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HOW EFFECTIVE IS 'GREENING' OF URBAN AREAS IN REDUCING HUMAN EXPOSURE TO GROUND LEVEL OZONE CONCENTRATIONS, UV EXPOSURE AND THE 'URBAN HEAT ISLAND EFFECT'?

Systematic Review

BOWLER, D., BUYUNG-ALI, L., KNIGHT, T. AND PULLIN, A.

Centre for Evidence Based Conservation - School of the Environment and Natural Resources - Bangor University – Bangor – Gwynedd - LL57 2BU

Correspondence: d.bowler@bangor.ac.uk
Telephone: +44 (0)1248 382953

Draft protocol published on website: 18 February 2008- Final protocol published on website: 16 May 2008 - Draft review published on website: 08 April 2009 – Final review posted on website: 12 May 2010

Cite as: Bowler, D., Buyung-Ali, L., Knight, T. & Pullin, A.S. 2010. How effective is 'greening' of urban areas in reducing human exposure to ground level ozone concentrations, UV exposure and the 'urban heat island effect'? CEE review 08-004 (SR41). Environmental Evidence: www.environmentalevidence.org/SR41.html.

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Summary

1. Background

Climate change is likely to have direct and indirect impacts on human health. Changes in temperature, ground-level ozone (O_3) and ultra-violet radiation (UV) are recognised public health issues, particularly in urban areas and their effects may be modulated by climate change. 'Urban greening' has been proposed as one possible intervention that may mitigate the human health consequences of these changes.

2. Objectives

This review evaluates the available evidence on whether urban greening interventions, such as tree planting or the creation of parks, affects temperature, ground-level O_3 and its precursors (volatile organic compounds, VOCs, or Nitrogen oxides, NO_x) or UV within the surrounding urban area.

3. Methods

Searches were performed using electronic databases, internet search engines and specialist websites and articles subjected to pre-defined inclusion criteria in a series of filters (title, abstract and full text) to identify the subset relevant for the review. The relevant articles were then grouped according to the type of green site under study (e.g. park or green area, tree, green roof, ground vegetation) and the basic methodology used to collect data. Further information on methodology, study characteristics and results were recorded from each study. Due to the diversity of studies, a narrative synthesis was conducted for most of the literature but a meta-analysis was performed on a subset of studies when appropriate.

4. Main results

In total, 212 relevant articles were found. Most studies address the effects of greening on temperature, with O_3 and UV being less studied.

The effects on temperature were assessed by three different methodologies: ground-level data collection, remote sensing data collection and modelling. The review focused on the 71 studies using ground-level data collection and these mostly suggest that a green site could be cooler than a non-green site. A meta-analysis conducted on park temperatures estimated that an urban park is on average around 1°C cooler than a built-up site in the day. A number of variables were identified that

could affect this relationship including factors of the green sites such as its area and vegetation type and other factors such as time of day or year. However, these studies were mostly site comparisons that sampled relatively small numbers of green sites. We did not find any studies that evaluated the effectiveness of an urban greening programme as part of a climate change adaptation strategy.

Studies on O_3 and greening addressed a number of different questions. Empirical studies investigated the ability of plants to release volatile organic compounds (VOCs) and suggested that some plants may contribute to O_3 production. Larger-scale empirical studies investigated the concentrations of ozone within urban green areas and demonstrated the complexity of interactions between O_3, its precursors and temperature.

Few UV studies were identified and they mostly investigated the ability of trees to provide protection by reducing human exposure.

The review did not identify any studies that investigated the direct effects of urban greening on human exposure to high temperatures, O_3 or UV, or any health-related consequences in the context of these variables. However, some articles were identified which predicted the human 'thermal comfort' of green and non-green environments, based on temperature and humidity measurements.

5. Conclusions

A considerable number of studies were identified that have aimed to assess how land cover including parks, green areas and trees affect temperature and to some extent O_3. These studies suggest that it may be possible to use greening interventions as an adaptation strategy to climate change, however, the evidence is based on observational studies rather than more rigorous experimental examination. Most studies have investigated temperature differences between green and non-green sites within an urban area but the impact of greening on nearby non-green areas is a subject requiring more research. Studies on O_3 indicate that any attempt to use greening to improve air quality would need to consider the biogenic emission of VOCs shown for some species, in order to estimate net air quality benefits. Few studies have been conducted on the effect of greening on UV.

There is insufficient evidence to guide the design of an urban greening programme. Further research is necessary to investigate the importance of the abundance and distribution of vegetation on the effectiveness of urban greening, for instance, the optimal distribution or parks; the difference between planting single versus clumps of trees and the importance of factors that may modify the significance of greening to temperature such as regional climate. Any urban greening programme that is implemented would need to be monitored to continue to test the hypothesis that they can improve urban areas for human health through reducing temperature, UV and ozone concentrations.

1. Background

It is now widely accepted that climate change is occurring because of the accumulation of greenhouse gases in the atmosphere, which has arisen from the combustion of fossil fuels (McMichael *et al*., 2003; IPCC, 2007). Climate change has been predicted to have far-reaching consequences for human health (McMichael *et al*., 2003; Patz *et al*. 2005; IPCC, 2007). The report published in 2008 by the UK Department of Health entitled 'Health Effects of Climate Change in the UK' (Department of Health & Health Protection Agency, 2008) discusses the range of possible affects of climate change on the environment and human health that can be expected in the UK. This systematic review focuses on the empirical evidence-base for using 'urban greening' as an adaptation strategy to increased temperatures, UV radiation levels and O_3 concentrations. Although there are other public health concerns arising from the potential effects of climate change, these were of particular interest to project advisers.

1) *Temperature*: One predicted consequence of climate change is an increase in the intensity and frequency of 'heat waves'. Heat wave events have been linked with various illnesses such as heat stroke (Department of Health, 2008) and have been associated with increased mortality, for instance, in southern Europe in 2003 (Stott *et al*., 2003). Climate change will mean that the UK is also at risk from heat waves (Taha, 1997). It has been predicted that there is a 1 in 40 chance that south-east England will have experienced a severe heat wave by 2012, resulting in 3000 immediate heat-related deaths (Donaldson & Keatinge, 2008). Increased temperatures can be particularly problematic in urban areas, where temperatures already tend to be a few degrees warmer than the surrounding countryside. This phenomenon is termed the 'urban heat island effect' and arises from the conversion of the land cover from vegetation cover to buildings and roads (Taha, 1997; Rosenzweig *et al*., 2006). It is important to emphasise that this is due to urbanisation and not a corollary of climate change. The change in land use with urbanisation leads to greater absorption and retention of heat within urban areas because of differences in the aerodynamic, radiative, thermal, and moisture properties of the urban landscape (Oke & Maxwell, 1975; Oke, 1989). For example, urban materials, such as concrete and asphalt, have different thermal and surface radiative properties to vegetation (Oke 1989; Taha 1997) and a reduction in the amount of visible sky ('sky view factor') arising from an urban layout of buildings and streets affects heat exchange (Holmer *et al*., 2008).

2) *Ozone*: The presence of O_3 in the stratosphere, the second layer of the Earth's atmosphere, is beneficial for human health by intercepting ultra-violet (UV) radiation from the sun. However, exposure to ground-level O_3 can have negative impacts on health, affecting the respiratory system and potentially may lead to chronic disease and in some cases, death. In the EU, around 21,400 premature deaths are linked to ground-level O_3 each year (EEA, 2007). Concentrations of O_3 have increased in recent decades and daily peak concentrations often exceed the current WHO guidelines of 50 parts per billion in many countries (PORG, 1997; Royal Society, 2008). Ozone is a secondary pollutant formed from the reaction of oxides of nitrogen (NO_x) with volatile organic compounds (VOCs), which may be biogenic (BVOC) or anthropogenic (AVOC), in the presence of sunlight (PORG, 1997). In countries with controls on pollution emissions, these precursors are predicted to decline however, predicting future changes in O_3 is more complex (Royal Society, 2008; Anderson *et al.*, 2008). Climate change is likely to impact on ground-level O_3 as the chemistry of O_3 production is sensitive to the meteorological conditions. For instance, high temperatures have been linked with high O_3 episodes (Johnson *et al.*, 2005; Lee *et al.*, 2006). However, the chemistry of ozone is complex and also depends on ratios of its precursor compounds, which can vary across an urban landscape, for instance, with vehicle emissions.

3) *Ultra-violet radiation*: Exposure to UV, particularly UVB, has a number of impacts on human health including an increased risk of basal cell carcinoma and melanoma (de Gruijl, 1999). UV levels have increased in recent history with the depletion of the 'ozone layer' however since the international ban of O_3-depleting chlorofluorocarbons, the 'ozone layer' has shown reduced thinning (Newchurch *et al.*, 2003). Climate change may affect exposure to UV through changes in cloud cover and human behaviour and it has been predicted that the incidence of skin cancers will increase (Diffey, 2004; Department of Health & Health Protection Agency, 2008).

Public health strategies are needed to allow adaptation to the predicted effects of climate change on the environment. One strategy that has been proposed is to 'green' urban areas, essentially by increasing the abundance and cover of vegetation (Rosenzweig, *et al.*, 2006; Handley & Carter, 2006; Gill *et al.*, 2007; Health Protection Agency, 2008). Greening of the urban environment may be incorporated in a variety of ways including the creation of parks, tree planting along streets and green roofs. The background for this review is to investigate the ability of greening to allow local adaptation to climate change within a particular urban area. Theoretical studies that use mathematical models or simulations to explore the consequences of greening interventions based on specific assumptions on material thermal properties clearly make important contributions to understanding the potential of greening to provide adaptation. This work has highlighted the potential importance of additional factors which may modify the effects of urban greening such as the height-to-width ratio of street canyons (Terjung and O'Rourke, 1981; Shashua-Bar et al. 2006; Ali-Toudert and Mayer, 2007 Alexandri and Jones, 2008). However, in this systematic review, we are interested in any relevant empirical evidence and take a broad approach by comparing observed differences in temperature, O_3 and UV between green and non-green areas.

1) *Greening and temperature*: Urban greening may affect temperatures through a number of processes (Oke, 1989). Evapotranspiration refers to the loss of water from a plant into the atmosphere as a vapour; this process can cool the air by using thermal energy (Grimmond & Oke 1991). In addition, shading from trees can act to cool the atmosphere below by simply intercepting solar radiation. Vegetation and the presence of open green spaces can also change the surface roughness of the landscape, which may affect air movements and therefore, in turn, local temperatures (Bonan, 1997).

2) Greening and Ozone: Vegetation can affect air quality a number of different ways. Plants may remove pollutants from the atmosphere by the interception and absorption of pollutants via the leaf surface and the leaf stomata (Smith *et al*., 2000). However, some species may also emit ozone precursors such as BVOCs (Peñuelas & Llusià, 2003). In addition, the effects of greening on temperature can also impact on O_3 formation due to the temperature sensitivity of the chemical reactions (PORG, 1997).

3) Greening and UV: Urban greening, particularly trees, may affect human exposure to UV by the interception or reflection of radiation (Heisler & Grant, 1997).

2. Objectives

To evaluate the effectiveness of 'greening' urban areas in reducing human exposure to ground-level O_3 concentrations, UV exposure and the 'urban heat island effect'.

Subject	Intervention	Comparator	Outcome
Temperature, UV, O_3 measured in an urban area with greening	Green site e.g. park, garden, tree, green roof, ground vegetation etc...	Presence vs absence Creation/enhancement vs no creation/enhancement	Quantitative measurements of any of the subjects

3. Methods

3.1 Question formulation

The review question was proposed by Natural England (a UK Government organisation) and reflects some of the findings of the recent UK Department of Health report on the health effects of climate change in the UK (Department of Health & Health Protection Agency, 2008). Stakeholders from various organisations (Appendix A) and subject experts acting as peer-reviewers were invited to comment on the proposed question and review protocol following the normal CEE consultation process.

3.2 Search strategy

3.2.1. Databases

Searching for relevant research data was conducted using a range of databases of different disciplines (environmental, ecological, public health) and document types (peer-reviewed, theses, grey literature) to ensure a comprehensive and, as much as possible, unbiased sample of the relevant literature was obtained. In each case, no time, or document type restrictions were applied. The following databases were used: Medline, Science and Social Science Citation Index , ISI Proceedings, Geobase, Environmental Sciences and Pollution Management sub-files (CSA), Science Direct, CAB, Directory of Open Access Journals, Copac, Index to Theses Online, Knowledge Network for Biocomplexity and National Library for Public Health.

3.2.2. Search terms

In each database, combinations of the following environment and climate change search terms, using wild card terms when appropriate, were applied:

Urban greening words: Urban and each of the following: green; vegetation; tree; open space; park or parks; wood; forest or garden

Outcome-related words: Climate; “Climate change”; “Heat island”; Temperature; Ultraviolet/UV; Ozone/O_3; “Heat wave” / Heatwave; “Volatile organic compounds”/VOC; “Nitrogen oxide”/NOx/NO2

For instance, the search string for Web of Science was: (urban AND (green* OR vegetat* OR tree* OR "open space*" OR park OR parks OR wood* OR forest* OR garden*) AND (climate OR "climate change" OR "heat island*" OR temperature* OR ultraviolet OR "UV" OR ozone OR "O3" OR "heat wave*" OR "heatwave*" OR "volatile organic compounds" OR "VOC*" OR "nitrogen oxide*" OR "NOx" OR "NO2"))

3.2.3. Web sites

Combinations of the above search terms were also used to search the internet using different search engines (www.dogpile.com; www.google.com; www.scirus.com). The first 50 hits from each search were checked for relevance, as a compromise between the amount of time spent searching and the efficiency of retrieval of relevant articles. Websites of specialist organisations were also searched (listed in Appendix B).

3.3 Study inclusion criteria

For an article captured by our search to be relevant for the review, it was required to meet all the following criteria i.e. to include a relevant subject, intervention, outcome and comparator as specified below:

Relevant subjects: Any one of temperature, UV, ground-level O_3 or its main precursors: NOx and VOCs in an urban area in any geographic location.

We were particularly interested in studies that investigated human exposures to these variables or health-related outcomes in an environmental context of changes in these variables in an urban greening situation. However, studies were included whether or not they linked these variables to public health.

Types of intervention: Creation, enhancement or presence of green spaces in urban areas**,** or the creation or enhancement of different types of urban greening

Enhancement of green spaces refers to any interventions that have changed the management of existing green spaces to increase the abundance of vegetation or area covered (e.g. additional planting). ‘Green spaces’ include any form of semi-natural environment (e.g. parks; green roofs) or plant species (e.g. trees) in urban areas. Urban areas include any town or city including suburbs; generally following the authors' definition of whether or not an area was urban.

Types of outcome: Quantitative measurements of the relevant subjects: temperature, UV and ground-level O_3 or its precursors, or changes in human exposures to these variables/recorded health outcomes.

Examples of comparators:

In order to evaluate the effectiveness of urban greening, we include studies which make one of the following types of comparisons:

- The presence of green space versus the absence of green space
- Creation versus no creation of green spaces
- Enhancement versus no enhancement of green spaces
- Changes in recorded outcomes before and after creation or enhancement of green space
- One type of urban greening versus a different type of urban greening

References captured from computerised databases were imported into an Endnote library and duplicates were removed. The above inclusion criteria were applied to each article in turn in order to identify the most relevant articles from those captured by the search. In the first instance, the inclusion criteria were applied to title only in order to efficiently remove clearly irrelevant citations. Articles remaining were then further filtered by viewing abstracts and then full text, to reach the final list of relevant articles. As web searches retrieved fewer documents and these could not be easily imported into Endnote, they were filtered initially on their title and abstract (or introduction section if an abstract was not available) and those relevant were recorded within an Excel spreadsheet; inclusion criteria were then applied again to the full text.

Title inclusion was conducted by one reviewer (LBA). At the start of the abstract inclusion stage, reviewer bias was assessed by Kappa analysis; two reviewers (LBA and DB) applied the inclusion criteria to 25% of the articles (n=213) and the Kappa statistic was calculated to measure the level of agreement between reviewers. Kappa was calculated to be 0.57 (95% C.I: 0.46, 0.68), which indicated 'moderate' agreement (Landis and Koch, 1977). This was followed by discussion of the discrepancies in inclusion decisions in order to strengthen the consistency in interpretation of relevance for the remaining articles.

3.4 Study critical appraisal

Critical appraisal was undertaken after full text inclusion of articles. A standard approach to critical appraisal in a systematic review would initially involve categorising the study design (e.g. randomized controlled trial, controlled trial or observation study with appropriate control). In this review, most of the relevant empirical studies followed a similar basic design: an observational study involving a site comparison between green and non-green area(s) within an urban area. To assess the quality of these studies, we recorded details of the sampling of the measured outcome (number of days measurements were taken, number of different green and non-green sites measured), which affect the reliability and generality of the study findings. Articles only using models or using remote sensing data collection have not been formally appraised.

3.5 Article grouping and data extraction

To enable comparison between similar sorts of studies, articles were firstly grouped by the outcome they measured (temperature, UV, O_3) and within each of these outcomes, articles were then grouped by their methodological approach (ground-level empirical data collection, modelling and, in the case of temperature, remote sensing data collection).

For each group of studies, an excel spreadsheet was designed which specified the information to be extracted from each study:

1) general information: geographic location and type of urban greening (e.g. green roofs, ground vegetation, trees, parks and green areas, unspecified vegetation cover and ‘other’).

2) methodology (for ground-level data collection): basic study design (experimental/observational), type of comparator, number of green/non-green sites studied, number of days and times of data collection, and any explicit attempt to control confounding variables.

3) results: descriptive information on the results (based on the author’s discussion and interrogation of data presented) and also any potential moderator variables which may affect the impact of greening on temperature, that were identified as important within the results of articles.

