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White Paper

The Green Roof: A more Sustainable & Resilient Wales on our Rooftops

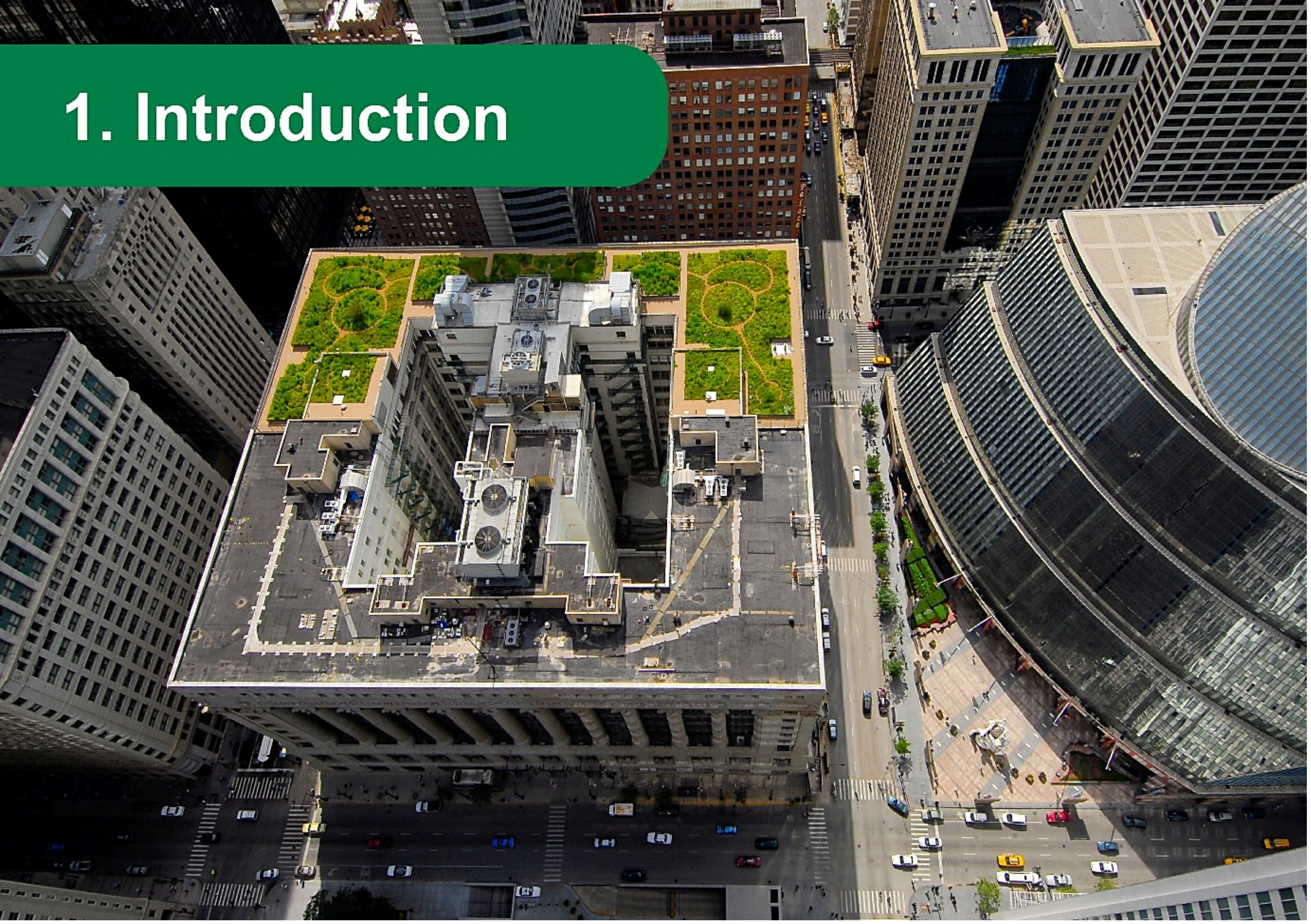
Overview

Climate change is a reality, and an increasingly urbanising Wales is vulnerable to its impacts. The Welsh Government has formed policies and legislation in an attempt to ensure Wales develops in a sustainable way, and is resilient to these changes. Despite this, the efforts of the Welsh Government are falling short of their sustainable development targets, and the nation, especially urban centres, remains vulnerable to climate change.

Green roofs are a multi-beneficial means of meeting the aims of the Welsh Government. By outlining the numerous benefits, and potential barriers to overcome, associated with their implementation, this White Paper finds that green roofing urban areas would be significantly beneficial to the people of Wales.

This White Paper advocates widespread green roof implementation in the urban areas of Wales, based on successful projects in other countries, by recommending draft policy, incentives and best practice guidelines and standards to encourage green roof uptake.

1. Introduction



1.1 | A Changing Climate

The scientific evidence is clear, climate change is a reality. The global climate has been steadily warming since the 19th century, and it is extremely likely that anthropogenic greenhouse gases (GHG) emissions are the primary driver of this warming (Stocker *et al*., 2013). Regardless of how successful global mitigation efforts may be to reduce these emissions, the legacy of past and current GHG emissions means that climate change over the next few decades is unavoidable, with an average of 1°C of further warming under the lowest, most optimistic emission scenario (Meinhausen *et al*., 2011). Adaptation to these future changes is essential to ensure society is prepared and well protected (Perry *et al*., 2009).

1.2 | Climate Change & Wales

The Met Office (2016) database shows average temperatures in Wales have increased since 1910, with the average annual temperature increasing from 8.69°C (between 1910-1939) to 9.22ºC in the last 30 years (1985-2015). Over this same period, summer precipitation has decreased (~30 mm) and winter precipitation has slightly increased (~10 mm). A climate change risk assessment for Wales by DEFRA (2012) indicate that these observed trends will likely continue and intensify over the coming decades. Evidence also suggests an increased risk of extreme weather events such as summer heat waves and winter storms (Kovats *et al.*, 2014; Christidis *et al.*, 2015).

The key climate trends for Wales are:

- **Hotter & drier summers**
- **Milder, wetter autumns & winters**

1.3 | Cities & Climate Change

The UN (2014) estimate over 54% of the global population live in urban areas, which is projected to increase to 66% by 2050. Consequently, the density of people, impermeable concrete surfaces, automobiles and emissions causes environmental issues unique to cities (Carter *et al.*, 2015). For example, the urban heat island effect (UHI), ie. the absorption of solar radiation by roads and buildings and the storage of this heat in the building material, increases local temperatures by 1-3ºC on average, but with extremes of 5-7ºC increases reported during the summer (Wilby, 2003).

The 2011 Census shows Wales is an increasingly urbanising nation, with 89.3% of the population living in 'built-up' (ie. villages, towns and cities) areas (ONS, 2013a; 2013b; Table 1). Consequently, the area of impermeable surfaces in Welsh urban areas has increased at the expense of green spaces (1%/year reduction between 2008 and 2011). This is set to be further exacerbated by a projected increase in housing by 15% (190,400 homes) by 2036, with most of these in the areas in Table 1 (Statistics for Wales, 2014). The CCC (2013) highlights this continued urbanisation may significantly increase surface water flood risk and exacerbate UHIs over the coming decades with projected climate change. For example, in Cardiff alone, the Cardiff Flood Risk Management Plan (2015) estimates flood risk damage to be £26 million a year, and £420 million over the next 25 years.

