Quantifying the Environmental Benefits of Trees in Towns

Roland Ennos

University of Manchester

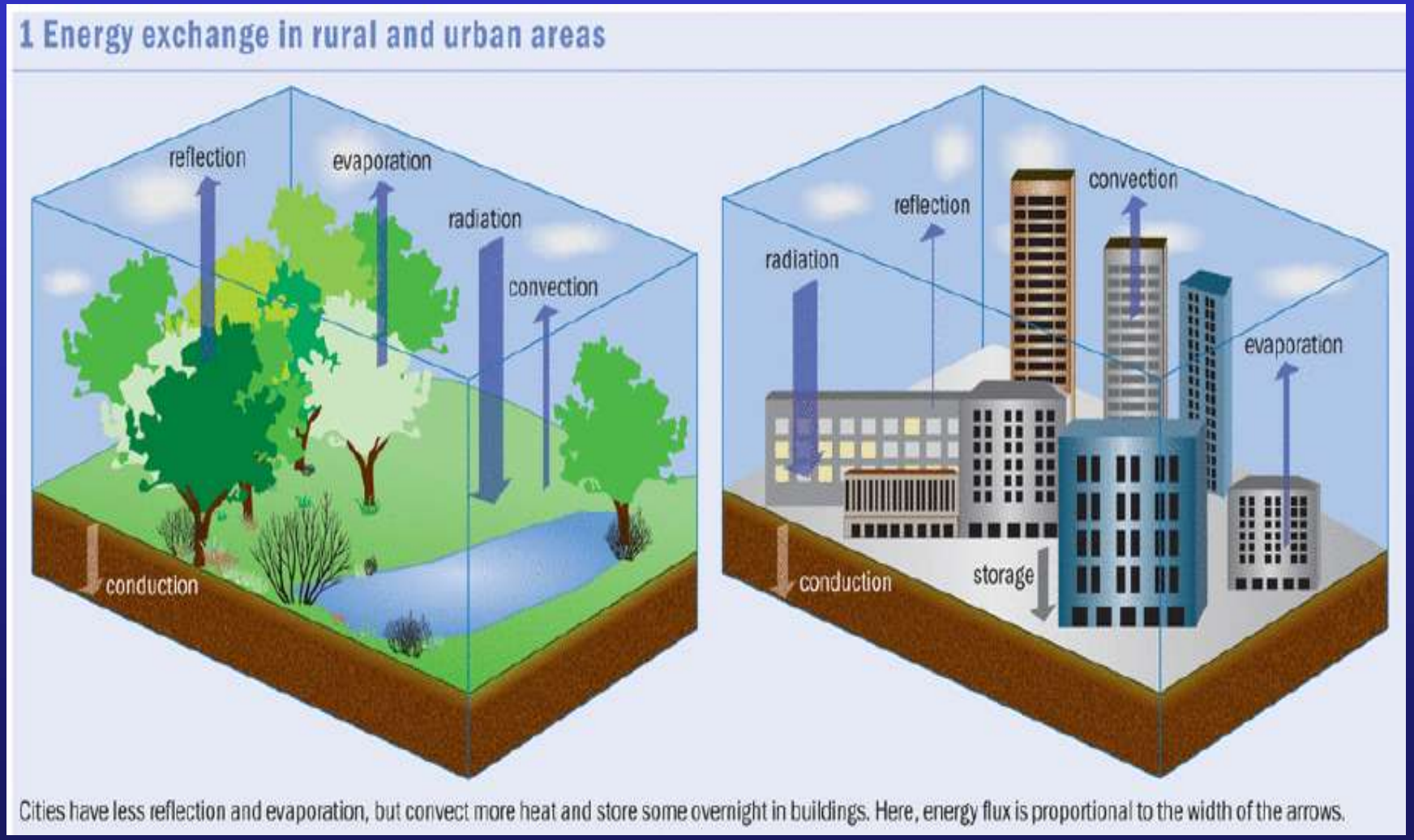
The Problem of Climate Change

1. Mean and Maximum summer temperatures are set to rise by up to 4ºC by 2080 in the UK.
2. Summer precipitation is set to fall by 30-40%.
3. Winter precipitation is set to rise by 30-40%.

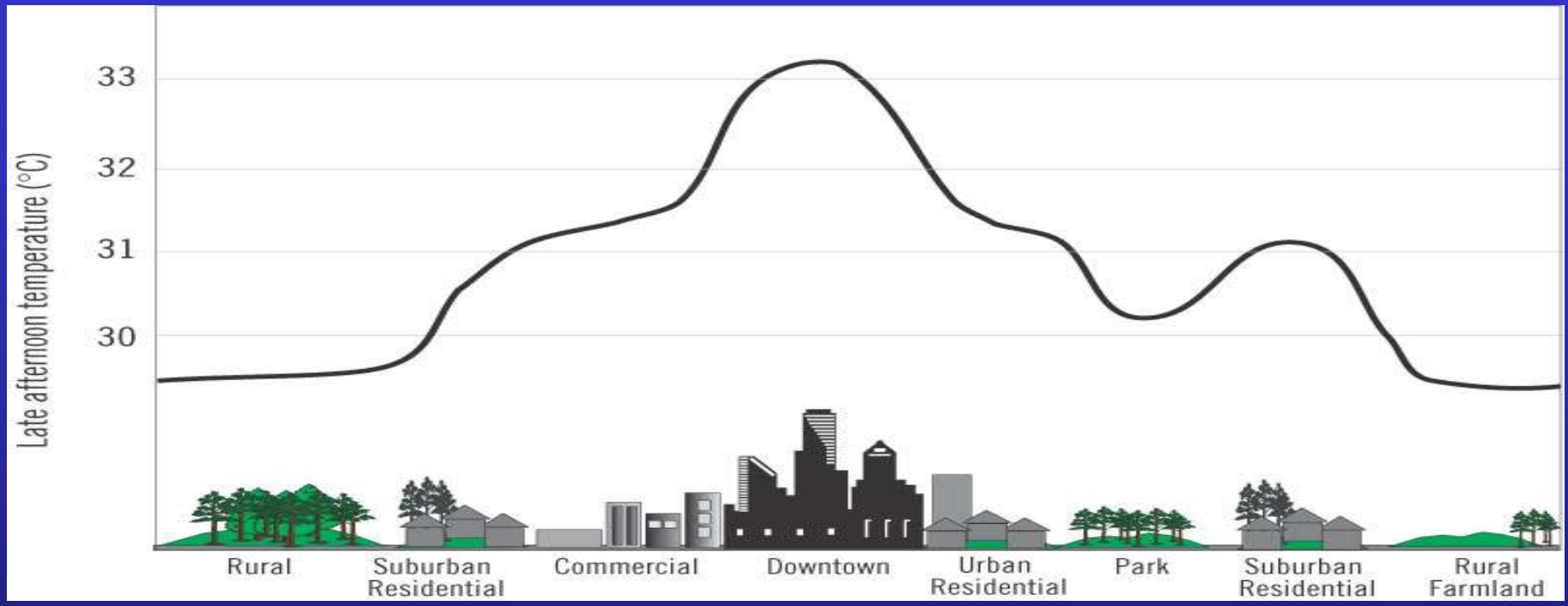
These changes are especially likely to cause problems in cities because of the additional effects of urbanisation.

The Urban Heat Island

Loss of vegetation in urbanisation alters the energy balance.



