IGNITION Nature-Based Solutions Evidence Base Headline Findings Report

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Contents

The IGNITION nature-based solutions (NBS) evidence base is a live repository of data and is therefore subject to change as new research is completed and entered. Therefore, the conclusions contained within this report were correct as of July 2020 edition. For the most current data, please review the databases at ignitiongm.com. However general benefit pathways described here remain useful insights into the performance of NBS.

The IGNITION project partners

The Prince's Responsible Business Network · Manchester City of Trees · Environment Agency · GMCA Greater Manchester Combined Authority · Groundwork · Manchester City Council · Royal Horticultural Society · Salford City Council · UKGBC · United Utilities · The University of Manchester · University of Salford Manchester

1. Introduction

Green and blue infrastructure helps to tackle a variety of urban challenges including flooding, drought and heat waves as well as improving air quality, biodiversity, productivity, health and well-being. To build resilience against the impacts of climate change across Greater Manchester, the IGNITION project aims to generate a significant uplift in functional green and blue spaces across the city, in line with the ambitions in Greater Manchester's 5 Year Environment Plan.

Achieving this uplift requires increased levels of public and or private investment in green infrastructure. At present, finance for green infrastructure is heavily reliant on government grants or philanthropic investment and often does not consider technical functionality and wider benefits. The IGNITION project is developing business models and funding mechanisms that can demonstrate a coherent case for public and private investment.

Evidence of the performance and potential economic, environmental, and social returns from installing green infrastructure is central to the investment case. This IGNITION evidence base acts as a central evidence repository of existing and emerging evidence to support the development of funding models for NBS.

2. Use and replication

The primary function of the evidence base is to gauge the amount of available evidence against the benefits of each NBS, to provide a more nuanced insight into the wide-ranging performance of these solutions. The databases can also be a starting point to scope the impact of each NBS for areas of risk for an organisation, to identify the most suitable intervention.

The databases can be used to identify interventions that will deliver the greatest impact in terms of building resilience such as flood-risk alleviation, or carbon offsetting. Similarly, they can be used to identify areas where an individual site could achieve the largest financial benefits by installing NBS. They also provide scope for calculating the potential co-benefits to support an installation proposal.

The evidence base has huge scope for replication and growth. The evidence items included in the database have been collated in a transparent way (see evidence methodology document), which should enable other cities or project to follow the same process. Furthermore, the evidence items captured in the databases can be used by other cities and countries to explore the performance of NBS.

Additional areas of evidence that would help to reflect the scale of variety in each NBS could be considered as part of future research. These could include
- urban agriculture and rooftop farming
- wildlife overpasses

- water butts and rainwater harvesting/recirculation
- permeable surfaces

In addition, evidence could be sought specifically linking to common design variations and technical functions and areas with limited numbers of evidence items.

3. Existing evidence

Nature-based solutions and green infrastructure are widely acknowledged to have the potential to deliver a range of benefits for society, more commonly referred to as ecosystems goods and services. A large body of existing research, using a range of quantitative, qualitative and mixed methods, already provides assessment of the benefits of green infrastructure.

The benefits of green infrastructure have also been the subject of a wide range of policy documents, reports, guidance, tool kits and case studies, both within the UK and internationally (e.g. The GM Natural Capital Account 2019[1]; the 25 Year Environment Plan 2018[2]; Green Finance Strategy 2019[3];). Accompanying these documents is a range of interactive tools, developed to try to measure and communicate the benefits of green infrastructure, such as i-tree eco, CaVAT, B£st, ARIES, Co$ting Nature, Green Infrastructure Valuation Toolkit and InVEST etc, tailored to a range of different audiences.

The purpose of the IGNITION evidence base is not to recreate existing work but to extract the most relevant quantitative and qualitative evidence to aid the development of a case for investment in NBS in Greater Manchester.

4. Defining nature-based solutions

Nature-based solutions is a relatively new term in environmental policy and management which is closely related to the broader term ‘green infrastructure’. In comparison to green infrastructure, NBS is more explicitly linked to delivering effective outcomes for society (‘solutions’) using nature.

> *NBS are commonly described as the deliberate use of natural features to help societies address a variety of environmental, social and economic challenges, such as climate change, food security, social and economic development, in sustainable ways*[4]

Due to the focus of the IGNITION project on Greater Manchester, the following range of natural features commonly considered under the heading of NBS in an urban setting were targeted for research:

- Sustainable drainage systems (SuDS) (including ponds, swales, basins, and raingardens)
- Green roofs
- Green walls and hedges
- Urban parks / green spaces

- Street trees /SuDS-enabled street trees

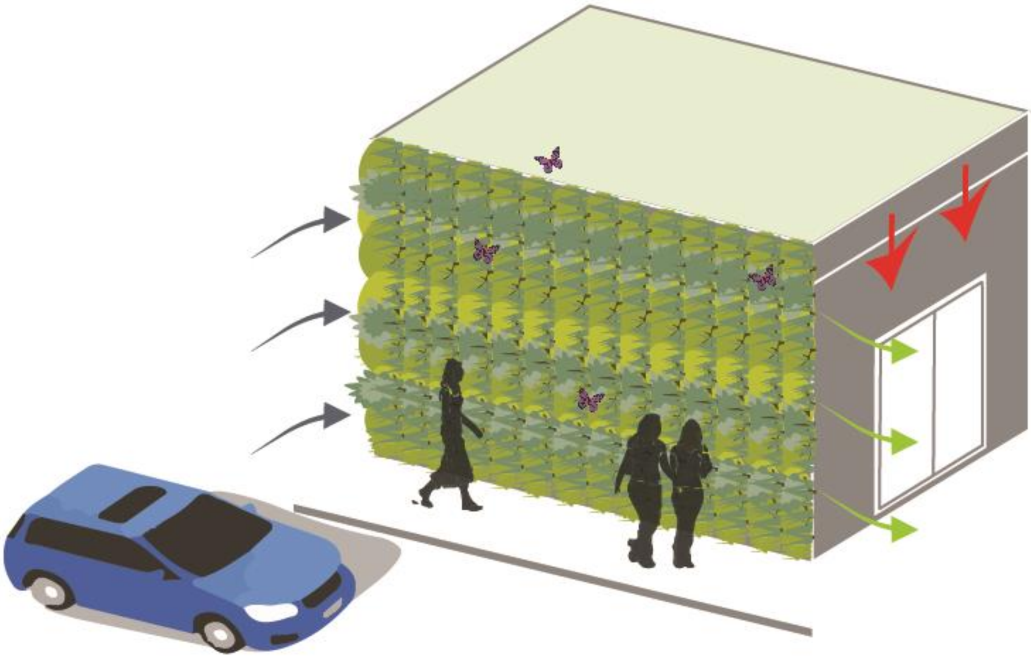
5. Headline Results

This summary of headline results and insights was compiled following the initial research period and updated with new data in the June 2020 IGNITION NBS evidence base review.

The quantitative figures quoted here are derived from the summary tables for each NBS database, where available, or in other cases a summary of any available qualitative evidence. Where a figure is taken from a single study, this is marked with an asterisk or referenced when included in the narrative. A full breakdown of the evidence items and references captured by the review is available in the accompanying databases for each NBS type.

The evidence base is a live document which will continue to be added to throughout the IGNITION project, the live nature of the evidence database means that the figures highlighted in this report will be subject to change. For the most current data, please review the databases at ignitiongm.com.

Green walls



Classification

Green walls refer to growing vegetation on or against a vertical surface. Green walls can be split into a variety of different classifications including 'green facades', where climbing plants are grown up or hang down from the bottom or top of a building, and 'living walls' where vegetation is actually planted into the structure of the wall itself using a modular or mat structure. Within the term green façade there are further subdivisions where climbing plants grow ‘directly’ on the wall structures, or ‘indirectly’ via a mesh, cable or trellis structure attached to the walls surface. Equally, there are various different types of living wall systems, including vegetated mats and felt systems, which provide pockets for plants, and modular systems which contain soil or growing media.

Other terms also used to refer to green walls include vertical greening systems, which specifically refer to structures that allow vegetation to spread over a building façade. Green screens and hedges are also included in the section on air quality benefits. Green screens refer to where a grid of mesh is covered with a densely woven climber such as ivy.

Evidence profile

192 evidence items were included in the database of evidence for green walls from 111 evidence sources. Evidence items were not evenly distributed across the benefits types;

23% focused on temperature, 14% on air quality and 15% on energy use, whilst only 1% covered amenity and 3% covered water quantity.

