Hydraulic performance of extensive green roofs in cold climate

Analyse des performances hydrauliques de toitures végétalisées extensives dans un climat froid

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RÉSUMÉ

Pour améliorer la connaissance de la performance et la conception de toitures végétales extensives dans un climat froid, des recherches sur le terrain ont été menées dans trois villes côtières de la Norvège. Cette recherche évalue la première année de résultats, compare ceux-ci avec des études similaires, et discute des paramètres qui sont importants pour une performance optimale. Aucune différence significative n'a été constatée entre les conceptions testées sur les différents sites. Les sites connaissent des différences importantes dans le niveau des précipitations annuelles, et de grandes différences en termes de rétention des eaux pluviales (en pourcentage). Cependant, lors de l'étude des valeurs absolues (mm d'eau pluviale retenue), les sites ont des performances similaires. Les résultats de l'étude norvégienne cadrent bien avec les résultats d'études réalisées dans des climats comparables, et avec des volumes de précipitations du même type. Le climat côtier, les basses températures des sites étudiés et la répartition uniforme des précipitations, laissent peu de temps aux toitures pour régénérer leurs capacités avant la prochaine averse. Ces facteurs doivent donc être pris en compte lors du choix de la conception de la toiture.

ABSTRACT

To increase the knowledge of performance and optimal design of extensive green roof in cold climate, field studies were established in three coastal cities in Norway. This paper evaluates the initial year of data, compare the result with studies from some comparable climates elsewhere, and discuss important parameters for optimal performance. No significant differences were found between the different roof build ups tested. The sites experience large differences in annual precipitation, and large differences in percentage stormwater retention. However, when studying absolute values (mm stormwater retained), the sites perform quite similar, and the results from the Norwegian study fits well with results from studies with comparable climates and precipitation volumes elsewhere. The costal and cold climate of the sites studies, with low temperatures and evenly distributed precipitation, leave little time for roof to regenerate its storage capacity between the events. This should be given special attention when choosing roof design.

KEYWORDS

Cold climate, Hydraulic performance, Green roof, Retention

1 INTRODUCTION

Extensive green roofs are used worldwide for retention and detention of stormwater runoff, especially in areas with temperate and warm climate. Lately, cold climate areas have also seen an increasing interest in green roofs, all though there is still a considerable knowledge gap regarding local performance and optimal design. In the summer of 2014, field study sites were established in three cities in Norway.

From a stormwater perspective, there is a need to evaluate the hydraulic performance of green roofs. Green roofs have multiple effects on stormwater runoff, however no uniform parameter for evaluation of performance exist. Some of the frequently used parameters include overall runoff volume reduction or parameters describing single events as retention (mm or %), peak reduction (mm or %), peak delay (min) and time to start runoff (min). This study focuses on parameters describing volume reduction and retention. Parameters describing delay are expected to be more affected by the scaling factor of the experiments (Hakimdavar et al., 2014) making direct field test comparisons difficult.

The objectives of this paper are: to evaluate the first year of data from three Norwegian green roof field studies; to compare the result with studies from comparable climates elsewhere; to discuss the performance and potential for green roofs as a function of the local climate.

2 METHODS

All three sites represent typical Norwegian costal climates with some distinct differences. The site in Trondheim (T) is the most northern. It is situated in the end of a large fjord and experience yearly about three months with temperatures below zero (normal average 5^{o}C). T had the least annual precipitation of the three sites (814 mm/year). Sandnes (S) and Bergen (B) experience a more typical costal weather with more precipitation and seldom temperatures below zero. Temperatures of S and B are quite similar (normal average 7.5^{o}C), but there is a major difference in annual precipitation, with B experiencing the most (3 710 mm/year versus 2 259 mm/year in S).

The roofs at each site are divided into 4 plots with different layers and vegetation, see Table 1. Precipitation is measured at a one-minute interval with a heated tipping bucket rain gauge (resolution 0.1 mm), while air temperature and -humidity and soil temperature and -humidity is measured at 15 min intervals. Runoff from the plots are directed to individual barrels with pressure transmitters measuring the water level. Levels are logged at break points with a minimum temporal resolution of 1 min and a maximum of 1 hour. When the barrels are full, they are automatically emptied with a pump.

Data have been recorded at the field stations for 14.5 months. Due to different initial problems with instruments and loggers, not all data were available for analysis. The following periods are included in the study; T: 05.12.14-11.10.15; S: 19.11.14-23.06.15 & 25.08.15-15.10.15; B: 01.08.14-31.05.15.