3.6 Data synthesis

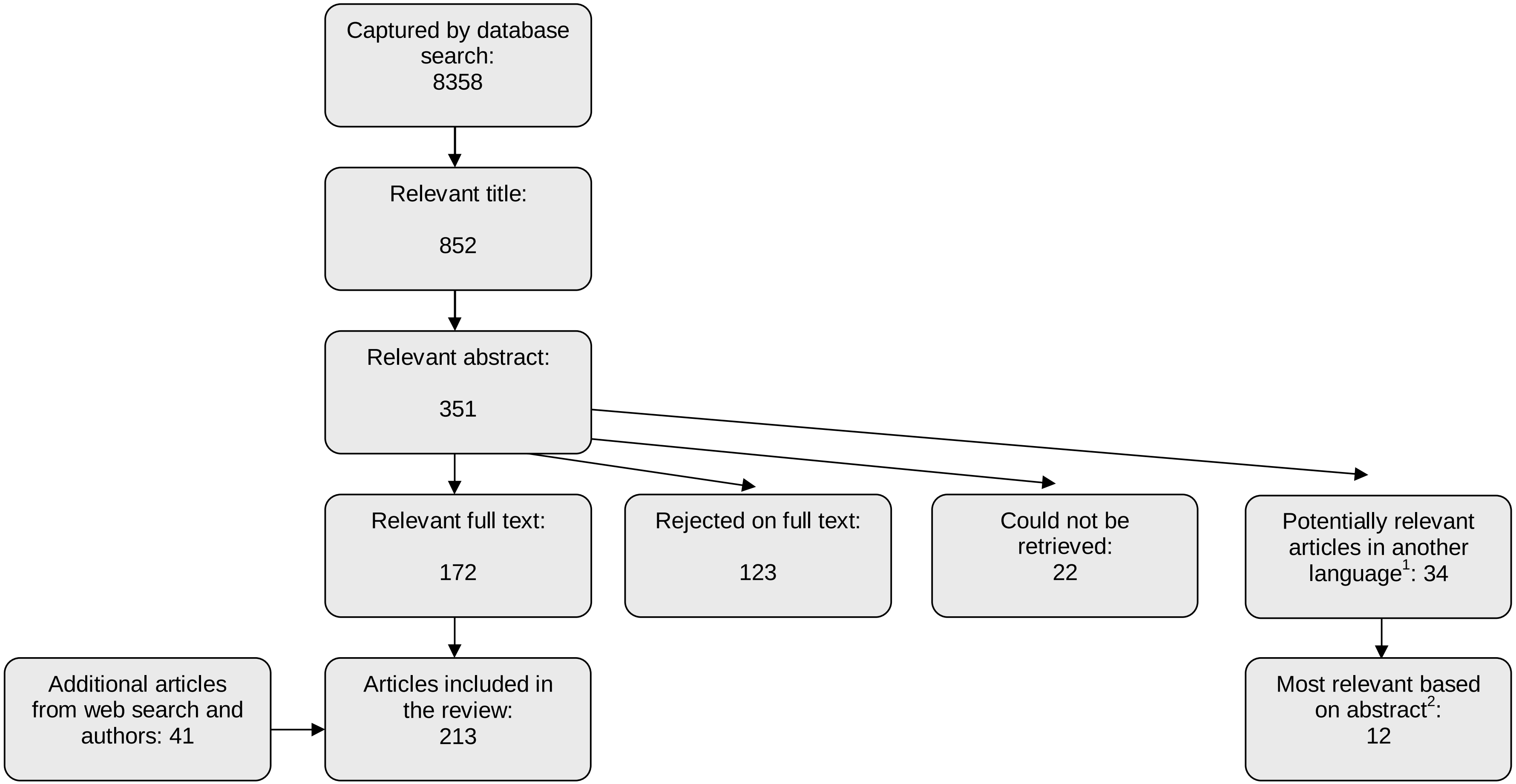
Different methods of synthesis were considered for the review. A quantitative synthesis would involve calculating effect sizes (i.e. the difference between the outcome with the intervention and the outcome in a comparator group without the intervention e.g. control; in this case, with and without greening) from (a subset of) studies in order to produce standardised measures of the impact of greening. Potentially, these could be synthesized into a summary effect size, weighting studies by the inverse of the variance (a measure of the precision) to reach generalized conclusions. For most of the articles included in this review a quantitative synthesis was not deemed suitable for the following reasons:

- Variability in the type of greening studied limited the number of studies that could be synthesized.
- Variability in the presentation of information by authors limits the ability to collect the necessary information for calculation of an effect size. For example, many studies did not present measures of variance nor clearly present sample size.

Consequently we initially undertook a qualitative synthesis with the aim of characterising the methodology of the studies and to summarise and discuss the findings using both authors' discussions of their data and also our interrogation of the data they present. Our assessment and narrative synthesis is focused on studies that investigated a greening intervention in at least one of the following categories: ground vegetation; wall or roof vegetation; trees (single, clusters or woods) and parks or green areas based on the author's description. This is because designing a urban greening programme will require consideration of the evidence for specific greening interventions rather than simply greening *per se*. We also focus on air temperature unless otherwise stated.

However, one sub-group of the studies (those comparing temperature inside and outside parks and gardens) is susceptible to a meta-analysis due to a combination of the number, similarity of studies and the standard of data presentation. In this sub-group, data on means, standard deviations and samples sizes of temperature measurements, or simply raw time series data on temperature, were extracted from each article (usually from a figure using TechDig 2.0 software). If necessary, the authors of these articles have been contacted to request the data that could not be obtained from the article. We used these data to calculate a mean and standard deviation of the temperature difference between the park and non-green area from data collected at the same time. This is then synthesised in a meta-analysis to provide an overall summary effect of the difference (weighted by the inverse variance) and a test of whether the difference varies significantly among different parks (‘heterogeneity’). Further details are provided within the results section and details on the data extraction for each study are presented in Appendix C.

Figure 1 The number of articles passing each stage of the search and inclusion process.



[1]The review has been able to include articles in some other languages (Spanish, Italian and German) but translation has not been conducted for other languages due to time and resource constraints (mostly Chinese but also Taiwanese, Polish, and Bulgarian).
[2]These 12 articles, written in languages not translated, are summarised (based on information in their abstract) in Appendix Q.

4. Results

4.1 Review statistics

The search for literature captured a large number of articles (n=8358; see Fig. 1). Only 10% had relevant titles and 4% were relevant on reading their abstract. Of these 351 articles, 172 were deemed relevant for the review after reading their full text. Only 22 out of the 351 could not be retrieved. An additional 40 articles were obtained from the web or from authors following reprint requests.

4.2 Description of studies

The majority (77%) of articles accepted at full text investigated the effects of urban greening on temperature, usually investigating the urban heat island effect (see Fig. 2). Far fewer studies investigated the effect of greening on O_3 (21%) and UV (2%). In the remainder of the review, we discuss each outcome in separate sections.

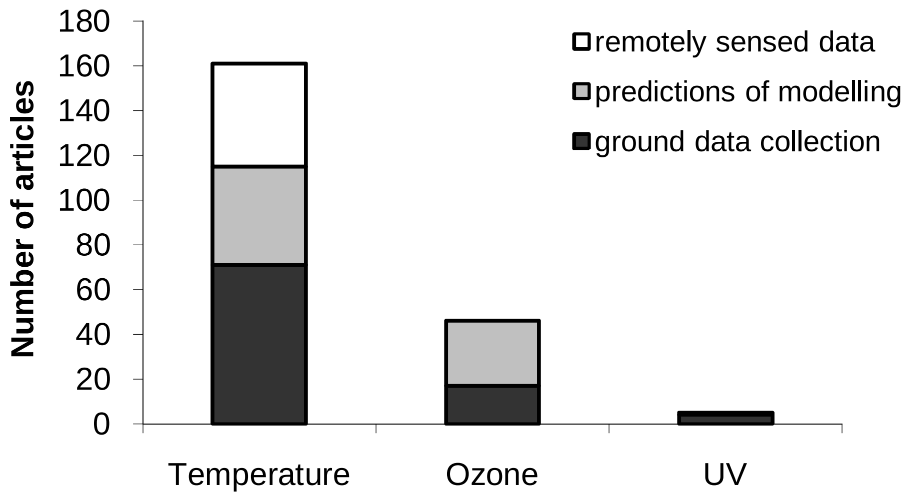


Figure 2 The number of articles that have studied each outcome, split by the methodology used in the article.

4.2.1 Temperature

a) Ground-level data collection

The impact of urban vegetation on temperature has received attention in many different parts of the world (Fig. 3). Most studies were within the temperate zone (77%).

Within each region, the most studied places/countries are:

Europe: UK, Germany and Spain

Asia: Japan, Singapore and China

Americas: North America

Africa: Morocco, Botswana

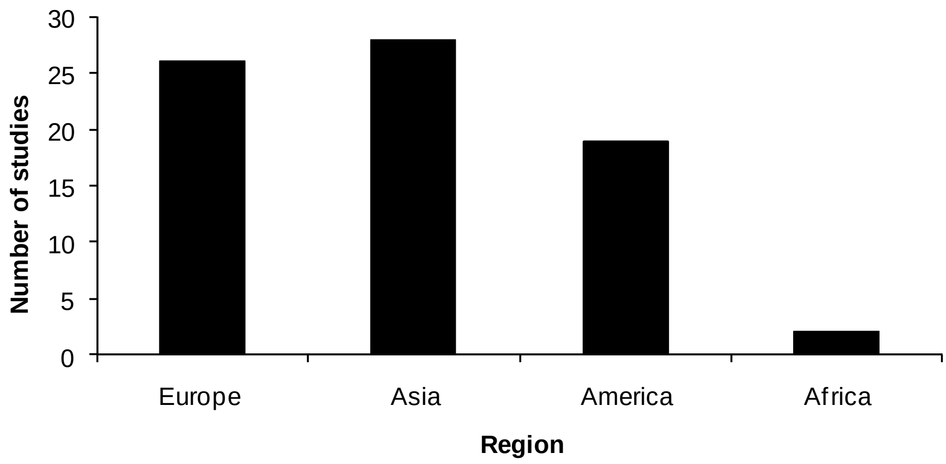


Figure 3 The number of studies which have collected data for a particular region. Note: y-axis is the number of studies rather than articles as some articles presented more than one study from different locations.

Study critical appraisal

We focus on studies measuring one of the following categories: ground vegetation; wall or roof vegetation; trees (single, clusters or woods) and parks or green areas (usually a mixture of ground vegetation and trees). Most studies followed a similar design and involved a site comparison that compared temperatures in existing green sites with those in non green sites within an urban area. However, these studies did vary in the amount of replication such as the number of days and the number of green sites that measurements were taken from, which can affect the reliability and generality of their results. A summary that presents these aspects of the methodology for different greening interventions is presented in Table 1.

We did not identify any studies that investigated the effects of the creation or enhancement of urban greening as part of an urban greening programme. Apart from a few of the experimental studies on green roofs, the majority of studies were observational studies that investigated ‘natural’ variations in greenness within an urban area as opposed to an experimental study in which the green element was controlled by the investigator. This study design means it can be difficult to separate the effects of any confounding variables, such as the urban topography surrounding the area or distance to the industrial centre, which may vary between sites, and also create differences in temperature.

Overall, the effects of parks and trees have received most attention in these observational studies. Many park studies only investigated one park, however, there were a few notable exceptions (up to 61 parks by one study; Chang *et al.*, 2007). Several of the studies on trees only investigated the temperature difference over a single day, or at least only one day was presented in the article. The effects of green roofs, ground vegetation and urban forests have been less studied, with generally a small number of different sites studied. This lack of true replication limits the general conclusions that can be drawn from a single study.

There were a number of other studies that compared sites with varying amounts of greenness, or investigated more heterogeneous greening interventions that could not be reliably categorised into a specific greening intervention.

Table 1 Details on the numbers of studies, total number of green sites and other aspects of their methodology for studies measuring one of the greening intervention categories.

Type of green site	No. of studies[1]	Median no. of green sites in a study	Total no. of green sites[2]	No. of experiments	No. measuring on 1 d only[3]
Green roof	6	1	14	4	0
Ground vegetation	6	1	10	1	1
Single/clusters of trees	9	3	373	0	4
Urban forest	4	1	4	0	0
Parks	23	2	124	0	5

[1]In a few cases one article presented more than one study e.g. more than one city.

[2]The total is the sum of all the green sites measured across all studies identified.

[3]In some of these cases, temperature measurements were taken on more than one day but only one day was presented in the article. As we are only able to draw conclusions based on the information presented, these studies were classed as measuring on only one day.

Quantitative synthesis

Meta-analysis can be a powerful technique to synthesize the results from different studies, allowing the prediction of an average effect and to statistically explore factors generating variation in findings among different studies. In this review, there was considerable diversity in the type of greening under study, times and dates of data collection and presentation of the data in the articles. This diversity has meant that it was not appropriate to conduct meta-analysis of the data from most of the articles.

A meta-analysis was pursued for the largest pool of articles, which investigated the temperature difference inside an urban park compared to an urban area either in the park surroundings or elsewhere in the town or city. Note we do not analyse the 'urban heat island' effect (urban – rural temperature difference) but differences in temperature within an urban area. This analysis was conducted using the subset of studies for which the relevant parameters (on variance and sample size of temperature measurements) could be calculated. We initially focus on any data collected during the day for each park studied (between 06:00 and 20:00; see Appendix C for details on extraction from each study). Using the extracted data, we calculated the effect size of each park, which reflects the average temperature difference between the park and the surrounding/built-up area. Figure 4 displays the effect sizes for each park that has been studied and the overall summary effect, which is a weighted average of these effect sizes. Pooling information across studies indicated that there was significant variation in the "effect size" of the presence of a park ($Q=489.57$; $df=24$; $p< 0.001$). To allow for this variation, we fit a random effects model, which allows for differences in the true effect of the park among studies (and weights each park by the inverse of the sampling variance and between-park variance). This predicted an average temperature reduction of 0.97^{o}C (95%CI = 0.74 to 1.19) in the park, based on this data. To note, similar results are obtained using aggregate data i.e. one average data point for studies measuring more than one park. It is important to emphasise that many of these studies only measured the temperature difference over one or a few days and therefore the generality of this result and the independence of data points within a study is questionable.

We also explored a number of factors that might explain the between-park variation (park size; study type (temperature difference between the park and its surroundings (usually within 500m) versus temperature difference between the park and an urban site elsewhere); data availability in article (all data versus subset of data); control for shade/sun between sites (controlled versus not clear); temperate versus tropical zone studies). The factors that we could investigate to explain heterogeneity were limited by those we could include in our analysis and therefore recognisably other factors could be hypothesized as important. In all cases, there was no evidence that these factors explained variation among studies using meta-regression or sub-group analysis (all p>0.05). There was also no evidence of publication bias in the data (Egger's test: p=0.943).

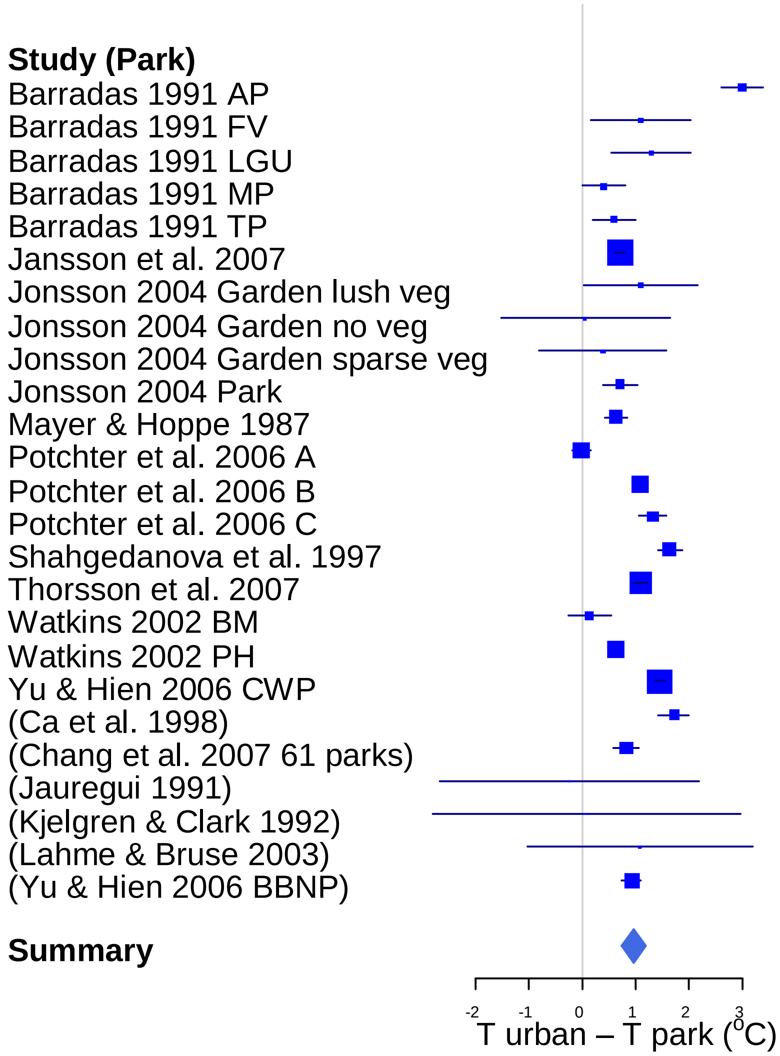


Figure 4 The air temperature difference between a built-up area and a park for each study using data, where available, between 06:00 and 20:00. The overall 'Summary' effect was calculated as a weighted average of all studies (shown as a diamond symbol). The vertical line indicates no temperature difference; positive values indicate that the park was cooler. The size of the symbol reflects the "weight" given to each study and was based on the inverse of the variance so that studies with greater precision in their estimate had greater weight. Horizontal bars display the confidence intervals for each estimate. Studies in brackets are those for which either a different method of calculation was used or only a subset of the relevant data was available in the article, which decreases the potential contribution of these studies to this analysis.

Analysis was also conducted using the subset of these studies containing data collected between 22:00 and 06:00, to investigate night-time differences; see Appendix C for details on extraction from each study. Figure 5 displays the effect sizes for each park that has been studied and the overall summary effect. There was significant variation in the "effect size" of the presence of a park (Q = 271.34; df=11; p< 0.001). A random effects model predicted an average temperature reduction of 1.15 ^{o}C (95%CI = 0.86 to 1.45) in the park, which is marginally (but not significantly as the confidence intervals overlap) greater than the temperature reduction predicted during the day. There was also no evidence of publication bias (Egger's test, p=0.18) and similar results were obtained using average data per study (i.e. averaging over data for more than one park in the same study).

Meta-regression was used to explore the effect of park size on the effect size statistic and initially indicated a positive effect of park size on the estimated cooling effect (Z=3.8, p<0.001) however this was driven by a single outlying data point from one larger park (Jauregui *et al*., 1991) and the effect was insignificant on removal of this study. There was also some indication in sub-group analysis that the cooling estimate was smaller in studies comparing the difference between a park and its surroundings (usually within 500 m from the park boundary) (0.65 ^{o}C; 95% CI = 0.43 to 0.87) than in studies where the temperature of the park was compared with an urban site elsewhere in the town or city (2.26 ^{o}C; 95 %CI = 1.14 to 3.37). There was also some indication that the effect size was greater in parks in the tropical zone (1.606 ^{o}C; 95 %CI = 0.995 to 2.217) compared to those in the temperate zone (0.696 ^{o}C; 95 %CI = 0.442 to 0.95). However, the confidence intervals of the groups overlap when aggregated data (one average effect size per study rather than per park) are analysed, which accounts for the potential non-independence of data from the same study. There was no difference between the estimate from studies where all data were available compared to those for which only a subset of data were presented in the article (p>0.05).

