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Proposed interventions to reduce noxious air pollution at Birmingham New Street station

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Birmingham New Street railway station in the UK has recently undergone a substantial redevelopment at a cost of more than £600 million. However, the unique underground tunnel geography of the platforms has remained virtually unchanged, which means that diesel exhaust gases are effectively trapped causing a daily build-up of air pollution in the station. A new ventilation system has been installed consisting of 98 bi-directional fans that are meant to disperse any air pollution out of the station. Unfortunately, the fans were triggered by carbon dioxide levels that do not significantly correlate with more serious air pollutants such as nitrogen oxides. In August 2018, new workplace exposure limits (WELs) were introduced for nitrogen monoxide (NO) and nitrogen dioxide (NO_2). However, during a recent measurement campaign, one of the new WELs would have been exceeded on most days. Network Rail has undertaken to introduce a number of interventions, including the installation of new nitrogen monoxide/dioxide sensors to drive the ventilation system together with new sonic wind sensors, encouraging train operating companies to switch off idling diesel engines and encouraging more electric/hybrid trains.

1. Introduction

The impact of air pollution on the health of workers and passengers in enclosed railway stations has been the subject of recent research in the UK where there is still a significant reliance on diesel trains (Thornes *et al.*, 2017). Diesel engine exhaust emissions (DEEE) are a complex mixture of chemicals and particles that vary depending on the engine type and exhaust system. Common to all diesel engines though is the emission of oxides of nitrogen (NO_x). Nitrogen oxides, while not a carcinogenic component of DEEE, do have effects on respiratory health that are concentration-related (Mills *et al.*, 2015; WHO, 2018a). This health risk led, in 2018, to the introduction in the UK of new workplace exposure limits (WELs) for nitrogen dioxide (NO_2) and nitrogen monoxide (NO, often called nitric oxide), which are both components of DEEE. There are also WELs for other constituents, including carbon monoxide (CO), carbon dioxide (CO_2) and formaldehyde, although there is no overall WEL for DEEE. It is employers who are responsible for managing the risk from exposure to DEEE and other hazardous substances to both workers and others who might be affected. In a station such as Birmingham New Street, in Birmingham, UK, the station owner and the train operators, who have employees working there, do have a legal duty, so far as is reasonably practicable, to manage the risks to health of their employees and users of the station (including passengers) from exposure to hazardous substances as specified by the Control of Substances Hazardous to Health Regulations 2002 (Coshh) (as amended) (HMG, 2002).

WEL values for nitrogen monoxide and nitrogen dioxide were recommended by the Scientific Committee on Occupational Exposure Limits in June 2014 (Scoel, 2014a, 2014b). They were included in the latest Health and Safety Executive (HSE) publication *EH40/2005 Workplace Exposure Limits* (HSE, 2018) following EU Commission Directive 2017/164 (EU, 2017), which established a fourth list of indicative exposure limit values for the health and safety of workers. These new WELs came into force in the UK on 21 August 2018 (ORR, 2018). WELs are expressed as time-weighted averages (TWAs) and there are normally two variations – the long-term exposure limit (LTEL), which is the maximum exposure permitted averaged over an 8 h period, and the short-term exposure limit (STEL), which is the maximum exposure permitted averaged over a 15 min reference period. The LTEL is designed to protect the workforce from concentrations of a substance that, over a long period of time, could cause long-term chronic ill-health effects. The STEL relates to peak exposure incidents and is designed to protect against immediate acute ill-health effects. A TWA is used where concentrations vary over time, as in an enclosed railway station as trains come and go. The current limit values for nitrogen monoxide and nitrogen dioxide are as follows.

- Long term. Nitrogen dioxide: 8 h LTEL 0·5 ppm (955 μg/m^3); nitrogen monoxide: 8 h LTEL 2·0 ppm (2500 μg/m^3).
- Short term. Nitrogen dioxide: 15 min STEL 1·0 ppm (1910 μg/m^3).

The evidence for these limit values relates to lung damage in the deep respiratory tract associated with both nitrogen monoxide and nitrogen dioxide (Scoel, 2014a, 2014b). Epidemiological studies have shown that symptoms of bronchitis in asthmatic children increase in association with exposure to nitrogen dioxide and reduced lung function growth is also linked to nitrogen dioxide (WHO, 2018a).

