A Technical Review on Blue and Blue-Green Roofs

Ryan Smith[1]and Seyed Masoud Sajjadian[1]

[1] School of Computing, Engineering and the Built Environment, Edinburgh Napier University

Abstract. Increased development of Greenfield areas to tackle housing shortages, combined with increased rainfall due to climate change has created drainage issues within urban areas, this has increased pressure on existing drainage infrastructure and has intensified the need to consider the use of sustainable drainage systems on new and existing grey infrastructures i.e. buildings, roads and pavements. Blue and blue-green roofs are widely considered a means of improving sustainability and flood resilience in urban areas for all new construction. This paper reviews such systems from a technological point of view and provides insight into their potential and the challenges of their buildability in the UK construction.

Keywords: Blue Roof, Blue-Green Roof, Drainage System

1. Introduction

The primary purpose of a roof is to provide protection from external weather conditions [1]. Traditional roofs direct water to a drainage system of pipes which convey the water to a downstream treatment source. Building regulations require surface water discharge from a building or paved surface to a storage container, Sustainable Urban Drainage System (SUDS), soakaway, public sewer or a water course [2]. However, due to climate change and the need to ensure sustainable development, UK Planning authorities will require a form of SUDS to be used on any new developments. The use of vegetated or 'Green Roofs' is not a new concept with evidence of use from 500BC [3]. Figure 1 shows the layers and its construction.

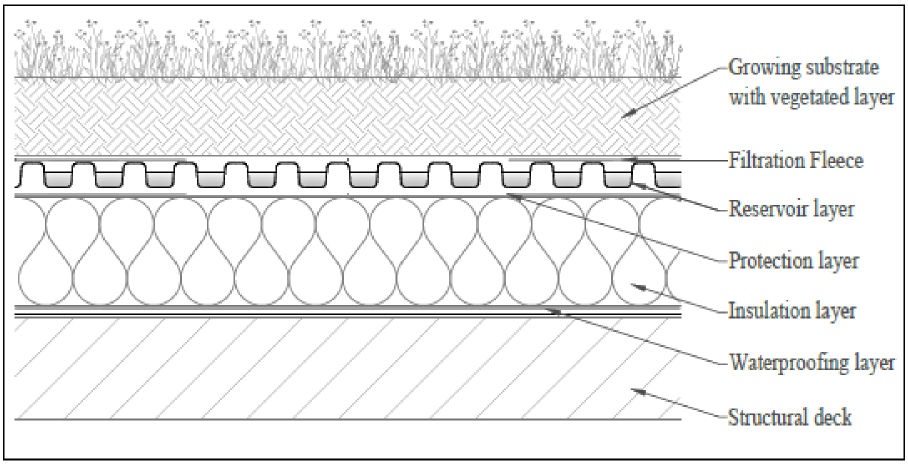

Figure 1. Green Roof detail drawing

A study by [4] found that a green roof in isolation can improve downstream water quality and reduce long term total runoff. However, they perform poorly during heavy rainfall events, its hydraulic performance once saturated is similar to that of a traditional roof. Therefore, it cannot act as a SUDS as shown in Figure 2 [5].

