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The London Urban Heat Island – Upwind Vegetation Effects on Local Temperatures

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ABSTRACT: Vegetation has the potential to cool the air in contact with it through evaporation of surface and transpired water. This effect may have significant benefits in reducing the need for mechanical cooling of a building or increase comfort in outdoor spaces. The actual depression in air temperature is variable and uncertain in its degree and reach. Data from a large measurement exercise in London, UK, allowed a detailed analysis of the effect of greenness on the nearby temperatures. 24 measurement sites in urban areas were used to gather hourly air temperature data for two years. Aerial photography was used to analyse the percentage greenness in 16 sectors surrounding each measurement station. These results were used as the basis for calculating an “upwind greenness” value as the wind direction changed. This allowed a dynamic index to be used for calculating the effect of wind direction on temperature in the presence of evaporative cooling and demonstrate the link more effectively. Inner and outer greenness were analysed separately to assess the extent of the cooling effect. This has application to urban planning when deciding on more sustainable development incorporating deliberate greening of an area.

Keywords: heat island, vegetation, transpiration, wind

INTRODUCTION

The presence of plants can reduce temperatures inside and outside buildings in a number of ways, and their effects can be felt locally or at a distance. This paper is concerned with identifying the potential daytime cooling that may be available from the presence of vegetation near to a building's location.

It can be difficult to assess and compare the reported cooling effects from different studies in the literature. This is because vegetation can cool in different ways, notably by shading the ground underneath, and by evapotranspiration, and the effectiveness of these will depend on wind speed, humidity, state of the soil, time of day, and season. Indeed a recent review study concluded that there was insufficient evidence to guide an urban greening programme [1]. However, we consider some examples of measurement and modelling studies to put the present work in perspective.

The cooling effects of wooded areas were examined in Israel at 11 different urban sites, on calm summer days [2]. The bulk of the cooling effect was attributed to shading, which at noon averaged about 2.5°C with an additional 0.5°C of cooling attributed to other effects, presumably evapotranspiration. Cooler air was noticeable up to about 100m from the sites.

Jauregui measured the effects of the large (500 ha) Chapultepec park in Mexico City [3]. This park contains

fountains, artificial lakes, trees, as well as museums and playgrounds. In an early morning transect, at the time of largest temperature contrast, the park was found to be 2-3°C cooler than adjacent areas and the cooling effect extended about 2km (about the width of the park) beyond the park's boundary. The relative openness of the park, would have allowed a higher nocturnal radiative cooling rate compared to the surrounding urban area and would have contributed to the cooling effect.

Relatively cool air over parkland may be advected to adjacent areas and help to cool buildings. Observations by Vu in West Tokyo [4], on a continuously sunny August day, showed that the air temperature in a 0.6km² park at midday, measured at 1.2m height, was more than 2°C lower than that measured in the surrounding commercial and parking areas. It was also determined that the park could reduce the noon air temperature in an adjacent commercial area by up to 1.5°C, over an area of about 0.5km².

Modelling studies can offer an indication of the potential cooling, within their limits of accuracy. Honjo [5] used numerical modelling to estimate the effect of air flowing across a green area and on to an urban area again, in summer conditions in Japan. The green area was 100-400m long and set at 4°C cooler than the upstream and downstream urban areas. The study suggested that air temperature, at a height of 2m, could be reduced by about half the difference in the

urban:green surface temperatures, i.e. 2°C. Moreover, the results suggested that a succession of relatively small green areas is more effective in cooling air than a single large one.

Ng used the software ENVI-met to model the effect of vegetation on air temperatures at pedestrian level in Hong Kong [6]. He concluded that if one third of the urban area were planted with trees, the air temperature would reduce by 1°C.

This selection of studies suggests vegetation will impart a definite and useful cooling effect upon the local air, but that the extent and degree of the effect is very difficult to predict. One aspect of this process is the degree of greenness in the upwind area of a site, which in general will vary in different directions. It is hypothesized that the upwind greenness is more strongly associated with a lowering of temperature than the general greenness of a site.