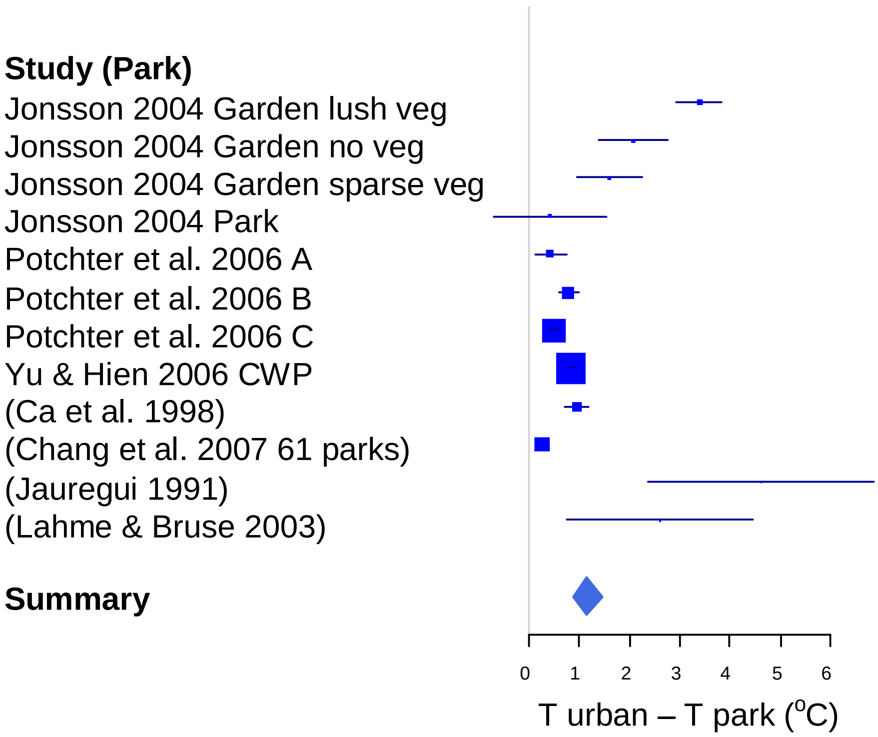


Figure 5 The air temperature difference between a built-up area and a park for each study using data, where available, between 22:00 and 06:00. The overall 'Summary' effect was calculated as a weighted average of all studies (shown as a diamond symbol). The vertical line indicates no temperature difference; positive values indicate that the park was cooler. The size of the symbol reflects the "weight" given to each study and was based on the inverse of the variance so that studies with greater precision in their estimate had greater weight. Horizontal bars display the confidence intervals for each estimate. Studies in brackets are those for which either a different method of calculation was used or only a subset of the relevant data was available in the article, which decreases the potential contribution of these studies to this analysis.

Qualitative synthesis

Ideally, further quantitative syntheses would have been conducted in this review, however, given the diversity of studies, there was a limited number of studies investigating similar greening interventions and presenting the necessary data for meta-analysis. Therefore, we have conducted a qualitative synthesis for most of the articles in this review. It is emphasized that this approach is less powerful and less robust and therefore conclusions drawn based on this qualitative synthesis should be made with caution. We deal with each greening intervention in a separate section.

Parks and Green areas

Studies that addressed the effects of parks and green areas all used an observational study design that involved a site comparison, and in most cases, this comparison was based on one green site (i.e. one park or green area) and one or more urban site. These studies can be divided into two groups.

1) *Temperature in an urban park/green area versus urban non-green sites*: Eight studies measured the temperature in a park or a ‘green area’, such as a garden or park, and compared this with the temperature in a built-up area in another part of the urban area.

2) *Temperature within an urban park compared to the built-up area surrounding the park*: Fifteen studies compared temperatures within a park with that of the built-up area immediately surrounding the park (usually within 500m). The advantage of this latter methodology is that the temperature comparison is made within a similar locality and may therefore potentially control for some other variables that may also affect temperature at a local scale.

The meta-analysis focused on data collected either during the day or at night for a subset of these articles where the relevant data (on variances and sample size as well as means) were available in the article or from the author. Here, we attempt to present more of the data, with information on studies that could not be included in the meta-analysis and using data from all times/dates measured or presented. Table 2 presents the estimates of the temperature effects of parks (T_{urban}-T_{park}, often termed the park cool island and abbreviated as PCI; Appendix C provides details of the calculations) based on all the information available. In both groups, most studies generally suggest that parks, on average, are a cooler environment than a built-up area. The results of both these groups of studies are summarised in Appendix D.

Table 2 The difference between the air temperature within a park or green area (e.g. garden) (Tp) compared to the surrounding built-up area (Tu). See Appendix C for details on extraction of data. The mean was calculated using all data presented at the dates/time of data collection. Warmest time of day was either identified or based on data between 12:00 and 16:00.

Citation[1]	Place	No. parks	Park size (ha)	Dates/ times of data collection	Comparison	Mean of Tu-Tp ˚C (range)	Mean difference at warmest time of day
Barradas 1991	Mexico City, Mexico	5	1.9 - 9.9	May-Nov (weekly) 07:00 and 15:00	Surroundings	1.3 (0.4 to 3)	1.99 (0.89 & 3.09)
Watkins 2002a	London, UK	1	c. 50[3]	Aug (1 day) 06:30 – 19:10	Surroundings	0.6	1.1
Watkins 2002b	London, UK	1	2.25	Sep (2 days[4]) 06:15 – 19:10	Surroundings	0.14	0.6
Chang *et al.* 2007	Taipei City, Taiwan	61	< 0.5 to > 25	Aug-Sep &Dec-Feb (? days) 11:00 – 15:00 21:00 – 1:00	Surroundings	0.46 (-3.2 to 3.3)	0.81 (-3.2 to 1.2)
Jansson *et al*. 2007	Stockholm, Sweden	1	15	July (3 days) 07:10 – 22:04	Surroundings	0.81	0.77
Lahme and Bruse	Essen, Germany	1	15[2]	Sep (1 day[2]) 15:30 and 22:00	Surroundings	1.8	1.1
Potcher *et al.* 2006	Tel Aviv, Israel	3	2.5 - 3.5	June-Aug (3 days) 24 hrs	Surroundings	0.73 (0.1 to 1.1)	0.94 (-0.6 to 2.3)
Yu & Hien 2006	Singapore	2	12 and 36	Jan-Feb (26 days), June (16) 24hrs	Surroundings	1.1 (0.9 to 1.3)	-
Spronken-Smith & Oke 1998	Vancouver, Vancouver	10	3 – 53	July-Aug (? days) "daytime and night"	Surroundings	2.1	-
Spronken-Smith & Oke 1998	Sacramento, California	10	2 – 15	Aug (3 days) "daytime and night"	Surroundings	2.6	-

Citation[1]	Place	No. parks	Park size (ha)	Dates/ times of data collection	Comparison	Mean of Tu-Tp ˚C (range)	Mean difference at warmest time of day
Miyazaki *et al*., 1996	Osaka, Japan	4	0.9 - 108	August (5 days) 13:30-15:50 and 5:00-18:47	Surroundings/ Urban site	1 (0.03 to 2)	0.8 (0.03 to 1.5)
Upmanis *et al*., 1998	Gothenberg, Sweden	3	2.4 - 156	Jan 1994 – Sept 1995 (?days) 2 – 3 hrs after sunset	Surroundings	1.7 (0.5 to 3.6)	-
Thorsson et al. 2007	Matsudo, Japan	1	2.1	March and May (25 days) 11:00-15:00	Urban square (250m west of park)	1.1	1.43
Jonsson 2004[5]	Gabarone, Botswana	4	NA	Sept – Nov (4 days) 06:00, 14:00 and 22:00	CBD	1.00 (0.61 to 1.86)	-0.59 (-1.97to 0.98)
Shahgedanova et al. 1997	Moscow, Russia	1	NA	All year (272 days) 07:00	City Centre	1.19	-
Kjelgren et al. 1992	Seattle, USA	1	NA	Aug (1 day[2]) 07:30 to 20:00	Urban plaza and Canyon	0.08	-0.08
Jauregui (1991)	Mexico City, Mexico	1	525	March (4 days[2]) 24 hrs	Urban site (700m south)	1.38	-3.6823
Mayer & Hoppe (1987)	Munich, Germany	1	0.16	July (1 day) 08:00 to 17:00	2 street canyons	0.6	0.6
Ca et al. 1998	Tama New Town, Japan	1	60	Aug (1 day[2]) 24 hrs	Nearby parking lot	1.5	2

[1]Other relevant studies from which this information could not be collected are listed in Appendix D.
[2]representative or only a subset of the data presented in the article
[3]area is approximated based in information in the article
[4]measurements on one cloudy day and one sunny day.
[5] also measured a golf course that is not included here

A number of different variables that may modify the cooling effect of a park have been investigated by these studies:

Park size: Four studies investigated the effect of the size of the park or green area on their estimation of its cooling effect (Barradas, 1991; Upmanis *et al.*, 1998; Bacci *et al.,* 2003; Chang *et al*., 2007). These studies measured several parks (from 3 to 61) and all took replicate measurements in several months, and were conducted in various cities: Mexico City, Gothenburg, Florence and Taipei City. Their results indicated that park size may influence its cooling effect and specifically that larger parks are either more likely to be cooler, or that their cooling effect is greater. In the most extensive park study by Chang *et al*. (2007) in Taipei City, Taiwan, the temperature inside and outside was compared for 61 different parks in the summer and winter, at noon and at night. The relationship with size was more evident in the measurements taken at noon and the larger the park, the more likely it was to be cooler. The summer/noon data showed that parks over at least 3 hectares were usually cooler than the temperatures in the surrounding urban area while the temperature difference was more variable for parks less than 3 hectares (Chang *et al*., 2007).

Distance from Park: Yu and Hien (2006) studied two large parks in Singapore, measuring temperatures over a period of around one month at increasing distance from the park up to *c*. 500 m from boundary. In both parks, the temperatures outside the park were greater, and temperatures gradually increased with increasing distance from the park boundary, which suggests that the cooling effect of the park extends beyond the park boundary. In a longer-term study, Upmanis *et al.* (1998) also demonstrated that the night-time cooling effect of a park could extend beyond the park boundary in a study in Gothenburg. The relationship between temperatures with distance was strongest for the largest of the three parks studied (156 ha) and the authors claim that the effect extended up to 1km but the data were not subject to any statistical analysis to more rigorously test this. Some evidence on the extension of the cooling effect is also presented by Watkins who studied a park in London (2002).

Season: Many studies collected data from more than one month however only four studies presented data which enabled a comparison of the effect of a park or green area between different seasons. Two of these studies indicated that the difference between a park and urban area was greater in summer (Shahgedanova *et al*., 1997;

Chang *et al*., 2001). However, this was not evident in another study of 6 different green areas in Florence in comparison with the city centre but only the maximum Park Cool Island effect was presented (Bacci *et al.,* 2003). The remaining study reported that the difference was greater in the dry season than the rainy season (Jauregui, 1991).

Weather: It is important to note that studies on the urban heat island effect often deliberately select clear and calm days in which to take temperature measurement as this is when the urban heat island is considered to be most detectable. This is also the most relevant to the problem of heat waves and so it limits the investigation in a relevant way. However, this limits investigation of the effect of different weather conditions on the link between land cover and temperature in this review. An exception is a short-term test by Watkins (2002) in which the difference between one park and surrounding streets in London was compared on a cloudy day and a sunny day. The park was found to be cooler on the sunny day only.

Park vegetation: One study compared two parks with trees to another park with very few with trees (Potcher *et al.,* 2006) over a few days in two years. Another, more detailed study investigated the effect of tree cover/area over 61 parks (Chang *et al*., 2007). In both cases, parks with more trees were linked with lower temperatures, at least during the day, and in this latter example this was not simply due to a tree shading effect as measurements were taken in an unshaded region of the park beneath a radiation shield. However, a study comparing temperatures within a park in Stockholm over four days found that air temperatures were not lower in areas shaded by trees compared to open areas when measured at 1.17m height but instead indicated that tree shading affected the thermal stratification of the air column (Jansson *et al*., 2007). Two further studies that compared temperatures of green areas with different types of vegetation (gardens, golf courses, parks with trees) in Botswana, Vancouver and Sacramento, report less consistent results on the effects of trees and different types of green area on temperature (Spronken-Smith & Oke, 1998; Jonsson, 2004) but the authors suggest the potential importance of irrigation and the retention of heat by trees from their data.

Urban factors: In their extensive study, Chang *et al.* (2007) found that the amount of paved area within a park explained variation in the temperature difference between the park and its surroundings. Parks with proportionally less paved areas were cooler in the summer at noon.

Time of day: Overall, the studies do not present a consistent picture on the diurnal changes in the cooling effect of a park. Four studies presented data which suggested that the temperature difference does not greatly vary over the day, or at least that no consistent trend could be observed based on the information presented in the article (Kjelgren & Clark, 1992; Miyazaki & Moriyama, 1996; Jonsson, 2004; Jansson, 2007). Two other studies supported a larger temperature difference in the afternoon, which is usually the warmest time of day (Barradas, 1991; Watkins, 2002). In studies measuring temperatures in the day and at night, the cooling effect appeared to be both sometimes greater (Almendros Coca, 1992; Spronken-Smith & Oke, 1998; Jauregui, 1991; Lahme & Bruse, 2003) and sometimes weaker (Potchter, 2006; Chang *et al*., 2007) in the night compared to the day. As there are many differences between these studies (e.g. type of park, times measured), teasing apart the mechanisms producing these results is difficult. Only one study was identified as focusing on night-time temperatures only and parks were cooler in this study (Upmanis *et al*., 1998).

Urban trees

Studies that investigated the effects of trees all used an observational study design that involved a site comparison. Unlike park studies, comparisons were usually based on more than one green site (i.e. several different individual trees) but half only compared measurements over a single day and so the consistency of any effects with different weather conditions cannot be verified.

Nine studies compared the temperature in sites with a tree or trees with those of a nearby treeless site (listed in Appendix E). Temperatures beneath tree canopies have been shown to be lower than temperatures in the open, at least during the day in a study of 11 sites with trees in Tel Aviv (Shashua-Bar & Hoffman, 2000) and in more limited studies in Freiburg and Manchester (Streiling & Matzarakis, 2003; Gill, 2006). Similar results were obtained in studies that investigated the effects of single trees (Souch & Souch, 1993; Bueno-Bartholomei & Labaki, 2003; Georgi & Zafiriadis, 2006; Golden *et al*., 2007; de Kauffman *et al.*, 2002). These studies range in the number of trees measured from one to 294 and were conducted in various countries: Brazil, Venezuela, Greece, Hungary and USA. Although, in one study that compared temperatures in different sections of street canyons with and without trees, there was no clear difference but measurements were only presented on one day (Gulyas *et al*., 2006).

These studies also highlight a number of factors that may moderate the cooling effect of a tree:

Tree characteristics: Different trees species have been shown to vary in their ability to reduce air temperature, for instance, in a study comparing 21 species (294 trees) in Thessaloniki Greece (Georgi & Zafiriadis, 2006) with more limited evidence in another study in Brazil (Bueno-Bartholomei & Labaki, 2003). This may be due to a number of factors such as tree size and tree canopy characteristics. However, Souch and Souch (1993) investigated 44 trees over a 15 day period in Indiana, USA and found that factors such as leaf area index, diameter and height did not explain variation in their cooling effects.

Number of trees: The relationship between tree number and the total cooling effect would be important to understand to design an urban greening programme. Two studies explicitly compared the effects of a single versus a cluster of trees on air temperature. One study compared only one site of each in Freiburg, Germany and results were only presented for one day; marginally higher temperatures were found under the single tree than the cluster (Streiling & Matzarakis, 2003). In a replicated study in Indiana, Souch and Souch (1993) found no difference between single or clumps (3 or 4 trees) of Sugar maple, *Acer saccharum*. However, the amount of visible shade provided by trees has been found to explain variation in temperatures between measurements points (Shashua-Bar & Hoffman, 2000; see also Shashua-Bar & Hoffman; 2002), which suggested tree clusters may be more effective than single trees.

Time of day: Studies that compared the effects of trees in the day and at night show that the cooling effect of a tree was only apparent in the day (Souch & Souch 1993; Shashua-Bar & Hoffman, 2000; Golden *et al*., 2007; see also Huang *et al*., 2008). This supports that the notion that the cooling effect is due to shading and it has been hypothesized that trees may hinder heat exchange at night-time.

Distance from trees: Shashua-Bar and Hoffman (2000) investigated 11 different sites with trees in Tel Aviv and investigated the decline in the cooling effect of these sites with distance during between July and August. The data suggested that the reduction in temperature by trees was perceptible up to 80m away.

Other: Using limited data on surface temperatures, Golden *et al*., 2007 demonstrate the importance of orientation of the tree with respect to a particular location in determining its cooling effect. However differences in the effects of trees between canyons of different orientations were not evident in another study but limited data was collected (Gulyas *et al*., 2006). Souch and Souch (1993) also compared air temperatures beneath the Sugar maple, *Acer saccharum* when growing in either a street (concrete) or grass environment, and found warmer temperature beneath those in the street. Shashua-Bar and Hoffman (2000) demonstrate the impact of the background temperature in determining the cooling effect of wooded sites. It is also worth noting here that buildings can also provide shade as well as trees (Gill, 2006).

Urban forests

This pool of studies was created to distinguish single or small clusters of trees from continuous tree coverage, which can by speculated to have different effects on temperatures. A site was defined as an 'urban forest' based either on the author's use of these words or, in one case, the author's described their site as a 'mature forest stand' that was within an urban area (Heisler & Wang, 1998). 'Urban forest' can also be used to refer collectively to the trees present across an urban area (i.e. not necessarily continuous tree coverage) but these studies are not included here. It is quite possible that other studies are relevant to study the effects of continuous tree coverage but this would require further details, preferably quantitative, on the specific nature of the green site, which was usually not available.

Four studies were identified which measured the temperatures within an 'urban forest' and compared them to temperatures in a non-green urban site (listed in Appendix F). These studies were conducted in various countries: India, China, USA and Turkey. In each case, only one urban forest site was studied. They all report lower temperatures in the forested site (Padmanabhamurty, 1991; Heisler & Wang, 1998; Yilmaz *et al*., 2007; Huang *et al*., 2008).

Green roofs

Six studies investigated the effects of green roofs on surface and/or air temperature. Four of these six studies were categorised as employing an experimental design, because the exposure of the site to vegetation was created by the researcher however the control of potential confounding variables was not clear. A 'before and after' design was used in one of these four cases. These studies compared sections of a roof with vegetation with sections of the roof without vegetation, and therefore addressed the local effects of green roofs. Apart from two studies, most studies only measured temperature above one green roof, and even in these two, it was the same roof divided up into different roof sections (listed in Appendix G). These studies were conducted in various countries: Wales, Japan, Singapore and Germany and generally took measurements over a few days, or at least data from only a few days were presented in the article.