Table 1. Key population statistics for the four largest urban centres in Wales following census data archived in 2001 from: Conwy County Borough Council (2003), City & County of Swansea (2003), the ONS (2004) and the National Assembly for Wales (2008), and in 2011 from the 2011 census database (ONS, 2011).

Area	Population		
	2001	**2011**	**% change**
Cardiff	310,000	346,090	+11.64
Swansea	223,301	239,023	+7.04
Newport	137,300	145,736	+6.14
Wrexham	128,476	134,844	+4.96

White *et al*. (2013) also suggest continued expansion of the monotonous, concrete urban environment may impact on the general well-being of its inhabitants by reducing space to engage with nature. A review by Public Health Wales (2012) finds this may be true for Wales with a lack of public access to green spaces.

1.4 | The Government's Current Response

Following the Government of Wales Act (2006), the Welsh Government has a legal duty to promote sustainable development under Section 79, and express its legislative powers to protect the environment and national biodiversity (Section 108: Subject 6). Numerous subsequent policies have been developed to provide a framework of duties for the nation to reduce emissions, develop sustainably and increase Wales' resilience to future changes:

- Climate Change Strategy for Wales (CCSW; Welsh Government, 2010)
- Well-being of Future Generations (Wales) Act (2015)
- Planning (Wales) Act (2015)
- Environment (Wales) Act (2016).

However, the latest set of Welsh Government sustainable development indicators show that, while many clear improvements are being made, indicators like GHG emissions or bird biodiversity show little or no improvement (Statistics for Wales, 2015b).

1.5 | Green Roofing

Roofs generally represent a third of the horizontal surfaces of urban areas (Oberndorfer *et al.*, 2007), contributing to increased runoff and UHIs. However, they could instead be used to counteract these issues. A 'green roof' (GR), sometimes known as an 'eco-roof' or a 'living roof', refers to the roof of a building partially, or fully, covered by vegetation (Figure 1).

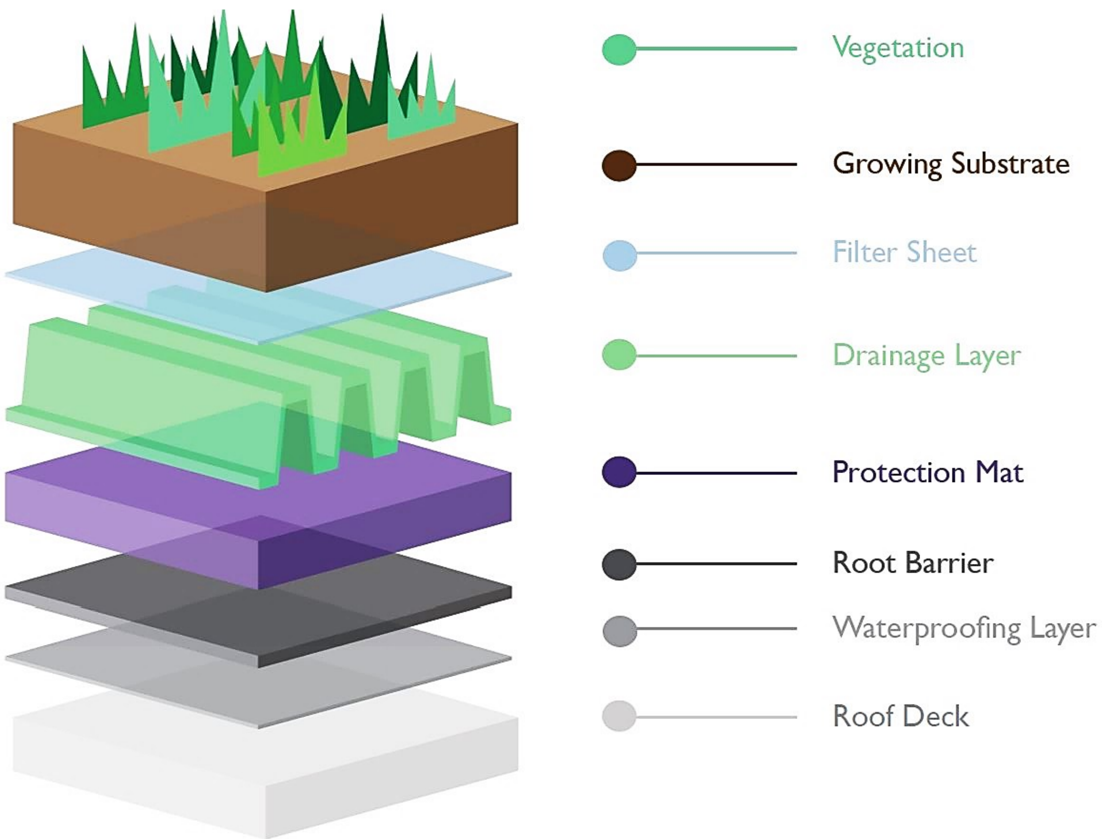


Figure 1. Cross-sectional representation of a typical GR (Growing Green Guide, 2016).

Modern GRs are characterised as either extensive or intensive (Table 2). With careful design, to limit erosion associated with a steep slope, GRs can either be retrofitted to a conventional roof or built as part of a new development for practically all roof types (GRO, 2011). However, extensive roofs are more common, as they weigh less and are easier to install, and as a result are a topic of greater research (Waterford, 2015). Therefore, this white paper will focus primarily on extensive GRs, but with reference where possible to intensive GRs.

Table 2. Typical characteristics of extensive and intensive GR. Created using information from Oberndorfer *et al*. (2007). Illustrative images of the extensive roof of the Providence St. Mary Medical Center, Washington and an intensive roof in Houston, Texas, U.S.A.

	Extensive	**Intensive**
		
Plant communities	Low-growing communities of plants and mosses (eg. *Sedum*)	Anything from grasses and mosses to shrubs and small trees
Average growing medium depth (cm)	2-20	>20
Structural requirements	Typical standard roof weight-bearing parameters: additional 70-170 kg/m^2	Planning required in design phase or structural improvements required: additional 290-970 kg/m^2
Maintenance	Low: weeding or mowing as necessary	High: Same maintenance as a garden at ground level
Accessibility	Generally functional as opposed to accessible (will need basic access for maintenance)	Typically easily accessible: designed to provide extra living space

2. Green Roof Benefits

2.1 | Increased Energy Efficiency

Conventional roofs on average have a very low albedo of 0.066, ie. reflects very little sunlight. In contrast, the vegetation layers of a GR have an average albedo of 0.18-0.2, with evapotranspiration and shading further reducing surface roof temperatures, making GRs up to eight times more thermally efficient than conventional roofing material (Li & Yeung, 2014; Figure 2). Experimental data from extensive GRs in Istanbul, Turkey (Ekşi & Uzun, 2013) and Ottawa, Canada (Liu & Baskaran, 2003) suggest a reduction of 75-80% heat through the roof.