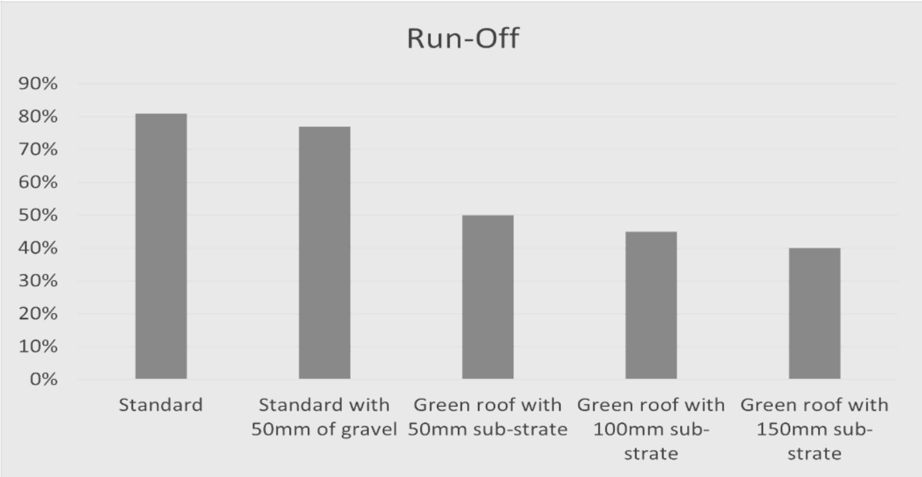

Figure 2. Green roofs run-off rates compared to standard roofs [5].

A blue roof is designed to attenuate a specific quantity of water and discharge it at a controlled rate into the building's drainage system [6]. This can be constructed as shown in Figure 3 which is termed a blue-green roof, it can alternatively be formed using modular paving of concrete slabs and the finished surface can be used as a podium deck.

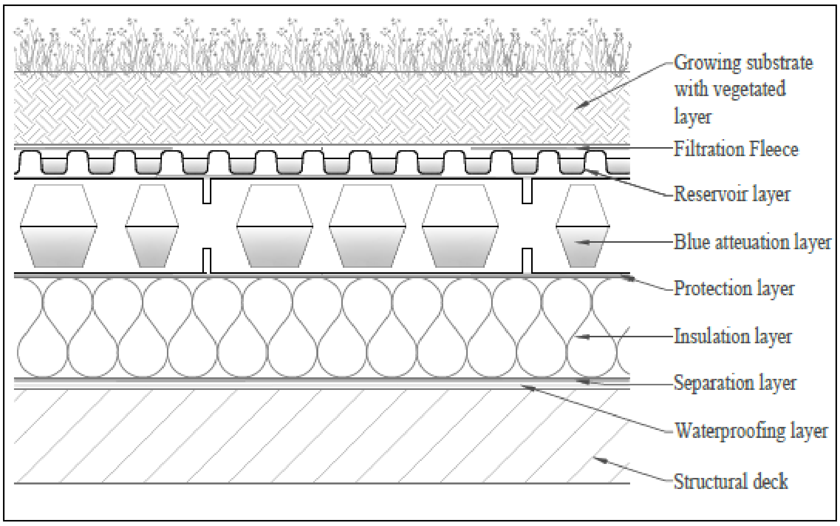

Figure 3. A blue-green roof detail drawing

An important feature of a blue roof is the outlets. Engineering calculations are required to determine the optimum number, size and position of outlets to ensure the roof can fully drain within 24 hours and be at least half empty within 12 hours. The rate of discharge is usually around 5-8 l/s [7]. It is also critical that sufficient emergency overflow is designed for outlets, this can be standalone or integral to the primary outlets. The outlets should be designed in a way that minimizes the risk of blockage, ensuring easy access for maintenance purposes[6]. Certification and compatibility of outlets and emergency overflow with such roofing systems are fundamental considerations.

Due to ongoing technological and policy advancements in the aforementioned area, building designers face challenges in staying informed. This paper aims to address this gap by offering a crucial technical review and methodology specifically focused on blue and blue-green roofs. Additionally, it reveals common challenges and presents a comparison of various products currently available in the UK market.

2. Review

The value of new construction work will continue to rise, reaching £128.2 billion by 2026 based on 2019 figures [8]. With all the proposed developments set to take place, inevitably, greenfield areas will be urbanised to create housing, commercial buildings and infrastructures. The predicted level of increased construction activity means, it is inevitable that existing greenfield areas will either be developed for new buildings and infrastructure or, existing city spaces will become denser. [9] found that the densification (where the volume of buildings within part(s) of cities is increased) of cities can reduce urban sprawl. This process is considered to be a more sustainable means of development. However, either approach will replace green spaces that allow rainfall to soak into the ground (infiltration), evaporate or be used by plants such as grasses and trees (evapotranspiration) [5]. With grey impermeable areas where any surface water must be conveyed to a drainage system by piped networks, blue-green roofing can alleviate the negative risks with the blue element being able to attenuate rainfall and release it at a controlled rate into the drainage network and ultimately watercourses. This helps replacing the areas of land which would have previously allowed water to naturally infiltrate. The vegetation within the green layer of the roof can help with lost evapotranspiration.

