $PM_{10}$ measurements were performed with GRIMM Nanocheck devices. For the analysis reported here, only the Nanocheck data were used, since the higher number of measurements allows more powerful statistical analyses.

Additional pollutants were measured at the different locations. For example, $PM_{10}$ was measured in the Netherlands and UK, whilevolatile organic compounds (VOCs) were measured in Belgium. The results of those measurements are reported in the individual reports. For this summary we focus on BC and $PM_{2.5}$, which was measured in all educational buildings.

*Obstacles faced in the recruitment and study phase*

In all educational buildings except in Brighton, UK (where the ventilation system is maintained by the University of Brighton itself), it was difficult and sometimes impossible to obtain correct information about the existing filters. Even in the University of Brighton, where the service contract was overseen by the university, obtaining information on filter type was difficult. Additionally, running repairs needed to be undertaken before the start of the project, indicating that maintenance of the system was not satisfactory.

In Belgium, ventilation system service agreements, as well as installation services, were very often outsourced to another subcontractor without informing the school management. Information about the existing ventilation system and filter type consequently had to be obtained from various involved persons, was very time consuming and often unsuccessful.

In Amsterdam, the school management was not aware of the presence of an existing F5 filter, which obviously had not been replaced in years, despite the fact that the school had a maintenance contract with an external company. The maintenance company was not aware of this filter (which was located in a box that could not be fully opened due to its location in a small and packed storage room). For the filtration study, an F9 filter was ordered but an F8 filter was delivered. Upon request, the filter manufacturer ensured that the filter was of F9 quality despite the fact that F8 was printed on the filter. At the end of the study period, they admitted that the filter was of F8 type after all. Consequently, we have unintendedly compared F8 filters with a test situation without filter (the existing F5 filter was tested in the baseline situation but was so saturated that the airstream through the filter was very low).

In The Hague, the existing filter type and the date of last filter change could not be recalled. According to the maintenance company, F5 filters were present in the system. We started the measurements with the existing F5 filters and ordered new F9 filters. However, when we installed the new filters it appeared that the existing filters were of F9 quality. Upon request of the school board, we then tested new F5 filters that were replaced by the F9 filters at the end of the study period.

4. RESULTS

*Measured indoor and outdoor air concentrations*

Table 2 presents the average indoor and outdoor $PM_{2.5}$ and BC concentrations in the seven educational buildings during teaching hours.

| No. | PM2.5 indoor | PM.25 outdoor | PM2.5 I/O | BC indoor | BC outdoor | BC I/O |
|---|---|---|---|---|---|---|
| 1 | 17.2 | 13.7 | 1.26 | 0.78 | 1.14 | 0.68 |
| 2 | 18.7 | 15.5 | 1.21 | 0.67 | 0.98 | 0.68 |
| 3 | 20.7 | 17.7 | 1.17 | 0.70 | 1.19 | 0.59 |
| 4 | 15.1 | 18.6 | 0.81 | 0.40 | 1.66 | 0.24 |
| 5 | 48.9 | 19.0 | 2.58 | 0.63 | 1.44 | 0.44 |
| 6 | 7.7 | 19.6 | 0.39 | 0.44 | 1.17 | 0.38 |
| 7 | 6.4 | 9.9 | 0.65 | 0.61 | 0.94 | 0.65 |

Table 2. Mean $PM_{2.5}$ and BC concentration measured outdoor and indoor (including both weeks with existing and new high efficiency filter), and indoor/outdoor (I/O) ratio of mean concentrations

Table 2 shows that there is a large variation in indoor $PM_{2.5}$ concentration between schools, with mean concentrations that varied from 6.4 to 48.9 µg/m$^3$, in contrast to the rather similar $PM_{2.5}$ outdoor concentrations. The indoor to outdoor (I/O) ratio varied from 0.39 to 2.58, with both extremes being measured in Limburg (Belgium). The variation in classroom BC concentration was smaller than for $PM_{2.5}$ and varied within a factor 2 between 0.40 (Antwerp) and 0.78 µg/m$^3$ (Amsterdam). The I/O ratios for BC were below unity in all schools. For $PM_{2.5}$ indoor sources are present in educational buildings (e.g., skin flakes, clothes fibers, resuspended particles) that can vary considerably, while indoor sources of BC can be assumed to be absent. Therefore the observed I/O ratios are in line with the expectation.

In the NL/UK it was possible to distinguish between $PM_{10}$, $PM_{2.5}$ and BC concentrations measured during teaching hours and outside teaching hours. During teaching hours, twofold to fivefold higher classroom $PM_{10}$ concentrations were measured compared to non-teaching hours. About twofold higher classroom $PM_{2.5}$ concentrations were measured during teaching hours (data not shown, see the separate publications for more information). The larger contrast for $PM_{10}$ than for $PM_{2.5}$ can be explained by educational activities resulting in resuspension of settled dust, mainly affecting the coarse fraction ($PM_{2.5-10}$).

