TURAS green roof design guidelines:

Maximising ecosystem service provision through regional design for biodiversity

TURAS

London Borough of Barking & Dagenham

BARKING RIVERSIDE

Institute for Sustainability

LivingRoofs

UEL University of East London

TURAS green roof design guidelines: Maximising ecosystem service provision through regional design for biodiversity

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Executive summary

- Transitioning Towards Urban Resilience and Sustainability (TURAS) is an FP7 funded European-wide research and development programme with the aim of enabling European cities and their rural interfaces to build vitally-needed resilience in the face of significant sustainability challenges through Knowledge Transfer Partnerships.
- The increasing proportion of people living in urban areas has led to a range of environmental issues and sustainability challenges. In order to ensure that urban living is sustainable and that cities have the resilience to cope with environmental change these challenges must be met.
- Restoration and re-creation of green infrastructure in urban areas is a potential solution to many of these challenges and in high density urban areas with little usable space at ground level, roof level green infrastructure has perhaps the greatest potential to contribute to re-greening urban areas.
- Given the increasing recognition that the natural environment can provide goods and services of benefit to humans and the planet ('ecosystem services'), and that these services can provide resilience for urban areas, the European Commission is now advocating well-planned green infrastructure that provides opportunities to protect and enhance biodiversity.
- In order to maximise biodiversity, and the associated ecosystem services, in urban areas it is necessary to incorporate local and regional environmental context into the design of urban green infrastructure.
- Unfortunately, the majority of green roof installations in London, across Europe and beyond are 'off-the-shelf' industry standard systems predominantly designed for aesthetics and stormwater attenuation and an assumption is made that by installing something green a range of additional ecosystem services will be restored.
- The resulting lack of plant diversity and habitat structure means that these green roof systems offer restricted biodiversity and associated ecosystem service benefits and mean that opportunities are missed for supporting urban biodiversity and building the associated resilience that biodiversity can provide.
- In order to ensure that further opportunities are not missed, it is necessary to take a local view of key ecosystems and habitats and incorporate these into green roof design using biomimicry.
- The following report details a Knowledge Transfer Partnership (KTP) established in Barking Riverside (London, UK) between Barking Riverside Ltd, the London Borough of Barking and Dagenham, Livingroofs.org, the University of East London and the Institute for Sustainability to establish whether there is a 'cost' associated with shifting away from industrial standard green roofs designed for SuDs towards more biodiverse systems designed based on regional habitat characteristics.

- An investigation was carried out using trial green roof test systems to compare the effect on performance in terms of a number of ecosystem services of moving away from an industrial standard sedum system to a more biodiverse green roof system comprising wildflowers typical of the Barking Riverside development area and of value to regional biodiversity of national conservation importance.
- Of the ecosystem service performances monitored, summarised results of water attenuation, thermal and biodiversity performance are included in the report.
- Rather than demonstrating an ecosystem service cost associated with moving away from industrial standard systems, the biodiverse green roof systems performed as well as or superior to the equivalent sedum systems for water attenuation and thermal insulation and far out-performed the sedum systems in terms of supporting a diverse flora.
- Results from the investigation are being fed into the design of green roofs throughout the Barking Riverside development.
- It is hoped that this KTP will act as a blue print for use throughout the TURAS partnership and beyond to promote the use of biomimicry of regional habitat of conservation value in the design of green roofs to maximise urban biodiversity.

1. Background

1.1 TURAS

Transitioning Towards Urban Resilience and Sustainability (TURAS) is an FP7 funded European-wide research and development programme. The “TURAS” project aims to bring together urban communities, researchers, local authorities and SMEs to research, develop, demonstrate and disseminate transition strategies and scenarios to enable European cities and their rural interfaces to build vitally-needed resilience in the face of significant sustainability challenges (Collier *et al*. 2013). To ensure maximum impact, the TURAS project has developed an innovative twinning approach bringing together decision makers in local authorities with SMEs and academics to ensure meaningful results and real change are implemented over the duration of the project. Eleven local authorities or local development agencies are involved as partners in the project and they will orient research and development from the outset towards the priority sustainability and resilience challenges facing their cities. Nine leading academic research institutions and six SMEs will work with these cities helping them to reduce their urban ecological footprint through proposing new visions, feasibility strategies, spatial scenarios and guidance tools to help cities address these challenges. The specific challenges addressed in TURAS include: climate change adaptation and mitigation; natural resource shortage and unprecedented urban growth.

Over the five year duration of the project, the feasibility of these new approaches will be tested in selected case study neighbourhoods. The impact of these new approaches will be measured and results compared between participating cities before a final set of strategies and tools will be developed for demonstration, dissemination and exploitation in other European cities. This report represents a dissemination tool from Work Package 2 (WP2) of TURAS - Greening Public and Private Urban Infrastructure. The aim of WP2 is to develop new visions, feasibility strategies, spatial scenarios and guidance tools to enhance the biodiversity and ecosystem service benefits of urban green infrastructure. This report represents an overview of the green roof design research carried out as part of TURAS to investigate the effect on ecosystem service provision of designing green roofs for regional biodiversity.

1.2 Urban Green Infrastructure

"*Green Infrastructure (GI) is the network of natural and semi-natural areas, features and green spaces in rural and urban, terrestrial, freshwater, coastal and marine areas*" (Naumann *et al*., 2011)

We live in an increasingly urbanised world where more than half the population already live in urban areas (United Nations 2012), and in England over 80% of people now live in towns and cities (UK National Ecosystems Assessment 2012). Built upon old models of high-density living and economic development, towns and cities suffer numerous environmental impacts associated with the loss of biodiversity (White 2002; Grimm et al. 2008; Pickett et al. 2011; Cook-Patton & Bauerle 2012):

- cities represent major consumers of energy;
- urban heat island effect leads to problems with air quality, energy use and ambient temperatures;
- large expanses of impervious surfaces result in rapid rainwater run-off and overloading of storm drains and increases the tendency of rivers to overtop their banks and flood surrounding land (Environment Agency 2002; Villareal *et al*. 2004; Mentens *et al*. 2006);
- quality and quantity of water held in the soil immediately beneath the hard surfaces is reduced;
- surface seepage to re-charge groundwater aquifers is reduced;
- effective desert conditions are created for wildlife squeezed between urban expansion and agricultural intensification;
- significantly reduced possibilities for contact with nature resulting in a reduction in the health and well-being of communities (English Nature 2003; Fuller & Irvine 2010).

The incorporation of green infrastructure into cities can help alleviate these problems and contribute to the provision of ecosystem services. A number of studies have researched the environmental and associated economic benefits that urban green infrastructure can provide, including stormwater amelioration and pollution uptake (Mann 2000; Mentens *et al*., 2006; Schroll *et al*., 2011; Nagase & Dunnett, 2012), urban heat island mitigation and energy conservation (Ernst and Weigerding 1985; Von Stülpnagel *et al*. 1990; Takakura *et al*. 2000; Bass *et al*. 2002; ; Niachou *et al*. 2001 Wong *et al*. 2003; Alexandri & Jones 2008; Bowler *et al*. 2010; Castleton *et al*. 2010; Lundholm *et al*. 2010), and a resource for urban biodiversity (Pickett *et al*. 2001; English Nature 2003; Grant *et al*. 2003; Baumann 2006; Brenneisen 2006; Köhler 2006; Schrader & Böning 2006; Schochat *et al*. 2006; Cadenasso *et al*. 2007; Kadas 2007; Hunter & Hunter 2008; Tonietto *et al*. 2011). These functions form an essential component of delivering sustainable development and their value is likely to become even more pertinent with the predicted future challenges posed by climate change.

1.3 Design with regional context

Green infrastructure in the built environment has traditionally been designed with limited consideration for biodiversity or regional context. Instead, a blend of horticultural fascination with exotic species, ease of maintenance, accessibility and an innate desire to control nature have led to aesthetic appeal and amenity value being the key drivers for urban greenspace design (Eisenberg 1998). Even selection of species suited to local climates has been limited with artificial irrigation and heavy management of urban landscapes common place.

Given the increasing recognition that the natural environment can provide goods and services of benefit to humans and the planet ('ecosystem services'), the European Commission and the UK government are now advocating well-planned green infrastructure that provides opportunities to protect and enhance biodiversity (UK National Ecosystem Assessment 2011; DEFRA 2011; HM Government 2011; Town and Country Planning Association and The Wildlife Trusts 2012; Secretariat of the Convention on Biological Diversity 2012; European Commission 2013). In response to this, there is a need to develop and monitor 'novel', biodiversity-focused designs for green infrastructure at roof, wall and ground-level, and investigate its contribution to urban biodiversity. The key first step to maximising the resilience and sustainability in such a process is ensuring that design is based on regional context both in terms of being climate and climate adaptation resilient and relevant to regional biodiversity of national and international conservation value. The 'added value' of such a biodiversity-focused climate resilient approach beyond biodiversity and ecosystem service benefits being more sustainable urban GI management with reduced requirements for fossil fuel use, artificial irrigation, and fertilizer and pesticide input.

2. Green roofs

2.1 Background

Roof tops in cities represent a significant unused space. Adding green (vegetated) roofs to buildings can provide environmental and economic benefits without reducing space available for development at ground level. The practice of adding vegetation to the roofs of buildings dates back centuries and the Nordic tradition of covering roofs with turf continues to the present (Grant 2006b). In more recent times, the term 'green roof' has been adopted and refers to a building roof which has been deliberately vegetated, typically with a commercially manufactured system comprising growing medium and plants.

Green roofs are generally characterised into two types, 'intensive' and 'extensive'. Intensive roofs tend to have deeper substrates (>200 mm) which can support shrubs and trees and generally they have the appearance of 'roof gardens'. Typically they require significant management and maintenance in terms of irrigation and fossil fuel use. Extensive green roofs typically have a shallower substrate layer (<150 mm), support low-growing, drought-tolerant plants and require low maintenance.

For reasons of cost, weight and maintenance, extensive green roofs are the most commonly adopted green roof format. A standard extensive green roof construction consists of: (1) a waterproofing and root resistant barrier; (2) a drainage layer which also acts as a water reservoir; (3) a filter membrane to prevent sediment blocking the drainage layer; (4) a growing medium (substrate); and (5) a vegetation layer (Figure 1).

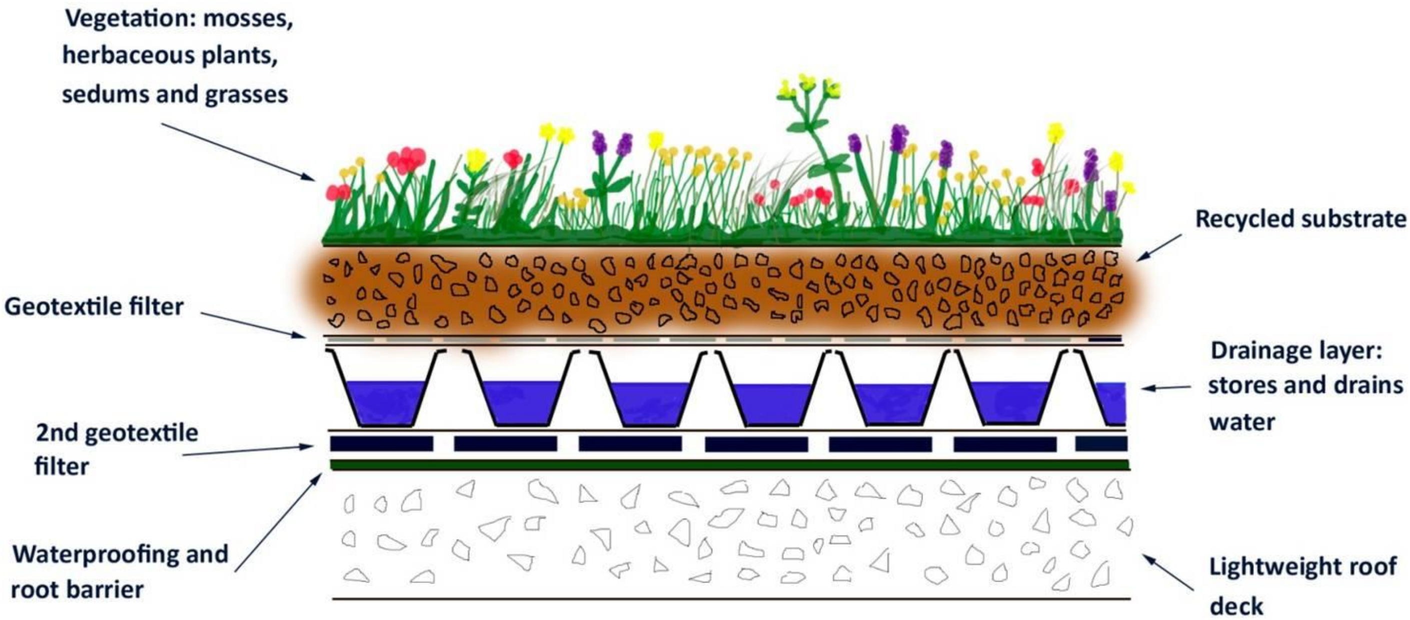


Figure 1. Typical extensive green roof design

Mirroring the pattern of ground level urban greenspace design, to date, the majority of green roof installations in London, across Europe and beyond are 'off-the-shelf' industry standard designs. Typically these feature shallow-substrate sedum-dominated extensive systems designed predominantly for aesthetics and stormwater attenuation (Dunnett and Kingsbury 2004; Snodgrass and Snodgrass 2006; Grant 2006a). Sedums are generally selected due to their drought-resistance enabling them to be tolerant of free draining SuDs system rooftop conditions and thus maintain a year-round perceived aesthetic. This focus on a narrow vegetation group means that the number and type of species in these systems is limited compared to the natural ecological communities green roofs are designed to mimic. The resulting lack of plant diversity and habitat structure means that these systems offer restricted biodiversity and associated ecosystem service benefits (Kadas 2007; Gedge *et al*. 2012; Cook-Patton & Bauerle 2012).

2.2 Designing for biodiversity

Research on alternative green roof systems which have used deeper substrates, undulating topography, and a variety of vegetation (‘biodiverse’ roofs), has shown that even modest modifications to the ‘standard’ green roof design can result in a wider variety of species utilising a roof (Brenneisen 2006; Köhler 2006; Gong 2007; Kadas 2007; Baumann & Kasten 2010; Tonietto *et al*. 2010). Key to the success of these studies was the technique of incorporating biomimicry into the design of green roofs by incorporating habitat features typical of regionally important habitats for nature conservation.

The majority of these studies have focused on recreating habitat features which mimic the exposed and arid characteristics of brownfield (post-industrial) sites. In intensively managed urban and rural environments, brownfield sites often represent some of the only remaining fragments of 'wildspace' in the landscape. This unmanaged nature of the sites lends itself to being able to support biodiversity of national and international conservation value and this value has been recognised internationally (Harvey 2000; Harabiš *et al.* 2013).

Typically comprising a blend of friable substrates and pockets of contamination, many brownfield sites represent open flower-rich resources with no management intervention that lend themselves to supporting many warmth-loving species at the edge of their range. Such is the value of the habitat in otherwise heavily managed urban and rural landscapes that, in the UK, the habitat typical of the highest quality brownfield sites has been characterised and recently been included in the new list of UK Biodiversity Action Plan (BAP) priority habitats (Riding *et al*. 2010) as Open Mosaic Habitats on Previously Developed Land.

The value of brownfield sites is the complexity of microhabitats within the wider mosaic, which support species throughout their lifecycles (Bodsworth *et al*. 2005). In much of the literature describing wildlife-rich brownfield sites, ephemeral pools/standing water, seasonal wet areas or inundation communities are described as essential components of the brownfield mosaic (Bodsworth *et al*. 2005; Buglife, 2009; Riding *et al*. 2010). This habitat mosaic is thus something that should be aspired to through biomimicry in green roof design. Green roofs are typically stressed exposed environments that lend themselves well to the creation of open flower-rich environments with bare areas and also, potentially, ephemeral wet areas.

With an increasing body of evidence to suggest that green roofs are able to support broad biodiversity if designed appropriately (Brenneisen 2006; Köhler 2006; Gong 2007; Kadas 2007; Baumann & Kasten 2010; Tonietto *et al*. 2010) and increasing recognition that rich biodiversity in cities can have enormous potential to mitigate the effects of climate change making them more sustainable and resilient (Secretariat of the Convention on Biological Diversity 2012) why are the majority of green roofs still incorporating industrial standard sedum systems rather than biomimicry of typically regional habitat of conservation value?

The simple answer appears to be that green roofs are installed predominantly as Sustainable Urban Drainage Systems designed to manage rainfall runoff from roofs, particularly when included in a development that involves moving from a greenfield or brownfield to hard landscaped state. Under such a scenario little consideration is put into their value for supporting regional biodiversity and rather an assumption of the intrinsic attributes of green roofs to support biodiversity is relied upon (Simmons *et al*. 2008) meaning that substantial biodiversity benefits can be missed. But is there a 'cost' associated with shifting away from green roofs designed for SuDs towards more biodiverse systems designed based on regional habitat characteristics? In order to answer this, it is necessary to carry out regional investigations of how green roofs design for biodiversity affect other green roof ecosystem service provisions.