Comparisons were made between green roofs and concrete, gravel or unspecified hard surfaced roofs. The effects on air temperature were found to be mixed with some evidence of a cooling effect in some studies (Harazona *et al*., 1991; Wong *et al*., 2003) but not in others (Alexandri & Jones, 2007; Hein *et al*., 2007). However, in these cases, limited data was collected and/or presented. The studies were more supportive that the surface temperature of green roofs could be cooler than non-green roofs (Wong *et al*., 2003; Alexandri & Jones, 2007; Hein *et al*., 2007 but not Köhler *et al*. 2002) although there was some variation in effects (Harazono *et al*., 1991; Takebayashi & Moriyama, 2007).

Ground vegetation

Six studies measured temperatures on or above a green site with grass and compared them to the temperatures of various urban surfaces such as concrete or asphalt (listed in Appendix H). These studies mostly used an observational site comparison design and measured a small number of different sites, usually one or two green sites, over periods of one day to one year. These studies were conducted in UK, China, USA, Japan and Turkey.

Three of the four studies that measured air temperatures demonstrated that temperatures were cooler above a grass surface than a concrete surface (Mueller & Day, 2005; Yilmaz *et al*., 2008; Huang *et al*., 2008; but not Kjelgren & Montague, 1998). In only one of these cases was temperature measured over a period of a year (Mueller & Day, 2005). The studies that measured surface temperatures as opposed to air temperatures were consistent in showing that grass had a lower surface temperature than an urban surface such as concrete or asphalt (Kjelgren & Montague, 1998; Mueller & Day, 2005; Gill, 2006; Yilmaz *et al*., 2008).

Differences in vegetation cover

Some studies focused on the temperature difference across sites with different amounts of greening rather than a comparison of a green site versus a non-green site, which has been the focus of our discussion so far. These were divided into two main groups:

(i) Tree cover

Three studies compared areas or sites with different amount of tree cover (Adnan, 1993; Grimmond *et al*., 1996; Simpson *et* al., 1994). Adnan (1993) compared temperature measurements at three stations, which differed in the percentage tree cover within a radius of two miles; the greater the tree cover within an area, the lower the temperature. Simpson *et al*. (1994) compared temperatures at four sites in a Californian neighbourhood with 38% surface tree with another four sites in a nearby neighbourhood with 20% surface tree cover. Measurements were taken continuously during August and usually, but not always, temperatures were found to be cooler in the neighbourhood with more trees, however, as the authors' note, other differences between the neighbourhoods may explain the difference. Grimmond *et al*. (1996) carried out a similar study comparing sites between neighbourhoods with different tree and shrub cover but the focus of the article was on the energy flux balance rather than temperature *per se*. The larger scale of these studies suggests they may demonstrate more generalised cooling effects of trees however, the influence of the amount greening in the immediate area to the measurement location as opposed to the effects of the wider surrounding area is not clear. Another study, Giridharan *et al*., 2007, compared 17 coastal area residential developments in Hong Kong, with several temperature measurement sites within each one. They investigated the effects of 16 variables including vegetation cover (above and below 1m) using multiple regression; there was some evidence that vegetation could have an effect but this depended on time of day and year, height of vegetation and weather conditions. For instance, during the nighttime, the effect was only significant for vegetation above 1m on peak summer clear sky days rather than cloudy days or in late summer although the same directional trends were observed at these other times. In contrast, during the daytime, effects of vegetation were not significant (at 5%) after accounting for the other variables in the model, and the directional effects were not wholly consistent. They also demonstrated effects of distance to the sea, sky view factor and surface albedo on temperature.

(ii) Green cover

An additional group of twelve studies compared temperatures across sites with different amounts of greening. In these cases, it was not clear what type of vegetation 'green' referred to and in some cases it seemed likely that 'green' was being used to refer to a mixture of possible greening intervention types. These studies are listed in Appendix I. We briefly outline these papers but quantitative synthesis is hindered by the variable nature of these studies.

A number of studies investigated the correlation between the percentage of green cover and temperature. Emmanuel and Johansson (2006) compared five streets with different amounts of percentage green cover in Colombo, Sri Lanka, collecting temperature measurements from April to May; the effects of greening were not discussed and the authors consider the importance of the height-to-width ratio of the street canyon. Eliasson & Svensson (2003) took temperature measurements over an 18-month period at 30 sites in Gothenberg, Sweden, using a regression analysis to compare the effects of a number of different variables including percentage vegetated surface. Katayama et al. (1993) compared sites which varied in two indices ('tree shade factor' and 'green covering ratio') within five different parks and shrines during the day in the summer in Fukouka, Japan; the relationship with temperature tended to be be negative, particularly with the 'green covering ratio'. Saito et al. (1991) investigated the effects of percentage green cover across a large number of sites in Kumamoto, Japan in August and September; the correlation with temperature was also found to be negative. Alonso et al. (2003) took temperature measurements along three transects across Salamanca, Spain, from January to May, estimating percentage green cover in 400m squares. Limited data were presented on maximum and minimum temperatures but these suggest lower temperatures in areas with more green space and less built-up/asphalt area.

Three other studies used vegetation indices from satellite data and correlated this with ground-collected temperature data. Sun et al. (2007) conducted traverses across Tainan, Taiwan, on four nights and related this to NDVI (vegetation index). Their data support a negative relationship between greening and nighttime temperature. Prats et al. (2005) also used NDVI to compare factors affecting the temperature across 238 measurement sites in Zaragova, Spain. Analysis of the 27 clear and calm days indicates that NDVI is negatively related to temperature but urban density and elevation are more important. Harlan et al. (2006) measured temperature in 8 different neighbourhoods over 12 months, and compared this with the Soil-Adjusted Vegetation Index. Data are presented on the thermal comfort index (combining temperature and humidity) during the summer and support a negative relationship with SAVI.

Other studies split the amount of greenness up into discrete categories. For instance, Theodosiou et al. (2002) compared areas with more or less green cover during September, November and December. In a study in London, Watkins (2002) compared 24 areas with different amounts of greenness (more or less than 30%), collecting temperature in the day and night from July to September. Higher greenness was associated with lower temperatures but a range of other factors were also important including wind speed, cloud cover, rainfall and solar radiation.

Other studies

The final set of studies includes those which for a number of reasons could not be simply pooled into one of the above categories. Greening types in this group included “soft cover” (trees, greens areas and waterbodies), “open areas”, plant/tree versus brick/glass/stone/bare ground, “forests and trees” and “vegetation”. In several cases, the presence of differences in greenness among sites being compared was identified by the review team as a possibility but this was not clear from the article. Due to the diversity of green types and comparator land cover types in these studies and/or lack of clarity on the type of green in these studies, we do not discuss these studies further here. These studies are listed in Appendix J.

Thermal comfort

A number of the studies discussed above also used the data collected to investigate the effects of greening on the level of human physiological comfort using a thermal comfort index (e.g. physiological equivalent temperature, PET). A number of different indices were presented, mostly combining temperature and humidity, and some also incorporated other variables such as wind speed. Focusing on the subset of these studies (listed in Appendix K) that make one of the simple comparisons between a green and a non-green site, as discussed in sections above, we find they are broadly in agreement that green areas can potentially be more comfortable environments in warm weather but also less comfortable in colder weather owing to the reduction in temperature. However, they also indicate that this effect is not necessarily consistent and raise some of the issues that may modify the cooling effect that have already been discussed above.

b) Remote sensing

Remote sensing technology, using satellite imagery, has been used to estimate land surface temperature using information from the surface reflectance of thermal energy. Given the coarser scale of these studies, the abundance of ground-collected temperature data and the lack of specificity in the type of 'green' under study in many cases, we did not fully explore this pool of studies for this review. However, many studies following this approach have demonstrated a negative correlation between vegetation indices such as NDVI (normalized difference vegetation index) and temperature, which is suggestive that urban greening may be effective in reducing temperature (e.g. Njoroge et al., 1999; Hung et al., 2006; Santana, 2007; Tiangco et al., 2008). These studies are listed in Appendix L and an endnote library is available from the lead reviewer, which contains the titles and abstracts of these articles.

c) Models

Our review focuses on the empirical evidence on the effectiveness of greening. Forty-six studies used a modelling approach to predict the effects of greening on temperatures. These studies are listed in Appendix M and an endnote library is available from the lead reviewer, which contains the titles and abstracts of these articles.

4.2.2 Ozone and its precursors

a) Empirical studies

Our review focuses on both O_3 and its main precursors: NOx and VOCs. Much of the work on the impact of urban greening on air quality considers the effects of shrubs and trees.

Study critical appraisal

The methodology of these studies varied depending on the question being addressed. Details on the methodology of studies are discussed within the synthesis.

Qualitative synthesis

Given the low number of studies that were found on ozone and greening in an urban context, these studies are synthesised in a qualitative, narrative synthesis rather than formal meta-analysis.

These studies can be divided into those that investigated the localised effects of single plants (seven studies) and others that were larger scale and usually investigated differences between a green and a non-green area (ten studies). Figure 6 shows the outcomes measured by each of these groups (listed in Appendix N).

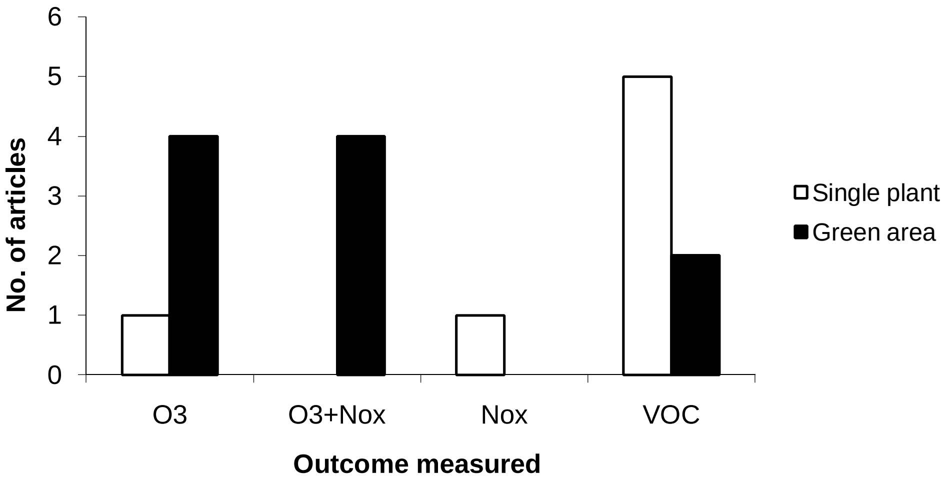


Figure 6 The number of articles that measured each outcome (NO_x and/or O_3, or VOCs) for studies that measured either at the level of a single plant or at the level of an urban green area.

<u>*Single plants*</u>

i) Ozone

Only one study was identified which investigated the ability of plants to absorb ozone for an urban context. Abdollahi *et al.* (1996) conducted a laboratory study to compare the ability of 12 plant species (usually three individuals of each), commonly used as urban landscape shrubs and trees in America, to absorb O_3. They found that the species varied in their ability to absorb O_3 but all species absorbed O_3 to some extent.

ii) Nitrogen oxides NO_x

Only one study was identified which investigated the ability of plants to assimilate NO_x. Takahashi *et al*. (2005) measured the ability of 70 species (1-3 individuals of each) of woody plants, typically used as roadside trees in Japan. The study compared their ability to assimilate NO_2 in their leaves using stable isotope labelled ^{15}NO2. All species were found to assimilate nitrogen (N) in their leaves, but species differed in their ability to assimilate N by a factor of 122 between the highest and lowest. In general, the assimilation capacity of deciduous species were greater than evergreen species, however, as the authors note, it is not clear if this difference would arise if tested over a long time period given that evergreen species retain their leaves all year. The study also suggested that species differed in their resistance to N as evidenced by the state of the leaves after the experiment, which could impact on their ability to assimilate N in the long term.

iii) Biogenic VOC emissions

Plants may absorb O_3 and NO_x, however, they can also emit VOCs into the atmosphere that can contribute to O_3 formation. The main active compounds are isoprene (C_5H_8) and monoterpene compounds ($C_{10}H_{16}$) and these compounds tend to be more reactive than anthropogenic sources of VOCs in producing O_3. Thus, in reviewing the effectiveness of urban greening in reducing ground-level O_3 it is important to understand variation in the emission of VOCs from plant species. This review has identified five studies which have addressed this issue, which are summarised in Table 3. These studies demonstrate that many, but not all, plants can emit VOCs and there is some evidence that this consistently varied between different species.

Some of these studies investigated the potential importance of different factors on the emission rate of VOCs from plants:

Urban stress: The effect of stress has been investigated by one study captured by our search, with low replication. Donovan (2003) compared the emissions from two individual trees of English Oak (*Quercus rober*) and Silver birch (*Betula pendula*) in both ‘stressed’ (roadside) and in ‘natural’ (park-like university campus) environments in the UK. The isoprene emitted by the oak was greater in natural conditions; the monoterpene emitted by the birch was greater in stressed conditions.

Season: The chemical reaction between VOCs and NOx that produces O_3 is sensitive to sunlight and therefore changes in VOC emissions over different seasons could be an important factor in the effects of plants on O_3. Two studies investigated the effect of season on emissions. Li *et al.* (2008) compared the amount of monoterpene and isoprene released by the Chinese pine, *Pinus tabulaeformis*, from June to September. The dominant VOC emitted was α-pinene, and its emission rate peaked sharply in August. Xiaoshan *et al.* (2000) compared the seasonal change in isoprene emission rates of two species, *Platanus orientalis* and *Pendula loud.*

Emission rates were greatest in summer, which was suggested to be related to leaf development, with the leaves being fully expanded in summer.

Light and Temperature: Several studies noted that the release of VOCs from vegetation is sensitive to temperature and light but we found only one study in our literature search that presented data on this. Xiaoshan *et al*. (2000) noted that in their study of urban trees in Beijing, emissions were greater on sunny days than on rainy and cloudy days. The diurnal change in emission rates also corresponded to the levels of photosynthetically active radiation (PAR) and air temperature. However, in general, limited data were identified in our literature search to confirm the relative importance of PAR and temperature.

Comparison of Ozone levels in green and non-green sites

i) Ozone and its precursors

Kuttler and Strassburger (1999) compared differences in O_3 and NO_x concentrations among various urban environments (green areas, roads and residential areas) in 12 measurement trips over the course of a 13-month period in Essen, Germany. Concentrations of NO_x were found to be generally lower in green areas when compared to residential or road environments, which was most likely to be a result of differences in traffic emissions. In contrast, levels of O_3 were found to be higher in green areas than residential and road environments. Greater O_3 levels in areas with low NO can be predicted on the basis of the complex chemistry of O_3 as the effect of NO_x on O_3 production is critically dependent on their relative concentrations. In a sequence of reactions, NO_x, in combination with VOCs, can lead to the formation of O_3, however, at high concentrations of NO, for example in areas polluted by vehicle emissions, nitrogen oxide can react with O_3 converting O_3 to O_2 and therefore lead to localised O_3 depletion (PORG, 1997; Syri *et al*. 2001). Thus, this 'titration effect' may cause lower concentrations of O_3 in urban areas polluted with nitrogen oxide (PORG, 1997). Another study in Italy also hypothesized that higher O_3 levels measured in an urban park when compared to an urban square was a result of lower traffic emissions of nitrogen oxide (Ciacchini *et al.,* 1997; see also Weber *et al.*, 2004). Three other studies were also identified which investigated the dynamics of O_3 or its precursors in green areas (Stroud *et al*., 2002; Allegrini *et al*., 2000; Mazzeo *et al*., 2005).

Table 3 Studies that have measured the emission of various VOCs from individual plants.

Citation	Place	Type of tree	Number of species(trees in total)	Key results
Corchnoy *et al*. 1992	Los Angeles, USA	Trees approved as street trees for LA	12 species (21 trees in total)	Large differences between species. One species did not emit any VOCs .
Donavan 2003[1]	West Midlands, UK	Tree species in the West Midlands	8 species (2-4 trees for each)	All species tested released either isoprene or monoterpene. English Oak had the highest emission rate.
Li *et al.* 2008	Shenyang, China	Urban Chinese pine street trees	1 species (3 trees)	Seasonal variation in emission rates.
Noe *et al*. 2008	Barcelona, Spain	Ornamental suburban trees	11 species (2/3 trees of each)	All species released monoterpene.
Xiaoshan *et al*. 2000	Beijing, China	Tree species in and around Beijing	12 species (1 to 13 measurements for each)	Some, but not all, trees released isoprene. Emissions greater on sunny days and in summer.

[1]they also report a desk-top literature search study that produced a database of emission factors for different UK plant species (http://www.es.lancs.ac.uk/cnhgroup/iso-emissions.pdf; Stewart 2000); see also available databases at http://www.es.lancs.ac.uk/people/cnh/

In larger scale studies, Cheung (2002) explored the link between temperature, O_3 concentration and land cover in the Washington Metropolitan Area. Using information from remote sensing tools and data from a number of O_3 monitoring stations (up to 17) in different counties, the authors demonstrated a positive association between O_3 concentrations and temperature and maximum temperatures at each station, which varied in strength among stations (14 to 41% of the variation in temperature explained by O_3). They also demonstrate a negative association between surface temperatures and vegetation cover (NDVI) among a subset of five monitoring stations, and suggested links between vegetation cover and O_3. Similar work by Xian and Crane (2006) in the Las Vegas valley presented the relationship between NDVI obtained from satellite imagery and O_3 concentrations from eight monitoring stations; the authors fitted a non-linear, "humped" curve to the relationship between NDVI and O_3, which suggested low O_3 at both high and low NDVI, however there were only eight data points which limits confidence in this result.

ii) VOCs

Only two studies were identified which compared VOCs in green and non-green sites in an urban area. O'Donoghue and Broderick (2007) presented a comparison of non-methane hydrocarbons between a park and a roadside site in Dublin, Ireland; lower levels were observed at the park site which was thought to be due to lower local pollution from traffic emissions. An additional small study, Streiling and Matzarakis (2003), studied the effect of a single tree cluster on VOCs, as well as O_3 and NO_x but data were only presented for a single day.

b) Models

Our review focused on the empirical evidence on the effect of greening on ozone. Modelling studies are listed in Appendix O and an endnote library is available from the lead reviewer, which contains the titles and abstracts of these articles.

