Green infrastructure and the urban heat island

Introduction and links to climate change

In urban areas, the warming effects of climate change will be combined with those of the urban heat island (UHI). Towns and cities are usually a degree or two warmer than surrounding rural areas, as a result of this UHI effect. The UHI is caused by two main factors:

- Buildings and other man-made surfaces are warmed by direct solar radiation. Heat absorbed during the day is released into the atmosphere at night, causing a general warming of urban air.
- Loss of vegetation in urban areas reduces the amount of cooling by evapotranspiration (Heidt and Neif, 2008).

Human activities also contribute to the UHI, for example:

- Small but significant amounts of heat generated by human metabolic processes.
- The effects of vehicles and industry.
- Waste heat from air conditioning (Smith and Levermore, 2008).

Summer heat in urban areas can also bring about:

- Increased levels of indoor and outdoor thermal discomfort.
- A likely increase in adverse health effects such as sunburn, skin cancer and cataracts (Kovats, 2008).
- An increase in direct energy costs associated with air conditioning.

The warming effects of climate change are likely to increase the intensity of the UHI in urban areas.

Evidence linked to heat amelioration

Green infrastructure (GI) in urban areas can ameliorate the warming effects of climate change and the UHI. Gill *et al.* (2007) have suggested that increasing the current area of GI in Greater Manchester by 10% (in areas with little or no green cover) would result in a cooling by up to 2.5 ^{o}C under the high emissions scenarios based on UKCP02 predictions.

GI reduces the impacts of higher temperatures in different ways:

- Trees and shrubs provide protection from both heat and UV radiation by direct shading (both of buildings and outdoor spaces).

- Evapotranspiration reduces the temperature in the area around vegetation by converting solar radiation to latent heat.
- Lower temperatures caused by both evapotranspiration and direct shading lead to a reduction in the amount of heat absorbed (and therefore emitted) by low albedo man-made urban surfaces (Dimoudi and Nikolopoulou, 2003).

An unpublished review by Bowler gives a good indication of what are thought to be the main mechanisms by which vegetation cools an urban area. The main points of the review are summarised in the table.

Table Summary of effects of urban green space on temperature, based on Bowler (unpublished).

Factors investigated	**Number of studies**	**Main effects**	**Comments**
Green area size	4	• Larger parks likely to be cooler than smaller parks (or cooling effect of larger parks is greater). • Parks of at least 3 ha usually cooler that the surrounding urban areas. • Temperature in parks of less than 3 ha more variable.	
Distance from park	3	• Cooling effect of park extends beyond boundary (temperatures outside park boundaries rise gradually as distance from green area increases). • Second study of three parks found similar effect at night. • Largest of the three parks (156 ha) showed the strongest relationship between temperature and distance.	
Vegetation type	2	• Higher numbers or larger areas of trees within a park lead to lower temperatures. • Cooling not simply an effect of shading, as temperature measurements were also taken in unshaded areas of park.	
Percentage of green cover in a wider urban area	3	• Temperatures lower on average in areas with higher percentage green cover.	• Other factors in areas monitored may be affecting temperature differences, e.g. amount of vegetation within immediate vicinity of temperature monitoring point.
Individual trees	9	• Temperature beneath canopies of individual trees usually lower than that of the surrounding air. • Some studies suggest that main cause of cooling is direct shading, and that different tree species vary in their ability to reduce local temperatures (possibly due to factors such as tree size and canopy characteristics). • One study of 44 species concluded that factors such as leaf area index, diameter and height do not seem to affect the amount by which a tree reduces local air temperature. • One study found that amount of visible shade provided by trees explained variations in temperatures between measurement points, and that cooling effect of trees could be detected up to 80 m away. • A study with sugar maples (*Acer saccharum*) found little difference in cooling effects between individual trees and small groups (3-4 trees). • Sugar maple study also found higher temperatures under individual trees in paved streets than under trees in grassy environments. • One study found marginally higher cooling effect from small groups as opposed to single trees. • Where trees are found in street canyons, the orientation of the canyon affects the amount of cooling provided by the tree.	• Something about the slightly contradictory nature of available evidence.

Practical considerations

To manage the heat amelioration effects of GI:

1. Determine which parts of large urban areas are most at risk from the effects of higher average levels of heat.
2. Quantify the effects that differing amounts of vegetation have on the local thermal environment.
3. Determine the current extent of local GI and the opportunities for its better management or expansion.

Tools

Methods and tools for assessing the risk of climate change and quantifying the effect of adaptation measures in urban areas are being developed by two research projects.

SCORCHIO

This project aims to develop tools that can quantify risk from the combined effects of the UHI and climate change, and show how best to target adaptation strategies over a large urban area (Smith and Lindley, 2008). Further details can be found on the project website at www.sed.manchester.ac.uk/research/cure/research/scorchio.

LUCID

LUCID is developing more localised tools for quantifying the effects of building structure and form, climate, energy use and effects on human health. Further details can be found on the project website at www.lucid-project.org.uk.

The effects of vegetation on urban climate have been looked at in a number of climate models. These models are usually used to characterise urban surfaces as part of a larger mesoscale meteorological model. The overall usefulness and accuracy of these models is the subject of a current study (Grimmond *et al*., 2009).

ENVImet

One of the models included in this study is ENVImet (Bruse and Fleer, 1998), available from www.envi-met.com. ENVImet can:

- Predict the effects of differing amounts of vegetation under different climate scenarios for a given urban area.
- Be used in conjunction with BOTworld software to look at the effects of its modelled climate scenarios on human thermal comfort (Huttner *et al.*, 2009; Bruse, 2009).