<table>
<tr><th>Benefit</th><th>Physical flow</th><th>Living wall</th><th>Green façade</th><th>Unit</th></tr>
<tr><td rowspan="2">Air quality</td><td>Nitrogen dioxide</td><td colspan="2">18-35%
[Mid-point 26.5%]</td><td>% Reduction in ambient concentration of NO_2 at street level in a street canyon</td></tr>
<tr><td>Particulate matter [PM10]</td><td colspan="2">22-50%
[Mid-point 36%]</td><td>% Reduction in ambient concentration of PM 10 at street level in a street canyon</td></tr>
<tr><td rowspan="3">Carbon</td><td rowspan="2">Carbon sequestration</td><td colspan="2">0.68</td><td>Avg. carbon kg yr. m^2</td></tr>
<tr><td colspan="2">0.14-3.18
[mid-point 1.66]</td><td>Rng. carbon kg yr. m^2</td></tr>
<tr><td>Carbon storage</td><td>No data</td><td>No data</td><td>Carbon kg m^2</td></tr>
<tr><td rowspan="2">Water quantity</td><td rowspan="2">Rainwater runoff reduction</td><td colspan="2"><75%</td><td>Max. % rainfall retained</td></tr>
<tr><td>No data</td><td>No data</td><td>Avg. rainfall intercepted m^3 annum per m^2</td></tr>
<tr><td rowspan="3">Water quality</td><td>Total nitrate removal</td><td colspan="2">30-83%
[Midpoint 57%]</td><td>Rng. % reduction in total Nitrates</td></tr>
<tr><td>Total suspended solids removal</td><td colspan="2">33-99%
[Midpoint 66%]</td><td>Rng. % reduction in total suspended solids</td></tr>
<tr><td>Total phosphate removal</td><td colspan="2">15-30%
[Midpoint 23%]</td><td>Rng. % reduction in total phosphates</td></tr>
<tr><td rowspan="3">Temperature</td><td>Indoor air temperature</td><td>4.8^{o}C*</td><td>2.7^{o}C
[Rng. 1.7-4^{o}C]</td><td>Avg. reductions in indoor air temp ^{o}C</td></tr>
<tr><td>Exterior wall temperature</td><td>3^{o}C
[Rng. 1-3^{o}C]</td><td>3.8^{o}C
[Rng. 0.4-7.1^{O}C]</td><td>Avg. reductions in exterior wall temp ^{o}C</td></tr>
<tr><td>Ambient exterior air temperature</td><td>0.5-4.1°C
[Midpoint 2.3°C]</td><td>1-3^{o}C
[Midpoint 1.5^{o}C]</td><td>Avg. reductions in exterior air temp ^{o}C</td></tr>
<tr><td rowspan="5">Energy use</td><td>Energy consumption for cooling</td><td>No data use green facades</td><td>19%
[Rng. 13-23%]</td><td>Avg. % reduction in energy use for cooling</td></tr>
<tr><td>Total energy consumption</td><td>15%
[Rng. 14-16%]</td><td>8%
[Rng. 8-9%]</td><td>Avg. % reduction in total energy consumption</td></tr>
<tr><td>Energy consumption for warming</td><td>5.2%
[Rng.4-6.3%]</td><td>1.6%
[Rng. 1.2-1.9%]</td><td>Avg. % reduction in energy consumption for warming</td></tr>
<tr><td>Thermal transfer</td><td>50%</td><td>No data</td><td>% reduction in thermal transfer</td></tr>
<tr><td>Thermal resistance</td><td>0.275
[Rng. 0.03-0.52]</td><td>0.09*</td><td>Avg. Increase in thermal resistance m2 kW</td></tr>
</table>

Health and well-being	Attention	Improvements in the selective attention of children in classrooms with green walls.		Selective attention
	Relaxation	Green façade appears to enhance human physiological and psychological relaxation compared to the building-wall.		Physiological and psychological relaxation
	Memory and recall	View of vegetation led to 12-15% improvement in memory and recall test in adults		Memory and recall
Noise	Reduction in noise levels	9.75dB [Rng. 4.5-15dB]	2.6dB [Rng. 1-4dB]	Avg. decibels dB reduction
		50%	No data use living walls	% sound energy reduction
Land and property value	Property value uplift	2.5%* [Rng. 2.5-20%]		Avg. % uplift in property price
	Land value uplift	2% [Rng. 1.4-2.7%]		Avg. % uplift in land price
	Rent price premium	No data		Avg. % rent price
Amenity	Liveable environment	*Promotes a liveable, restorative and aesthetically pleasing environment*		
Biodiversity	Birds and arthropods.	*Birds exploited the green walls for various reasons (including nesting, food and shelter). Research also showed the capacity of vegetated façades to shelter arthropods. Hedges are known to have high value for biodiversity*		
Local economic growth	Staff turnover	18%		% reduction in staff turnover after GI investment
	Sick leave	10%		% reduction in sick leave
	Productivity	15%		% increase in worker productivity with green office environments

Carbon

7 evidence items from 3 evidence sources

A small number of studies were identified on the carbon sequestration and storage benefits of green walls, in comparison to other NBS. Green walls have some capacity to sequester carbon annually, but the amount they could potentially sequester is thought to be less than that of green roofs. The average amount of carbon sequestered by green walls was 0.68kg carbon per year per m^2; however, figures reported in the database ranged from 0.14 to 3.18kg carbon per year per m^2.

Air quality

26 evidence items from 16 evidence sources

Vegetation is widely acknowledged to be able to improve air quality through influencing local dispersion patterns, aiding the deposition of pollutants, the trapping of dust and other pollutants, and the removal of airborne pollution through plant surfaces. In comparison to artificial surfaces, such as buildings and roads, vegetation can remove pollutants more efficiently from the atmosphere and therefore serve as a sink for atmospheric pollutants.

However, some studies on aerodynamics have also demonstrated that vegetation can in some instances have a negative effect on air quality. For example, while vegetation in street canyons may improve air quality by removing pollutants, it may also worsen air quality by inhibiting street ventilation. Therefore, the results reported here should be used with caution and understood to be dependent on the local context.

The value of green walls is mainly reported on in relation to deposition and potential to immobilise particles. Evidence items included in the database have also often focused on the benefits in street canyons and dense urban areas or close to roads. In street canyons, nitrogen dioxide (NO_2) can be reduced by 18-35% and coarse particulate matter (PM10) by 22-50% at street level. Notably green walls caused less accumulation of pollutants compared to trees. However, city-scale modelling studies suggest that deposition of green wall vegetation can make only a modest improvement to ambient air quality, approximately a 5% reduction in ambient local pollution concentrations.

Green screens and hedges also have benefits through diverting air pollution from reaching footpath areas by generating local vortices. Where positioned as a barrier to roadside pollutants, hedges and green screens were found to result in a 15-61% reduction in ambient pollution concentrations behind the barrier, and a 7-15% reduction in coarse particulate matter (PM10).

Water quantity

5 evidence items from 2 evidence sources

The plants and media contained in green walls can help promote interception, infiltration, and evapotranspiration of rainwater runoff, performing a similar function to green roofs, rain gardens, bioswales, and pervious pavement in reducing stormwater runoff.

Only two studies in the evidence base reported on the water quantity benefits delivered by green walls. One study suggests that green walls could retain maximum of 75% rainfall runoff[5], whilst another study reports rainfall runoff retention as being between 63% or 94% depending on the severity of the rainfall event.[6]

Water quality

18 evidence items from 4 evidence sources

The plants and media contained in green walls consume and filter water and can potentially help improve greywater quality.

The studies included on the evidence base on the capacity of green walls to improve water quality. The greatest benefits of green walls were in relation to total suspended soils, which were reduced by 33-99%; total nitrates, which were reduced by 30-83%; and total phosphate, which were reduced by 15-30%. These benefits were related to living walls rather than green facades. If green walls were specifically engineered to treat greywater, these benefits could be further enhanced.

Temperature

45 evidence items from 20 evidence sources

Green walls can alter temperatures through an evaporative cooling effect provided by vegetation, the physical shading of solar radiation, and an increase in thermal insulation in the winter. The degree that green walls could alter temperatures was related to the prevailing climate characteristics, the amount of vegetation, and urban geometry.[7] It is important to note that the magnitude of the benefits of green walls was found to be much greater for tropical and sub-tropical environments than the maritime temperate climate of the UK and Northern Europe.

The figures reported in the summary are focused on the benefits for temperate climates in Northern Europe and the UK, where possible, for the cooling effects, however, winter insulation benefits data is taken from studies from all locations.

Studies reported on the cooling or insulating benefits of green walls, including exterior surface wall temperature reductions, ambient exterior air temperature reductions, indoor temperature reductions, and night-time insulating effects.

Average indoor air temperature reductions were 2.7^{o}C for green facades and 4.8^{o}C, for living walls. Exterior surface temperature studies were largely available for green facades rather than living walls. Average exterior wall surface temperature reductions were reported at around 3.8^{o}C from green facades and 3^{o}C from living walls. Ambient exterior air temperature reductions from green facades and living walls ranged from 0.5^{o}C to 4.1^{o}C, with a midpoint of 2.3^{o}C for living walls and, 1.7 to 3^{o}C with a midpoint of 1.5^{o}C for green facades.

Energy use

28 evidence items from 18 evidence sources

Studies reporting on reductions in energy use were closely linked to the cooling benefits of green walls, with studies reporting on reductions in energy consumption from reduced cooling, as well as the insulating effect from reduced energy consumption for warming and increased thermal resistance to heat loss. Many more studies were available on the benefits of green walls in sub-tropical and tropical climates, but only temperate climates have been included here.

Evidence items included in the green walls database suggest that total energy consumption reduction ranged from 14-16% for living walls and 8-9% for green facades. These figures are derived from a reduction in energy consumption from seasonal heating and cooling.

Reductions in energy consumption for cooling is less applicable in the UK where there is much less widespread use of air conditioning for cooling, however where available estimates for temperate climates were included.

These studies suggest a 13-23% reduction in energy use for cooling. There were also potential benefits from reduced energy use for warming in the winter period of between 4-6.3% for living walls and 1.2-1.9% for green facades. The installation of green walls was also thought to lead to a measurable increase in thermal resistance from 0.03-0.52 kw per m^2 for living walls and 0.09 kw per m^2 for green facades.

Health and wellbeing

14 evidence items from 12 evidence sources

Limited quantitative evidence was available directly relating to the health and well-being benefits delivered by green walls. The majority of studies included in the database were either based on indoor green walls and plants, or on a 'view of nature', and these were taken as proxies for a view of a green wall or an indoor green wall. A wide range of benefits was reported, including: (1) improvements in the selective attention of children in classrooms where a green wall was present, (2) enhanced human physiological and psychological relaxation compared to the built-wall, and (3) a 12-15% improvement in memory and recall test in adults.

Noise

10 evidence items from 8 evidence sources

Both the vegetation and the media used to construct green walls can reduce noise levels for the users and residents of the buildings they are installed on through absorbing acoustic energy.