Table 1 Description of sites

Location: Trondheim (T) 63.4^{o}N Roof configuration: 4 plot of 7.6 m*2.0 m. 16% slope, orientation east.	Plot 1: Sedum mat and 10 mm felt mat. Plot 2: Sedum mat and 25 mm mineral wool. Plot 3: Sedum mat, 50 mm substrate, drainage mat and 5 mm felt mat. Plot 4: Sedum mat, 50 mm substrate and drainage mat.
Location: Bergen (B) 60.4^{o}N Roof configuration: 4 plot of 4.9 m * 1.6 m. 27% slope, orientation east	Plot 1: Sedum mat and 10 mm felt mat. Plot 2: Sedum mat and 25 mm mineral wool. Plot 3: Sedum mat, 50 mm substrate and drainage mat. Plot 4: Sedum mat and 3 mm felt mat.
Location: Sandnes (S). 58.9^{o}N Roof configuration: 4 plot of 5.4 m * 1.6 m. 27% slope, orientation northeast.	Plot 1: Sedum mat and 10 mm felt mat. Plot 2: Sedum mat, 50 mm substrate, drainage mat and 5 mm felt mat. Plot 3: Sedum mat and 3 mm felt mat. Plot 4: Sedum mat and 25 mm mineral wool.

Runoff was calculated from changes in level in the barrels, divided by a ratio for roof area/barrel area. Three different correction procedures were carried out on the data to handle the following situations: (1) noise from measuring error; (2) evaporation from barrels; (3) missing data when pump was running.

For seasonal performance comparisons, the results were divided into three seasons: Winter season, monthly temperature normal below zero; Cold season, monthly temperature normal 0-11 ^{o}C;

Temperate season, monthly temperature normal above 11°C.

To investigate single events, a minimum of 6 hours antecedent dry weather period (ADWP) was used to define a precipitation event. Precipitation events with a sum < 0.2 mm were excluded. For each precipitation event the corresponding start of the runoff event was defined as when accumulated runoff exceeded 0.1 mm. If the runoff extended into the next precipitation event, the events were combined. Parameters describing volumes, intensity peaks and times (start/stop/peak) for both precipitation and runoff were identified for each event. Event analysis was not carried out for winter data, as snow melt is not necessarily connected to the corresponding precipitation. A comparison of precipitation data to study typical ADWPs were based on one year of data from the period 01.08.2014-01.08.2015.

For comparisons between the different roof build ups at the same site, a Kruscal Wallis test and an ANOVA (ln-transformation) were performed on retention(mm) with a significance level of $p=0.05$.

3 RESULTS AND DISCUSSION

3.1 Differences between roof build ups

The overall volume reduction based on accumulated data for precipitation and runoff showed some individual differences between the different plots at each site, however, no statistical significant difference was found at any of the sites, neither for all events nor for only larger events (> 20 mm precipitation). Based on this the data from the different plots were averaged for further analysis.

3.2 Overall retention based on accumulated data

The average retentions (%) and monthly absolute retentions (mm) are presented in Figure 1, as a function of seasons and site. Best overall performance with respect to percentage reduction of runoff was observed in T (30%) followed by S (25%), while the poorest retention was observed in B (17%). However, when studying the absolute retention per month (mm), B show the highest retention followed by S and at last T. The most likely explanation for this is the differences in precipitation between the sites. B experienced most precipitation of all the sites in the experimental period (316 mm/month), followed by S (189 mm/month) and T (74 mm/month). Stovin (2010) reported an annual retention of 50.2% from a field study in Sheffield. Sheffield has costal climate, and comparable temperatures to B and S, but the annual precipitation in Sheffield is much less (825 mm/year). Stovin et al. (2013) modelled retention over 30 years at four sites, and found a retention of 19% for NW Scotland. NW Scotland has an average precipitation (226 mm/month) which is comparable to the Norwegian studies, and the results fits well with the observed results from B and S. Locatelli et al. (2014) reported a cumulative retention of 53% in Apr-Oct and 35% in Nov-Mar from a study in Odense, Denmark. Odense has slightly higher temperatures compared T, no evident winter, and an average comparable precipitation (50-60 mm/month). If we disregard the winter data, the results from T is quite similar to those reported from Odense.