Modelling with ENVImet can be time consuming and ideally needs large amounts of processing power.

Certain American systems can be used to calculate a dollar value for ecosystem functions (such as the reduction in the amount of energy needed for air conditioning when trees are planted near to buildings). The two main systems used for valuing such ecosystem services are i-Tree and CITYgreen.

i-Tree
This method has been adapted for use in other countries, but needs local climate and tree species data. More information can be found at www.itreetools.org.

CITYgreen
A GIS-based system used to calculate the economic benefits of urban forests; this program needs detailed land use data to be effective. A recent report detailed a number of key points that would need to be addressed before CITYgreen could be used effectively in the UK (Kingston *et al.,* undated).

Case studies

- Turning the Chicago urban forest project into action on the ground.
- Adaptation Strategies for Climate Change in the Urban Environment (the ASCCUE Project).

Knowledge gaps

- The Read report on forestry and climate change (2009) notes that most local authorities do not have basic inventory data for their urban trees and woodland.
- The Bowler review noted that more detailed, statistically valid experimentation is necessary to get a better picture of the mechanisms by which vegetation cools the surrounding environment.
- The incorporation of urban parameters (including vegetation) into predictive weather models needs to be improved for the UK. A review of these models is currently under way (Grimmond *et al.*, 2009), and the SCORCHIO and LUCID projects may also address this issue.
- More work is needed on methods for valuing certain ecosystem services, including the cooling effects of urban GI.
- There is a lack of standardised land cover and land use information for urban areas in the UK.
- More information is needed on suitable species for use in climate change adapted GI, such as those that show heat and drought tolerance, resistance to frost damage, and other relevant physiological characteristics.

Citations of national policies/priorities

The Climate Change Act (2008) requires certain organisations to produce climate change risk assessments and adaptation plans. See the Defra website at www.defra.gov.uk/environment/climate/documents/rp-list.pdf for a full list of these organisations.

References

Bowler, D. (unpublished). How effective is ‘greening’ of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the ‘urban heat island effect’? Draft review downloadable from the website of Collaboration for Environmental Evidence, Systematic Review No. 41, (www.environmentalevidence.org/index.htm).

Bruse, M. (2009). Analysing human outdoor thermal comfort and open space usage with the Multi-Agent System BOTworld. Talk presented at 7th International conference on urban climate, Yokohama, Japan, available from www.envi-met.com.

Bruse, M. and Fleer, H. (1998). Simulating surface–plant–air interactions inside urban environments with a three dimensional numerical model. *Environmental Modelling and Software* **13**, 373–384.

Dimoudi, A. and Nikolopoulou, M. (2003). Vegetation in the urban environment: microclimatic analysis and benefits. *Energy and Buildings* **35**, 69–76.

Gill, S.E., Handley, J.F., Ennos, A.R. and Pauleit, S. (2007). Adapting cities for climate change: the role of green infrastructure. *Built Environment* **33** (1), 115–133.

Grimmond, C.S.B., Best, M., Barlow, J., Arnfield, A.J., Baik, J.-J., Baklanov, J., Belcher, S., Bruse, M., Calmet, F., Chen, P., Clark, P., Dandou, A., Erell, E., Fortuniak, K., Hamdi, R., Kanda, M., Kawai, T., Kondo, H., Krayenhoff, S., Lee, S.H., Limor, S.-B., Martilli, A., Masson, V., Miao, S., Mills, G., Moriwaki, R., Oleson, K., Porson, A., Sievers, U., Tombrou, M., Voogt, J. and Williamson, T. (2009). Urban surface energy balance models: model characteristics and methodology for a comparison study. In: *Meteorological and air quality models for urban areas,* eds A. Baklanov, S. Grimmond, A. Mahura and M. Athanassiadou. Springer, Heidelberg, New York, 97–123.

Heidt, V. and Neif, M. (2008). Benefits of urban greenspace for improving urban climate. In: *Economy, planning and management of urban forests:international perspectives*, eds M.E. Carreiro, Y.C. Song and J. Wu, J. Springer, Heidelberg, New York, 336–345.

Huttner, S., Bruse, M., Dostal, P. and Katzschner, A. (2009). Strategies for mitigating thermal heat stress in central European cities: the project KLIMES 7th International conference on urban climate, Yokohama, Japan. Poster presented at 7th International conference on urban climate, Yokohama, Japan, available from www.envi-met.com.

Kingston, R., Cahill D., Handley, J., Tzoulas, K. and James, P. (undated). Toward a green infrastructure valuation model: assessing the potential for the CITYgreen GIS software for use as a tool for qualifying the economic benefits of green infrastructure in the UK. Natural Economy Northwest. http://www.naturaleconomynorthwest.co.uk/resources+reports.php

Kovats, S.,ed. (2008). *Health effects of climate change in the UK 2008*. An update of the Department of Health report 2001/2002. Health Protection Agency, England.

Read, D.J., Freer-Smith, P.H., Morison, J.I.L., Hanley, N., West, C.C. and Snowdon, P., eds (2009). *Combating climate change – a role for UK forests*. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. The Stationery Office, Edinburgh.

Smith, C. and Levermore, G. (2008). Designing urban spaces and buildings to improve sustainability and life in a warmer world. *Energy Policy* **36** (12), 4558–4562.

Smith, C. and Lindley, S. (2008). *SCORCHIO workshop report*. Available from www.sed.manchester.ac.uk/research/cure/research/scorchio/publications