Cities Alive

Green Building Envelope

ARUP

"Cities need green sizes
S, M, L and XL otherwise the human
ecosystem is incomplete."

Gil Peñalosa quoted in "Happy City"
by Charles Montgomery (2013)

Foreword

We want to shape a better built environment; one that is better for its inhabitants while also being sustainable and affordable.

Urbanisation is accelerating around the world and will continue until 7 bn people live in cities by the end of the century. Can these cities be improved by increasing their vegetation content, particularly in building façades? Can we use these green façades to reduce energy consumption and improve air quality and people's well-being?

These are complex questions that demand a multi-disciplinary approach to reach a reasonable view. Experts from eight skill networks around the world came together in Berlin in 2015 to cross-examine these questions using research already carried out. Working from the basic premise outlined in the "Cities Alive" document, we considered whether green façades can have a special role to play in improving our cities for their inhabitants. This document gives you some insight into our conclusions.

Tristram Carfrae
Deputy Chairman Arup

Contributors

Contents

Introduction

Green Building Envelopes

Rudi Scheuermann

> "City green has a serious influence on the micro-climate in our built environment and the sustainability of building operation.

In ever denser cities the space for "green infrastructure" such as parks, green recreational spots and trees in street canyons is being depleted. What is often considered and belittled as "green architectural decoration" is however an important element in our built environment which must not be underestimated. Besides the many health and well-being aspects resulting in significant stress relief for human beings, there are a number of effects which have serious influence on the micro-climate in our built environment and the sustainability of building operation.

The reduction of urban up-heating (heat island effects), and the filtering of fine dust in the streets where people move about are just two of the most important aspects. Reduced noise levels can also be an additional benefit if green infrastructure is applied in the right way.

The idea of "Cities Alive: Green Envelope" is to investigate and pursue the initiative of "Cities Alive: Rethinking Green Infrastructure", started by Tom Armour, to offer additional areas in the form of building envelopes and provide the dense inner city with surfaces for effective and applied green infrastructure.

These roof and façade areas aim to improve the environment by replacing a significant amount of the ground on which cities have been built in dense urban agglomerations. If we imagine that we could replace 30% of

Existing situation in Manchester

Optional regreening of the city

the total sealed areas of cities by offering about 20 - 25% of the buildings and making use of about 20 - 25% of each building envelope, i.e. façade and roof areas, we could achieve significant benefits to improve the micro-climate in cities.

Indeed, if we consider that plants grow on substrate which also contributes to dampening the inner city traffic noise, we are creating an environment of cooler and cleaner air with less noise, from which people benefit in cities, but also within buildings, as improved conditions allow for extended periods of natural ventilation, thus reducing the amounts of energy required for cooling all year round; and giving building occupants more freedom to control their individual environment by means of healthier and more beneficial natural ventilation. Furthermore, green envelopes can be applied to both existing and new buildings, and therefore the overall improvements to the micro-climate of cities can be much reinforced, as the majority of the built fabric consists of existing buildings of considerable age. Activating them to contribute to improved and more sustainable performance is an important aspect in the design of existing cities. Additional benefits such as better stormwater management avoiding flood risks, improved biodiversity, significant absorption of CO_2 etc. will follow.

But the real focus for us at Arup is on improving and providing healthier, more pleasant living conditions for a better and more comfortable existence for human beings in cities. And we feel that making the benefits measurable is an important aspect of bringing individually considered effects together, being able to quantify rather than just qualify benefits as a whole. The outcome allows a clearer cost-benefit analysis to put cities and their building authorities, and also developers and investors, in a position where they understand that investment in green infrastructure – as an important element of the built city environment – is no longer just “architectural decoration”, but an essential, urgently needed element to improve the sustainable operation of buildings with lower energy consumption, and much improved and significantly healthier living conditions for cities’ inhabitants.

Key Findings

Acoustics
Air Pollution
Urban Heat

Key Findings

Martin Pauli

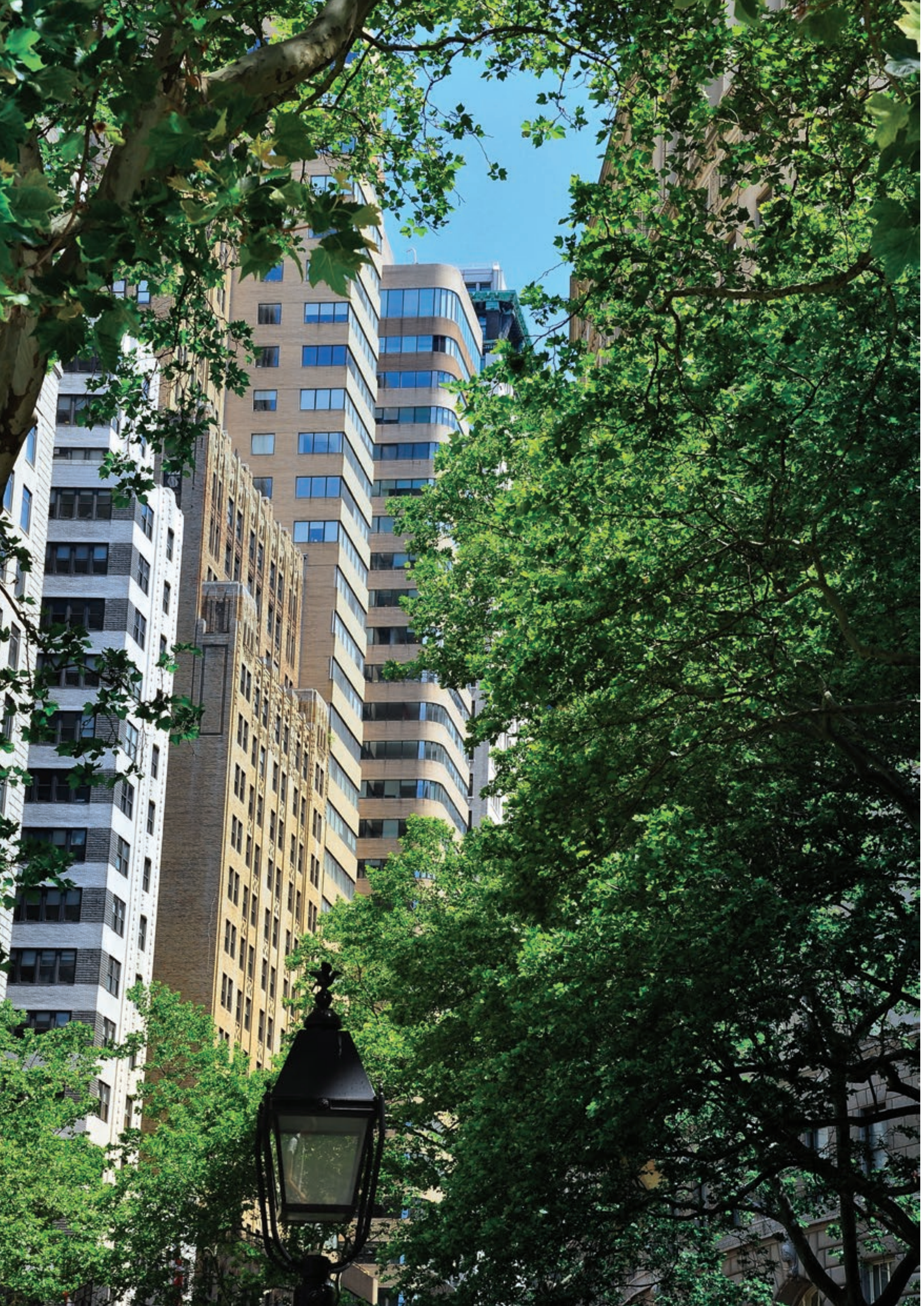
“Five global cities have been in the focus of this global research study which proved positive effects of green building envelopes on urban ecosystems.

This global Arup research study aims to provide insights into the impact of green building envelopes on our urban ecosystem. This system is subject to drastic changes regarding available space, mobility, food, water and the general way people live in cities.

More than fifteen Arup specialists around the globe aimed to quantify the frequently discussed benefits of green building envelopes regarding their potential to mitigate urban noise, air pollution and heat. Five global cities – Berlin, Hong Kong, Melbourne, London and Los Angeles – have been evaluated. Unsurprisingly, both the morphology and the geographical and climatic context have a significant impact on noise, pollution and heat. Working with a variety of digital tools, our teams were however able to prove the positive contribution made by green envelopes to our urban ecosystems, leading to the following conclusions.

Air pollution

Green façades can result in local reductions in concentrations of particulate matter, typically between 10 and 20%. However, the level of reduction is highly dependent on the configuration of the buildings and street in terms of the ratio of the height of the buildings to the width of the street. The reductions are localised within the street canyon, and overall reductions on the air mass in the city as a whole will be much lower. However, green envelopes do provide an opportunity to improve air quality in selected areas.



Acoustics

Green façades can reduce sound levels from emergent and traffic noise sources by up to 10 dB(A). They do not significantly improve noise level reduction close to a noise source, but show greater improvements with increasing distance from the source up to the point where ambient noise begins to dominate. Green façades are unlikely to have a noticeable acoustical impact when a neighbourhood's sound environment is dominated by distributed sound sources. In general they are likely to have a greater acoustical impact during the night, when ambient noise levels are lower and the soundscape is dominated by emergent sound sources.

Urban heat

For the Urban Heat Island (UHI) effect, it was found that there is a variety of city-associated parameters like the grid, solar radiation, canyon height-to-width ratio, thermal mass and the percentage of green space that influence the effect independent of green envelopes. Green façades are most effective in reducing UHI in cities with a height-to-width (H/W) ratio greater than 2 – very dense urban city centres like Hong Kong or Melbourne fall into this category – peak temperature reductions of up to 10°C having been modelled. Green cities like Berlin experience limited benefit compared to denser cities with more concrete surfaces. Cities with wide streets and low-rise buildings like Los Angeles benefit more from greenery at street level, whereas at building level, green envelopes have the biggest impact on cities with a height-to-width ratio of less than 1 and a sunnier climate – a reduction of 8% was predicted for a low-rise building in LA, whereas denser European or Asian cities only saw reductions of 2 - 3%.

Based on the results of this research study, our aim was to develop the individual modelling methodologies further and refine them in order to quantify potential effects for more cities. Moreover, applying the approach to more urban typologies such as squares, courtyards and districts would enhance seamless integration into future planning processes on both an urban and a building scale. This enables us as planners, designers and engineers to contribute positively to more liveable future ecosystems and cities.

Background

Acoustics
Air Pollution
Urban Heat

Background

Jonelle Simunich

We – as humans – are inherently tied to nature and, more specifically, to vegetation; utilising land for crops, trees for shade and oxygen to breathe.

Over time the human population has become increasingly urban – the congregation of people in densely built space swelling from 34% in 1960 to 54% in 2014, denoting a remarkable shift in how we occupy the Earth and adjusting our visions for our communal future.[1]

Shifting rural to urban populations present an assortment of issues to be remedied, creating possibilities to develop a uniquely innovative future. Negative impacts and devastations have paved the way for a global interest in sustainability, natural remedies and ecological retrofits. Whereas roughly half the global population resides in cities, this same populace consumes approximately 70% of the world's energy.[2]

This set of circumstances offers designers a unique opportunity to correct and improve towns and cities, e.g. by utilising Nature's inherent ability to filter and improve air quality, absorb sound and cool surroundings.