Figure 2. Thermal properties of a green (left) and tar (right) roof of the Chicago City Hall, Illinois, U.S.A adapted from (EPA, 2008b).

The extra layers of a GR, especially intensive GRs, also provides additional insulation (Oberndorfer *et al*., 2007). In Greece, Niachou *et al*. (2001) find that 69% of the time during July, indoor temperatures exceeded 30°C under a conventional roof, compared to only 15% under a GR. Temperatures also remained below 32°C under the GR, whereas this was exceeded 16% of the time under a conventional roof. Overall, GRs maintain stable, cooler indoor temperatures (Figure 3), which indirectly reduces costs and GHG emissions by reducing the demand for mechanical cooling or heating (Li *et al*., 2010). For example, Bass & Baskaran (2003) find this stability led to reductions of 6% and 10% of cooling and heating energy (21,000 kWh), respectively, in a year in Toronto, Canada. This reduces the negative long-term effects of air conditioning, which can increase local temperatures by 1-2°C through waste energy (Ohashi *et al*., 2007).

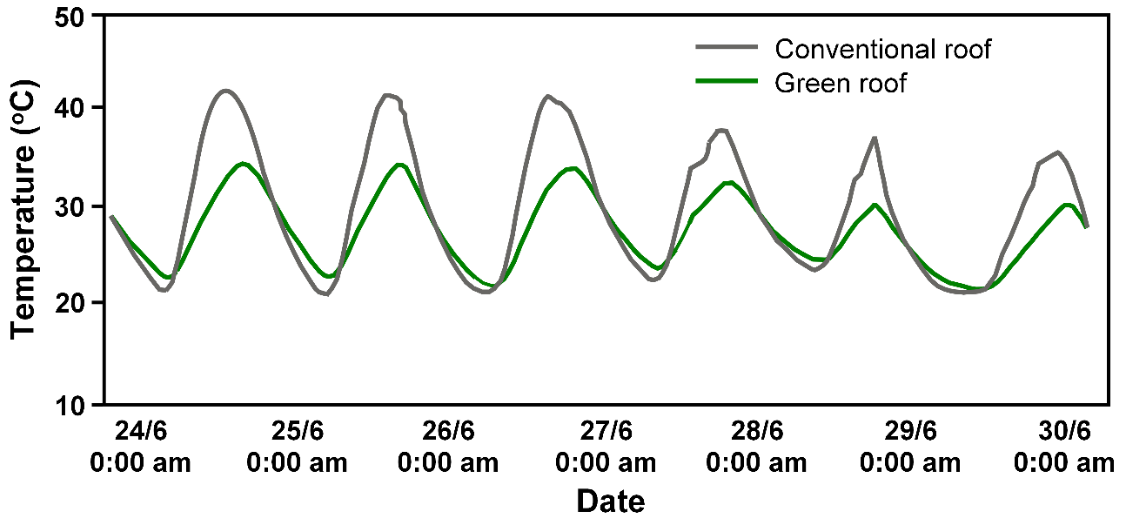


Figure 3. Comparison of the average interior temperature of buildings with a conventional and a GR in Pennsylvania, U.S.A. Created using data in Garrison *et al*. (2012).

There is also a common misconception that roof surfaces may only be used for either GRs or solar panels, not both. Solar panel efficiency decreases, on average, by 0.5%/°C above 25°C. By maintaining stable and cooler temperatures, GRs maintain panels' efficiency, increasing power output by up to 4% (Chemisana & Lamnatou 2014).

2.2 | Runoff Management

GR plant cover intercepts precipitation which later evaporates or is taken up by the plant (Poë *et al*., 2015). GR average annual precipitation retention is typically between 30-86% (Li & Babcock, 2014), greatly reducing storm-water runoff (Figure 4) and delaying this discharge by up to five hours (Wong *et al*., 2014). Vegetation also filters pollutants from runoff. Gregoire & Clausen (2011) find a GR in Connecticut, USA, reduced zinc concentrations in runoff by 82% in comparison to a conventional roof. Additionally, GR vegetation protects the roof surface below from weather damage, doubling its lifespan on average (Carter & Keeler, 2008).

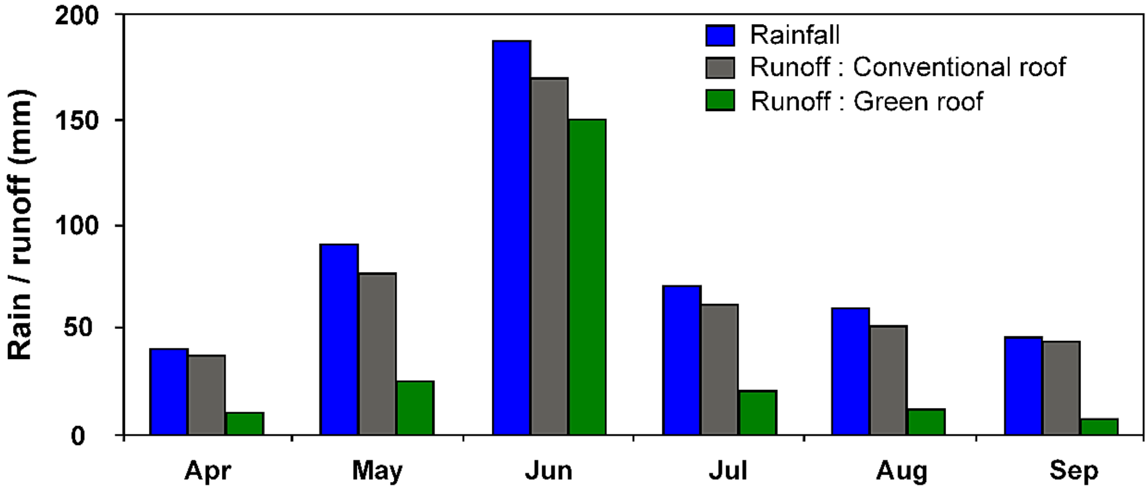


Figure 4. Storm-water runoff retention for an extensive GR in comparison to a conventional roof in Ottawa, Canada, in 2002. Created using data from Liu & Baskaran (2003).

2.3 | Improved Air Quality

Air pollution has decreased in Welsh urban areas since 1995, but there are still a number of days where air pollution exceeds National Air Quality Standards. On average these standards are exceeded 44 days/year in Port Talbot, and >15 days/year in Cardiff between 2008 and 2014 (Statistics for Wales, 2015a). The high surface area and roughness provided by GR vegetation not only naturally sequesters CO_2 (by up to 2% of local atmospheric concentrations; Li *et al*., 2010), but also acts an effective filter for PM_{10} and other air pollutants. Yang *et al*. (2008) found a GR in Chicago, U.S removed 8.5 g of air pollutants/m^2/year.

2.4 | Direct Economic Gain

If an area the size of Toronto's roofs (50 million m^2) was greened, Banting *et al.* (2005) find >$35 million would be saved per year in the benefit areas discussed above (Figure 5). Additionally, the average rent of homes in New York with GRs was 16% higher than homes with conventional roofs (Ichihara & Cohen, 2011). This may be even higher in the UK with an average 34% rise in property value with increased local greenery (CABE, 2005). A new GR industry may also reduce the high unemployment rate in Wales (Statistics for Wales, 2016), as GRs have created hundreds of new jobs per year in the U.S.A, through their installation, design and maintenance (GSA, 2011).

