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Review article

Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review

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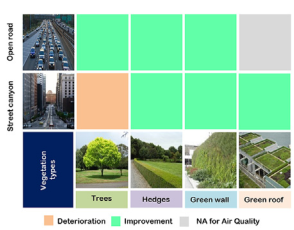
HIGHLIGHTS

- Green infrastructure can play a significant role in mitigating urban air pollution.
- Air quality changes in local built environments due to vegetation are assessed.
- Low-level hedges improves air quality in street canyons unlike high-level trees.
- Green green walls and roofs are effective to reduce pollution in streets/open roads.
- Prior design of green infrastructure should be performed for improving air quality.

GRAPHICAL ABSTRACT



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ABSTRACT

Intensifying the proportion of urban green infrastructure has been considered as one of the remedies for air pollution levels in cities, yet the impact of numerous vegetation types deployed in different built environments has to be fully synthesised and quantified. This review examined published literature on neighbourhood air quality modifications by green interventions. Studies were evaluated that discussed personal exposure to local sources of air pollution under the presence of vegetation in open road and built-up street canyon environments. Further, we critically evaluated the available literature to provide a better understanding of the interactions between vegetation and surrounding built-up environments and ascertain means of reducing local air pollution exposure using green infrastructure. The net effects of vegetation in each built-up environment are also summarised and possible recommendations for the future design of green infrastructure are proposed. In a street canyon environment, high-level vegetation

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Open roads
Urban trees and hedges
Green wall
Green roof

canopies (trees) led to a deterioration in air quality, while low-level green infrastructure (hedges) improved air quality conditions. For open road conditions, wide, low porosity and tall vegetation leads to downwind pollutant reductions while gaps and high porosity vegetation could lead to no improvement or even deteriorated air quality. The review considers that generic recommendations can be provided for vegetation barriers in open road conditions. Green walls and roofs on building envelopes can also be used as effective air pollution abatement measures. The critical evaluation of the fundamental concepts and the amalgamation of key technical features of past studies by this review could assist urban planners to design and implement green infrastructures in the built environment.

1. Introduction

Air quality in the built environment continues to be a primary health concern as the majority (i.e., 54% in 2014) of the world's population currently lives in urban areas, and this is projected to rise to 66% by 2050 (United Nations, 2014). Traffic emissions are the main source of air pollution in cities around the globe (Kumar et al., 2016, 2015, 2013). Green infrastructure in the built environment has been considered as one potential urban planning solution for improving air quality as well as enhancing the sustainability of cities for growing urban populations (Irga et al., 2015; Salmond et al., 2016). These green solutions include street trees, vegetation barriers (including hedges), green (or living) walls, and green (or living) roofs. These types of vegetation act as porous bodies which influence local dispersion patterns, and aid the deposition and removal of airborne pollutants (Escobedo and Nowak, 2009; Fantozzi et al., 2015; Janhall, 2015; Nowak, 2006; Yin et al., 2011). Apart from possible air pollution reduction, urban green infrastructure also provides benefits such as urban heat island mitigation (Chen et al., 2014; Gago et al., 2013), potential reduction in energy consumption (Berardi et al., 2014; Pérez et al., 2014) and noise pollution (Berardi et al., 2014; Cohen et al., 2014; Salmond et al., 2016), better stormwater management (Czemiel Berndtsson, 2010; Roy et al., 2012) and climate change mitigation (Matthews et al., 2015). In addition, eco-services provided by green interventions assist in improving the health and well-being of the urban population in several ways (Dean et al., 2011; Nowak et al., 2014; Tzoulas et al., 2007).