56%

of the global population will reside in cities by 2025 consuming 70% of the world's energy

Acoustics

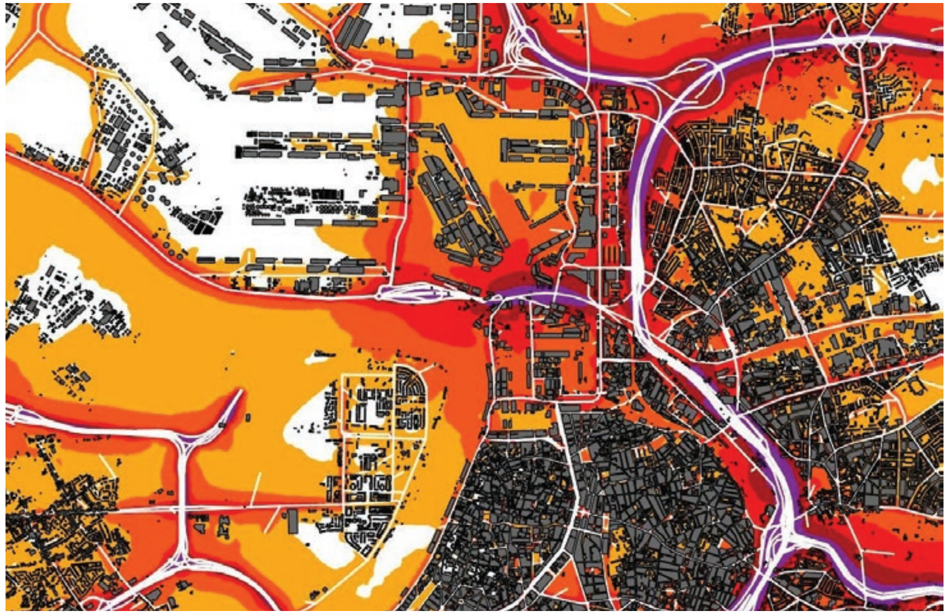
Noise poses a significant risk to health and well-being in urban societies. The World Health Organization (WHO) cites noise as a leading environmental nuisance[3] that reduces work productivity, disturbs sleep, impairs cognitive functioning, and can cause cardiovascular disease and contribute to mental illness.[4]

While the health effects of indoor and occupational noise are well known, there is increasing evidence that exposure to excessive noise in the outdoor public spaces of the city poses as great a risk to health and well-being.[5]

Perception of loudness is related to sound pressure level, measured in decibels (dB). A 3 dB decrease is just perceptible, while a 5 dB decrease is clearly noticeable and a 10 dB decrease corresponds to a halving of loudness.[6] There is no scientific consensus on what constitutes a meaningful reduction in sound levels in an urban setting, but a number of European noise codes have defined the minimum level for sound emergence as either 3 or 5 dB.[7]

Since the 1970s, a number of sustainable techniques for noise abatement have been developed, including tree belts, ground plantings, green roofs and vegetated barriers. These technologies have been shown to reduce sound levels by between 5 and 15 dB(A).[8,9,10,11,12]

The impact of green façades on urban noise is not as well established, but in the past five years researchers affiliated with the HOSANNA project (Holistic and Sustainable Abatement of Noise by optimized combinations of Natural and Artificial means)[13], which is supported by the European Commission, have published evidence indicating that green façades can act as effective sound absorbers. In a 2015 study, for example, a team of researchers from universities in Spain and Chile found that a façade module consisting of closely planted shrubs absorbed about half the sound energy it was exposed to across a broad frequency spectrum.[14]



In an urban context, green façades have the potential to absorb sound energy that would normally be reflected between the concrete, glass and steel façades of a street canyon. Recent modelling studies have shown that green façade constructions similar to the Spanish and Chilean researchers' mockup could reduce noise from road traffic by up to 1.6 dB(A)[15] and noise from a single point source by between 2 and 5 dB(A).[16]

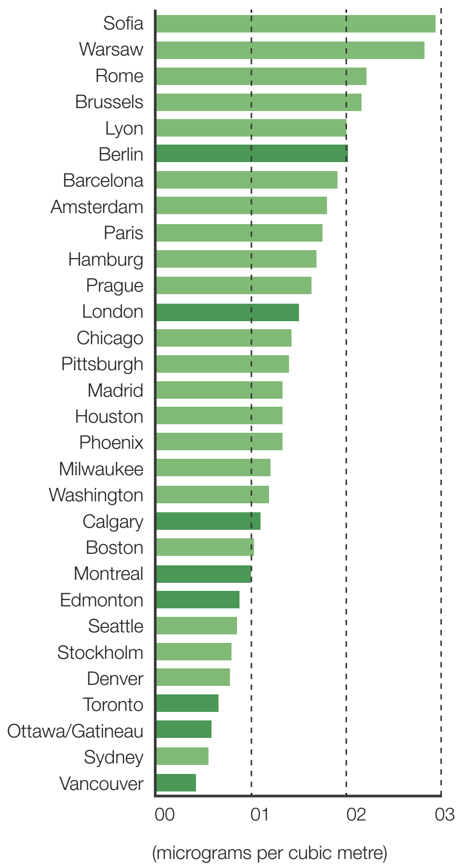
Air Pollution

Air pollution is the complex mixture of gaseous, solid and liquid particles in the air. The list of airborne contaminants in urban spaces is extensive and includes some of the following: dust, pollen, factory emissions, soot, smoke, and motor vehicle exhaust.

The WHO estimates that poor air quality led to seven million deaths in 2012; and Yale University's Environmental Performance Index has calculated that over 1.78 billion people have inhaled polluted air over the past decade.[17] Air quality is a key driver for public health, particularly in urban areas where the population is heavily exposed to poor air quality. Breathing polluted air has been shown to trigger or exacerbate health problems such as asthma, lung disease and a variety of other medical issues.[18]

Globally, cities are recognised as having worse air pollution than their rural and suburban surroundings; with cities in South Asia considered to have the worst air quality

Average ambient concentration in selected European and North American cities



of all. These places suffer from pollution levels ten times higher than the WHO air quality standards. New Delhi, India is the most polluted city, followed closely by cities in Pakistan and Bangladesh.[19] Broadening the scope to include nations, China emerges with the worst air quality worldwide. Methods to combat air pollution are continuously being invented, tested and improved. Resolutions increasingly include urban vegetation, removing old high-pollution vehicles from the roadways, encouraging companies to use the cleanest obtainable technologies, exchanging outdated wood stoves with cleaner replacements and investing in green alternatives in public transportation.[20]

Urban Heat

The Urban Heat Island (UHI) effect describes an urban area whose temperature is considerably warmer than the surrounding suburbs and rural regions. Metropolitan hardscapes are the primary cause of this effect: concrete sidewalks, asphalt roadways, steel and glass façades, and other solid surfaces which radiate rather than absorb heat. This increased heat takes a toll on urban spaces, buildings and the community, and may result in increased peak energy demands, amplified air pollution levels, poor water quality, higher cooling costs, modified wind and precipitation patterns, heat-related illnesses and an increase in mortality rates. As global urban populations continue to rise, so too will energy consumption and poor air circulation, resulting in higher temperatures for city residents. The United States Environmental Protection Agency advises that an urban area with a population exceeding 1 million may be 1 – 3°C hotter in the daytime and up to 12°C warmer in the evening than surrounding areas.[21]

Each decade since 1900, New York City's temperature has increased at a mean rate of 0.16°C; a rate that is expected to speed up in coming years. The New York Panel on Climate Change predicts that the average temperature in NYC will increase by 2.3 - 3.2°C by 2050; at which point residents will experience a tripling of heat waves. Furthermore this may lead to a repetition of tripling of heat waves by 2080.[22]

Innovative methods to document and calculate rising temperatures in cities continue

3.2°C

increase of average temperature in New York City by 2050 causing a tripling of heat waves

12°C

hotter evening temperatures in urban areas with a population exceeding 5 million than in surrounding areas

to emerge. One such example is the work recently completed at Monash University in Melbourne, where researchers are utilising drone technologies to map the urban forms contributing to UHI.[23] This detailed examination will provide the basis for future designers and builders to gain thorough knowledge of the causes of UHI and drive them to develop innovative solutions.
Nature is the best and most recognised method of remediation. Plants absorb the sun's energy, provide shade and perform evapotranspiration – evaporation from the leafy parts of the plant – [24] resulting in lower urban temperatures, cooler surfaces and cleaner air.
So increasing the quantity and quality of vegetation, parks and open green spaces within a city can reduce urban temperatures.

> "Increasing the quantity and quality of vegetation, parks and open green spaces within a city can reduce urban temperatures.

Quality of Life

'When it comes to "social cohesion" nature is much more important than age, gender, education and income combined'

BioScience Journal (11/2015) reporting on research undertaken by Cardiff University

Quality of Life

Tom Armour

The quality of urban environments and urban life experienced by people is under stress from a wide range of issues, but principally from the effects of higher urban populations and the effects of climate change.

People are now being confronted by hotter conditions in cities, poorer air quality, flood events and extreme weather, noisier environments and loss of biodiversity, and this is set to get worse. These impacts have a significant effect on people's health, well-being and stress levels and ultimately their quality of life. Tackling these huge challenges requires a multi-layered approach.

The state of people's health is rarely out of the news and there is huge concern about the persistence in health inequalities, mental health, heart disease, increasing obesity and aging populations. The first public parks were created to improve the quality of life and provide relief for urban citizens. Increasingly, global research has widely proved the positive link between the natural environment and people's ability to relax and socially interact, and there is a strong argument for delivering the therapeutic benefits of green space on projects for both physical and mental health.

The natural environment therefore has a fundamental role to play in promoting quality of life, and is an essential to creating better internal and external places, and spaces where people want to live, work and visit. The components of cities – new and existing buildings, roads, streets and open spaces – need to deliver more in terms of nature in the form of multi-functional green and blue infrastructure.

More space to operate successfully in providing resilience to climate change, and more space for city residents, workers and visitors for relaxation, social interaction, exercise and a reduction in stress levels. These moves can also help deliver economic benefits by reducing health service costs, adding to a city's appeal to attract businesses, workers and tourists, as well as boosting economic activity.

Space in denser urban environments with growing urban populations means that land for healthy and functional 'green' space has to compete with development and 'grey' city infrastructure. Whilst our city parks, squares, open spaces and streets support networks of green and blue infrastructure, we need to maximise and seek out new spaces and surfaces in the city to support quality of life. This is where buildings as a component of cities can make a vital contribution by fundamentally adopting nature-based design approaches. This can be through new ways of providing new development and important retrofitting and refurbishment of existing buildings in cities.

This approach, which focuses on a different way of addressing societal challenges, fits in with current EU policy[25], which is to position Europe as the world leader in nature-based solutions. This is to be achieved by developing research and innovation and by implementing nature-based solutions at a greater speed and a wider scale across Europe. This agenda also builds on and supports other closely related concepts and policies, such as the ecosystem services, ecosystem-based adaptation and green and blue infrastructure policies.

Key features of more liveable cities are the widespread presence of clean attractive public spaces and buildings, walkable city centres and safer neighbourhoods, and a diverse and vibrant street culture supported by the presence of Nature. As shown, daily contact with Nature is essential for quality of life; as we gravitate towards the cities, it is the built environment's responsibility to deliver this if we want to continue thriving,


Benefits
Well-Being
Aesthetic Quality
Placemaking
Air Quality
Urban Heat
Acoustics
Stormwater
Biodiversity
Energy
Urban Agriculture

Benefits Introduction

Alistair Law

“ In ever denser cities the space for “green infrastructure” is getting reduced more and more. So we need to look to our buildings to do some of the work!

Our existing green infrastructure, such as parks, street trees, gardens and green recreational spots, already provides significant ecosystem services to our cities. But as we apply greater stresses on our cities through increased urbanisation, climate change impacts and uncontrolled development, this will not be enough. Our buildings provide enormous untapped potential in making our cities not only more attractive to live in but also more resilient.

Countries like Singapore have shown that, with limited space and a fast growing population, green infrastructure both horizontal and vertical is essential to attracting and retaining talent. The Sustainable Growth Strategy for Singapore targets 0.8ha of green space for every 1,000 persons and aims to increase greenery in high-rise buildings to 50ha by 2030.

Apart from the softer benefits in terms of well-being, placemaking and aesthetic enhancement, there is significant scientific evidence to show that this also brings improvements in air quality, Urban Heat Island reduction, noise reduction, stormwater attenuation and urban biodiversity. There is also the potential for energy production and urban agriculture helping to reduce transport waste.

In order to be realised, these benefits require a distributed and managed “green infrastructure” network on both a city and a neighbourhood scale. This can help reduce the load on traditional infrastructure systems. One size does not fit all; the potential green envelope interventions are numerous, often bringing with them multiple benefits in each case.

Well-Being

The affirmation of the importance of Nature in human well-being goes back as far as the temples of Asclepius, the Greek god of healing, which were built far from towns, on hills overlooking the sea[26]. Nature can be a source of inspiration, mental regeneration and stress reduction, according to significant research.

