Silva Balcanica 22(2):17-24 (2021)
doi: 10.3897/silvabalcanica.22.e69245

RESEARCH ARTICLE

Possible benefits from greening of public transport stops in Sofia, Bulgaria

Mariam Bozhilova, Miglena Zhiyanski

Forest Research Institute, Bulgarian Academy of Sciences, 132, "St. Kliment Ohridski" Blvd.1756 Sofia, Bulgaria

Corresponding author: Mariam Bozhilova (mariam@bozhilova.bg)

Academic editor: Margarita Georgieva | 28 May 2021 | Accepted: 29 June 2021 | Published 27 July 2021

Citation: Bozhilova, M., M. Zhiyanski (2021) Possible benefits from greening of public transport stops in Sofia, Bulgaria, Silva Balcanica 22(2): 17-24. https://doi.org/10.3897/silvabalcanica.22.e69245

Abstract

Public transport shelters provide an unused surface that can be utilised in various ways, including for unconventional landscaping. The benefits from greening of public transport shelters are insufficiently studied and unutilised. The article evaluates some of the advantages, which may result from the construction of green public transport shelters in the central part of Sofia.

There are a total of 2780 aboveground public transport stops in Sofia. In the surveyed area were located 257 stops, 150 of which had shelters at the time of the study. The potential of greened shelters to remove PM_{10} and CO_2 from the ambient air was estimated for several different scenarios. If 250 public transport shelters had been entirely greened (roof and three walls) with *Festuca* sp., the removed PM_{10} would have been about 20 kg/yr., or 0.01% of the yearly emissions of PM_{10} from transport in the surveyed area. The sequestered CO_2 would have been 17047.3 kg /yr., or approximately the CO_2 emitted by 40 diesel cars with an average daily mileage of 10 km per day for a year. The reduction of PM_{10} and CO_2 was not significant, however, in a big city with intensive construction and a constantly increasing population, every possibility for greening needs to be explored. Green stops may be used in combination with other measures. Proper selection of plant species and design solutions maximising the green surface will increase the benefits.

Keywords

CO_2 sequestration, green roofs, PM_{10}, public transport stops, urban areas

Introduction

According to the definition of the European Commission (2013), green infrastructure is a strategically planned network of natural and semi-natural areas with environmental features designed and managed to deliver a wide range of ecosystem services. It can enhance urban resilience through specifically promoting ecosystem services linked to reduced flooding risk, urban heat island reduction, improved air quality, reduced energy consumption in buildings, carbon storage, conservation of wildlife habitat and the provision of recreation and leisure amenities that improve the well-being of urban residents (Zuniga-Teran et al., 2020). This makes green infrastructure an increasingly promoted tool for mitigation of the negative impacts of urbanisation. It can be difficult to create new or even to maintain the existing green spaces in some urban areas as population density grows and essential housing increases. For this reason, green infrastructure needs to be planned as a creative combination of natural and artificial structures designed to achieve specific resilience goals (Staddon et al., 2017). In the most densely built-up areas, unconventional green spaces may be used to provide the benefits of green infrastructure.

Public transport plays an important role in the life of every big city. Its stops are relatively evenly distributed throughout the city, along the main roads and, often, in places with high levels of air pollution. Right after a bus stop, concentrations of pollutants, such as nitrogen oxides (NO_x) and particulate matter (PM), are high, followed by a decline due to higher emissions during the speed acceleration and lower emissions during cruise and de-acceleration (Xing et al., 2019). Bus stops can lead to the formation of convoys of cars after a stopped vehicle and, thus, lead to increased pollution before the stop. Neighbourhoods with more bus routes and bus stops show higher PM_{10} concentrations (Park et al., 2018).