The Office of Rail and Road (ORR) is the national independent health and safety regulator for the UK rail network and associated activities. The HSE publication *Control of Diesel Engine Exhaust Emissions in the Workplace* (HSE, 2012) provides practical guidance to employers on how to conduct a simple health risk assessment on the likely impact of DEEE on employees and others (e.g. passengers) who may be affected by their work. For example, the HSE guidance suggests the use of carbon dioxide as a relatively cheap and easy-to-use marker for DEEE in the workplace. Values above 1000 ppm 8 h TWA can indicate faulty or poorly designed or maintained control systems (ORR, 2018). Hickman *et al*. (2018), however, showed that there is only a limited correlation between carbon dioxide and nitrogen dioxide at Birmingham New Street station.

As well as occupational health WELs there are also public health guideline levels such as the daily air quality index (DAQI), which is based on EU and World Health Organization (WHO) air quality standards (Defra, 2013). Although in law these levels do not currently apply for passengers in railway stations, the DAQI is a useful indicator, especially for vulnerable groups (old people, young children, pregnant women and people with asthma and other respiratory problems) of the level of air pollution to expect. Recently, the WHO outdoor guideline values for nitrogen dioxide (200 $\mu g/m^3$ (1 h average) and 40 $\mu g/m^3$ (annual average)) have been also confirmed as appropriate indoor guidelines (WHO, 2018b). This is particularly important for enclosed (effectively indoor) railway stations if the general public are to be encouraged to switch modes from private car to public transport. Encountering high levels of air pollution in a railway station can be considered a significant unwanted 'unintended consequence' of transport policy designed to reduce car traffic in low-emission urban zones.

A comparison of occupational and public health limit values suggests that occupational exposure levels are much higher than public health levels, although the reference periods are different. For nitrogen dioxide, the DAQI index gives a moderate threshold exposure level (TWA for 1 h) of 200 $\mu g/m^3$, which is much lower than the WEL 15 min limit of 1910 $\mu g/m^3$. This is because workers are considered to be fit and healthy compared with the more vulnerable general public. However, it is probable that if passengers are exposed to levels of nitrogen dioxide pollution greater than the WEL 15 min limit of 1910 $\mu g/m^3$ it could represent a major public health issue for vulnerable passengers with breathing difficulties such as asthma, bronchitis or chronic obstructive pulmonary disease. For outdoor air, the WHO states that, in the short term (1 h), for concentrations exceeding 200 $\mu g/m^3$, nitrogen dioxide is a toxic gas that causes significant inflammation of the airways (WHO, 2018a).

It is therefore appropriate to compare the observed levels of nitrogen monoxide and nitrogen dioxide air pollution at Birmingham New Street station with existing occupational health and public health guidelines. It is hoped that this will provide a benchmark that future improvements can be measured against.

2. Monitoring campaign at Birmingham New Street station

In order to carry out an appraisal of the air quality health risk exposure, an extensive monitoring campaign to measure air pollution levels in and around Birmingham New Street station was undertaken during the autumn and winter of 2016/2017 (Hickman *et al*., 2018). New Street station had recently undergone extensive redevelopment that was completed in September 2015, although some platform improvements continued for another year. The redevelopment included the installation of 98 impulse fans triggered by a similar number of carbon dioxide sensors (Thornes *et al*., 2017). This fan system, however, was not fully operational at the time of the monitoring, due to ongoing platform works. Further improvements are still underway as discussed below.

Diffusion tubes for the monitoring of nitrogen dioxide were deployed for four weeks during October and November 2016. All 12 platforms, the three passenger lounges and ten sites around the station were monitored. The long-term guideline annual average limit value set by the EU for nitrogen dioxide is 40 $\mu g/m^3$ and all sites significantly exceeded this value. The centre of platforms 2, 3, 10 and 11 had values exceeding 500 $\mu g/m^3$, while the blue and yellow lounges had values exceeding 300 $\mu g/m^3$ compared with values outside the station of 47–85 $\mu g/m^3$ (Hickman *et al*., 2018). Continuous 1 min monitoring of nitrogen monoxide and nitrogen dioxide was carried out for a total of 68 d during the period from 17 November 2016 until 23 January 2017 (Hickman *et al*., 2018).