A Knowledge Transfer Partnership was established in London between Barking Riverside Ltd, the London Borough of Barking and Dagenham, Livingroofs.org, the University of East London and the Institute for Sustainability to establish a protocol for investigating this question and to act as a blue print for use throughout the TURAS partnership and beyond to promote the use of biomimicry of regional habitat of conservation value in the design of green roofs to maximise urban biodiversity.

3. Case study example – Barking Riverside Knowledge Transfer Partnership

3.1 The London context

In its new National Planning Policy Framework (NPPF), the UK coalition government recommends that development be channelled towards urban areas and encourages the 'recycling of derelict and other urban land' (DCLG 2012). Derelict, previously developed land is commonly termed 'brownfield' land. In recent times, there has been recognition that a number of urban brownfield sites support distinctive and unique wildlife assemblages of significant conservation value (Gilbert 1989; Eversham *et al*. 1996; Gibson 1998; Harvey 2000; Eyre *et al*. 2003; Roberts *et al*. 2006). These sites contain an open mosaic of successional habitats which provide a dynamic and heterogeneous landscape, often of greater biodiversity value than intensively managed green spaces such as parks and agricultural land (Gibson 1998; Chipchase & Frith 2002; Roberts *et al*. 2006; Lorimer 2008; Buglife 2009). Consequently, if redevelopment of brownfield land is to be environmentally sustainable, the ecologically valuable features of these sites must be incorporated into landscape design both at ground and roof level through the provision of innovative brownfield landscaping, green walls and biodiverse green roofs (Connop *et al*. 2011).

Given that urban intensification is a key principle of planning policy in England, and brownfield land is under the greatest pressure to fulfil this target, there is a need to find innovative green infrastructure solutions that can: (a) be incorporated into high-density urban areas; and (b) benefit brownfield communities of conservation value. Incorporating vegetated (green) roofs and walls, and 'wildlife friendly' soft landscaping into new and existing urban developments provides an opportunity for the government to meet its commitments to GI and sustainable development (DCLG 2012; HM Government 2011).

3.2 Barking Riverside

Barking Riverside in the London Borough of Barking and Dagenham, East London represents an example of just such a site. The Barking Riverside site was a 443 acre brownfield site situated in the south of the borough sandwiched between a major trunk road that is heavily used for freight traffic and a heavily industrialised but strategically important employment area. The site was identified for its potential for the creation of a new sustainable community comprising:

- 10,800 new units;
- 1 district centre;
- 3 schools;
- 25,000 new residents planned over the 20 year build.

In addition to the enormous potential of the site for development in line with National Planning Policy Framework, the planning process also recognised the value of the greenfield state of the site in terms of local ecosystem service provision. This included its value as accessible greenspace for health & well-being, pluvial and fluvial stormwater management and significant biodiversity value including numerous rare and protected species (such as water voles, grass snakes, bumblebees and numerous birds).

In recognition of this ecosystem service value, the planning consent set out a number of conditions to ensure sustainability was interwoven in all aspects of the development. This included:

- the development of sustainable public transport infrastructure;
- the conservation of the site's valuable biodiversity;
- the retention of 40% of the site as green space;
- the development of a comprehensive Sustainable Urban Drainage (SuDS) master plan including the use of green roofs on 40% of the properties combined with swales, rain gardens, balancing ponds and the existing creek network.

As part of the process of ensuring that sustainability was at the core of the design of the Barking Riverside development a Knowledge Transfer Partnership has been established at Barking Riverside between Barking Riverside Ltd, the London Borough of Barking and Dagenham, Livingroofs.org, the University of East London and the Institute for Sustainability to investigate how green infrastructure design can increase the sustainability and resilience of the development as part of the TURAS FP7 programme.

It is hoped that the work that is carried out by TURAS at Barking Riverside will provide practical pointers as to how the new and very diverse community can be established while being able to accommodate the very real challenges of living alongside industry and supporting sustainable and resilient biodiverse rich green infrastructure.

3.3 The phase 1 Barking Riverside green roof experiment

As part of the Knowledge Transfer Partnership at Barking Riverside, a green roof experiment was set up to investigate how green roof design effects ecosystem service performance with a particular view of looking at whether there is any ecosystem service 'cost' in terms of moving from traditional sedum-based industrial standard green roof systems to more biodiverse systems that utilize biomimicry of the existing valuable brownfield site conditions in their design. The establishment of the green roof was also supported by a number of local and international businesses and organisations. A list of the organisations that so generously supported the construction is provided in Appendix 1

To achieve this aim, thirty-two green roof test beds were constructed at the Barking Riverside site on top of four shipping containers (Figures 2 and 3). The containers were used to mimic a typical flat roof system on which green roofs would be located. Each test bed has a dimension of 2 metres by 1.37 metres with a depth of 0.3 metres. The bays were designed to be suitable for testing extensive green roofs only. Each test bay had a central drainage outlet for rainfall runoff. The bays were designed to be identical so that the structural elements of the test beds could be manipulated to assess their performance in relation to each other.

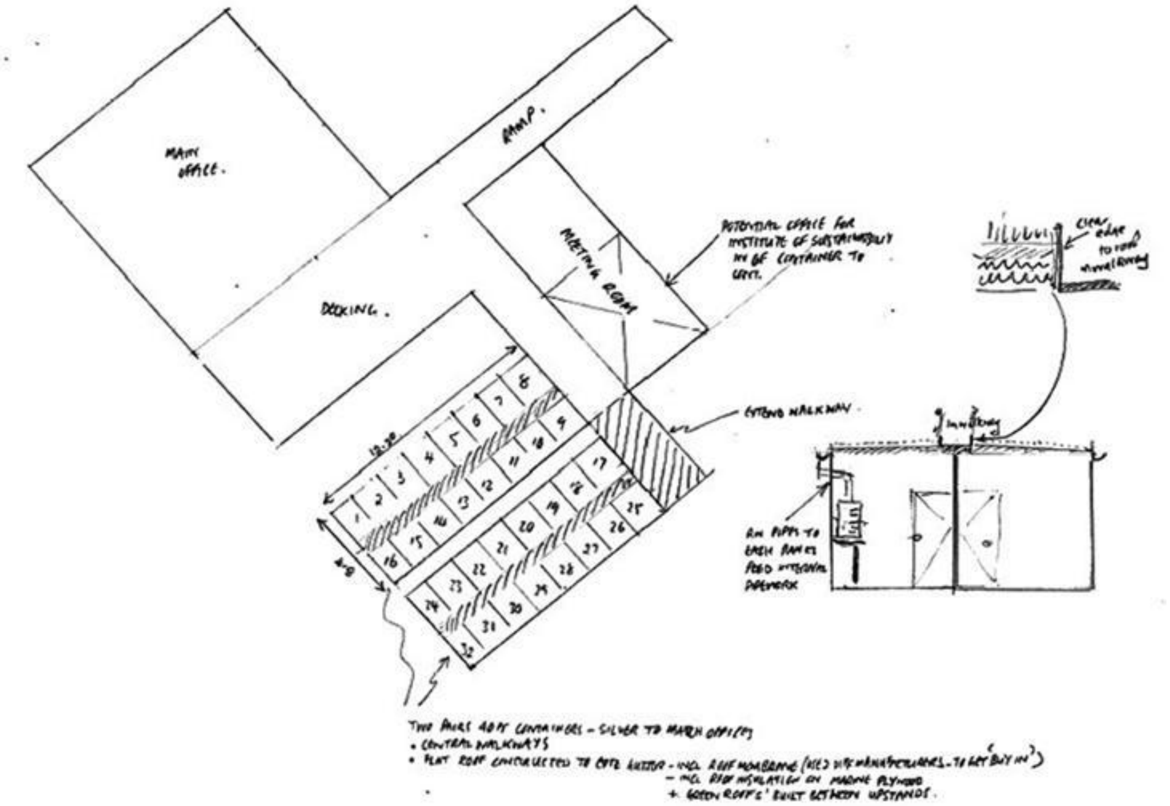


Figure 2. Plan of green roof test bays at Barking Riverside Offices.

Figure 3. Completed green roof test bays with water proofing at Barking Riverside Offices.

Standard extensive green roof systems were installed in each test bay with the exception of three that were left empty to act as typical flat roof controls. Different designs were installed to compare between standard sedum systems and alternative systems using a more biodiversity-friendly wildflower and plug plant mix typical of the Barking Riverside brownfield site. All design features were standardised with the exception of vegetation cover, drainage layer depth and aggregate depth so as to enable direct comparison of performance of sedum versus wildflower systems for a variety of roof designs

ABG Roofdrain composite drainage boards were used. The two drainage layer depths incorporated were 25mm depth (corresponding to a storage volume of 5.5 L/m²) and 40mm depth (corresponding to a storage volume of 12 L/m²). These were selected as being typical of standard green roof drainage systems. Also a standard ABG recycled aggregate extensive green roof substrate was used on all of the green roof bays. Two aggregate depths of 50 mm and 100 mm were used.

In total 9 different design variables were incorporated into the green roof test bays with 3 replicates of each type. These 9 variables were:

3 x sedum roofs with 25 mm drainage layer and 50 mm substrate layer [S/25/50]

3 x wildflower roofs with 25 mm drainage layer and 50 mm substrate layer [W/25/50]

3 x sedum roofs with 40 mm drainage layer and 50 mm substrate layer [S/40/50]

3 x wildflower roofs with 40mm drainage layer and 50 mm substrate layer [W/40/50]

3 x sedum roofs with 25 mm drainage layer and 100 mm substrate layer [S/25/100]

3 x wildflower roofs with 25 mm drainage layer and 100 mm substrate layer [W/25/100]

3 x sedum roofs with 40mm drainage layer, and 100mm substrate layer [S/40/100]

3 x wildflower roofs with 40mm drainage layer and 100 mm substrate layer [W/40/100]

3 x empty control roofs

In an attempt to reduce the effects of any other environmental variables caused by the location of each treatment within the test set up, the location of each bay was randomised within the experimental design. The results of the randomised positioning of the test bays are detailed in Figure 4. Figure 5 shows the completed and planted test bays.

A1 - 11 - S/25/50	B1 - 12 - S/25/50		C1 - 17 - S/40/100	D1 - 2 - W/25/100
A2 - 10 - S/25/50	B2 - 6 - S/25/100		C2 - 13 - W/40/100	D2 - 16 - S/40/100
A3 - 8 - W/25/50	B3 - 15 - W/40/100		C3 - 9 - W/25/50	D3 - 1 - W/25/100
A4 - 20 - W/40/50	B4 - 7 - W/25/50		C4 - 5 - S/25/100	D4 - 3 - W/25/100
A5 - 4 - S/25/100	B5 - 14 - W/40/100		C5 - Empty 2	D5 - 22 - S/40/50
A6 - 24 - S/40/50	B6 - 18 - S/40/100		C6 - 23 - S/40/50	D6 - Empty 3
A7 - Empty 1				D7 - 21 - W/40/50
				D8 - 19 - W/40/50

Figure 4. Randomised layout of the green roof test bays at Barking Riverside Offices.

Figure 5. Installed green roof test bays at Barking Riverside Offices.

Once established, the roofs were monitored to assess any difference in performance between the industry standard sedum roofs and the biodiverse roofs in relation to two of the key ecosystem services for which green roofs are installed, stormwater attenuation and thermal insulation. The performance of the roofs for biodiversity was also assessed.

Water attenuation monitoring

To assess the rainfall run off from each test plot, piping was constructed below each green roof test bay that ran into a tipping bucket rain gauge this then emptied into a water reservoir from which water samples could be taken. The reservoir overflowed into a waste pipe which released water at ground level outside the containers. A diagram and image of the water monitoring equipment is presented in Figure 6.

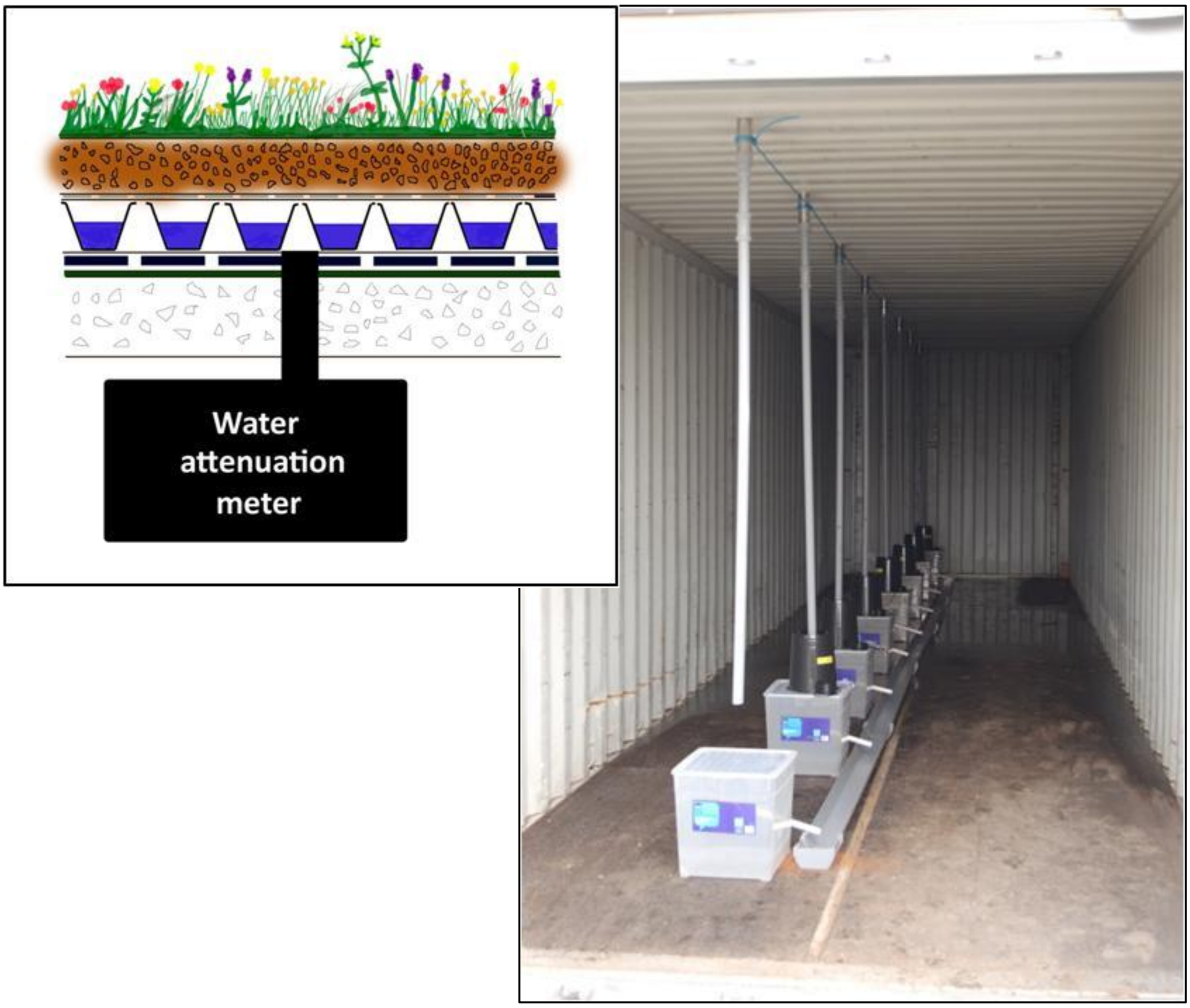


Figure 6. Plan and image of rainfall runoff monitoring equipment beneath the green roof test bays at Barking Riverside Offices.

Rainfall runoff gauges were connected to a PC with data logging programme to record live data each time a rain gauge recorded a tip due to rainfall runoff. Each gauge was calibrated to calculate the volume of rain required to flow through the gauge to generate one tip. Each tip was not found to be a constant volume. Instead, tip volumes were found to be correlated with runoff rates. So a calibration correlation was calculated for each tipping bucket gauge. This was used to calculate runoff volumes. Data spreadsheets were then analysed to assess whether there was any ecosystem service 'cost' in moving away from sedum systems to biodiverse green roofs of regional value in terms of attenuation performance.

Thermal performance

Thermal sensors were inserted at various depth within the green roof profiles during construction (Figure 7). The depths sensors were positioned corresponded to:

1) Beneath the roof system

2) Beneath the drainage layer

3) Beneath the substrate layer

4) Approximately 5 cm above the substrate.

