LUNGS OF THE CITY

Final report pilot project Stadhuisplein Eindhoven

SUMMARY

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Project summary

The population size is increasing worldwide, and the number of inhabitants in cities in particular is growing rapidly. In the Netherlands, it is expected that three-quarters of the total population growth will take place in the large municipalities. This is also the case in Eindhoven, where a planned densification of urban areas will lead to a jump in scale from 235,000 to 300,000 residents in 2040, with an increase in high-rise buildings in the city center. In order to make the city even more attractive for living, working and recreation, 'Healthy Urbanization' is an important theme in future urban development.

Healthy urbanization

A healthy living environment is very important for healthy urbanization. The population's health is influenced by both their own behavior and by environmental factors. The living environment has a major impact on the burden of disease (4-14%) and three quarters of this figure is attributable to air quality. The individual's own living habits can be influenced, but the environment in which he or she lives can hardly be. Although the air quality in Europe and in the Netherlands has improved over the years, in many places it does not meet the World Health Organization's (WHO) guidelines, which were made more stringent in September 2021.

The impact of air pollution in urban areas

In a city, many sources of air pollution are present, such as traffic, domestic heating and industry, but much of the pollution originates from outside the city. Exposure to poor air quality has a negative influence on the health of city residents, particularly for vulnerable groups such as children, the elderly and people with underlying conditions. Besides the negative health effects, air pollution also causes considerable economic damage (e.g. sick leave). In terms of air quality, the geographic location of the city of Eindhoven is particularly unfavorable: the city is surrounded by industrial and agricultural areas, major roads and an airport.

Of all types of air pollution, particulate matter (PM) causes the most health damage. Health issues resulting from exposure to particulate matter are mainly manifested as cardiovascular and respiratory conditions; recently there has also been a lot of attention for the presumed causal relationship with an increased risk of infection and a more serious progression of COVID-19. It is well established that exposure to particulate matter causes health issues, but recently, it has also been shown that a reduction in exposure leads to an improvement in health. Moreover, it has been shown by several authorities that air quality policy is cost effective and has multiple socio-economic benefits.

Improvement of urban air quality is therefore an important focus area in policies with regard to 'healthy urbanization'. Eindhoven has been pursuing an active policy for years to improve the air quality, as a pilot city in the 'Smart and Healthy City' (Slimme en Gezonde Stad) program and recently as one of the municipalities participating in the national 'Clean Air Agreement' (Schone Lucht Akkoord, SLA)[1]. In line with the latter, the municipality announced its ambitions with regard to improvement of air quality in the Bidbook 'Health gains from cleaner air in 2030' (Gezondheidswinst door Schone Lucht in 2030)[2], with a range of measures aimed at achieving at least 50% health gains for the residents of Eindhoven.

Improvement of air quality at hotspots

Mounting scientific evidence and expanding market-experience increasingly enable the implementation of targeted and validated measures to reduce ambient particulate matter concentrations. In 2014, an air purification technology developed by ENS Clean Air was first experimentally applied in a parking garage in the municipality of Cuijk (the Netherlands). As a result:

- Substantial reductions of the particulate matter concentrations were measured inside the parking garage.
- Signals were received (from local shopkeepers and people living nearby) of reduced particulate matter pollution levels in the direct surroundings of the parking garage (as a result of lower particulate matter emissions through the parking garage's ventilation exhausts).

This gave rise to the idea of the implementation of air purification technology in existing infrastructure within the urban environment: **The 'Lungs of the City' approach**. In this approach, urban infrastructural facilities and buildings such as parking garages, traffic tunnels, public transport stations and street furniture serve as air-purifying Lungs in the City, with the aim of reducing particulate matter concentrations at locations where high concentrations coincide with a high degree of public exposure; the so-called hotspots (Figure 1).

Figure 1 — *The principle of the Lungs of the City as applied in an underground parking garage.*

Living Lab Eindhoven

In the Lungs of the City project, the center of Eindhoven served as a 'Living Lab' for research into large-scale implementation of air purification technology in the public environment. The key question being: **'What is the added value of targeted integration of air purification for the improvement of urban air quality?'** The study investigated to what extent particulate matter concentration can be reduced, during relevant periods, and how this translates into a reduction of health risk, an indicator which is of great importance for embedment of mitigation measures in (local) policies. This project was carried out by a consortium consisting of the municipality of Eindhoven, Eindhoven University of Technology, Air Liquide, and ENS Clean Air; and consisted of three phases:

Phase 1: Feasibility study (2015-2016)

Using airflow simulation, it was shown that the Lungs of the City approach has great potential (Figure 2). Particulate matter concentrations were reduced by 30 to 50% in the direct vicinity of parking garages and by 10% up to a distance of one kilometer. The results of this study were published in a peer-reviewed scientific journal[3].