The result is an urban heat island

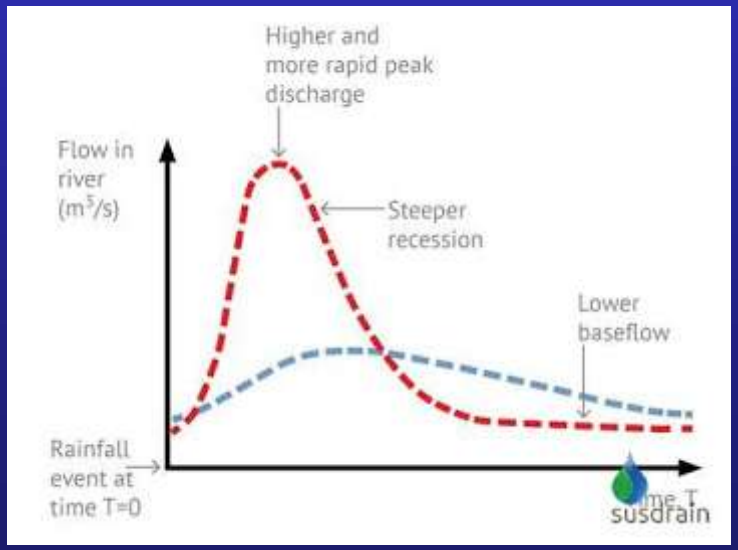


This can reach 4ºC in the day and 7ºC at night

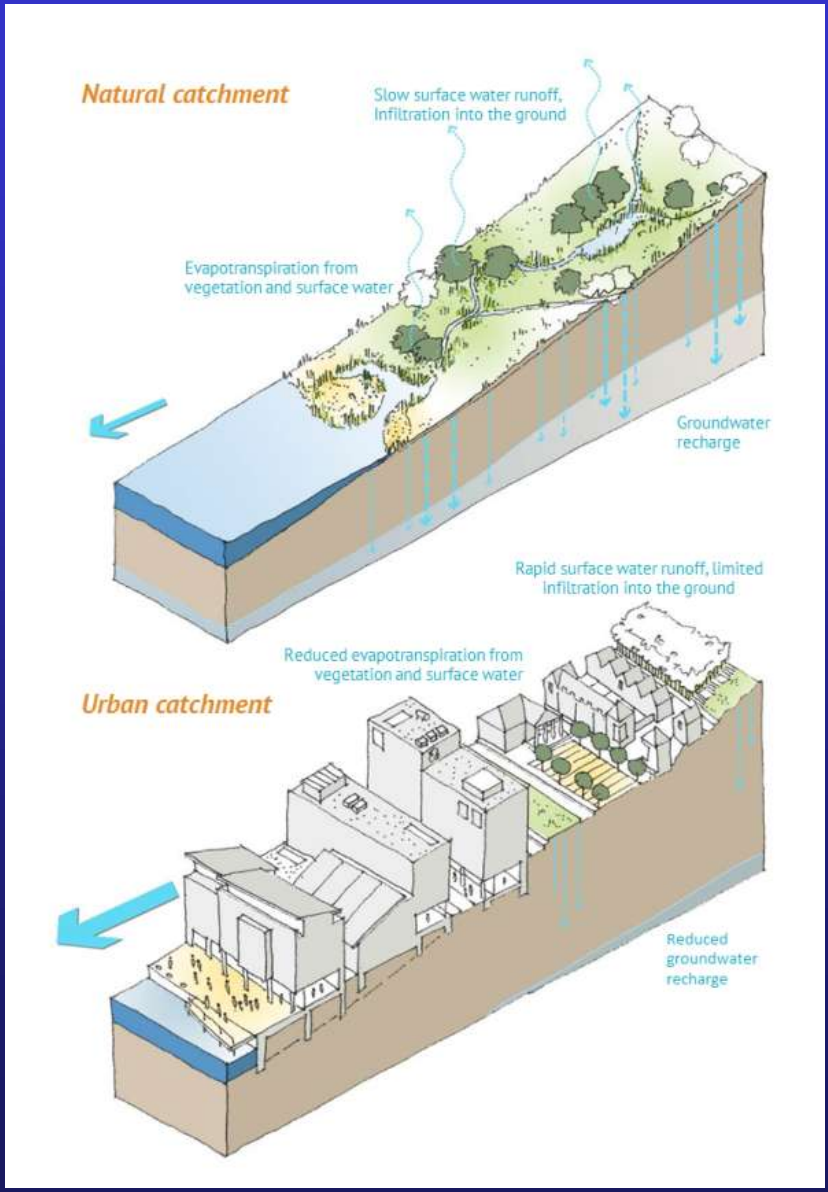
This will make cities more uncomfortable and increase the need for air conditioning

Increased Surface Runoff

Replacement of greenspace by buildings results in earlier and greater runoff of rainfall.

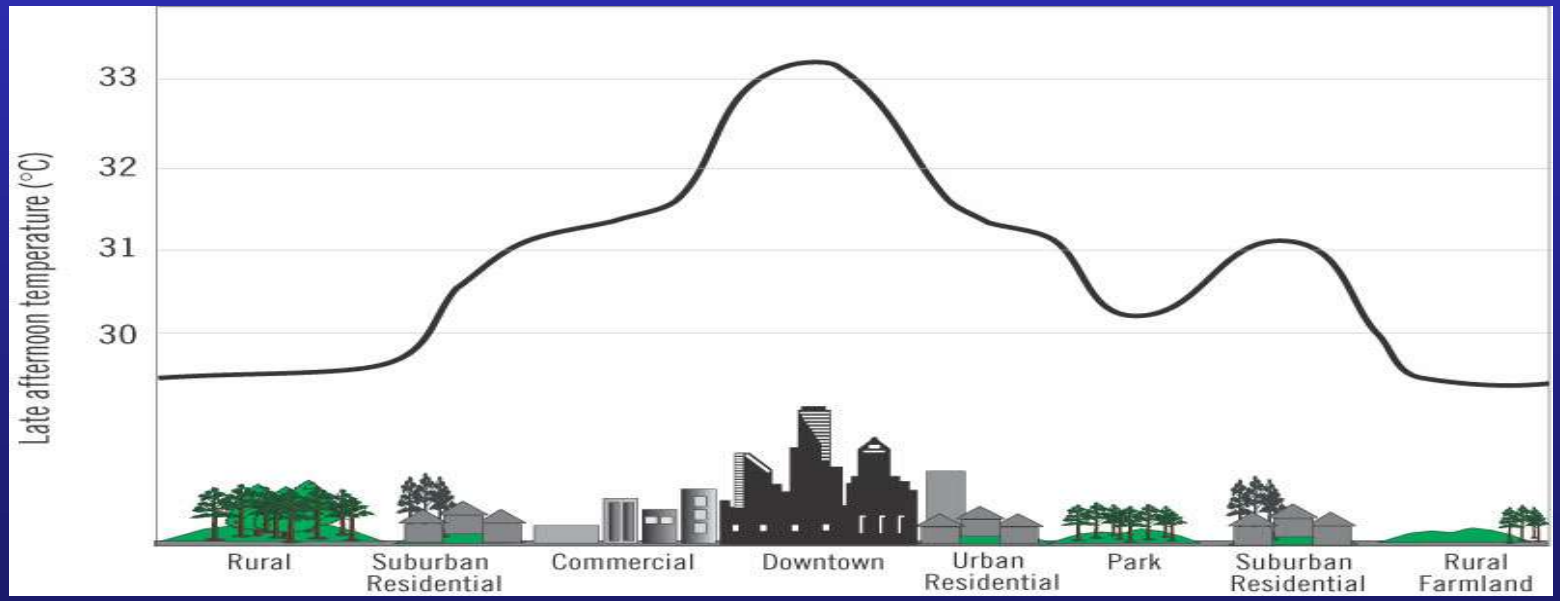


Climate change will increase the likelihood of surface flooding



How Can Trees Help?

Incorporating trees and other vegetation reverses the process of urbanisation, so it has the potential to provide cooling and prevent rainfall runoff, climate proofing the city.



Therefore it’s important to quantify their benefits

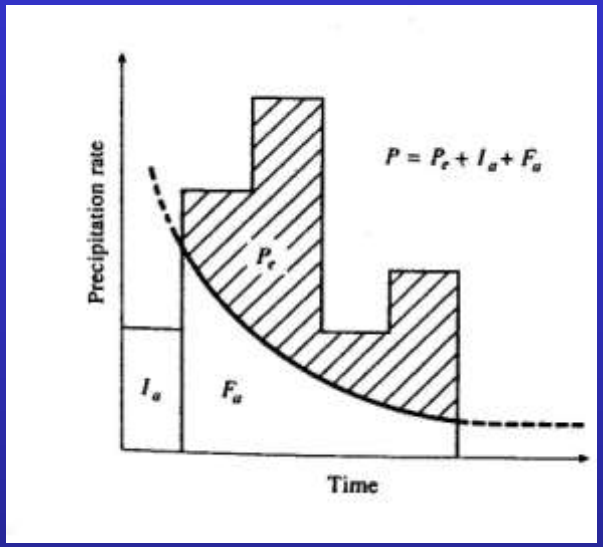
Quantifying The Effect of Trees In Reducing Runoff

1) Estimating using hydrological models

I_a = initial interception

F_a = amount retained

P_e = runoff



Results: Woodland has runoff of only 50-60%, compared with 95-98% for buildings and roads, so adding 10% tree cover would reduce runoff by only 5%.

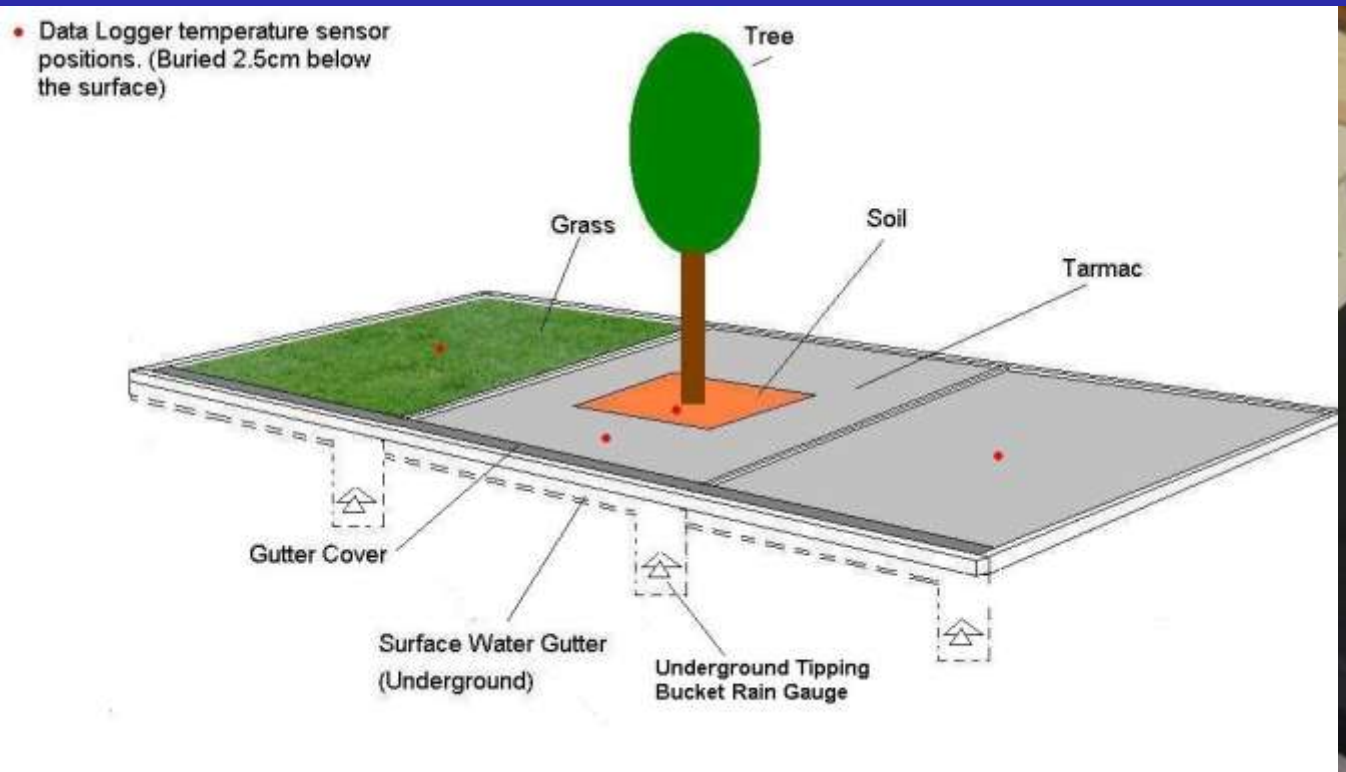
But urban trees are planted singly into concrete, so is this correct?