The construction of the grey infrastructure (buildings, roads and car parks) replace permeable areas with hard impermeable surfaces. This means rooftops provide valuable space which can be utilised for drainage [10]. Besides, it is currently estimated that there are 28 million existing homes within the UK, and a large percentage of the stock requires refurbishment at various levels [11]. Within the non-domestic sector, there are an estimated 1,656,000 non-domestic buildings in England and Wales [12] and 230,000 within Scotland [13]. This represents a very large potential for development of blue and blue-green Roof systems. The value of works relating to repairs and maintenance is also set to rise according to studies by the [8], reaching an estimated £73 billion by 2026.

The design of a blue-green roof aims to replicate the natural drainage patterns observed in the undeveloped green field areas of a site. and protect the receiving water course

[14]. Green and blue roofs are considered to be a part of the SUDS elements, providing source control. They can perhaps be considered the most used SUDS in buildings [15] [16].

The use of blue-green roofs on new developments presents an opportunity to develop sites in conjunction with the 3 pillars of sustainability, which are Social, Environmental and Economic [17]. Many of the social benefits of blue-green Roofs are derived from the green element rather than the blue water retention elements. With the use of this system, it is possible to create green spaces in an otherwise built-up grey environment, studies have shown that this will have a positive impact on the health and well-being of humans. [18] found that a connection with nature could reduce stress, improve emotions and increase attention and control. This view was further supported by [19] who stated people who lived or worked around nature tended to experience lower rates of mental and physical illnesses and were likely to be more resilient to stressful circumstances. However, [18] noted this is a qualitative findings as one person's perception is not the same as another's.

The use of blue-green roofs provide many environmental benefits. This can be found in the form of mitigating flood risks. A study by [20] found that Green Roofs could help decrease CO_2 in the atmosphere by the vegetation directly capturing it through the process of photosynthesis and by the capture and storage of carbon within its root system. There is no established method to calculate a U-Value for a blue-green Roof, and the green and blue layers should be discounted for the purposes of a calculation unless the thermal conductivity of the landscaping can be certified [21]. However, [22] found that the added thermal mass can prevent the external environment from adversely affecting the interior environment, therefore the heating and cooling demand can be reduced.

In urban areas with dense infrastructure, a phenomenon occurs where the grey infrastructure absorbs the sun's heat during the day, leading to the development of a local microclimate that can be approximately 10 degrees warmer than the surrounding rural regions[23]. This is called the Urban Heat Island (UHI) which can affect energy use within buildings and increase cooling requirements, it can also impact the quality of life due to pollution and the effects of heat on the human body. Both [20] and [22] found that the greening of roofs could reduce the effects of UHI by creating a cooling effect through increased thermal mass and evaporation.

The installation of blue-green Roof Systems (BGRS) can yield economic advantages. The use of them can satisfy planning and building regulation requirements, allowing urban areas to be further developed and densified. By increasing the adoption of BGRS to mitigate flood risks, additional benefits can also be obtained, particularly in reducing damages caused by flooding.

It is commonly thought that a blue roof is more costly to construct than a traditional roof, however, [24] found that taking into account the reduced drainage infrastructure could lead to a blue roof being less costly than a traditional roof and a 25% saving was possible by using a blue roof over a traditional roof with underground attenuation.

Along with the many benefits a blue-green Roof can bring, there are inevitably some associated drawbacks. The design process is complex and will require the input of specialist consultants throughout the design, construction and use phases. Robust project management is also required to avoid any confusion between any of the involved parties, this can have serious implications, structural failure and other defects due to installation of Green Roofs are noted in [25] [26] [27]. Therefore, architectural detailing and construction practices are important. Failure of the membrane itself is unlikely to happen, the critical point in the design are noted as follows:

- The top of the parapet
- The junction between the roof deck and parapet or adjoining wall,
- Plinths for rooftop plant and the penetrations for drainage outlets and fixings.