The principal theories are 'Attention Restoration Theory'[27]and the other stress reduction theory from 'Restorative Environments'[28]. Kaplan and Kaplan (1989) wrote about the restorative aspects of 'contact with nature' on direct attention. They did a study on the impact of nature on work stress and satisfaction by observing 168 public-sector workers. They noted that not all types of natural setting contain the full range of restorative elements, but many do. They identified four essential qualities of these restorative aspects of nature. The stress reduction element of nature described by Hartig (1991) has been best demonstrated in the study by Ulrich (1984) on the impact of window views on patient recovery at a Pennsylvania hospital. In comparison with the wall-view group, the patients with the tree view had shorter post-operative hospital stays, received fewer negative evaluative comments from nurses, took fewer moderate and strong analgesic doses, and had slightly lower scores for minor post-surgical complications. This clearly confirmed the benefits of views of nature, something that has become rarer in cities.

Aesthetic Quality

Apart from functional aspects of green infrastructure, the aesthetic qualities it can bring are significant. It provides an aesthetic that is potentially timeless owing to natural regeneration. Building envelopes have been covered with plants like ivy, wisteria and clematis for centuries, merely enriching the original architecture. This provides not only seasonal colours but also something that changes year after year. Green roofs provide an attractive backdrop for building occupants, which can help encourage innovation and creativity. The variety of aesthetic choices of green interventions is enormous and really depends on the architects' vision, from very formal palettes to interventions that are much wilder.

The psychological connotations of green infrastructure are multiple, as mentioned in the section on well-being. In addition there are the psychological and physical interactions. A study showed that people with complex views of nature can accept more glare on their computer screens than those without.[29]

Placemaking

As estate agents say, 'location, location, location' is what drives potential buyers. This corresponds to both residential and commercial developments. The price difference between different areas can be enormous, and this is driven by desirability created by local amenities (cafés, bars, restaurants), mixed usages (commercial, educational, residential), and recreational spaces such as parks.

The most expensive property in cities such as New York and London surrounds exceptional green parks such as Central Park and Hyde Park for good reason. Some of the most successful developments have created 'destinations' rather than just a collection of buildings, by integrating green spaces in their developments. The Cheonggyecheon urban renewal project in Seoul, which turned a freeway into a public park, is a good example of how new places can be created around green spaces and the economic and societal benefits that can have. These benefits are replicated on a smaller scale with city gardens.

As urbanisation increases, the number of people moving to cities will start to place strain on existing green infrastructure. Therefore, as space becomes rarer, desirable places will need to be created through new vertical and horizontal greening. Havens of peace can be created through new forms of green infrastructure. This is essential to create attractive places for people in cities to escape the 24-hour culture for short periods.

Air Quality

Today cities suffer from levels of air pollution which have been shown to affect human health significantly [30,31]. Large metropolitan cities like London and New York regularly exceed WHO limits for particulate matter. Cities like Paris have introduced bans on cars on heavy pollution days with recommendations for the frail and infirm to avoid going outside. Along with other strategies such as wet cleaning of streets and the enhancing of sustainable transport media, the ecosystem services of plants in terms of pollutant filtration are being taken into account increasingly in city planning and urban policies.

Significant research has shown that urban vegetation has the potential to filter fine and ultra-fine particles (PM less than 10 microns in diameter) through deposition on the leaf surfaces. With precipitation or deliberate wetting, these deposits can be washed directly into the drain avoiding re-suspension. Studies have shown that green infrastructure such as trees and other vegetation can reduce volatile fine and ultra-fine particles by up to 60% [32].

Therefore the use of vegetation such as street trees, roadside vegetation, vertical gardens, roof gardens or green façades can prove to be an effective long-term strategy in the reduction of particle concentration.

Solar Leaf

A Bioreactive Façade

Jan Wurm

The BIQ house built for the International Building Exhibition (IBA) Hamburg in 2013 is the first architectural project realised worldwide featuring flat panel photobioreactors, generating biomass and heat as part of an integrated energy concept.

129 storey-high panels with a total net surface of 200m² are oriented to the south, generating heat that equals the annual heat demand of the passive house design. Three years after completion and monitoring of the BIQ, the relevance of the SolarLeaf system has outgrown the initial theme of carbon-neutral energy sources to become a demonstrator for closed-loop urban systems by linking the resource streams of carbon, heat, water and biomass. In the near future the system is to be scaled up and implemented at district level, in combination with a decentralised waste water treatment plant consuming waste products, to cultivate highly valuable algal biomass as a resource for the pharmaceutical industry.

Urban Heat

The concreting over of natural spaces and the use of low-reflective materials on buildings contribute to the Urban Heat Island effect. This is caused both by the loss of natural spaces that benefit from adiabatic cooling and by the impact of certain materials commonly used in urban construction such as asphalt and concrete. Countries such as Greece have painted their buildings white for centuries to avoid overheating.

Vegetated roofs can offer similar benefits; in the height of summer they can be close to the ambient temperature, whereas a conventional roof can be up to 50 degrees higher.[33]

Trees can provide significant reduction in the UHI effect by absorbing it above street level, preventing pavements from heating up, offering adiabatic cooling for occupants, and providing surprising additional benefits such as reductions in skin diseases.[31]

City scale benefits have been shown by research by Gill et al. (2007) following UKCP02: if Greater Manchester increased its green infrastructure by 10% (in areas with limited or no green cover) it would reduce average temperatures by up to 2.5 degrees centigrade. Therefore the benefits of a distributed network of green infrastructure can be significant, and they can be easily and cheaply achieved through favourable planning policies. Green envelopes would provide immense support for this effect with direct benefits.

Acoustics

Street canyons are typically made up of hard and dense materials such as concrete, brick, asphalt and glass that reflect sound and increase the overall noise level on the street. While green façades cannot effectively mitigate direct sound, they can absorb sound that would otherwise be reflected between building façades or bend round their corners, reducing the overall level of noise. Green façades have the potential to reduce both ambient noise, i.e. the background sound of a city made up of many noise sources, and noise from emergent sources, i.e. individual sources such as motorcycles, sirens and construction equipment that exceed the ambient level.

The acoustical benefits of green façades go beyond measurable reductions in noise level. They can create a psychological perception of quiet that complements physical reductions of sound energy. They can also introduce and unmask sounds of Nature, creating a more pleasing soundscape.

Stormwater

Already, cities around the world are struggling to prevent flooding during heavy rainfall. Future climate scenarios predict more extreme weather events and rising sea levels leaving delta cities struggling to cope. Green infrastructure acts as a natural buffer, helping to prevent flash flooding by increasing the time between weather events and discharge.

To handle the increased demands on sewer systems, major cities are having to upgrade their fixed infrastructure at significant cost. An alternative or mitigating method would be to create both permanent and temporary stormwater retention systems. If all new developments were required to contribute, the net impact would be significant. Hidden stormwater retention tanks have been built beneath sports pitches in cities like Hong Kong to mitigate stormwater effects.

City aquifers are also being depleted in cities where pumping has been permitted. Concreting over means they are not being replenished. Cities should adopt landscaping strategies that favour ground infiltration and contribute to the maintaining of ancient aquifers. Green roofs would to some extent avoid the need for all this very expensive technical infrastructure by helping to retain stormwater while providing a more pleasurable view on to rooftops.

Biodiversity

Rapidly increasing population growth and urbanisation are leading to increased pressure on land to provide the ecosystem services that support human well-being and maintain ecological function. As our cities grow larger and demand more resources, how we build has a greater impact on biodiversity. Designing buildings that enhance biodiversity would have a cumulative effect as part of the larger urban ecological system, playing an important role in maintaining global biological diversity.

In addition to the documented benefits of vegetated roofs and walls, environments with more biodiversity are associated with greater benefits in terms of human psychological health and well-being than comparable environments with less biodiversity. Enhancing biodiversity in urban ecosystems can positively impact the quality of life and, through its educational effect, the preservation of biodiversity in natural ecosystems.

Building elements such as vegetated roofs and green walls are becoming common design features, but are often not designed to enhance biodiversity and do not act with the surrounding area as part of a functioning ecosystem. The holistic design of biodiverse building envelopes could range from consciously enabling spontaneous colonisation to recreating cliff ecosystems along an intensity gradient most appropriate to the climate, site, client and architectural intent.

Retrofitting
with Green Envelopes

Chris Jofeh, Jimmy Li

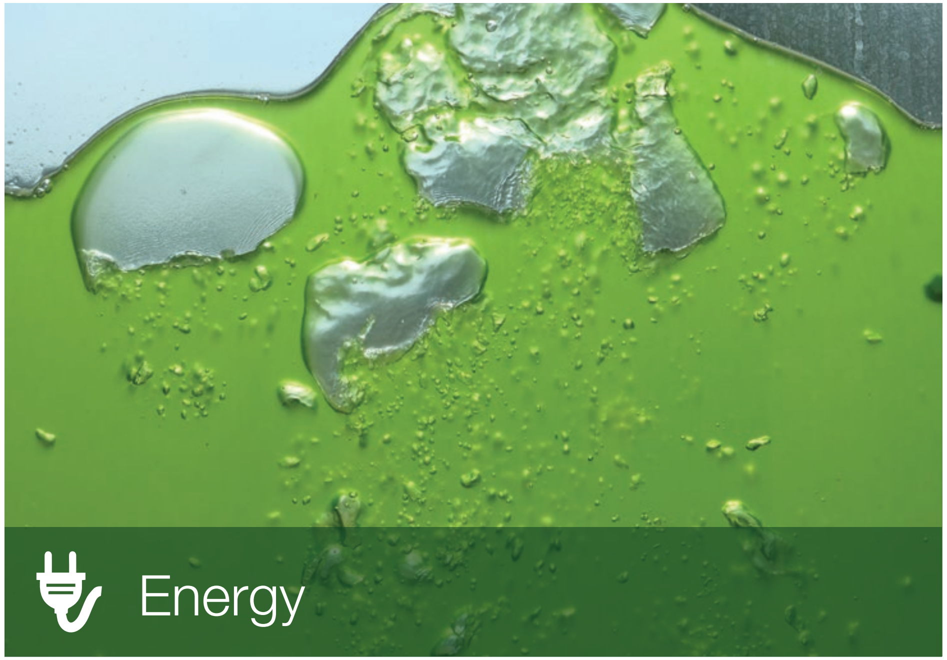
It is reasonable to expect that at least 80% of the buildings in our cities will still be in use in 2050.

These buildings have great potential to contribute to improving the conditions of our cities, not only within the buildings but also on the streets.

The ability of green façades to reduce the cooling loads on buildings is well known and has been quantified. What is possibly less well understood is that green façades can improve the air quality in city streets. Plants can remove not only carbon dioxide but also particulate air pollutants such as smoke and dust. Inhalation of smaller dust particles can cause health problems, and public health is improved if dust concentrations are reduced.

Vegetated environments are good for people. Exposure to Nature provides relief from the pressures of high-density living, improves people's ability to focus, cope with stress and generate creative ideas, and decreases anti-social behaviour.

While much attention is rightly being given to improving the sustainability of our existing building stock, we should not forget the contribution that green façades on these buildings can make to improving the quality of life on the streets of our cities.



Energy

Cities have enormous potential for capturing the energy they receive, be it heat, wind or sunlight. A renewable energy mix for significant developed countries is no longer merely an option, but is now enshrined in law under climate reduction commitments. Micro-generation has a significant part to play in this mix as countries realise that aging power stations will require significant new investment if they are to be replaced. As part of planning regulation, cities like London are favouring renewable generation, requiring a minimum percentage carbon reduction target on all new developments. The efficiency of photovoltaic cells has also increased significantly over the last few years, with a reduction in cost making them an attractive option for developers trying to fulfil their commitments. With new technology such as Perovskites under development, the efficiency curve still has significant potential. Combined with green roofs which can help keep ambient temperatures cooler, the efficiency of these panels can be enhanced.

Solar thermal panels have been used in hotter climates for producing hot water for many years. Wind turbines have been developing fast to provide systems that are not only more compact, but also cheaper and more attractive.

