Roofs Above Roads: Nature-Based Management of Roof Runoff in Copenhagen

Des toits plutôt que des routes : Gestion du ruissellement des toitures par des solutions fondées sur la nature à Copenhague

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RÉSUMÉ

Les solutions fondées sur la nature pour la gestion des eaux pluviales (NBSsw) constituent des infrastructures à faible empreinte carbone offrant des services écosystémiques substantiels. Toutefois, elles ne sont pas encore privilégiées pour l'adaptation urbaine face à l'intensification des précipitations. Le ruissellement des toitures, contrairement à celui des surfaces routières, présente une énergie potentielle exploitable permettant son transfert gravitaire vers des dispositifs hors sol, verticalisés et plus efficients en termes d'occupation spatiale. Ces dispositifs permettent également la rétention de volumes extrêmes sur des espaces adjacents à programmation multiple, comme démontré par le projet Green Climate Screen à Copenhague.

Cette étude mobilise une analyse SIG pour évaluer si l'objectif climatique de Copenhague à l'horizon 2100—augmenter de 30 % la capacité de drainage du système unitaire afin de maintenir un niveau de service décennal—peut être atteint en déviant exclusivement le ruissellement des toitures vers des NBSsw hors sol. Sur les 6000 ha du bassin versant unitaire, 4000 ha sont imperméabilisés, dont 1500 ha de toitures. Déconnecter 30 % des surfaces scellées (1200 ha) apparaît théoriquement réalisable par la seule déconnexion des toitures.

L'analyse examine enfin la faisabilité de cette approche, notamment les conditions foncières et la disponibilité locale d'espaces permettant l'implantation de NBSsw verticalisés.

ABSTRACT

Nature-based solutions for stormwater management (NBSsw) offer low carbon footprints and substantial ecosystem services, yet they have not become the preferred pathway for adapting cities to more extreme precipitation. Unlike runoff from roads, roof runoff holds potential energy that enables conveyance into vertically configured, aboveground NBSsw elements, which are more space efficient and allows for detention of extreme volumes on double programmed neighboring areas, as exemplified with the Green Climate Screen in Copenhagen This study uses GIS analysis to examine whether Copenhagen's 2100 climate adaptation target of increasing the drainage capacity of the combined sewer system by 30 % to maintain a 10-year service level can be met solely by diverting roof runoff into aboveground stormwater elements. The combined sewer catchment of Copenhagen is around 6000 ha, of which 4000 ha are sealed surfaces, distributed with 2500 ha of roads/pavements and 1500 ha of roofs. A target of disconnecting 30 % of sealed surfaces corresponds to 1200 ha, which thus in theory can be achieved through roof disconnections alone. In addition to providing potential energy for gravity-driven conveyance, roof runoff is typically cleaner than road runoff and is often located adjacent to areas that would benefit from increased ecosystem services. The paper discusses the feasibility of this strategy with particular focus on ownership conditions and the local availability of space for implementing vertically oriented NBSsw.

KEYWORDS

Pressurized NBSsw; Retrofitting; Roof runoff, Roof disconnection, Spatial analysis

INTRODUCTION

Copenhagen is increasingly threatened by extreme rain events, particularly within the combined sewered catchment that serves 90% of the city. According to the Copenhagen Climate Adaptation Plan, the drainage capacity must be increased by 30 % by 2100 to maintain service up to the 10-year event (Municipality of Copenhagen, 2011). This increase can be achieved by two distinct strategies: one is to expand the detention and discharge capacity of the existing sewer system by 30 %, and the other is to reduce pressure on the system by disconnecting 30 % of currently connected surfaces and managing that water locally through retention and detention, often referred to as Nature-based Solutions for stormwater management (NBSsw).

Although the sewer expansion strategy is well established, it involves a high carbon footprint (Brudler *et al.*, 2016) and operates with a single-scoped climate resilience target (Sørup *et al.*, 2019). In contrast, NBSsw offer lower carbon emissions, contribute to broader resilience including drought and heatwaves, and enable stormwater to function as a resource that supports ecological and socio-cultural services (*ibid*). Their main limitations are substantial space requirements and the governance-related complexity of replacing a single pipe network with many distributed systems.

With the emergence of pressurized NBSsw, as demonstrated by the Green Climate Screen in Copenhagen, the Rain Dike, the Rain Mound and the Raised Raingarden (Lausen *et al.,* 2022; Jensen *et al.,* 2025) stormwater can be managed in a more space efficient way and if even cope with extreme events (>10 y) by detention on double programmed neighboring areas. Pressurized stormwater NBSsw depend on potential energy and are therefore suitable only for roof runoff.

The objective of this study is to explore the ability of roof disconnection to meet the 30 % drainage enhancement target for Copenhagen and to assess the feasibility of this climate adaptation strategy in terms of ownership complexity and space availability.

METHODS

ArcGIS was used to conduct spatial analysis of distribution of sealed surfaces on roofs and paved areas within the combined sewered area of Copenhagen, and to describe ownerships of roofs (buildings) and land availability near buildings.

Data on drainage systems in Copenhagen was obtained from the City of Copenhagen and included the following six categories: combined sewered system, separated sewered system, stormwater-only system, wastewater-only system, unsewered, and other/undefined system types.

National data on land cover (MiljøGIS) within the combined sewered area included the following 14 categories: asphalt, pavers, gravel, unpaved, green roof, green house, concrete, cobblestones, solar cells, fields, buildings, watercourse, lake, ocean. This 14 was reduced to three categories by excluding watercourse, lake and ocean, and merging green roof, green house and buildings into 'Roofs', asphalt, pavers, concrete, cobblestones, and solar cells into 'Paved' and gravel, unpaved, and fields into 'Pervious'.