BACKGROUND

The present study is based on an analysis of air temperature data collected at 24 sites in London, UK, over a two year period. This was part of a wider study measuring hourly simultaneous air temperatures across London using 85 measurement stations to assess the impact of the urban heat island on the cooling load of buildings [7]. See Fig. 1. All air temperatures were measured at 6m height inside radiation shields, generally attached to, but offset from, street lighting columns

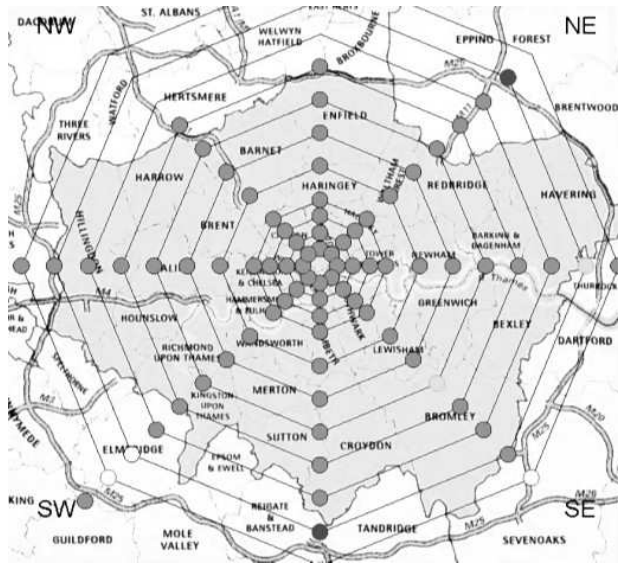


Figure 1: Measurement stations across London for measuring hourly air temperature at 6m height.

Previous analysis of these data has considered the effect of the heat island on cooling demand and how this relates to a concomitant reduction of the heating demand [8, 9]. The balance of these is very much dependent on the internal gains in buildings as well as their geographical position within the urban heat island [10]. Greenness was one of the factors investigated in a regression analysis of the impact of various site parameters on local air temperature [11]. It was found to be associated with a cooler temperature, but was of lesser importance than local surface albedo. In that study local influences were examined up to a 50m radius of any particular site, but a wider potential for affecting microclimate is explored in this paper (up to 500m).

METHOD

Air temperature data from a sub-sample of 24 sites was selected to cover different types of location within the London conurbation. The hourly data used for the analysis were taken from two summer periods (August and September 1999 and July, August and September 2000), a total of 153 days. Daytime data alone were used, when evapotranspiration is active, to reveal the potential impact of vegetation more effectively.

Image analysis

Each of the 24 sites was assessed for its presence of vegetation using aerial images. A literature review suggested that a few hundred metres was a typical limit of influence of a green area, and the area within 500 metres of a site was chosen for assessment. The assessment circle was also divided into sectors to enable analysis by wind direction. An inner circle to 125 m radius, and outer annulus were also defined. This provided for the percentage greenness to be measured in 16 places (8 sectors; inner and outer).

For each site, nine aerial photographs were obtained from the internet (Cities Revealed – images from Geoinformation Systems) and joined together to cover a 1.5km square. Using Golden Software’s Surfer programme, a sector reticule was drawn and this was embedded in the 1.5km image after centring on the measurement site. This was exported as a single JPEG image and then converted to a TIFF image.

Image analysis software, Scion Image, was used to measure the area of all green areas, after scaling. Scion Image could measure only 8-bit colour images, and it was necessary to convert the 24-bit images to 8-bit first. Because a good deal of colour information is lost in the process, the measurement work was done with a 24-bit image loaded in a separate programme and registered with the Scion image window, so that in cases of ambiguity, the clearer picture could be consulted. Area measurement data were transferred directly to Excel from

Scion Image and the 16 sectorial greenness percentages per site were then calculated.

Fig. 2 shows an example of measurement for one site, at Regents Park, central London. Green areas, drawn dashed in black and white, are shown ready for measurement in the NW to N sector.