Figure 1 shows the maximum 15 min and 8 h nitrogen dioxide average values in the middle of platforms 10/11 in comparison with the new occupational WELs. The new 8 h TWA of 955 $\mu g/m^3$ would have been exceeded on only 1 d; however the new 15 min STEL of 1910 $\mu g/m^3$ would have been exceeded on 26 out of the 68 days. On Christmas Day and Boxing Day there were no passenger trains, so the likely exceedance of 26 out of 66 days is close to 40%. Figure 2 suggests that the new 8 h TWA for nitrogen monoxide would have been exceeded on 57 out of the operational 66 days monitored, which translates to 86% of the days.

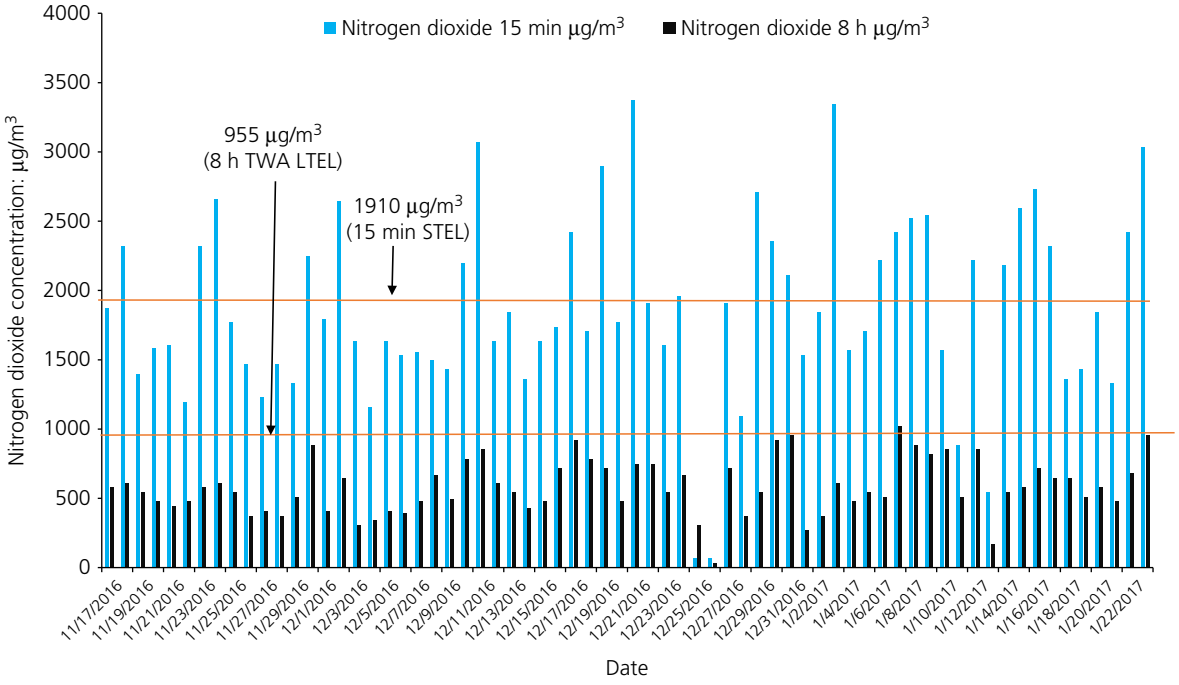

Figure 1. Retrospective assessment of nitrogen dioxide concentrations in Birmingham New Street station in comparison with the new WELs (26 out of 68 days had at least one 15 min exceedance of STEL). The figure shows the daily maximum 15 min average nitrogen dioxide concentrations and the maximum 8 h average nitrogen dioxide concentrations