Urban Agriculture

Cities have significant potential to produce their own food. In recent history this has been driven through necessity, with cities like Havana setting up ‘huertos’ or allotments following the collapse of the USSR. With growing urbanisation this is changing to a different sort of necessity, the need to be connected with the earth despite living in cities. Demand for allotments has steadily increased in recent years, with waiting lists in the UK in 2013 of 52 people per 100 allotments (TNAS 2013).

Other movements such as ‘guerilla gardeners’ have deliberately seeded empty plots of land and then harvested the fruits that grew in them. This is making way for more commercial growers who have taken over vacant rooftops in cities, such as Gotham Greens in New York or Grow Up in London. There is the potential not only to make money from unused spaces, but also to connect people to the produce they eat, closing food circuits.

Apart from economic or food production benefits there are enormous benefits in terms of well-being. Urban agriculture has tremendous potential for creating community spirit. Apart from the physical exercise and the mental health benefits from ‘growing your own’, it has been shown that eating habits are also improved. Alaimo et al. (2008) showed that fruit and vegetable consumption increased by 40% for those involved in community gardening.

Design Approach

Systems

Functional Plants

Green Building Envelope

1. Urban farm
2. Greenhouses
3. Vertical farming
4. Beehives and highways
5. Wildlife corridors
6. Integrated habitat creations
7. Flood residence
8. Water storage
9. Sustainable urban drainage
10. Bioremediation
11. Green wall - top down
12. Green wall
13. Modular plant walls
14. Seeded living walls
15. Moss walls
16. Tree façade
17. Bioreactive façade
18. Green roofs
19. Wildlife roofs
20. Wet roofs
21. Urban vegetation
22. City gardens
23. Photovoltaic roofs
24. Wind turbines and micro-generation

System 1/4

Urban farm

As space becomes scarcer in cities and people yearn for the pleasures of 'growing their own', the use of roof space can provide space for 'sky allotments'. Raised beds provide ease of cultivation and lower structural loads. They often become community spaces that help to keep people active and encourage social interaction.

Benefits:

Greenhouses

Commercial urban farming requires controlled conditions. Cities like New York already have examples of commercial greenhouses on roofs growing high-value crops such as basil. It is then sold in the shops below thus closing food circuits and making use of available space.

Benefits:

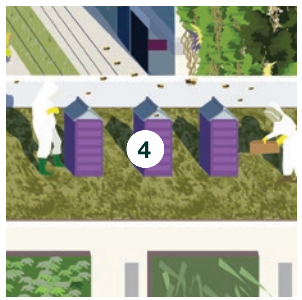
Vertical farming

As flat areas like roofs are utilised, vertical façades are left. Through the use of double-skin façades and new mechanical systems, plants can now be grown vertically. Building owners could start generating new revenue from their buildings or providing 'home-grown' supplies to their own office canteen.

Benefits:

Beehives and highways

Bees are essential to a healthy ecosystem. 40% of the planet's food production requires bees for pollination as part of the food chain. Well managed colonies of bees distributed across cities help support all green infrastructure around them as well as offering a tasty, locally produced delicacy. A 'bee highway', a network of rooftop pollination and habitation spaces, can provide rest and feeding spaces for bees.



Benefits:

Wildlife corridors

Historically, cities have had a wealth of wildlife, helping to support natural ecosystems and enriching city life. Strategic green corridors can be developed by green roofs or façades that connect parks and green spaces across cities by prioritising green infrastructure along these routes.

Benefits:

Integrated habitat creation

Buildings produce great habitats for supporting wildlife with lots of nooks and crannies for sheltering birds and bats. Insect hotels and bird and bat boxes can easily be incorporated in the architectural design, often without visible signs from the exterior, except to the discerning visitor…

Benefits:

System 2/4

Flood resilience

City aquifers are becoming depleted and city drainage systems are reaching their limits, resulting in regular flood events. Rather than building larger sewers, a cheaper solution would be to stop concreting over cities. Use façades, roofs, pocket parks, urban water features and floodable spaces to manage extreme weather events locally.

Benefits:

Water storage

Reducing the time between precipitation and discharge could make the difference between a city flooding and a barely noticeable rain event. Water storage tanks can be created under recreational spaces at minimal cost compared to huge city drainage schemes.

Benefits:

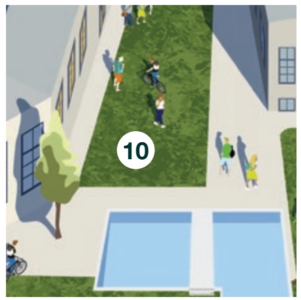
Sustainable urban drainage

Swales and habitats can be built alongside busy thoroughfares, slowing down the drainage of water into mains sewers, as well providing absorbent conditions, habitats for plants and animals and recreational space for people. They can also create value for local businesses by encouraging people to dwell longer.

Benefits:

Bio-remediation

Ponds with reed beds can be used to clean grey water coming off new developments at both ground and roof level. Not only reducing the burden on existing city services, they can also help to store and slow water as part of a sustainable urban drainage system.



Benefits:

Green wall - top down

Hanging climbers can be grown in balcony boxes / planters and allowed to drape covering walls below. These plants help produce attractive wall coverings at low cost, with the planter also being able to be used for vegetation at balcony level.

Benefits:

Green wall - ground up

Climbers placed on optimal orientations can grow fast, covering walls with the help of stainless steel or other meshes that provide support and help train the plants. This is a low-cost alternative with climbing plants growing in the ground or in planters at the base of walls.

Benefits:

Green Envelopes
Cost-Benefit Analysis

Kirstin Weeks, Haico Schepers

Living envelopes can offer a broad range of benefits – energy, heat island and air quality benefits as discussed in this report, but also stormwater management, habitat creation or urban agriculture, roof longevity, real estate value improvement and human wellness through biophilia.

Arup worked with a team of academic researchers in 2012 to complete a comprehensive research review and cost-benefit analysis of green roofs for the United States Government. The study found that green roofs had a higher 25-year net present value to the owner than conventional roofs, but that by far the biggest potential value they offer is to the community, suggesting a justification for government to implement supportive policy (as has been done notably in Switzerland). One study cited in the US Government report demonstrates the key role played by stormwater in green roof cost-effectiveness. Walmart commissioned Arup to evaluate data from their half-green, half-white research store roof. The green roof demonstrated impressive stormwater management, including retention of 60 - 90% of all stormwater (retaining up to 8.8 cm even though the roof soil was only 7.6 cm deep), peak runoff delay of 1.25 – 3.25 hours, and 65% average runoff rate reduction. The cost-benefit study found that in a city with stringent stormwater policy, a green roof could produce net first cost savings for Walmart, and deliver energy and maintenance savings thereafter.

System 3/4

Modular plant walls

Modular plant walls can provide instant greenwall solutions where trays can be grown off-site or installed in situ ready-planted. Robust plant choices and less manicured walls are essential to minimise maintenance. They provide instant beneficial effects and also help provide habitat for insects and wildlife.

Benefits:

Seeded living walls

Greenwall systems can be provided that are grown in situ directly from seed. This provides robust greenwalls that are less manicured, but perfect for seed mixes such as wildflowers. They provide a perfect habitat for insects and wildlife and are cheaper than mature plant systems.

Benefits:

Moss walls

Moss walls provide attractive wall coverings that help support insect life. Walls that are shaded with minimal wind and can easily be kept moist are ideal. Rough surfaces that moss can adhere to are required. Proprietary systems can also help with sound absorption.

Benefits:

Tree façade

Trees provide enormous capacity to absorb CO_2 and fine particles and provide cities with lungs. Façades of buildings can be covered in trees by placing planters across the façade. Careful selection of tree type can maximise effect with minimal root requirements and therefore support.

Benefits:

Bio-reactive façade

High-value micro-algae can be grown efficiently on the façades of buildings, absorbing CO_2 as well as reducing the energy demands of traditional cultivation. Grown in transparent tanks very similar to double-glazed windows, they can provide a source of revenue for building owners by being utilised as an industrial raw material.

Benefits:

Green roof

As cities become denser, access to green space will become more competitive. Alternative spaces for workers and residents to interact foster a sense of community by creating new meeting places. They also offer recreational space and the potential for 'alternative' meeting rooms.

Benefits:

Urban Cliff

Tessa Brunette

Building envelopes represent globally distributed, locally extensive artificial ecosystems that are one scale of a hierarchy of interconnected structures and relationships.

Buildings themselves can be likened to cliffs through their verticality, shallow sub-strate and extreme soil-moisture conditions, and building envelopes could be designed to mimic these natural habitats using the ana-logy of the urban cliff.

Designing habitats as urban cliffs would allow for biodiversity to be integrated in ways most appropriate to the climate, site, client and architectural intent, providing habitat for plants and animals appropriate to the designed micro-sites. On one end of the scale, materials that encourage growth such as lichens or algae could be used on harder planar surfaces, while on the other, vegeta-tion can be incorporated architecturally as living walls, living roofs, planter boxes and trellis and trough systems. Fauna can be accommodated using our current building methodologies with minimal visual impact or additional cost.

Understanding the cliff ecosystem that is being recreated on building envelopes al-lows for the selection of appropriate species that will thrive in the harsh conditions, but also means that natural cycles such as sea-sonal growth and dieback will be evident.

System 3/4

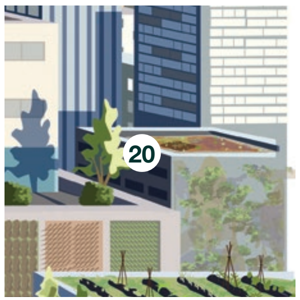
Wildlife roofs

These are perfect spaces that can offer views of Nature for people who overlook them as well as spaces for insects and birds to utilise as part of green corridors. These can either be under and around rooftop plants or on non-accessible ledges. They can also help reduce temperatures around PV units.

Benefits:

Wet roofs

Wet roofs can reduce temperatures in office buildings, helping to cut the cooling loads which are the highest energy load in many of them. They can also slow the effects of rainfall by providing temporary storage. The water can be released more slowly into city drainage systems or stored and used elsewhere on buildings, e.g. in toilet flushing or vegetation irrigation.



Benefits:

Urban vegetation

During the masterplanning of new developments the integration of trees as part of the setting of a building can provide significant micro-climatic improvements including shade and cooling for occupants and visitors. Vegetated buffers not only provide attractive backdrops to new developments but also help absorb stormwater.

Benefits:

City gardens

New park and recreation spaces for people are difficult to create in our already hyper-dense cities. A distributed network of city gardens utilising roof space and obsolete infrastructure can provide local recreational spaces for city inhabitants, as well as spaces that provide biodiverse habitats, making our cities far richer in their composition.

Benefits:

Photovoltaic roofs

Cities have huge potential for creating energy. Lots of building surfaces remain unused. As the efficiency of photovoltaic units improves and their costs decline, their adoption will only increase. Surrounding green vegetation on roofs and façades helps to reduce local temperatures, thus increasing their efficiency.

Benefits:

Wind turbines and micro-generation

Micro-generation through wind has enormous potential in cities that are highly exposed to wind. With other energy sources such as solar and geothermal, it can provide part of a reliable renewal energy mix. In combination with vegetated building envelopes it can also provide an attractive addition to urban architecture.

Benefits:

Functional Plants

Christian Ulrichs, Vanessa Hörmann

Greening cities markedly increases the quality of life. The city is not only embellished; the urban climate is also appreciably improved. Greened spaces provide places of oxygen production and carbon dioxide absorption.

Furthermore plants are able to cool down overheated cities by shading and transpiration. Plants help to clean the air by removing particulate matter and pollutants like ozone and NO_X.

The prevalence of asthma in children is reduced if they live in or near greened areas. The above-mentioned properties and the psychological effect lead to the improved well-being of people in cities. Even passive contact with green spaces leads to a reduction of blood pressure and stress levels.

These are only a few examples of the benefits plants offer in urban areas. Therefore, we believe that in the future city planners will focus more on "functional" aspects of plants than they do today.

Although plants have to face several challenges in the city, like soil compaction and drought stress, they can offer many benefits if the right ones are chosen. This depends mainly on soil, climate conditions, and space available.

To overcome difficulties relating to climate conditions it is generally recommended to choose indigenous plants. They are adapted to the particular environment and thus can be easily kept in good condition, which is absolutely necessary if plants are supposed to improve the air quality.