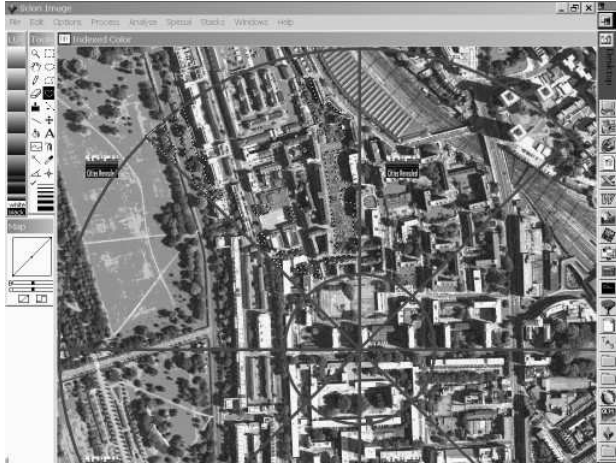


Figure 2: Determining the percentage greenness of each sector at a measurement site. Each sector was divided into an inner and outer section.

Statistical analysis

The percentage values of greenness by 45° sector, at inner (125m) and outer (125-500m) distances were used to produce an upwind greenness value. This was derived as follows:

- The wind direction each hour was rounded to the nearest 45° compass direction.
- The percentage greennesses of the two 45° sectors adjacent to this were averaged to give a mean greenness of the relevant upwind quadrant (90° sector) for one hour.
- The quadrant values for the daytime hours in a particular day were then averaged.
- The resulting mean upwind percentage greenness was then compared to a threshold of 30%, and a greenness index ascribed a value of 1 (less than 30% greenness) or 2 (30% or higher greenness).

This greenness index was computed for each of the 153 days of the dataset for the 24 sites and analysed with the corresponding mean temperature difference (ΔT), i.e. the local heat island intensity, between the site and a rural reference station 18 miles (29 km) west of London.

The assumption here was that land cover downwind of a site is much less relevant, and that stronger associations with ΔT would be found by examining the upwind land cover. Using Statistica software, a factorial

ANOVA was run on ΔT and: Upwind InnerGreen index (a value of 1 or 2) and Upwind OuterGreen index (a values of 1 or 2). A factorial design allows the separate evaluation of, for example, the effect of high outer greenness combined with low inner greenness for a site.

To identify the effect of considering upwind greenness, the data were analysed in two stages. The “site” greenness was used in the ANOVA first. Site greenness used a mean value of all eight sectorial percentage greennesses which was then compared to the 30% threshold and assigned a greenness index of 1 or 2. This was done for the inner and the outer areas separately. A second ANOVA was then run on the upwind version of the data.

RESULTS

Figs. 3 and 4 show the results of the factorial ANOVA of both the site mean greenness and of the upwind greenness.

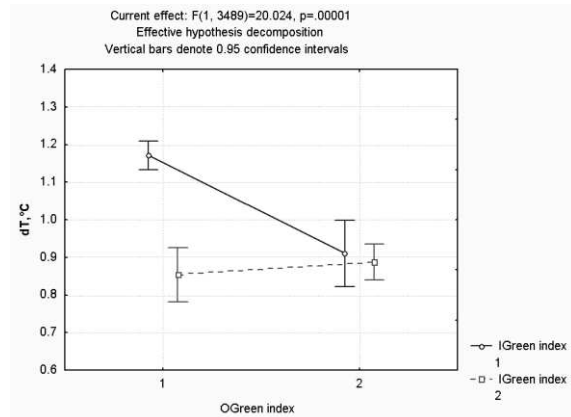


Figure 3: The mean urban heat island intensity of 24 sites grouped according to each site's inner and outer greenness index (daytime).

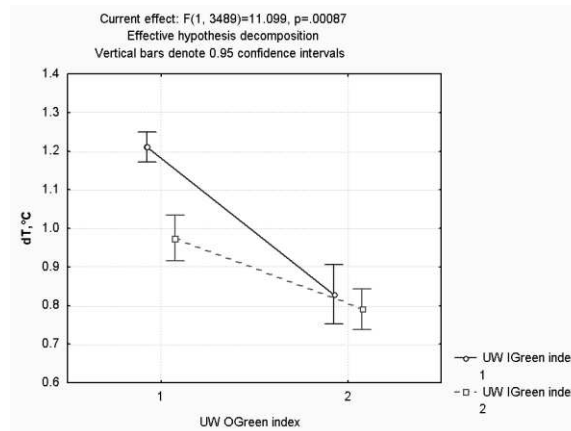


Figure 4: The mean urban heat island intensity of 24 sites grouped according to each site's inner and outer upwind greenness index (daytime).