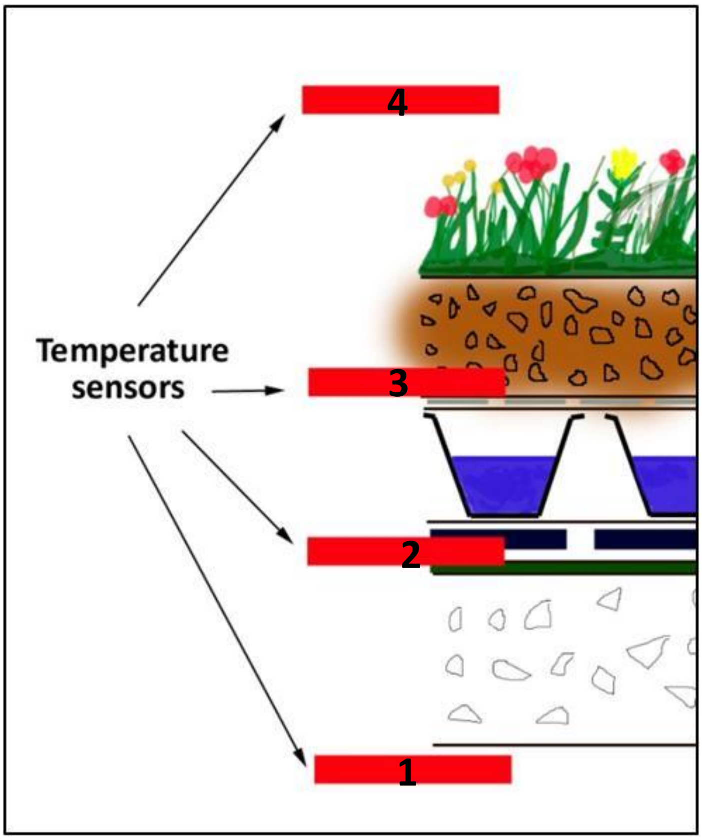


Figure 7. Plan of temperature senor monitoring equipment within the green roof test bay profiles at Barking Riverside Offices.

The sensors beneath the roof system and above the substrate were insulated from surrounding temperatures and direct sunlight to ensure that they were accurately measuring ambient temperatures of their environments. Temperature sensors were connected to a PC with data logging programme to record live data every 15 minutes during the experiment. Temperature sensors were calibrated before insertion into the roof layers

Biodiversity value

A range of measures were used to assess biodiversity value. This included floral diversity surveys and fixed-point photo monitoring, pitfall trapping and records of pollinator visits. Floral diversity surveys were carried out at least monthly over the entire period of the experiment (2010 to present). The floral diversity surveys consisted of an inventory of all of the identifiable wildflower species on each green roof test bay. Flower identification followed Stace (1997).

Weather station

In addition to the green roof monitoring equipment, a Vantage Pro 2 weather station was installed next to the green roof experiment to monitor environmental conditions on site including rainfall, rain rate, wind direction and temperature (Figure 8).

Figure 8. Location of weather station next to green roof test bays at Barking Riverside Offices.

3.4 Experimental results

Rainfall runoff

Figures 9 to 12 below detail the paired flow rate runoff patterns from a series of rainfall events for each sedum and wildflower green roof design pair.

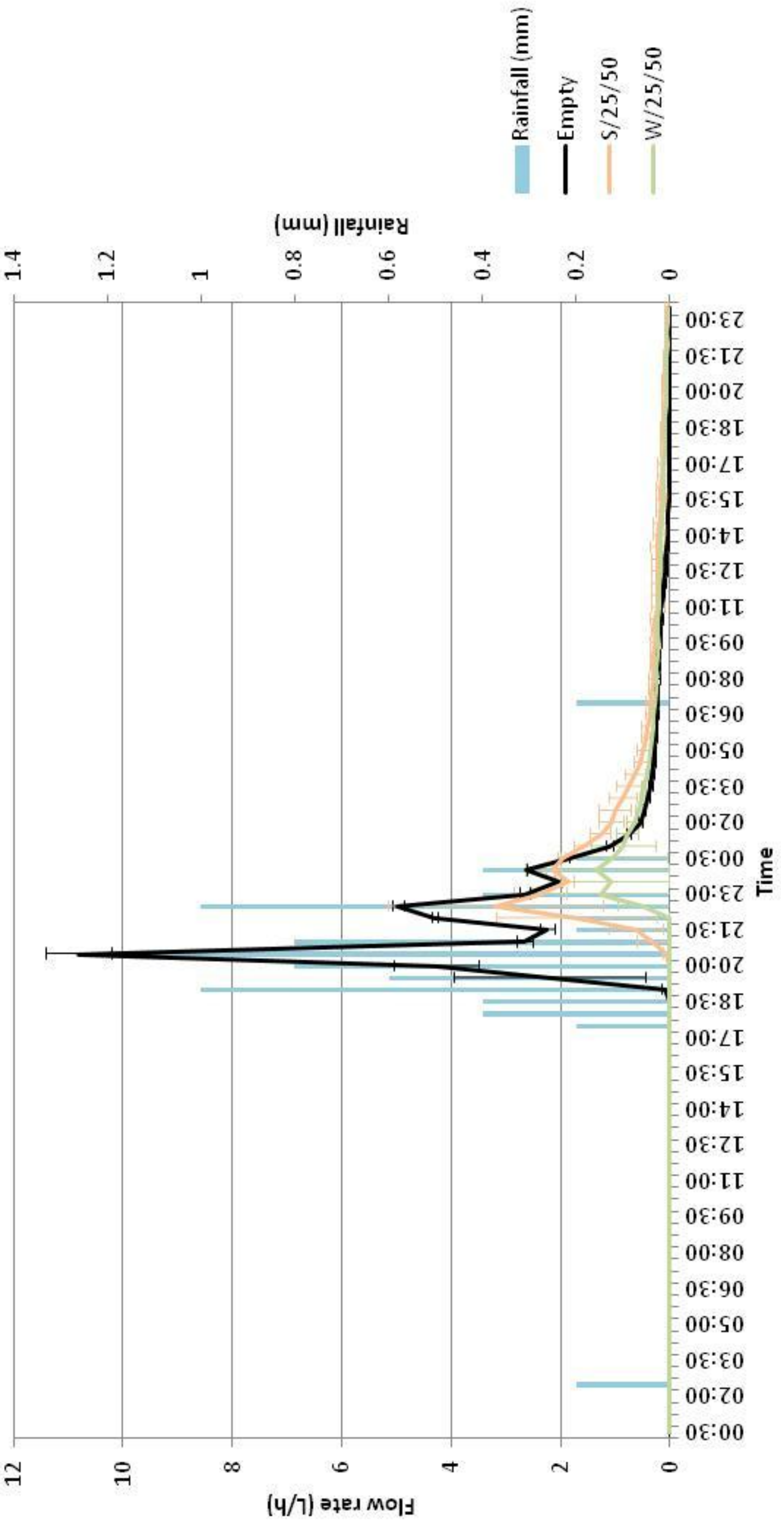


Figure 9. Average rainfall runoff patterns from control roofs and 25 mm drainage, 50 mm substrate sedum and wildflower roofs at Barking Riverside, 29th/30th September 2010. Error bars represent the standard error of the mean (n = 3).

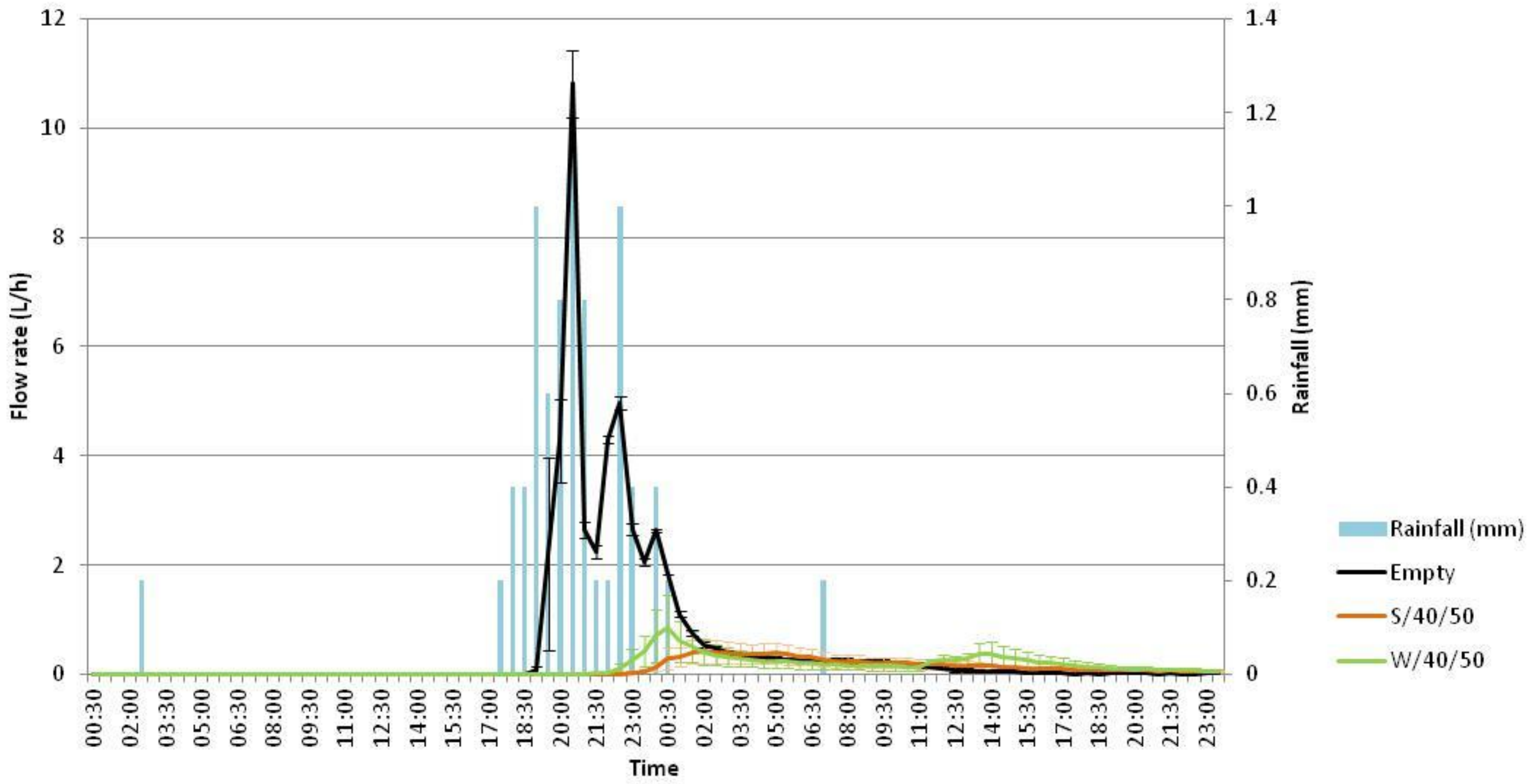


Figure 10. Average rainfall runoff patterns from control roofs and 40 mm drainage, 50 mm substrate sedum and wildflower roofs at Barking Riverside, 29th/30th September 2010. Error bars represent the standard error of the mean (n = 3).

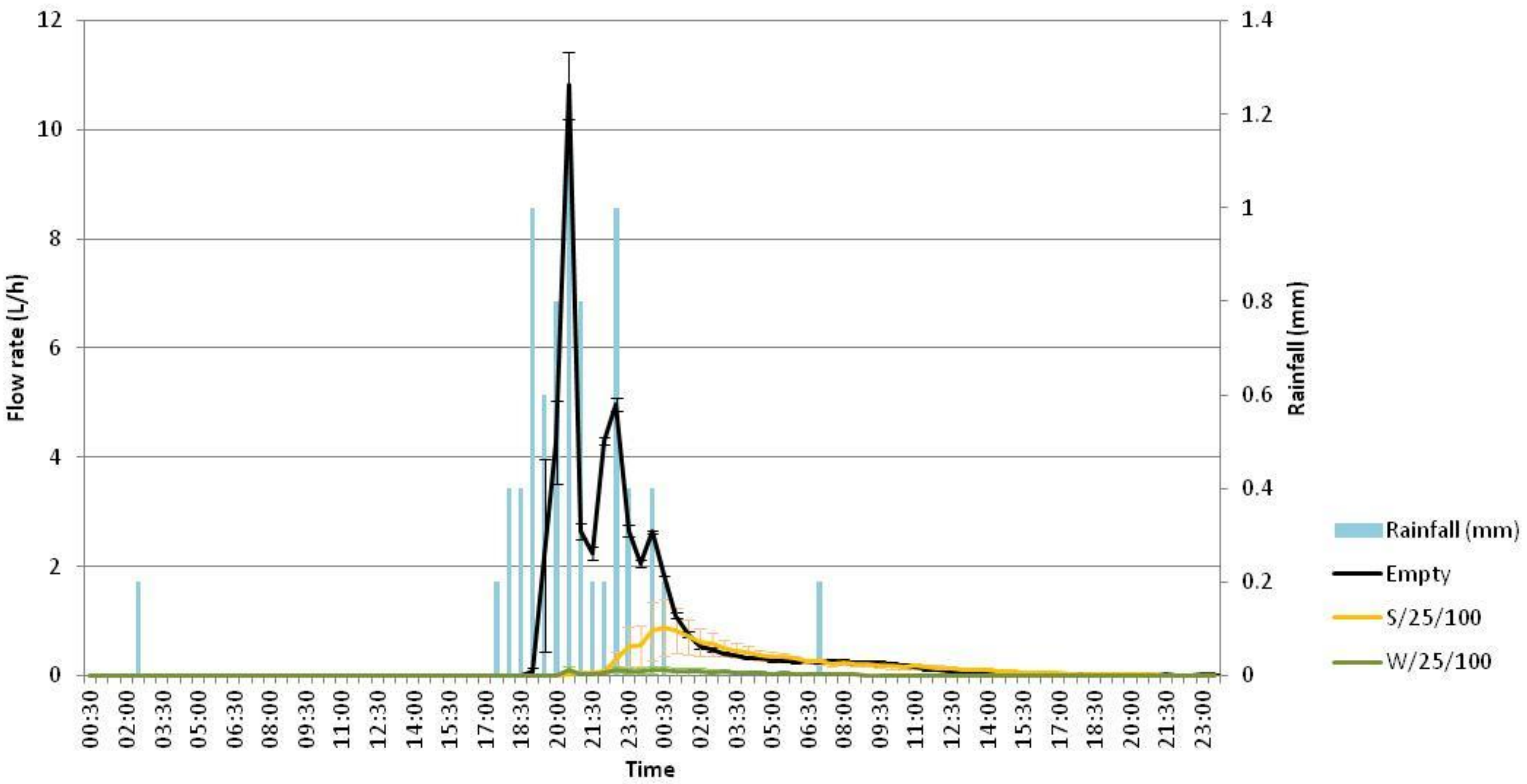


Figure 11. Average rainfall runoff patterns from control roofs and 25 mm drainage, 100 mm substrate sedum and wildflower roofs at Barking Riverside, 29th/30th September 2010. Error bars represent the standard error of the mean (n = 3).

