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Review article

Passive methods for improving air quality in the built environment: A review of porous and solid barriers

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HIGHLIGHTS

- Porous and solid barriers can act as passive methods for improving air quality.
- Experimental or modelling studies don't capture all complexities of dispersion.
- Passive barriers offer other benefits (shading, noise reduction, aesthetics, eco-system service).
- These passive barriers can be implemented as new or retrofitted from existing systems.
- Developing design guidelines is required before it is adopted by urban planners.

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ABSTRACT

Protecting the health of growing urban populations from air pollution remains a challenge for planners and requires detailed understanding of air flow and pollutant transport in the built environment. In recent years, the work undertaken on passive methods of reducing air pollution has been examined to address the question: "how can the built environment work to alter natural dispersion patterns to improve air quality for nearby populations?" This review brings together a collective of methods that have demonstrated an ability to influence air flow patterns to reduce personal exposure in the built environment. A number of passive methods exists but, in the context of this paper, are split into two distinct categories: porous and solid barriers. These methods include trees and vegetation (porous) as well as noise barriers, low boundary walls and parked cars (solid); all of which have gained different levels of research momentum over the past decade. Experimental and modelling studies have provided an understanding of the potential for these barriers to improve air quality under varying urban geometrical and meteorological conditions. However, differences in results between these studies and real-world measurements demonstrate the challenges and complexities of simulating pollutant transport in urban areas. These methods provide additional benefits to improving air quality through altering dispersion patterns; avenue trees and vegetation are aesthetically pleasing and provides cooling and shade from direct sunlight. Additionally, real-world case studies are considered an important direction for further verification of these methods in the built environment. Developing design guidelines is an important next stage in promoting passive methods for reducing air pollution and ensuring their integration into future urban planning strategies. In addition, developing channels of communication with urban planners will enhance the development and uptake of design guidelines to improve air quality in the built environment.

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1. Introduction

Vehicular emissions are the predominant source of air pollution in the majority of urban environments throughout the world (Kumar et al., 2013; Wang et al., 2008). Personal exposure to a large fraction of these pollutants occurs during individual commuting (Goel and Kumar, 2014, 2015; Knibbs et al., 2011), which is associated with adverse health impacts for both urban inhabitants (Pope et al., 2009) and built infrastructure (Kumar and Imam, 2013; Tiwary and Kumar, 2014). Airborne particulate matter (PM), including very small ultrafine particles (UFP, <1 μm) are such pollutants sourced from vehicles' exhaust emissions (Kumar et al., 2010), and has made the issue of air pollution exposure in cities worldwide even more challenging (Kumar et al., 2014). To improve air quality in the built environment, three approaches outlined by McNabola et al. (2013) may be considered: (i) controlling the quantity of pollution (g), (ii) controlling the emission intensity (g km^{-1}), and (iii) controlling source-receptor pathways (g m^{-3}). Each method provides its own benefits for improving air quality. The combination of these strategies requires a framework to ensure their successful implementation (Roumboutsos and Kapros, 2008).

As urban populations continue to grow, and the majority of people now live in urban areas (United Nations, 2009), methods to improve air quality in the built environment have become more important than ever before. The implementation of emission standards to reduce urban pollution will take years to achieve desired results. Removing vehicles from urban areas to create zero pollutant emission zones is also not an easy option for most urban areas. Therefore, alternative solutions such as implementing passive methods for improving air quality and reducing personal exposure must be considered (McNabola, 2010).

In the case of vehicle emissions, altering the pathway between the pollutant source and receptor can reduce the concentration of personal exposure for pedestrians (Garcia et al., 2014). Pollutants emitted from a vehicle can behave differently in the atmosphere and therefore distinct processes exist for each pollutant (De Nevers, 2000). For example, De Nevers (2000) discusses the behaviour of some primary pollutants that react with other gases to create secondary pollutants, while others remain in an inert state and are dispersed by local meteorological conditions. In an urban context, increasing the distance between the source and receptor can reduce personal exposure to vehicular emissions, where transport emissions is considered the predominant source of pollution in the built environment (Kaur et al., 2005; King et al., 2009; Zhao et al., 2004). Segregating vehicles and pedestrians by increasing the number of pedestrianised streets is another solution (Briggs et al., 2008), yet this is a solution that requires substantial planning and can lead to new pollutant hotspots. More recently, McNabola (2010) reported that literature in the area of the passive methods for reducing personal exposure and presented evidence for research opportunities to improve air quality through altering local dispersion patterns.

A significant amount of research has taken place in the past decade on passive methods that can improve urban air quality, with each method presenting a unique solution to the challenge. These methods have included forms of porous (trees and vegetation) and solid (noise barriers, low boundary walls, and parked cars) barriers (McNabola, 2010). Considering this relatively new area of research, this review article outlines the future potential for these methods for improving urban air quality and suggests how they can be incorporated in future urban planning strategies. In addition to methods for controlling the quantity or intensity of emissions, passive methods to improve urban air quality offer a potential long-term solution to urban air quality. As most of these barriers are existing components in the built environment, implementing or retrofitting these systems presents a potentially low cost option compared to other methods. This paper examines the effectiveness and suitability of these methods to optimise local dispersion patterns and provide potential solutions for reducing personal exposure.

2. Passive methods for improving air quality

A range of passive methods have been identified to reduce personal exposure to primary pollutant concentrations in the built environment (Table 1).

These mechanisms can improve air quality and provide healthier conditions for urban dwellers (Amorim et al., 2013a; McNabola, 2010). This study focused on relevant publications from the least ten years, specifically dealing with the impact of passive methods that impact specifically on pollutant dispersion to potentially improve air quality in the built environment.

These passive methods are grouped either as a porous or solid barrier, based on its ability to either partially or fully act as a baffle between a pollutant source and individual or a group of receptors (McNabola, 2010). The passive barriers can protect human health by influencing localised dispersion. Reducing pollutant concentrations is dependent on local meteorological conditions and the geometry of the built environment. The findings from this review presents comparative and contrasting results that provide an evidence base for the true effectiveness of passive methods to improve urban air quality.

3. Porous barriers

Green infrastructure offers a porous media that can provide a barrier between traffic emissions and nearby populations, potentially benefiting urban air quality by influencing localised turbulence and altering natural dispersion patterns. In addition, these porous barriers promote filtration and deposition of pollutants, particularly different sizes of airborne particulates, thus affecting local pollutant concentration in a different manner to gaseous pollutants (Janhäll, 2015). They also provide an aesthetically pleasing component amidst the colder building facades.

3.1. Trees and vegetation

Trees and vegetation affect localised pollutant deposition and offer additional benefits of filtering out particulate pollutants (Fig. 1). Previous investigations have explored and quantified the macro-scale impacts of trees and vegetation on air pollution in the built environment (Janhäll, 2015; Nowak et al., 2006; Setälä et al., 2013; Tallis et al., 2011; Vos et al., 2013). Janhäll (2015) recently reviewed the literature on vegetation effects on urban and local-scale for a range of particulate concentrations, noting the ability for vegetation to remove PM pollutants through dispersion and deposition. This paper focuses primarily on micro-scale impacts of urban green infrastructure, either as avenue trees or hedgerows in a street canyon or arterial roads or highways with mixed roadside vegetation.

Janhäll (2015) reviewed multiple studies that measured changes in pollutant concentrations in the presence of vegetation at both urban and local scales: eleven modelling investigations, six wind tunnel experiment studies, six sets of field experiments, with several studies adopting a combination of modelling and field measurements. These studies examined a range of particulate and gaseous pollutants and details relating to the details focused upon it each study is outlined in Table 2.