The cooling effects of green roofs

RHS

The benefits of green roofs are well known, but their temperature moderating effects are not. Tijana Blanusa and Madalena Vaz Monteiro investigated which plants are best at cooling, and why.

Green roofs are increasingly becoming an important component of green infrastructure in modern cities. Through history we have seen them both in their intensive forms, such as ornamental roof gardens, but also in their extensive forms, such as turf roofs on Scandinavian log buildings. In more recent times their manifestations have diverged even further: from intensively managed roof gardens on a deep layer of substrate to 1m deep, where even trees would be considered, to extensive, shallow roofs on substrates of less than 10cm, often with sedum cover, on warehouses, offices, schools or blocks of flats.

Over the last decade an intermediate type has emerged, with moderately deep substrates to 20cm deep. These are known as semi-extensive roofs and have been gaining popularity due to their potential to host a wider range of plant species than extensive roofs, while still requiring less structural support, installation and maintenance cost than intensive roofs.

Roofs are not an easy environment for plants to thrive in. They are typically windier and more exposed than a ground-level plot. Also, due to the shallowness of the substrate, extensive and semi-extensive roofs are also drier in summer and could freeze during winter.

Benefits of green roofs

Green roofs can be developed for a number of reasons. Support for urban biodiversity, particularly small invertebrates and urban birds, has been mostly in the public eye. For

Madalena Vaz Monteiro

Semi-extensive green roofs (above left) can provide good wildlife habitat and assist in rainwater run-off management but, unless species are chosen carefully, they will not contribute significantly to cooling of the roof or building.
The authors tested a range of species for their cooling effect, such as *Stachys byzantina* and *Bergenia cordifolia* (above right). These are being grown in an industrial green roof substrate of 70% crushed brick and 30% loam. The experiments started when ground coverage of 90% or greater was reached.

those purposes, a mixture of grass and succulent cover on the roof, with some variation in substrate depth and the presence of a few log piles would perform well. This cover would also protect and insulate the roof membrane from temperature fluctuations, thus increasing its longevity. The cover might also help with storm-water retention and act to slow the discharge of rainwater into drainage systems.

Green roofs, therefore, provide a number of simultaneous benefits. But they have started receiving more attention recently for their potential to insulate roofs and therefore buildings. This insulation by roof vegetation reduces energy consumption for cooling in the summer. Also, in milder climates where roofs are seldom snow-covered in winter, roof vegetation can reduce energy consumption for heating.

Choosing plants for their ability to cool

Plants on roofs cool by shading the surface, by reflecting the incoming light energy, and through the process of evapotranspiration (i.e. controlled water loss through small leaf pores called stomata). Cooling through evapotranspiration is particularly important, as it is an effective way of consuming heat without warming up surrounding surfaces. Transpiration is specific to plants and thus puts them in a unique position which no artificial material could exhibit. However, artificial materials can provide shade and reflectance.

The most widely used species on extensive and semi-extensive green roofs are *Sedum* such as *S. album* and *S. acre*. *Sedum* establish rapidly, provide good surface coverage, and are effective in decreasing storm water run-off while requiring very low maintenance. However, because of their structure and the way they biologically function (they tend to conserve the water rather than transpire it), *Sedum* and similar succulents are unlikely to offer substantial evapotranspirational cooling and associated reduction in air temperature when the weather is hot and dry.

For our research we have therefore focused on understanding which species exhibit sufficient evapotranspiration to provide measurable surface, and potentially, building, cooling. We also wanted to find those that are robust enough to tolerate the adverse conditions associated with roofs and facades, and have acceptable ecological properties such as promotion of urban biodiversity. Candidates are likely to be broad-leaved, relatively vigorous, perennial plants. These might be appropriate for green roofs, especially if semi-extensive systems are used to provide anchorage for their root systems.

Experiments

In the period 2009–2013 we conducted a series of experiments ➤

in glasshouses and controlled environment chambers, as well as outdoors in summer and winter. We tested a range of perennial succulent and broad-leaved species. Plants were chosen on the basis of differences in canopy leaf areas, leaf thickness, evapotranspiration rates, leaf colour, and presence or absence of leaf hairs. All these traits contribute to the regulation of leaf temperature and can thus contribute to environmental and building cooling. For example, pale-coloured leaves potentially reflect more energy, larger canopies could provide better shading, and thinner leaves might store and re-emit less heat.

In the early experiments we tested a mix of *Sedum* species (an industry-standard, green-roof matting comprising a random mix of *S. acre*, *S. album*, *S. sexangulare* and *S. spurium*) against *Stachys byzantina*, *Hedera hibernica* and *Bergenia cordifolia*.

In the early experiments plants were glasshouse-grown under well-watered and dry-watering regimes in a 20cm-deep, green-roof substrate. A range of growth and plant physiological parameters was measured. These included water loss through leaves, leaf temperature, substrate temperature, and air temperature 10cm above the plants.