4.2.3 Ultra-violet radiation

Many studies have measured solar or global radiation but only four articles (three empirical studies and one model) were identified that addressed different questions on the effects of urban greening on UV, and one further review paper which presents data is also included here

Gies *et al*. 2007 investigated the UV protection provided by urban trees in Australia, comparing measurements in the shade of trees and in the full sun for six different species commonly used in the Australian urban environment (four trees of each) around noon (solar noon=time with highest sun elevation) on five different days. All trees were found to provide some UV protection and this effect was greater for some trees but the rank order was not consistent over different days.

Heisler *et al*. 2003 measured UV in and near the shade of trees and demonstrated lower UV irradiance at sites shaded by a tree in the USA. However, the authors also emphasise that visible radiation is not necessarily a good guide to UV radiation due to the contribution of the diffuse radiation from the sky; the fraction of sky visible is therefore also thought to affect UV rather than simply visible shade (Heisler *et al*. 2003). Grant *et al.* 2003 compare the leaves of 20 deciduous tree species in their ability to reflect or transmit UV. They found that much of the UV was not transmitted through the leaf however there was variation in leaf reflectance. The reflectance of tree leaves can be important, for example, if leaves are good reflectors of radiation in a certain waveband, sites near trees may potentially receive more radiation than those in the open. Similar data and further discussion by these authors are presented within Heisler and Grant (2000) and Heisler and Grant (2005).

5. Discussion

5.1 Evidence of effectiveness

The rigour of our review was limited by the number of studies we could formally synthesize in a meta-analysis. Therefore, we have conducted a qualitative synthesis for most of the articles in this review and it is emphasized that this approach is less powerful, and therefore that conclusions drawn on this should be made with caution.

Temperature

There have been a considerable number of studies which have aimed to study the effects of different types of vegetation cover on temperatures in urban areas. This has mostly involved a study of the effects of existing land cover on the urban heat island effect rather than a study of changes in temperature with the creation or enhancement of greening as part of an urban greening programme. In this review, we have focused on the synthesis of the subset of studies investigating specific greening types rather than simply greening *per se* because designing an urban greening strategy will require considering the most effective way vegetation can be used.

Most of the studies identified in this review investigated the effects of parks, green areas and/or trees. Studies that have measured temperatures within and outside urban parks have generally found that average temperatures are lower inside the park. Our meta-analysis on the subset of studies from which data were available indicates that on average a park is around 1^{o}C cooler than a built-up area during the daytime (0.97^{o}C; 95%CI = 0.74 to 1.19). Similarly, air temperatures beneath a tree tend to be, on average, cooler than beyond a tree canopy. Greening has been hypothesised to lead to cooler environments as a result of evapotranspiration and shading, however, the studies do not allow an assessment of the relative importance of these factors. Although some studies provided detail on the location of their temperature measurement e.g. in sun/shade and/or under the protection of a radiation shield, this was not made clear in all articles, which limits interpretation of these findings. A few studies have been conducted on the effects on air temperature of short vegetation such as green roofs and ground vegetation, which presumably could only be cooler from evapotranspiration and these are less consistent in their observed effects on air temperatures. A small number of studies presented evidence to support a cooling effect beyond the boundary of the green area however too few studies have explicitly tested this effect to be able to speculate on the strength and shape of this relationship and the factors that may affect it. Thus the spatial scale as well as temporal scale over which greening can be expected to have a cooling effect is not clear.

Most of these studies are observational studies that compare existing variation in greenness within an urban area, without any data collection before the creation of the green space. Most studies also only investigated a small number of distinct green sites. For instance, most studies on parks only investigated one park even if they did take several measurements within the park. This is perhaps not surprising given the types of interventions involved, which limits the feasibility of conducting experimental work and measuring many different sites. However, in the absence of experimental greening, base-line data and this low replication of independent observation, it is important to consider the impact of any potential confounding variables that may explain the differences between green and non-green areas apart from greenness *per se*. For instance, perhaps the one park that was measured in a study was located in an area that was already cooler, for instance, due to surrounding urban features. Different studies may be complicated by different confounding variables and the extent to which these variables are important is not clear. However, studies which compared temperatures within a park with those in the immediate surrounding area may be less likely to be confounded and therefore to reflect the actual greening effect and these studies did find consistent evidence of a difference in temperatures. However, these studies may also underestimate the cooling effect of a park if the effect extends beyond the immediate park boundary area.

There was a lack of statistical analysis in the articles and thus of hypothesis testing of the effect of greening on the outcome. This meant that inferences we have drawn on the results of a study were based on a combination of author discussion and our interrogation of data presented in graphs/tables. In some cases, limited data were presented, which limited the conclusions we could draw on a particular study. The lack of rigorous analysis limits the confidence we can have in the interpretation of study findings.

Ozone

Empirical studies on O_3 addressed the effects of greening both at the level of a single plant and at the level of a green area. There is some evidence from laboratory and field studies that single plants release VOCs and therefore that they may have the potential to contribute to O_3 production. The studies that we have reviewed indicate that plants vary in the amount of VOC emissions released but how much this varies between individuals of the same species and the role of other variables is not clear. We identified fewer studies that investigated the ability of plants to absorb O_3 and NO_x but this was based on our literature search for studies focused on urban areas and thus there may be other relevant studies which have studied this in other contexts.

A few studies have compared the concentrations of O_3 and VOC in green and non-green sites. They demonstrate the complexity of O_3 production and particularly the non-linearity of the effects of NO_x. Some suggested that the lack of traffic and lower level of nitrogen oxides within a park may provide conditions which promote the production of O_3, leading to greater O_3 concentrations within a park. This effect arises from the conversion of O_3 to O_2 at high nitrogen oxide concentrations, for instance, from traffic emissions.

UV

Few studies were identified which investigated the effect of vegetation on UV in an urban context. The studies we reviewed investigated UV protection provided by trees and the reflectance of leaves. These studies show that a tree canopy can provide UV protection.

Impacts on human exposure and human health with climate change

The review did not identify any studies that investigated the direct effect of urban greening on human exposure to high temperatures, O_3 and UV. Similarly, we did not identify any studies that investigated direct effects of urban greening on health-related outcomes, for instance, on hospital admissions during a high O_3 episode. However, it is important to note that our review was only interested in studies that investigated health and greening if this was conducted with an explicit link to one of our variables of interest (i.e. temperature, O_3 and UV).

Thus, our review has discussed studies which consider the impact of green space on these environmental variables without specific consideration of human exposure or the relevance of these studies in the context of climate change. Clearly changes in human behaviour could impact on how green space affects human exposure to these variables.

5.2 Reasons for variation in effectiveness

Meta-analysis can be used for statistical exploration of the variation in effectiveness among different studies. However, the diversity of studies in the review has meant that a meta-analysis has only been conducted on a small subset of the articles. Factors that may explain variation in the effects of greening have been identified using data presented within studies rather than comparing results and factors between studies in meta-analysis (Table 4). We only list here factors considered in articles included in this review, and therefore this list is not exhaustive and other factors could be hypothesized as important.

Table 4 Factors that empirical studies included in our review have identified as potentially important moderator variables.

Temperature	Ozone	*UV*
Size of green area *Type of vegetation* *Time of day* *Time of year* *Weather/climate (e.g. temperature, cloud cover, wind)* *Urbanisation*	*Plant species* *Season* *Physiological Stress* *Light and temperature*	*Tree species*

5.3 Review limitations

There are a number of limitations to our discussion and conclusions:

1) Literature search: The large number of studies which were identified as relevant for the review has meant that a bibliography search of these studies was not conducted.

2) Defining greening interventions: The variety of possible greening interventions led to studies being grouped in a number of broad greening categories based on the information presented in articles. In most cases, the greening intervention was defined following the terms used by the author. However, vagueness in description of the type greening limits the accuracy of the pooling. A more precise categorisation would require further information, preferably quantitative, from the authors, which may not be available.

3) Lack of quantitative synthesis: Only a limited meta-analysis was conducted given the variation among studies in the data collected. This means that this review has not been able to predict an average cooling effect of greening (weighting studies by the inverse of the variance i.e. by the precision of their estimate of their effect) or explore the amount of uncertainty in this effect, or explore heterogeneity across studies e.g. effects of geographic location.

4) Limitations in the scope of the review: There are areas of research relevant to the sustainable use of greening which were beyond the scope of this review. For instance, there has been research on the damaging effects of O_3 on vegetation (Hayes *et al*., 2007), which may hinder their ability to absorb O_3 in the long-term. This is an important consideration for the sustainable use of vegetation as a climate change strategy.

6. Reviewers' Conclusions

6.1 Implications for policy

There is some evidence that trees and parks may provide, at least at a local scale, a cooler environment. However, this is based on observational data rather than data from more rigorous experimental study. In addition, these empirical studies do not directly test the ability of greening to allow adaption to climate change. Therefore this hypothesis should continue to be tested through experiment and appropriate monitoring

The evidence on the effects of greening on O_3 is more complicated, however, it is clear that the type of tree species used in a tree planting scheme would have to be carefully selected to avoid using a species emitting high levels of BVOCs.

Given that greening interventions, such as tree planting, have different impacts that may include providing shade and protection from UV but also the emission of VOCs that may contribute to O_3 production, the net benefits are not clear.

The studies we reviewed demonstrate the range of factors that can affect temperature, O_3 and UV and therefore it seems likely that in order to predict the impact of greening in a given locality, specific information on the local environment would be required.

The evidence available does not allow us to provide specific recommendations on how an urban greening programme should be implemented, for instance, the necessary abundance and positioning of vegetation in an urban area for sufficient effectiveness.

In addition, further work would need to identify whether the associated potential impact of greening on these environmental variables is relevant from a public health perspective. For example, there is currently lack of clarity about a possible threshold effect for the impact of O_3 on health (Royal Society 2008). If a threshold is confirmed, then of most interest would be the ability of greening to lower ground-level O_3 levels to below the threshold. Similarly, the public health significance of the magnitude of the temperature reduction of greening would also need to be confirmed and whether this reduction would occur at the most relevant times of day and times of year.

6.2 Implications for research

Few studies attempted to carry out a statistical analysis of their results and most studies only considered a small number of different green sites. This means that many of the articles, particularly those where the green and non-green study sites were not located near to each other, may suffer from problems associated with confounding variables. For instance, there may be additional factors that are different between green and non-green sites and cause the temperature difference rather than the greening. We would therefore encourage more explicit consideration of the importance of potential confounding variables within articles written on this topic so that this is transparent to any reader. Techniques such as multiple regression may, to some extent, be able to account for the relationships between other variables and temperatures when multiple sites are measured and therefore allow focus on the effect of greening in future studies.

In addition, the extent to which non-green areas may be affected by the presence of green areas is not clear. A few studies suggested that the effect of a park or areas with trees could reduce temperature in the surrounding non-green area. However, this requires further investigation, specifically the change in temperature with distance from the green area. This would have implications for the abundance and distribution of greening necessary in an urban area for there to be a general cooling effect rather solely localised cool islands within green areas. The hypothesized importance of irrigation on the cooling effects of green space also warrants further study.

Given the limitations in conducting well-replicated and experimental research on these topics, drawing results across different studies becomes even more important to be able to make more general conclusions rather than simple case studies of individual parks in an urban area. Our review undertook a meta-analysis on the temperature reduction in a park. Further meta-analyses in this area would require studies to measure and present data on temperature in more standardized and comparable ways, so that data can be synthesised.

7. Acknowledgements

We thank Dave Stone (Natural England) and the stakeholders/subject experts for their input into the review protocol.

8. Sources of support and potential conflicts of interest

None declared. This review was funded by Natural England.

9. Background references

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Glossary

Solar reflectance *(also albedo*): Albedo is a measure of a surface's ability to reflect sunlight (encompassing wavelengths in the visable, infra-red and ultraviolet bands). Albedo is measured on a scale of 0-1, where a value of zero indicates a surface that absorbs all solar radiation and a value of 1, a surface that reflects all radiation (EPA 2009).

ASTER: the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument attached to satellite 'Terra' in 1999 as part of NASA's Earth Observing System (NASA 2009). ASTER is currently being used to generate detailed maps of land surface temperature, reflectance and elevation (NASA[a] 2009).

ATLAS (Advanced Thermal Land Applications Sensor): An airborne remote sensor instrument developed by NASA and widely used to study Urban Heat Islands, ATLAS can detect wavelengths in 15 multispectral channels, in the visible, near infra-red and thermal bands and produces surface images at a resolution of 10m and higher (Gluch et al 2006).

Biogenic hydrocarbons (also *Biogenic VOCs*): Naturally occurring, biogenic hydrocarbons are those organic compounds (including volatile organic compounds –see later entry) that are emitted from trees and vegetation. High-emitting species can significantly contribute to the formation of smog and thus urban greening strategies must consider species-specific emission rates when selecting trees for wide-scale planting (Chameides et al 1998).

Evapotranspiration: The process by which plants release water to the surrounding air, and thus dissipate ambient heat (EPA 2009).

Green roof: Describing rooftops planted with vegetation, the term encompasses a range of different types, from more 'intensive' green roofs with thick layers of soil or inorganic growing media which may contain a wide range of plant species and may even support tree species, to simple turf-covered roofs (EPA 2009).

Heatwave: A period of unusually and uncomfortably hot weather, formally defined as when "*the daily maximum temperature of more than five consecutive days exceeds the average maximum temperature by 5 °C (9 °F)*" (Frich et al 2002).

Landsat: The Landsat satellites, part of a joint project between the US Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), represent the longest continuous collection of 'space-based' remote sensing land data (USGS 2009). Early satellites provided surface images using Multispectral scanners (MSS); later the Thematic Mapper (TM) sensor was developed, providing improved resolution and additional shortwave radiation bands. The current Landsat satellite uses the Enhanced Thematic Mapper Plus, which captures images of the Earth's surface at a resolution of 30m in the visible and IR bands, a 60m spatial resolution thermal band, and a resolution of 15m for the 'panchromatic' band (visible wavelengths through to near infrared) (UGS 2009).

MODIS: The Moderate Resolution Imaging Spectroradiometer (MODIS) captures land cover data in 36 spectral bands aboard the Terra (EOS AM) and Aqua (EOS AM), together viewing the complete surface of the Earth each 1-2 days (NASA[b] 2009).

Nitrogen Oxides (NOx): *NOx* is the term given to the family of gases that are oxide compounds of nitrogen, such as nitrogen oxide, nitrous oxide and nitrogen dioxide NO and NO_2 are important precursors of ground level ozone (EPA 2009).

Normalized Difference Vegetation Index (NDVI): An index that uses satellite-derived radiation values to quantify the density of surface vegetation cover. NDVI is based on the formula: NDVI = (NIR — VIS)/(NIR + VIS), where NIR is near infra-red radiation and VIS is visable radiation (NASA[c] 2009).

Ozone (O_3): A triatomic molecule comprised of three oxygen molecules, ozone is a colourless, highly reactive gas. Ozone is found in the stratosphere, where it forms a protective layer that shields the Earth from ultraviolet radiation, and in the troposphere, where it is a harmful pollutant that can irritate the human respiratory system and damage vegetation (EPA 2009).

Park Cool Island: The reduction in temperature that can be measured within a park in comparison to temperatures of surrounding urban area

Physiological equivalent temperature (PET): PET is defined as the "*air temperature at which, in a typical indoor setting (without wind and solar radiation), the heat budget of the human body is balanced with the same core and skin temperature as under the complex outdoor conditions to be assessed*" (Höppe 1999, p. 71).

Phytoremediation (also *bioremediation*): These terms refer to the ability of plants to sequester, extract and detoxify pollutants from the air, water and soil (Meagher 2000). In an urban context, green roofs and street trees are important for the mitigation of non-point source pollutants and urban runoff.

Precursor pollutant: A term used to refer to primary pollutants which, when released into the atmosphere, are involved in reactions which drive the formulation of other, secondary, pollutants. Examples include sulphur oxides (form sulphur dioxide, sulphates) and nitrogen oxides (form nitrogen dioxide, ozone).

Remote sensing: Using instruments mounted on aircraft or satellites, remote sensing is a method by which the radiative characteristics of the Earth's surface (EPA 2009).

Sensible heat flux (see also Latent heat flux): The transfer of heat energy between the Earth's surface and the atmosphere through the processes of convection and conduction.

Sky View Factor (SVF): The sky view factor is a measure often used to characterise urban geometry. SVF can be defined as the "*ratio between radiation received by a planar surface and that from the entire hemispheric radiating environment*" (Watson & Johnson 1987, cited in Svensson 2004, p. 201).

Surface roughness: Simply, surface roughness can be defined as the vertical deviation of surface topography from an ideally smooth and planar surface. In the context of urban heat islands, surface roughness is important in terms of impacts on wind flow characteristics and is used to indicate the presence of vegetation, buildings and other uneven surfaces in urban areas (EPA 2009).

Thermal comfort: Commonly described in psychological terms, thermal comfort is defined as "the condition of mind which expresses satisfaction with the thermal environment" (ASHRAE 1997, cited in Höppe 2002).

Urban canopy: A concept similar to that of a 'vegetative canopy', used to describe the assemblage of trees, buildings and other structures in an urban area, and the spaces between them (AMS 2009).

Urban canyon: The urban canyon is defined as "*the three-dimensional space bounded by a street and the buildings that abut the street*" (Emmanuel 2005, p. 23).

Urban Heat Island (UHI): A metropolitan area with a significantly higher ambient air temperature than surrounding rural areas (Weng et al 2004). The urban heat island effect is primarily attributed to the replacement of vegetation with buildings, roads, and other heat-absorbing surfaces.

Volatile organic compounds (VOCs): A classification covering all organic compounds with a boiling point in the range 50°C-260°C, excluding pesticides (WHO 1989, cited in Brown et al 2004). Methane is the most common VOC and many are "precursors" that react in sunlight and heat to create ozone.

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Appendix A - Project Stakeholders

Organisation	Project contact/s
Biological Sciences, University of Essex	Jo Peacock
BRASS ESRC Centre, Cardiff University	Julie Newton
British Heart Foundation, University of Oxford	Charlie Foster
BTCV	Calum MacIntosh Yvonne Trchalik
CABE	Helen Beck
Countryside Council for Wales	James Parkin
DEFRA	John Robbins
Department of Health, England	Mala Rao
Environment Agency	Roger Milne Anthea Hawke
Forest Research	Liz O'Brien
Forestry Commission	Marcus Sangster
Glasgow Centre for Population Health	Fiona Crawford
Health Protection Agency	Richard Jarvis
Institute for Rural Health	Jane Randall-Smith
MRC Southampton University	Stephen Holgate
National Public Health Service for Wales	Andrew Jones Malcolm Ward
Natural England	Kevin Charman William Bird
NICE	Hugo Crombie
North East Community Forests	Janine Ogilvie
Offender Health, Department of Health, England	Sara Moore
RSPB	Martin Harper
Scottish Executive	George Morris
Sustainable Development Commission	Larissa Lockwood
Sustainable Development Research Network/PSI	Kate McGeevor Ben Shaw
UK Public Health Association	Angela Mawle UKPHA Health & Sustainable Environments Special Interest Group
Wales Centre for Health	Sue Mably
Welsh Assembly Government	Ronnie Alexander

Appendix B - Website search

The websites of the following organisations were searched for publications.