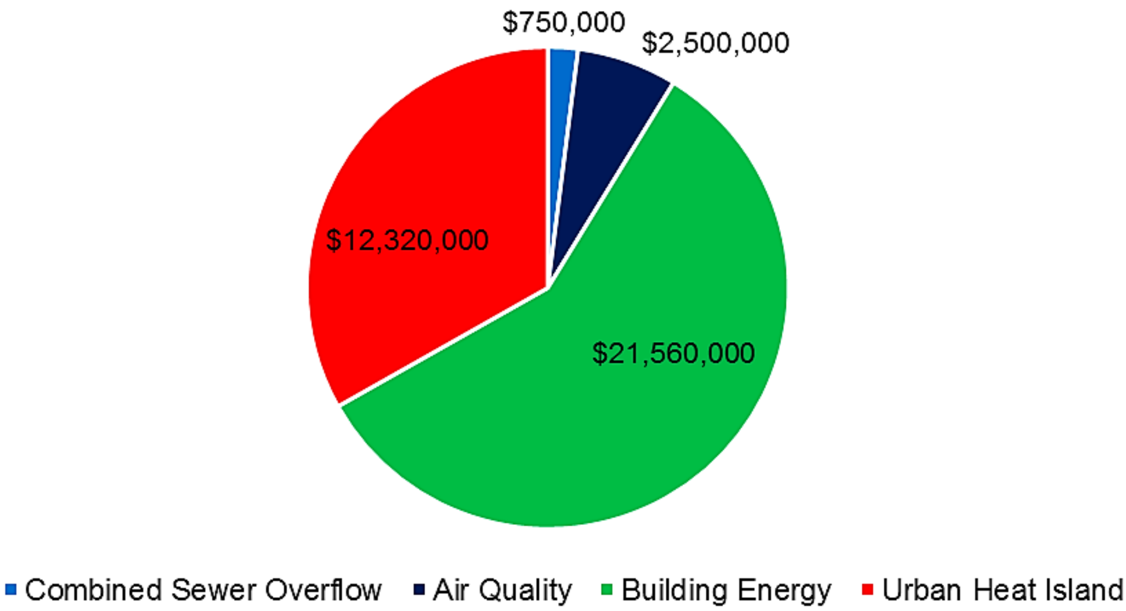


Figure 5. Modelled economic benefit of installing GRs throughout Toronto ($37,130,000). Created using data from Banting *et al*. (2005).

2.5 | Urban Biodiversity

GRs create 'vegetated islands' within the urban landscape, providing rare refuge against heat, wind and predators for invertebrates (Schindler *et al*., 2011), birds (Strohbach *et al*., 2009) and even bats (Parkins & Clark, 2015). For example, Kadas (2006) finds >120,000 invertebrates on an extensive GR in Canary Wharf, London, 10% of these were nationally scarce or rare species. Intensive GRs may facilitate greater biodiversity with increased vegetation and soil depth (Obendorfer *et al*., 2007). A review by Fernandez-Cañero & Gonzalez-Redondo (2010) finds 29 species of bird have been reported to breed and roost on GRs, with Velazquez (2005) finding some species previously absent, returned to an area following the construction of GRs.

2.6 | Enhanced Quality of Life

In Wales, the cost of mental illnesses are significantly high at >£7.2 billion a year (Friedli & Parsonage, 2009). The Welsh Government (2015b) prescriptions database reveals >4.7 million antidepressants were dispensed in Wales in 2014, costing >£19 million, due to a lack of alternatives (WTW, 2016). GRs could provide one of these much needed alternatives.

Simply living in view of nature is worth up to £300/person/year in health benefits (UK NEA, 2011). Multiple studies involving >1,200 people in total have shown increased exposure to nature resulted in better overall health and wellbeing (Barton & Pretty, 2010). Experimental studies have also linked reduced surgical recovery time (Ulrich, 1984), and reduced blood pressure (Hartig, 2003), with increased exposure to natural environments. On average, 10,000 individuals across Britain experience lower mental stress with increased green space in urban areas (White *et al*., 2013), with Lee *et al*. (2015) finding just a 40 second view of a GR increases attention retention in comparison to a conventional roof. Furthermore, unlike most urban surfaces, the vegetation and substrate of GRs absorb sound waves, reducing noise by up to 46 dB (Theodosiou, 2009), ie. the equivalent of reducing the noise of traffic to a running stream.

3. Green Roof Implementation

3.1 | Current Green Roof Policy & Legislation in Wales

Currently, there is no explicit statement of policy encouraging the use of GR in Wales. However, it is evident from Section 2 that GRs would support a wide range of key national policies and legislation. They would:

- Provide a Sustainable Drainage System (SuDs) under Schedule 3 of the UK Flood and Water Management Act (2010), and meet the aims of the Water Strategy for Wales (2015), to effectively mitigate flooding and maintain water quality.

- Ensure sustainable and more efficient buildings, whilst also increasing biodiversity and improving people's general well-being, thereby meeting the multiple aims of the Planning Policy Wales (PPW; 2016), the Well-being of Future Generations (Wales) Act (2015), and the Environment (Wales) Act (2016).

- Contribute to reducing GHG emissions by 80% by 2050 and mitigating environmental risks, such as UHI – key aims of the CCSW (Welsh Government, 2010) and the Environment (Wales) Act (2016).

- Progress the desired 'Green Growth' approach, broadening the current skills and industries base by developing a new green industry, and making Wales a more attractive and innovative place to live, work and establish businesses (Welsh Government, 2016).

3.2 | Public Perceptions of Green Roofs

Despite the high potential success of GRs, any new policies require public support to be fully successful and achieve its maximum potential (Campbell, 2012). As GRs in the UK are largely rare, understanding of national GR perception is limited, however the one study in the UK suggests GR are significantly more preferred and had a more positive affective quality than conventional roofs (White & Gatersleben, 2011). This is supported by the widespread appeal of GRs in areas such as Singapore (Wong *et al*., 2010) and Spain (Fernandez-Cañero *et al*., 2013). However, a review by Li & Yeung (2014) finds commonly reported barriers that influence GR public opinion and uptake, primarily:

- High installation costs
- Lack of government incentives
- Lack of awareness regarding the multiple benefits of GR
- GR design (eg. uniform colour decreases aesthetic appeal; Fernandez-Cañero *et al*., 2013).

3.3 | Installation Costs & Alternatives

Sproul *et al*. (2014) argue that the comparatively higher installation costs of GR will deter decision-makers, and advocate cheaper alternative roofing technologies, which are specifically designed to either increase reflectivity (white roofs; WR) or retain rainfall (blue roofs; BR). However, despite their uses, these cheaper, alternative roof technologies lack the multi-benefit characteristic associated with GRs (Table 3).