Public transport shelters are commonly considered just as functional elements of the transport system. Their design is based on technical parameters and standardisation. Public transport shelters are neglected by urban designers and by the scientific debate (Brovarone, 2021). They are an unused surface that can be utilised in various ways, including building unconventional landscaping with a number of ecosystem functions. Greening of public transport shelters is already a fact in some cities in Europe, including Amsterdam, Utrecht, Eindhoven (the Netherlands), Sheffield, London (England), etc. In Utrecht, 316 bus stops are greened with *Sedum* sp. to improve the air quality and promote pollination (Benoliel et al., 2021). In Bulgaria, there are green public transport shelters in Stara Zagora (one shelter) and Burgas (two shelters). However, green public transport stops are still a rare element of the urban environment. The possible benefits are insufficiently studied and unutilised.

Sofia is the capital and largest city of Bulgaria. The significance of the city's green system is recognised and reflected in series of urban plans since 1880 (Kovachev et al., 2012). The intensive development of Sofia in the recent decades attracts resources to the city, but also puts serious pressure on the available space and public services (Vision for Sofia, 2020).

The centre of the city is classified as an area with adverse conditions and atmospheric pollution above the maximum permissible concentration from transport and domestic sources (Mihailovich et al., 2009). All air quality monitoring stations in the city report exceedances in terms of total suspended dust and fine dust particles. Road transport is a serious problem as a source of air pollution due to the high motorisation of the city and inadequate road infrastructure (Mihailovich et al., 2009). The decreasing coverage of green areas in combination with intensive construction in Sofia causes serious problems (Deneva et al., 2008). It is necessary to assess existing opportunities for unconventional landscaping, especially in the city centre.

In the article are evaluated some of the possible benefits from the construction of green public transport shelters in the central part of Sofia. Based on data on the existing aboveground public transport stops and the dimensions of the most common shelters, the amount of PM_{10} and CO_2 that can be removed from the air in the implementation of several different scenarios of greening is calculated. Recommendations are given to increase the benefits.

Materials and methods

The survey covers the central part of Sofia with an area of 891.5 ha (Fig. 1). The location of aboveground public transport stops is extracted from Open Street Map. The information is verified and supplemented using the Street View function of Google Earth and field checks. The dimensions of two of the most widely used shelter types in the survey area are measured and used to calculate the area which can be greened.

The yearly amount of PM_{10} from transport in the survey area is calculated based on UCTM (2015). The potential yearly reduction of PM_{10} and CO_2, which may result from the greening of shelters, was calculated for the greening of 50, 100 and 250 public transport shelters from the two measured shelter types, based on records of other authors. For each type calculations were made for greening with *Sedum* sp. and *Festuca* sp. for four different greening scenarios: greening of the roof only; greening of the roof and the back wall; greening of the roof, the back wall and one of the side walls; greening of the roof, the back wall and the two side walls.

Results and discussion

There are a total of 2780 aboveground public transport stops in Sofia. They are located along the busiest roads with the heaviest traffic, including places with high levels of air pollution. In the survey area are located 257 public transport stops (Fig. 1). About 150 of them currently have shelters.

Two of the most widely used shelter types in the city are with length/width/height respectively 370/150/230 cm and 470/150/230 cm. The area which can be greened in four different greening scenarios (greening of the roof only; greening of the roof and