Improvement of air quality depends mainly on plant species, stomatal conductance (rate of gas exchange), environmental conditions, and pollutant concentration in the atmosphere. In general trees are most effective due to their huge surface.

Broadleaf trees provide a surface area for removal of pollutants that is up to 12 times the area of land they cover. Several studies indicate that deciduous trees are better in filtering gaseous pollutants because they have a higher stomatal conductance and are less sensitive to air pollutants than conifers. By contrast, it seems that the latter capture larger amounts of particulate matter due to the larger surface area of their needles and their more complex shoot structure. Additionally, the needles are not shed during the winter, so these trees keep on improving the air all the year round. But not only trees improve the air quality. Smaller plants do this as well, which is especially advantageous if only little space is available.

Green walls or roofs, for instance covered with moss or grasses, have a cooling effect and bind particulate matter as well. In the end a mixture of different local plants is the best choice for greening a city and thus improving air quality and human well-being.

Particulate matter removal

Pine species should be used more in urban areas because of their ability to capture large quantities of particulate matter, including during winter when pollution concentrations are highest. *Pinus sylvestris* and *pinus mugo* have been excellent at capturing PM in different studies.

Cooling

Over 70% of the air temperature variance in urban green sites and their surroundings can be explained by these main factors:

- the partially shaded area under the tree canopy and
- the air temperature of the non-wooded surroundings adjoining the site

Phytoremediation

Willow species have been tested for phytoremediation purposes. The uptake of cadmium and zinc by the various *salix* species in particular has been demonstrated in medium-polluted soils, providing sufficient evidence that they are worth considering for phytoextraction purposes.

Water absorption

Bryophytes can be featured in contemporary green roofs that insulate, cool, reduce the impact of stormwater runoff, and filter air pollutants. The filter potential is relatively high since mosses do not have a waxy cuticle and thus absorb water-soluble pollutants more easily on their large surface.

Five Global Case Studies

Acoustics
Air Pollution
Urban Heat Islands

Modelling

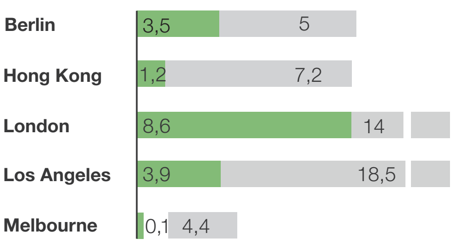
Five Global Case Studies

Introduction

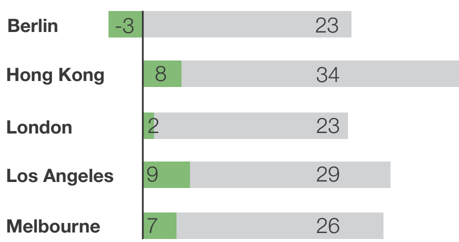
Five case study cities have been selected in order to quantify the benefits for different urban morphologies, geographical and climate contexts.

This study focuses on Berlin, London, Hong Kong, Melbourne and Los Angeles, which vary significantly with regard to their morphology, climatic and geographic context. In each of the cities, one street was chosen in order to study and model the effects on a manageable scale. The specific street section is described on the following pages. Moreover the study takes the specific climatic context into consideration, aiming to identify correlations between climatic conditions and the Urban Heat Island effect and air pollution.

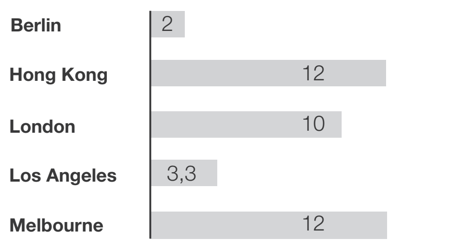
Population in million, urban centre and metropolitan area



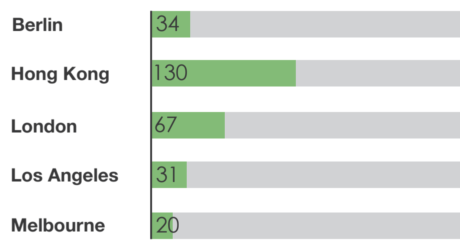
Minimum and maximum temperature in degrees celsius



Temperature differential from city to surrounding areas



Air quality index scale, based on the US EPA standard is used for indexing air pollution.



Five Global Case Studies
Morphology

Los Angeles
H/W 0.25

Berlin
H/W 1.20

London
H/W 0.8

Melbourne
H/W 2.46

Hong Kong
H/W 5.00

Air Pollution

Cristina Sanjuan & Michael Bull

Green envelopes provide an opportunity to improve air quality in selected areas.

Short story

As the use of fossil fuels such as coal for heating and power generation has decreased in cities, emissions from motor vehicles have increased. One of the most important traffic-related pollutants is fine particulate matter known as PM10 and PM2.5. Studies have shown a clear association between levels of particulate matter in the air and adverse impacts on human health. There is therefore an imperative to reduce particulate matter concentrations in urban areas.

The policy initiatives to date have concentrated on the reduction of emissions at source (i.e. from vehicle exhausts) but these have failed to reduce concentrations in large urban areas sufficiently to below standards set nationally and by the World Health Organization. As a result, further measures are required to reduce concentrations of particulate matter in cities; the use of green façades is an approach that offers the potential to provide significant mitigation, as the leaf surfaces of the plants intercept and remove particles from the atmosphere.

This report has used computational fluid dynamic modelling to determine the effectiveness of green envelopes to reduce pollutant concentrations. It has examined how the different street and building configurations in five major world cities (London, Berlin, Melbourne, Hong Kong and Los Angeles) affect the air flow at street level and over a green façade, and then predicted the level of removal for particulate matter from the atmosphere.

The main conclusions of the study are as follows:

- Green façades can result in local reductions in concentrations of particulate matter, typically between 10 and 20%;
- The level of reduction is highly dependent on the configuration of the buildings and street in terms of the ratio of the height of the building to the width of the street;
- The reductions are localised within the street canyon and overall reductions on the air mass in the city will be much lower. However, green envelopes do provide an opportunity to improve air quality in selected areas.

Air Pollution
Introduction & Methodology

Health effects of air pollution

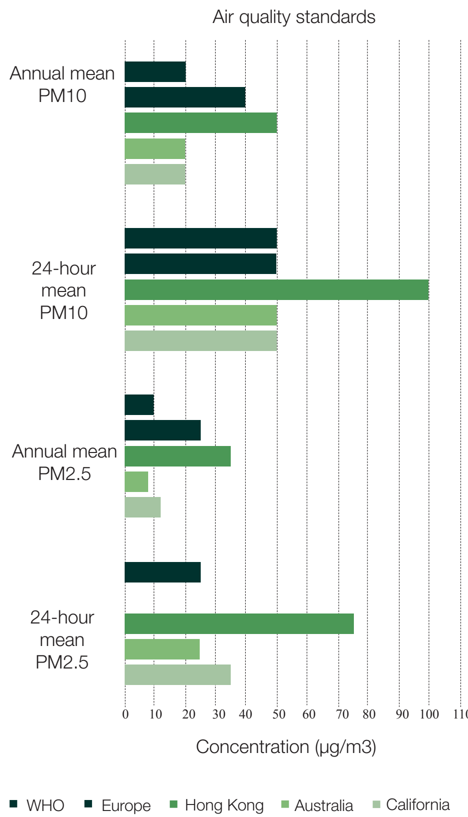
There is widespread evidence that prolonged exposure to particulate matter can adversely affect the human respiratory and cardiovascular system, leading to an increased risk of premature mortality and thus reduced life expectancy for the population. To date, no threshold has been found below which no adverse health effects would occur from exposure to particulate matter. Recent studies have found that particle exhaust emissions from diesel vehicles have a strong association with respiratory mortality.[34]

Worldwide, 3.7 million premature deaths in 2012 were able to be attributed to exposure to poor air quality. Approximately 200,000 of these were in Europe and 900,000 in south-east Asia. The most common reasons for these deaths are believed to be heart disease and stroke, in almost 80% of the cases, followed by lung diseases. These estimates are based on data for population exposure to fine particulate matter (PM2.5 concentrations). The World Health Organization (WHO) has developed guidelines for ambient levels of air pollutants, based on the latest scientific knowledge and epidemiological studies. The air quality guidelines for particulate matter are presented in the graphic on the right.

Methodology

To provide a qualitative illustration of the main phenomena of pollutant dispersion in urban street canyons, CFD simulations were undertaken for a reference wind of 4 m/s from the west. The simulations are based on a simplified street canyon configuration, with west wind over the buildings. Additionally, two pollutant sources were included in the model: a) pollution drifted by the urban wind which could be considered as the background pollution, and b) pollution from car exhausts. The simulation model includes two passive scalars to trace the trajectory of the two pollutants. As a result, the wind field and the relative distribution of the pollutants depending on their source are represented.

Air quality guidelines for particulate matter in different regions



3.7m

premature deaths in 2012 attributed to exposure to poor air quality

25%

of these cases occurred in South-East Asia

Air Pollution

The Urban Impact on Particle Filtration

The main mechanism of particle filtration in plants is the deposition of particles on the surfaces of leaves.

This is a complex phenomenon that is not yet thoroughly understood, because it depends on many factors related to the particle matters, the properties of the plants, the pollution distribution in the urban context, and the structure of the wind field.

Meteorological parameters

The model used in this research does not include the effect of humidity, so the particle sizes remain constant independent of the relative humidity (RH). It increases the size of the particles up to 1.2 at 80% RH in relation to dry air, increasing the particle filtration.

Wind field

The local impacts of air pollutant releases vary widely according to the local meteorological conditions. Wind speed is an important factor in diluting pollutant releases, and wind direction is crucial for determining which location pollutant emissions may impact. In urban configurations, the wind speed inside street canyons depends on the aspect ratio of the streets and their relative orientation to the prevailing wind direction.

Particle diameter

The term 'particulate matter' is used to describe any particles suspended in ambient air, which can have varying sizes and chemical composition. Their size usually ranges from 10nm to 100µm and their formation includes three different modes. Most air pollution regulations refer to PM10 and PM2.5, which describe particles with an aerodynamic diameter equal to or less than 10µm and 2.5µm respectively.

Plant species

While the particles' size (and shape) and the meteorological parameters are generally dictated by the context, the plant species selection and the plant configuration inside the urban context are factors that should be seriously considered during the urban design. From the filtration capacity point of view, one of the most interesting characteristics that should be considered during the selection of the plant is the density of leaves, otherwise known as the leaf area index.

660 m^2

of leaf area can be assumed in some cases for 1 m^2 of plant area

Air Pollution
Modelling Results

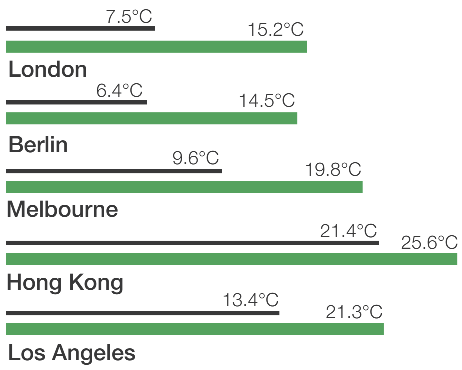
Melbourne

Melbourne has a high urban density. The typical street canyon has an average aspect ratio of H/W=2.5. The wind inside the street canyon forms a vortex that does not penetrate the whole depth of the street, leaving the part near the ground unaffected. Pollutants from traffic sources are concentrated at the bottom of the street canyon in the leeward side, and ascend through the leeward façades. Pollutants above the roof level are brought into the street canyon in the air passing down the windward façade.

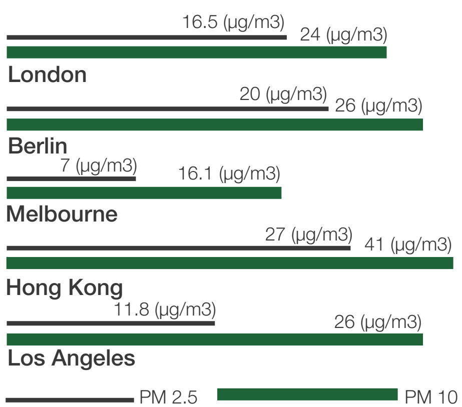
Berlin

The case of Berlin is similar to that of London. The urban configuration has a typical street canyon aspect factor of H/W=1.2. The air forms a single recirculation vortex inside the street canyon, going down through the windward façade and up through the leeward. The pollutants perform identically to those in London in our test case.