Altostratus Inc
Air Quality Management Districts in the U.S.
California Energy Commission
California Air Resources Board
California Environmental Protection Agency
California Public Utlities Commission
California Resources Agency
Centre for Urban and Regional Ecology
Center for Urban Forest Research
Commission for Architecture and the Built Environment
CDC
Environment Agency
Environmental Protection Agency
European Environment Agency
Forest Research
Forestry Commission
Greater London Authority
Greenspace (including Greenspace Scotland)
Health Protection Agency
Houston Advanced Research Center
Intergovernmental Panel for Climate Change
Lawrence Berkeley National Laboratory
Parliamentary Office of Science and Technology
RIVM
National Aeronautics Space Administration
National Trust
Natural England
Scottish Executive
Scottish Environment Protection Agency
Scottish Natural Heritage
Tyndall Centre for Climate Change Research
UFORE
UK Climate Impacts Programme
UK MAB Urban Forum
UK Public Health Association
The US Environment Protection Agency
US Department of Energy (DOE)
WHO

Appendix C - Data extraction for Table 2 and Meta-analysis

Data extraction for Table 2 and the meta-analysis was conducted as follows.

In general, for the table we average all measurements that could be calculated within a study, and over each park if more than one park was studied in the same town or city. We also, where possible, provide an estimate of the average difference at the warmest time of day, either based on the temperature difference at the warmest time of day if this could be identified, or based on differences between 12:00 and 16:00 [dependent on times of data collection within study].

For the meta-analysis, in order to allow synthesis of most of the articles, the effect size was calculated a single parameter: the temperature difference between the inside and outside of a park. This is because some studies only present the temperature difference rather than the temperature of each site. Replication is based on different times of measurement rather than different sites of measurement within a green area because more of the data were presented in the former manner. To limit the effects of pseudoreplication, in cases where studies had measured more frequently than every hour, we restrict the sample size estimate used in calculating the standard error of the effect size to hourly measurements (i.e. n=24 in a study measuring data points over a 24 hour period even if measurements were taken more frequently). We focus on data collected during the day between 08:00 and 16:00 (for the first meta-analysis) and between 22:00 and 06:00 (for the second analysis) from which we could estimate a mean, standard deviation and sample size necessary for each analysis. When data is presented for different seasons, we focus on summer months.

The specific details for each study are shown below (see Appendix D for further details on study methodology):

Barradas, 1999

- For table: Mean calculated by averaging mean differences of each park from Table 1; range is the minimum and maximum mean from different parks. Temperatures at warmest time of day are calculated from data presented in Fig 3a and 3b for two parks using the estimates from the maximum mean in the afternoon.
- For meta-analysis: Data on means and standard deviation of the temperature difference for each park were extracted from Table 1. The author was emailed to request sample size, from which we could use the exact SDs presented in the table but no reply was received. We extract data from Fig 2 which presents SE for use in the meta-analysis.

Saito et al. (1991)

- Data not presented in a form that could be used to calculate the parameters of our table and meta-analysis. We could not identify the authors email address after an internet search to request the information. This study was therefore not used in the meta-analysis.

Watkins 2002a – Primrose Hill

- For table: mean based on average difference of measurements inside and outside the park for the day and maximum based on differences at warmest time of day at 3pm; values for these parameters were estimated from Table 6.1 (and in text).
- For meta-analysis: Raw data available in the thesis in Table 6.1 and therefore calculations of mean, standard deviation and sample size of the temperature difference were made from the raw data.

Watkins 2002b – British Museum

- For table: mean based on averages of means for streets on both days minus park mean and difference at warmest times of day based on average difference of maximums for streets on both days minus park maximum as presented in Table 6.4.

- For meta-analysis: author emailed to request data as a measure of variance is not presented in the thesis. The author kindly sent information on means, standard deviations and sample size to use in the meta-analysis.
-

Chang et al. 2007
- For table: mean based on values presented in text and maximum and minimum are obtained from maximum and minimum median of data observed in Fig 3 Temperature difference at warmest time of day is estimated using summer/noon and range based on extraction from Fig 3a of min and max at summer/noon.
- For meta-analysis: Due to queries over sample size, the author was emailed for raw data. The data were not received. Thus, we are not able to use data at the park level and calculate average and SD based on the 61 park medians in Fig 3a (midday) and Fig 3b (night).

Jansson et al. 2007
- For table: Mean of the temp difference for all measurements for all times and day was calculated from Fig 3 and the difference at warmest time of day on each day is also calculated using Fig 3 to also identify the warmest times of day.
- For meta-analysis: Mean difference was calculated using data on the difference in temperature extracted from Fig 3, and standard deviations and sample size calculated. We used data between 06:00 and 20:00 for the first analysis.
-

Lahme & Bruse, 2003
- For table: Average difference calculated using temperature of the Park and Built up data (Not interface) over both times: 15:30 and 22:00. Temperature difference at warmest time of day is presented as data for 15:30 alone.
- For meta-analysis: authors emailed to request all the data as only a representative weather day is presented in the article. Authors kindly replied to say that it is not possible to provide data. We therefore can only calculate an effect size based on a subset of the data. In this case, we calculated the average difference between the measurements in the park and outside at 15:30 for the first analysis and 22:00 for the second analysis and calculated the standard deviation as the pooled standard deviation combining each group at each time.

Potcher et al. 2006
- For table: data on average differences at all times were extracted from Fig 4 and the average calculated from all measurements. Range calculated from average difference for each park. Data on difference at warmest time of day were also taken from Fig 4 with warmest times for each park on each day identified from Fig 3b urban temperatures. This could only be done for one day.
- For meta-analysis: the subset of the above data presented in Fig 4 between 06:00 and 20:00 for the first analysis and between 22:00 and 0:600 for the second analysis was used and the means and standard deviations for each park were calculated.

Yu & Hein
- For table: to calculate mean difference for each park, Fig 5 (BBNP) and 11 and 12 (CWP) and were used to estimate the mean outside park and the mean inside park for each park, from which the difference was calculated.
- For meta-analysis: the authors emailed for data. The full data was kindly sent for CWP and so the relevant parameters were calculated from the raw data. For the second site, BBNP, we calculated the average difference for sites inside and outside the BBNP from Fig 5 and the pooled standard deviation from Fig 6 for the meta-analysis.

Ca et al. (1998)
- Data was extracted from Fig 3 and 7 for grass and asphalt on an hourly basis and the mean and sd of temperature difference calculated.

Spronken-Smith & Oke 1998

- The data for Vancouver were estimated using the average calculated from daytime and night time average presented in Table 2.
- The data for Sacramento: daily average from averages presented in Table 3.
- For meta-analysis: Author emailed for data as a measure of variance could not be calculated based on data presented in the article but no reply was received.

Upmanis et al. 1998

- For table: average temperature difference was calculated from averaging median values of the car and mobile traverses presented in Table 6.
- For meta-analysis: Attempts to contact the authors to request data on variances by email failed and the correct email address could not be found in an internet search.
-

Miyazaki et al. 1996

- For table: data on the average temperature difference between the park and surroundings/ built-up area were extracted and averaged from Table 4-7. The difference at warmest time of day is calculated using only the noon data extracted from Table 4 and 5 and all data from 6 and 7.
- For meta-analysis: measures of variances are not presented in article. We were unable to locate an email address for the author to request this information. This study was therefore not used in the meta-analysis.

Jonsson (2004)

- For the table: Data on air temperature difference were extracted from data presented in Fig 11 (this is presented as the Urban Heat Island effect (U-R) rather than temperature but as the same rural reference station is used, the difference between park and CBD should be the exact temperature difference). We calculate the average by averaging over all times presented (we assume data points with the same symbols were measured on the same day). Temperature difference at the warmest time of day is based on the difference calculated at 14:00 from Fig 11. We focus on data from the gardens and parks and not the golf course given we are interested in urban greening interventions.
- For meta-analysis: After extraction for the table, we use data at 06:00 and 14:00 for the first analysis and data at 22:00 for the second analysis.

Shahgedanova et al. (1997)

- For table: Average data could be extracted straight from the Table II and summer and winter data averaged.
- For meta-analysis: Average data and standard deviations, and sample size, could be extracted straight from the Table II; the summer data were used in the meta-analysis.

Almendros (1992)

- We were unable to locate an email address to request further information from the author on the data. This study was therefore not used in the meta-analysis.

Kjelogren & Clark (1992)

- For the table: The data were extracted from Fig 1 and the average difference between the park and the average of the urban sites (plaza and canyon). Data at the warmest time of day were estimated using data collected between 16:00 and 17:00 which was the warmest time of day.
- For the meta-analysis: the author was emailed for the raw data as data were only presented for one of the measurement days. The author kindly responded to inform that the data could not be sent. We incorporate these data based on the amount presented and calculate the standard deviation as the pooled standard deviation combining each group.
-

Thorsson et al. (2007)

- The authors kindly provided the raw data for the means, standard deviations and sample sizes to be calculated for the table and meta-analysis. We used the subset of the data when data were collected from both sites at the same time/day and calculate the mean and SD of the temperature difference measurements. Temperature at warmest time at day was identified using the urban sites.

Jauregui (1991)

- For table: Data presented in Fig 6 were used to estimate an average temperature difference between the park and the urban site. Difference at the warmest time of day is estimated using data at 14:00 which was the greatest temperature observed.
- For the meta-analysis: The author was emailed to request the data as only a subset is presented in the article but no reply was received. We therefore can only incorporate this study based on the limited data presented, calculating the mean and SD of the temperature differences based on data in Fig 6.
-

Bacci & Morabito (2003)

- Data are presented as a maximum cool island. Authors were emailed to request data. There was no response and therefore these data are not included in the meta-analysis.

Gomez et al. (1998)

- There were queries over data presented. Authors were contacted to request data and the authors kindly responded but the queries were not resolved. We were therefore unable to incorporate this data into the analysis.

Mayer & Hoppe (1987)

- For the table: Temperatures were extracted from the figure (on an hourly basis at 08:00 to 16:00) and the average difference between the backyard and the average of the two street canyons was calculated. Difference at the warmest time of day based on temperatures at 12:00 which appeared to be the warmest time of day.
- For the meta-analysis: the same data above were used with the standard deviation and sample size calculated based on the average difference at each time.

Summary Tables

Note that it is possible for a study to be listed in more than one appendix if it studied more than one greening intervention or measured more than one relevant outcome. Details presented on data collection varied because of variation in reporting this information within the individual articles.

Appendix D - Parks and Green area studies

(i) Studies in the temperate zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Almendros Coca, M. A. (1992). "Aspectos climaticos del parque del Retiro (Madrid) Translated Title: Climate features of Retiro Park, Madrid." Estudios Geograficos 53(207): 217-239.	Madrid	Spain	1 park compared to the urban zone.	Temperatures from 23 measuring points within the park were compared with an urban zone in the day in the shade and night for various months.	Limited data were presented. Effect of the weather stability.
Bacci, L. and M. Morabito (2003) Thermohygrometric conditions of some city parks of Florence (Italy) and their effects on human well-being. Proc. of Fifth International Conference on Urban Climate, Lodz (Poland), 1-5 September	Florence	Italy	6 different green areas are compared with the historic town centre	Measurements were taken over 24 hrs from Dec to Feb (winter) and June to Aug (summer).	The maximum cooling effect depends on park size and the season.
Ca, V. T., T. Asaeda, et al. (1998). "Reductions in air conditioning energy caused by a nearby park." Energy and Buildings 29(1): 83-92.	Tama New Town	Japan	1 park and other urban locations.	Measurements were taken from June to September over 24hrs.	Limited data on air temperature presented. Surface temperatures also taken.
Gomez, F., E. Gaja, et al. (1998). "Vegetation and climatic changes in a city." Ecological Engineering 10(4):	Valencia	Spain	2 green areas and various other urban sites	Temperatures measurements along traverses through the urban area. Data presented for a single	Limited data presented.

355-360.				night in February – other days measured.	
Honjo, T., K. Narita, et al. Observation of cool island effect in urban park (Shinjuku Gyoen). Proceeding of the International Conference on Urban Climate, Lodz,	Tokyo	Japan	1 park	Temperatures taken in the centre and at the park boundary during the night in summer.	
Jansson, C., P. E. Jansson, et al. (2007). "Near surface climate in an urban vegetated park and its surroundings." Theoretical and Applied Climatology 89(3-4): 185-193.	Stockholm	Sweden	1 park and its surroundings	Measurements were taken over 3 days in July (14 points within the park and 27 points outside) between 07:00 and 23:00 using an unshieled thermocouple.	Temperate tends to be cooler inside the park. Studied differences between shady and open areas within the park - difference in air temperature not clear. Surface temperatures also taken.
Kjelogren, R. K. and J. R. Clark (1992). "Microclimates and tree growth in three urban spaces." Journal of Environmental Horticulture 10(3): 139-145.	Seattle	USA	1 park compared with a plaza and a street canyon in the CBD	Measurements were taken from dawn to dusk from June to August using a fan-assisted psychrometer – data from one day presented but another 6 days measured. Surface temperatures also taken. An attempt to compare similar sites was made.	The data presented suggested little difference in air temperature. Surface temperature is also presented.
Lahme, E. and M. Bruse (2003) Microclimate effects of a small urban park in densely built-up areas: Measurements and model simulations. ICUC5, Lodz 1-5-September 2003, 4 pages	Essen	Germany	1 park and its surroundings	5 points inside; 3 outside and others at the interface. Data from one day at 15:30 and 22:00 in September is presented which was considered to have the most representative weather. Other data available.	
Mayer, H. and P. Hoppe (1987). "Thermal comfort of man in different	Munich	Germany	1 backyard with grass and trees is	Measurements taken on one day in July from 07:00 to 17:00.	The backyard is cooler than one street canyon but not the other.

urban environments." Theoretical & Applied Climatology 38(1): 43-49.			compared with two street canyons, with different orientations, and also a spruce forest.		
Miyazaki, H., M. Moriyama, et al. (1996). "Field study on green canopy as urban cool-spot." Nature and Human Activities 1: 51-56.	Osaka	Japan	1 park and its 3 surrounding streets	Measurements were taken at noon and in the evening of 1 day in August. Other parks also studied. Surface temperatures also measured.	....
Potchter, O., P. Cohen, et al. (2006). "Climatic behavior of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel." International Journal of Climatology 26(12): 1695-1711.	Tel Aviv	Israel	3 parks and its surroundings	Fixed and mobile measurements were taken over 4 days in June-Aug over 24 hours inside an unaspirated radiation shield.	Two of the parks were consistently cooler. The park with no trees was sometimes warmer than the surroundings.
Saito, I., O. Ishihara, et al. (1991). "Study of the Effect of Green Areas on the Thermal Environment in an Urban Area." Energy and Buildings 15(3-4): 493-498.	Kumamoto	Japan	2 small green areas and their surroundings	Fixed observations were taken over a month (August); additional observations were taken between 07:00 and 19:00.	Limited data presented from the field observations. They indicate the park was cooler.
Shahgedanova, M., T. P. Burt, et al. (1997). "Some aspects of the three-dimensional heat island in Moscow." International Journal of Climatology 17(13): 1451-1465.	Moscow	Russia	1 park was compared to a city centre site.	Temperature was measured all year. Data presented at 07:00 am; also collected at 13:00. Other urban sites were also measured.	The park was on average cooler but effects varied with season and time of day. Limited data was presented.
Spronken-Smith, R. A. and T. R. Oke (1998). "The thermal regime of urban parks in two cities with different summer climates." International Journal of Remote Sensing 19(11): 2085-2104.	Vancouver	Canada	10 parks and their surroundings	Measurements were taken in June-August in 19 traverses in the day and night within a radiation shield. Parks covered range of types (savannah, garden, multi-use, forest).	Parks were cooler and there was variation between park types

Spronken-Smith, R. A. and T. R. Oke (1998). "The thermal regime of urban parks in two cities with different summer climates." International Journal of Remote Sensing 19(11): 2085-2104.	Sacramento	USA	10 parks and their surroundings	Measurements were taken in August over 3 days in the day and night within a radiation shield. Parks covered range of types (savannah, garden, multi-use, forest).	Parks were cooler and there was variation between park types
Thorsson, S., T. Honjo, et al. (2007). "Thermal comfort and outdoor activity in Japanese urban public places." Environment and Behavior 39(5): 660-684.	Matsudo	Japan	1 park compared with a square in the city centre	Measurements were taken over 17 days during March and May between 11:00 and 15:30 in full sun. Surface temperatures also taken.	Temperature where usually lower in the park.
Upmanis, H., I. Eliasson, et al. (1998). "The influence of green areas on nocturnal temperatures in a high latitude city (Goteborg, Sweden)." International Journal of Climatology 18(6): 681-700.	Göteborg	Sweden	3 parks and their surroundings.	Night-time measurements were taken over a period of a year and a half, 2-3 hrs after sunset. Several measurement points inside and outside the park.	Park was cooler to an extent depending on park size and sky view factor.
Watkins, R. 2002a. The impact of urban environment on the energy used for cooling building. Chapter 6. Brunel University.	London	UK	1 park and surrounding streets	Measurements were taken over a single day in August from 6:30 until 19:10 using a shaded fast response digital thermometer. 5 points inside and outside the park.	The park was cooler and the greatest difference occurs at the warmest time of day. Discussion of the effects of street trees and wind direction.
Watkins, R. 2002b. The impact of urban environment on the energy used for cooling building. Chapter 6. Brunel University.	London	UK	1 park and 4 surrounding streets	Measurements taken on a sunny and a cloudy day in September from 6:35 am to 7.10 (cloudy day) and from 6.15 am to 3:10 pm (sunny day) using a thermometer shielded with a concentric reflector.	The park was cooler on the sunny day but not on the cloudy day.