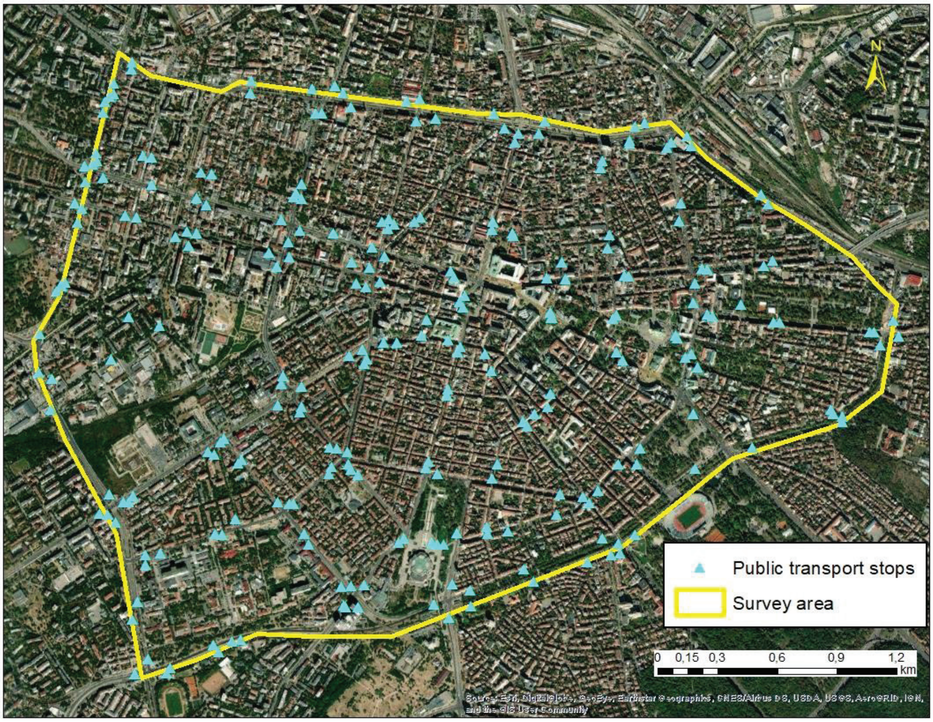

Figure 1. Aboveground public transport stops in the central part of Sofia.

Table 1. Area available for greening per public transport shelter.

Dimensions	Area (m^2)			
	Roof	Roof + back wall	Roof + back wall + 1 side wall	Roof + back wall + 2 side walls
370x150x230	5.55	14.06	17.51	20.96
470x150x230	7.05	17.86	21.31	24.76

the back wall; greening of the roof, the back wall and one of the side walls, greening of the roof, the back wall and the two side walls) is given in Table 1.

The yearly amount of PM_{10} from transport in the survey area is about 150 t/yr. (calculated based on UCTM, 2015). There are no specific surveys of the influence of green public transport stops on air quality. However, studies of green roofs have shown that depending on the used plant species, PM_{10} reduction may vary from 0.42 g/m^2.yr. for roofs greened with *Sedum album* to 3.21 g/m^2.yr. for roofs, greened with *Festuca rubra* (Speak et al., 2012). According to Yang et al. (2008), short grass can reduce 1.12 g/m^2.yr., while tall herbaceous plants can reduce 1.52 g/m^2.yr. The potential amount of PM_{10} that can be removed from the air in different scenarios of greening is given in Table 2.

Table 2. PM10 removed by greened public transport stops (g/yr.).

Number of greened shelters	PM_{10} reduction (g/yr.)			
	Roof	Roof + back wall	Roof + back wall + 1 side wall	Roof + back wall + 2 side walls
Sedum sp., 370x150x230				
1	2.3	5.9	7.4	8.8
50	116.6	295.3	367.7	441
100	233.1	590.52	735.4	882
250	582.8	1476.3	1838.6	2205
Sedum sp., 470x150x230				
1	3	7.5	9	10.4
50	148.1	375.1	447.5	520
100	296.1	750.1	895	1039.9
250	740.3	1875.3	2237.6	2599.8
Festuca sp., 370x150x230				
1	17.8	45.1	56.2	67.3
50	890.8	2256.6	2810.4	3370.5
100	1781.6	4513.3	5620.7	6741
250	4453.9	11283.2	14051.8	16852.5
Festuca sp., 470x150x230				
1	22.6	57.3	68.4	79.5
50	1131.5	2866.5	3420.3	3974
100	2263	5733	6840.5	7948
250	5657.6	14332.7	17101.3	19869.9

One public transport shelter with a length of 470 cm, entirely greened with *Sedum* sp., can remove about 9 g PM_{10}/yr. If 250 of these shelters are greened with *Sedum* sp. the removed PM_{10} will be about 2.6 kg/yr. If they are greened with *Festuca* sp. the removed PM_{10} will be significantly higher – about 20 kg/yr. This equals 0.01% of the yearly emissions in the survey area or the PM_{10} emitted from transport in the survey area for less than a day.