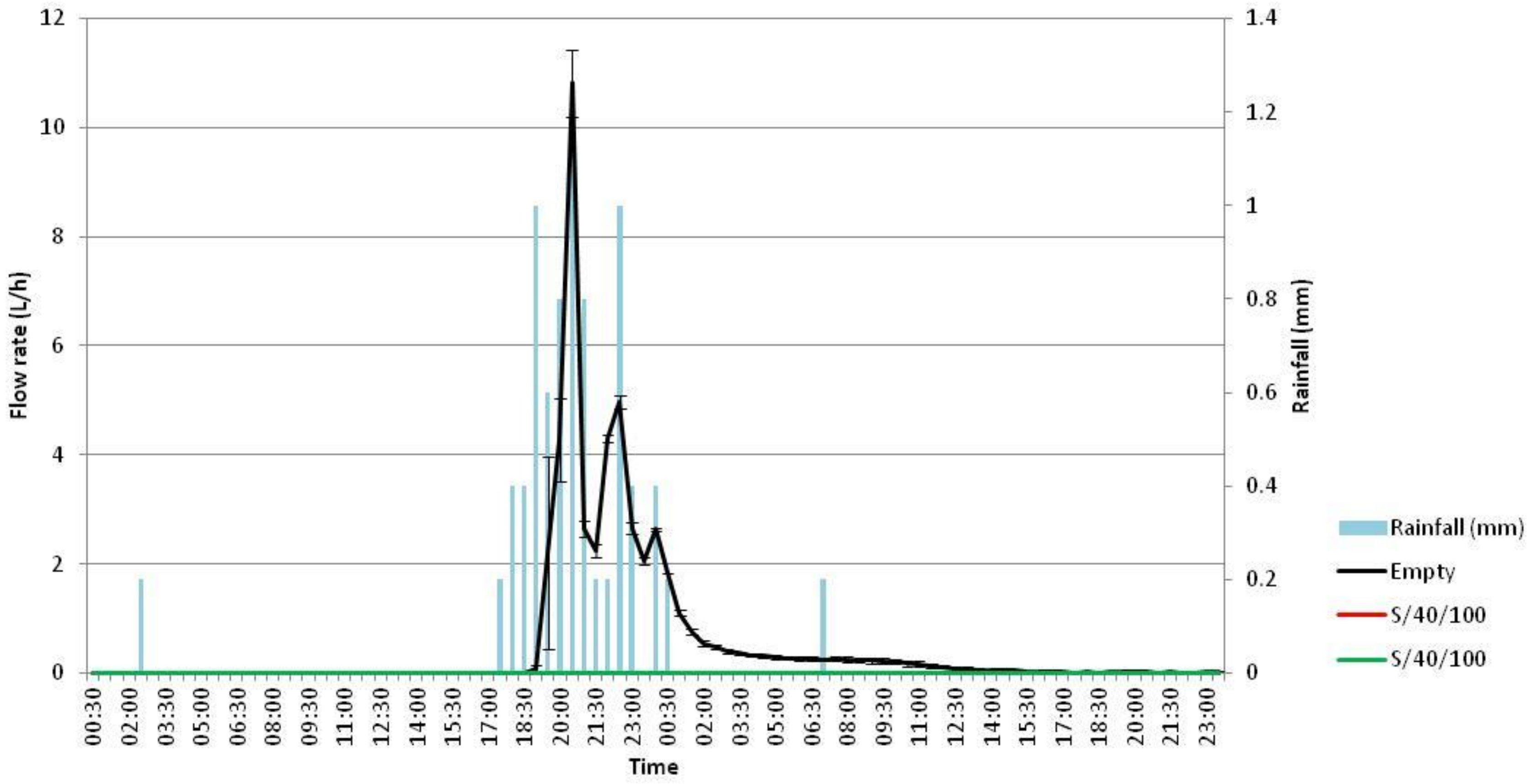
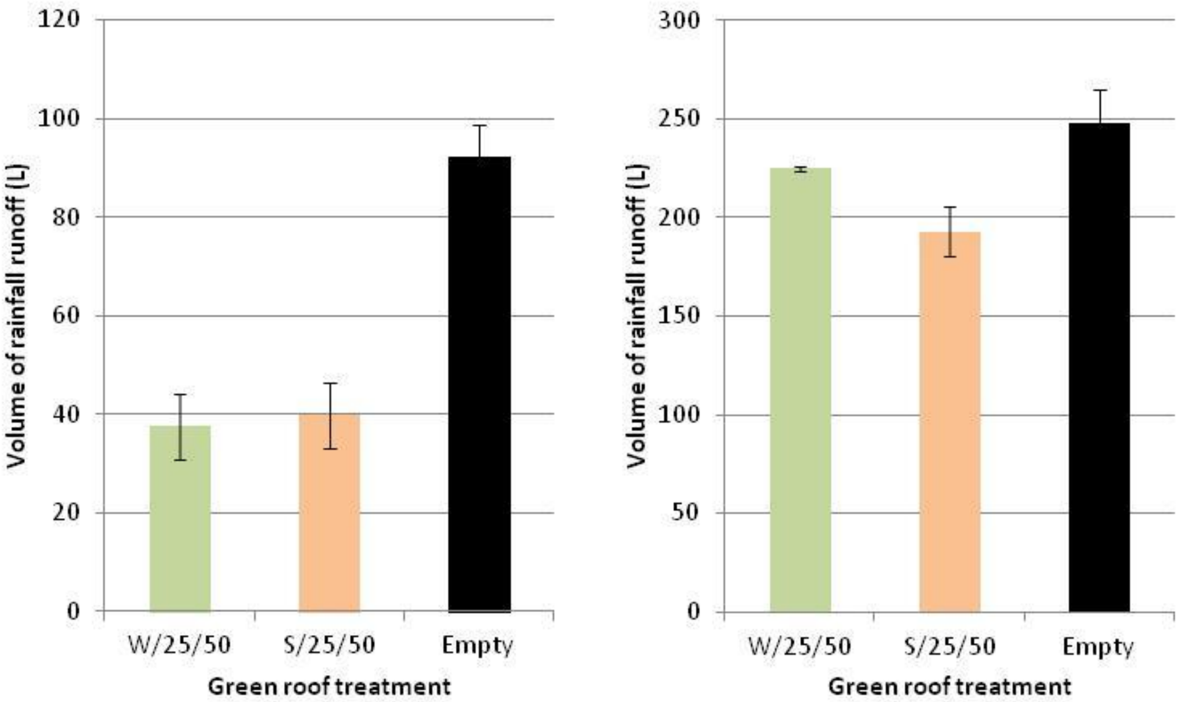


Figure 12. Average rainfall runoff patterns from control roofs and 40 mm drainage, 100 mm substrate sedum and wildflower roofs at Barking Riverside, 29th/30th September 2010. Error bars represent the standard error of the mean (*n* = 3).

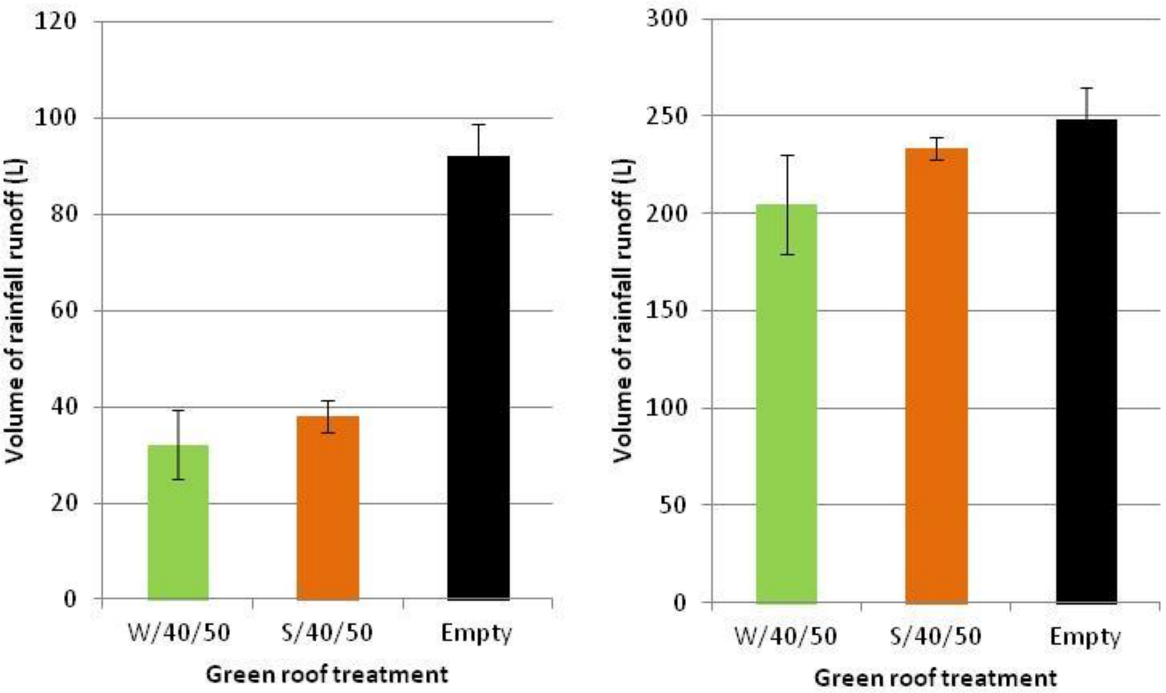
As can be seen from the above Figures (9 to 12), for the rain event on the 29th and 30th September 2010, the biodiverse green roof outperformed the equivalent sedum green roof for three of the four green roof designs. This included total rainfall runoff, reduction of peak flow and delay in peak flow, all factors that are considered critical for a roof's performance as a Sustainable Urban Drainage component. This pattern of biodiverse green roofs typically performing as well as or better than equivalent sedum systems was replicated when looking at total rainfall attenuated over longer periods Figures 13 to 16.



i) **ii)**

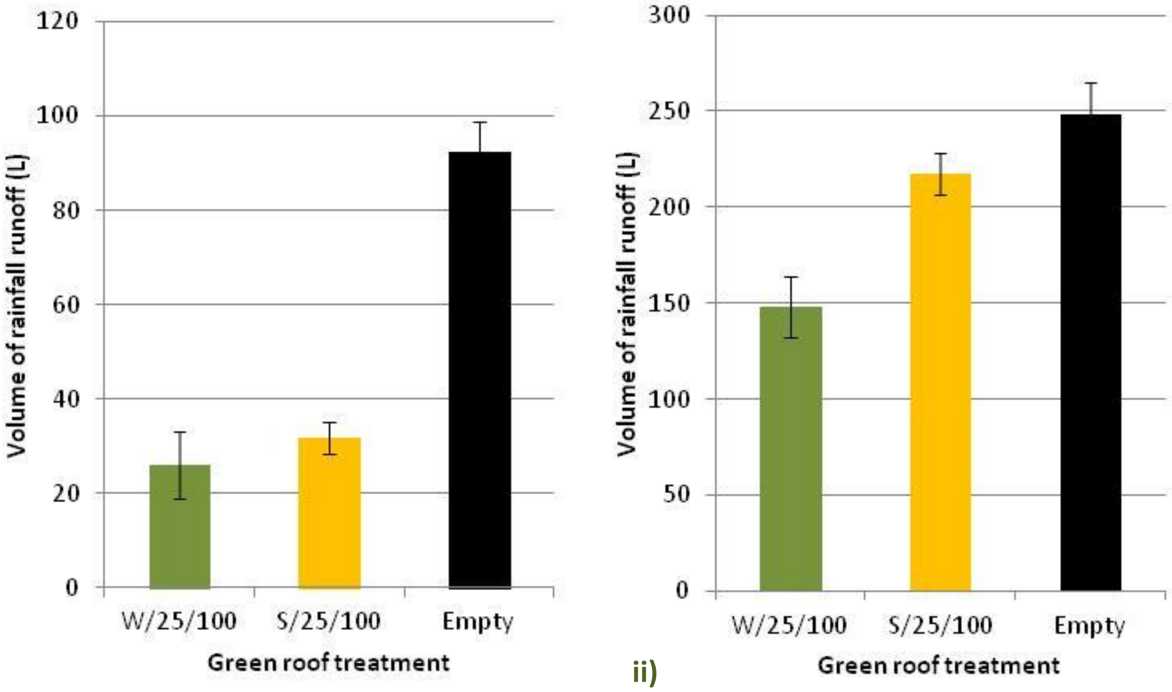
Figure 13. Average percentage rainfall attenuation for empty control roofs and 25 mm drainage, 50 mm substrate sedum and wildflower roofs at Barking Riverside for i) the summer months July to September 2010, and ii) the winter months October to December 2010. Error bars represent the standard error of the mean (*n* = 3).

Data from these analyses did not reveal any specific ecosystem service cost of moving away from the industry standard sedum system to a biodiverse green roof system based on biomimicry of surrounding habitat to enhance biodiversity. Quite the opposite in fact, with the majority of analyses demonstrating improved water attenuation with wildflower based biodiverse green roof systems. This was the case both during summer time when green roofs would be expected to perform optimally and during winter time when the roofs would be expected to perform sub-optimally due to decreased evapotranspiration.



i) ii)

Figure 14. Average percentage rainfall attenuation for empty control roofs and 40 mm drainage, 50 mm substrate sedum and wildflower roofs at Barking Riverside for i) the summer months July to September 2010, and ii) the winter months October to December 2010. Error bars represent the standard error of the mean (*n* = 3).



i) ii)

Figure 15. Average percentage rainfall attenuation for empty control roofs and 25 mm drainage, 100 mm substrate sedum and wildflower roofs at Barking Riverside for i) the summer months July to September 2010, and ii) the winter months October to December 2010. Error bars represent the standard error of the mean (*n* = 3).

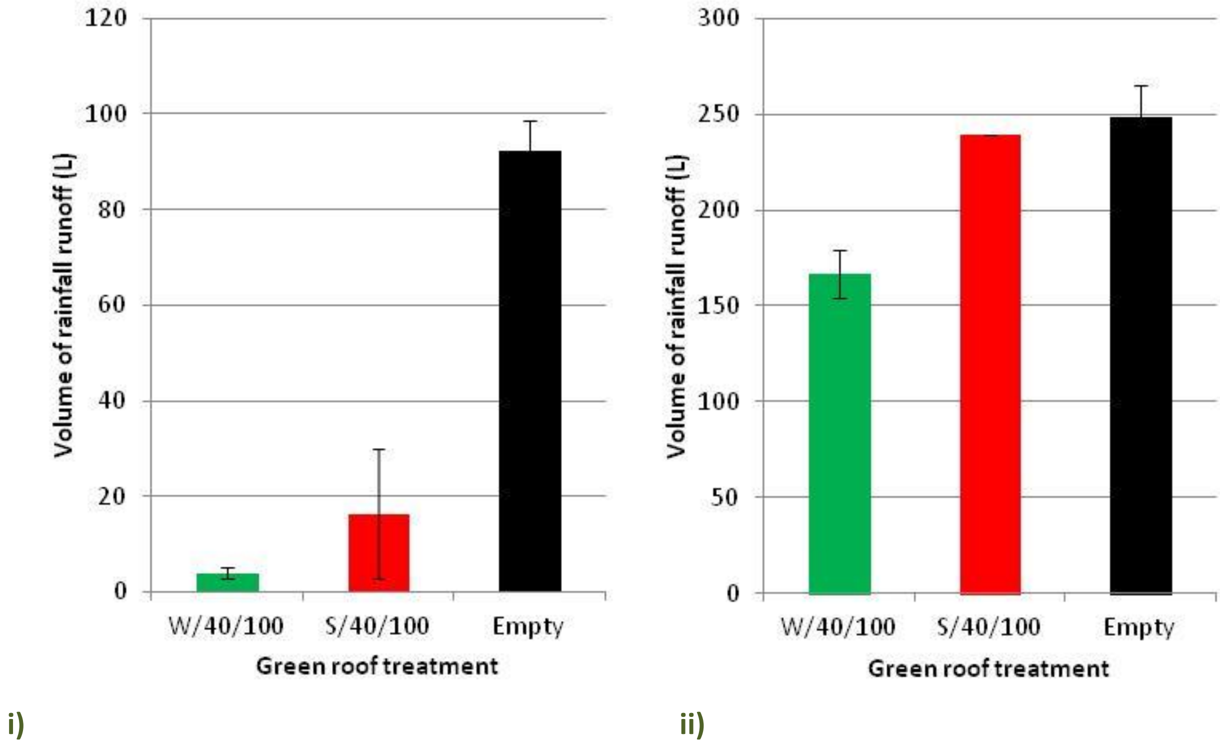


Figure 16. Average percentage rainfall attenuation for empty control roofs and 25 mm drainage, 100 mm substrate sedum and wildflower roofs at Barking Riverside for i) the summer months July to September 2010, and ii) the winter months October to December 2010. Error bars represent the standard error of the mean (*n* = 3).

Thermal performance

Figures 17 to 20 represent the average temperature captured by sensor number 4 (the sensor approximately 5cm above each green and control roof) on each of the green roof treatments every fifteen minutes throughout the hottest day of each year of recording. This value represents the contribution that each roof system makes to the ambient environment surrounding the building.

Similarly to the rainfall runoff data, Figures 17 to 20 demonstrated that there was no pattern of ecosystem service 'cost' when changing from industrial standard sedum green roof systems to equivalent biodiverse green roof systems in terms of the thermal dynamics immediately above the roofs. Indeed for the majority of sedum and biodiverse green roof pairs, the biodiverse system outperformed the sedum system in terms of cooling the air immediately above the roof when compared to a flat roof control. Of particular interest was the fact that this was always the case for the shallowest green roof systems.

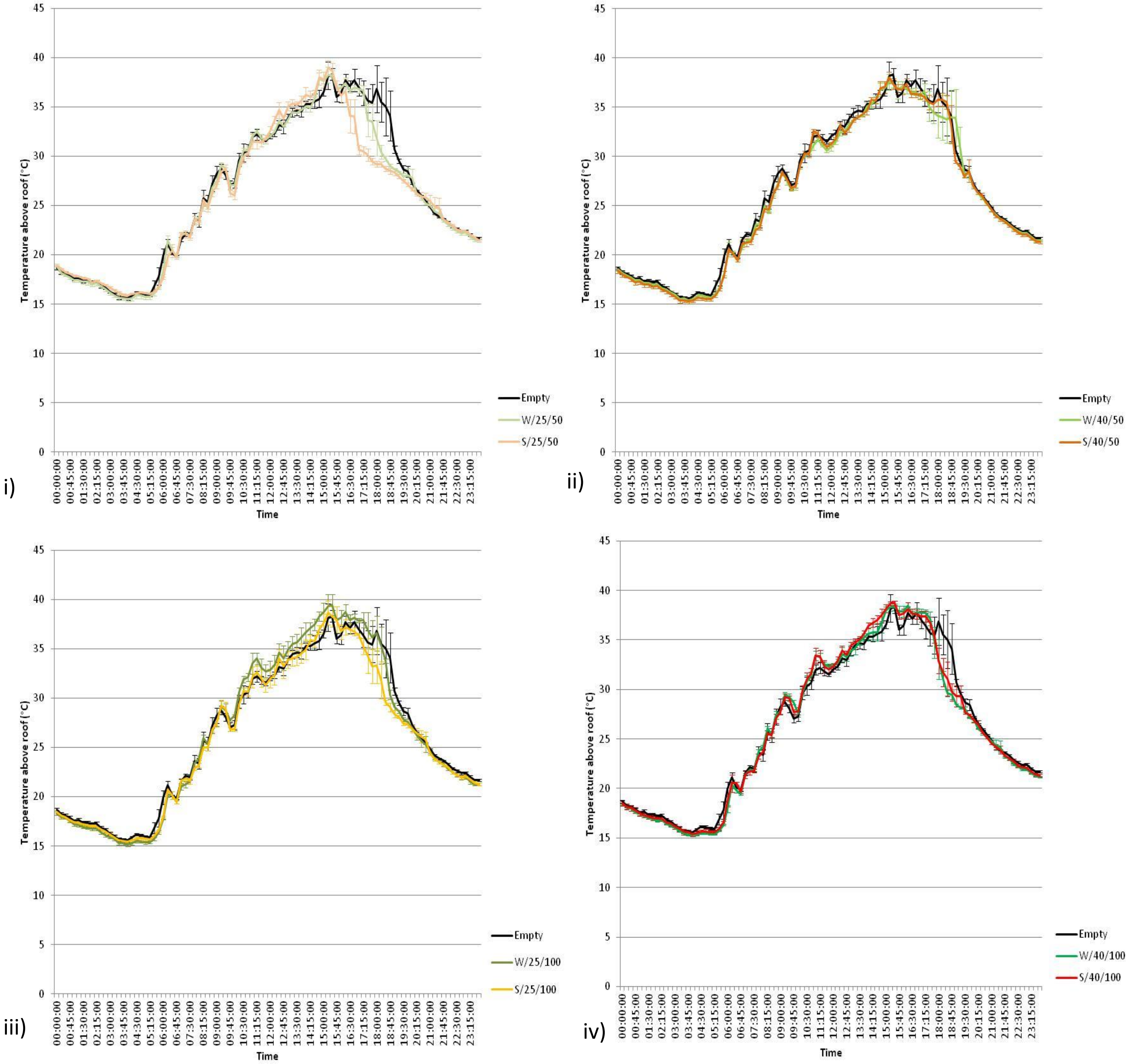


Figure 17. Average temperature immediately above the green and control roofs at Barking Riverside on the hottest day of 2010 (9th July). i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