2) Experimental Studies

We built 9 experimental plots in South Manchester

Experimentally Measuring the Effects of Trees and Grass on Runoff

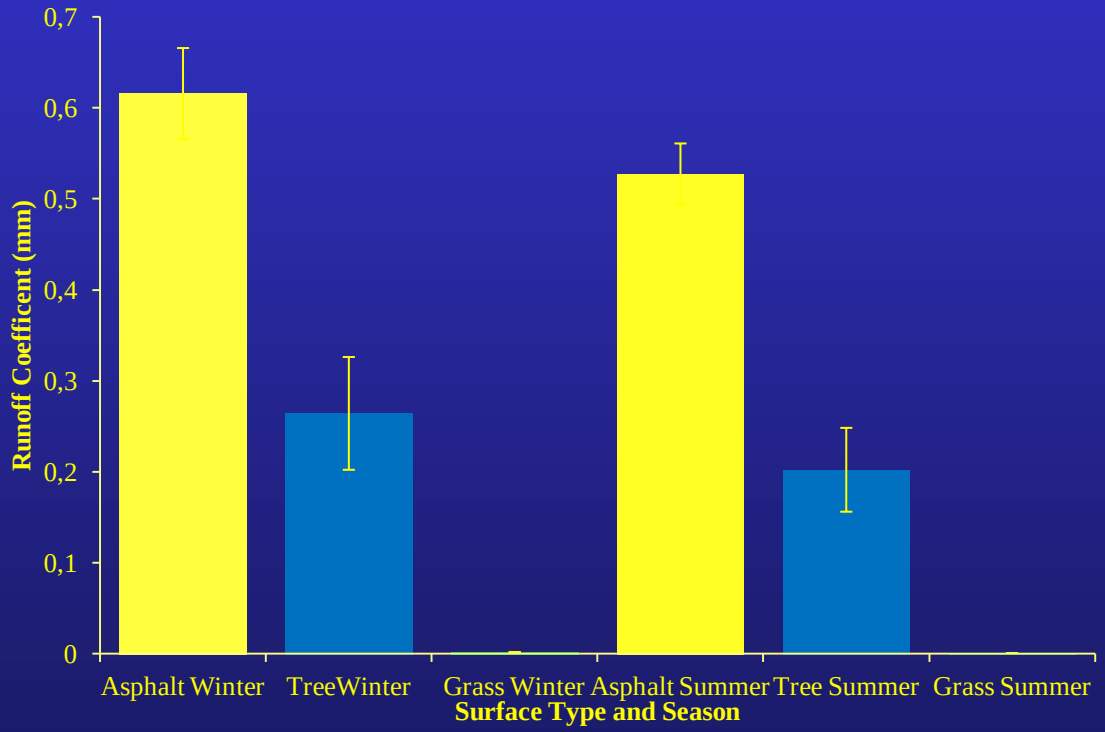
Experimental plots were designed to measure temperature and runoff.



Tipping bucket gauge

Results

1) Trees reduced runoff by 60% across the whole plot, despite covering only 35% of it (water infiltrated the hole).
2) Grass reduced runoff by 99%!



The planting method is very important and far more research is needed to investigate the optimum methods.

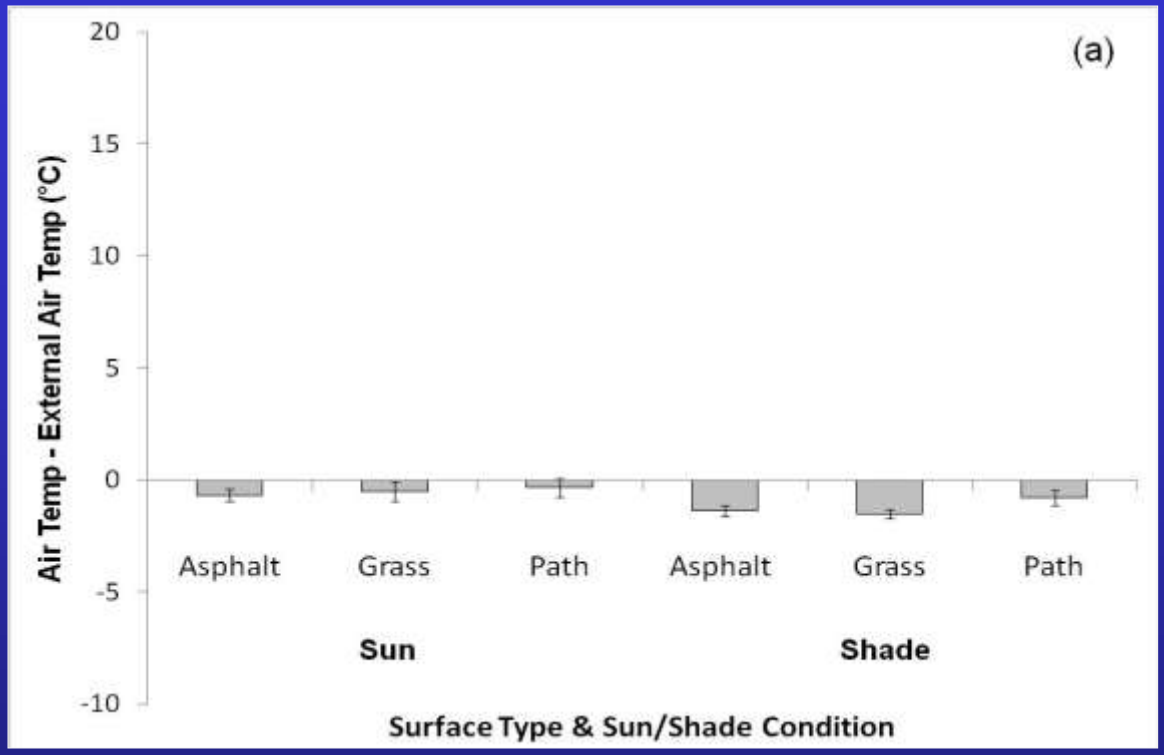
Quantifying the Cooling Effect of Trees

Approach 1: Measuring Air Temperatures

Many researchers have measured air temperatures

a) Within vs Outside Parks
b) Beneath vs Away from trees

Results: Whitworth Park (Armson et al, 2012)



Results overall (Bowler et al, 2010)

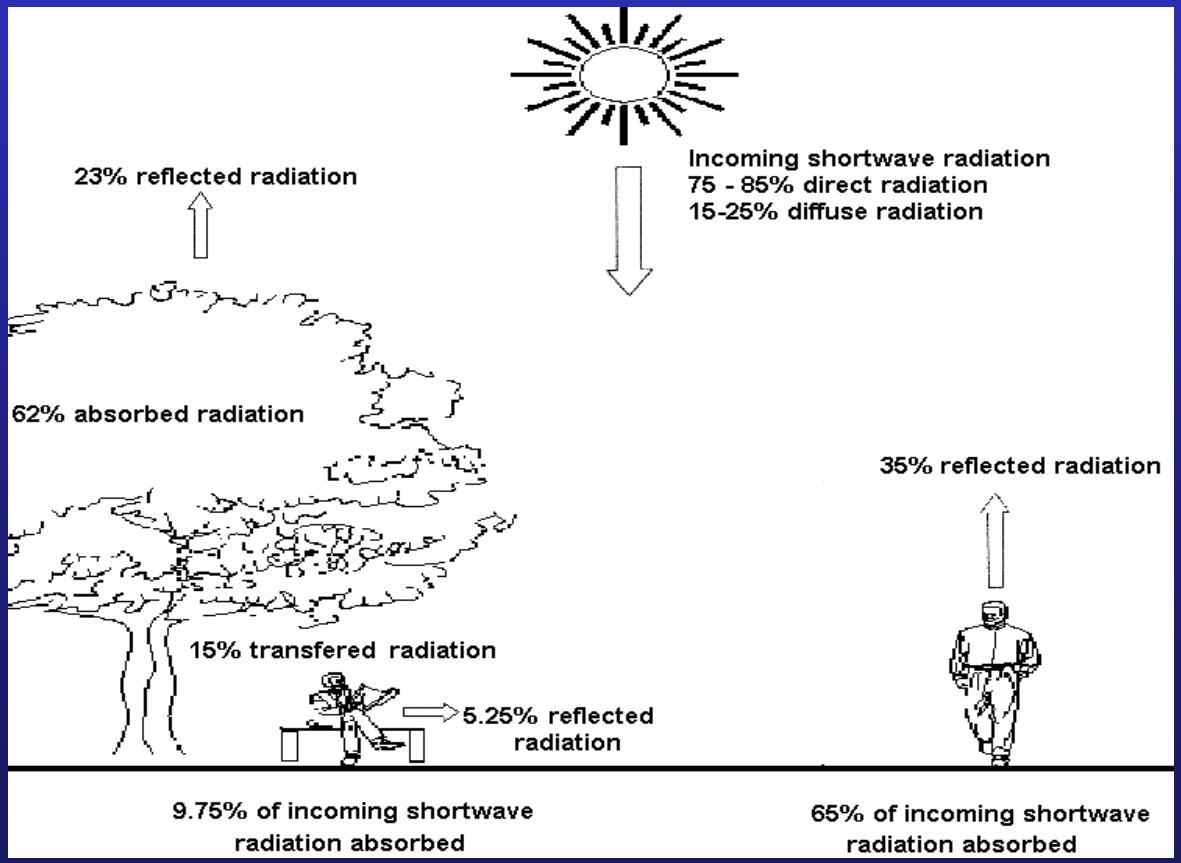
Air temperatures are only slightly lower in parks or tree shade, even on hot days: mean difference ~ 1°C!