According to Kuronuma et al. (2018), the annual CO_2 sequestration of *Sedum aizoon* is 1.232 kg/m^2.yr. and of *Festuca arundinacea* – 2.754 kg/m^2.yr. The potential amount of CO_2 that can be removed from the air in different scenarios of greening is given in Table 3.

According to Fontaras et al. (2017), the average European vehicle emits 119.2 g/km/diesel fuel and 122.7 g/km/petrol. This means that one 470 cm-long public transport shelter greened with *Sedum* sp. can sequester the CO_2 emitted by a diesel car for a mileage of nearly 256 km. If 250 of the bigger shelters are greened with *Sedum* sp., they will

Table 3. CO2 sequestered by greened public transport stops (kg/yr.).

Number of greened shelters	CO_2 sequestration (kg/yr.)			
	Roof	Roof + back wall	Roof + back wall + 1 side wall	Roof+ back wall + 2 side walls
Sedum sp., 370x150x230				
1	6.8	17.3	21.6	25.8
50	341.9	866.1	1078.6	1293.6
100	683.8	1732.2	2157.2	2587.2
250	1709.4	4330.5	5393.1	6468
Sedum sp., 470x150x230				
1	8.7	22	26.3	30.5
50	434.3	1100.2	1312.7	1525.2
100	868.6	2200.4	2625.4	3050.4
250	2171.4	5500.9	6563.5	7626.1
Festuca sp., 370x150x230				
1	15.3	38.7	48.2	57.7
50	764.2	1936.1	2411.1	2891.7
100	1528.5	3872.1	4822.3	5783.4
250	3821.2	9680.3	12055.6	14458.5
Festuca sp. 470x150x230				
1	19.4	49.2	58.7	68.2
50	970.8	2459.3	2934.4	3409.5
100	1941.6	4918.6	5868.8	6818.9
250	4853.9	12296.6	14671.9	17047.3

be able to sequester the CO_2 emitted by 18 diesel cars with an average daily mileage of 10 km per day. If they are greened with *Festuca* sp., they will be able to sequester the CO_2 emitted by 40 diesel cars with an average daily mileage of 10 km per day.

Conclusion

In the central part of Sofia are located 257 public transport stops, 150 of them currently having shelters. If 250 shelters entirely greened (roof and three walls) with *Festuca* sp. are located in the city centre, the removed PM_{10} will be about 20 kg/yr. This equals 0.01% of the yearly emissions of PM_{10} from transport in the survey area. The greened shelters will be able to sequester 17047.3 kg CO_2/yr. This is approximately the CO_2 emitted by 40 diesel cars with an average daily mileage of 10 km per day for a year.

The reduction of PM_{10} and CO_2 in the air will not be significant even if green shelters are built at each public transport stop in the survey area. However, in a big city with intensive construction and a constantly increasing population, every possibility for greening needs to be explored. The problem of air pollution in urbanised areas cannot be solved with a single solution. A combination of measures is needed in accordance with the available resources and the specifics of the area.

In this sense, green stops can be used in combination with other measures and green infrastructure to mitigate air pollution and provide additional benefits. The undisputed ecological benefits should be assessed it the context of the constructional features of roof greening (pros and cons). To maximise the effect, different design solutions may be used to increase the area available for greening. The selection of plant species can also increase the effect.

Acknowledgements

The study is part of the implementation of a project within the framework of an approved action under the European Research and Technology Cooperation Program COST: CA17133 – Implementing nature based solutions for creating a resourceful circular city, Contract KP-06-KOCT/22 from 16.12.2019 „Green Infrastructure – Integration Opportunities on the Road to a Circular Economy, a Sustainable and Healthy Urban Environment“ funded by the National Science Fund – Ministry of Education and Science, Bulgaria.

References

Benoliel, M.A., M. Manso, P.D. Ferreira, C.M. Silva, C.O. Cruz. 2021. "Greening" and comfort conditions in transport infrastructure systems: Understanding users' preferences. – Building and Environment, 195. https://doi.org/10.1016/j.buildenv.2021.107759

Brovarone, E.V. 2021. Design as if bus stops mattered: exploring the potential role of public transport stops in the urban environment. – Urban Design International, 26, 82-96. https://doi.org/10.1057/s41289-020-00132-8

Deneva, M., L. Bozhkov, V. Naydenova. 2008. The green system of Sofia. – Conference reader: International conference urban green spaces-a key for sustainable cities, Sofia, pp. 16-20.