Reported reduction in sound levels ranged from 1 to 15dB; notably, the sound reductions which could be specifically attributed to green facades were 1 to 4dB, whereas the benefits from living walls ranged from 4.5 to 15dB.

Land and property value

11 evidence items from 9 evidence sources

Studies included in the evidence base related to land price uplift, property value uplift and building durability. Average property value uplift was reported to be 2.5% and land value uplift was 2%. No evidence was found on rent price uplift.

Qualitative evidence statements were also included on increased building durability due to the installation of green walls. Durability benefits were linked to the reduced exposure of building exterior surfaces to sunlight, air temperature fluctuations, acid rain and air pollution, leading to greater longevity of the building exterior surface material.

Amenity

2 evidence items from 2 evidence sources

Although limited studies were found on the amenity value of green walls, there were a number of qualitative evidence statements around their potential to promote a more liveable, restorative and aesthetically pleasing environment.

Biodiversity

14 evidence items from 9 evidence sources

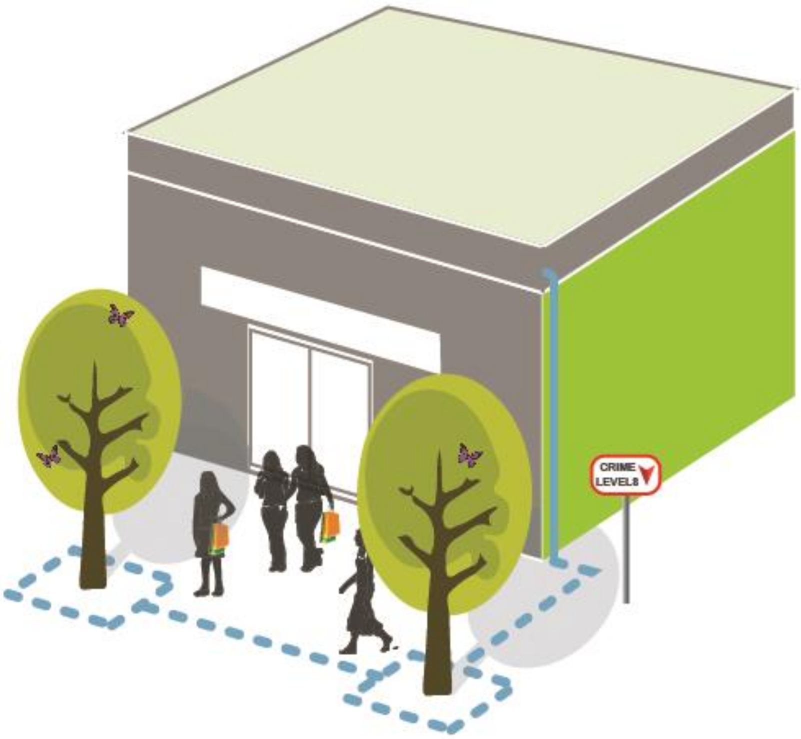
Studies reported that birds exploited the green walls for various reasons, including nesting, food and shelter. Capacity of vegetated façades to shelter arthropods is also evidenced.

Local economic growth

12 evidence items from 8 evidence sources

In general, studies on the economic benefits of green walls for local business suggested that high-quality green spaces can help businesses build a good image and improve their reputation, which will encourage inward investment and employment into an area. Studies reported here are not specifically related to green walls but refer to views of greenery or indoor plants. These are taken as proxies for the view of a green wall or an indoor green wall. The provision of visually stimulating spaces including elements of the natural environment was linked to an 18% reduction in staff turnover for workplaces, a 10% reduction in sick leave, and a 15% increase in worker productivity with green office environments.

Street trees and SuDS-enabled street trees



Classification

Street trees refer to any tree located next to or within a public road. They can be combined with SuDS (including tree pits and trenches) resulting in SuDS-enabled street trees. Urban amenity trees are also included in this category; these are taken as any urban trees that are not grown or managed for their value as a timber crop and that provide other benefits or values.

Evidence profile

193 evidence items were included in the database for street trees and SuDS-enabled street trees, from 107 evidence sources. Evidence items were not evenly distributed across the benefits types: air quality evidence items accounted for 20%, temperature 13%, water quantity 11%, and health and well-being 11%.

A range of research designs have been used to generate evidence, including experimental studies, field studies, modelling and numerical studies, and surveys of populations interaction with street trees.

Benefit type	Physical flow	Street trees	SuDS-enabled street trees	Unit
Air quality	Pollution removal	0.17 [Rng. 0.04-0.39]	*No data*	Avg. NO_2 removed kg yr. per tree
		0.11 [Rng. 0.05-0.93]	*No data*	Avg. PM10 Removal kg/yr./per tree
Carbon	Annual carbon sequestered	5.5 [Rng. 3.5-10]	*No data*	Avg. carbon sequestered kg/yr./per tree
	Total carbon storage	231.6 [Rng. 7.6 to 852]	*No data*	Avg. carbon stored kg/per tree
Water quantity	Rainwater runoff reduction	43% [Rng. 5.2% - 79%]	78%*	Avg. % runoff volume retention
		3.3 [Rng. 0.14-11.3]	*No data*	Avg. rainfall intercepted m^3 annum per tree
		No data	81% [68min delay in peak flow]	Avg. % peak flow attenuation
Water quality	Pollution removal	70%*	*No data*	Avg. % reduction in nitrate concentrations
Temperature	Cooling or insulating	11^{o}C [Rng. 10 - 12^{o}C]	*No data*	Avg. reduction in surface temperature ^{o}C
		3^{o}C [Rng. 0.9 - 5.2^{o}C]	*No data*	Air temperature reductions °C
		3.8 - 15^{o}C [Mid 9.4 ^{o}C]	*No data*	Globe temperatures reductions °C
Energy use	Energy savings	0 - 288 kWh [midpoint 144]	*No data*	kWH savings per tree/annum from cooling energy savings
		30%	*No data*	% Avg. annual seasonal cooling-energy savings per tree
		18%*	*No data*	% heating savings through insulation

Health and well-being	Health and well-being	Each additional tree per km of street was associated with 1.38 fewer antidepressant prescriptions per 1000 population per year		Number of fewer antidepressant prescriptions per 1000
		An increase in tree density of 1 standard deviation led to a 29% lower early childhood prevalence of asthma		% prevalence of early childhood asthma
Noise	Reduction in noise levels	4dB [Rng. 4-8dB]	*No data*	Avg. decibels [dB] reduction per tree
Amenity	Improvement in road safety	*Qualitative evidence not suitable for quantitative synthesis*	*No data*	% increase per tree
	Reduction in crime levels	1.2% decrease in crime levels for every 1% increase in tree canopy	*No data*	% decrease per tree
Land and property	Property value uplift	4.7% [Rng. 4.27 - 5%]	*No data*	% uplift in property price from the presence of street trees
	Rent value uplift	6.15% [Rng 5.3 - 7%]	*No data*	% uplift in rent uplift from the presence of street trees
Biodiversity	Biodiversity	*Qualitative evidence not suitable for quantitative synthesis*	*No data*	n/a
Local economic growth	Increase willingness spend on products	10-50% [mid 30%]	*No data*	% increase per customer based on the presence of street trees in central business districts
	Increased patronage of restaurants	30-50% [mid 40%]	*No data*	% increase in restaurant patronage
	Decreased sick leave of workforce	23%	*No data*	% reduction in sick leave taken by workforce who have a view of nature

Carbon

17 evidence items from 11 evidence sources

Carbon dioxide is sequestered into street trees through the biochemical process of photosynthesis and stored as carbon within the trunk, branches and leaves, as well as biomass below ground in tree roots and soil. The capacity of trees to store carbon varies depending on the species, the size of the tree and the stage of growth. It also greatly depends on management regimes and human-induced disturbance. Carbon reduction benefits have generally been found to be highest in large, long-lived and fast-growing species.[8]

Many of the evidence sources included in the database had used the i-tree eco methodology, to estimate the volume of carbon sequestered and stored by tree stocks using sample plots of tree measurements, including one study from Greater Manchester by City of Trees.

An average of 5.5kg carbon sequestered per year per tree is included, with a range of 3.5-10kg per year per tree. Total carbon stored both above and below ground by trees was 231.6kg per tree, but there was a significant range reported across the evidence items included in the evidence base from a minimum of 7.6 to a maximum of 852kg per tree.

Air quality

38 evidence items from 17 evidence sources

Street trees remove air pollution by the interception and deposition of pollutants on plant surfaces, the absorption of gaseous pollutants through the leaf stomata, and the alternation of air masses. Although one of the greatest benefits from trees may come from their ability to disperse air and increase the effective distance between the source and the receptor thus reducing exposure to pollutants, the effect of street trees is complex.

Street trees can potentially contribute both positively and negatively to urban air pollution in different contexts. Because trees may alter air movement, especially in restricted spaces such as urban street “canyons,” they can affect the physical transportation of polluted air masses. This can, in some cases, reduce ventilation of street canyons, increasing air pollution or, in other contexts, enhance ventilation by increasing surface roughness and thus turbulence reducing air pollution.[9] Urban vegetation can also affect air quality negatively in other ways due to the allergenic effects of pollen and fungal spores.

The evidence items included in the database suggest that street trees can result in a positive effect on air quality, if used in the right context. On average, street trees could remove on 0.17kg NO_2 per tree annually, and 0.11kg Particulate Matter (PM^{10}) per tree per year. In terms of a percentage reduction in ambient concentration of NO_2, evidence items reported a reduction of between 1-21%. The benefits in terms of a percentage reduction in ambient concentration of NO_2 rise considerably for woodlands, stands or shelterbelts of trees where the expected reduction range was between 7-59%.

