Atmospheric Environment 139 (2016) 75–86

Contents lists available at ScienceDirect

Atmospheric Environment

journal homepage: www.elsevier.com/locate/atmosenv

Influence of roadside hedgerows on air quality in urban street canyons

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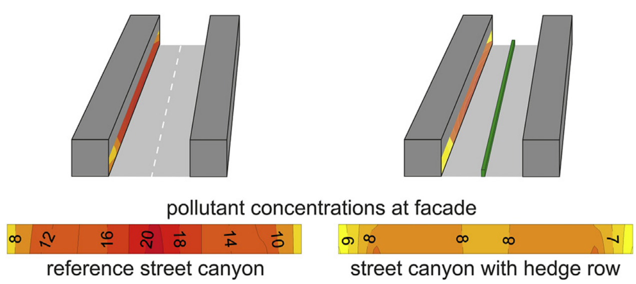
HIGHLIGHTS

- Hedgerows can improve air quality on footpaths and at facades in urban street canyons.
- One central hedgerow leads to greater improvements than two sidewise hedgerows.
- Hedgerows should extend over the entire length of the street canyon without clearings.
- Hedge height and hedge permeability (porosity) influence strength of improvement.
- Greatest improvements in canyon center when approach wind is perpendicular.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 21 January 2016
Received in revised form
5 May 2016
Accepted 9 May 2016
Available online 10 May 2016

Keywords:
Pollutant dispersion
Traffic emissions
Pollutant exposure
Urban vegetation
Urban greening
Porous barriers

ABSTRACT

Understanding pollutant dispersion in the urban environment is an important aspect of providing solutions to reduce personal exposure to vehicle emissions. To this end, the dispersion of gaseous traffic pollutants in urban street canyons with roadside hedges was investigated. The study was performed in an atmospheric boundary layer wind tunnel using a reduced-scale (M = 1:150) canyon model with a street-width-to-building-height ratio of $W/H = 2$ and a street-length-to-building-height ratio of $L/H = 10$. Various hedge configurations of differing height, permeability and longitudinal segmentation (continuous over street length L or discontinuous with clearings) were investigated. Two arrangements were examined: (i) two eccentric hedgerows sidewise of the main traffic lanes and (ii) one central hedgerow between the main traffic lanes. In addition, selected configurations of low boundary walls, i.e. solid barriers, were examined. For a perpendicular approach wind and in the presence of continuous hedgerows, improvements in air quality in the center area of the street canyon were found in comparison to the hedge-free reference scenario. The pollutant reductions were greater for the central hedge arrangements than for the sidewise arrangements. Area-averaged reductions between 46 and 61% were observed at pedestrian head height level on the leeward side in front of the building for the centrally arranged hedges and between 18 and 39% for the two hedges arranged sidewise. Corresponding area-averaged reductions ranging from 39 to 55% and from 1 to 20% were found at the bottom of the building facades on the leeward side. Improvements were also found in the areas at the lateral canyon ends next to the crossings for the central hedge arrangements. For the sidewise arrangements, increases in traffic pollutants were generally observed. However, since the concentrations in the end areas were considerably lower compared to those in the center area, an overall improvement remained for the street canyon. The configuration of a sidewise arranged discontinuous hedgerow resulted in general in area-averaged increases in concentrations in the range of 3–19%. For a parallel approach wind, reduced

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http://dx.doi.org/10.1016/j.atmosenv.2016.05.014

concentrations of up to 30% at the facades and up to 60% at pedestrian level were measured with a sidewise continuous hedgerow arrangement. It is concluded that continuous hedgerows can effectively be employed to control concentrations of traffic pollutants in urban street canyons. They can advantageously affect the air quality at street level and can be a significant remedy to the pedestrians' and residents' exposure in the most polluted center area of a street canyon.

1. Introduction

Urban street canyons with high traffic volume are frequently problematic in terms of air quality. Natural ventilation is limited and traffic emissions accumulate in their lower part and in particular at street level. As a consequence, pedestrians and residents are exposed to high levels of traffic pollutant concentrations with adverse health effects. Besides direct reductions of traffic emissions, passive pollutant control measures are considered suitable for remedy. In this context, solid and porous structures in urban street canyons (low boundary walls, noise protection walls, on-street parking cars, trees, shrubs, hedges), which affect flow and dispersion are increasingly discussed (see McNabola (2010) and the review articles by Gallagher et al. (2015) and Janhäll (2015) for a general overview). The effect of these structures in street canyons on air quality can be positive as well as negative. Janhäll (2015) pointed out that while low vegetation, e.g. hedges, can filter out particulate matter (PM) because of its proximity to the emission sources, high vegetation, e.g. trees, reduces the mixing and dilution with clean air from aloft and results in increased concentration levels.