Road traffic emits a variety of harmful pollutants in the form of particulate matter – PM_{10} (particulate matter ≤ 10 μm), $PM_{2.5}$ (≤ 2.5 μm) and ultrafine particles (UFP; <100 nm) – and gaseous pollutants such as the nitrogen oxides (NO_x), carbon monoxide (CO) and in minor part sulphur dioxide (SO_2). As for the air pollution abatement performance of various types of green infrastructure, either individually or in combination, in different urban environments (Gallagher et al., 2015), the majority of studies have focused on pollutants such as the PM_{10} (Heal et al., 2012; Maleki et al., 2016), $PM_{2.5}$ (Ayubi and Safiri, 2017; Heal et al., 2012), UFP (Chen et al., 2016; Kumar et al., 2014), NO_x (Beevers et al., 2012; Michiels et al., 2012), CO (Bigazzi and Figliozzi, 2015; Chen et al., 2011), and black carbon (Li et al., 2016a; Rivas et al., 2017a,b) that have implications for the adverse health effects. In future, urban green infrastructure can be implemented as a passive air pollution control measure in cities through limited alterations in the built environment (McNabola, 2010). The urban environments accounted for in the studies reviewed here were either near an open road or in an urban street canyon with high traffic volumes. For example, the impact of trees in street canyons were examined by numerous studies (Abhijith and Gokhale, 2015; Amorim et al., 2013; Buccolieri et al., 2011, 2009; Gromke et al., 2008; Gromke and Ruck, 2007; Hofman et al., 2016; Li et al., 2013; Moonen et al., 2013; Salim et al., 2011a; Salmond et al., 2013; Vos et al., 2013; Wania et al., 2012: Jeanjean et al., 2017). These studies generally indicated that the presence of trees increases the pollution concentration in a street canyon. Other studies investigated pollutant exposure in street canyons with hedges and reported that low-level hedgerows generally reduces pollutant levels along the footpath (Gromke et al., 2016; Li et al., 2016b). Likewise, a few studies investigated the air pollution removal potential of vegetation along busy urban highways, reporting that vegetation barriers and trees along roads reduced roadside pollutant concentrations (Brantley et al., 2014; Hagler et al., 2012; Lin et al., 2016; Tong et al., 2016). A few studies also indicated that roadside vegetation can have adverse effects on air quality under certain conditions (Tong et al., 2015). Recently, Baldauf (2017) summarised the vegetation characteristics that influence the beneficial and adverse effects of roadside vegetation on near-road air quality. A number of past studies also examined the air pollution removal potential of green roofs and green walls (Joshi and Ghosh, 2014; Ottelé et al., 2010; Pugh et al., 2012) or the combinations of green infrastructure with other passive pollution control methods (Baldauf et al., 2008; Bowker et al., 2007; Tong et al., 2016; Baik et al., 2012; Tan and Sia, 2005). Overall, a general conclusion from these studies was that green infrastructure had both positive and negative impacts on air quality at street levels, depending on the urban and vegetation characteristics.

As summarised in Table 1, previous review articles on this topic have discussed particulate matter (PM) removal by vegetation (Janhall, 2015), the suitability of passive methods to reduce pollutant exposure (Gallagher et al., 2015), vegetation design characteristics for roadside applications (Baldauf, 2017, 2016; Baldauf et al., 2013) and pollutant deposition on plant canopies (Litschike and Kuttler, 2008; Petroff et al., 2008). Furthermore, previous reviews have focused on the benefits of urban infrastructure such as urban heat island mitigation from trees (Gago et al., 2013), thermal performance of green facades (Hunter et al., 2014) and energy aspects of green roofs (Saadatian et al., 2013). Recently, Berardi et al. (2014) published a state-of-the-art review on air pollution mitigation by green roofs. However, there is still a need to systematically review and summarise the individual findings of various published research studies on numerous types of green infrastructure that consider local air quality improvements in the diverse urban environment. Going beyond the scope of existing reviews on this topic, this article: (i) provides a detailed quantification of local scale aerodynamic effects and reduction potentials of urban vegetation such as trees, hedges, green wall and green roofs in both built-up (street canyon) and open road configurations, (ii) describes the individual and combined effects of the built environment, metrological and vegetation characteristics on neighbourhood air quality, (iii) identifies vegetation types and characteristics that result in the least pollutant exposure in various urban areas, and (iv) recommendations for deploying green