Water quantity

22 evidence items from 14 evidence sources

Natural drainage is hindered by sealed surfaces in urban areas. Urban street trees can play a role in reducing water runoff and managing urban surface water through intercepting rainfall, evapotranspiration of rainwater which falls on branches and leaves, and encouraging infiltration of rainwater. SuDS-enabled street trees have additional benefits through encouraging greater infiltration and retaining rainwater runoff in specially designed tree pits. A number of factors can influence the runoff regulation function of street trees, including rainfall intensity and duration of precipitation events, climate, slope, and vegetation characteristics.

A number of studies included in the evidence base use i-trees' eco methodology, however, experimental studies and field studies monitoring data from SuDS-enabled streets trees in the Greater Manchester region were also available. Only one study was available on the performance of SuDS-enabled street trees.

The evidence items included in the database suggest that on average street trees retain approximately 43% of runoff volume, and SuDS-enabled streets tress an average of 78% of runoff volume. However, it must be highlighted that there was a considerable range in the amount of runoff volume reduction reported by different studies, between 5.2 - 79%. The amount of rainfall intercepted by street trees was also estimated at on average 3.2 m^3 per annum per tree. While SuDS-enabled street trees also showed the capacity to on average reduce peak flow by 81%.

Water quality

2 evidence items from 2 evidence sources

Very little evidence was found on the water quality benefits of street trees. Only one quantitative evidence item was reported in the evidence base which suggests that on average street trees can result in a 70% reduction in nitrates.

Temperature

25 evidence items from 14 evidence sources

Street trees cool temperatures through canopy shading, absorption, blocking and reflection of solar radiation received by impervious urban material and evapotranspiration. They can shade nearby buildings and reduce the heat storage of building surfaces, thus modifying indoor temperatures and reducing risk of indoor overheating. Furthermore, street trees may shelter building during the wintertime by blocking prevailing winds.

The body of evidence suggests that the average reduction in surface temperature via tree canopy shading is 11^{o}C and has an average air temperature reduction under tree canopies of 3^{o}C. In addition, several studies reported on reduction in globe temperature (or physiologically equivalent temperature) ranging from 3.8^{o}C to 15^{o}C. Globe temperature is a biometeorological parameter that describes the thermal perception of an individual. However, the cooling effects of trees on climates was found to be dependent on the species, climate, tree placement, position and size and growth conditions.

Energy use

18 evidence items from 8 evidence sources

Both the cooling effect of street trees during the summertime and the sheltering effect during wintertime have informed further studies on energy savings for nearby buildings. Many of these studies included in the database quantified estimated energy savings benefits through approximating equivalent reduced use of air conditioning units. Very little work has been carried out in the UK or Northern Europe, where the use of air conditioning is much rarer and therefore the applicability of these studies for the UK is questionable. Studies included in the database were mostly from the North America and the UK as well as international review papers.

The quantitative evidence items included in the database indicate quite mixed results in this area, with energy savings from reduced cooling ranging from 0 to 288 kWh per tree. One study reports winter energy savings per tree was reported to result in an 18% energy saving from reduced heating.[10] However, as highlighted in the section on temperature, the energy savings recorded were conditional on the quantity of trees and their placement.

Health and well-being

22 evidence items from 13 evidence sources

Street trees are a common and accessible form of urban nature. By providing views of natural and green environments, street trees can contribute to a positive living environment, and could be linked to stress reduction via a visual amenity pathway. Thirteen qualitative and quantitative studies were captured in the evidence base on the health benefits of street trees, far less than available for green space. These studies were split across a range of different health and well-being components, from reduced exposure to UV to increased physical activity levels, mortality rates, birth outcomes and depression. Some of the key findings are highlighted here, however, the range in subjects covered were not suited to quantitative synthesis; instead, a qualitative overview is provided in the next paragraphs.
In relation to mental health and well-being benefits, a review study indicated that spending time within sight of trees and walking in a natural environment have been associated with lowered blood pressure and lower stress levels.[11] One study found that each additional tree per kilometre of street was associated with 1.38 fewer antidepressant prescriptions per 1,000 population per year (95% confidence interval).[12] Another reports that having more trees in a neighbourhood (measured as a higher percentage of tree canopy) was associated with more positive mental health, particularly among those aged 55 and older.[13]

In terms of physical health, evidence is available on the benefits of trees as a barrier to ultra-violet radiation (UV), with one study reporting a 40-60% reduction in UV exposure compared to full sun.[14] An increase in tree density of one standard deviation led to a 29% lower early childhood prevalence of asthma.[15] However, trees, grasses, and other plants release pollens, which can aggravate allergies and asthma in susceptible people. Some evidence reports that people who live in neighbourhoods with a higher density of trees on their streets report significantly higher health perception and significantly less cardiometabolic conditions[16], while tree loss was associated with a statistically significant increase in mortality related to cardiovascular and lower-respiratory tract illnesses.[17]

Noise

9 evidence items from 4 evidence sources

Only four studies were available on the noise reduction benefits of street trees. Collectively they suggest that roadside vegetation, such as street trees, has the potential to act as a noise barrier by reflecting and absorbing acoustic energy. Quantitative estimates reported by two studies suggested an average four-decibel reduction in sound energy per tree, with a range between 4 and 8dB. In comparison a solid wall decreases sound energy by 15 decibels.

Land and property value

15 evidence items from 10 evidence sources

A clear link was made by a number of studies between the presence of street trees and an uplift in land price, property price and rent price. The majority of evidence items included in the database were derived from hedonic pricing studies and surveys of buildings and investment decisions.

Studies included in the database suggested an average uplift in property price of 4.7%, an average uplift in rent price of 6.15%, and land price premium ranging from 6-15%, due to the presence of street trees nearby. Differences in property, land and rent uplift were linked to whether trees were mature or young and the quantity of trees. Notably a high number of street trees were linked to a 17% increase in property value in one study[18] and a view of woodland linked to an 18% increase in property price.[19] Occupancy of commercial property was also found to increase with extensive planting of trees linked to a 38% in occupancy.[20]

Amenity

7 evidence items from 5 evidence sources

Studies reporting on the amenity benefits of street trees suggest that the presence of trees increases the use of public space, enhancing surveillance, and may also serve as a symbol of neighbourhood social control, if the trees appear to be well cared for.

These studies suggest that the presence of trees has several associations with crime levels. One study reported a 1.2% decrease in crime levels for every 1% increase in tree canopy.[21] In particular, these benefits seem to be related to a drop in violent crime. Street trees were also thought to have beneficial effects on road safety, with tree-lined streets reported to make it feel like the street is narrower and encourage slower driving and providing a buffer between pedestrians and road vehicles.

Biodiversity

7 evidence items from 4 evidence sources

The biodiversity value of trees is a longstanding area of research which is was not possible to capture in this rapid evidence review.

Included studies, specifically mentioning street trees, generally reported that street trees in urban landscapes provide a range of ecosystem services, including habitat, refugia, food, and corridors for other fauna and flora. Furthermore, street trees were also thought to provide connectivity between forest remnants and riparian vegetation strips in cities, providing corridors for the dispersal of small mammals, birds and less-conspicuous fauna such as butterflies, moths and beetles. Notably, one study reported that fauna abundance is often lower in the inner city, where tree density is lower, than in suburban and outer-urban areas.[22]

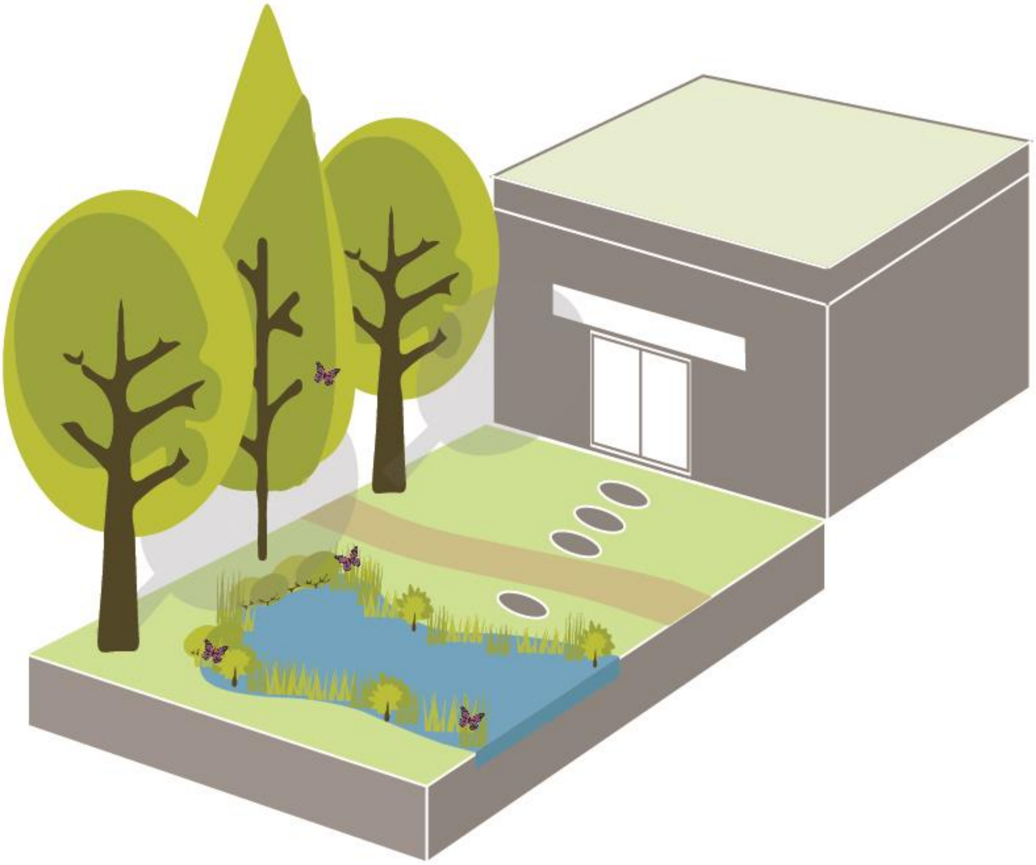
Local economic growth

11 evidence items from 5 evidence sources

Consumer behaviour is affected by the physical environment, or streetscape greening, outside shops and street trees can help to form more positive consumer experiences in central business districts.