The impact of avenue trees in urban street canyons on air quality was investigated in numerous studies in the recent years (Abhijith and Gokhale, 2015; Amorim et al., 2013; Balczo et al., 2009; Buccolieri et al., 2011, 2009; Gromke, 2011; Gromke et al., 2008; Gromke and Blocken, 2015a, 2015b; Gromke and Ruck, 2012, 2009, 2007; Gross, 1997; Jin et al., 2014; Li et al., 2013; Moonen et al., 2013; Ries and Eichhorn, 2001; Salim et al., 2011; Salmond et al., 2013; Vos et al., 2013; Vranckx et al., 2015; Wania et al., 2012). In general, these studies found increased concentrations of traffic pollutants in street canyons with avenue trees whose crowns hindered natural ventilation and reduced the air exchange with the surroundings. Gromke and Ruck (2012) report on wind tunnel experiments with a generic street canyon model: Depending on the wind direction, average and peak increases in concentrations at the leeward wall amount to up to 146 and 205%, respectively, in comparison to the tree-free situation. By their field measurements in an urban street canyon in Auckland, New Zeeland, Salmond et al. (2013) revealed a marked influence of leafed trees on the vertical exchange of traffic emissions and increased NO_2 concentrations in and below the crown layer. In a case study, Vranckx et al. (2015) found that the trees in a busy street canyon in Antwerp, Belgium, caused an annual average increase of 8% in elemental carbon and of 1.4% in PM_{10} from traffic emissions.

Investigations of the effect of elongated solid and porous barriers (noise protection walls, vegetation strips) on the dispersion of traffic pollutants were mainly performed at roadsides outside central urban areas or along highways (Al-Dabbous and Kumar, 2014; Baldauf et al., 2008; Bowker et al., 2007; Hagler et al., 2012; Steffens et al., 2012; Tiwary et al., 2008). These studies mainly focused on the effects of barriers on particulate matter dispersion. Their potential to affect particle number, mass and size distribution was examined. Bowker et al. (2007) found lower downwind concentrations for a combination of a noise protection wall with vegetation in comparison to the solid wall only. Baldauf et al. (2008), in general, measured reductions in concentrations of carbon monoxide and PM in the range of 15–50% in the lee of noise protection walls. However, increased concentrations were observed behind the barriers for certain meteorological conditions. Hagler et al. (2012) found reductions in ultrafine particle (UFP) concentrations behind a noise protection wall of also up to 50% but state that the effects of vegetation barriers were inconclusive since in some cases higher UFP concentrations were measured in their lee. Solid barriers in urban street canyons such as on-street parking cars or low boundary walls and their effect on the dispersion of traffic pollutants were addressed in numerical and field studies (Abhijith and Gokhale, 2015; Gallagher et al., 2013, 2012, 2011; King et al., 2009; McNabola, 2010; McNabola et al., 2009, 2008). These studies revealed that roadside solid barriers can act as baffle plates which redirect the flow and thereby affect the dispersion at street level. They can result in increased as well as in decreased concentrations depending on the approach wind direction, canyon geometry and barrier position. For on-street parking cars, the effect depends additionally on the parking angle. Under perpendicular wind conditions, Gallagher et al. (2011) and Abhijith and Gokhale (2015) for parallel parking report reductions in pedestrian exposure of 49 and 28%, respectively, and for angle parking increases of 28 and 34%, respectively. In a symmetrical street canyon with central low boundary wall, reductions on the footpath of up to 40% under perpendicular wind and of up to 75% under parallel wind were found by McNabola et al. (2009). However, in asymmetrical street canyons with different building heights, low boundary walls resulted in increases of up to 19% and in decreases of up to 50% at pedestrian level (Gallagher et al., 2012).

Regarding the impact of low vegetation such as shrubs or hedges inside urban street canyons on the dispersion of traffic pollutants, however, appropriate investigations are missing. Few studies examined the effect of rather wide shrub greenbelts on the dispersion of PM in urban roads flanked by low-rise buildings (Chen et al., 2015; Shan et al., 2007). Shan et al. (2007) studied the effect of 15 m wide shrub greenbelts on both sides of a road in Shanghai, China. For total suspended particulates (TSP), they measured removal efficiencies between 30 and 65%. Chen et al. (2015) investigated 2.5–3.5 m wide shrub greenbelts along streets in Wuhan, China. PM_{10} removal efficiencies between 7 and 10% were found for shrubs with heights smaller than 1.60 m. In a recent study Li et al. (2016) measured carbon monoxide (CO) concentrations next to a road in Shanghai, China. In street sections which were flanked by hedgerows and trees, reductions in CO concentrations ranging from 24 to 53% were found on the footpath and bicycle way compared to vegetation free sections. However, a comparison with slender hedgerows in urban street canyons is limited since in the above mentioned studies, the greenbelts were rather wide or in combination with trees.

The preceding survey of existing investigations reveals a knowledge gap regarding the impact of roadside hedges on air quality in urban street canyons. Low and slender vegetation strips such as hedges in urban street canyons have received little