Table 3. Comparison of environmental services provided by GR, WR and BR, and the installation cost of each roof type. Ticks indicate services provided by roof type, with a cross indicating this service is not provided or has a negligible impact on that service, in comparison to conventional roofing. Created using data and reviews from (NYC Environmental Protection, 2007; Kolokotroni *et al*., 2013).

Roof Type	Environmental services provided by roof type:					
	Thermal Efficiency	Flood Mitigation	Increased Biodiversity	Improved Air/water Quality	Enhanced Aesthetics	Installation Cost (£/m^2)
GR	✓	✓	✓	✓	✓	80-140[a]
WR	✓	✗	✗	✗	✗	5-21[b]
BR	✗	✓	✗	✗	✗	3-5[b]

[a] – Lowest estimate based on the installation cost of the *Sedum* GR on St. David's, Cardiff (Land Securities, 2013), and highest based on a rough estimate by the Green Roof Centre (n.d) for an intensive roof.

[b] – Lacking data from the UK, thus estimations are based on \$/ft^2 data (converted to £/m^2 for comparability) from the U.S.A by EPA (2008a) for WR, and NYC Environmental Protection (2007) for BR.

A cost-benefit analysis, in 2006 American dollars, by Clark *et al*. (2008) find that 2,000 m^2 of extensive GR would cost \$464,000, over a third more to install versus a conventional roof (\$335,000). However, over its lifetime, a GR would save >\$200,000 (\$3,392/year), in benefits similar to those in Figure 5. Based on the average cost of extensive GR installation in Cardiff (Table 3) and adjusting this data by Clark *et al*. (2008) for inflation, green roofing just the building area of an 800 m^2 radius around Cardiff's city centre (Figure 6), would annually save £814,542 returning the installation costs (>£40 million) within ~50 years.

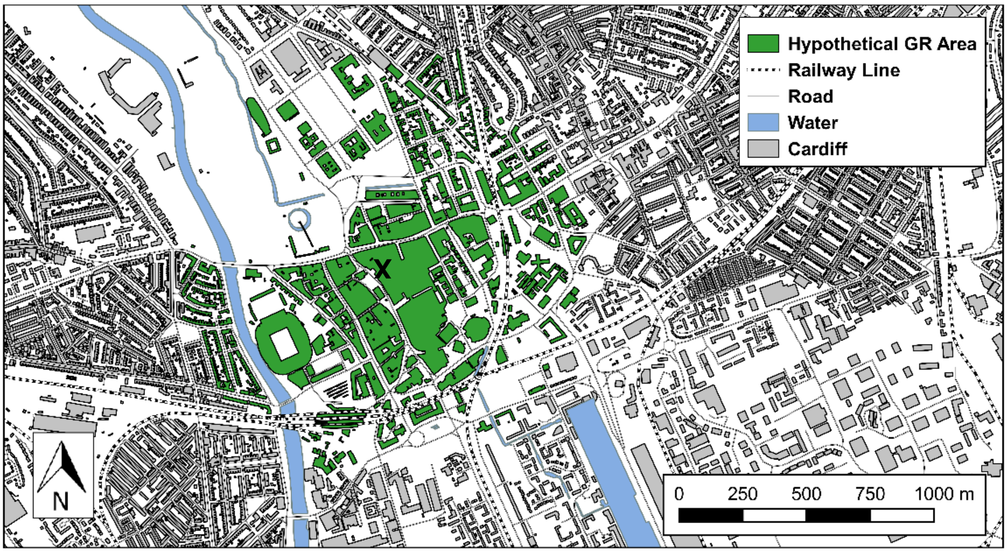


Figure 6. Hypothetical GR implementation in an 800 m^2 radius around Cardiff city centre (**X**). Data downloaded from the Digimap database (EDINA, 2016), with building area (and assumed approximate roof area; 586,755 m^2) calculated in QGIS (v. 2.12.2).

However, this return period is likely overestimated, with data lacking regarding the full economic gains in mental health benefits, or the gradual reduction in installation cost as the GR industry develops, as observed in Germany (>four times reduction) over the past 50 years (Philippi, 2006). Furthermore, the economic benefits of increased urban biodiversity and resilience to climate change remain unknown or unaccountable, but societally invaluable.

3.4 | Overcoming Barriers

A number of cities, and even countries (an estimated 14% of Germany was green roofed in 2001; Herman 2003), have successfully capitalised on the benefits of widespread GR installation, largely in response to policy/legislation and economic incentives (Table 4), counteracting most of the common barriers in Section 3.2. Incentives are key to prompt behaviour change, especially with the high cost and lack of short-term economic benefits of GRs (GLA, 2009). The success of GR economic incentives is illustrated in Portland, U.S.A where coverage more than doubled (24,300 to 57,745 m^2) within just 4 years (Table 4).

Additionally, incentives may extend beyond direct economic gain, by making GRs an attractive option for developers (Table 4). Implementation of these policies have been accompanied by awareness and involvement schemes, and best practices guidelines to support developers, and to ensure GR benefits were maximised (Kazmierczak & Carter, 2010).

Table 4. Latest estimates of GR coverage in cities of major GR utilising nations, and the measures behind their implementation. Stuttgart and Basel's coverage was estimated by Kazmierczak & Carter (2010), Düsseldorf's by the Umweltamt Landeshauptstadt Düsseldorf (2016), with Chicago and Toronto's coverage available from the City of Chicago (2016a) and City of Toronto (2016b), respectively. Portland's coverage was estimated by the EPA (2008b) up until 2007, and supplemented here with data from the City of Portland (2016).

Area	**GR coverage (m^2)**	**GR Measures**	
		Legislation/Policy	**Economic incentives**
Stuttgart, Germany	300,000	Section 8 of the Federal Nature Conservation Act (2009) & the German Federal Building Code (1997) enforces the preservation & provision of green spaces, such as GR, in urban areas	Subsidises 50% of the costs or a maximum of €17.90 (~£13)/m^2 (IGRA, 2015)
Düsseldorf, Germany	871,000		50% reduction in storm-water tax for owners with a GR (Umweltamt Landeshauptstadt Düsseldorf, 2016)
Basel, Switzerland	700,000	GRs are required on all new buildings with flat roofs, with some natural cover on roofs >500 m^2 (Nature and Landscape Conservation Act: Section 9; Building and Planning Act: Section 72)	GR projects receive CHF 20 (~£11)/m^2 in 1996-1997 and CHF 30-40 (£13-18)/m^2 (Brenneissen, 2008)
Toronto, Canada	196,000	Legal requirement for buildings with a floor size >2,000 m^2 (Toronto Municipal Code: Chapter 492 (2013))	GR projects receive CAN$75 (~£41)/$m^2$, up to a maximum of $100,000 (~£54,000; City of Toronto 2016a).
Chicago, U.S.A	516,950	Developments that receive assistance from the City must include sustainable elements such as a GR (Sustainable Development Policy)	Expedited & cheaper roof permit process with a GR (Green Permit Program; City of Chicago, 2016b)
Portland, U.S.A	57,745	Mandatory energy/water efficiency for new city owned buildings (Green Building Policy)	GR projects receive $50 (~£35)/$m^2$ under the 2008-2012 Ecoroof Incentive (City of Portland, 2016)