Studies included in the evidence base indicate that people are prepared to pay more for parking and shoppers are willing to pay between 10-50% more for goods and services in central business districts that have a high-quality tree canopy. A high-quality tree canopy was also linked to increased patronage of restaurants, with a 30-50% rise in patronage.[23] In addition to an increased willingness to pay, evidence sources included in the database suggest that if workers can see elements of the natural environment, such as street trees, from their workspace they report fewer ailments. One study reports that green workspaces and workers with a view of nature were linked to a 23% drop in sick leave, greater job satisfaction, and a greater likelihood of better staff retention and morale.[24]

Urban green space



Classification

Urban green spaces are areas that are naturally or artificially covered with vegetation (e.g. grass, bushes or trees), where water can permeate through the soil and vegetation (e.g. soil, grass, parks, etc.). They can range from playing fields to highly maintained environments or relatively natural landscapes. Urban green spaces is an extremely widely used term. For this review the following sub-terms were included under urban green space: urban parks, urban green vegetation, roadside greenery, roadside verges, urban green cover, amenity grassland, sports pitches, urban herbaceous vegetation and urban vegetated institutional land.

Evidence profile

317 evidence items were included on urban green space, from 163 different evidence sources. 24% of evidence items were related to health and well-being, 13% on carbon and

10% on land and property values. In comparison, only 2% covered local economic benefits and 3% looked at noise and biodiversity.

Benefit	Description	Summary findings	Unit
Air quality	NO_2 removal	2.6%*	% reduction in ambient concentration of NO^2 50m inside a park
	Particulate matter (PM_{10})	9.1%*	% reduction in ambient concentration of PM_{10} 50m inside a park
		1.45*	PM_{10} captured g m^2 yr.
Carbon	Carbon sequestration	0.2 [Rng. 0.09 - 0.41]	Avg. carbon sequestered kg yr. m^2
	Above ground carbon storage	1.01 [Rng. 0.1 – 3.16]	Avg. carbon stored kg m^2
	Below ground carbon storage	5.9 [Rng. 1.4 – 7.7]	Avg. carbon stored kg m^2
Water quantity	Runoff	6.8 [Rng. 6 – 8]	Avg. runoff from green spaces l m^2 for per 10mm rainfall event
		3.36 [Rng. 0.6-4.8]	Avg. runoff from green spaces l m^2 for per hour 40mm rainfall event
	Infiltration rate	30% [Rng. 18 - 35%]	Avg. % annual rainfall retained or infiltrated
Water quality	All pollutants	85%*	% reduction in all pollutant concentrations
	Suspended sediments	42 - 100% [Midpoint 71%]	% reduction in total suspended sediment concentrations
	Phosphorous	22 – 95% [Midpoint 58.5%]	% reduction in total soluble phosphorous concentrations
	Nitrates	31 - 100% [Midpoint 65.5%]	% reduction in total soluble nitrate concentrations
Temperature	Air temperature	2.7°C [Rng. 0.5 - 7°C]	Avg. air temperature reductions daytime °C
	Night-time temperature	1.2°C	Avg. air temperature reductions night-time °C
Energy use	Annual cooling savings	15.4 [Rng. 9.7 - 24.7]	kWh per day (data from non-UK studies)
		10-17% [Midpoint 13.5%]	% seasonal cooling-energy savings per day
Health and well-being	Mental health	Not possible to summarise	Not possible to summarise
	Physical health	Not possible to summarise	Not possible to summarise
Noise attenuation	Sound reduction	4	Decibels reduction per m2
Land and property value	Direct or close proximity to a park or green space	9.5% [Rng 2.6 - 20%)	Avg. % uplift in property value
	Between 100-600m from a green space or park	3.1% [Rng. 0.5 - 8%]	Avg. % uplift in property value

	Every 100m closer to a green space	1%	% increase in property value every 100m closer to a green space
	Rent	7%*	% uplift in rent
Biodiversity	Biodiversity	Not possible to summarise	Not possible to summarise
Amenity	Quality of life	85%*	% of people consider that the quality of public space and the built environment has a direct impact on their lives and on the way they feel
	Crime rates	56% and 48%*	% reduction in violent and property crimes associated with higher levels of greenness
Local economic growth	Willingness to pay more for goods and services	10%*	% increase in WTP for products associated with high green cover
	Park visitor spend	50%*	% park visitors also visit a local business before or after visiting the park.
	Commercial trading rates	40%*	% increase in commercial trading rates after investment in well planned green space

Air quality

29 evidence items from 13 evidence sources

Urban green spaces and parks can alter levels of air pollution in the urban landscape both via deposition and by affecting the transport and dilution of polluted air masses. Vegetation provides surfaces for dry deposition and immobilisation of pollutants such as Particulate Matter (e.g. PM10), and absorption of gaseous pollutants such as nitrogen dioxide (NO_2) and sulphur dioxide (SO_2).

Vegetation can also affect the physical transportation and dilution of air masses. In some cases, the presence of vegetation will increase ventilation by encouraging increase turbulence and enhancing vertical mixing of air masses thus reducing pollution, while in other contexts (such as in a street canyon) vegetation can, in some instances, have the opposite effect and lead to reduced ventilation. The beneficial effect of parks on air quality is the product of both increased opportunities for deposition and greater opportunities for the dilution of air masses.[25] However, the maintenance of urban vegetation can, in some cases, also result in emissions of some greenhouse gases.

Quantitative evidence items indicate that urban parks can lead to a 2.6% reduction in ambient concentrations of NO_2 50m inside a park, and a 10% reduction 100m inside parks. Parks have a greater benefit for coarse particulate matter (PM10) with a 9.1% reduction recorded 50m inside parks, and a 30% reduction at 100m. In terms of the amount of PM10 captured, this is estimated to be on average 1.45g PM10 per m^2 per year based on average amounts across a range of different urban vegetation types. The additional benefits of trees have and woodland areas have largely been excluded from these averages to provide a more conservative estimate of the benefits of urban parks.

Although it is evident that vegetation has potential to reduce air pollution, evidence items included in the database reported mixed results with the level of benefits was found to depend on the local context. For example, vegetation takes up more pollutants where pollution concentration are high, which supports the placement of vegetation near to emission sources such as roads. Some studies suggest that the effect of vegetation is relatively minor in some contexts. however, others were able to provide quantitative estimates of the reduction potential of vegetation. The potential of urban vegetation to filter air pollution was also found to differ depending on species, as the filtering capacity of vegetation increases with leaf surface area, and thus is higher for trees and bushes than for grasses.

Carbon

40 evidence items from 12 evidence sources

Carbon is sequestered in vegetation through photosynthesis and is stored as biomass both above ground vegetation and below ground. On average urban parks, vegetation and green spaces and grassland were found to sequester 0.2kg carbon per year per m^2. Average carbon storage above ground was around 1kg carbon per m^2, and below ground 5.9kg carbon per m^2.

Evidence included in the database highlights that the vast majority of above ground carbon storage takes places in trees, with a much smaller proportion stored in shrubs and herbaceous vegetation. While urban greenspace helps reduce atmospheric carbon, both directly and indirectly, they can also contribute to carbon emissions through the consumption of energy for landscape management activities, such as mowing, pruning, irrigation, and fertilisation.[26]

Water quantity

22 evidence items from 4 evidence sources

Natural drainage is severely hindered by surface sealing in urban areas. Urban green spaces, parks and vegetation can help intercept rainfall, enabling direct infiltration into the more permeable soil underneath vegetation and store water in branches and leaves prior to evaporation. The capacity of vegetated and green areas to reduce surface water runoff is thought to be influenced by the intensity and duration of rainfall events, climate, slope, and vegetation characteristics; for example, while trees contribute to reduce rainfall through interception, grasses absorb rainwater and enable greater infiltration.

Only limited evidence sources were found reporting on the water quantity benefits of green spaces and parks. The evidence items included in the database suggest that urban green spaces infiltrate on average 30% of the rainfall that falls on then annually, compared to built-up areas which infiltrate approximately 6%. Two evidence sources provide figures on estimated runoff events for urban green spaces for light rainfall events (10mm) and storm events (40L per hour runoff rates reported for light rainfall events (10mm/day) suggest that on average urban green spaces runoff rates would be around 6.8 l m^2 per event. For heavier events, using a different source, average figures suggest urban green spaces could result in 3.4 l m^2 per hour for a heavy storm event. In comparison, built up land has a much higher runoff rate of 34.3 l m^2 per hour.

Water quality

19 evidence items from 7 evidence sources

Urban green spaces can improve water quality through infiltration, deposition and absorption. The evidence sources generally reported on roadside vegetation, grass verges and buffer strips alongside roads rather than urban parks. Meta-analysis studies suggest that roadside vegetation could result in an 85% reduction in all pollutants. Evidence items included in the database reported 42-100% reductions in total suspended sediments (midpoints 71%), 22-95% reductions in total soluble phosphorous (midpoints 58.5%), and 31-100% reduction in total soluble nitrate concentrations (midpoint 65.5%). Buffer strips consistently reduced the concentration of suspended solids and total metals in storm water runoff. However, the pollution mitigation capacity of vegetation strips is thought to be dependent on (i) the physical properties of the buffer e.g. slope, width, soil type and vegetation cover, (ii) the properties of the pollutant in question and (iii) the placement of the buffer and thus its proximity to pollutants.[27]

Temperature

24 evidence items from 17 evidence sources

Urban green spaces and parks can help cool urban areas through (i) evaporative cooling, (ii) greater reflectance of heat energy and less thermal storage compared to buildings and road, and (iii) shading of heat absorbing surface. The temperature difference produced between urban green spaces and surrounding built up areas can also create inverse air temperature profiles which lead to greater air flow and heat advection.