*Efficiency of the high performance F9 filter*

The efficiency of the newly installed F9 filter to lower indoor $PM_{10}$, $PM_{2.5}$ and BC was expressed in percentage reduction. In the NL and the UK, the efficiency of the existing filter and the new filter were calculated separately from the slope (b1) of the regression equation:

$$\text{CONC}\textit{indoor} = b_0 + b_1 * \text{CONC}\textit{outdoor}$$

The regression slope ($b_1$) describes the fraction of outdoor particles that penetrates indoors. The efficiency of the F9 filter to remove particles was calculated relative to the existing filter. For example, in school 2 (The Hague), with the existing F5 filter, the infiltration coefficient (slope) for BC was 0.84, indicating that for each 1 µg/m$^3$ increment in outdoor BC, 0.84 µg BC/m$^3$ penetrates into the classroom. With an F9 filter the infiltration coefficient was reduced to 0.27. This means that the F9 filter reduced the infiltration of outdoor BC with 68%. Similarly in Brighton, F9 filters proved highly efficient at reducing ingress of outdoor BC and $PM_{10}$ by 49% and 72% respectively.

In Belgium a slightly different statistical analysis was performed, with one regression model analysing all indoor and outdoor measurements together, using a dummy variable for the filter type:

$$conc_{indoor} = b_0 + b_1 * conc_{outdoor} + b_2 * filter$$

Where the dummy variable had a value of 0 in the existing situation (F7) and of 1 in the new situation (F9). The relative efficiency of the F9 filter (compared to F7) can be calculated from the ratio of the predicted indoor concentration in a situation with new filter (dummy = 1), compared to existing filter (dummy = 0), based on the measured outdoor concentration during the study period at each school.

For instance, at school 3 (Antwerp) the average outdoor BC concentration was 1.19 µg/m$^3$ (1190 ng/m$^3$). For this school, the following regression equation was found:

$$conc_{indoor} = 434 + 0.247 * conc_{outdoor} - 163 * filter$$

This equation results in a predicted indoor BC concentration of 434 + (0.247*1190) = 728 ng/m$^3$ with F7 filter (filter = 0). With F9 filter (filter = 1) the indoor BC concentration is 163 ng/m$^3$ lower (565 ng/m$^3$), which is a reduction of 22%.

Table 3 summarizes the reduction percentages at all schools.

| Nr. | Location | Existing filter | New filter | BC | $PM_{2.5}$ | $PM_{10}$ |
|---|---|---|---|---|---|---|
| 1 | Amsterdam | None | F8 | 53% | 56% | 83% |
| 2 | The Hague | F5 | F9 | 68% | 20% | 17% |
| 3 | Antwerp, school 1 | F7 | F9 | 22% | 16% | n.s. |
| 4 | Antwerp, school 2 | F7 | F9 | 11% | 34% | n.s. |
| 5 | Limburg, school 1 | F7 | F9 | 16% | 18% | n.s. |
| 6 | Limburg, school 2 | F7 | F9 | 49% | 59% | n.s. |
| 7 | Brighton | G4 | F9 | 49% | 38% | 72% |

Table 3. Reduction (%) in indoor air concentration with the new filter compared to the existing filter

Table 3 demonstrates that the application of a high efficiency F9 filter (F8 in Amsterdam) resulted in lower BC and $PM_{2.5}$ concentrations in all buildings. On average, 36% lower indoor BC and 34% lower $PM_{2.5}$ concentrations were measured compared to the existing situation. Somewhat lower BC reduction percentages were found in Belgium, which is in line with the expectation, since in the existing situation rather efficient (F7) filters were present. For $PM_{10}$ the indoor concentrations were dominated by classroom activities and in Belgium, the indoor-outdoor relations were non-significant.

## 5. CONCLUSION

This study implies that the application of high performance air filtration can reduce exposure to traffic-related air pollution of school children at hotspot locations. However filtration is only effective if filters are frequently replaced and the ventilation system is properly maintained. In this study we encountered a variety of maintenance-related problems. If the maintenance fails, air filtering might pose health risks from inadequate ventilation. We advise to develop an assurance system that guarantees proper maintenance of filter systems at schools. This is, however, complicated by the absence of a legal framework. If a filter is applied and proper maintenance is guaranteed, F9 is the best choice. Siting schools away from busy roadways is always the preferred option, however.

## 6. DISSEMINATION AND PRESENTATIONS

- presentation for school board governors and municipal school housing governors in Amsterdam (24 September 2013) about health effects of traffic-related air pollution and mitigation measures (filtering). Number of participants ± 25
- Joaquin reference board meeting 2013 (Marieke Dijkema) Number of participants ± ??
- discussion/meeting with Amsterdam school housing staff members about possible ways to guarantee proper maintenance of filter systems (21 April 2015). Number of participants ± 10
- presentation for ca. 50 environment & health advisors working for the Department of Health Services, 17 September 2015
- poster presentation at Joaquin Cleaner Air Better Health conference, Amsterdam, 11 June 2015. Number of participants ± 200?
- presentation at Healthy Buildings Europe, Eindhoven, 18-20 May 2015: Stranger M., Constandt K., Staelens J., Maes F., Lazarov B., Marc L., Goelen E. (2015). Improving school indoor air quality. Number of participants ± 25

## 7. REFERENCES

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