Average temperature range on an annual basis in 5 case study cities.
Data taken from local weather stations.

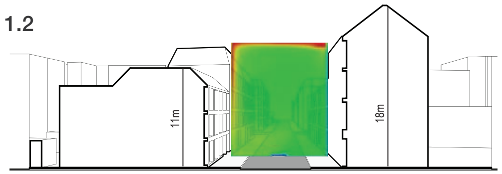


Monitored background pollution concentration



Wind field and distribution of pollutants inside a representative canyon in Berlin.

Berlin
H/W ASPECT RATIO 1.2



Percentage of reduction of pollutant concentration. Percentage change due to green walls.

	Dim. PM 2.5 City	Dim. PM 10 City	Red. PM 2.5 Street	Red. PM 10 Street
Berlin H/W 1.20	0.35	0.20	15.94	12.02
Hong Kong H/W 5.00	1.2	0.82	21.84	14.26
London H/W 0.80	3.5	0.82	22.37	15.39
Los Angeles H/W 0.25	0.09	0.10	12.02	12.26
Melbourne H/W 2.46	0.87	0.39	> 20.00	> 20.00

The urban air volume, considered when calculating the benefits of green façades, has been calculated with the atmospheric boundary layer height at each hour. The values in the table represent yearly average values.

No air volume above the building roofs has been considered. The values in the table represent yearly averaged concentration values.

Air Pollution
Conclusion

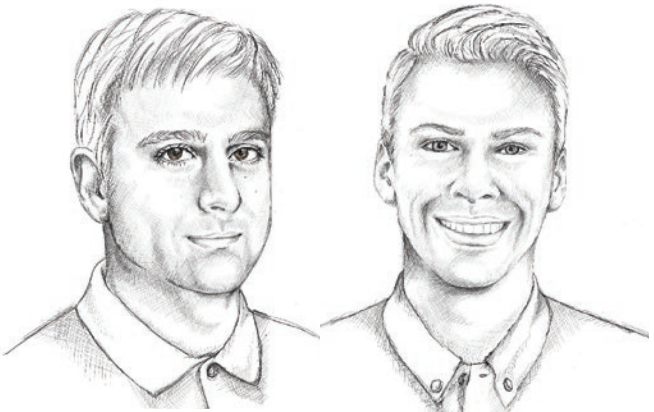
The biggest advantage of green façades is their capacity to reduce air pollution inside the street canyons without increasing pollutant concentrations at pedestrian level.

This is because green façades represent large green areas that do not interfere in the wind structures created inside the street canyons, and are aligned with main flows that carry the pollutants.

One
Green façades can result in local reductions in concentrations of particulate matter, typically between 10 and 20%.

Two
The level of reduction is highly dependent on the configuration of the buildings and street in terms of the ratio of the height of the building to the width of the street.

Three
The reductions are localised within the street canyon and overall reductions on the air mass in the city as a whole will be much lower. Therefore, green envelopes do provide an opportunity to improve air quality in selected areas.



Acoustics

Raj Patel & Willem Boning

The results of our study demonstrate that green building envelopes have the potential to reduce urban noise levels noticeably.

Short story

Computer modelling studies were conducted on a range of different streetscape and building configurations to evaluate the effect of building and block depth, height, length, and road width on urban noise. Point sources (single noise events) and line sources (continuous streams of traffic) were studied in each configuration.

The results of our studies demonstrate that green façades have the potential to reduce urban noise levels noticeably. Our main conclusions are that green façades:

- can reduce sound levels from emergent and traffic noise sources by up to 10 dB(A).
- do not significantly improve noise level reduction close to a noise source, but show greater improvements with increasing distance from the source up to the point where ambient noise begins to dominate.
- are unlikely to have a noticeable acoustical impact when a neighbourhood's sound environment is dominated by distributed sound sources.
- are likely to have a greater acoustical impact during the night, when ambient noise levels are lower and the soundscape is dominated by emergent sound sources.

This study focused on quantifiable acoustic properties, but it is also important to consider qualitative psychological benefits. The addition of natural sounds including birdsong, water dripping and leaves rustling is likely to create a more pleasing, relaxing soundscape, and the visual image of greenery could create perceptions of reduced noise above and beyond measurable reductions.

Acoustics
Introduction & Method

Physical aspects of urban noise

The noise people hear on a city street is made up of three components: direct sound energy travelling straight from a noise source to a listener's ears; reflected sound energy, which builds up between the road surface and building façades; and diffracted sound energy, which bends round the corners of city blocks.

Street canyons are typically made up of hard and dense materials such as concrete, brick, asphalt and glass that are sound reflecting and increase the overall noise level on the street.[35] While green façades cannot effectively mitigate direct sound, they can absorb sound that would otherwise be reflected between building façades or bend round their corners, reducing the overall level of noise.

Green façades have the potential to reduce both ambient noise, i.e. the background sound of a city made up of many noise sources, and noise from emergent sources, i.e. individual sources such as motorcycles, sirens and construction equipment that exceed the ambient level. Irregular sounds such as these can be disturbing when they significantly exceed ambient noise levels, as they are very difficult to ignore.[36]

Beyond measurable reductions

The acoustical benefits of green façades go beyond measurable reductions in noise level. They can create a psychological perception of quiet that complements physical reductions of sound energy. They can also introduce and unmask sounds of nature, creating a more pleasing soundscape.
A recent survey of 105 people living in apartments facing a noisy ring road in Ghent, Belgium, found that residents with a view of vegetation were five times less likely to report annoyance due to noise than residents without any greenery in their view.[37] In lab studies, the colour green alone has been shown to reduce perceptions of loudness compared to other colours.[38]
Green façades can provide a habitat for birds, whose songs have been found to contribute to a more pleasing natural soundscape.[39,40] "It is well known," writes one environmental science researcher, "that water and bird songs are sounds that produce relaxation in humans more than do human sounds, as has been proved physiologically."[41]

Acoustical modelling

Previous modelling research has demonstrated that green façades have the potential to reduce urban noise levels noticeably. The applicability of green façades to different urban conditions remains unstudied, however. No two cities are alike in their street layouts, architectural forms or patterns of use and it is important to understand how these and other variables affect the noise-mitigating performance of green façades.
To gain an initial understanding of how green façades reduce noise in different cities, we carried out two independent computer modelling studies, the first isolating the acoustical effect of individual urban variables and the second predicting their combined effect on typical urban layouts in Hong Kong, Berlin, London, Los Angeles and Melbourne.

The impact of urban variables

In our first modelling study, we investigated the impact of different architectural and urban variables on a green façade's effectiveness at reducing street-level noise using the acoustic computer simulation programme CATT. The purpose of the study was twofold: first, to determine the general range of sound level reductions likely to be achievable with the installation of green façades, and second, to assess the relative significance of the individual variables.

Acoustics
Urban Variables and Sound Level Reduction

Base model

For our base condition, we modelled a 300-m-long street canyon representing the typical block structure of Wan Chai, a densely populated neighbourhood in Hong Kong with narrow streets and tall buildings. A sound source was located in the middle of an intersection 1 m above street surface and assigned a flat-spectrum sound pressure level of 100 dB measured 1 m from the source to represent the sound of a piece of construction equipment.[42] An ambient noise level of 72 dB(A) was selected, representing a daytime level typical of Wan Chai based on measurements taken by the Hong Kong Environmental Protection Department.[43]

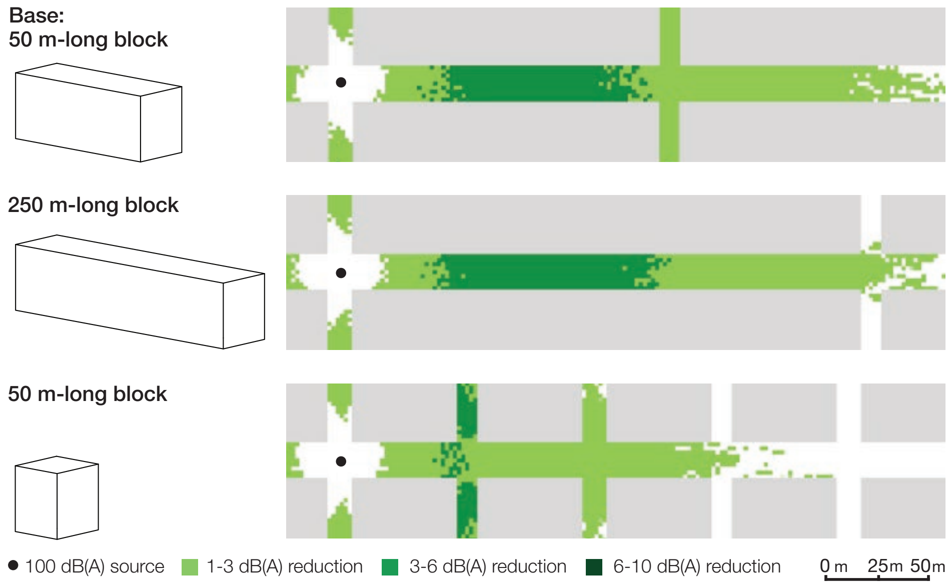
Two scenarios were tested, the first representing a typical street canyon with hard, sound-reflecting façades, and the second a street canyon treated with green façade modules with sound-absorbing properties matching those found in the Spanish-Chilean study cited earlier. The differences in level between the untreated and green façade scenarios were visualised to show the spatial pattern of sound level reduction.

Block length

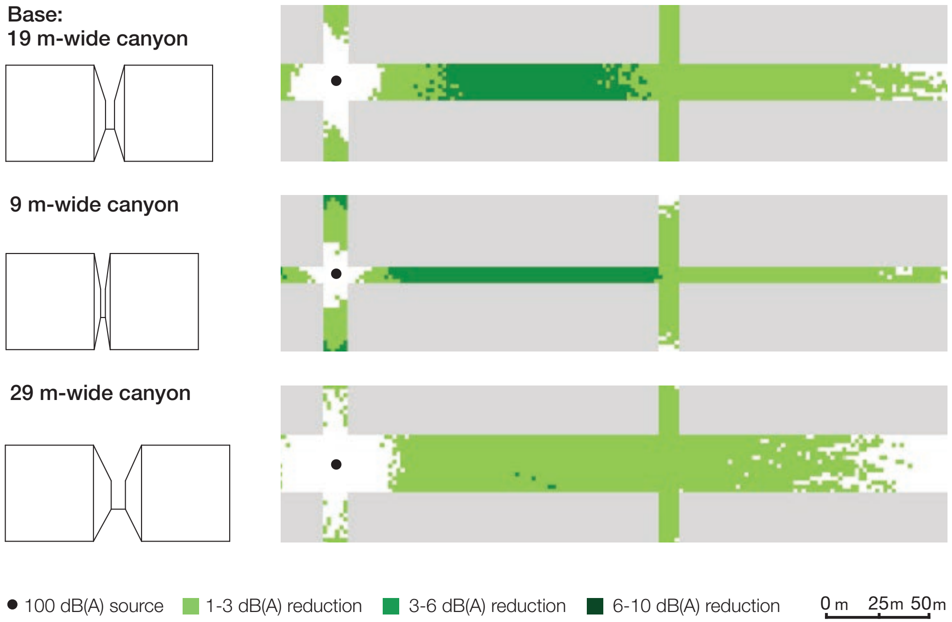
Three block lengths were tested. The base condition resulted in sound level reductions of 3 - 6 dB(A) starting about a third of the way down the first block and continuing almost to the end of that block. The long block condition resulted in a similar pattern, with a slightly longer area of 3 - 6 dB(A) reductions. In the short block condition, 3 - 6 dB(A) reductions were limited to a small area at the end of the first block and around the intersection into the cross street. The extent of 1 - 3 dB(A) reductions was also shorter than in the base and long block conditions.

Overall, the results indicate that breaks in the street wall created by cross-streets have an impact on the spatial pattern and level of sound attenuation. In a city with short blocks, the impact of sound attenuation may be felt more in streets without a direct line of sight to the source compared to cities with longer blocks, where the effect will be felt more in streets directly exposed to the source.