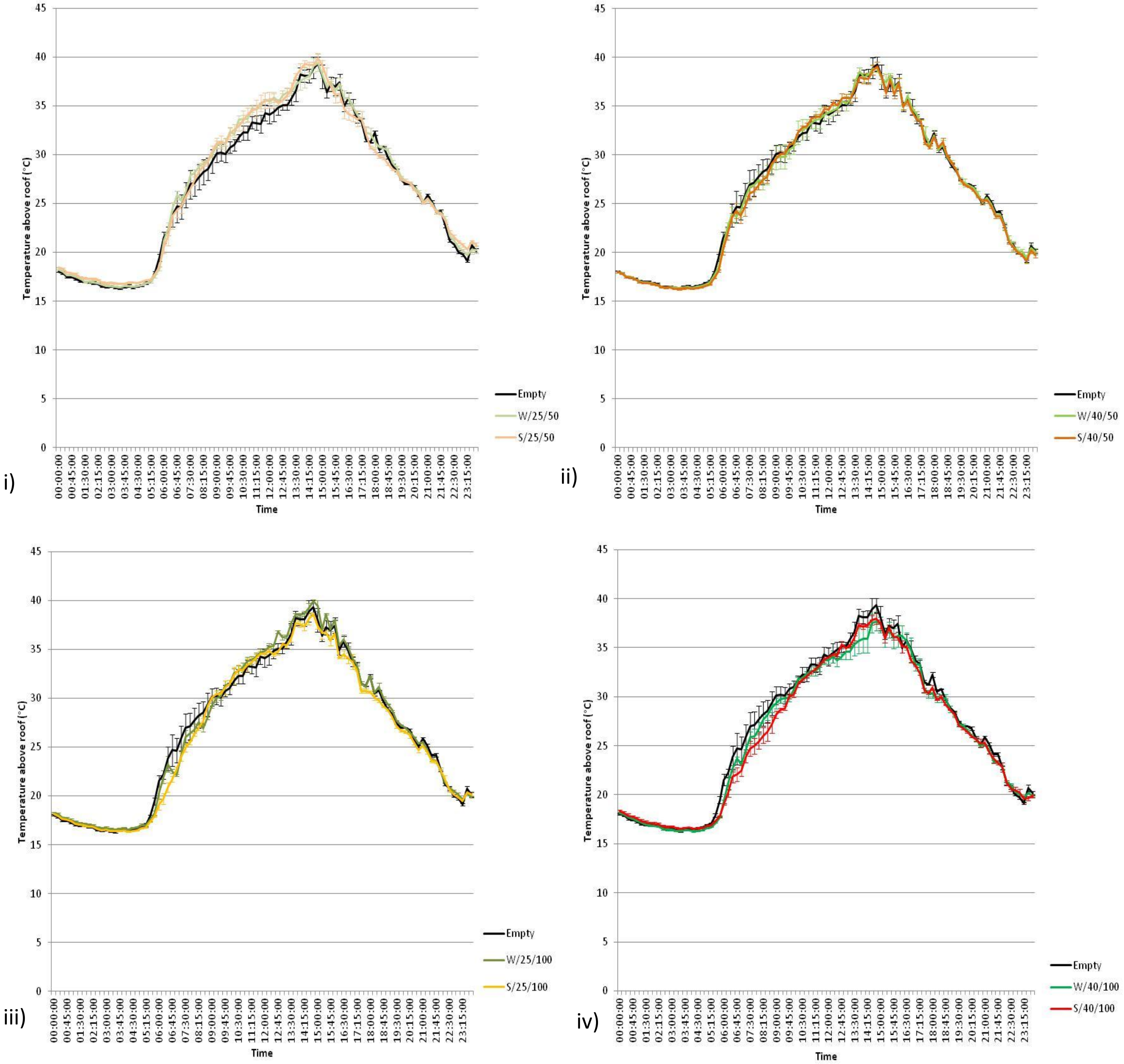


Figure 18. Average temperature immediately above the green and control roofs at Barking Riverside on the hottest day of 2011 (27th June). i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

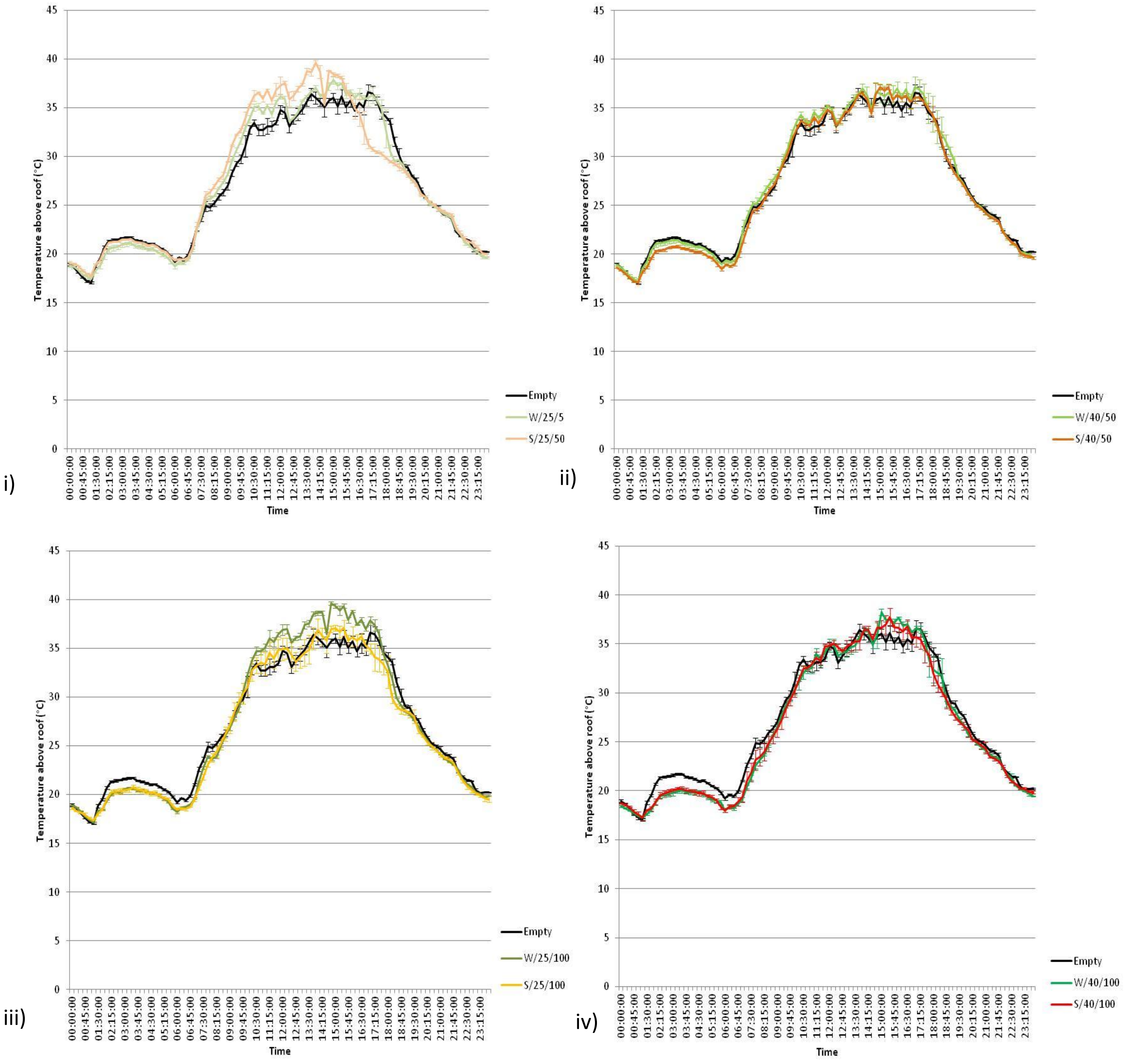


Figure 19. Average temperature immediately above the green and control roofs at Barking Riverside on the hottest day of 2012 (18th August). i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

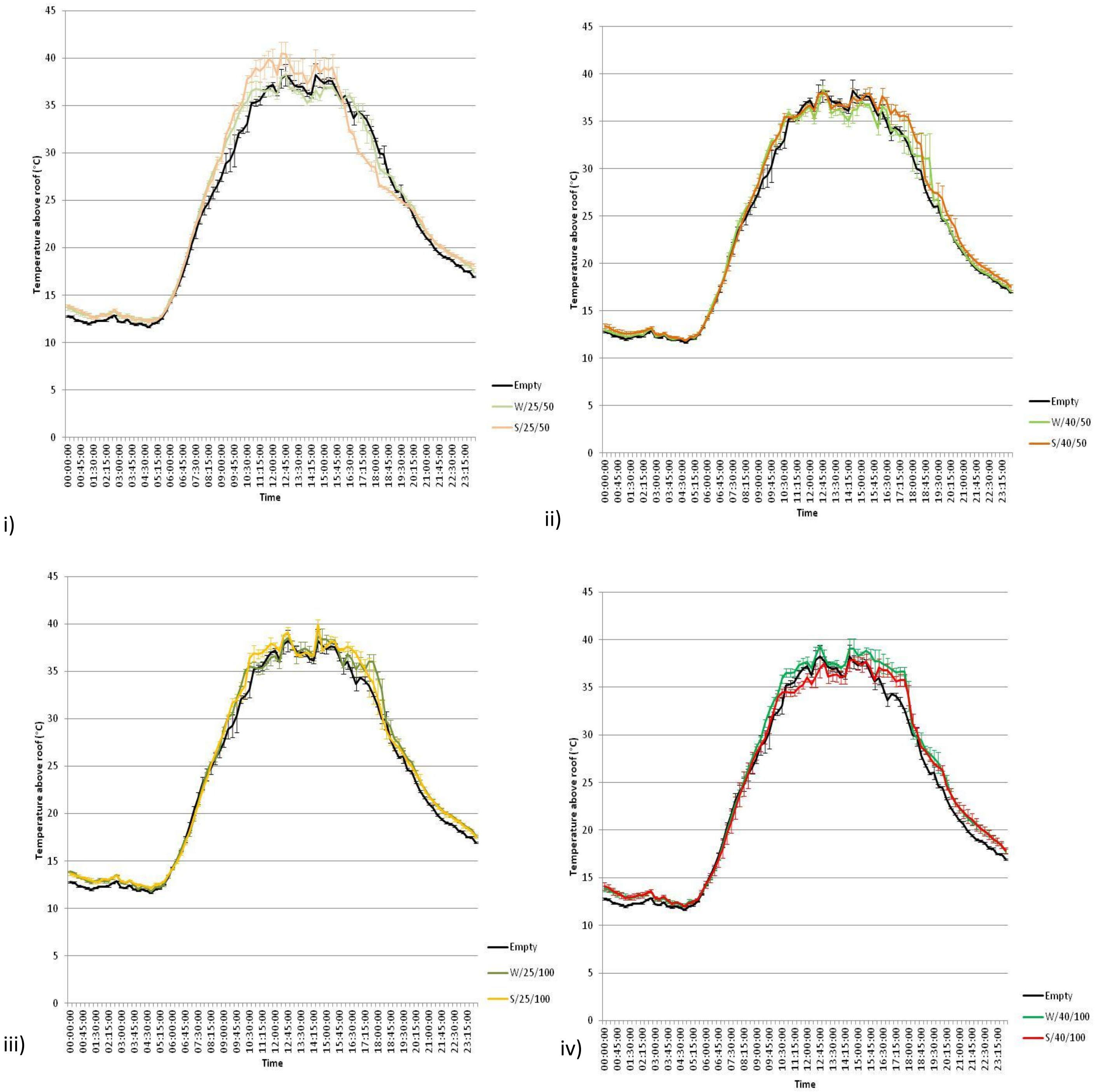


Figure 20. Average temperature immediately above the green and control roofs at Barking Riverside on one of the hottest day of 2013 (13th July) [Data for hottest day unavailable due to power cut on site]. i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

Figures 21 to 24 represent the average temperature captured by sensor number 1 (the sensor beneath each green and control roof) on each of the green roof treatments every fifteen minutes throughout the hottest day of each year of recording. This value represents the contribution that each roof system makes to insulating the space in the building beneath each roof system.

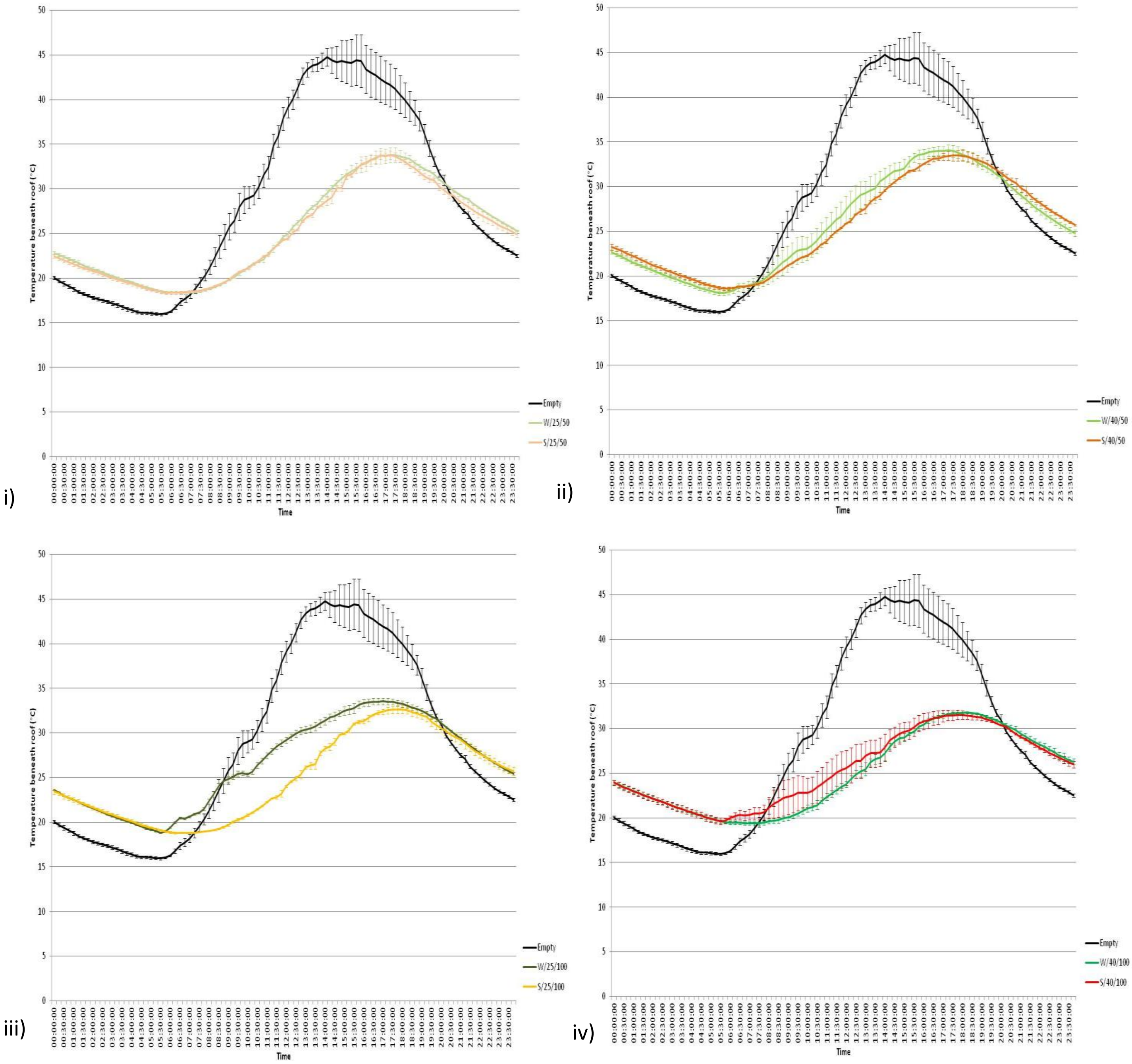


Figure 21. Average temperature immediately beneath each green and control roofs at Barking Riverside on the hottest day of 2010 (9th July). i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