Many of the evidence items included in the database on the cooling effect of parks are reported from studies of large parks and on daytime air temperature reductions. On average they report a 2.7°C reduction in daytime air temperatures from central urban parks, from studies in the UK, Sweden, Slovenia and Rotterdam. A range of surface temperature reduction were reported. A 15-20°C reduction in surface temperatures in summertime was reported by a study of a large park in London[28].

The cooling effects of urban parks and green spaces have been shown to extend beyond the park boundary. This effect is caused by the difference in surface and air temperature between the cooler green spaces and the warmer built up areas surrounding it causing advection. Generally, the cooling effect appears to extend by at least the width of the park or green space but has been shown to be farther for large parks. Temperature reduction lessens with increasing distance and depends on surface area, vegetation type and spatial conjunction.

Energy use

17 evidence items from 5 evidence sources

The cooling effects of urban parks and green spaces can be translated into energy savings for nearby buildings. The majority of studies included in the database on energy saving for parks were sourced for Beijing, China, which has a subtropical climate and therefore the applicability of these findings for North West England is an issue. These studies report an average saving of 15.4 KW per day, and a 10-17% reduction in energy use for cooling per day.

Health and well-being

77 evidence items from 52 evidence sources

A significant body of literature has developed around the health and well-being benefits of access to urban green spaces and parks. Studies cover positive benefits for mental health, stress, general health, or self-reported health, all-cause mortality, cardiovascular mortality, physical activity, obesity and cholesterol levels, heart rate and blood pressure, type 2 diabetes, pregnancy outcomes, and the behavioural and cognitive development of children. The quantity and variety of evidence means that it was not possible to summarise these evidence items in this report. However, in general, these studies have shown positive associations between health indices and access to green environments, but the underlying mechanisms of this association are not always clear.

Land and property values

33 evidence items from 14 evidence sources

The presence of parks and urban green spaces contribute to the enhanced attractiveness of an area, recreational opportunities and environmental functions which can all contribute to individuals' willingness to pay a price premium for properties nearby. The majority of studies included on land and property uplift were from the UK, US and the Netherlands and were generally hedonic pricing studies. These studies suggest that direct or very close proximity to an urban park or green space can result in a 9.5% price premium (range 2.6-20%), while properties between 100 and 600m from a park or green space showed on average a 3.1% uplift in property value (range 0.5-8%). Whilst every 100m closer to a green space resulted in a 1% increase in property value. Only one study was included on rent premium, which reported a 7% rent uplift for properties close to green space.[29]

Noise

9 evidence items from 7 evidence sources

Urban green spaces act as a vegetative barrier to sound and has the capacity to absorb acoustic energy. Studies reported on average a 4 decibel reduction in sound noise per m^2. However, qualitative evidence included in the database also suggested that although urban parks are generally associated with lower noise levels, they are not significantly lower than those in typical home environment.

Biodiversity

11 evidence items from 5 evidence sources

The biodiversity value of urban park and greenspace has been the subject of extensive research which it has not been possible to fully capture in this review. In general, the studies indicated that the biological diversity (or biodiversity) value of urban greenspace is immensely variable, but all greenspace by definition contains some biodiversity. Green infrastructure (GI) can support urban biodiversity by providing a more suitable habitat for species relative to conventional, impervious "grey" infrastructure. Even small urban green spaces, such as parks, can be incredibly diverse, depending on their connectedness and their habitat quality.[30]

Amenity

29 evidence items from 20 evidence sources

In addition to benefits such as air quality, water quantity reductions and carbon sequestration, studies also indicated that green spaces have a range of well-established benefits for quality of life, social cohesion, and reduced crime rates.

Evidence items included in the database suggest that social ties are strong in greener neighbourhoods, and natural space can play an important role both in the attachment people have to the area they live and their interactions with other local residents. One survey included in the database indicated the 83% more individuals engage in social activities in green space compared to a scarcely vegetated one, whilst 85% of people considered that the quality of open public space has a direct impact on their lives and the way they feel. Green space was also reported to play an important role in fostering social interactions and promoting a sense of community, and there were associations between the quantity and, even more strongly, the quality of streetscape greenery and perceived social cohesion at the neighbourhood scale.

The value of greenspace was further supported by studies reporting resident willingness to pay for access. 80-98% of respondent from two studies were willing to pay for access to, or recovery of possible loss of, green space. Average willingness to pay for access was estimated to be £31 per year, and £2.45 per week.[31]

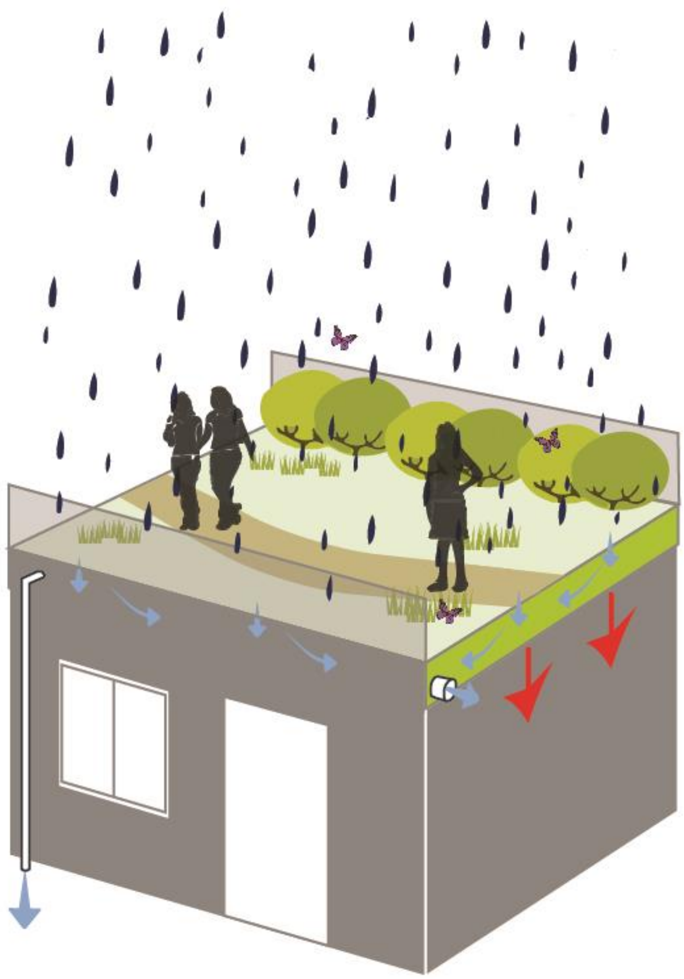
Crime rates were correlated with greenness of neighbourhoods by a number of studies included in the database and showed that the greener a building's surroundings were the fewer crimes were reported. One evidence item showed the apartment buildings with higher amounts of surrounding greenery had 48% fewer property crimes and 56% fewer violent crimes.[32] Although some studies suggest that all types of crime have lower rates of occurrence in the greener areas. A number of studies included in the database made a distinction between the benefits of greenery for violent crime reduction but less so for property crime. Suggesting instead that vegetation abundance is significantly associated with lower rates of assault, robbery, and burglary, but not property theft.

Local economic growth

7 evidence items from 7 evidence sources

Urban green spaces can contribute towards local economic growth in a number of ways. Some of the evidence included in the database highlights that consumer behaviour is affected by the physical environment. Shoppers are thought to be willing to pay more in areas with large trees and other vegetation, with a 10% increase in willingness to pay for products linked to urban vegetation. 50% of park visitors will also visit a local business before or after vising a park. Investment in a well-planned green space can increase people's enjoyment of an area and attracts businesses; in one study, this resulted in a 40% increase in commercial trading rates.[33]

Green roofs



Classification

Green roofs can be very broadly understood as any instance where there is vegetation intentionally growing on a built structural horizontal surface. A range of alternative terms are also used to describe green roofs including living roofs, eco-roofs, roof gardens, brown roofs, green-blue roofs and even green cloaks. The main difference between green roofs taken account of in this evidence review is between intensive and extensive green roofs; these differ in regard to their substrate depth. Extensive roofs are under 150mm in depth, while intensive roofs are over 150mm.

Evidence profile

A total of 256 evidence items were included in the database of evidence for green roofs from 168 evidence sources. Evidence items were not evenly distributed across the benefits types: 24% focused on energy use, water quantity, 20% on temperature and 18% on water quantity, whilst no studies were found on amenity value or local economic growth. A range of research designs have been used to generate evidence, including experimental studies, field studies, modelling and numerical studies and surveys of a population’s interaction with green roofs.

There was notably much less data available on intensive green roofs than extensive green roofs. However, where the benefit pathway is not thought to be linked to substrate depth, the evidence available for one can be used for both. It should also be noted that some benefits types such as air quality, carbon, health and well-being, biodiversity and amenity, are extremely dependent on the horticulture (e.g. plant species) utilised, the depth of the substrate and accessibility of the roof. However, in some cases it is possible to use the green spaces database to reflect these benefit pathways where there are few studies specifically focused on green roofs.