The ANOVAs shows the interaction between the inner and outer greenness of a site on the mean urban heat island intensity (ΔT) for the grouping. The vertical bars in both figures show the range within which the true means are likely to lie, with a statistical confidence of 95%.

The most obvious result from comparing the two figures is that there is a clearer differentiation of the sites with higher greenness when that is considered in terms of the upwind direction alone. The wider separation of the groups is also associated with a higher degree of confidence in the results as there is no longer an overlap in the confidence intervals of high inner greenness means. In addition, in Fig. 4, all greener groups now become cooler (a lower ΔT) at the higher greenness index.

The main results from looking at site and upwind greenness are:

- **Any** high greenness (inner or outer for the whole site, or inner or outer upwind) is associated with a group of sites that have a lower temperature.
- Sites with high **upwind** inner and outer greenness are cooler by 0.42°C than sites with low upwind inner and outer greenness.
- Sites with high **site** inner and outer greenness are cooler by 0.29°C than sites with low site inner and outer greenness.
- When there is low **inner** greenness (site or upwind), the effect of outer greenness is greater where this is upwind (0.38°C reduction compared to 0.27°C).

The results show that greenness is associated with a lower air temperature. When two areas of green land are in line with the wind direction towards the measurement station there is a maximum reduction of mean temperature (0.42°C) between this group and the group with areas of low green land in line with the wind direction.

When a site has low inner greenness, the effect of outer green land on reducing the temperature is more pronounced when this is in line with the wind direction. This and the other results seem intuitively correct, but the confidence bands shown on the ANOVA figures, which are based on a sample of 24 sites, mean that the distinction between site and upwind, or dynamic percentage greenness is indicative of a likely effect rather than good evidence for it.

DISCUSSION

One of the attractions of greenness for urban planning is the ability of plants to cool the air, which is likely to become more important in many cities with continually increasing concentrations of greenhouse gases. An uncertainty is the degree and spatial extent of the daytime cooling, as well as the reduction in ground radiative cooling at night-time.

The current study has looked at the effects of green areas upwind and in-line with a location. Although the results are promising, greater confidence and detail is needed to be able to contribute to urban planning guidelines. One of the reasons for the comparatively small effect observed when considering upwind rather than general greenness is that both wind direction and wind speed in urban environments can be very variable. The wind data used in this analysis is taken from the regional meteorological station, at Heathrow Airport, up to 25 miles (40 km) from some of the measurement stations.

At low wind speeds, convection currents in urban areas can further complicate the wind regime, and at night-time local circulations of air currents have been observed between urban parkland and the surrounding area [12]. Another characteristic that is likely to affect the spatial influence of green areas is their size. In the analysis of upwind greenness a fixed area of potential influence was used, up to 0.5km away. No attempt was made to distinguish between a sectorial area of, for example, 100% greenness, which was isolated, and one that was part of a much larger parkland area. Similarly the grouping of data using a threshold of 30% greenness may not have drawn a high enough distinction between green areas and non-green areas, and allowed the urban built fraction to have too great a confounding influence.

Nevertheless, the data and results provide some evidence to support the application of planting upwind of more built up areas in order to modify the latter's microclimate. This planting need not necessarily be monolithic, but may beneficially be distributed at a number of small sites upwind and close to urban areas liable to higher temperatures.

CONCLUSION

Long term measurements of air temperature in the conurbation of London have been used to assess whether a site's air temperature is related to the presence of green areas. 24 sites were investigated and using image analysis of aerial photographs the percentage greenness in each of eight 45° sectors was calculated. Further, the inner part of the sector to 125m radius was evaluated separately from the outer part, up to 500m radius.

The analysis found that when the sites were grouped according to their percentage greenness, the group with both high greenness inner and outer sectors, analysed in line with the wind direction, was 0.42°C lower in temperature than the group with low inner and outer greenness. This compared with a reduction of 0.29°C when wind direction was not included in the analysis.

These reductions are quite small, but suggest there is likely to be a benefit in taking wind direction into account when planning green planting to mitigate the effects of urban heat islands and wherever high air temperatures occur.

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