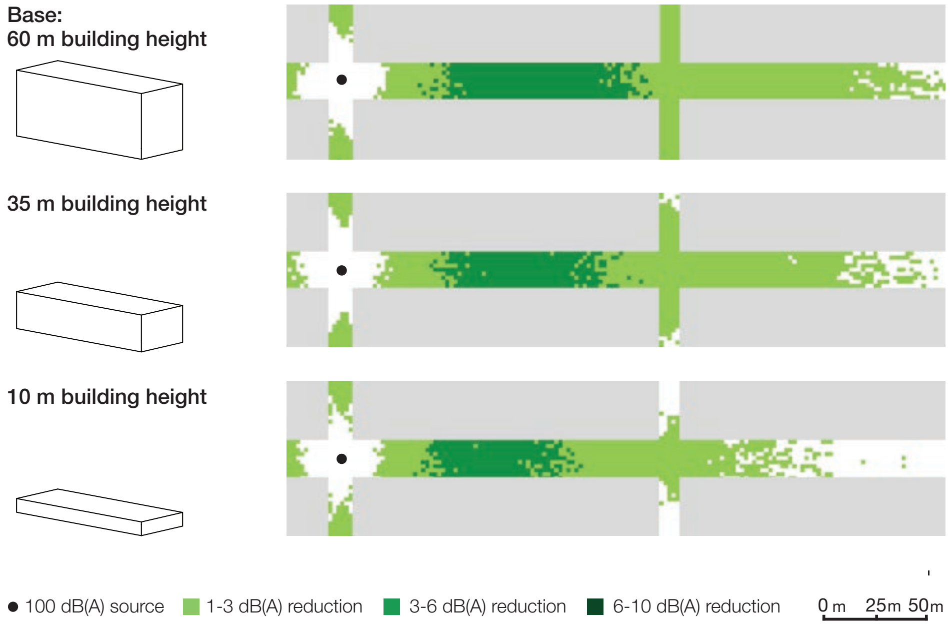
Impact of different block lengths on noise reduction from the application of green façades



Impact of street canyon width on noise reduction from the application of green façades



Impact of building height on noise reduction from the application of green façades



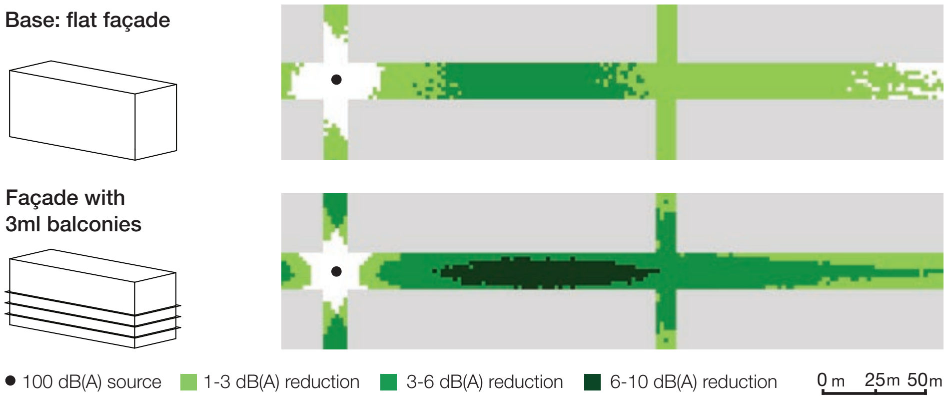
Street width

Three street canyon widths were tested, one 10 m narrower than the base Hong Kong condition and one 10 m wider. The narrower condition resulted in 3 - 6 dB(A) reductions starting somewhat closer to the source than in the base condition and continuing until the very end of the first block. In the wider condition, no reductions greater than 3 dB(A) were observed. Overall, the results of this test show that street width can have a moderate impact on emergent source noise reduction, with narrower streets resulting in greater reductions spread over larger areas.

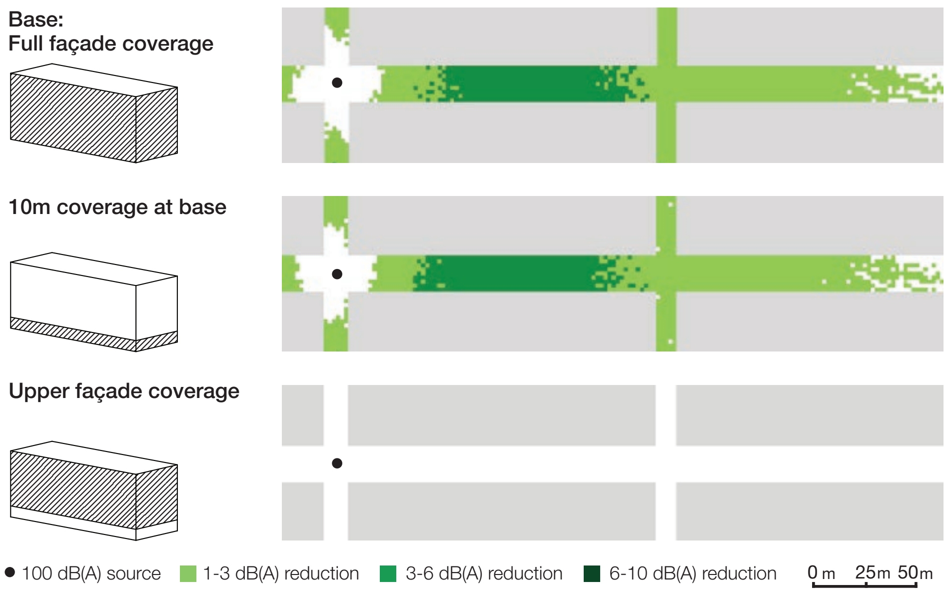
Building height

Three building heights were tested. As the 60-m buildings in the Hong Kong base model are very tall by average urban standards, the other heights were chosen to be 25 and 50 m shorter. The pattern of sound level reduction was similar for all three heights, demonstrating that building height has only a minor impact on the noise attenuation of an emergent source.

Impact of overhangs on noise reduction from the application of green façades



Impact of green façade coverage area on noise reduction from the application of green façades



Overhangs

Two façade geometries were tested, the base condition flat and the second condition featuring three 3-m-deep balconies at 10m vertical intervals up the façade. Significantly greater levels of sound reduction were observed in the balcony condition, with reductions of 3 - 6 dB(A) extending round the corner of the first intersection and part-way down the second block, and reductions of 6 - 10 dB(A) covering a large area of the first block.

The results indicate that in a street with balconies or other overhangs, applying a green façade will have a much more notice-able acoustical impact than in a street with relatively flat façades. This is likely because horizontal façade elements trap more sound energy at street level than those of a flat, vertical façade.

Green façade coverage area

Three green façade coverage patterns were tested. In the base condition, the entire fa-çade was covered in green façade modules. In the second condition, only the bottom 10 m of the façade was covered. In the third condition, the top of the façade was covered, excluding the bottom 10 m. The first two conditions resulted in an almost identical coverage pattern, while the third condition showed no sound level reductions exceeding 1 dB(A).

The results suggest that to efficiently reduce noise levels, a green façade must cover the base of a building but need not cover upper levels. This finding is only valid, however, for sources and receivers at street level. For sources and/or receivers located above street level, sound reflections from the upper façades of buildings in the street canyon will contribute to the overall sound level. If priority is given to reducing noise reduction for building occupants rather than street-level occupants, or if elevated noise sources such as aircraft dominate the soundscape, a greater green façade coverage area will likely be needed to provide noise attenu-ation.

Acoustics
Case Studies

A second modelling exercise was carried out to investigate the combined impact of architectural and urban variables on traffic sound level reductions across larger urban areas. We modelled five street plans corresponding to typical block structures in Hong Kong, Berlin, London, Los Angeles and Melbourne.

This study was carried out using SoundPLAN, an acoustics simulation software developed for large-scale environmental noise studies. Each model contained two line sources, each with a constant level of 80 dB(A), representing traffic noise on arterial roads.

Ambient noise was not factored into the study. For each city and each source scenario, a model with hard façades was evaluated against a model with green façades.

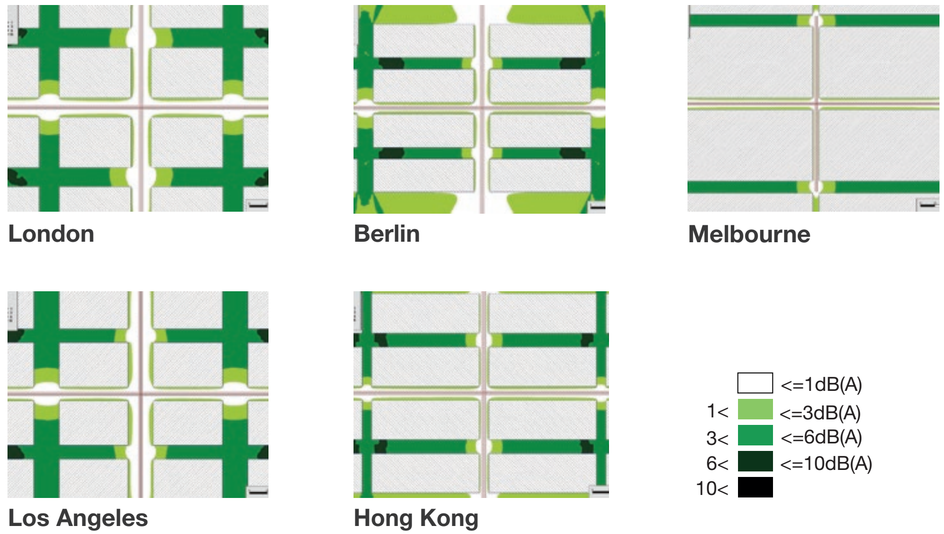
The road surface and untreated hard façade surfaces were assigned a sound absorption coefficient of 0. The green façade was assigned a sound absorption coefficient of 0.4, taken from the Spanish-Chilean study cited earlier.

The results of the line source tests show similar patterns of sound level reduction from city to city. In each city, there are reductions of 1 - 3 dB(A) along the edges of the line source streets and reductions of 3 - 6 dB(A) in other streets. Small areas of 6 - 10 dB(A) reductions are visible in areas distant from the line sources. The findings of this study indicate that the beneficiaries of traffic noise reduction from green façade application are not people occupying busy arterial streets, but those occupying calmer adjacent streets.

6-10 dB(A)
reductions are visible in areas distant from the line source

1-3 dB(A)
along the edges of the line source

Line source sound level reductions in all five case studies.



Acoustics
Conclusion

One
Green façades could reduce sound levels from emergent and traffic noise sources by up to 10 dB(A).

Two
Green façades do not have a significant impact on noise level reduction close to a noise source.

Three
Green façades have a greater acoustical impact with increasing distance from the source up to the point where ambient noise begins to dominate.

Four
Green façades are unlikely to have a noticeable acoustical impact when a neighbourhood's sound environment is dominated by distributed sound sources.

Five
Green façades are likely to have a greater acoustical impact during the night, when ambient noise levels are lower and the soundscape is dominated by emergent sound sources.

Urban Heat Island Effect

Peter Alspach & Alexej Göhring

There is a variety of city-associated parameters like the grid, solar radiation, canyon height-to-width ratio, thermal mass and the percentage of green space that influence the effect independent of green envelopes.

Short story

In this study the climatic impact of green building envelopes for buildings and cities has been examined in order to quantify a potential mitigation of the Urban Heat Island effect. For both cases a CFD modelling approach was chosen, and the results have been compared with recent studies found in the literature.

It was found that there is a variety of city-associated parameters like the grid, solar radiation, canyon height-to-width ratio, thermal mass and the percentage of green space that influence the effect independent of green envelopes.

Our main conclusions are:

- Green façades are most effective in reducing UHI in cities with a H/W ratio greater than 2 – very dense urban city centres like Hong Kong or Melbourne fall into this category – with peak temperature reductions of 10°C being predicted. Mean reductions are much smaller than peak reductions.
- Green cities like Berlin experience limited benefit compared to more dense cities with more concrete surfaces.
- Cities with wide streets and low-rise buildings like Los Angeles benefit more from greenery at street level.
- At building level green envelopes have the biggest impact on cities with a height-to-width ratio of less than 1 and a sunnier climate – a reduction of 8% was predicted for a low-rise building in LA whereas denser European or Asian cities only saw reductions of 2 - 3%.