(ii) Studies in the Tropical Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Barradas, V. L. (1991). "Air temperature and humidity and human comfort index of some city parks of Mexico City." Int J Biometeorol 35(1): 24-8.	Mexico City	Mexico	5 parks and their surroundings	Measurements taken in mobile traverses weekly during the rainy season (May to November) at 07:00 and 15:00. For two parks, some measurements were also taken every 2 hours during the day.	Based on data presented, parks appear to be consistently cooler than their surroundings. Effects of park, size, vehicle traffic and pavements.
Chang, C. R., M. H. Li, et al. (2007). "A preliminary study on the local cool-island intensity of Taipei city parks." Landscape and Urban Planning 80(4): 386-395.	Taipei City	Taiwan	61 parks and their surroundings	1 point inside each park and 4 outside in an unshaded location but under a radiation shield. Measurements were taken at noon (11 -15) and night (21-1) in the summer (August to September) and winter (December to February).	On average, parks were cooler but there were effects of park size, turf, shrub and tree cover; paved area and season of year and time of day.
Jauregui, E. (1991). "Influence of a Large Urban Park on Temperature and Convective Precipitation in a Tropical City." Energy and Buildings 15(3-4): 457-463.	Mexico City	Mexico	1 park and urban site	Temperatures were measured over a 3 year period. 2 sites in the parks presented.	Temperature appears to be slightly higher in the park during the day but lower at night and early morning.
Jonsson, P. (2004). "Vegetation as an urban climate control in the subtropical city of Gaborone, Botswana." International Journal of Climatology 24(10): 1307-1322.	Gaborone	Botswana	5 different green areas (1 park, 3 gardens and 1 golf course) compared to the CBD.	Temperatures were measurement and compared at different times during the day and evening over 4 days during September to November using a cylindrical radiation shield.	There was evidence of temperature differences between the green areas and the CBD but these were not consistent. Effects of the amount of greenery and type of day.
Yu, C. and W. N. Hien (2006). Thermal benefits of city parks. Energy and Buildings 38, 105-120.	Singapore	Singapore	2 parks and their surroundings	In total, 12 points inside a park and 10 outside a park were taken along transects in Jan and Feb	Temperatures were lower within the park and tend to increase with increasing distance from the park.

				(Park 1) and June (Park 2) over 24hrs. Measurements taken within a white painted wooden box.	

Appendix E - Tree studies

(i) Studies in the Temperate Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Georgi, N. J. and K. Zafiriadis (2006) The impact of park trees on microclimate in urban areas. Urban Ecosystems 9, 195-209.	Thessaloniki	Greece	294 trees (21 species) - beneath and nearby	Temperatures measured during the day between July and August. No. of days not clear.	Temperatures were lower beneath the trees and amount varied between different species.
Gill, S. E. (2006). "Climate change and urban greenspace." Ph.D. Manchester 56-10571(B1e).	Manchester	UK	3 tree canopies - beneath and nearby in the same open area	Measurements taken on one day in September between 13:00 and 15:30.	Lower surface temperature in the shade of a tree canopy.
Golden, J. S., J. Carlson, et al. (2007). "A comparative study of the thermal and radiative impacts of photovoltaic canopies on pavement surface temperatures." Solar Energy 81(7): 872-883.	Phoenix	USA	1 trees - beneath and nearby	Surface and air temperatures measured over a 24 period on one day in June.	Results presented indicated it was cooler beneath the tree during the day but not at night. Information on surface temperature highlight the effect of tree orientation.
Gulyas, A., J. Unger, et al. (2006). "Assessment of the microclimatic and human comfort conditions in a complex urban environment:	Szeged	Hungary	3 trees - beneath and nearby	Measurements taken on 1 day in August between 05:00 and 21:00.	Based on graph presented, temperatures are similar.

Modelling and measurements." Building and Environment 41(12): 1713-1722.					
Souch, C.A. & Souch, C. (1993). The effect of trees on summertime below canopy urban climates: a case study Bloomington, Indiana. Journal of Arboriculture 19(5): 303-312.	Bloomington	USA	44 trees – 5 categories (species/environment /number)	Measurements taken during the day over a 15-d period beneath trees and at an open reference site 8km away.	Temperatures were cooler beneath the trees at midday but not in the morning, and tended to be warmer beneath in the evening. Effects of tree environment (street vs grass) but little effect of species/tree number (single vs clumps)
Shashua-Bar, L. and M. E. Hoffman (2000). "Vegetation as a climatic component in the design of an urban street - An empirical model for predicting the cooling effect of urban green areas with trees." Energy and Buildings 31(3): 221-235. See also Shashua-Bar, L. and M. E. Hoffman (2002). Quantitative evaluation of the effects of built-up geometry and trees on diurnal air temperature in canyon-type courtyards. Advances in Building Technology, Vols I and Ii, Proceedings. M. Anson, J. M. Ko and E. S. S. Lam. Amsterdam, Elsevier Science Bv: 1493-1500	Tel Aviv	Israel	11 sites with trees (gardens, courtyards, avenues and streets) and nearby treeless sites	Temperatures measured at 06:00, 09:00, 15:00, 18:00 and 24:00 between July and August (2 to 5 days per site) using a sling hygrometer.	During the day, temperatures were cooler in the sites with trees but not at night or early morning. Effects of tree shade area, background temperature and distance from trees.
Streiling, S. and A. Matzarakis (2003). "Influence of single and small clusters of trees on the bioclimate of a city: A case study." Journal of Arboriculture 29(6): 309-316.	Freiburg	Germany	2 trees/clusters - beneath and nearby	Temperatures measured on 2 days in September from 07:00 to 18:00. Only one day presented.	Limited data presented

(ii) Studies in the Tropical Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Bueno-Bartholomei, C. L. and L. Labaki (2003) How much does the change of species of trees affect their solar radiation attenuation? Proceeding of the International Conference on Urban Climate, Lodz, v.1, p.1-4	Campinas	Brazil	14 trees (12 species) - beneath and nearby	Temperatures measured over 5 days, starting at 07:00 until 17:30.	Temperatures were lower beneath the tree but the amount depended on the time of day and the presence of leaves on trees.
de Kauffman, M. G., M. V. Machado, et al. (2002). The "Cuji" tree: Useful roofing for temporary activities in the hot-humid climate of Maracaibo, Venezuela. Xxx Iahs World Congress on Housing, Housing Construction: an Interdisciplinary Task, Vols 1-3. O. Ural, V. Abrantes and A. Tadeu. Coimbra, Wide Dreams Projectos Multimedia Lda: 1555-1562.	Maracaibo	Venezuela	1 trees - beneath and nearby	Temperatures measured over 3 days, 24 hrs between November and April.	Copy of article obtained is poor. Text suggested that temperature were cooler during the day but not at night.

Appendix F - Urban forests studies

(i) Studies in the Temperate Zone

Citation	**Urban area**	**Country**	**Comparison**	**Data collection**	**Key results**
Heisler & Wang (1998). Semi-empirical modelling of spatial	Atlanta	US	a stand of mature trees in botanical	Temperatures taken over 27 days in July, 24hrs.	Temperatures were lower with more tree cover.

differences in below canopy urban air temperature using GIS analysis of satellite images, on-site photography and meterological measurements. In: preprints of 23rd conference on agrciultural and forest meterology. November 2-6, Albuquerque, Boston, MA. Amercian Meterological Society:206-209.			gardens compared to two urban areas		
Huang, L. M., H. T. Li, et al. (2008). "A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China." Building and Environment 43(1): 7-17.	Nanjing	China	an urban forest, urban centre, urban water area and rural area	Temperatures measured over 24 hrs from July to September.	Urban forest site was cooler than urban commercial centre site. This study also studies differences between concrete, lawn, trees and water areas within each site.
Yilmaz, S., S. Toy, et al. (2007). "Determination of climatic differences in three different land uses in the city of Erzurum, Turkey." Building and Environment 42(4): 1604-1612. See also Toy et al. 2007	Erzurum	Turkey	an urban forest vs city centre, and rural area	Temperatures measured at 07:00, 14:00 and 21:00 from August to June under a Stevenson Screen.	Average temperatures were lower and varied less within the urban forest, however, they had had higher minimum temperatures.

(ii) Studies in the Tropical Zone

Citation	**Urban area**	**Country**	**Comparison**	**Data collection**	**Key results**
Padmanabhamurty, B. (1991). "Microclimates in Tropical Urban Complexes." Energy and Buildings 15(1-2): 83-92.	Delhi	India	inside and outside an urban forest	Not clear.	Data presented suggest temperatures were lower in the urban forest.

Appendix G - Ground vegetation studies

(i) Studies in the Temperate Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Gill, S. E. (2006). "Climate change and urban greenspace." Ph.D. Manchester 56-10571(B1e).	Manchester	UK	1 surface of built structure, hard impervious vs grass (and also tree) within 2 different urban open areas	Measurements taken on one day in September between 13:00 and 15:30 with and without shade from building/tree.	Unshaded grass surface tended to have a lower temperature than unshaded hard impervious surface.
Huang, L. M., H. T. Li, et al. (2008). "A fieldwork study on the diurnal changes of urban microclimate in four types of ground cover and urban heat island of Nanjing, China." Building and Environment 43(1): 7-17.	Nanjing	China	1 site of concrete, water vs lawn (and trees/woods) within 3 different urban areas (and 1 rural area)	Temperatures taken 24 hrs over 6 days during July to September.	Air temperature over lawn tends to be cooler than over concrete.
Kjelgren, R. and T. Montague (1998). "Urban tree transpiration over turf and asphalt surfaces." Atmospheric Environment 32(1): 35-41.	Southern Illinois	USA	1 asphalt vs 1 turf site	Temperatures measured from dawn till dusk over 3 days during July and August using an aspirated thermocouple psychrometer.	Lower air temperatures over the turf on only 1 of the 3 days; this was thought to be due to the closeness of sites and air mixing. Surface temperatures were lower on all 3 days.
Mizuno, M., Y. Nakamura, et al. (1991). "Effects of Land-Use on Urban Horizontal Atmospheric-Temperature Distributions." Energy and Buildings 15(1-2): 165-176.	Osaka Expo '70	Japan	concrete, asphalt, 'buildings', water, bare ground vs grass (no of independent sites	Temperatures were measured in the day and night in summer, autumn and winter (? days/times) in a tube painted white.	Effect of grass (rather than simply 'green') is not clear based on figures presented.

			not clear)		
Mueller, E. C. and T. A. Day (2005). "The effect of urban ground cover on microclimate, growth and leaf gas exchange of oleander in Phoenix, Arizona." International Journal of Biometeorology 49(4): 244-255.	Phoenix	Arizonia	1 plot of concrete, asphalt and gravel vs turf	Temperatures measured every 5 minutes during the day using the protection of a radiation shield (08:00 to 17:00 every 2/3hrs) and at night (sunset, and 2/3hrs later) during most of the year	Air and surface temperatures cooler over turf and this effect was greater during the summer months.
Yilmaz, H., Toy, S., Irmak, M.A., Yilmaz, S. & Bulut, Y. (2008). "Determination of temperature differences between asphalt concrete, soil and grass surfaces of the City of Erzurum, Turkey " Atmosfera 21(2): 135-146	Erzurum	Turkey	1 area of concrete, bare soil vs grass	Temperatures measured over 24 hrs during 15 days in August	Lower air and surface temperature above the grass than the other surfaces.

(ii) Studies in the Tropical Zone

None found.

Appendix H - Green roof studies

(i) Studies in the Temperate Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Alexandri, E. and P. Jones (2007). "Developing a one-dimensional heat and mass transfer algorithm for describing the effect of green roofs on the built environment: Comparison	Cardiff	Wales	1 concrete vs 1 green site on a roof	Temperatures measured 24hrs over a few days (5?) in August	Air temperatures shown in graph temperature not clearly different over the grass versus the concrete. Data suggest surface temperatures may have been lower on the grass.

with experimental results." Building and Environment 42(8): 2835-2849.					
Harazono, Y., S. Teraoka, et al. (1991). "Effects of Rooftop Vegetation Using Artificial Substrates on the Urban Climate and the Thermal Load of Buildings." Energy and Buildings 15(3-4): 435-442.	Osaka	Japan	1 concrete vs green site on a roof	Temperatures were measured 24 hrs over 1 year. Data from 4 selected 'clear' days presented.	Air temperatures are cooler above the green roof, and surface temperature mostly, at least in the day, and also display less variation on the green roof
Köhler, M., M. Schmidt, et al. (2002). "Green roofs in temperate climates and in the hot-humid tropics - far beyond the aesthetics." Environmental Management and Health 13(4): 382-391.	Neubranden berg	Germany	1 gravel vs 1 green roof	Temperatures (surface) measured over 24hrs in May, July, Sept and Dec.	No clear effect of greening on average surface temperatures.
Takebayashi, H. and M. Moriyama (2007). "Surface heat budget on green roof and high reflection roof for mitigation of urban heat island." Building and Environment 42(8): 2971-2979.	Kobe	Japan	1 site of concrete, bare soil, reflectance paint (white and grey) vs lawn on a roof	Temperatures (surface) taken over 24 hrs. Data shown for 6 days in August and November (other data available).	The results are mixed and no consistent effects of greening are apparent. There is some evidence that the surface temperature is more likely to be lower on the green roof in August but not November.

(ii) Studies in the Tropical Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Hien, W. N., T. P. Yok, et al. (2007). "Study of thermal performance of extensive rooftop greenery systems in the tropical climate." Building and Environment 42(1): 25-54.	Singapore	Singapore	before vs after a green roof (1 roof divided up into 4 separate green areas)	Temperatures measured over 24hrs. Two days in June (before) are compared with four days in February (after) in a white wooden box.	Mixed results but surface temperatures tend to be lower for the green roof; effects on air temperature vary. This can depend on the type of green roof - how much vegetation.
Wong, N. H., Y. Chen, et al. (2003). "Investigation of thermal benefits of	Singapore	Singapore	1 hard surface vs garden roof	Temperatures taken over 24hrs in 17 days in	Results on air temperature are mixed and depend on height above

rooftop garden in the tropical environment." Building and Environment 38(2): 261-270.			divided up into 6 different vegetation types	October/November under the protection of a white wooden shelter- data presented and analysed for only 2 days, which were clear days.	surface and vegetation type. Some evidence that the green roof was cooler in the afternoon and night. Surface temperatures are greater on the hard surface.

Appendix I - Tree/Green Cover studies

(i) Studies in the Temperate Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Adnan, Z. (1993). "Cooling impact of urban trees." Pakistan Journal of Forestry 43(2): 75-84.	California	USA	3 areas with different tree coverage	Temperatures were measured 24hrs in the August of 3 years at different sites.	Based on data presented, the site with higher tree coverage is, on average, cooler.
Alonso, M. S., J. L. Labajo, et al. (2003). "Characteristics of the urban heat island in the city of Salamanca, Spain." Atmosfera 16(3): 137-148.	Salamanca	Spain	areas with different amounts of green cover - comparison presented based on 3 sites	3 transects through the city were conducted in the night(2hrs after nightfall) and daytime (3-4pm) from January to May	Results presented on maximum and minimum temperature indicate that areas with more green cover are cooler. Limited data presented.
Eliasson, I. and M. K. Svensson (2003). "Spatial air temperature variations and urban land use - a statistical approach." Meteorological Applications 10(2): 135-149.	Gothenberg	Sweden	30 areas with different amounts of 'green', and other urban areas	Temperatures were measured over a period of 18 months, 24hrs.	Significant effects but directions of effects are not clear based on data presented.
Grimmond, C. S. B., C. Souch, et al. (1996). "Influence of tree cover on summertime surface energy balance fluxes, San Gabriel Valley, Los Angeles." Climate Research 6(1): 45-57.	Los Angeles	USA	2 neighbourhoods with higher (30%) and lower (10%) tree and shrub coverage.	Temperatures were measured during July, 24 hrs.	Discussed the effects on energy balance flux rather than temperature itself.
Harlan, S. L., A. J. Brazel, et al.	Phoenix	USA	A site in the	Data collected over 12 months	Neighbourhoods differed in

(2006). "Neighborhood microclimates and vulnerability to heat stress." Soc Sci Med 63(11): 2847-63.			backyard of 8 different neighbourhoods which vary in the Soil-Adjusted Vegetation Index amongst other factors	but article focuses on temperatures at 17:00 from the start of June until the end of August.	temperature; the relationship between temperature and SAVI is not examined in the article but the relationship to themal comfort is tested. SAVI is negatively related to human thermal comfort, particularly during a 5 day heatwave.
Katayama, T., A. Ishii, et al. (1993). "Field Surveys on Cooling Effects of Vegetation in an Urban Area." Journal of Thermal Biology 18(5-6): 571-576.	Fukouka	Japan	Comparison of sites which vary in tree shade factor and green covering ratio within 5 different parks and shrines, and also the ratio of 'natural covering' of 1km square grids across the city	Temperatures were taken at various times during the day in summer (no. of days not clear)	Relationship between the natural covering of 1km grids and average air temperature is negative; at smaller scales, the relationship between air temperatures and green covering ratio (at 10,20 or 50m) tends to be negative, and to a less extent the relationship between the tree shade facto and air temperature
Prats, J. M. C., S. M. Vicente-Serrano, et al. (2005). "The effects of urbanisation in the climate of Zaragoza (Spain): The urban heat island and its conditioning factors." Boletin De La Asociacion De Geografos Espanoles(40): 311-327.	Zaragova	Spain	Comparison of sites with different NDVI	Temperatures measures in transects across the city during the night, starting 3 hrs after sunset. Data was collected over a year but 27 days that were clear and calm were selected for analysis.	The data suggested a negative relationship between NDVI and mean temperature, but elevation and urban density were more important.
Rohinton Emmanuel. Summertime urban heat island mitigation: propositions based on an investigation of intra-urban air temperature variations. Architectural Science Review, 40(4): 155-164	Michigan	US	5 urban areas with different 'green' and paved covers, and a rural site	Temperatures were measured in June and July during the day (09:00-18:59) and night(22:00-04:59)	Temperatures tend to be lower in areas with more green cover; other differences also discussed (tall buildings, air stability).
Saito, I., O. Ishihara, et al. (1991).	Kumamoto -	Japan	green covering % for	Temperatures measured in	There is a negative correlation

"Study of the Effect of Green Areas on the Thermal Environment in an Urban Area." Energy and Buildings 15(3-4): 493-498.	city-wide		many sites	August and September, during the time 10.40-15.45 and 04.00-05.20.	between the temperature and green cover in the day and night; the relationship is stronger at night.
Simpson, J. R., D. G. Levitt, et al. (1994). Effects of Vegetative Cover on Climate, Local Scale Evaporation and Air Conditioning Energy Use in Urban Southern California. 21st Conference on Agricultural and Forest Meteorology/11th Conference on Biometeorology and Aerobiology. Boston, Amer Meteorological Soc: 345-348.	Los Angeles	USA	8 areas (paired neighbourhoods) with different tree coverage	Measurements taken from December to October, 24 hrs.	Areas with higher tree cover were cooler, particularly at night.
Theodosiou, T., N. Chrisomallidou, et al. (2002). Microclimate, open spaces and sustainable planning: A comparative analysis for the Mediterranean climate. Protection and Restoration of the Environment Vi, Vols I - Iii, Proceedings. A. G. Kungolos, A. B. Liakopoulos, G. P. Korfiatiset al. Thessaloniki, Grafima Loannis Tsarouchidis: 1393-1400.	Thessaloniki	Greece	more (57%) or less green (38%)	Measurements were taken September, November and December, 24hrs.	Higher green cover was associated with lower temperature, this effect was particularly consistent in winter. Measurements were taken on different days.
Watkins, R. 2002. The impact of urban environment on the energy used for cooling building. Chapter 5. Brunel University.	London	UK	24 areas with different amounts of greenness (split by <30% and >30%)	Temperature measurements were collected from July to September and presented during the daytime (08:00 to 17:00) and night-time (22:00 to 04:00)	Higher greenness is associated with lower temperatures. Other factors are also important such as wind speed, cloud cover, rainfall and solar radiation. The direction of the wind in relation to the park is important; some evidence that the effect of park is greater upwind.