3.5 | Conclusions & Recommendations

GRs represent a multi-beneficial means to meet the various aims of the Welsh Government: to ensure a sustainable and resilient future for Wales, which is increasingly invaluable in the face of continued economic and climatic change. The Welsh Government should implement GRs in a similar way to the areas in Table 4. The following draft policy is a simplified version to be developed further, to fully benefit and reflect the aims of the Welsh Government:

Developers in Wales should incorporate GRs, where feasible. It is expected that this will include GR construction that delivers, and maximises, as many of these services as possible:

- **accessible, and/or improved appearance of, roof space**
- **mitigation of & adaptation to climate change**
- **SuDs**
- **increased biodiversity.**

In taking this policy forward, it is essential to develop preferred standards and guidelines for designers to adhere to, regarding how the various environmental benefits can be achieved (GLA, 2008). These guidelines could be developed using the GR code of best practice for the UK by GRO (2011). The Technical Advice Notes (TAN), which accompany the PPW (2016), provide planning advice on particular subjects, and represent the ideal documents to develop and disseminate GR guidelines/standards, either accompanying, or incorporated into, existing documents such as the TAN12: Design and/or TAN5: Nature Conservation and Planning.

Similar to areas in Table 4, GRs should be constructed on government/council-owned buildings and buildings over a certain size, to develop the GR industry, with education campaigns to engage with the public and fully raise awareness of GRs and their benefits. Meanwhile, the Welsh Government should also establish incentive schemes to further encourage uptake by mitigating installation costs and by offering expedited permit/license applications for GR developments. An indicative cost-benefit analysis in London, suggests a subsidy of ~£17/m^2 is justified by the quantifiable local environmental benefits of installing GRs (similar to those in Figure 5) in the UK (GLA, 2009). Funding sources for these incentives may include the £13 million set aside for 2016/2017, contributing to the £21 million previously allocated, by the Welsh Government and the EU as part of the ‘Green Growth Wales’ initiative (Welsh Government, 2015a; 2016). Given the benefits of storm-water management and energy saving, utility companies could also be involved in funding a GR programme, in a similar way to the Energy Saving Fund in Switzerland (Brenneissen, 2008). As the market grows, direct financial incentives may be withdrawn or reduced as installation costs reduce (GLA, 2009).

It is vital to ensure that a new GR policy supports current legislation, as opposed to replacing it, to ensure GRs are not misused to warrant activities that negate the benefits of GRs like natural habitat destruction. Reviewing this draft, and developing future policies, is essential to emulate the successes of other countries to implement GRs and make Wales a more resilient, prosperous and sustainable nation.

4 | References

Banting, D., Doshi, H., Li, J., Missios, P., Au, A., Currie, B. & Verrati, M. (2005) 'Report on the Environmental Benefits and Costs of Green Roof Technology for the City of Toronto' [Report]. Toronto: Ryerson University.

Barton, J. & Pretty, J. (2010) What is the Best Dose of Nature and Green Exercise for Improving Mental Health? A Multi-Study Analysis. *Environmental Science & Technology*, **44** (10): 3947-3955.

Bass, B. & Baskaran, B. (2003) 'Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas' [Report]. Ottawa: National Research Council Canada, Institute for Research in Construction.

Brenneissen, S. (2008) 'From Pilot to Mainstream: Green Roofs in Basel Switzerland'. In: Sixth Annual Greening Rooftops for Sustainable Communities Conference (April 30 – May 02; Baltimore). Available online at: http://www.greenroofs.org/grtok/policy_browse.php?id=63&what=view.

CABE. (2005) 'Does money grow on trees?' [Report]. Available online at: http://webarchive.nationalarchives.gov.uk/20110118095356/http://www.cabe.org.uk/files/does-money-grow-on-trees.pdf.

Campbell, A. (2012) Policy makes mass politics. *Annual Review of Political Science*, **15**: 333-351.

Cardiff Flood Risk Management Plan. (2015) 'Cardiff Flood Risk Management Plan' [Report]. Available online at: https://www.cardiff.gov.uk/ENG/resident/Community-safety/Flood-and-Coastal-Erosion-Risk-Management/Flood-Risk-Management-Plan/Pages/default.aspx.

Carter, J., Cavan, G., Connelly, A., Guy, S., Handley, J. & Kazmierczak, A. (2015) Climate change and the city: Building capacity for urban adaptation. *Progress in Planning*, **95**: 1-66.

Carter, T. & Keeler, A. (2008) Life-cycle cost–benefit analysis of extensive vegetated roof systems. *Journal of Environmental Management*, **87** (3): 350-363.

CCC. (2013) 'Progress reducing emissions and preparing for climate change in Wales' [Report]. London: Committee on Climate Change.

Chemisana, D. & Lamnatou, C. (2014) Photovoltaic-green roofs: an experimental evaluation of system performance. *Applied Energy*, **119**: 246-256.

Christidis, N., Jones, G. & Stott, P. (2015) Dramatically increasing chance of extremely hot summers since the 2003 European heatwave. *Nature Climate Change*, **5**: 46-50.

City & County of Swansea. (2003) '2001 Census Socio–Economic Profile' [Report]. Swansea: City & County of Swansea.

City of Chicago. (2016a) Chicago Green Roofs [Online]. Available at: http://www.cityofchicago.org/city/en/ depts/dcd/supp_info/chicago_green_roofs.html. [Access Date: 15/04/2016].

City of Chicago. (2016b) Overview of the Green Permit Program [Online]. Available at: http://www.cityofchicago.org/city/en/depts/bldgs/supp_info/overview_of_the_greenpermitprogram.html. [Access Date: 15/04/2016].

City of Portland. (2016) Ecoroof Incentive [Online]. Available at: https://www.portlandoregon.gov/bes/article/547491. [Access Date: 15/04/2016].

City of Toronto. (2016a) Eco-roof Incentive Program [Online]. Available at: http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=3a0b506ec20f7410VgnVCM10000071d60f89RCRD. [Access Date: 15/04/2016].

City of Toronto. (2016b) Green Roofs [Online]. Available at: http://www1.toronto.ca/wps/portal/contentonly?vgnextoid=3a7a036318061410VgnVCM10000071d60f89RCRD. [Access Date: 15/04/2016].

Clark, C., Adriaens, P. & Talbot, F. (2008) Green roof valuation: a probabilistic economic analysis of environmental benefits. *Environmental Science & Technology*, **42** (6): 2155-2161.

Conwy County Borough Council. (2003) '2001 Census key statistics: Wrexham' [Report]. Available online at: http://www.conwy.gov.uk/upload/public/attachments/534/Wrexham_2001_Census_area_profile.pdf.

DEFRA. (2012) 'A climate change risk assessment for Wales' [Report]. London: DEFRA.

EDINA. (2016) Digimap [Online]. Available at: http://digimap.edina.ac.uk/. [Access Date: 20/04/2016].

Ekşi, M. Uzun, A. (2013) Investigation of thermal benefits of an extensive green roof in Istanbul climate. *Scientific Research and Essays*, **8** (15): 623-632.