Benefit	Physical flow	Extensive (<150mm)	Intensive (>150mm)	Unit
Air quality	Nitrogen dioxide (NO_2)	24% [Rng. 21 - 27%]		Avg. % reduction in NO_2 directly above green roof
	Sulphur dioxide (SO_2)	22% [Rng. 7 - 37%]		Avg % Reduction in SO_2 directly above green roof
	Particulate matter (PM10)	14%*		% Reduction in PM10 directly above green roof
	All pollutants	77 [Rng. 69-85]		Avg. quantity of pollutants captured kg ha yr.
Carbon	Carbon sequestration	1.28 [Rng. 0.05-2.5]	*No data*	Avg. kg Carbon m^2 yr

	Carbon storage	0.375*	*No data*	Avg. kg Carbon m^2
Water quantity	Runoff retention	62% [Rng. 34-82%]	75%*	Avg % rainwater runoff retained
	Runoff interception	12.7 [Rng. 2-20mm]	*No data*	Avg. mm of rainwater runoff retention
	Peak flow reduction	73% [Rng. 57-88%]	*No data*	Avg. % peak flow reduction
	Peak flow delay	131 mins [Rng. 35-300 mins]	*No data*	Avg. runoff delayed minutes
Water quality	Total nitrate	80%*		Avg. % retained Nitrates
	Total suspended solids	70%*		Avg. % retained TSS
	Total phosphate	67%*		Avg. % retained Phosphate
Temperature	Air temperature	0.8°C [Rng. 0.5-1.5°C]	1.06°C* [Max. 4.2°C]	Avg. reduction in temp of directly overlying air °C
	Surface temperature	6.5°C [Rng. 2 - 20°C]	14.5°C [Rng. 7 - 22°C]	Avg. reduction in surface temperature °C
	Indoor air temperature	2°C [Rng. 2 - 4°C]	Rng. 0.3 - 4°C	Avg. reduction in indoor temperature °C
Energy use	Energy savings	6.7% [Rng. 1 - 20%]		Avg. % total energy savings for the space directly below the green roof
	Energy savings from cooling	16% [Rng. 0-60%]		Avg. % energy saved on cooling for the space directly below the green roof
	Energy consumption for warming	3.6% [Rng 0.5-13%]		Avg. % energy saved on heating for the space directly below the green roof
Health and well-being	Health and well-being	*Direct health benefits can be taken from green spaces database only if the green roof is accessible for individuals to receive these benefits.*		n/a
Noise	Reduction in noise levels	11db [Rng. 2.5-23dB]	46dB*	Avg. dB reduction in sound energy
Land and property	Roof lifespan increase	23 yrs.	No data	Increase roof longevity years -compared to a conventional flat roof life span of 20 yrs.
	Property value	2.9% [Rng. 0.5-5%]		Rng. % uplift in property value for a non-accessible green roof

		6.9% [Rng. 0.5-16.2%]	Rng. % uplift in property value for an accessible green roof
Amenity	*No data at present*		
Biodiversity		*Provides habitats for spiders & beetles. The value of green roofs is also included as net gain.*	n/a
Local economic growth	*No data at present*		

Air quality

22 evidence items from 12 evidence sources

Green roofs can help to improve ambient air quality in much the same way as described for urban green spaces in section 4.3. Only limited quantitative data was available on the amount of pollutants that could potentially be removed by green roofs. Studies suggest that green roofs could remove around 24% of ambient nitrogen dioxide levels, 22% of sulphur dioxide levels, and 14% of particulate matter levels in the air immediately above them. Across all pollutants, averaging from three evidence items, it was suggested that 69-85kg of pollutants could be deposited, and captured, per ha of green roofs every year, this equates to around 0.0077 kg per m^2 per year.

The potential of green roofs to improve air quality is highly dependent on the horticulture utilise, as this can range from a basic sedum layer to extensive gardens. Intensive roofs can support horticulture that provide higher pollution removal rates compared to solely grass roofs, such as shrubs and trees.

Carbon

7 evidence items from 5 evidence sources

Carbon dioxide is sequestered through vegetated components of green roofs and can also be stored as biomass both in above ground vegetation and in the roof substrate and media, depending on the roof design. The evidence base captures annual carbon sequestered, total carbon stored (above and below ground) and carbon emissions savings via energy reductions for green roofs.

Studies reported that annual carbon sequestered by green roofs averaged at 1.28kg carbon per m^2 per year, with carbon storage at around 0.4kg carbon per m^2. Reported carbon emission saving will be dependent on the energy saved by the roof through reduction in energy use for heating and cooling from thermal insulation.

Evidence items recorded in the database also highlighted that a reduction of carbon from green roofs is very dependent on the horticulture utilised and depth of substrate or 'below ground' area. Intensive roofs are deeper and can support horticulture that provides higher pollution removal rates.

Water quantity

45 evidence items from 31 evidence sources

Green roofs can help manage rainfall at source through intercepting and storing rainwater; they can also enable evapotranspiration of water back into the atmosphere. The quantity of water which can be intercepted and stored on a green roof is highly dependent on the depth and type of growing medium, the type of drainage layer and vegetation used. Generally, the deeper the substrate the greater the average annual water retention.

The green roofs evidence base captures quantitative and qualitative information on the performance of green roofs in relation to rainwater runoff retention (% avg retained and % rng retained), runoff intercepted (mm), peak flow reduction (%), Peak Flow Delay (mins). This is a benefit with abundant data covering multiple units, not all units found are considered in summary due to variance and quantity.

Taking some average figures from the evidence items in the database suggests that on average extensive green roofs (with less that 150mm substrate) can retain 62% of runoff, with a range reported between 34% and 82% for certain rainfall events. In terms of runoff interception, figures reported in the database ranged from 2-20mm with an average of 12.7mm. Evidence items for peak flow reductions and delay were less frequent, but average figures suggest a 73% delay in peak flow and a 131 minute average delay to runoff. For intensive green roofs an average of 73% runoff retention can be made from a range of 51-89%.

Water quality

29 evidence items from 14 evidence sources

Whether green roofs can improve water quality is unclear. The studies included in the database present mixed results on the performance of green roofs, with conflicting results on almost all pollutants. In some cases, studies reported that green roofs were leaching pollutants whilst other studies reported reductions in pollutants. This could be due to the variance in substrate media used. It was also indicated that the variability in the results could be the product of the initial bedding-in period, as some studies reported initial leaching of pollutants and then a reduction over subsequent years. Water quality performance was also dependent on the horticulture used on the green roof.

Figures from one study are included that reported 80% average retained nitrates, 70% average retained total suspended solids and 67% average retained phosphates.[34]

Temperature

51 evidence items from 37 evidence sources

Green roofs can have a cooling effect in much the same way as urban grasslands, outlined in Section 4.3. By removing heat energy from the air through evapotranspiration, shading and reducing heat absorption, green roofs can decrease the roof surface and the temperature of the overlying air mass. Cooling the surface of the roof has a knock-on effect for indoor air temperature. In addition, the vegetation layer and substrate depth also act as a thermal insulation feature of green roofs and has a greater effect with deeper growing media. The thermal insulation effect of green roofs varies throughout the day and at night surface temperature can potentially be higher due to stored heat.

Included studies report on overlying air mass temperature, surface temperature (°C), heat flux, and indoor air temperature and solar energy gains.

The evidence items suggest that extensive roofs could reduce overlying air temperatures on average 0.8ºC and intensive by 1.06ºC on average. Evidence on surface temperature reductions were only available for extensive roofs and indicate an average cooling effect of 6.5ºC, with a large range of 2 – 20ºC, and 14.5ºC for intensive green roofs, with a large range of 7-22ºC. Average air temperature reductions were 2ºC for extensive green roofs with a range of 0.3-4ºC for intensive.

Energy use

61 evidence items from 37 evidence sources

Energy savings from green roofs are estimated based on both their cooling and insulating effect. The majority of evidence items included in the evidence base are derived from studies from subtropical, continental, Mediterranean and tropical climates, rather than temperate climates like the UK. The geographical distribution of these evidence items is a significant limitation for applicability of evidence items for the UK context, as much of these evidence savings derived from reduced energy use for air conditioning, which is much less common in the UK.

Studies in the database report on total energy savings, energy savings from cooling [summer in non-temperate climates], energy consumption for warming and increased insulation value compared to conventional roof. These evidence items suggest an average of 6.7% total energy reductions in the space directly below the green roof, for energy savings specific to cooling this average is 16% and for warming this average is 3.6%. Although no evidence items are included in the database for intensive green roofs it is anticipated that the energy savings will be greater as a result of their deeper substrates. For example, one study reports a 25% increase in insulation value compared to conventional roofs.[35]

Health and well-being

1 evidence items from 1 evidence sources

Only one study was included in the database referencing the health benefits of green roofs and this was an estimate base on reduction in air pollution. Health benefits from generic greenspace, can in some instances be considered applicable for green roofs; for example, if the green roof is accessible or visible for individuals.

Noise

8 evidence items from 6 evidence sources

Similarly to green spaces, vegetated green roofs can potentially act as a barrier to sound and have the capacity to absorb acoustic energy. Studies report an average 11dB reduction in sound energy from extensive green roofs, and a 46dB reduction from intensive green roofs. The capacity of green roofs to reduce sound energy was suggested to be related to soil moisture levels, with low soil moisture levels linked to reduced noise attenuation capacity.

Land and property

27 evidence items from 20 evidence sources

Green roofs can add to the natural and sustainable appearance of buildings, as well as providing space for recreation where possible. Studies detail an association between green roofs and increased property and land value, with further data on this within the green space database that could be similarly applicable.

These evidence items suggest that green roofs are linked to an increase in property value, suggesting an uplift of between 0.5-5% for a non-accessible green roof, and 0.5-16.2% in an accessible green roof. In addition to increased land and property value the database also includes extensive evidence on green roofs extending the life of the roofs, due to increased protection from UV.

Biodiversity

5 evidence items from 5 evidence sources

Green roofs provide a habitat and growing area, however, the studies indicate that the biodiversity present is very dependent on the type and extent of green roof, as well as the horticulture and water quantity it supports.