Phase 2: Effect studies (2017-2018)

A temporary intervention setup was placed on the city hall square (Stadhuis-plein) in Eindhoven: an air purification setup removed particulate matter from the (ventilation) exhaust air, of the parking garage below the square, and then released the purified air over the square. Measurements were carried out on, and in the direct vicinity of the square, using high-end monitoring equipment for particulate matter concentrations and weather conditions. The results of this measurement campaign are being used for publications in peer-reviewed scientific journals[4,5]. Measurements showed that:

- Urban particulate matter mainly consists of the smaller, most harmful particulate fraction (PM_1) (legislation only applies to the coarser particulate fractions, PM_{10} and $PM_{2.5}$).
- There are large differences in local particulate matter concentrations between the various measurement locations (as a result of variations in building density and local flow phenomena).
- Very large differences in local particulate matter exposure occur, as a result of variations in traffic intensity.
- The particulate matter concentrations in the underground parking garage are substantially higher than the background concentrations in the city; active treatment of exhaust air from the parking garage contributes to reduced particulate matter exposure at street level.
- The particulate matter concentration in the parking garage's ventilation exhaust air can be substantially reduced by air purification (to below the background concentration); the parking garage is thus transformed into an air-purifying element.

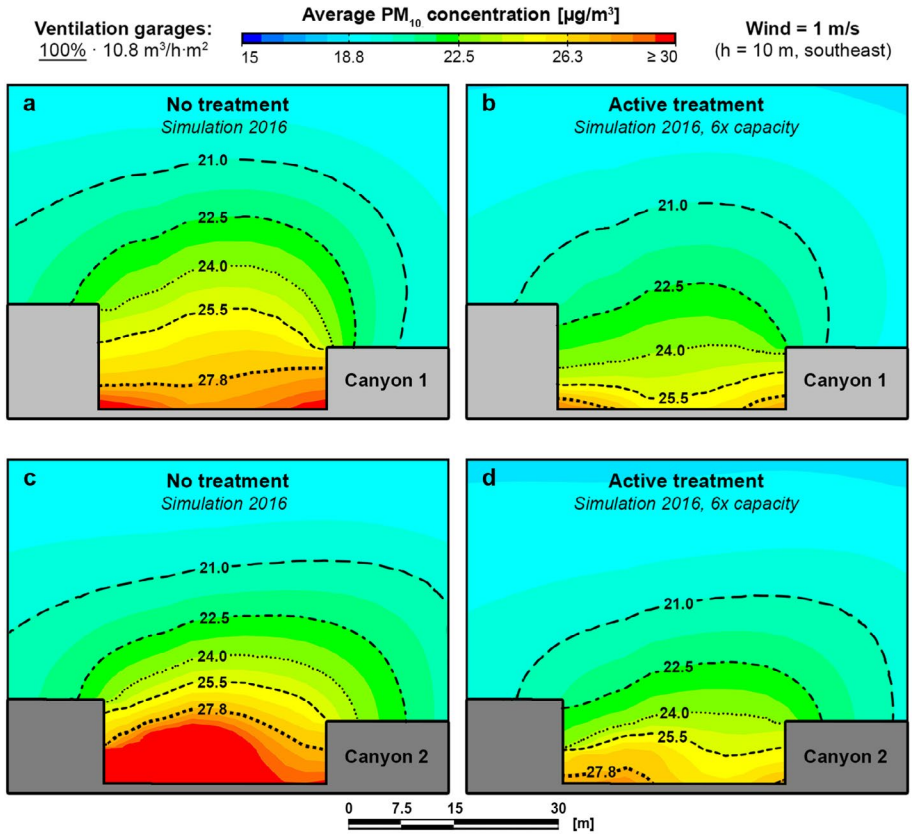

Figure 2 — PM_{10} concentrations in a vertical cross-section for a situation (a, c) without and (b, d) with the application of air purification in adjacent parking garages, at two different positions in a street canyon.

Phase 3: High-resolution computer models (2015-2021)

Throughout the project, high-resolution computer models were developed with which the effects of air purification interventions can be (virtually) determined. Implementation of the (measurement) results from the effect studies in Eindhoven and in other (pilot) projects led to a refinement of the 2016 feasibility study (phase 1). The required air purification capacity, as applied in the feasibility study, appeared to be over-estimated: The ambient air quality improvement, by means of air purification in parking garages, is achievable with only 55% of the originally calculated purification capacity (Figure 3). The results of these simulations are being used for publications in peer-reviewed scientific journals[5,6,7].