The latter point is more significant to note as unlike traditional roofs, the waterproof layer will not be exposed upon completion, it will be buried below the blue-green layers. Additionally, each of the layers within the construction have low rates of water permeability, therefore if any defect were to occur it may go unnoticed for a long period [26]. A review of eleven common types of roofing membranes suitable for use in blue roof constructions can be seen in table 1.

Table 1: Roofing membranes and their applications

Group	Sub-Group	Description	Application	For use on	Native attenuation/drainage system
1	a,x	Reinforced styrene-butadiene-styrene (SBS) bitumen membrane	Loose, partially or fully bonded	Deck to BS 6229:2018, BS 8217 and NHBC 7.1	Yes
1	x	Flexible polypropylene alloy (FPA).	Bonded or mechanically fixed	Deck to BS 6229:2018, BS 8217 and NHBC 7.1	No
2	y	Polymethyl methacrylate liquid applied	Liquid	Concrete, screed, asphalt, timber, existing membranes, metal, plastic, glass	No
2	y	Single component polyurethene liquid applied waterproofing membrane. With glass fibre reinforcement	Liquid	Concrete, Mortar, Ceramic, Metal, Timber, PVC, bitumin, PU boards	No
3	y	Polymer-modified bitumen and membrane sheet	Hot melt	Concrete, metal, timber	No
3	a,x	Polymer-modified, rubberised bitumen-based membrane, including 30% recycled material content	Hot melt	Deck to BS 6229:2018, BS 8217 and NHBC 7.1	Yes
3	a,y	Bitumen, natural rubbers and a blend of polymers reinforced with polyester	Hot melt	Concrete, Brick, Block, Timber, Metal	Yes
3	a,y	Refined bitumen, synthetic rubbers, 25% recycled rubber content and other additives	Hot melt	Concrete, Block, Timber	Yes
4	a,x	Atactic polypropylene (APP) polymer-modified bitumen membrane reinforced with a glass-fibre mat and a non-woven polyester core.	Torch	Deck to BS 6229:2018, BS 8217 and NHBC 7.1	Yes
4	x	Styrene-butadiene-styrene (SBS) copolymer-modified bitumen sheet	Torch	Deck to BS 6229:2018, BS 8217 and NHBC 7.1	No
5	y	Glass-reinforced polyester resin	Cold applied set by a catalyst	OSB3	No

Table 1 shows membranes are produced from a range of different materials each with a particular application method. Some limitations are learnt in relation to which substrates they could be applied to and that a very limited number of manufacturer's produced their own drainage systems. This means that third party components would be required leading to more complications in relation to compatibility and or warranty issues.

For the purposes of this review, the products have been grouped and subgrouped based on their characteristics. Group one membranes are formed in a roll supplied reinforced sheet material that could be lain loose (with ballast), fully, partially bonded or mechanically fixed to its substrate. Group two membranes are liquid applied with reinforcement mesh fibre being rolled in before curing. Group three membranes comprise hot melt bitumen with proprietary mesh reinforcement that can be applied. Group four membranes are roll supplied reinforced sheet material and torch applied, a flame is used to melt the back of the membrane and then pressure applied to its substrate. The group five membrane consists of a cold-applied polyester resin set by a catalyst, fibre mesh is rolled in as reinforcement before the product curing.

A common factor to each membrane is a series of ancillary components such as primers, flashings and reinforcement layers which are to be used for specific scenarios to which the manufacturer's guidance should be strictly adhered to. Subgroup "x" indicates where the product can be used on a substrate in compliance with BS 8271, BS 6229 and NHBC standard 7.1, these are broad brush terms defining the suitability of a given substrate material and the level of preparation required. Subgroup "y" indicates where a specific substrate is declared as suitable with a much more limited potential use. Subcategory "a" indicates systems which have native drainage and attenuation layers and drainage components supplied by the manufacturer of the membrane. Therefore products with subcategories "x" and "a" should be more versatile. The green layers tend to be out of the scope of the research carried out as the planting medium and planting itself are generally supplied separately. However, all the products reviewed are suitable for use with blue and blue-green roofs provided suitable ancillary components are used.