Sustainable drainage systems (SuDS)

Classification

SuDS can be defined as any system utilising natural resources in place of grey infrastructure for water drainage and management. A large number of techniques can be classified as SuDS, from bioswales to rain gardens, bio-retention ponds to soakaways. The data collected in the SuDS database is categorised under three main systems: (i) storage facilities, (ii) filter strips and (iii) swales and infiltration. All specific techniques falling under these headings are described in more detail within the database 'Type' sheet. Only those types of SuDS utilising vegetation of a 'green element' were include in the database, as the focus of IGNITION is on delivering NBS.

Evidence profile

A total of 143 evidence items were included in the database for SuDS, from 89 evidence sources. Evidence items were not evenly distributed across the benefits types: 40% focused on water quality, 29% on water quantity, 15% on carbon, 8% on biodiversity, 4% on land and property value 3% on temperature and 1% on amenity.

A range of research designs have been used to generate evidence, including experimental studies, field studies, modelling and numerical studies and surveys of populations interaction with SuDS. When collating the data, UK studies were found to be more limited than expected and many reports and papers were restricted access – future updates may be able to address these issues.

Notably, the benefits for air quality, energy use, health and well-being, amenity and local economic growth were suggested to be highly dependent on the type of horticulture used in the SuDS designs, the type of SuDS and the accessibility of the SuDS. Therefore, it is only appropriate to use some of the conclusions from the urban green spaces database to supplement the findings from the SuDS database. Whilst there is data on amenity, land and property value and health and well-being for SuDS and green spaces, it must be considered how accessible the SuDS area is to provide these benefits, as many facilities are fenced off or beside highways.

Benefit	Physical flow	Storage facilities	Filter strips and swales	Infiltration	Unit
Air quality	Pollution removal	*No data*			n/a
Carbon	Annual carbon sequestered	0.183 [Rng. 0.09-0.31]	0.27 [Rng. 0.034-0.62]	No data	Avg. kg C m^2 yr.
	Carbon storage	1.57-2.28	3.05-5.04	No data	Avg. kg C m^2
Water quantity	Peak flow reduction	70% [Rng. 36-99%]	57% [Rng. 52-61%]	40%* [Rng. 40-85%]	Avg. % reduction
	Peak flow delay	16mins	33-34mins [midpoint 33.5mins]	No data	Minutes
	Runoff reduction	72% [Rng. 35-100%]	69% [Rng. 50-88%]	60%*	Avg. % runoff retained
	Runoff reduction	35-90.4% [midpoint 62.69%]	25-100% [midpoint 62.5%]	*No data*	% reduction in total runoff
Water quality	Total nitrate removal	51% [Rng. 30-79%]	19-70% [midpoint 44.5%]	65%*	% Nitrate removal
	Total suspended solids removal	68%*	79% [Rng. 56-95%]	43% [Rng. 36-50%]	% Total suspended solids removal

	Total phosphate removal	55% [Rng. 50-60%]	62% [Rng. 40-85%]	48% [Rng. 45-51%]	% Phosphate removal
Urban heat island (UHI)	Reduction in air temperature	*Sparse data, three studies reported blue space has the potential to increase air temperature, one study reports lower temperature above blue space in city in daytime*			n/a
Energy use	Cooling/heating	*No data*			n/a
Health and well-being	Attention	*No data*			n/a
	Memory and recall				
Noise	Reduction in noise levels	*No data*			n/a
Land and property	% house price premium	0.9%*			Avg. % house price premium with a small blue space within 200m of a property
	% property premium close to water	3.6%*			Avg. % house price premium with a large blue space close to the property
Amenity	No consistent physical flow data	One UK willingness to pay study shows a positive value, one South African study shows a negative value due to badly designed and maintained SuDS			n/a
Biodiversity	No consistent physical flow data	Strong qualitative data on increase in biodiversity in storage facilities, with many studies in the UK. One UK study reports that SuDS ponds have 60-80% species richness as a natural pond			n/a
Local economic growth	Staff turnover	*No data*			
	Sick leave				
	Productivity				

Air quality

No studies were able to be included in the database which specifically related to the benefit of SuDS for air quality. The potential to improve air quality is dependent on the area and type of horticulture used. Comparable evidence for this could be taken from the urban green spaces database, where appropriate, as it contains data on urban turf, roadside vegetation, road verge, lawns and shrubs, which are included in the design of many SuDS such as rain gardens and swales. If the SuDS incorporates trees, this data can be taken from the street trees database.

Carbon

21 evidence items from 15 evidence sources

SuDS have the capacity to sequester and store carbon in the same way as urban green spaces. In addition, carbon can also be sequestered and stored in detention ponds and wetlands areas, which often form part of storage facilities type SuDS. Carbon sequestration and storage evidence for 'dry' SuDS can be taken from the urban green spaces database (see 5.3). Additional evidence reported here focuses on the carbon sequestration potential of 'wet' SuDS, specifically detention ponds; this evidence is not suitable to be generalised across other SuDS types.

The evidence reports that storage facilities and filter strips and swales can sequester on average 0.183kg and 0.27kq carbon per m^2 per year, respectively. Storage facilities are reported to store 1.57-2.28kg of carbon per m^2, whilst filter strips and swales are reported to store 3.05-5.04kg of carbon per m^2. No data was included for infiltration SuDS. An outlier study reported 17kg of carbon per m^2 per year which may be from wetlands.

Water quantity

41 evidence items from 26 evidence sources

SuDS are primarily designed to manage water, and can affect water quantity through retention or storage, infiltration or reducing peak flow volumes by providing engineered hydraulic pathways suitable to the site location and geographical elements. As these on-site aspects differ widely, each SuDS design will differ quite substantially as will performance.

The majority of the included data is from peak flow reduction, with smaller amounts of data on peak flow delay and runoff reduction. Taking a range of evidence items across all SuDS types, peak flow reduction can be reduced by 36-99%, peak flow delay by 16-34 minutes and general runoff reduction from 35-100%. Detailed splits of this data are available in the summary table.

Water quality

57 evidence items from 26 evidence sources

A large amount of evidence was included in the SuDS database for water quality for different SuDS types. The evidence items included in the database report on the percentage of total nitrate removal, total suspended solids removal and total phosphate removal.

The benefit pathway indicated by the evidence items is that SuDS can deliver reduction of total nitrates, total phosphates and total suspended solids. Only one study captured in the evidence base showed increased oxidisable nitrate is effluent in an infiltration SuDS and one study reports an increase in phosphate in filter strip and swale SuDS.

Taking a range of evidence items across all SuDS types, nitrates can be reduced by 19-79%, total phosphates from 40-85% and total suspended solids from 36-95%. Detailed splits of this data are available in the summary table.

Temperature

4 evidence items from 4 evidence sources

Very few studies were found that reported on the effect of SuDS on temperature. The evidence included a focus on water surface, urban lakes, urban water bodies, blue space and urban rivers. These can be linked to a storage facility type SuDS in design. The majority of studies reported that blue space has the potential to increase air temperature due to the high thermal inertia limits of water preventing nocturnal cooling once it is warmed. For 'dry' SuDS, the benefits reported for urban green spaces can be used where appropriate.

Energy use

No specific studies were included in the SuDS database on energy use, however, there is a potential benefit pathway here linked to reduced energy use, specifically as a result of water treatment. Further research will be necessary to obtain quantitative data for the SuDS database. For 'dry' SuDS, it is possible to instead use the energy savings from reduced cooling and heating energy sources from small greenspaces as a proxy. However, the mixed findings from the temperature section suggest that the energy reduction benefits from SuDS may not be so straight forward.

Health and well-being

No studies were captured in the SuDS database on the relationship between health and well-being and SuDS. As SuDS may be incorporated into a larger green space, evidence items from the urban green space database could be used as a proxy for SuDS. However, as SuDS may sometimes be closed off to public access for safety reasons this may not be applicable if there is no scope for interaction.

Land and property value

The presence of SuDS can in some cases add to the natural and sustainable appearance of buildings. No specific studies on the effect of SuDS on property and land value were found during the evidence review. Evidence items included in the SuDS database are from two sources that make reference to generic "blue space"; however, small green spaces and street trees could potentially be used as a proxy value for certain SuDS. The studies that are included for blue spaces suggest a 0.9-3.6% increase in property premiums nearby.

Amenity

2 evidence items from 2 evidence sources

Research on the amenity value of SuDS is limited; this may be due to access and location associated with many SuDS types. Research that can be captured under the term amenity is extremely varied in its focus and findings. The results from the evidence review are mixed with one’s willingness to pay (WTP) study, completed in the UK, indicating a positive value for ponds, whilst one South African study shows a negative value due to badly designed and maintained SuDS. Another study argues for artful rainwater design to contribute to the quality of urban landscapes.

Biodiversity

12 evidence items from 12 evidence sources

SuDS provide a provision of habitat for wildlife in creating sites of ecological value whilst also increasing the quality of the surrounding area by improving water quality and reducing flooding.

There is qualitative evidence supporting the value of storage facility type SuDS for biodiversity. The qualitative nature of these studies is not suited to quantitative synthesis and therefore a brief outline of the qualitative findings has been provided instead.

Looking at the biodiversity value of SuDS in terms of species richness, a UK study included in the database reports that SuDS ponds have around 60-80% of the species richness of a natural pond. Supporting this study, another reports that a number of species, species richness and diversity were found to be higher in bioretention swales than in garden bed and lawn-type green spaces, respectively.[36] Surveys of ecological quality in SuDS ponds in Scotland have also reported a reasonable level of biodiversity, however, the ecological status of these systems could still be further improved.[37] A study of SuDS in Scotland, specifically focusing on the value of SuDS for amphibians, reported that many SuDS were of similar ecological quality to wider countryside ponds but that the quality of ponds is not equitably distributed between neighbourhoods inhabited by different socio-economic classes.[38]

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Please note: References included here are from when a specific study is quoted in the report, for a full list of sources used to create the summary tables please see the IGNITION NBS evidence bases.

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