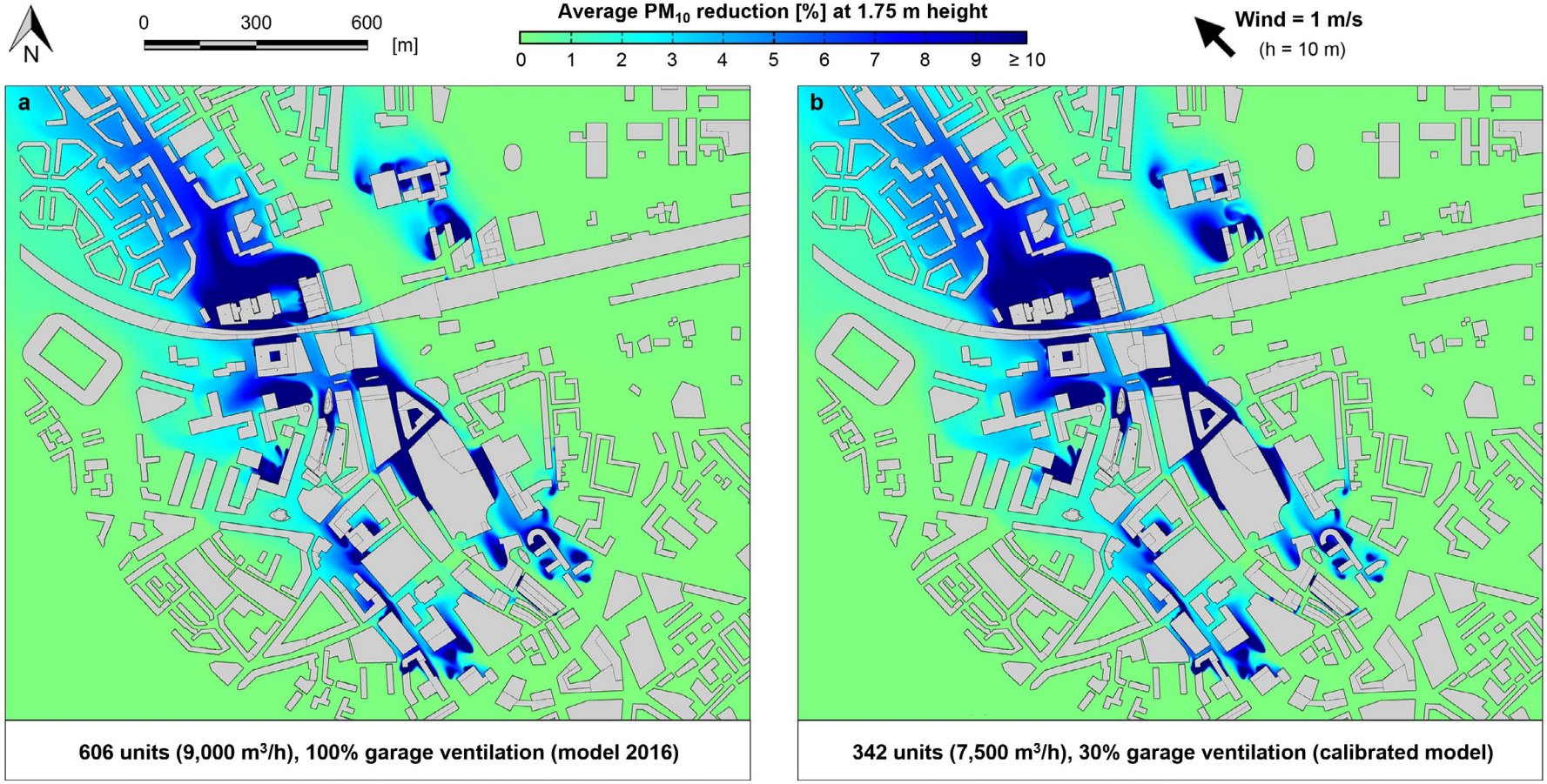

Figure 3 — *PM_{10} concentration reduction at 1.75 m height when applying (a) 606 Aufero systems in the 2016 model and (b) 342 Aufero systems in the recalibrated model.*

Reduced health risk

The project results show that Lungs of the City is a technically feasible strategy that can contribute to significant reductions in particulate matter exposure. The positive health effect of non-inhaled particulate matter can be quantified at a local level. Based on the absolute PM_{10} concentration reduction, which varies from about 0.5 to 10 µg/m³ in the study area, for the modeled scenario, the reduced exposure risk for the present population can be calculated. Application of the Environmental Health Risk (Milieu Gezondheids Risico, MGR) Indicator shows that the overall health risk can be reduced by 0.5 to 1.5 points in percentage (Figure 4). This may seem insignificant, but the 3-4% burden of disease, directly attributed to poor air quality, is reduced by about 25% in the study area.