EPA. (2008a) 'Reducing Urban Heat Islands: Compendium of Strategies – Cool Roofs' [Report]. Washington, D.C: U.S. Environmental Protection Agency.

EPA. (2008b) 'Reducing Urban Heat Islands: Compendium of Strategies - Green Roofs' [Report]. Washington, D.C: U.S. Environmental Protection Agency.

Fernandez-Cañero, R, Emilsson, T., Fernandez-Barba, C. & Herrera Machuca, M. (2013) Green roof systems: a study of public attitudes and preferences in southern Spain. *Journal of Environmental Management*, **128**: 106-115.

Fernandez-Cañero, R. & Gonzalez-Redondo, P. (2010) Green Roofs as a Habitat for Birds: A Review. *Journal of Animal and Veterinary Advances*, **9** (15): 2041-2052.

Friedli, L. & Parsonage, M. (2009) 'Promoting mental health and preventing mental illness: the economic case for investment in Wales; [Report]. Available online at: http://www.publicmentalhealth.org/Documents/749/Promoting%20Mental%20Health%20Report%20%28English%29.pdf.

Garrison, N., Horowitz, C., Lughino, C., Devine, J. & Beckman, D. (2012) 'Looking Up: How Green Roofs and Cool Roofs Can Reduce Energy Use, Address Climate Change, and Protect Water Resources in Southern California' [Report]. New York: NRDC.

GLA. (2009) 'Economic incentive schemes: for retrofitting London's existing homes for climate change impacts' [Report]. London: Greater London Authority.

Green Roof Centre. (n.d) Green Roof FAQ [Online]. Available at: http://www.thegreenroofcentre.co.uk/green_roofs/faq. [Access Date: 20/04/2016].

Gregoire, B. & Clausen, J. (2011) Effect of a modular extensive green roof on stormwater runoff and water quality. *Ecological Engineering*, **37**: 963-969.

GRO. (2011) 'The GRO green roof code: Green roof code of best practice for the UK 2011' [Report]. Sheffield: Groundwork.

Growing Green Guide. (2016) Green Roofs [Online]. Available at: http://www.growinggreenguide.org/technical-guide/construction-and-installation/green-roofs/. [Access Date: 20/04/2016].

GSA. (2011) 'The Benefits and Challenges of Green Roofs on Public and Commercial Buildings: A Report of the United States General Services Administration' [Report]. London: ARUP.

Hartig, T., Evans, G., Jamner, L., Davis, D. & Garling, T. (2003) Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology*, **23**:109-123.

Herman, R. (2003) Green roofs in Germany: yesterday, today and tomorrow. In: Greening Rooftops for Sustainable Communities. (29-30 May, Chicago: 41-45).

Ichihara, K. & Cohen, J. (2011) New York City property values: what is the impact of green roofs on rental pricing?. *Letters in Spatial and Resource Sciences*, **4** (1): 21-30.

IGRA. (2015) 'International Green Roof City Network Case Study: Stuttgart, Germany' [Report]. Available online at: http://www.igra-world.com/images/city_network/IGRN-Case-Study-Stuttgart-IGRA.pdf.

Kadas, G. (2006) Rare Invertebrates Colonizing Green Roofs in London. *Urban Habitats*, **4** (1): 66-86.

Kazmierczak, A. & Carter, J. (2010) 'Adaptation to climate change using green and blue infrastructure. A database of case studies' [Report]. Manchester: Manchester University.

Kolokotroni, M., Gowreesunker, B. & Giridharan, R. (2013) Cool roof technology in London: An experimental and modelling study. *Energy and Buildings*, **67**: 658-667.

Kovats, R., Valentini, R., Bouwer, L., Georgopoulou, E., Jacob, D., Martin, E., Rounsevell, M. & Soussana, J-F. (2014) 'Europe'. In: Barros, V., Field, C., Dokken, D., Mastrandrea, M., Mach, K., Bilir, T., Chatterjee, M., Ebi, K., Estrada, Y., Genova, R., Girma, B., Kissel, E., Levy, A., MacCracken, S., Mastrandrea, P. & White, L. (eds). 'Climate Change 2014: Impacts, Adaptation and Vulnerability. Part B: Regional Aspects' [Report]. Cambridge: Cambridge University Press.Met Office & CEH. (2014) 'The Recent Storms and Floods in the UK' [Report]. Exeter: Met Office.

Land Securities. (2013) 'St. David's, Cardiff: Green Roof' [Report]. Available online at: https://www.bcsc.org.uk/documents/view?id=169.

Lee, K., Williams, K., Sargent, L., Williams, N., & Johnson, K. (2015). 40-second green roof views sustain attention: The role of micro-breaks in attention restoration. *Journal of Environmental Psychology*, **42**: 182-189.

Li, J-F., Wai, O., Li, Y., Zhan, J-M., Ho, Y., Li, J. & Lam, E. (2010) Effect of green roof on ambient CO_2 concentration. *Building and Environment*, **45** (12): 2644-2651.

Li, W. & Yeung, K. (2014) A comprehensive study of green roof performance from environmental perspective. *International Journal of Sustainable Built Environment*, **3** (1): 127-134.

Li, Y. & Babcock, R. (2014) Green roof hydrologic performance and modelling: a review. *Water Science Technology*, **69** (4): 727-738.

Liu, K. & Baskaran, B. (2003) 'Thermal Performance of Green roofs through Field Evaluation—Ottawa' [Report]. Ottawa: National Research Council Canada, Institute for Research in Construction.

Meinhausen, M., Smith, S., Calvin, K., Daniel, J., Kainuma, M., Lamarque, J., Matsumoto, K., Montzka, S., Raper, S., Riahi, K., Thomson, A., Velders, G. & van Vuuren, D. (2011) The RCP greenhouse gas concentrations and their extensions from 1765 to 2300. *Climatic Change*, **109**: 213-241.

Met Office. (2016) Download regional values [Online]. Available at: http://www.metoffice.gov.uk/climate/uk/summaries/datasets. [Access Date: 09/04/2016].

National Assembly for Wales. (2008) 'Key Statistics for Newport' [Report]. Cardiff: National Assembly for Wales.

Niachou, A., Papakonstantinou, K., Santamouris, M., Tsangrassoulis, A. & Mihalakakou, G. (2001) Analysis of the green roof thermal properties and investigation of its energy performance. *Energy and Buildings*, **33** (7): 719-729.

NYC Environmental Protection. (2007) 'Stormwater Management Through Sound Land Use' [Report]. New York: New York City Department of Environmental Protection.

Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R., Doshi, H., Dunnett, N., Gaffin, S., Kohler, M., Liu, K. & Rowe, B. (2007) Green roofs as urban ecosystems: Ecological structures, functions, and services. *BioScience*, **57** (10): 823-833.

Ohashi, Y., Genchi, Y., Kondo, H., Kikegawa, Y., Yoshikado, H. & Hirano, Y. (2007) Influence of Air-Conditioning Waste Heat on Air Temperature in Tokyo during Summer: Numerical Experiments

Using an Urban Canopy Model Coupled with a Building Energy Model. *Journal of Applied Metrology and Climatology*, **46**: 66-81.