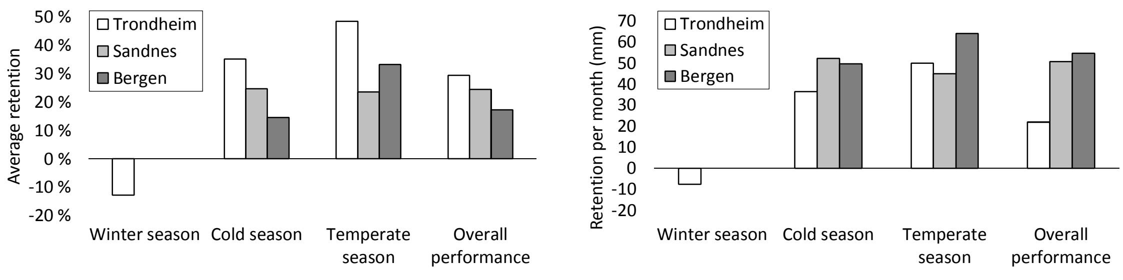

Figure 1. Average seasonal retention in percentage (left) and in absolute values (right)

3.3 Study of specific events

Immediately, when studying volume reduction in percentage, there seemed to be large differences between the performances at the three sites. However, there is also a large variation in precipitation. When studying retention per event as a function of precipitation the differences were not as obvious.

Figure 2 shows retention per event as a function of total precipitation divided by sites and seasons. The results are quite scattered. This is as expected as the initial humidity is not included, which is probably the most important factor governing the retention capacity of a green roof. Still, some interesting observations can be extracted. (1) For small precipitation event (<10 mm) there is a linear relationship between precipitation and retention, with retention capacities up to 100%. (2) For medium precipitation events (10-50 mm), retention values up to 13 mm were observed, indicating the potential storage capacity in the tested roofs. (3) Larger precipitation events (>50 mm) gave higher retentions, but this were long durations events (> 48 h), composting of several precipitation events and one could expect that mechanisms for regeneration can take place within the event. An event study is therefore not ideal for studying these effects.

The main factor governing regeneration of green roofs is evapotranspiration. Evapotranspiration is influenced by several parameters with temperature, air humidity, solar radiation, type of vegetation and roof build up being the most important. In T, where precipitation often is based on showers, the precipitation events count for 17% of the time, leaving the roof to regenerate its storage capacity in 83% of the time. S and B has a more evenly distributed precipitation where the events count for respectively 31% and 41% of the time, leaving less time for roof regeneration. Median ADWPs vary accordingly with 1.5 days for T and 0.8 days for S and B, with a 95% percentile of 8.2 days for T, 6 days for S and 4.8 d for B. For all sites, the tendency of short ADWPs combined with low temperatures is a challenge for regeneration, and should be given special attention when designing green roof to local conditions. More attention should be given to optimise the process of regeneration, while plant draught is less challenging in these climates. Further work will be done to study the effect on regeneration of storage capacity by studying climatic data affecting evapotranspiration, and humidity data from the green roofs.

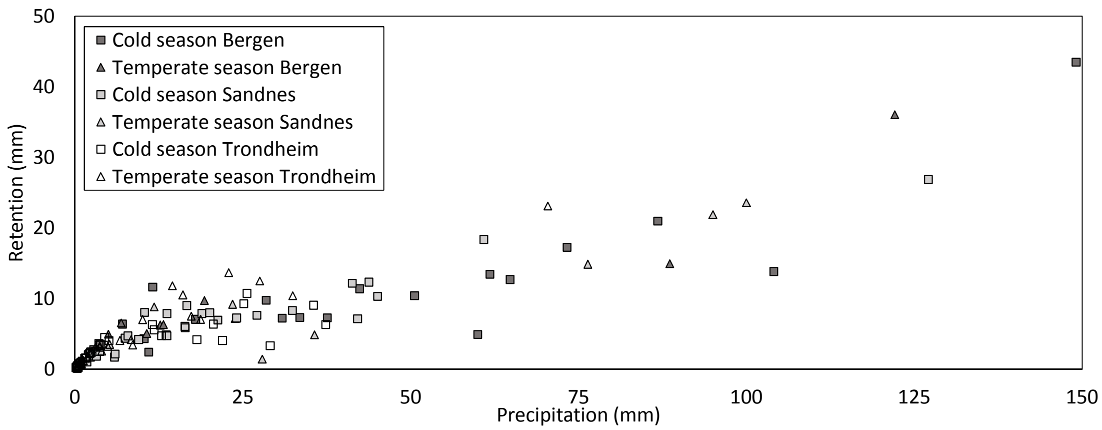

Figure 2. Retention versus sum precipitation for all sites divided by cold and temperate season

4 CONCLUSION

No significant differences were found between the different roof build ups. Results on average volume retention is strongly dependent on total precipitation volumes. Results from the Norwegian study fits well with results from studies with comparable climates and precipitation volumes. Costal and cold climate with low temperatures and evenly distributes precipitation leave little time for roof to regenerate its storage capacity between the events. This should be given special attention when choosing roof design.

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