Compared to other studies found in the literature, the predicted changes are much less. This is attributed to the fact that many experimental set-ups are not performed on true office buildings, but on simplified structures often lacking internal loads and windows.

Urban Heat Island Effect
Introduction & Methodology

In their study entitled “Renewable and sustainable energy,” Pérez et al. note that most studies pertaining to green façades and green walls have been carried out in Europe and Asia respectively. They also note the lack of standardisation for green façades given the limited application of existing research of varying systems and conditions. The authors identify the following as influencing the efficacy of vertical greenery systems (VGS):

- type of construction system used to place plants on the building façade
- climate influences on plant species and impacts on their growth (in addition to thermal impacts on buildings)
- type of plant species used.

Key trends identified by Pérez et al. include the following for traditional green façades:

- For traditional green façades east and west orientations can have great importance in energy reduction during summer. Additional studies on the orientation of façades are needed. There is also an observed direct relation between foliage thickness and surface temperature reduction.
- For double-skin green façades, it is observed that most studies have been conducted in warmer climates; thus, there is a need to carry out more studies in varying climates. The range of temperature reductions reported in such warmer climate studies are from 1 degree Celsius to 15.18 degrees Celsius.
- Looking at past simulations which examined VGS, it is generally found that VGS are an effective tool for energy savings during the cooling period in warm temperatures and in arid climates. Reported reductions most frequently ranged between 20 and 30%, being particularly noticeable with west façade orientations.

Summarising, Pérez et al. point to key findings from past studies which have performed simulations to determine the thermal behaviour of green façades in buildings.[44] Included in this is a 2009 study carried out by Wong et al. entitled “Energy simulation of greenery systems”, which sought to simulate the effects of green façades on the temperature and energy consumption of buildings. The authors performed a thermal calculation of the envelope thermal transfer value to determine the effects on the thermal performance of the building envelope.

Methodology

To assess the reduction in building energy, a typical office building for each city was modelled within its typical surrounding. The energy consumption was modelled using Energy Plus and the green vertical façades for each building orientation were modelled as solid shades.

Office occupancy, equipment, lighting and building constructions are based on the California standard Title 24. It is understood that building construction and schedules vary between different cities and countries. However, for the benefit of relative comparison and as a first pass, it was decided to keep the modelling inputs the same for all locations.

Urban Heat Island Effect
The Urban Impact on Heat Island Reduction

City grid

The city grid determines the main street orientations and façade exposures. European cities tend to be built more like a spider's web and have street orientations in all directions, whereas modern cities (e.g. Los Angeles and Melbourne) tend to have two primary street orientations.

Solar radiation

Direct solar radiation is the mechanism that heats a city. The building surfaces absorb the solar radiation and do three things: transmit it into the building, re-radiate it back to other buildings and the sky, and heat up the surrounding air through convection.

Canyon height-to-width ratio

The topology of the street canyons determines the amount of exposed solar radiation that can be absorbed and the ease of ventilation of the street canyons. Tall canyons (H/W > 2) will see reduced air ventilation rates and as such trap solar gains.

Canyon ventilation rates

The orientation of a canyon to the wind direction and the effective wind speed within that canyon will determine the capacity of solar absorbed heat transmitted (convected) to the air.

Thermal mass

Building surfaces and streets have thermal mass that stores energy. This does two things: it reduces peak surface temperatures, and it releases the absorbed heat later.

Percentage of green spaces

Green surfaces, such as parks and green roofs, will transform the solar radiation through photosynthesis into plant growth and oxygen and thus reduce the amount of solar re-radiation and convection. To model the plant surface temperatures, the plant model from Energy Plus was used.

Plant properties

The density of plant foliage and plant type play a role in the plant surface temperatures. For example, dried grass will provide little benefit in reducing the UHI effect compared to a lush, wet golf course.

Urban Heat Island Effect

Modelling Results Building Level

Results

Several studies claim that energy reductions of 20 - 50% are possible with green façades. This study was not able to align with those results. It was found that for most typical office buildings a reduction in mean and peak energy consumption of 2 - 8% can be achieved. The amount of energy reduction can be categorised by climate and building topology.

The reduced effects are likely due to the facts that:

One

Building walls are well insulated and solar gains are less critical.

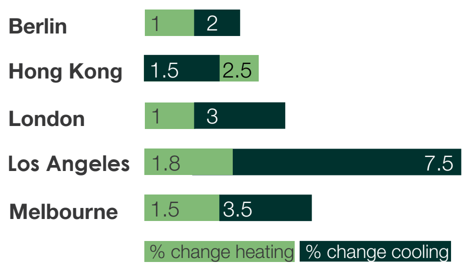
Two

Most of the environmental cooling demand enters through the windows. Since that was left unchanged, the cooling reductions are minimal.

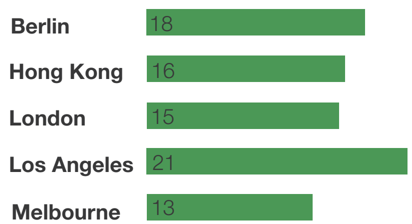
Three

Internal loads tend to dominate cooling demand for most office buildings with a decent construction.

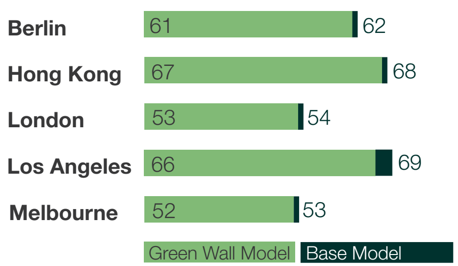
Savings in building energy demand
percentage change due to green walls



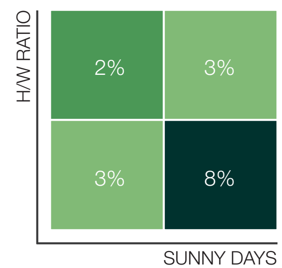
Max. surface temperature difference between base case and green wall surface in °C



Annual end use energy by city
Annual energy use [kBTU/sf]



Climate zones and city topologies where green façades provide the most energy savings



Urban Heat Island Effect
Results of City Modelling

City level

To calculate the effect that vertical green façades would have on an urban scale would require a relative comparison for a city with and without green façades. The effect of the green façades would most likely be perceived in a reduction in air temperature over the urban landscape, typically referred to as the Urban Heat Island (UHI) effect.

Results

Predicting the UHI effect was not the aim; instead, the change in air temperature to the urban atmosphere was calculated. It was found that vertical façades have the greatest impact on UHI in dense city topologies. Once the city is widespread (e.g. Los Angeles), most of the solar radiation will be absorbed on the streets instead of along the buildings. Similarly, once the cities are fairly green (e.g. Berlin), the relative benefit of adding vertical green façades makes a smaller difference.

For canyon ratios greater than 2.5, vertical green façades are a more effective means of reducing overheating of the street canyons.

8%

of reduction in mean and peak energy consumption can be achieved for typical office buildings

10.5°C

potential reduction of overheating for canyon ratios greater than 2.5 may be achieved with vertical green façades

Calculated maximum change in air temperature due to green façades in correlation with height-to-width ratio of canyons Annual Energy Use [kBTU/sf]

Urban Heat Island Effect
Conclusion

Some of the main trends that were identified suggest that:

One

Green façades increase benefits for pedestrian circulation. They effectively remove 50% of the solar radiation (typical reflected shortwave + longwave radiation).

Two

Green façades are most effective in reducing UHI in cities with a height-to-width ratio greater than two (H/W > 2). Very dense urban city centres would fall into this category (e.g. Hong Kong, Melbourne, Madrid etc.). Reductions in peak air temperatures of the order of 10ºC were predicted.

Three

Mean reductions in UHI are much less than peak reductions. For most areas the mean reduction is a fraction of a degree compared to the peak. This is in line with UHI observations that tend to be extreme during heat waves.

Four

For cities that are already fairly green, such as Berlin, green façades are of limited benefit compared to cities that have more concrete and are denser (e.g. London, Madrid, Hong Kong).

Five

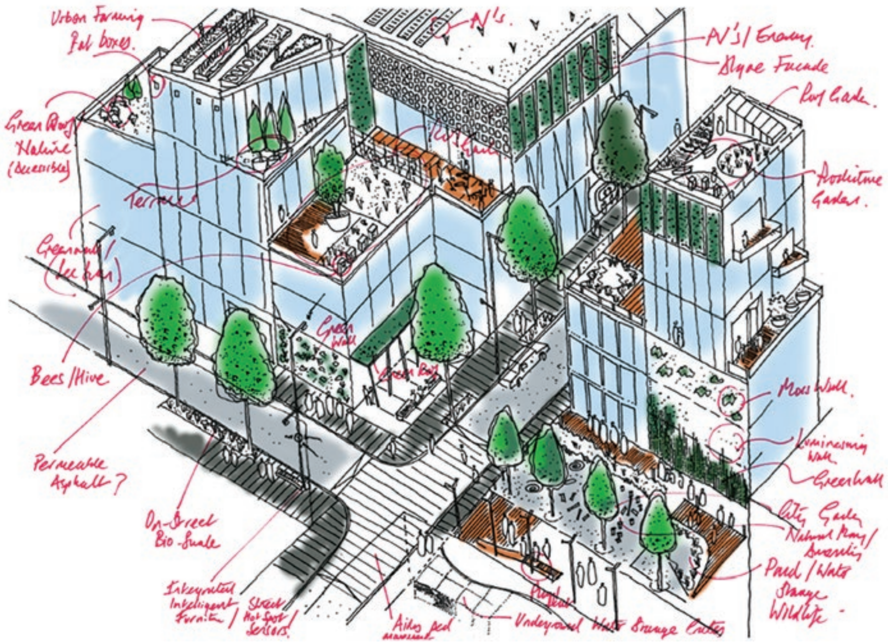
Cities with wide streets and low-rise buildings (Los Angeles) would benefit from more greenery at street level since those areas trap most of the solar gains.

Six

Green façades have the biggest impact on reducing building energy consumption in cities where the height-to-width ratio of the street canyons is less than one (H/W < 1) and even more so in sunny climates. A reduction of 8% was predicted for a low-rise office building in Los Angeles, whereas denser European or Asian cities only saw reductions of 2 - 3% in annual and peak cooling energy.

Outlook

To shape a better world we must shape better cities. The health and well-being of urban citizens should be the focus of design considerations in the future.



Cities are now facing critical issues that significantly affect people's health. These include inner city noise, fine dust pollution generated by the traffic and the development of heat island effects in ever denser urban environments. There is increasing pressure on existing recreational spaces, parks, open spaces and streets that form the "green lungs" of our cities. These important areas are competing for space with new development, utilities and services and other city infrastructure. The effects of climate change are also increasing pressure, especially on more vulnerable groups of the urban population such as children and the elderly. The trend of growing city densities and increasing urban populations is creating an urgent need to address these issues. As available ground surface area becomes ever more limited in our cities and urban environments, all available surfaces need to be considered.

It is evident that all components of the city can contribute to creating healthier environments. For instance our open spaces, parks and streets can be modified or retrofitted to operate more multi-functionally, thus maximising their effectiveness – open spaces in cities can also be modified to capture and temporarily hold flood water, or more street trees can be planted to increase the percentage of canopy cover in cities to help address urban heat, tackle air pollution, create shelter and positively influence local micro-climates.

Buildings too, as major components of the city, can make a far greater contribution to benefiting their external environment. To this end, building envelope surfaces need to be considered as an essential resource. This requires a move away from more traditional and inwardly focused performance considerations for buildings, instead looking at how envelope surfaces can perform to create healthier environments, better social conditions for people, and resilience to the effects of climate change. This approach will also stimulate economic benefits in terms of more attractive buildings and environments for residents, tenants, workers, visitors and tourists. For existing buildings and future developments, developers, planners, practitioners and designers of the built environment in all disciplines need to take on the challenge and responsibility of creating more positive and healthier approaches to building design.

Green building envelopes can contribute significantly and thus become a default design approach for building design. This will require a significant rethink of current design considerations, but if we can make health and well-being a starting point for all building design, we can shape a better world.

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