ONS. (2004) '2004 Local Authority studies: Analysis of data and evidence for Cardiff' [Report]. Newport: Office for National Statistics.

ONS. (2011) *Table KS101UK: 2011 Census, Key Statistics and Quick Statistics for local authorities in the United Kingdom - Part 1* [Database]. Available online at: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/publications/re-reference- tables.html?e dition=tcm%3A77-327143.

ONS. (2013a) '2011 Census: Characteristics of Built-Up Areas' [Report]. Newport: Office for National Statistics. Available online at: http://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/characteristicsofbuiltupareas/2013-06-28.

ONS. (2013b) '2011 Census Analysis - Comparing Rural and Urban Areas of England and Wales' [Report]. Newport: Office for National Statistics. Available online at: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/dcp171776_337939.pdf.

Parkins, K. & Clark, J. (2015) Green roofs provide habitat for urban bats. *Global Ecology and Conservation*, **4**: 349-357.

Perry, S., Arnell, N., Berry, P., Dodman, D., Fankhauser, S., Hope, C., Kovats, S., Nicholls, R., Satterthwaite, D., Tiffin, R. & Wheeler, T. (2009) 'Assessing the costs of adaptation to climate change' [Report]. London: International Institute for Environment and Development.

Philippi, P. (2006) How to get cost reduction in green roof construction. In: Greening Rooftops for Sustainable Communities Conference (May 11 – 12; Boston). Available online at: https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=2&cad=rja&uact=8&ved=0ahUKEwjwyND9haPMAhUpKsAKHVBZC8cQFggjMAE&url=http%3A%2F%2Fwww.greenrooftechnology.com%2F_literature_53259%2FHow_to_Get_Cost_Reduction_in_Green_Roof_Construction&usg=AFQjCNEcV7vBvQirjRu-DcBubCijWur7wA&sig2=aPrZ957Q6icWFiS0NN5I-Q.

Poë, S., Stovin, V. & Berretta, C. (2015) Parameters influencing the regeneration of a green roof's retention capacity via evapotranspiration. *Journal of Hydrology*, **523**: 356-367.

Public Health Wales. (2012) 'Green space, reduction of health inequities, and cost effectiveness of interventions' [Report]. Cardiff: Welsh Government.

Schindler, B., Griffith, A. & Jones, K. (2011) Factors Influencing Arthropod Diversity on Green Roofs. *Cities and the Environment (CATE)*, **4** (1): Article 5.

Sproul, J., Wan, M., Mandel, B. & Rosenfeld, A. (2014) Economic comparison of white, green, and black flat roofs in the United States. *Energy and Buildings*, **71**: 20-27.

Statistics for Wales. (2014) 'Household projections for Wales (2011-based)' [Report]. Cardiff: Welsh Government.

Statistics for Wales. (2015a) *12. Air quality - Days when air pollution is moderate or higher (ENV)* [Database]. Available online at: https://statswales.wales.gov.uk/ Catalogue/Sustainable-

Development/Sustainable-Development-Indicators/NumberOfDaysWithModerateOrHigherPollutionLevels.

Statistics for Wales. (2015b) ‘Sustainable Development Indicators, 2015’ [Report]. Cardiff: Welsh Government

Statistics for Wales. (2016) ILO unemployment rates by Welsh local areas and year [Online]. Available at: https://statswales.wales.gov.uk/Catalogue/Business-Economy-and-Labour-Market/People-and-Work/Unemployment/ILO-Unemployment/ilounemploymentrates-by-welshlocalareas-year. [Access Date: 20/04/2016].

Stocker, T., Qin, D., Plattner, G-K., Tignor, M., Allen, S., Boschung, J., Nauels, A., Xia, Y., Bex, V. & Midgley, P. (2013) ‘Climate Change 2013 The Physical Science Basis’ [Report]. Cambridge: Cambridge University Press.

Strohbach, M., Haase, D. & Kabisch, N. (2009) Birds and the city: urban biodiversity, land use, and socioeconomics. *Ecology and Society*, **14** (2): 31.

Theodosiou, T. (2009) Green Roofs in Buildings: Thermal and Environmental Behaviour. *Advances in Building Energy Research*, **3**: 271-288.

UK NEA (2011) ‘The UK National Ecosystem Assessment: Technical Report’ [Report]. Cambridge: UNEP-WCMC.

Ulrich, R. (1984) View through a window may influence recovery from surgery. *Science*, **224** (4647): 420-421.

Umweltamt Landeshauptstadt Düsseldorf. (2016) Themen im Focus – Dachbegrünung [Online]. Available at: http://www.duesseldorf.de/umweltamt/luft/stadtklima/dachbegruenung.shtml. [Access Date: 23/04/2016].

UN. (2014) ‘World Urbanization Prospects: Highlights’ [Report]. New York: United Nations.

Velazquez, L. (2005) Organic greenroof architecture: Sustainable design for the new millennium. *Environmental Quality Management*, **14** (4): 73-85.

Waterford, D. (2015) 21st Century Homestead: Urban Agriculture. Raleigh: Lulu.

Watkiss, P., Hunt, A. & Savage, M. (2014) ‘Early Value-for-Money Adaptation: Delivering VfM Adaptation using Iterative Frameworks and Low Regret Options’ [Report]. Oxford: Global Climate Adaptation Partnership.

Welsh Government. (2010) ‘Climate Change Strategy for Wales’ [Report]. Cardiff: Welsh Government.

Welsh Government. (2015a) ‘Green Growth Wales: Investment Support’ [White Paper]. Cardiff: Green Growth Wales.

Welsh Government. (2015b) *Prescriptions dispensed in the community* [Database]. Available online at: http://gov.wales/statistics-and-research/prescriptions-dispensed-community/?lang= en.

Welsh Government. (2016) 'The business of becoming a sustainable nation' [Report]. Available online at: http://gov.wales/docs/det/publications/160412-business-of-becoming-a-sustainable-nation-en.pdf.

Wilby, R. (2003) Past and projected trends in London's urban heat island. *Weather*, **58**, 251-260.

WTW. (2016) 'Green Infrastructure: A Catalyst for the Well-being of Future Generations in Wales' [Report]. Available online at: http://www.wtwales.org/sites/default/files/green_infrastructure.pdf.

White, E. & Gatersleben, B. (2011) Greenery on residential buildings: Does it affect preferences and perceptions of beauty?. *Journal of Environmental Psychology*, **31**: 89e98.

White, M., Alcock, I., Wheeler, B. & Depledge, M. (2013) Would You Be Happier Living in a Greener Urban Area? A Fixed-Effects Analysis of Panel Data. *Psychological Science*, **24** (6): 920-928.

Wong, G. & Jim, C. (2014) Quantitative hydrologic performance of extensive green roof under humid-tropical rainfall regime. *Ecological Engineering*, **70**: 366-378.

Wong, N., Tan, A., Tan, P., Sia, A. & Wong, N. (2010) Perception studies of vertical greenery systems in Singapore. *Journal of Urban Planning and* Development, **136**: 330-338.

Yang, J., Yu, Q. & Gong, P. (2008) Quantifying air pollution removal by green roofs in Chicago. *Atmospheric Environment*, **42** (31): 7266–7273.