3. UK Building Regulations

Building regulations are in place to make sure all new buildings are constructed to ensure the health, safety, welfare, and convenience of anyone who is in or about them [28]. Current building regulations require surface water to be safely removed from the roof of a building or any paved impervious area. In England, this should be to a soakaway, infiltration system, water course or sewer [29]. In Scotland any discharge from a building or paved surface to a storage container should utilise SUDS, soakaway, public sewer, or watercourse [2]. SUDS are defined as a series of drainage components which are interlinked with the purpose to collect, manage, control, and treat surface water runoff [7].

Planning legislation may insist upon the use of SUDS, for example within Scotland the Water Environment and Water Services (WEWS) (Scotland) Act 2003 mandates that SUDS be used on new developments, however, this excludes single dwellings and discharges to open coastal waters. Provision is made within England and Wales by way of the Flood and Water Management Act 2010 for using SUDS, but this is not mandatory. Table 2 summarises the existing regulation about green and blue-green roofs in the UK.

Table 2: A summary of the existing UK regulations about blue and blue-green roofs.

Standard	Focus
3.6 – Building (Scotland) regulations 2004 (Current regulations within Scotland)	Every building, and hard surface within the curtilage of a building, must be designed and constructed with a surface water drainage system that will: a. ensure the disposal of surface water without threatening the building and the health and safety of the people in or around the building, and b. have facilities for the separation and removal of silt, grit and pollutants.
Approved Document H3 – The Building Regulations 2010 (Current regulations within England)	(1) Adequate provision shall be made for rainwater to be carried from the roof of the building. (2) Paved areas around the building shall be so constructed as to be adequately drained. (3) Rainwater from a system provided pursuant to sub paragraphs (1) or (2) shall discharge to one of the following, listed in order of priority: (a) an adequate soakaway or some other adequate infiltration system; or, where that is not reasonably practicable, (b) a watercourse; or, where that is not reasonably practicable, (c) a sewer

The use of blue and blue-green roof are also in line with the UK's climate change act. Issue of climate change has seen the frequency and intensity of storm rainfall events increase. [30] found that the rainfall in excess of 50mm per day during autumn and winter has increased at a noticeable rate between 1960 and 2020. This could additionally rise by 24% per every degree kelvin that the UK's mean surface temperature rises meaning further increases in extreme rainfall events [30].

4. Conclusion

The amplified precipitation levels can lead to challenges in highly urbanised and densely built areas, particularly where extensive impermeable grey infrastructure exists. During intense rainfall events, the existing drainage systems can become overwhelmed, resulting in flooding or contamination of water supplies. This study provides insight on the effectiveness of blue and blue-green roof systems in mitigating such risks and enhancing surface water resilience. This study acknowledges that designing and detailing such systems is complex and that the design of green and blue-green roofs should minimise roof penetrations and seams while utilising components that are compatible with the systems. This ensures seamless integration of all elements for efficient water management and drainage and enhances the system's performance and longevity.

References

[1] British Standards, "BS 6229:2018 Flat roofs with continuously supported flexible waterproof coverings - Code of practice," BSI, London, 2018.

[2] S. Parliament, "The Building (Scotland) Regulations 2004," 2004.

[3] M. Shafique, R. Kim and M. Rafiq, "Green roof benefits, opportunities and challenges – A review," *Renewable and Sustainable Energy Reviews,* vol. 90, pp. 757 - 773, 2018.

[4] W. D. Martin and N. B. Kaye, "A simple method for sizing modular green–blue roof systems for design storm peak discharge reduction," *SN Applied Sciences,* vol. 2, 2020.

[5] CIRIA, CIRIA C753 The SuDS Manual, CIRIA, Construction Industry Research and Information Association, 2015.

[6] NFRC, "NFRC Technical Guidance Note for the construction and design of Blue Roofs.," The National Federation of Roofing Contractors.

[7] British Standards, "BS 8582-2013 - Code of practice for surface water management for developed sites," BSI, London, 2013.

[8] T. C. I. T. Board, "CSN Industry Outlook - 2022-2026," CITB, 2022.