Problem: There's no way of relating this to the overall urban heat island!

Quantifying the Cooling Effect of Trees

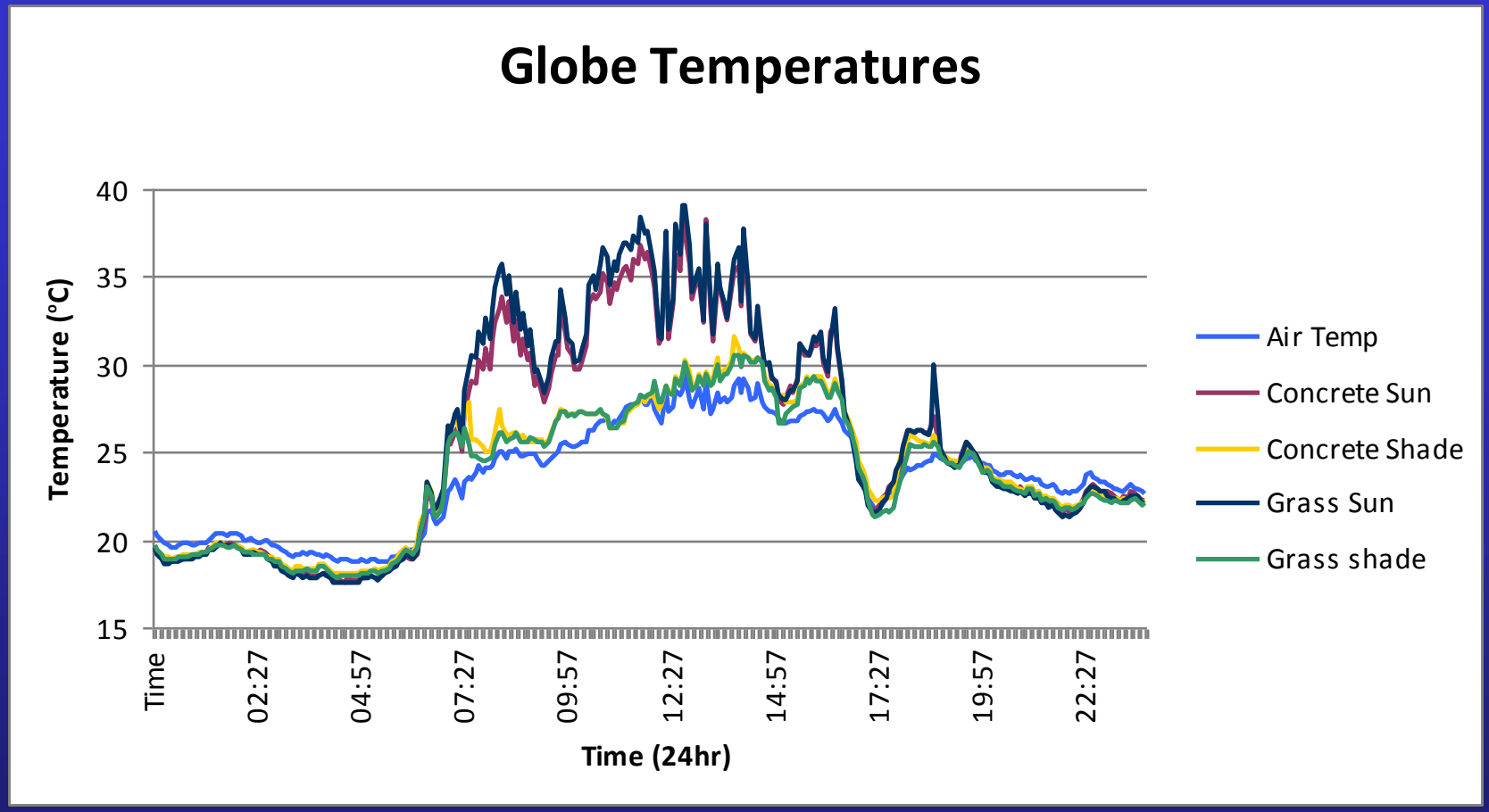
Approach 2: Measuring Radiant Temperatures

Trees act like cool parasols, providing shade to people and so directly cooling them.



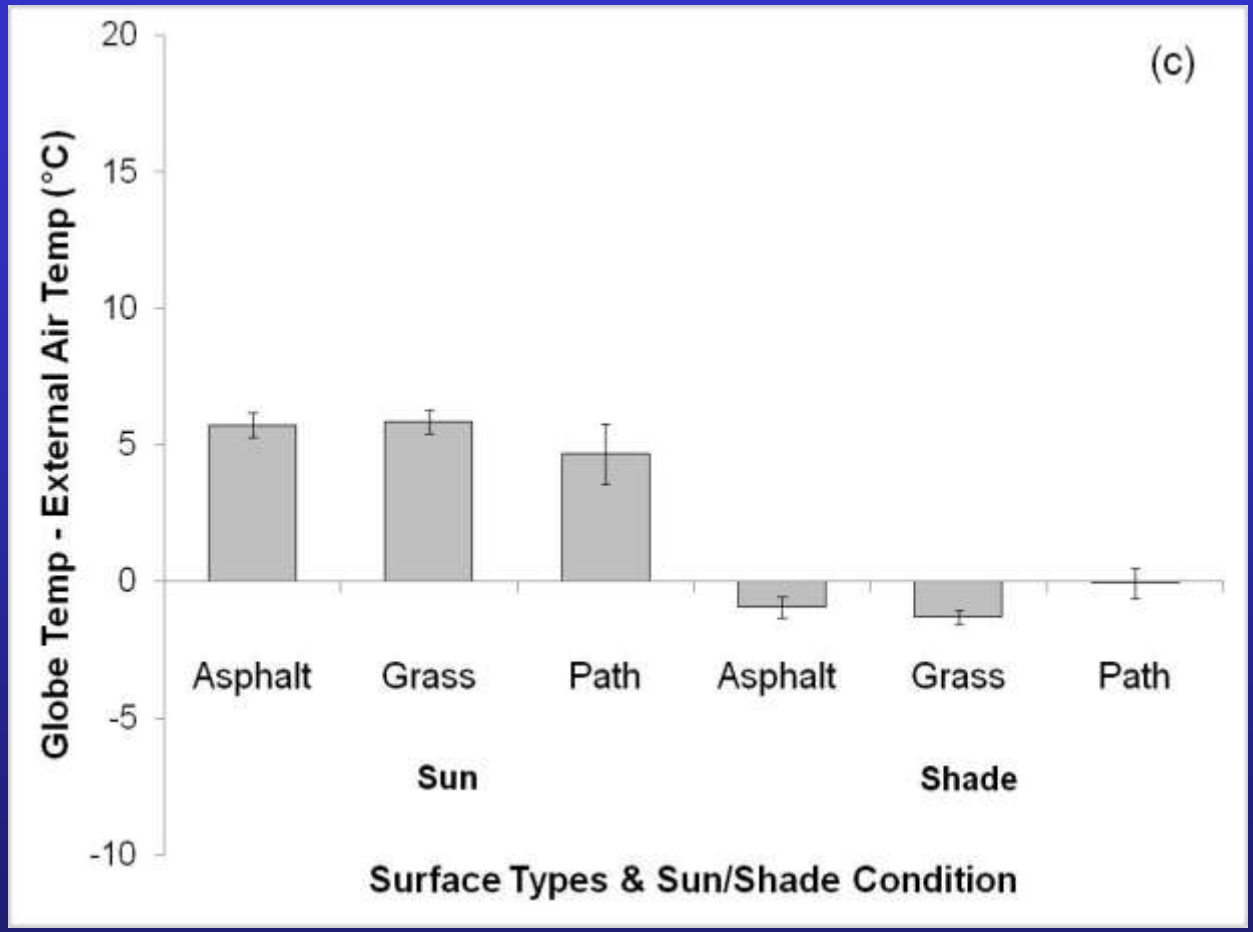
We used globe thermometers to measure the radiant temperature (how hot you actually feel) in sun and tree shade.