Figure 4 — Health risk reduction percentage in accordance with the Environmental Health Risk (MGR) indicator as a result of air purification in 16 parking garages.

Broad range of applicability

The Lungs of the City concept can be integrated into the urban environment in many ways. Parallel to the Lungs of the City project in Eindhoven, several related research projects and impact studies (based on integration of active air purification in existing infrastructure) have been carried out worldwide, using airflow simulations and field measurements. This has resulted in extensive insight into the optimal use of air purification technology in a variety of applications (Figure 5). At area scale, air purification has been applied in traffic-intensive areas, such as next to a highway, in a traffic tunnel, in narrow city streets (street canyons), in a city park, in schoolyards and in vehicles such as street sweepers. At building scale, it concerns applications in various parking garages, train and metro stations, a bus terminal and the courtyard of a school building. Each individual application has a local effect. With more applications, cumulative effects can be achieved, which cover a larger area.

Air quality as instrument for urban development

Clean (urban) air is of pivotal importance to all stakeholders: citizens, governments, knowledge institutions and companies. The Lungs of the City concept can effectively complement national and regional air quality policies. Taking on local sources is the most effective way to limit the spread of harmful pollutants and to reduce exposure to local peak concentrations. However, most of the particulate matter originates from outside the city and is therefore not reduced by mitigating local emissions. **Integrated active air purification reduces the contribution of both local sources and background sources in local particulate matter concentrations**. Lungs of the City is therefore a meaningful addition to existing policies to improve urban air quality.

A maximum effect is achieved by targeting mitigation measures at 'hotspot' locations, where exposure risks are high. The overall effect of air purification was illustrated using a model-based approach in the Lungs of the City project in Eindhoven: It was demonstrated that targeted air purification results in substantially reduced health risk for the population. A calculation was made of the reduction in socio-economic costs for the population in the city center and surrounding neighborhoods. Also, a number of business models for financing such mitigation measures are discussed.

The importance of healthy urbanization is generally accepted and has been translated into actions and policies, all over the world. With the emerging insight into targeted implementation of the Lungs of the City approach, an important instrument has been added to the toolkit for increasing urban sustainability and improvement of the living environment. The city of the future can be self-purifying, and the first steps to make this achievable have been taken in Eindhoven.

[1] https://www.rijksoverheid.nl/documenten/convenanten/2020/01/13/bijlage-1-schone-lucht-akkoord

[2] Gemeente Eindhoven (2021) 50% Gezondheidswinst door Schonere Lucht in 2030 – Bidbook gemeente Eindhoven.

[3] Blocken B, Vervoort R, van Hooff T (2016) Reduction of outdoor particulate matter concentrations by local removal in semi-enclosed parking garages: A preliminary case study for Eindhoven city center, Journal of Wind Engineering and Industrial Aerodynamics 159:80-98 (doi: 10.1016/j.jweia.2016.10.008).

[4] Vervoort R, Jenniskens G, van Hooff T, Blocken B (*in preparation*) Full-scale measurements of spatiotemporal PM concentration distribution in the city center of Eindhoven and generalized implications for experimental assessment of PM mitigation strategies.

[5] Subject of a detailed study titled "Reduction of Particulate Matter concentrations by local removal in the city centre of Eindhoven: A full scale validation study", to be published later as part of PhD-research by R. Vervoort on flow phenomena in relation to air quality in urban areas.

[6] Vervoort R, van Hooff T, Blocken B (*in preparation*) Reduction of particulate matter concentrations inside semi-enclosed parking garages by means of active PM removal.

[7] Vervoort R, Gijsbers R, van Hooff T, Blocken B *(in preparation)* Large-scale reduction of particulate matter concentrations in urban environments: additional numerical analyses for the city center of Eindhoven.