National data (Ejendomsstatistik) on ownership of buildings (=roofs) included nine categories: private person, social housing association, private company, independent endowment, cooperative housing association, municipality, state, others and unknown.

Land availability near roofs was described by calculating the ratio of parcel-area to roof-area within each owner category.

RESULTS AND DISCUSSION

The combined sewered area of Copenhagen covers an area of approximately 6,300 ha, of which approximately 2,300 ha are pervious. The 4,000 ha of sealed surfaces connected to the combined sewer is distributed with approximately 1,700 ha on roofs (buildings) and 2,300 ha on paved areas, including roads, pavements, parking areas, etc. See Figure 1.

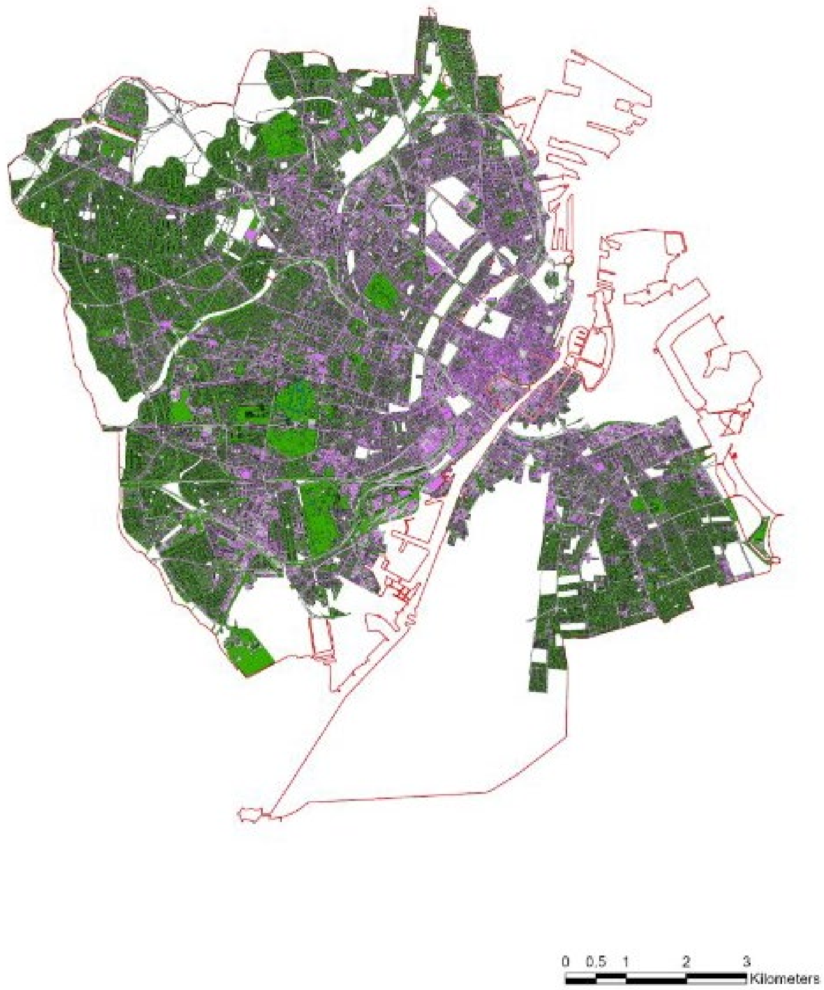

Figure 1. The combined sewered area of Copenhagen, with three land cover classes: Roofs (purple), Paved (grey) and Pervious (green). White areas are not sewered or served by a separated system.

Thus, the target of 30 % enhanced drainage capacity in the combined sewered catchment can be reached by disconnecting 30 % of the 4,000 ha sealed area, or 1,200 ha, corresponding to approximately 80 % of the total rooftop area (Table 1).

The feasibility of such a large undertaking depends on several factors, including the willingness of building owners to collaborate with the drainage authorities, and the availability of space near the buildings for constructing nature-based solutions. As shown in Table 1, no single owner category can provide the full 1,200 ha of rooftops, which implies the need for a phased strategy in which the most cooperative owner groups are approached first. These groups may be ordered from most to least likely to collaborate as follows: public buildings owned by the state or municipality, buildings managed by professional or semi-professional housing organisations such as social or cooperative housing associations, and privately owned large buildings operated by companies. If these owner categories are approached approximately 1,000 ha of roof can be disconnected. Table 1 also presents the parcel-to-roof ratio for each category. This indicates that municipal buildings represent an optimal starting point because they typically have large parcels relative to their roof area, making them attractive for initial implementation and learning.

Table 1: Total parcel ownership area, rooftop area and parcel-to-roof ratios in the combined sewered area of Copenhagen. *Unknown is in most cases roads.

Property Owner	Parcel Area (ha)	Rooftop Area (ha)	Average parcel-to-rooftop ratio
Municipality	954	161	5.9
State	298	62	4.8
Social Housing Association	506	180	2.8
Cooperative Housing Association	503	244	2.1
Private Company	797	300	2.7
Private Person	1369	407	3.4
Independent Endowment/Institution	397	155	2.6
Others	366	164	2.2
Unknown*	1073	48	22.5
Total	6263	1722	

CONCLUSION

The study demonstrates that even a mature, fully built-out city like Copenhagen can pursue a nature-based stormwater management strategy for future climate adaptation. Such an approach has the potential to deliver up to two-thirds of the drainage capacity increase required by 2100.

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