Results: Permanent Tree Shade



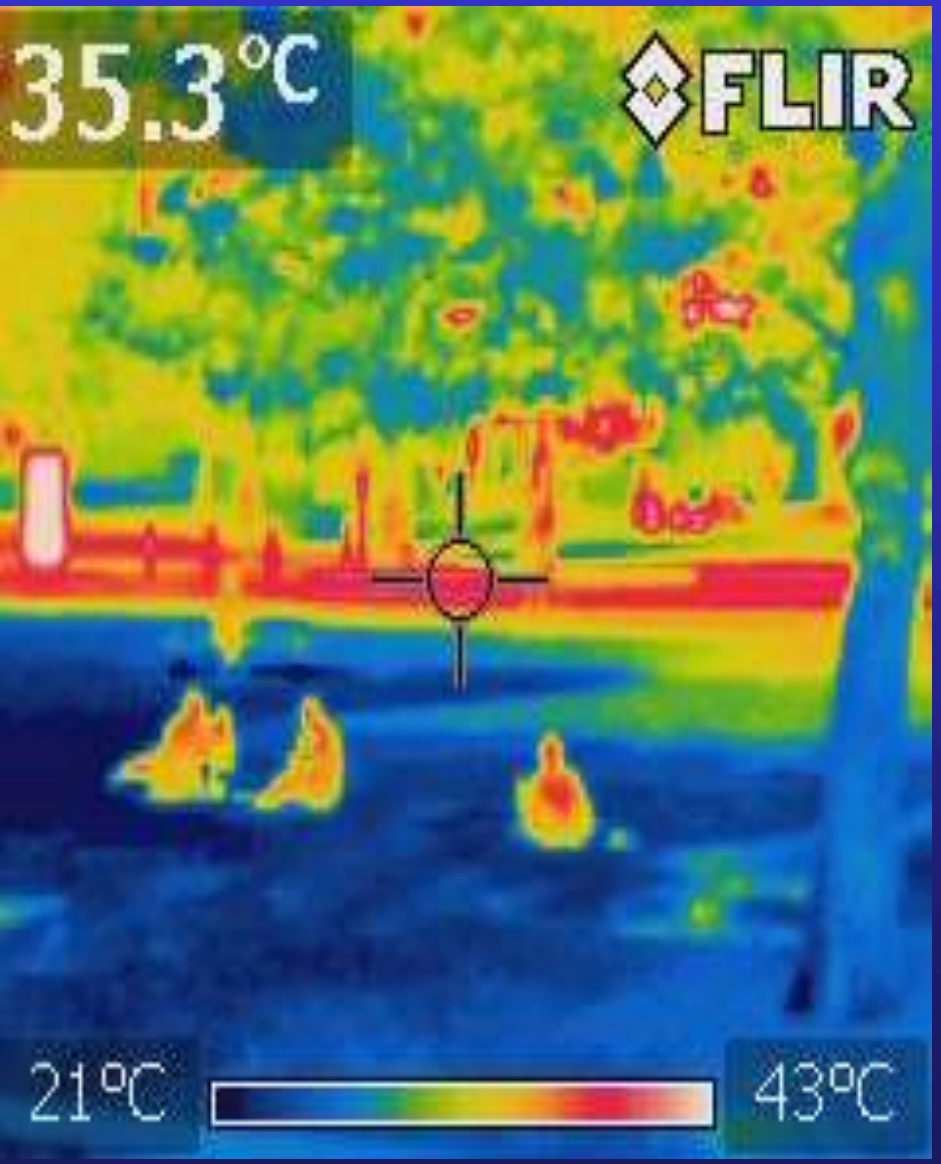
- Tree shading reduced globe temperatures on hot sunny days

Results: Effect of Park Trees



- Tree shading reduced maximum globe temperatures by 5-7ºC to close to air temperature.
- Surface cover had little effect on globe temperature.

This explains the distribution of park-goers



And conference goers!

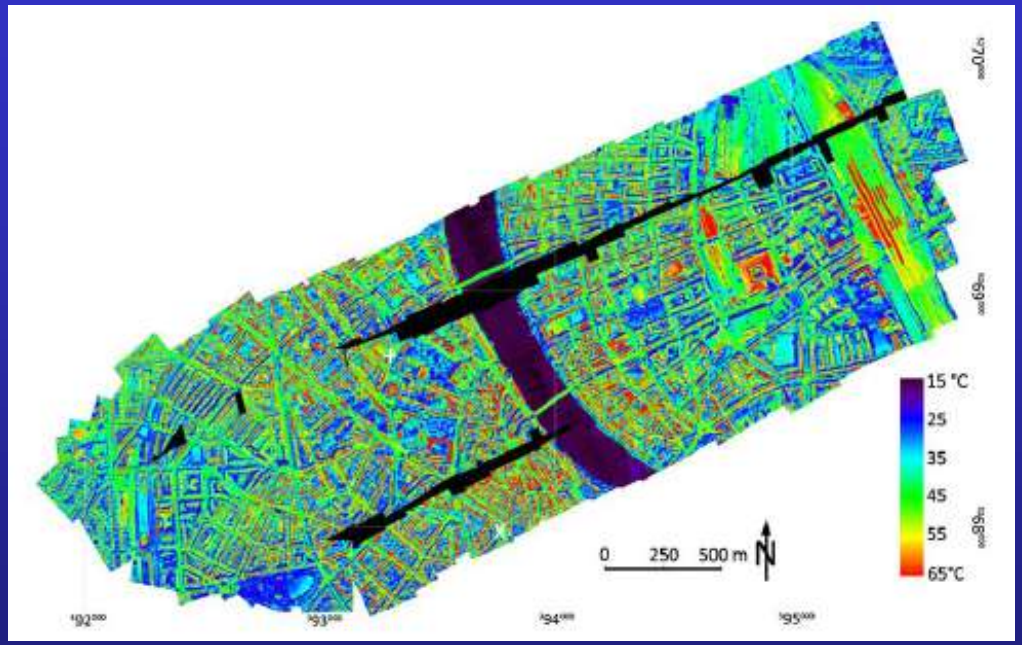
Approach 3: Measuring Surface Temperatures

Tree shade and evapotranspiration cool the surface so measuring surface temperatures can help tell you their regional cooling effect.

Therefore many researchers have investigated surface temperatures

a) On Grass vs Concrete
b) On Trees vs Concrete
c) In tree shade vs In full sun

Surface Temperatures in Basle at Midday (Leuzinger et al, 2010) (Using Infra red cameras)



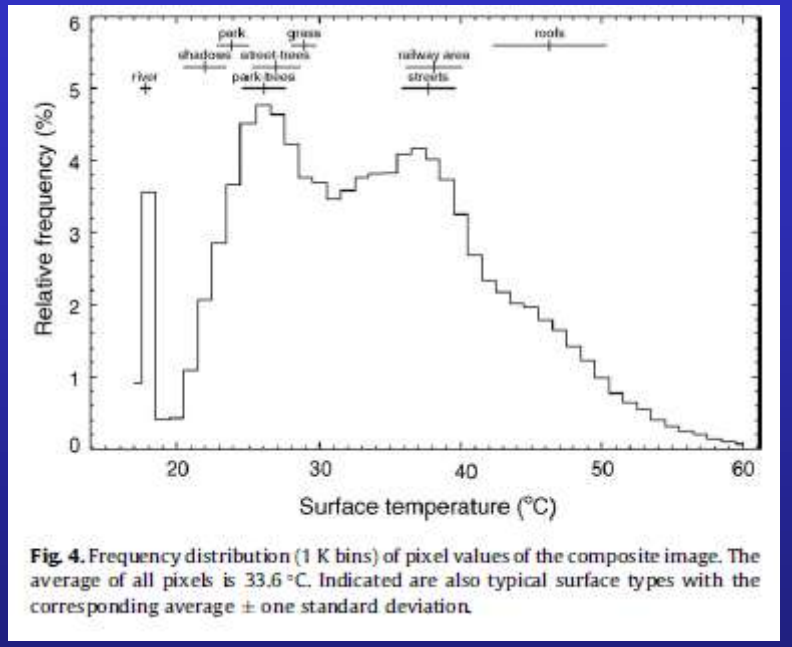
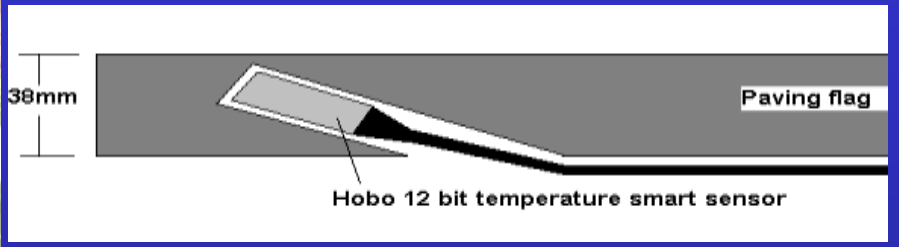


Fig. 4. Frequency distribution (1 K bins) of pixel values of the composite image. The average of all pixels is 33.6 °C. Indicated are also typical surface types with the corresponding average ± one standard deviation.