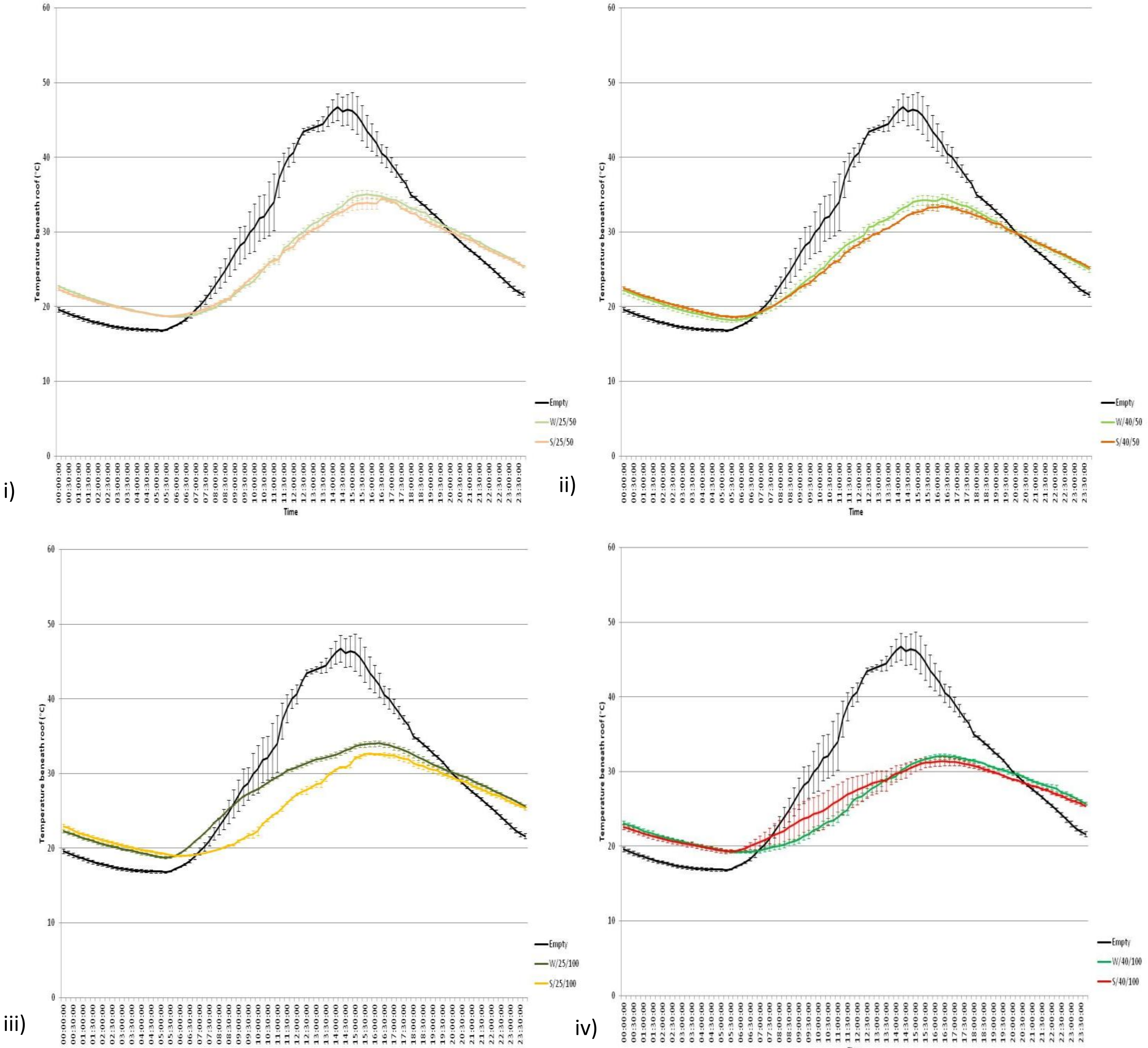


Figure 22. Average temperature immediately beneath each green and control roofs at Barking Riverside on the hottest day of 2011 (27th June). i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

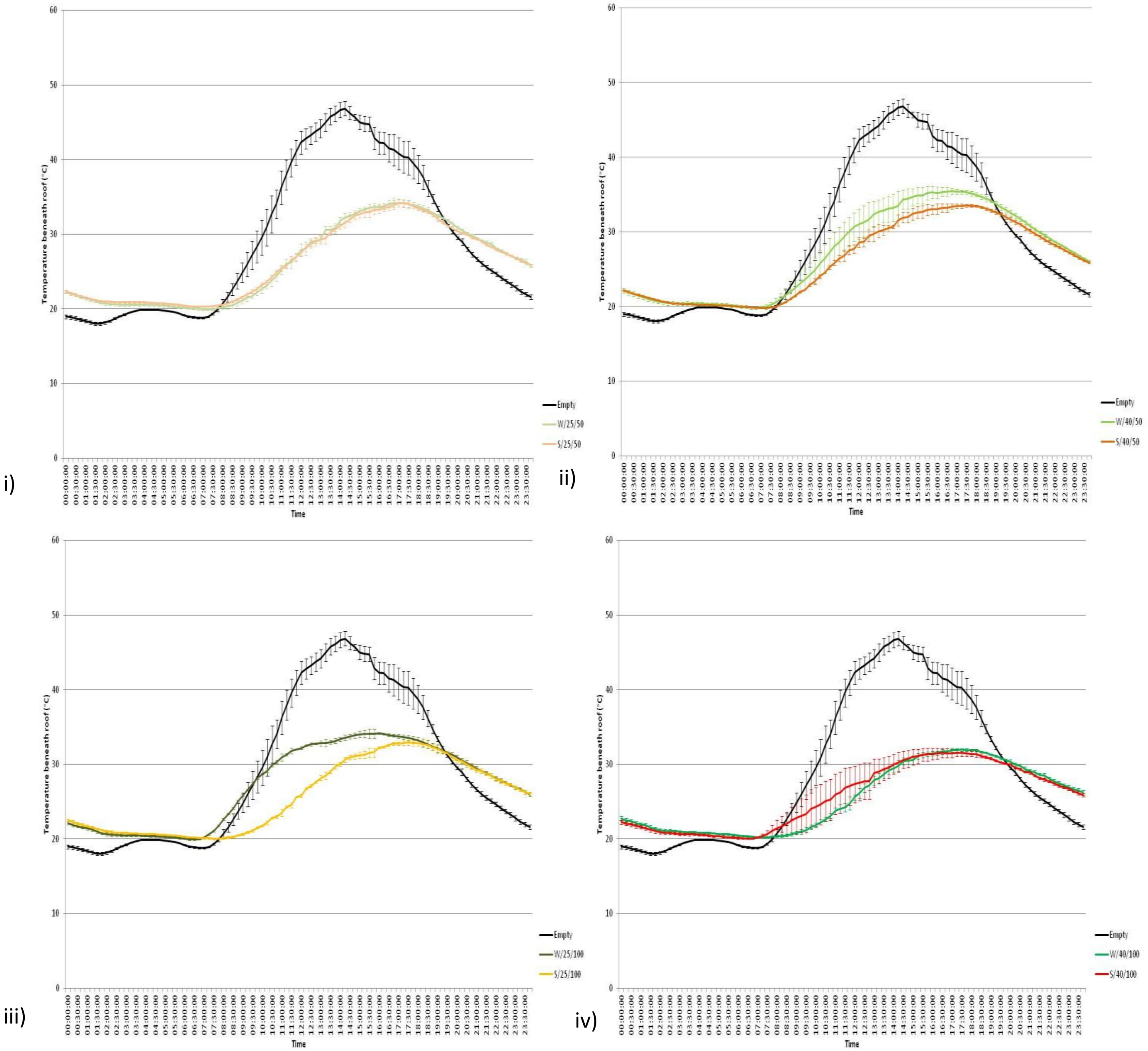


Figure 23. Average temperature immediately beneath each green and control roofs at Barking Riverside on the hottest day of 2012 (18th August). i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

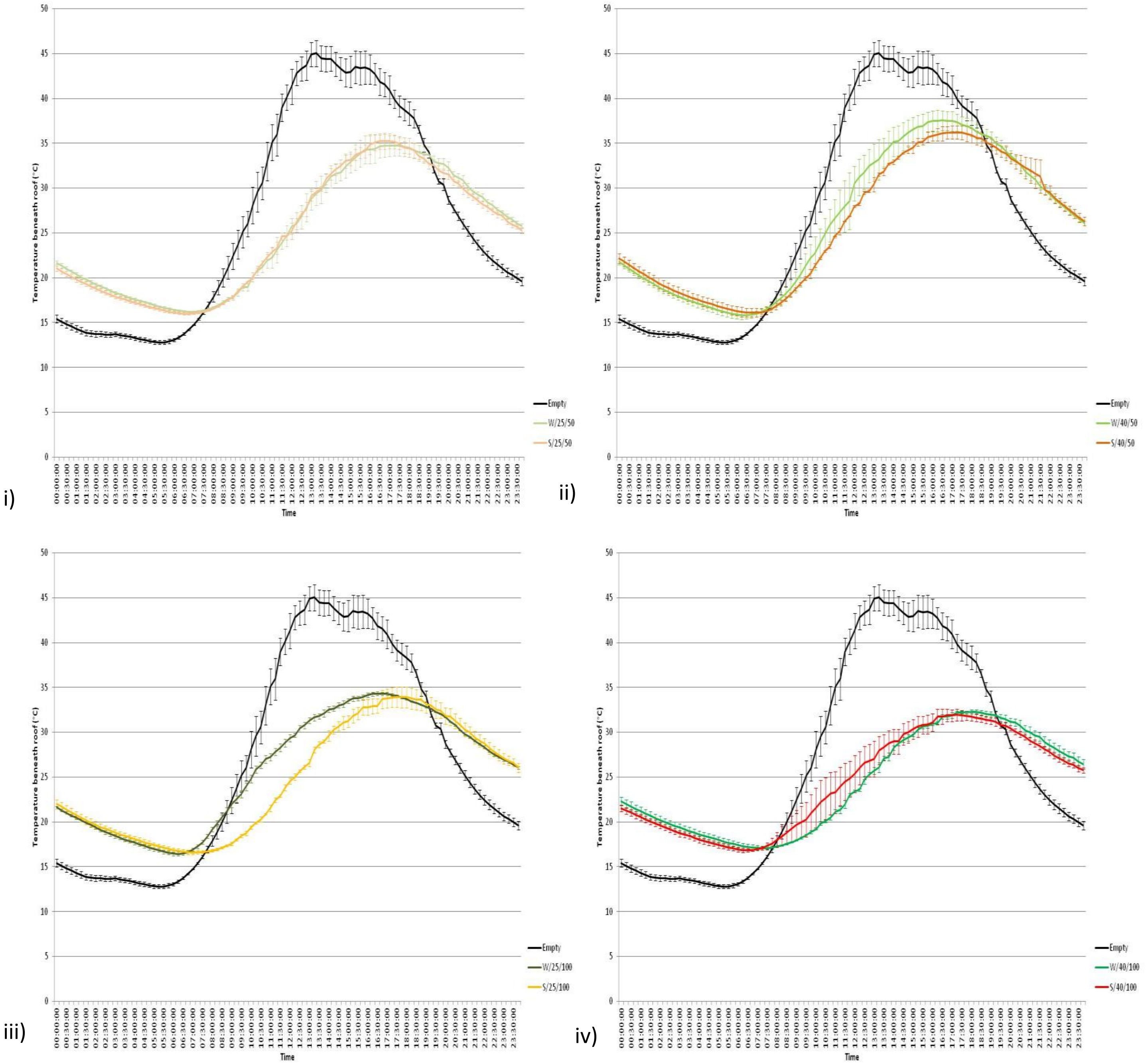


Figure 24. Average temperature immediately above the green and control roofs at Barking Riverside on one of the hottest day of 2013 (13th July) [Data for hottest day unavailable due to power cut on site]. i) Green roof pair W/25/50 and S/25/50; ii) Green roof pair W/40/50 and S/40/50; iii) Green roof pair W/25/100 and S/25/100; iv) Green roof pair W/40/100 and S/40/100. Error bars represent the standard error of the mean (*n* = 3).

Similarly to the data from sensor 4 (above the roofs), Figures 21 to 24 demonstrated that there was no definitive pattern of ecosystem service 'cost' when changing from industrial standard sedum green roof systems to equivalent biodiverse green roof systems in terms of the thermal dynamics immediately below the roofs. Nevertheless, for the majority of sedum and biodiverse green roof pairs, the sedum system slightly outperformed the biodiverse system in terms of insulating the space immediately below the roof. This was likely to be due to the sedum vegetation being more drought tolerant, and thus performing better, during the hottest driest periods of the year. When compared to a standard flat roof control however the difference between the green roof systems was minimal and both performed as an effective insulating layer reducing daily maximum temperatures by more than 10°C.

To investigate this trend towards a slight reduction in the insulation properties of green roofs when moving from sedum to a biodiverse system it is necessary to investigate the patterns in greater detail. As such, analyses of longer time periods were carried out rather than just focusing on the hottest day of the year. Figures 25 to 28 detail the results of this analysis.

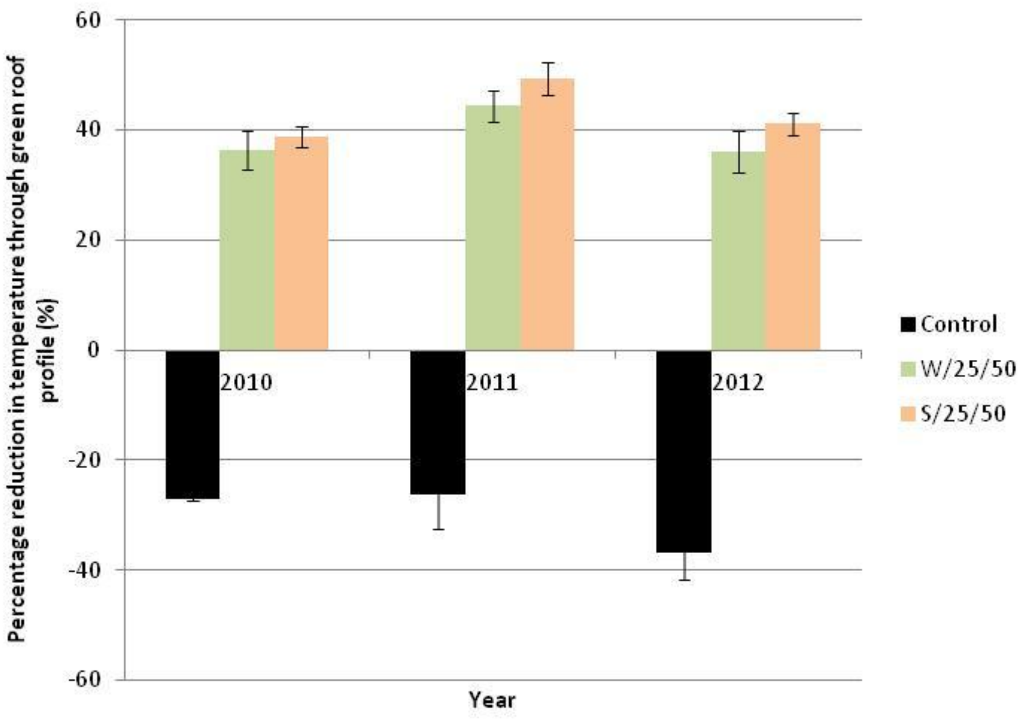


Figure 25. Average percentage reduction in temperature through control, W/25/50 and S/25/50 green roof profiles for the month of July, 2010 to 2012. Reduction in temperature calculated from the difference in temperature between sensor 4 (above the roof) and sensor 1 (beneath the roof). Error bars represent the standard error of the mean (*n* = 3).

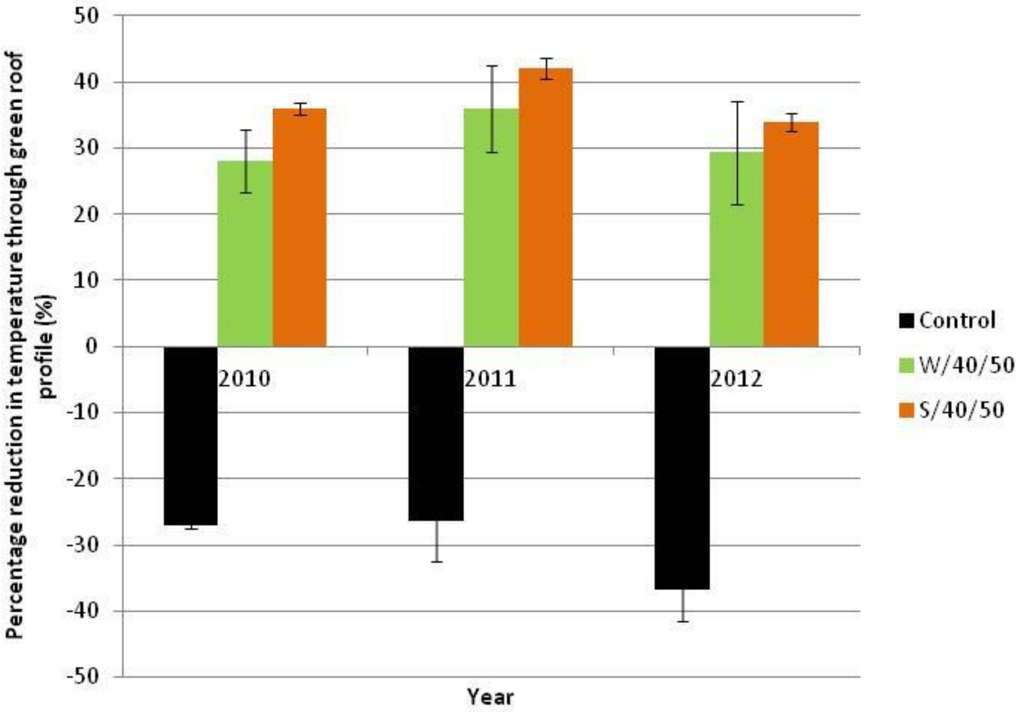


Figure 26. Average percentage reduction in temperature through control, W/40/50 and S/40/50 green roof profiles for the month of July, 2010 to 2012. Reduction in temperature calculated from the difference in temperature between sensor 4 (above the roof) and sensor 1 (beneath the roof). Error bars represent the standard error of the mean (*n* = 3).