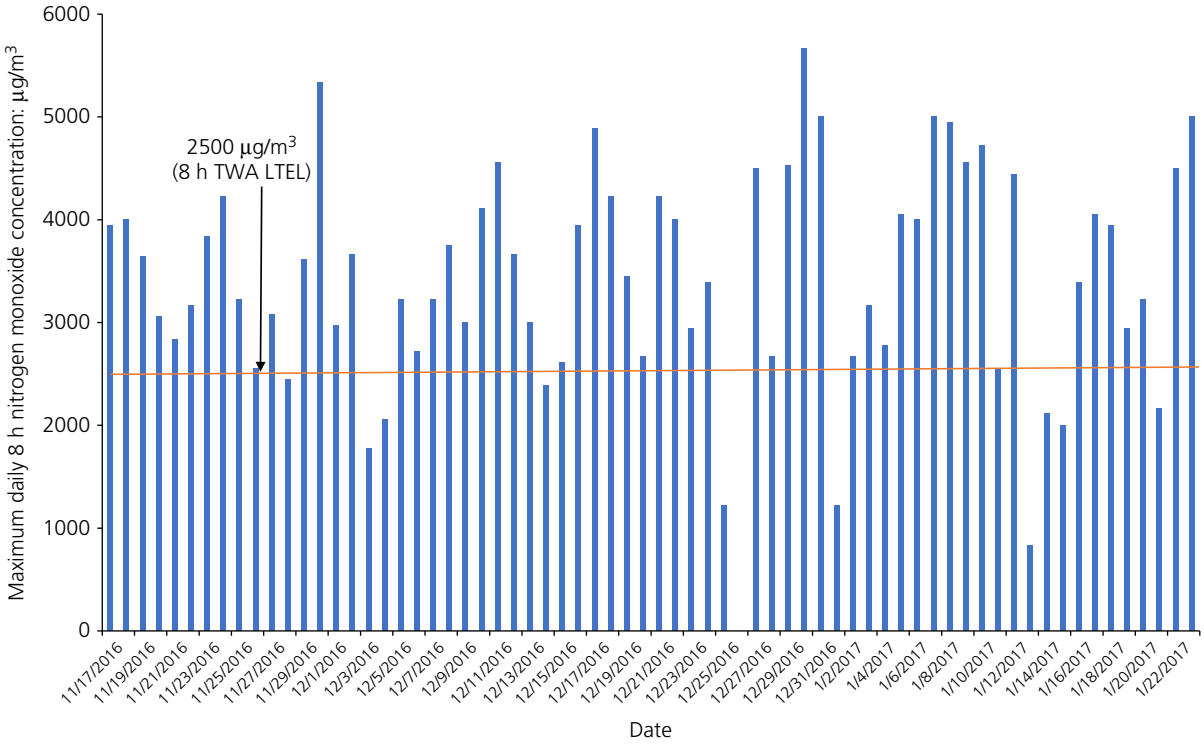

Figure 2. Retrospective assessment of daily maximum 8 h nitrogen monoxide concentrations in Birmingham New Street station in comparison with the new nitrogen monoxide WEL

These results from the continuous air quality monitoring at New Street station suggest the new WEL values for nitrogen oxides may have been frequently exceeded, which gives concerns for both occupational and public health.

Figure 3 shows the daily 1 h maximum DAQI for nitrogen dioxide. The figure shows that the value exceeded the 'very high' level 10 (600 μg/m^3) on 98·5% of the days (65 out of 66). For comparison, the equivalent Birmingham roadside measurements for Tyburn Road are shown – which were significantly lower.

Short-term exposure to nitrogen dioxide is associated with respiratory illnesses, mortality and hospital admissions (Mills *et al.*, 2015). Passengers frequently spend up to 15 min waiting on platforms for trains and regular commuters are potentially at long-term as well as short-term risk to their health. The Institution of Mechanical Engineers (IMechE) report *A Breath of Fresh Air* (IMechE, 2018: p. 20) states

> Over half (56%) of all trips by rail are for commuting and business purposes. Regular commuters encounter this air pollution [in enclosed railway stations] twice a day up to 250 days a year. Thus these travellers may experience short-term (acute e.g. asthma) and long-term (chronic e.g. bronchitis) health problems.

3. Proposed interventions by Network Rail

Following the measurement campaign at New Street station (Hickman *et al.*, 2018), Network Rail – in consultation with the ORR – introduced a number of interventions to reduce the levels of air pollution in the station. The ORR has published revised internal guidance (RIG) for their inspectors (ORR, 2018: p. 1).

> This RIG summarises the current evidence base on health risks associated with exposure to diesel engine exhaust emissions (DEEE) and advises inspectors about action to take in securing compliance with the Control of Substances Hazardous to Health Regulations 2002 (COSHH) (as amended) in respect of exposure to DEEE in the railway operating environment.

The ORR guidance outlines the range of controls that an employer needs to consider in achieving adequate control of DEEE under the Coshh regulations.