[9] L. Rosenberger, J. Leandro, S. Pauleit and S. Erlwein, "Sustainable stormwater management under the impact of climate change and urban densification," *Journal of Hydrology,* vol. 596, 2021.

[10] K. V. Mai, "Productive Blue-Green Roofs for Stormwater Management.," *Green Energy and Environmental Technology,* pp. 1 - 12, 2022.

[11] C. L. Council, "National Retrofit Strategy," Construction Leadership Council, 2021.

[12] O. F. N. Statistics, "The Non-Domestic National Energy Efficiency Data-Framework 2021 (England and Wales)," 2021. [Online]. Available: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1007402/non-domestic-need-2021.pdf.

[13] S. Government, "Energy efficiency in non-domestic buildings," 2022. [Online]. Available: https://www.gov.scot/policies/energy-efficiency/energy-efficiency-in-non-domestic-buildings/.

[14] S. Illman and S. Wilson, CIRIA C768 - Guidance on the construction of SuDS, CIRIA , 2017.

[15] F. Chan, J. Griffiths, D. Higgitt, S. Xu, F. Zhu, Y.-T. Tang, Y. Xu and C. Thorne, *"Sponge City" in China—A breakthrough of planning and flood risk management in the urban context,* 2018.

[16] C. Rey-Mahía, F. P. Álvarez-Rabanal, L. A. Sañudo-Fontaneda, M. Hidalgo-Tostado and A. M. Suárez-Inclán, "An Experimental and Numerical Approach to Multifunctional Urban Surfaces through Blue Roofs," *Sustainability,* vol. 14, no. 3, 2022.

[17] D. Krug, OFFSITE CONSTRUCTION: Sustainability Characteristics, Buildoffsite, 2013.

[18] K. J. H. Williams, K. E. Lee, L. Sargent, K. A. Johnson, J. Rayner, C. Farrel, R. E. Miller and N. S. G. Williams, "Appraising the psychological benefits of green roofs for city residents and workers," *Urban Forestry & Urban Greening,* vol. 44, 2019.

[19] Y. Abdul, E. Munkley and A. Yates, "BREEAM - Greening the Built Environment - The Benefits of Selecting Ecological Options," BRE Global, 2018.

[20] M. Shafique, X. Xue and X. Luo, "An overview of carbon sequestration of green roofs in urban areas," *Urban Forestry & Urban Greening,* vol. 47, 2020.

[21] B. Anderson and L. Kosmina, "BR 433 Conventions for U-value calculations," BRE, 2019.

[22] The Green Roof Organisation, The Green Roof Code, The Green Roof Organisation, 2021.

[23] The Royal Meteorological Society, "Urban Heat Islands (UHIs)," 2017. [Online]. Available: https://www.rmets.org/metmatters/urban-heat-islands-uhis. [Accessed 10 October 2022].

[24] C. Harrop, *Blue-roof Thinking,* CIBSE, 2010.

[25] Buildings Department, "Final Investigation Report on the Collapse of Roof Structure of Chan Tai Ho Multi-Purpose Hall of Ha Fa Kuang Sports Centre of City University of Hong Kong, Tat Chee Avenue, Kowloon on 20 May 2016 (The Redacted Version)," The Government of the Hong Kong Special Administrative Region: Hong Kong, China, 2017.

[26] E. Andenæs, B. Time, T. Muthanna, S. Asphaug and T. Kvande, "Risk Reduction Framework for Blue-Green Roofs," *Buildings ,* vol. 11, no. 5, 2021.

[27] N. S. Bunkholt, B. Gullbrekken, B. Time and T. Kvande, "Process induced bulding defects in Norway - development and climate risks," 2021.

[28] S. Parliament, *Building (Scotland) Act 2003,* 2003.

[29] H. Government, *The Building Regulations 2010,* Government, HM, 2013.

[30] D. Cotterill, P. Stott, N. Christidis and E. Kendon, "Increase in the frequency of extreme daily precipitation in the United Kingdom in autumn," *Weather and Climate Extremes,* vol. 33, 2021.