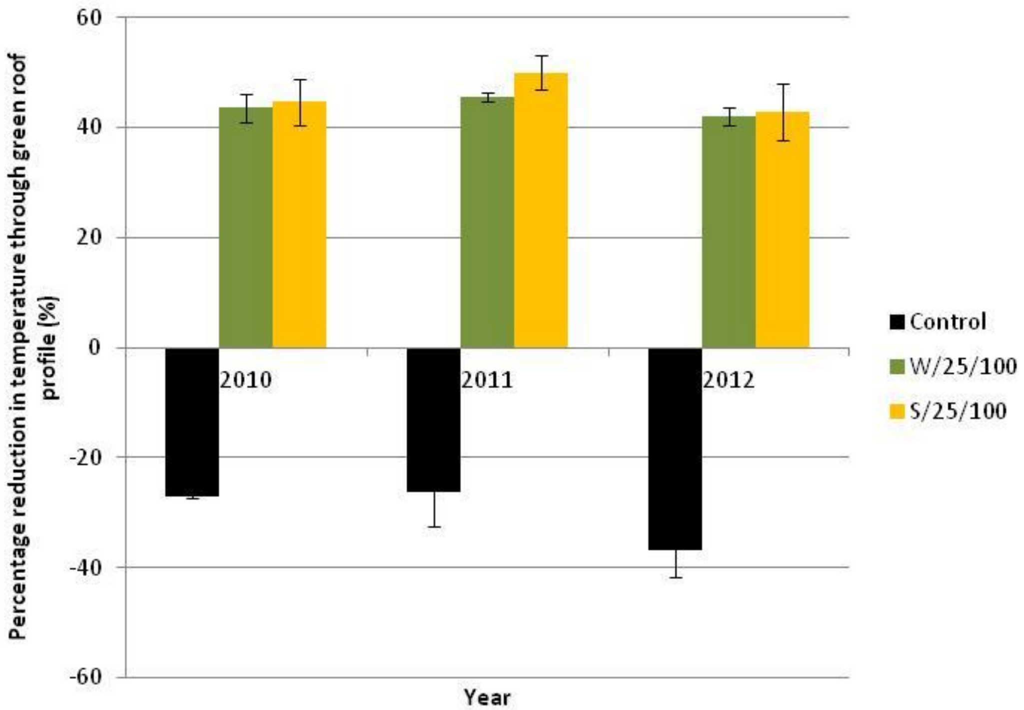


Figure 27. Average percentage reduction in temperature through control, W/25/100 and S/25/100 green roof profiles for the month of July, 2010 to 2012. Reduction in temperature calculated from the difference in temperature between sensor 4 (above the roof) and sensor 1 (beneath the roof). Error bars represent the standard error of the mean (*n* = 3).

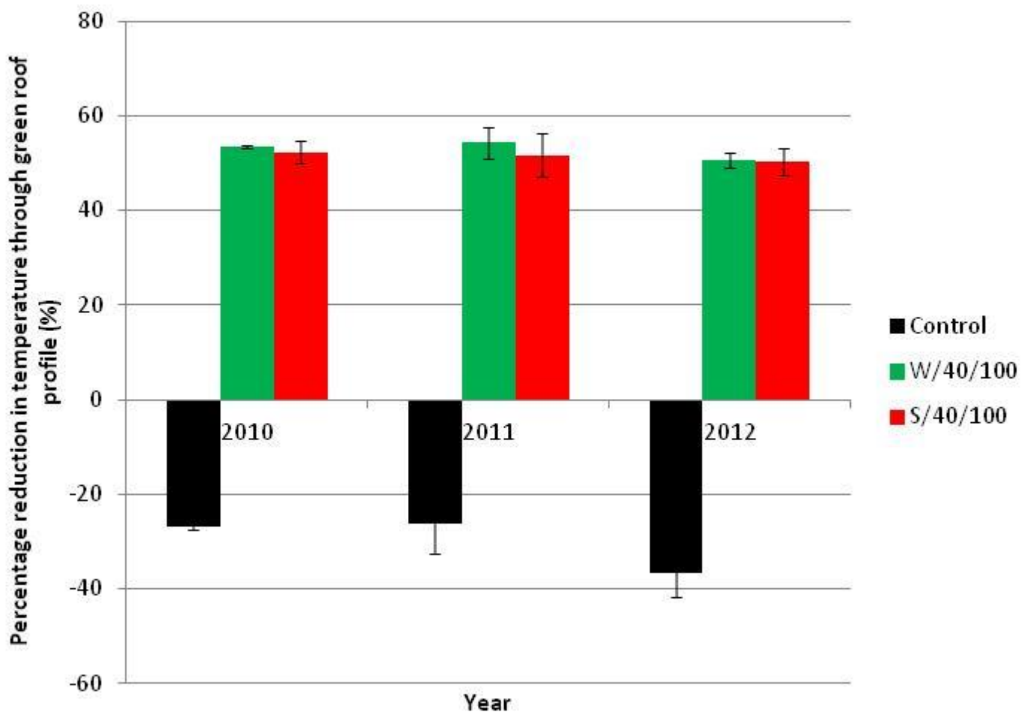


Figure 28. Average percentage reduction in temperature through control, W/40/100 and S/40/100 green roof profiles for the month of July, 2010 to 2012. Reduction in temperature calculated from the difference in temperature between sensor 4 (above the roof) and sensor 1 (beneath the roof). Error bars represent the standard error of the mean (*n* = 3).

Detailed analysis of the thermal insulation properties of industrial standard sedum roofs and more biodiverse roofs revealed no definitive pattern of ecosystem service 'cost'. Whilst the shallower green roof systems demonstrated a greater level of insulation from the sedum roof systems (Figures 25 to 27) the deepest systems (Figure 28) showed the reverse of this trend with the biodiverse system providing the most insulation. Compared to the performance of the control roofs, however, any difference between the sedum and biodiverse systems was negligible and not significant (p= 0.54; 0.20; 0.81; 0.92).

Biodiversity

In addition to the thermal and water attenuation ecosystem service provision by the green roof systems, a measure was made of the relative biodiversity value of the sedum compared to the biodiverse roof systems. Figures 29 to 32 represent selected results from monthly floral surveys carried out on each roof test bay. Floral diversity is a key indicator of biodiversity as it is a vital foundation for supporting the complex food web of insects, birds and bats associated with green roofs. Surveys from early, mid and late summer 2010 to 2012 are represented to reflect the floral diversity at the time when most insects would be active on the roofs.

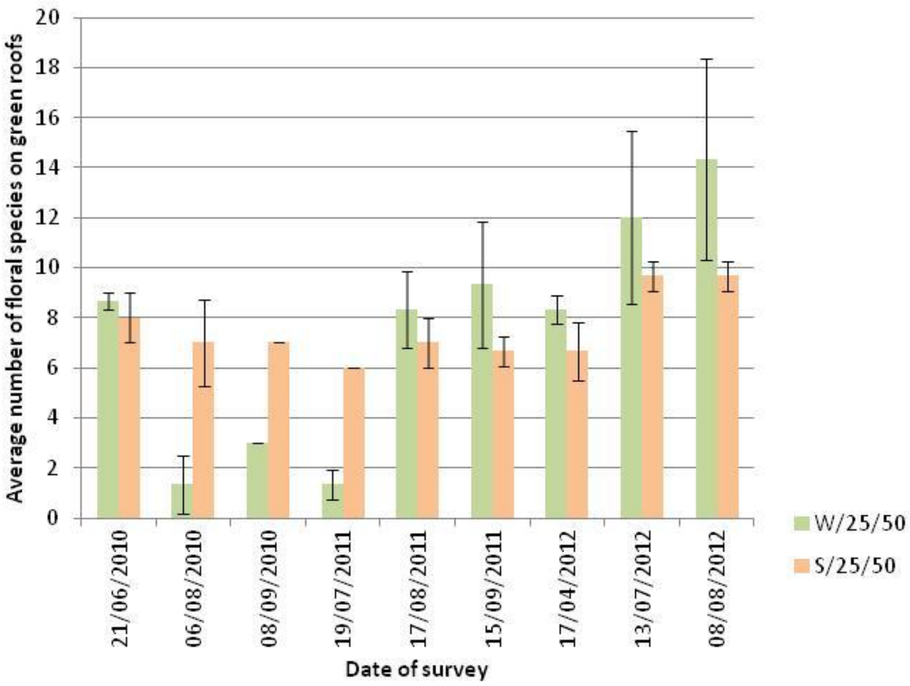


Figure 29. Average number of floral species recorded on W/25/50 and S/25/50 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (*n* = 3).

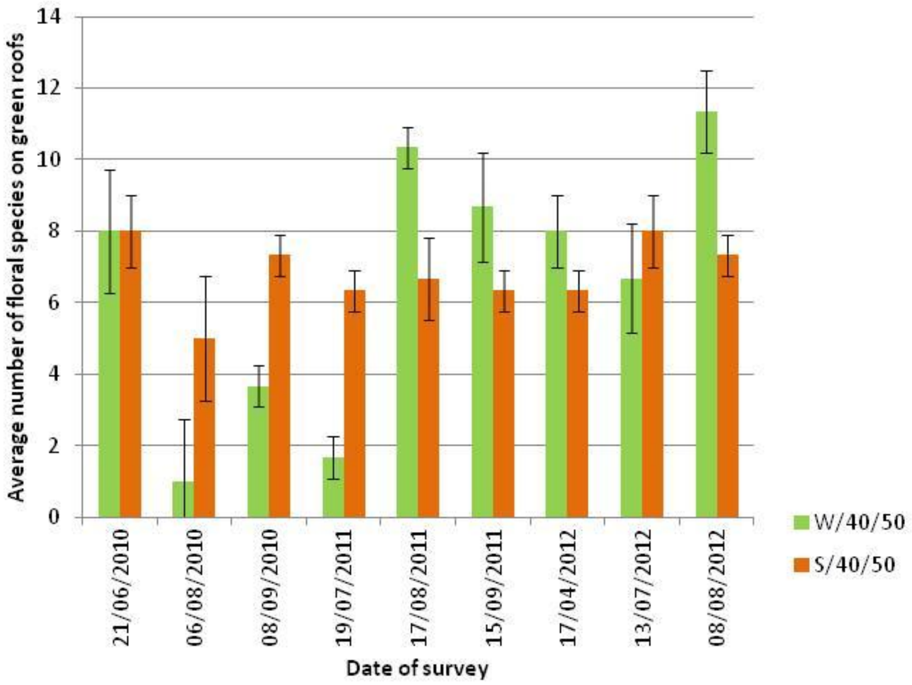


Figure 30. Average number of floral species recorded on W/40/50 and S/40/50 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (n = 3).

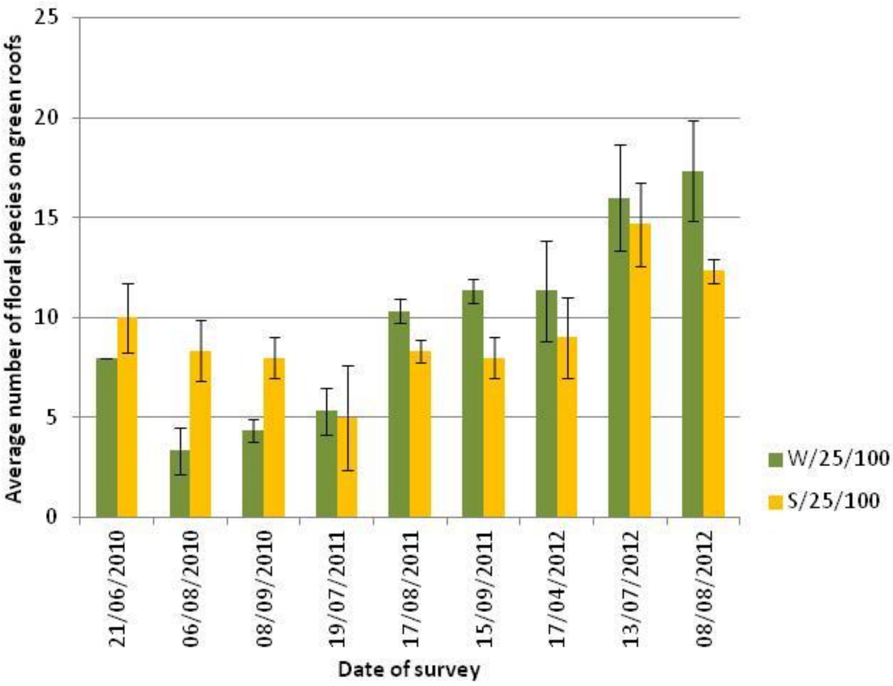


Figure 31. Average number of floral species recorded on W/25/100 and S/25/100 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (n = 3).

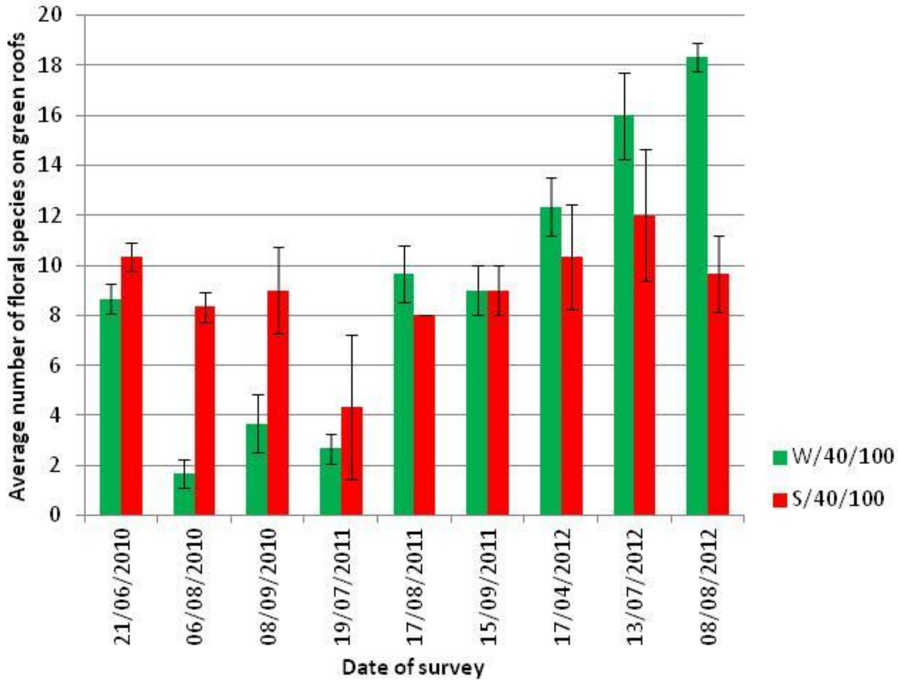


Figure 32. Average number of floral species recorded on W/40/100 and S/40/100 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (n = 3).

The general pattern observed from Figures 29 to 32 is one of increasing floral diversity over time on the biodiverse green roofs and relatively constant floral diversity on the sedum roofs. Certainly, over time it appears to be the biodiverse roofs that are providing the greatest floral diversity. This is even more pronounced if analysis of biodiversity in terms of floral genera is carried out instead of floral species. By grouping similar species under genera groupings it is possible to get a more functional measure of biodiversity groupings Functional group diversity is based on the theory that organisms can be categorised as belonging to groups that differ in traits in relation to ecosystem functioning and that greater functional group diversity correlates with greater ecological functional diversity (Lavorel *et al*. 1997). Biodiversity in the form of ecological functional diversity is critical for building resilience in ecosystems such as green roofs. The diversity-stability hypothesis dictates that more diverse ecosystems are more likely to thrive during a given environmental perturbation and thus compensate for competitors that are reduced by that disturbance (Tilman & Downing 1994; Fischer *et al*. 2006).