Results

In our study *Stachys* outperformed the other tested species in terms of leaf-surface cooling, substrate cooling beneath the canopy, and, during short intervals over the hottest, still periods, the air above the canopy when soil moisture was not limited (Blanusa *et al*. 2013). For example, we found on one of the hottest days of the experiments (with a maximum air temperature of 28°C) that temperature of the substrate below *Stachys* was 12°C cooler than under *Sedum*, and 15°C cooler than for bare, uncovered ground. This could have significant implications for the temperature of a building, as well as a reduced need for summer air conditioning, if these plants were installed on the roof. *Stachys* is unlikely to be as resilient as *Sedum* in terms of survival in the most drought-prone, extensive green roofs (5–10cm deep), but is a drought-adapted species in its own right, capable of survival and persistence in semi-extensive (20cm deep) systems.

This suggested to us that our hypothesis about plants differing in their ability to cool was founded. We therefore became interested in expanding the range of species, and also understanding which plant traits are specifically linked with better provision in cooling. Pale leaf colour and leaf hairiness of those species that cooled best in our early experiments prompted us to consider these traits in more detail in subsequent studies.

In our more recent experiments (Vaz Monteiro *et al*., manuscript in preparation) we have therefore included additional species, such as *Heuchera* (several cultivars with different leaf colour, from purple to yellow), *Salvia* (with different leaf hair length) and *Sempervivum* (different leaf thicknesses) alongside *Stachys* and *Sedum*. In some of the experiments we attempted to cool the ground surface by using artificial shade (a pergola) or by painting the surface white to increase reflectance. We also conducted the experiments outdoors, to understand if the principles we established in the controlled environment would still be valid in real-life situations.

We found that the presence of thinner-leaved plants improved substrate cooling compared with the artificial shade, and this would likely lead to building cooling too. Herbaceous plants insulated the substrate best – *Salvia* and *Stachys* provided most cooling and potential insulation. This is because they offer more substrate shading and protection, and had lowest leaf and canopy temperatures. This causes lower levels of heat release into the substrate underneath. In contrast, succulent *Sempervivum* warmed up the substrate underneath during some parts of the hottest days. *Sedum*, another succulent, perhaps

Madalena Vaz Monteiro

A range of plant species being tested on outdoor experimental plots to understand what mechanisms plants employ to cool their leaves and the surrounding environment.


Madalena Vaz Monteiro

Heuchera 'Obsidian' in a controlled environment experiment where leaf temperature and thermal emission from the canopy were measured along with substrate temperature at different depths.

surprisingly, performed better, acting intermediately between the best and worst cooling plants.

Our research showed that water loss by evapotranspiration is the main mechanism that contributed to better cooling effects of plant cover. Therefore, choosing plants which transpire more and keeping them sustainably watered is important for reduction of temperatures. Larger canopy sizes and presence of pale-coloured leaf hairs also had a small positive influence on temperature lowering

Installing a green roof

Before one begins the task of installing a green roof and unlocking its environmental benefits, a few conditions have to be met.

As a simple rule, DIY installation of green roofs should only be attempted on small built structures such as sheds. For inexperienced installers, shallower and lighter, extensive green roofs should be the initial choice. Once you have experience then heavier structures can be considered. Only undertake the work if you have an understanding of the weight the structure can take. Alternatively, check with a chartered structural engineer or surveyor that the roof will be able to take the weight of the design. Also, check if planning permission is required from your council.

As a rough guide for DIY installations, only a flat or lightly sloped roof up to 20° should be used. Before starting, the roof surface should be cleaned and protected with a waterproof layer, such as a pond liner, which will also act as a root barrier. The roof's principal components are: root barrier, drainage layer, water retention layer and, on top, a substrate layer for the plants to grow in.

The plant choice for green roofs could start with readily available *Sedum* mixes, which come as mats that are simply rolled out. *Sedum* is advantageous because if its resilience, little need for roof structural reinforcement, and ease of management. However, with substrates more than 10cm in depth and in the UK climate, you could try grass mixes, small bulbs or drought-adapted herbaceous perennials.

Conclusion

The research presented here is at an early stage in terms of its practical application. We are currently working to make our ideas more relevant for domestic gardeners. To achieve that we are researching longevity and maintenance needs of our best performing species with high transpiration rates. The success of our best performers depends on the maintenance of evapotranspiration, which means irrigation during the hottest, driest periods of summer. We are therefore also investigating the use of household grey-water and its cost and impact on the annual benefit of green roofs.

REFERENCE

Blanusa, T, Vaz Monteiro, MM, Fantozzi, F, Vysini, E, Li, Y & Cameron, RWF (2013)
Alternatives to *Sedum* on green roofs: can broad leaf perennial plants offer better 'cooling service'? *Building and Environment* 59: 99–106

ACKNOWLEDGEMENTS

This work was funded by the RHS and a PhD training grant to Vaz Monteiro from the Portuguese Ministry of Science and Technology.

FURTHER INFORMATION

For more information about green roofs visit: https://www.rhs.org.uk/advice/profile?pid=289

Tijana Blanusa is an RHS Senior Horticultural Scientist.
Madalena Vaz Monteiro is completing her PhD at the University of Reading, under Blanusa's supervision.