There are two major problems that are being addressed at New Street station – firstly, reducing the DEEE from the large number of diesel trains that are still operating in the station and secondly, ensuring that the ventilation system is working efficiently. Prevention is better than cure and the progressive removal of diesel-only trains should be the highest priority, with train operators and the Department for Transport (DfT) driving this change. However, while diesel trains remain in use, Network Rail, the train operators and their rolling stock suppliers need to continue to work together to limit DEEE in enclosed railway stations by both engineering and operational changes.

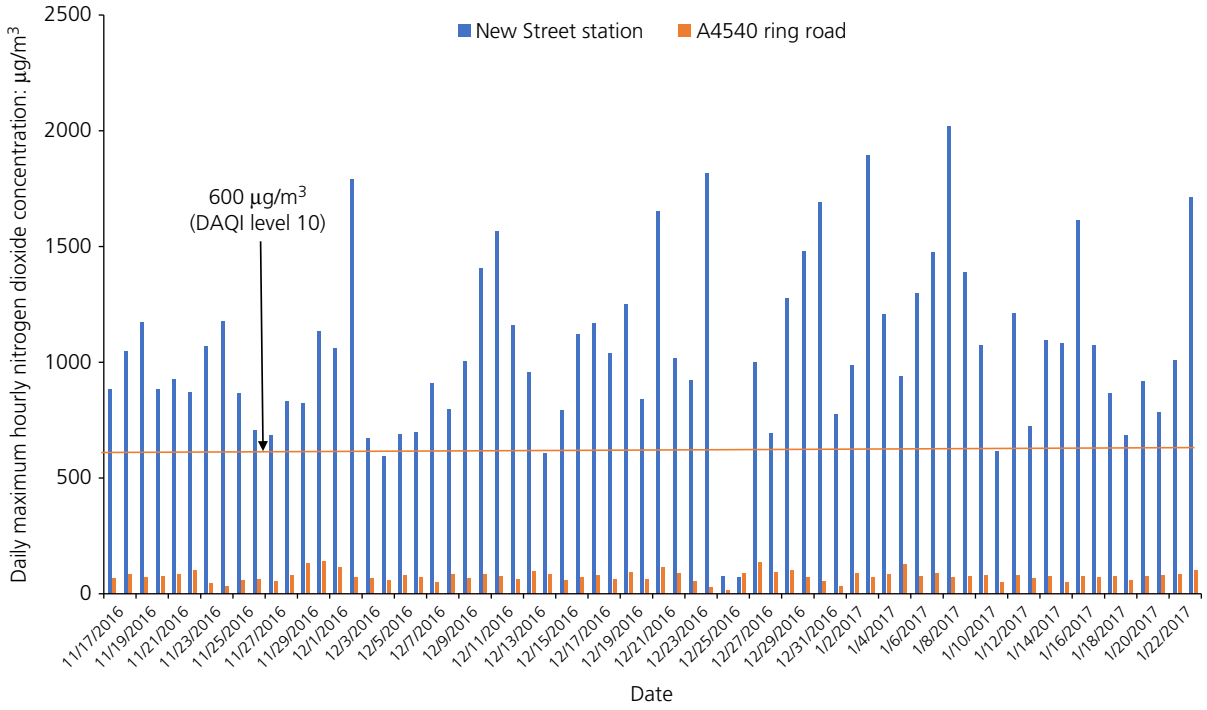

Figure 3. Retrospective assessment of the DAQI (65 out of 68 days exceeded DAQI level 10), showing nitrogen dioxide concentrations measured in Birmingham New Street station and on the Tyburn Road (A4540)

There are approximately 600 diesel train movements within Birmingham New Street station each day, representing about half of all train movements. Virtually all are passenger trains, with very few engineering or freight trains. None of the diesel trains are covered by the latest non-road mobile machinery regulations that control DEEE emissions (Hickman *et al*., 2018). Network Rail has therefore been liaising with train operating companies to explore the retrofitting of emission control equipment and, more urgently, to ensure that diesel train engines are switched off, whenever possible, to avoid idling in the station. A clear correlation between diesel train idling and levels of nitrogen oxides was highlighted by Hickman *et al*. (2018). This action will also reduce unwanted noise levels.