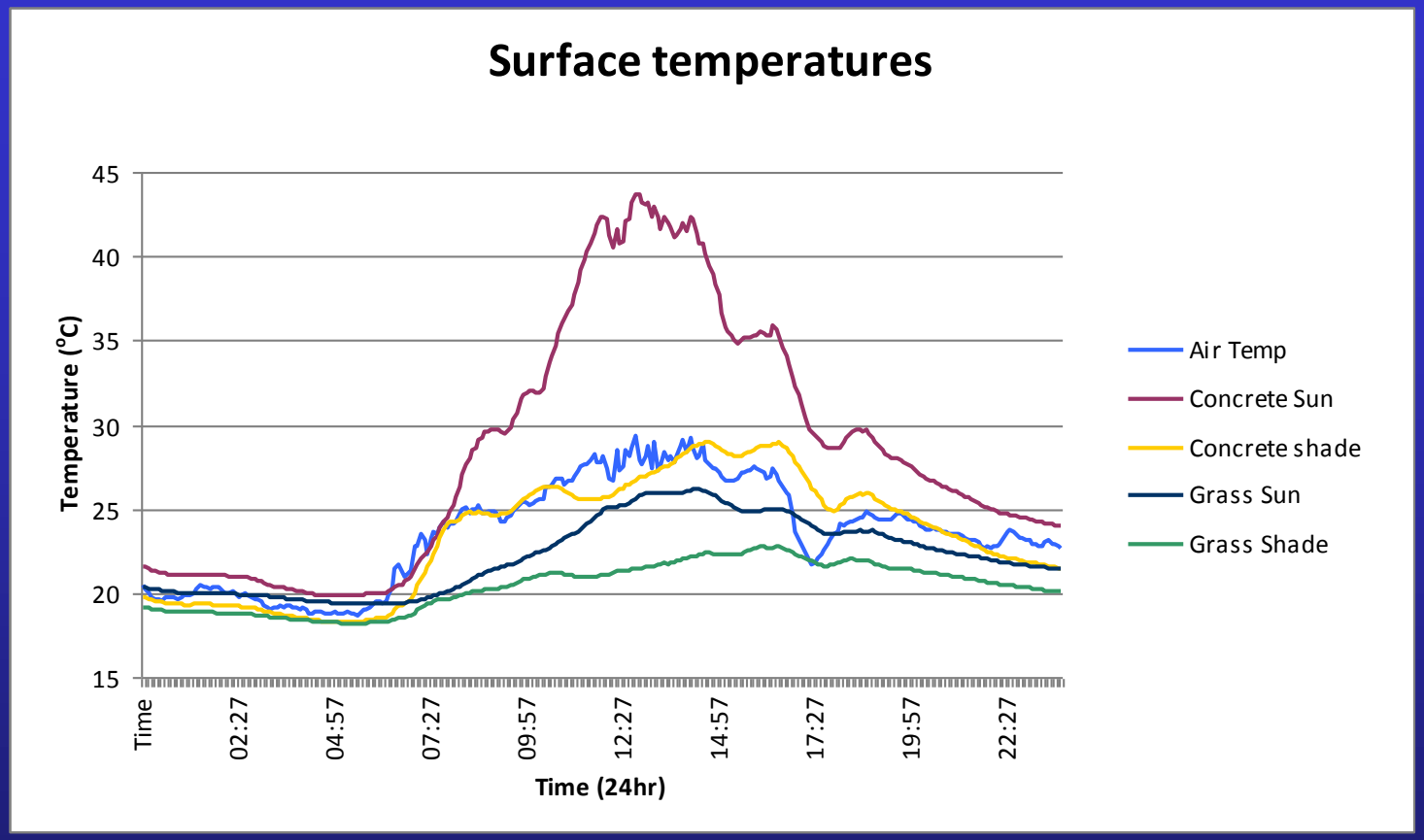
Grass and trees cooled the surface by up to 15-20ºC

Measuring the Effects of Permanent Tree Shading (Armson et al, 2012)



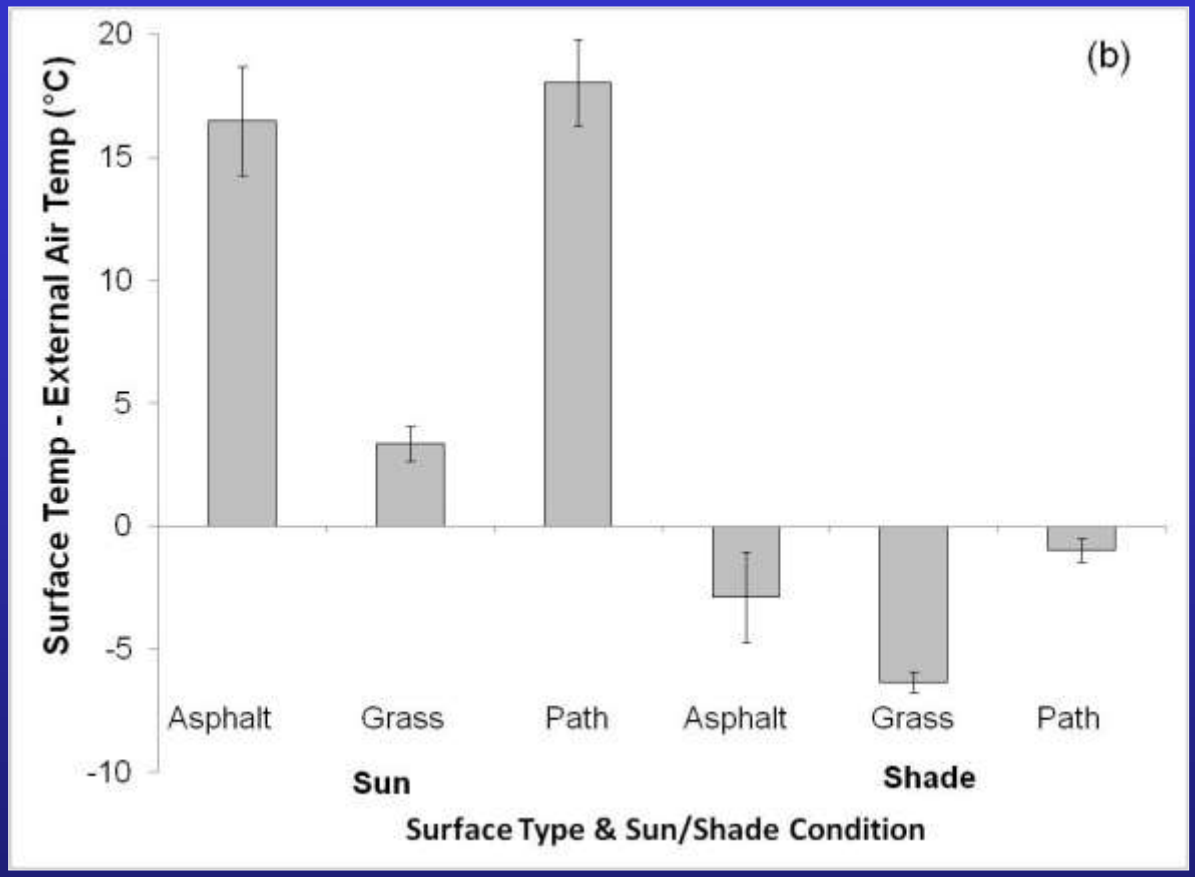
- We compared surface temperatures in grass with those in concrete.
- We compared surface temperatures in the sun with those in the shade of trees.

Results: Surface Temperatures over the day



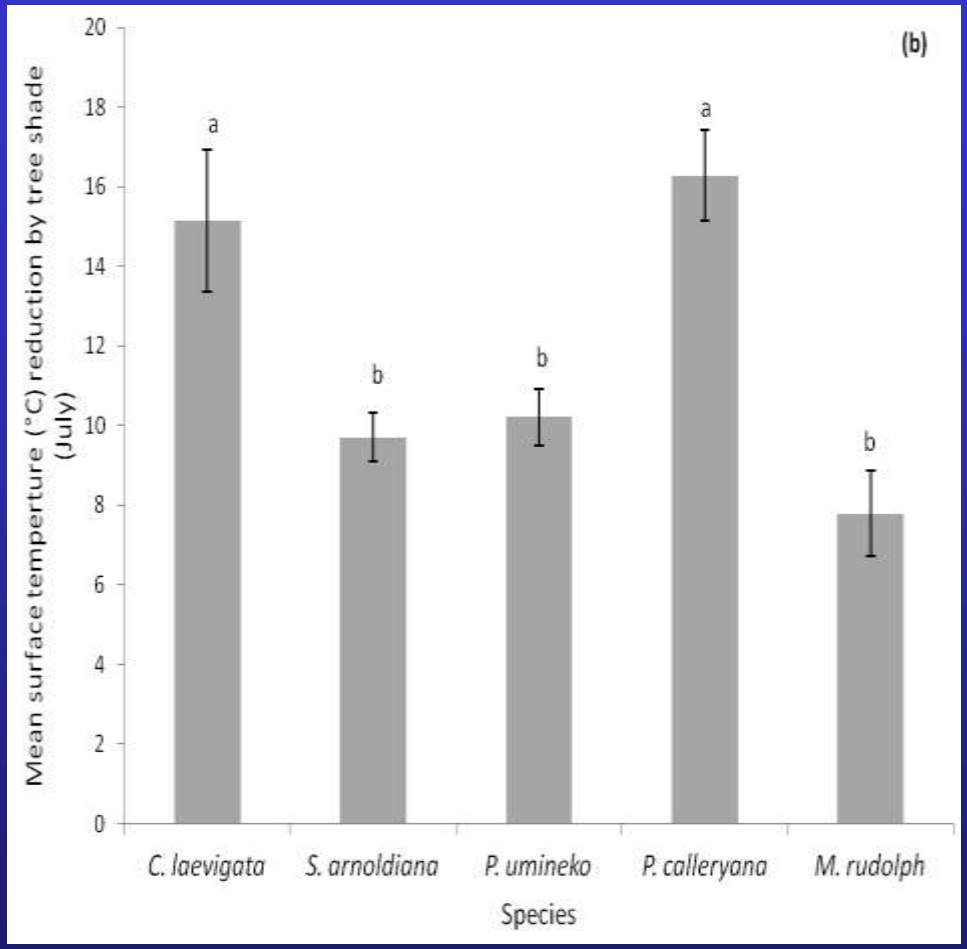
Grass and tree shading reduced surface temperatures during hot sunny days.