European Commission. 2013. Green Infrastructure (GI)-Enhancing Europe's Natural Capital. Communication from the Commission to the European parliament, the Council, the European economic and social committee and the Committee of the regions. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52013DC0249

Fontaras, G., N.G. Zacharof, B. Ciuffo. 2017. Fuel consumption and CO_2 emissions from passenger cars in Europe-Laboratory versus real-world emissions. – Progress in Energy and Combustion Science, 60, 97-131. https://doi.org/10.1016/j.pecs.2016.12.004

Hewitt, C.N., K. Ashworth, A.R. MacKenzie. 2020. Using green infrastructure to improve urban air quality. – Ambio, 49, 62-73. https://doi.org/10.1007/s13280-019-01164-3

Kovachev, A., G. Tsolova, V. Shahanov.2012. The Significance of Urban Greenspace System of Sofia for a Sustainable City. – International Forum 'Natural resources and Ecology of the Far Eastern Region, 25-26.

Kuronuma, T., H. Watanabe, T. Ishihara, D. Kou, K. Toushima, M. Ando, S. Shindo. 2018. CO_2 payoff of extensive green roofs with different vegetation species. – Sustainability, 10. https://doi.org/10.3390/su10072256

Mihailovich, L., P. Terziev, P. Dikov. 2009. Amendment of the General Development Plan of Capital Municipality (change), Municipal Enterprise Sofproekt. 40pp. (in Bulgarian). https://www.sofia-agk.com/Pages/Render/353

Open Street Map, Relation Sofia-City. World Wide Web electronic source. Last update 10 May 2021. URL: https://www.openstreetmap.org/relation/1739543

Park, S.H., D.W. Ko. 2018. Investigating the Effects of the Built Environment on $PM_{2.5}$ and PM_{10}: A Case Study of Seoul Metropolitan City, South Korea.-Sustainability, 10. https://doi.org/10.3390/su10124552

Speak, A.F., J.J. Rothwell, S.J. Lindley, C.L. Smith. 2012. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. – Atmospheric Environment, 61, 283-293. https://doi.org/10.1016/j.atmosenv.2012.07.043

Staddon, C., S. Ward, L. De Vito, A. Zuniga-Teran, A.K. Gerlak, Y. Schoeman, A. Hart, G. Booth. 2018. Contributions of green infrastructure to enhancing urban resilience. – Environment Systems and Decisions, 38, 330-338. https://doi.org/10.1007/s10669-018-9702-9

UCTM (University of Chemical Technology and Metallurgy). 2015. Analysis and evaluation of the implementation of the Program for air quality management of Sofia Municipality. (In Bulgarian).

Vision for Sofia. 2020. Methodological guidelines for developing a long-term vision for the development of Sofia and the suburbs. https://vizia.sofia.bg/wp-content/uploads/2019/12/VISION-SOFIA-ACTIONS-FINAL.pdf (In Bulgarian).

Xing, Y., P. Brimblecombe, Z. Ning. 2019. Fine-scale spatial structure of air pollutant concentrations along bus routes. – Science of the Total Environment, 658 (25), 1-7. https://doi.org/10.1016/j.scitotenv.2018.12.001

Yang, J., Q. Yu, P. Gong. 2008. Quantifying air pollution removal by green roofs in Chicago. – Atmospheric Environment, 42, 7266-7273. https://doi.org/10.1016/j.atmosenv.2008.07.003

Zuniga-Teran, A.A., C. Staddon, L. de Vito, A.K. Gerlak, S. Ward, Y. Schoeman, A. Hart, G. Booth. 2020. Challenges of mainstreaming green infrastructure in built environment professions. – Journal of Environmental Planning and Management, 63(4), 710-732. https://doi.org/10.1080/09640568.2019.1605890