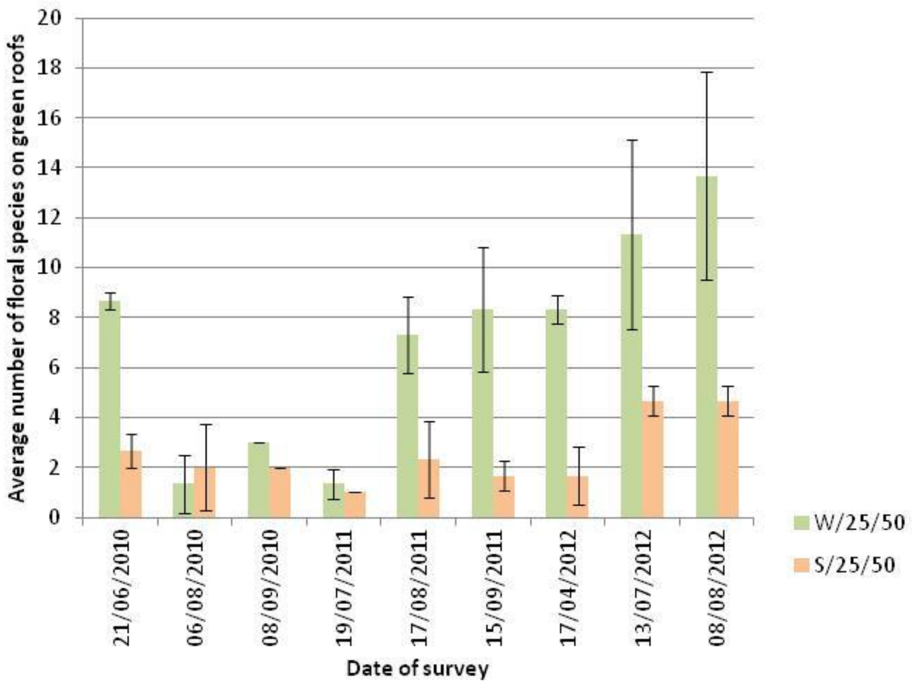


Figure 33. Average number of floral genera recorded on W/25/50 and S/25/50 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (n = 3).

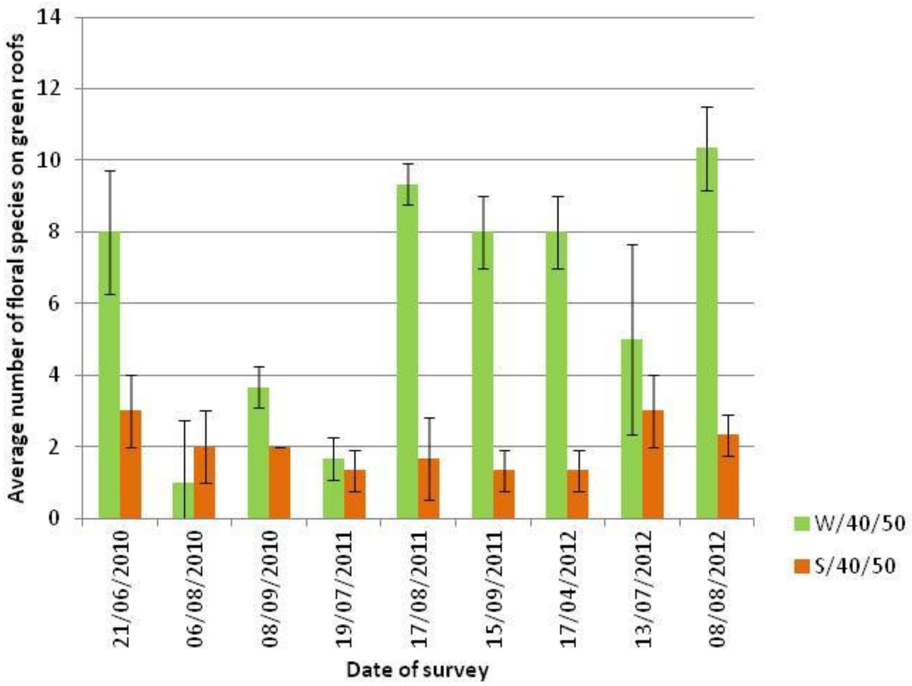


Figure 34. Average number of floral genera recorded on W/40/50 and S/40/50 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (n = 3).

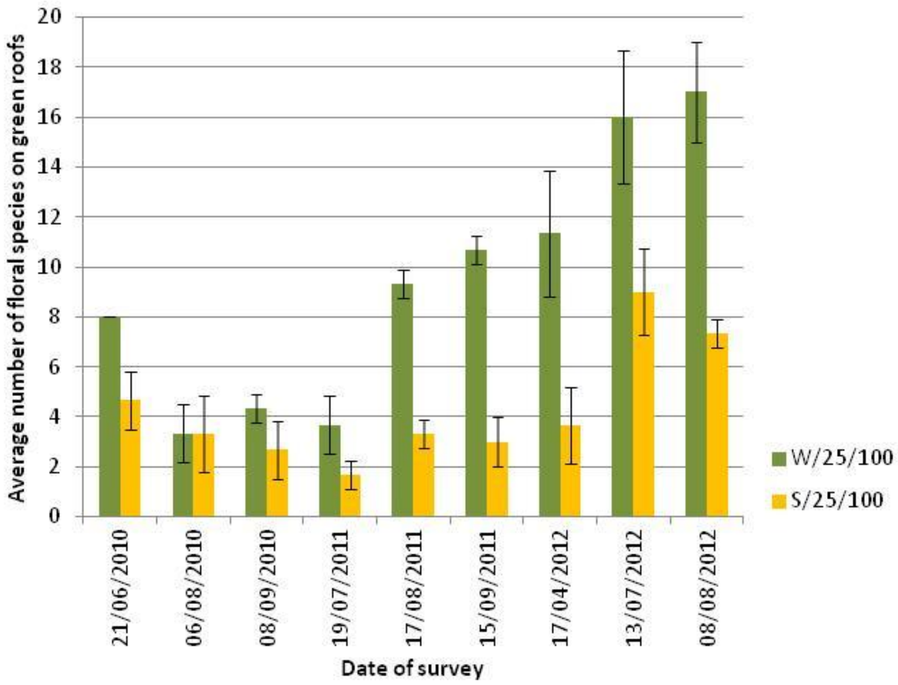


Figure 35. Average number of floral genera recorded on W/25/100 and S/25/100 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (*n* = 3).

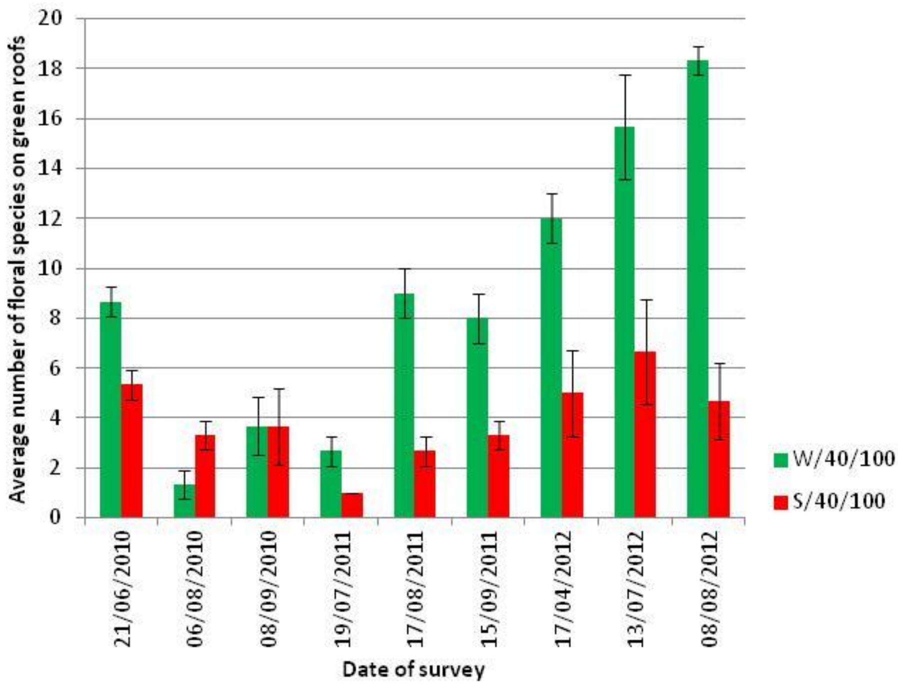


Figure 36. Average number of floral genera recorded on W/40/100 and S/40/100 green roof bays during the summer, 2010 to 2012. Error bars represent the standard error of the mean (*n* = 3).

By grouping floral composition into genera, and thus grouping similar species, it is possible to obtain a more functional view of floral diversity on the roofs. Results of this demonstrated to an even greater extent the divergence between the sedum and equivalent biodiverse roofs in terms of floral provision. With the exception of August 2010 (when a drought had followed the installation of the roofs) the biodiverse roofs far exceeded the sedum roofs in terms of floral genera diversity.

A similar pattern is observed if biodiversity is measured in terms of flower head availability for nectar and pollen foraging insects rather than just in terms of floral present. To measure this number of flowers/inflorescences of each flowering plant species that were present and available to foraging insects within each green roof test plot were recorded. For counts of the number of flowers, one flower 'head' was counted as a head (e.g. *Trifolium* species), spike (e.g. *Prunella vulgaris*), capitulum (e.g. *Centaurea nigra*), umbel (e.g. *Achillea millefolium*) or individual flower (e.g. *Ranunculus acris*) (Bowers 1985; Dramstad and Fry 1995; Carvell 2002; Carvell *et al*. 2004). Flower identification followed Stace (1997). Counts were made for the sedum and biodiverse roofs on the deepest substrate and drainage layer for the summer months in 2012. Results are presented for total number of flowers/inflorescences and diversity of species in flower (Figures 37 and 38).

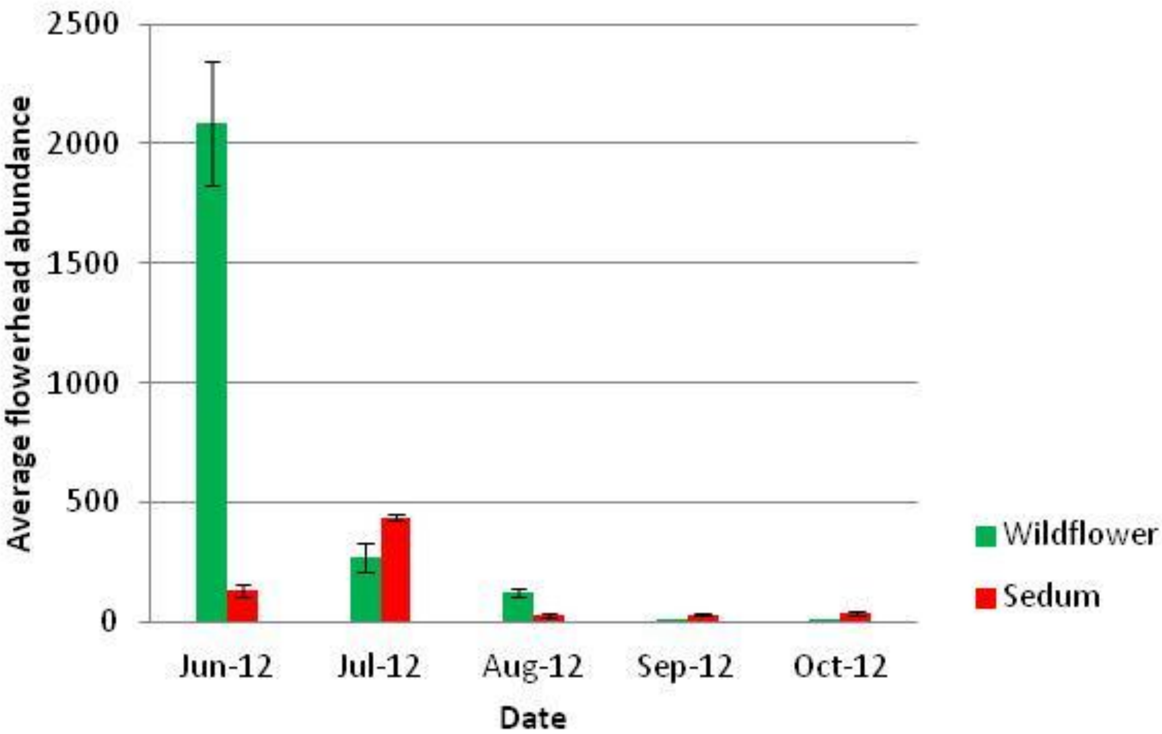


Figure 37. Average number of flowers/inflorescences on W/40/100 and S/40/100 green roof bays during the summer 2012. Error bars represent the standard error of the mean (*n* = 3).

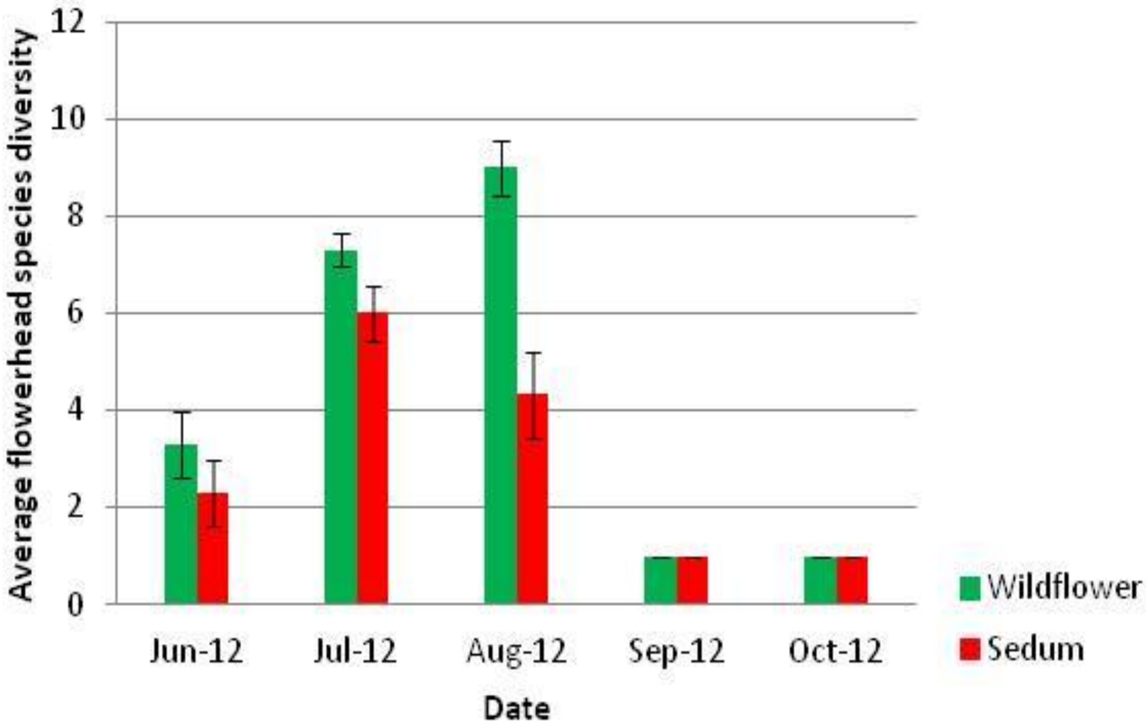


Figure 38. Average number of floral species in flower on W/40/100 and S/40/100 green roof bays during the summer 2012. Error bars represent the standard error of the mean (*n* = 3).

Similarly to counts of total number of floral species and genera, biodiverse roofs outperformed sedum roofs in terms of total number of flowers/inflorescences present and total number of flowering species present for the majority of months throughout the summer 2012. This was particularly the case in early summer when the biodiverse wildflower roofs were carpeted in flowers.

3.5 Discussion

The Barking Riverside green roof Knowledge Transfer Partnership has proved to be a real success in terms of investigating best practice for using biomimicry in green roof design to support locally important biodiversity and associated ecosystem services. Rather than demonstrating an ecosystem service cost associated with moving away from industrial standard sedum systems, the biodiverse green roof systems monitored performed as well as or superior to the equivalent sedum systems for water attenuation and thermal insulation and far out-performed the sedum systems in terms of supporting a diverse flora suitable for a broad range of foraging insects.

Such results demonstrate that there is no reason that industrial standard sedum green roofs should be rolled out like a uniform carpet across urban landscapes globally at the expense of regionally typical habitats and habitat features more suitable for supporting local biodiversity.

Results from the investigation are currently being fed into the design of green roofs throughout the Barking Riverside development in a hope that green roofs can make a significant contribution to the sustainability of the development and the conservation of the wildlife on the brownfield site prior to its development.

It is hoped that this KTP case study will act as a blueprint for use throughout the TURAS partnership and beyond to promote the use of biomimicry of regional habitat of conservation value in the design of green roofs to maximise urban biodiversity. For green roof design within the Thames Corridor, the design principles detailed in the 'Creating green roofs for invertebrates – a best practice guide' (Gedge *et al*. 2012) is an excellent starting point. It is hoped that the example set within this research partnership will encourage other such partnerships to develop globally with a view to investigating and extending the limits of understanding as to the habitats and ecosystems that can be created at roof level and the biodiversity of regional, national and international conservation priority that can be supported in urban areas through green roof implementation.

4. Acknowledgements

The initial Knowledge Transfer Partnership could not have been established without the generous support of numerous partners. Too numerous to detail here, a list is included as Appendix 1. Long-term monitoring of the research facilities and data analysis would not have been possible without the support of the Transitioning towards Urban Resilience and Sustainability (TURAS) EC FP7 research funding.

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Appendix 1

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