Results: Surface Temperatures at Midday



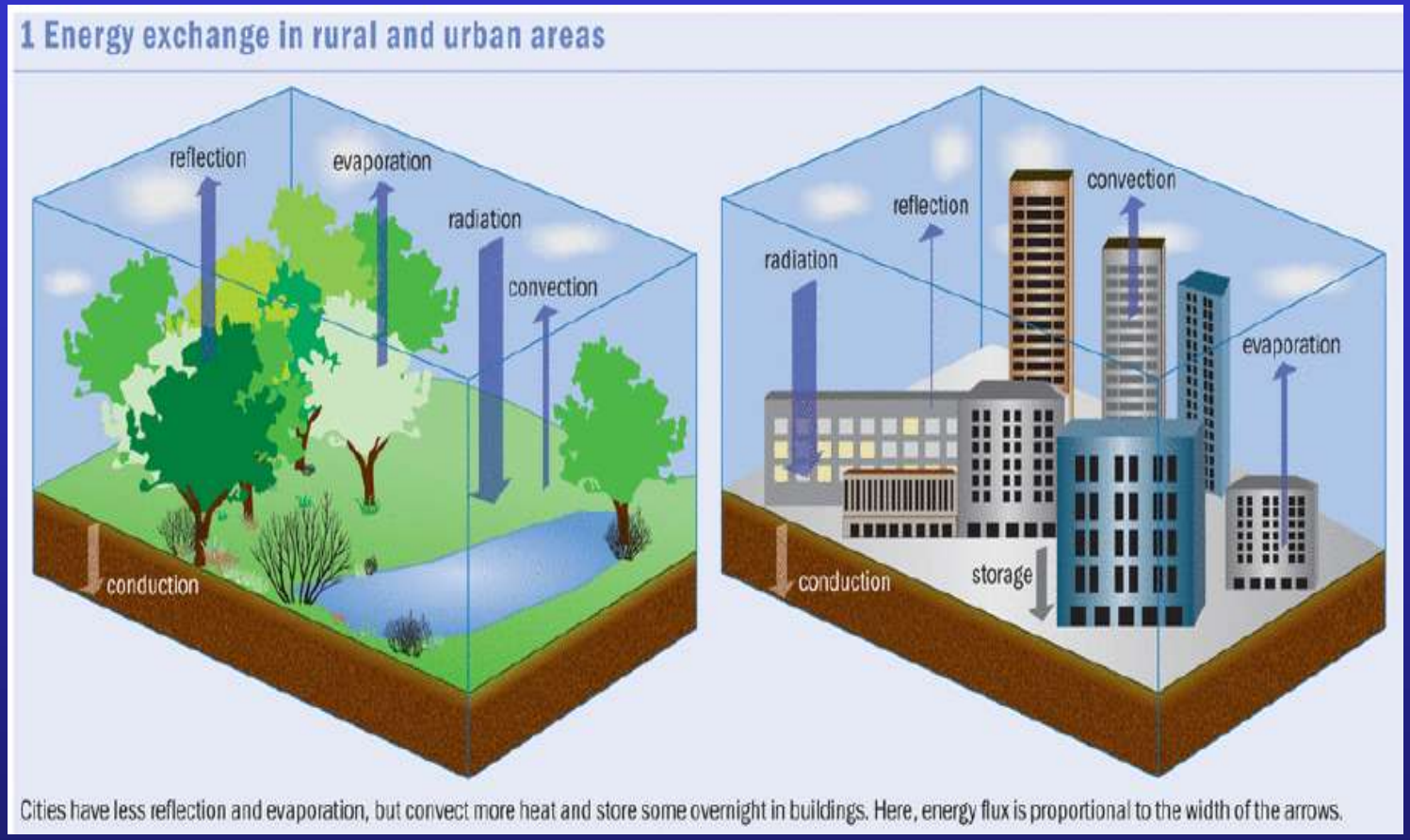
- Grass cooled the surface by 15 to 20ºC
- Tree shading cooled the surface by 15ºC to 20ºC

Results: The effects of small street trees



Street trees with higher leaf area indices provided more surface cooling.

Approach 4: Measuring the Energy Balance



Most cooling is provided by evapotranspiration, so a final approach is to measure water loss from trees

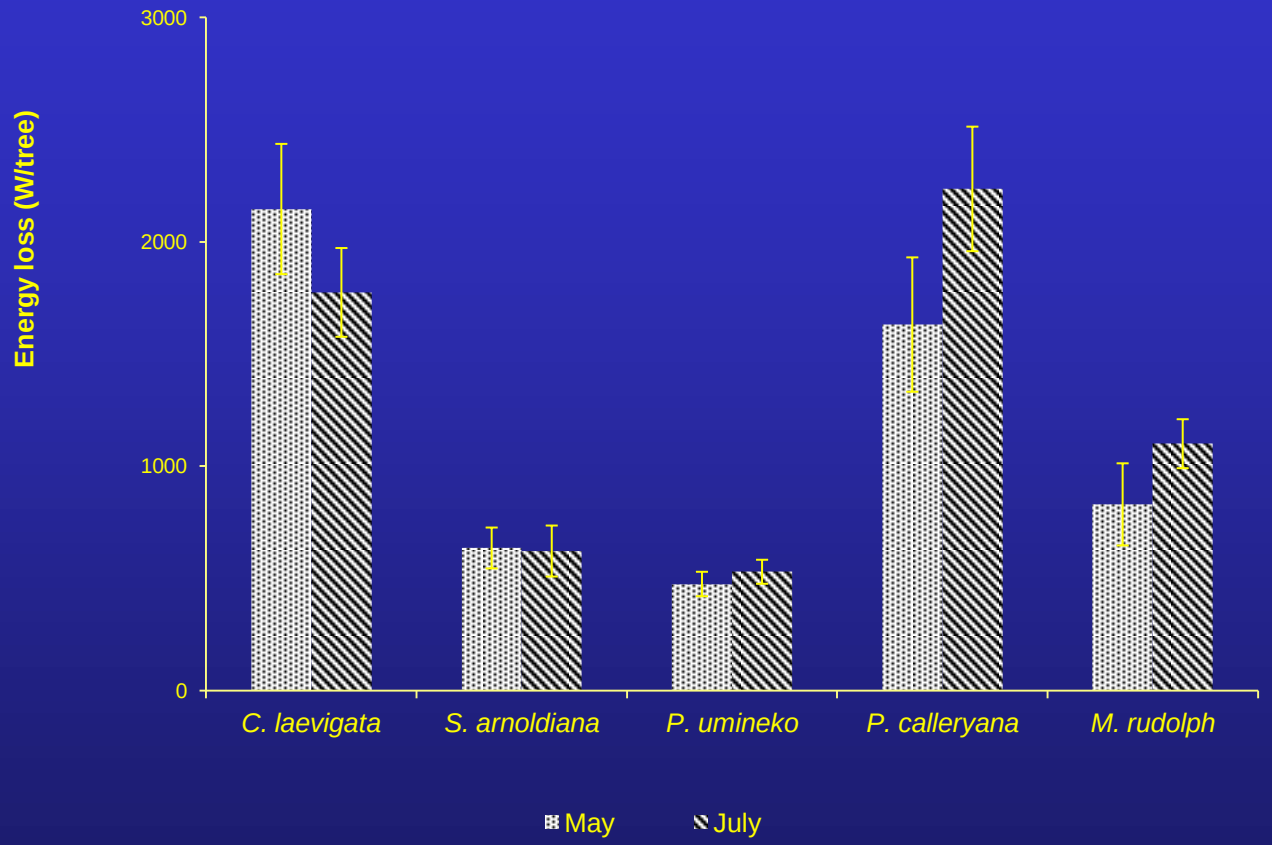
Measuring water loss from trees

Several researchers have investigated water loss using Sap flow meters and porometers

Water loss depends massively on the tree species

Water loss from Actual trees

1) Water loss depends on tree species



Water loss differs by a factor of 4! Trees with higher leaf area index performed better.

Effect of Growing Conditions on the Cooling Benefits of the street tree *Pyrus calleryana* Chanticleer

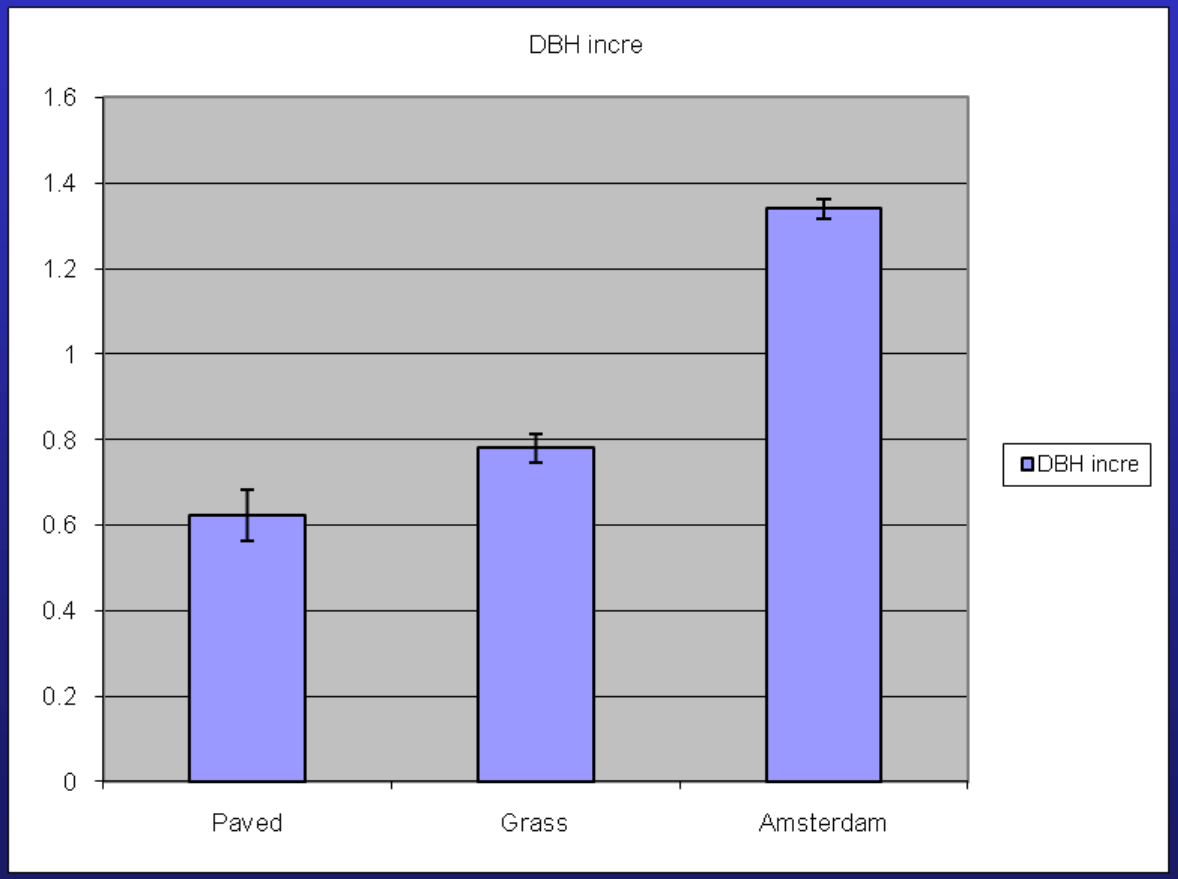
Experiment 1
Three soil conditions were compared