[8] Suez Air Division, RATP, Air Parif. https://www.ratp.fr/groupe-ratp/newsroom/developpement-durable/la-region-ile-de-france-la-ratp-et-le-groupe-suez

[9] Studio Roosegaarde. https://www.studioroosegaarde.net/stories/smog-free-tower

[10] BlueWoods. https://www.skycleaner.rs/en/

[11] Suez Air Division. https://www.youtube.com/watch?v=EgZPfb7N9kw&feature=emb_logo

[12] Ravo Benelux. https://ravobenelux.fayat.com/nl/productassortiment/ravo/hygion

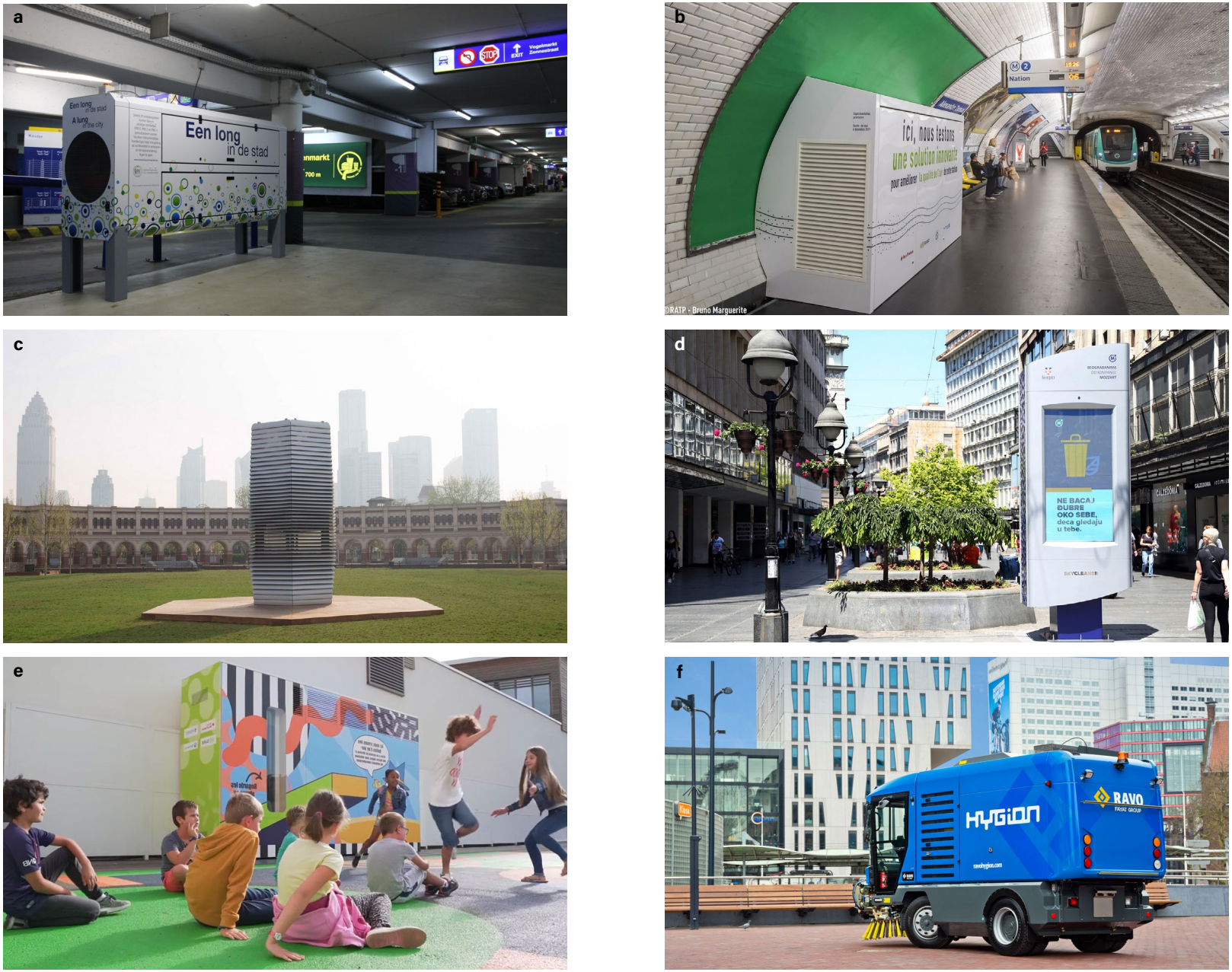

Figure 5 — *Integration of air purification in (a) Interparking parking garage Kouter in Ghent (Belgium), (b) Alexandre Dumas metro station in Paris (France)[8], (c) the Smog Free Tower in Tianjin (China)[9], (d) the Skycleaner in Belgrade (Serbia)[10], (e) the AirAvanced-InspiR in a schoolyard in Poissy (France)[11] and (f) the HYGiON street sweeper[12].*

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