The ventilation system was recently installed (completed in 2015) to include 98 bi-directional fans. The fan speed and direction was controlled using carbon dioxide sensors and simple wind sensors. However, air quality monitoring results (Hickman *et al*., 2018) at New Street station suggest little correlation between the levels of carbon dioxide and nitrogen oxides, leading to a number of proposed design changes and the introduction of nitrogen oxides sensors. ORR's revised guidance captures and reflects this.

When using bi-directional fans it is important to take into account wind velocity so that the fans blow in the direction of the wind rather than against it. This requires the careful placement of permanent and reliable sonic wind sensors that control the ventilation system automatically.

Other proposed interventions at New Street station include the continuous running of the ventilation system at times of peak DEEE production, during the morning and evening rush hours. However, venting the DEEE into the city centre needs careful monitoring to ensure that sufficient mixing and dilution is taking place. Hickman *et al*. (2018) found elevated levels of nitrogen oxides outside the station even with minimal ventilation. Further monitoring around and within the station is required to estimate the impact, performance and effectiveness of the ventilation system and the contribution to outdoor nitrogen oxides concentrations from other potential nitrogen oxides sources such as diesel taxis.

The impulse fan enhancement project is still progressing with a revised computational fluid dynamics model due to commence that incorporates 103 new nitrogen oxides sensors as well as new carbon dioxide sensors, all of which will require additional careful maintenance. Upon completion of the modelling and a check of the outputs, it will then progress into the implementation phase during 2020. It is hoped that building management system integration will mean acquisition of real-time emission data to inform risk assessments of occupational exposures and adequacy of control of nitrogen oxides levels against the new WELs for short- and long-term exposure.

4. Other suggested interventions

There is an urgent need for a re-examination of the health risk exposure thresholds in enclosed railway stations combined with a need for accurate real-time measurements of the main DEEE constituents and other sources of air pollution. The IMechE recommends that the Department for Environment, Food and Rural Affairs should work with the DfT to introduce air quality monitoring equipment into enclosed railway stations as soon as possible in order to provide a benchmark for targeted future improvements in air quality (IMechE, 2018).

A reduced number of diesel trains using the station could be specified when new rail franchises are negotiated. For example, the Cross Country passenger rail franchise was up for renewal in 2019 (DfT, 2018a), although this has now been delayed. Currently, Birmingham New Street station is the major hub for Cross Country trains, which has a fleet of 92 diesel trains (five HST sets, 29 class 170 Turbostars, 34 class 220 Voyagers and 24 class 221 Super Voyagers) that have already served approximately two-thirds of their estimated working life of 30 years and do not meet the latest emission standards. Although more than half of the Cross Country network is not yet electrified, there are sections – such as Birmingham to Manchester – that are. The new franchise could insist on the use of a number of hybrid trains that could utilise the electric network where possible, to the benefit of air quality in Birmingham New Street, Manchester Piccadilly and other enclosed railway stations (DfT, 2018b). In the meantime, other franchises (Avanti Trains, West Midlands Trains and Arriva Trains) are experimenting with automatic engine shutdown, battery-powered station entry and departure, hydrogen trains, exhaust filters and new cleaner diesel trains that meet the latest EU specifications.

Further research to estimate the effectiveness of all the proposed interventions is currently underway.

5. Conclusions

Having considered a range of occupational and public health limit values for nitrogen monoxide and nitrogen dioxide, it is clear that the air quality at Birmingham New Street station, for both workers and passengers, needs significant improvement through effective interventions. It is hoped that the nitrogen monoxide and nitrogen dioxide measurements presented here can be considered as a benchmark for future improvements to be compared against. An enclosed railway station is unusual in that both workers and passengers are subject to the same air pollution and there are few other locations where this happens to such an extent. It is probable that if occupational exposure limit values are exceeded, particularly the 15 min STEL for nitrogen dioxide, then passenger health is potentially at risk.

It is imperative that levels of nitrogen monoxide, nitrogen dioxide and other air pollutants in enclosed railway stations are lowered to improve air quality. Practical interventions and

robust monitoring need to be instigated as soon as possible to meet both occupational and public health standards. Currently, improvements to the ventilation system within Birmingham New Street station have been implemented to improve air quality. However, in the long term, it is probably more important to reduce the sources of air pollution in enclosed railway stations than to rely uniquely on ventilation, which in turn could escalate a station's carbon dioxide footprint and noise levels.

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