1) Conventional tree pits
2) Grass Verges
3) Pits containing Amsterdam soil

Results

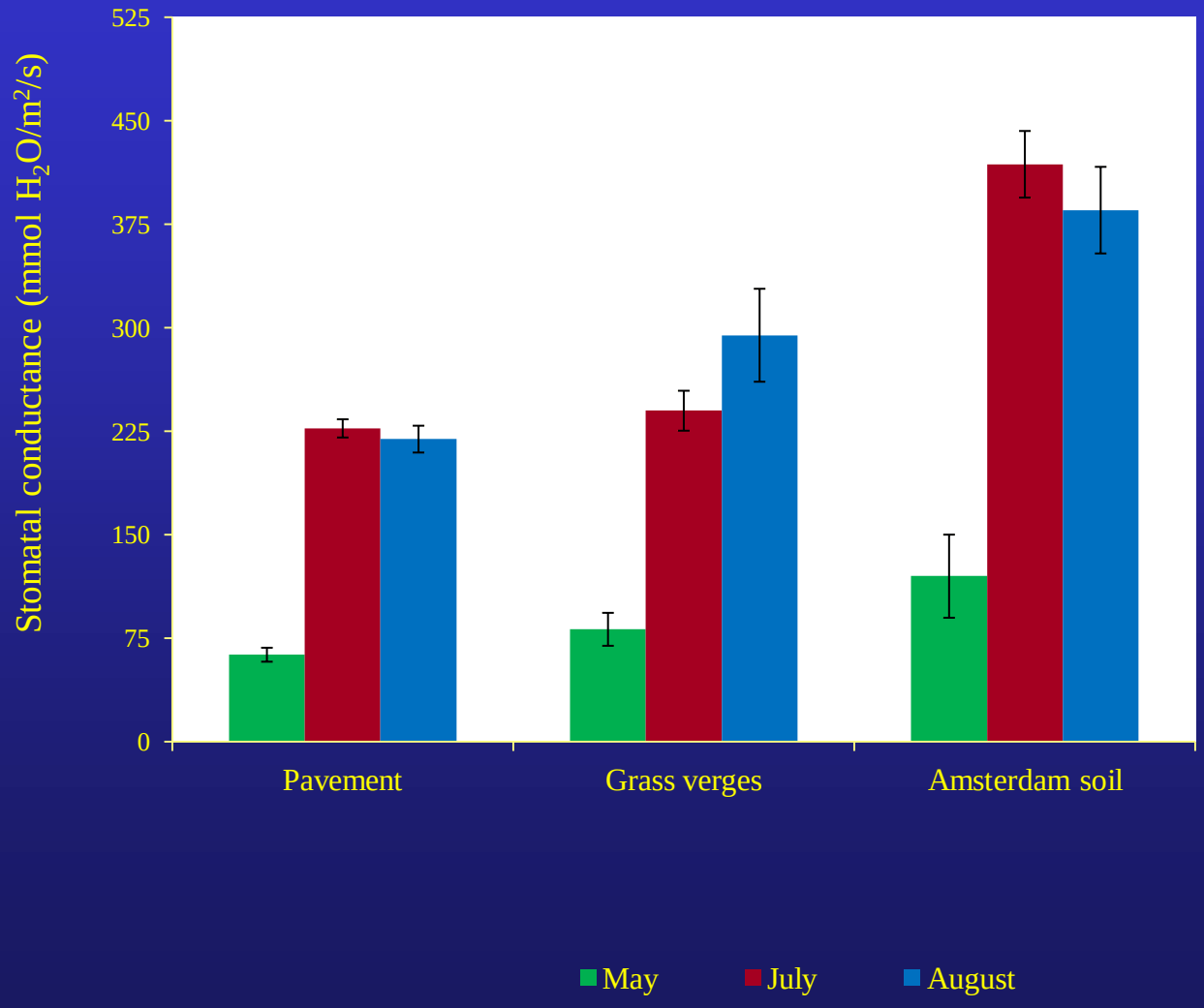
Trees planted in Amsterdam soil had twice the DBH growth

DBH Increment (cm yr^{-1})

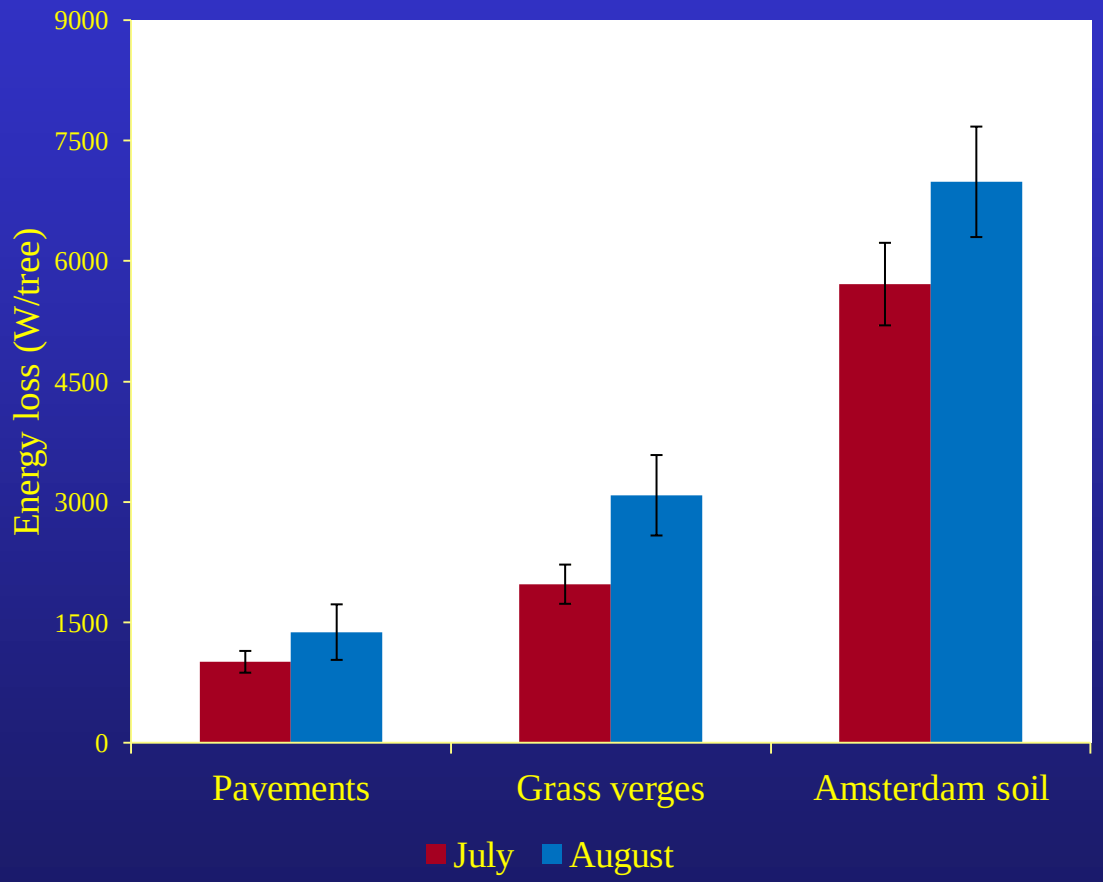


Growth Medium

Their leaves also had twice the stomatal conductance



Consequently trees in Amsterdam Soil provided 5 times the cooling per tree - around 7kW!



Maximum cooling can be over 600 Wm^{-2}

Experiment 2: Effects of pit size and growing media on *Pyrus calleryana* trees

1) Conventional Pit

2) Pit with Urban Soil

3) Large Pit with Root Cells

Results

1) Conventional Pit 2) Pit with Urban Soil 3) Large Pit with Root Cells

Trees in open pits grew twice as fast and produced four times the cooling!

Summary

1) Trees can provide large reductions in runoff, but their effectiveness depends on the planting regime.
2) Tree shade can reduce local air temperature by 2ºC but reduces radiant temperatures by 5-7ºC , improving human comfort.
3) Trees reduce surface temperatures by up to 20ºC, reducing the urban heat island effect.
4) Evapotranspiration from trees releases up to 60% of the incoming energy, reducing the urban heat island effect.
5) Effectiveness depends strongly on species and growth conditions: fast-growing trees with higher leaf area index perform far better than slow-growing ones.

Future Research

1) More research needs to be performed on the hydrological benefits of trees.
2) More research needs to be done investigating the growth and performance of large street trees.
3) Research needs to investigate the relationship between tree growth and cooling ability.
4) Trees need to be included into urban climate models.

Acknowledgements

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