(ii) Studies in the Tropical Zone

Citation	Urban area	Country	Comparison	Data collection	Key results
Chen-Yi Sun, Hsien-Te Lin, Wen-Sheng Ou The Relationship Between Urban Greening and thermal environment. 2007 Urban Remote Sensing Joint Event	Tainan Metropolis Central Area	Taiwan	Comparison of grids (size?) which vary in NDVI	4 traverses across the city (1 in April, 1 in July and 2 in August) taking temperature measurements between 21:00 to 00:00.	On each of the 4 days, the relationship between NDVI and the estimated Urban Heat Island effect is negative.
Emmanuel, R. and E. Johansson (2006). "Influence of urban morphology and sea breeze on hot humid microclimate: the case of Colombo, Sri Lanka." Climate Research 30(3): 189-200.	Colombo	Sri Lanka	5 streets with different levels of green cover	Temperatures collected during April to May, 24hrs.	The effect of greening is not discussed. Height to width ratio of the street canyon is important.
Giridharan, R., S. S. Y. Lau, et al. (2007). "Urban design factors influencing heat island intensity in high-rise high-density environments of Hong Kong." Building and Environment 42(10): 3669-3684.	Hong Kong	China	17 areas with different vegetation cover (split by <1m and >1m)	Temperatures were located from the 17 locations from June to October, during the day (13:00 to 18:00) and night (18:00 to 22:00)	There are not effects of vegetation on temperature but this depends on the time of day, weather, height of vegetation and time of year. This study uses multiple regression to explore a whole range of factors such as Sky view factor, surface albedo, altitude, average height to floor area ratio, location quotient and proximity to sea.

Appendix J - Mixed and other greening interventions studies

(i) Studies in the Temperate Zone

Citation	Urban area	Country	Greening comparison

Blankenstein, S. and W. Kuttler (2004). "Impact of street geometry on downward longwave radiation and air temperature in an urban environment." Meteorologische Zeitschrift 13(5): 373-379.	Krefeld	Germany	built up with vegetation; built-up no vegetation and vegetation only
Gomez, F., N. Tamarit, et al. (2001). "Green zones, bioclimatics studies and human comfort in the future development of urban planning." Landscape and Urban Planning 55(3): 151-161. See also Gomez, F., L. Gil, et al. (2004). Climate indicators for cities. Sustainable City Iii: Urban Regeneration and Sustainability. N. Marchettini, C. A. Brebbia, E. Tiezzi and L. C. Wadhwa. Southampton, Wit Press. 18: 91-102. Gomez, F., V. Sifre, et al. (2006). Sustainability in cities: the green areas and climatic comfort as fundamental parameters. Sustainable City Iv : Urban Regeneration and Sustainability. U. Mander, C. A. Brebbia and E. Tiezzi. Southampton, Wit Press/Computational Mechanics Publications: 83-93.	Valencia	Spain	hard cover (concrete paving, tiles, badly facing streets or ones without trees) vs soft cover (lawns, soft earth, low bushes, properly facing streets or tree-lined streets)
Graham, E. (1993). "The urban heat island of Dublin City during the summer months." Irish Geography 26(1): 45-57.	Dublin	Ireland	"open areas" - areas of park, water bodies vs built-up areas
Heist et al., (2000). Thermal infrared radiative effects of various urban materials upon vegetation. Advanced remote sensing course project. Western Michigan University.	Michigan	US	single plant in pot, trees vs brick, glass, stone, ceramic, dry wood
Heist et al., (2000). Thermal infrared radiative effects of various urban materials upon vegetation. Advanced remote sensing course project. Western Michigan University.	Michigan	US	brick, glass, stone, ceramic, dry wood vs trees
Kempeneers, S. (1982). "The integration of bioclimatology in an environmental study." Energy and Buildings 4(2): 85-89.	Kenitra	Morocco	two types of 'district' are compared - different in amount of vegetation?
Livada, I., M. Santamouris, et al. (2002). "Determination of places in the great Athens area where the heat island effect is observed." Theoretical and Applied Climatology 71(3-4): 219-230.	Athens	Greece	various urban locations

Mao, L. S., Y. Gao, et al. (1993). "Influences of street tree systems on summer micro-climate and noise attenuation in Nanjing City, China." Arboricultural Journal 17(3): 239-251.	Nanjing	China	street trees - deciduous vs mixed tree systems
Mizuno, M., Y. Nakamura, et al. (1991). "Effects of Land-Use on Urban Horizontal Atmospheric-Temperature Distributions." Energy and Buildings 15(1-2): 165-176.	Osaka Expo '70	Japan	buildings', water; bare ground vs grass, tall trees; low trees
Mizuno, M., Y. Nakamura, et al. (1991). "Effects of Land-Use on Urban Horizontal Atmospheric-Temperature Distributions." Energy and Buildings 15(1-2): 165-176.	Senri New town Centre	Japan	Residential areas; commercial areas; ponds; bare ground vs small forest
Mizuno, M., Y. Nakamura, et al. (1991). "Effects of Land-Use on Urban Horizontal Atmospheric-Temperature Distributions." Energy and Buildings 15(1-2): 165-176.	Senri New town Centre	Japan	green vs residential and commercial areas
Oke TR (1979). Advectively assisted evo-transpiration from irragated urban vegetation. Boundary-layer Meterology. Vol 17 (2): 167-173.	Vancouver	Canada	irrigated lawn
Sun, B., T. Wu, et al. (2006). "A preliminary study on effects of four urban greenbelt types on human comfort in Shenzhen, P.R. China." Chinese Forestry Science and Technology 5(2): 84-92.	Schenzen	China	lower crown density (0.2) ns higher crown density (0.7/0.8)
Welsch, J. (1985). "Climatic investigation of spaces around housing blocks in the Berlin-Kreuzberg district as a contribution to the improvement of living conditions." Klimatische Untersuchung von Blockinnenhöfen im Bereich von Berlin-Kreuzberg als Beitrag zur Verbesserung der Wohnumfeldsituation. 34(12): 844-854.	Berlin	Germany	6 fixed sites and 93 mobile sites with varying plant abundance and structure amongst other factors

(ii) Studies in the Tropical Zone

Citation	**Urban area**	**Country**	**Greening comparison**
Emmanuel, R. (2005). "Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR), Sri Lanka." Building and Environment 40(12):	Colombo	Sri Lanka	"hard cover" = buildings, paved areas, roads vs "soft cover"=trees, green areas, waterbodies

1591-1601.			
Kruger, E. and B. Givoni (2007). "Outdoor measurements and temperature comparisons of seven monitoring stations: Preliminary studies in Curitiba, Brazil." Building and Environment 42(4): 1685-1698.	Curitiba	Brazil	built area; paved area vs forests and trees
Kruger, E. and B. Givoni (2007). "Outdoor measurements and temperature comparisons of seven monitoring stations: Preliminary studies in Curitiba, Brazil." Building and Environment 42(4): 1685-1698.	Curitiba	Brazil	built area; paved area vs forests and trees
Wong, N. H. and C. Yu (2005). "Study of green areas and urban heat island in a tropical city." Habitat International 29(3): 547-558.	Singapore	Singapore	various urban locations

Appendix K - Thermal comfort studies

(i) Studies in the Temperate Zone

Citation	Urban area	Country	Measures of thermal comfort	Greening intervention
Bacci, L. and M. Morabito (2003) Thermohygrometric conditions of some city parks of Florence (Italy) and their effects on human well-being. Proc. of Fifth International Conference on Urban Climate, Lodz (Poland), 1-5 September	Florence	Italy	Scharlau Index for winter months, Apparent Temperature (AT) index for summer months	Green Areas
Ca, V. T., T. Asaeda, et al. (1998). "Reductions in air conditioning energy caused by a nearby park." Energy and Buildings 29(1): 83-92.	Tama New Town	Japan	Predicted Mean Vote	Parks
Georgi, N. J. and K. Zafiriadis (2006) The impact of park trees on microclimate in urban areas. Urban Ecosystems 9, 195-209.	Thessaloniki	Greece	Discomfort Index Values	Trees

Gomez, F., L. Gil, et al. (2004). "Experimental investigation on the thermal comfort in the city: relationship with the green areas, interaction with the urban microclimate." Building and Environment 39(9): 1077-1086. See also Gomez, F., N. Tamarit, et al. (2001). "Green zones, bioclimatics studies and human comfort in the future development of urban planning." Landscape and Urban Planning 55(3): 151-161. Gomez, F., L. Gil, et al. (2004). Climate indicators for cities. Sustainable City Iii: Urban Regeneration and Sustainability. N. Marchettini, C. A. Brebbia, E. Tiezzi and L. C. Wadhwa. Southampton, Wit Press. 18: 91-102. Gomez, F., V. Sifre, et al. (2006). Sustainability in cities: the green areas and climatic comfort as fundamental parameters. Sustainable City Iv : Urban Regeneration and Sustainability. U. Mander, C. A. Brebbia and E. Tiezzi. Southampton, Wit Press/Compu	Valencia	Spain	Thom's discomfort index, wet-bulb globe temperature, the Vinje's cooling power	Soft cover
Gulyas, A., J. Unger, et al. (2006). "Assessment of the microclimatic and human comfort conditions in a complex urban environment: Modelling and measurements." Building and Environment 41(12): 1713-1722.	Szeged	Hungary	PET	Trees
Harlan, S. L., A. J. Brazel, et al. (2006). "Neighborhood microclimates and vulnerability to heat stress." Soc Sci Med 63(11): 2847-63.	Phoenix	USA	Human thermal comfort index	Soil-Adjusted Vegetation Index

Kempeneers, S. (1982). "The integration of bioclimatology in an environmental study." Energy and Buildings 4(2): 85-89.	Kenitra	Morocco	Discomfort index; resultant temperature; P4SR	Vegetation cover
Mao, L. S., Y. Gao, et al. (1993). "Influences of street tree systems on summer micro-climate and noise attenuation in Nanjing City, China." Arboricultural Journal 17(3): 239-251.	Nanjing	China	Discomfort Index Values	Trees
Mayer, H. and P. Hoppe (1987). "Thermal comfort of man in different urban environments." Theoretical & Applied Climatology 38(1): 43-49.	Munich	Germany	PET, PMV	Green Areas
Potchter, O., P. Cohen, et al. (2006). "Climatic behavior of various urban parks during hot and humid summer in the Mediterranean city of Tel Aviv, Israel." International Journal of Climatology 26(12): 1695-1711.	Tel Aviv	Israel	PET	Parks
Streiling, S. and A. Matzarakis (2003). "Influence of single and small clusters of trees on the bioclimate of a city: A case study." Journal of Arboriculture 29(6): 309-316.	Freiburg	Germany	PET	Trees
Sun, B., T. Wu, et al. (2006). "A preliminary study on effects of four urban greenbelt types on human comfort in Shenzhen, P.R. China." Chinese Forestry Science and Technology 5(2): 84-92.	Schenzen	China	Human thermal comfort index	Trees
Thorsson, S., T. Honjo, et al. (2007). "Thermal comfort and outdoor activity in Japanese urban public places." Environment and Behavior 39(5): 660-684.	Matsudo	Japan	Thermal perception; PET	Parks
Toy, S., S. Yilmaz, et al. (2007). "Determination of bioclimatic comfort in three different land uses in the city of Erzurum, Turkey." Building and Environment 42(3): 1315-1318.	Erzurum	Turkey	THI and "beer garden days"	Trees

(ii) Studies in the Tropical Zone

Citation	**Urban area**	**Country**	**Measures of thermal comfort**	**Greening**

				intervention
Barradas, V. L. (1991). "Air temperature and humidity and human comfort index of some city parks of Mexico City." Int J Biometeorol 35(1): 24-8.	Mexico City	Mexico	Thermal comfort index	Parks
Emmanuel, R. (2005). "Thermal comfort implications of urbanization in a warm-humid city: the Colombo Metropolitan Region (CMR), Sri Lanka." Building and Environment 40(12): 1591-1601.	Colombo	Sri Lanka	Temperature Humidity Index; Thermal Strain index	Soft cover

Appendix L - Remote sensing of temperature

Aniello, C., K. Morgan, et al. (1995). "Mapping Micro-Urban Heat Islands Using Landsat Tm and a Gis." Computers & Geosciences 21(8): 965-&.

Bai, X. H., S. H. Tang, et al. (2003). Study of relation between thermal distribution and the underground medium in urban area. Igarss 2003: Ieee International Geoscience and Remote Sensing Symposium, Vols I - Vii, Proceedings - Learning from Earth's Shapes and Sizes. New York, I E E E: 1392-1394.

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Appendix N - Empirical studies on ozone

Citation	Urban area	Country	Outcome	Data collection	Key results
Abdollahi, K. K., J. Sun, et al. (1996). Relative ability of urban trees and shrubs in removing ozone (O-3). Proceedings of the 1996 Society of American Foresters Convention - Diverse Forests, Abundant Opportunities, and Evolving Realities. Washington, So	urban shrubs and trees	USA	O3	Ozone uptake rates were quantified for sapling 12 species (various number of individuals) using a controlled plant-air pollution laboratory system.	All species tested (Thuja orientalis, Pinus elliottii, Cupressocyparis leylandii, Camellia japonica, Elaeagnus angustifolia, Sapium sebiferum, Koelreuteria paniculata, Liriodendron tulipifera, Fraxinus velutina, Rhododendon luteum, Viburnum buddleifolium, Cleyera japonica) could uptake ozone. This varied from 0.34 mg O3 dm2 hr (Azalea) to 0.096 (Russian Olive).
Allegrini, I., M. A. Giannini, et al. (2000). Statistical analysis of ozone	Rome	Italy	O3	Measurements taken at a green park and a high motor traffic	Rather than compare these two sites, the article aims to predict

concentration: a forecasting and control model in urban areas. Urban Transport V: Urban Transport and the Environment for the 21st Century. L. J. Sucharov. Southampton, Wit Press.				street.	the dynamics of ozone in the environment.
Cheung, 2002, Extreme heat, ground level ozone concentration and the urban heat island effect, in Washington DC	Washington Metropolitan Area	USA	O3 (and temperature)	Ozone concentrations were available from 17 monitoring stations throughout the region. Temperature and NDVI were measured from satellite imagery. No. of days of measurement in analysis not clear.	Air temperatures correlated with maximum 1-hr average ground level O3 concentrations, and surface temperatures were linked with NDVI. Suggested links between O3 and NDVI.
Ciacchini, G., M. Vincentini, et al. (1997). "Ozone measurements in the urban and extra-urban areas of Pisa during the summer of 1995." J Environ Pathol Toxicol Oncol 16(2-3): 111-7.	Pisa	Italy	O3	Measurements were taken in five different areas (Pisan coastline; an urban area with a high volume of traffic, a rural area; Monte Serra and within a small urban park. Ozone was measured hourly from June to September.	Ozone levels change over the season. The park tends to reach higher ozone concentrations than the urban site during the day. Effects of sea breeze and altitude.
Corchnoy, S. B., J. Arey, et al. (1992). "Hydrocarbon Emissions from 12 Urban Shade Trees of the Los-Angeles, California, Air Basin." Atmospheric Environment Part B-Urban Atmosphere 26(3): 339-348.	street trees approved for Los Angeles	USA	BVOC	Emission rates (isoprene and monoterpenes) of 12 species were tested using a dynamic flow-through enclosure technique in an outdoors environment. In all but two species, only one specimen was examined (3-8 measurements on each). Nine individuals of the Canary Island pine were examined.	There were differences between trees. Ranking of trees based on emission rates (lowest to highest): Crape myrtle, Camphor, Aleppo pine, Deodar cedar, Italian Stone pine, Monterey pine, Brazilian pepper, Canary Island pine, Gingko, California pepper, Liquidambar, Carrotwood. Measurements on difference specimens of the Canary Island pine show that emissions can vary between different individuals. Any emissions from the Crape myrtle were not

					detectable.
Donovan, R. G. (2003). "The development of an urban tree air quality score (UTAQS) and its application in a case study." Ph.D., Lancaster 54-13585 (BL: DXN085750)(D8).	trees common in the West Midlands	UK	BVOC	Isoprene and monoterpene emission for 8 species (2-4 trees for each) were measured using a dynamic PTFO branch enclosure. Oak and Silver Birch were tested in natural (park-like university campus) and stressed (along urban roads) conditions.	All species tested (Lawson Cypress, Hawthorn, Leyland Cypress, Sycamore, Hazel, Goat Willow, English Oak and Silver Birch) released either or both isoprene or monoterpene. Oak in 'natural' conditions emitted the most isoprene.
Kuttler, W. and A. Strassburger (1999). "Air quality measurements in urban green areas - a case study." Atmospheric Environment 33(24-25): 4101-4108.	Essen	Germany	O3, NO2/NO	12 measurements trips were made around the city, over a period of 13 months, incorporating different land used (motorways, main and secondary roads, residential areas and green area).	Green areas had less NO and NO2, but more O3. Concentrations depended on wind speed.
Li, D. W., Y. Shi, et al. (2008). "Volatile organic compound emissions from urban trees in Shenyang, China." Botanical Studies 49(1): 67-72.	street trees located in Shenyang	China	BVOC	Measurements of the isoprene and monoterpene emission of Chinese Pine located in streets taken once a month between May and September. 3 trees were measured. Emissions were collected using a bag-enclosure method around the foliage.	Various compounds were released; α-pinene was most abundant and this was greatest in August compared to other months. The seasonal variation of other compounds was different.
Mazzeo, N. A., L. E. Venegas, et al. (2005). "Analysis of NO, NO2,O-3 and NOx concentrations measured at a green area of Buenos Aires City during wintertime." Atmospheric Environment 39(17): 3055-3068.	Buenos Aires City	Argentina	O3 and NO2/NO	Measurements taken over 38 days from August to September, every half hour, within a green area.	The article focuses on the diurnal dynamics of ozone and its relationship with nitrogen oxides.
Noe, S. M., J. Penuelas, et al. (2008). "Monoterpene emissions from ornamental trees in urban areas: a case study of Barcelona, Spain." Plant Biology 10(1): 163-169.	Barcelona University campus	Spain	BVOC	11 species (2/3 individuals of each) of non-native trees were tested for emissions using a cuvette. Trees were either found on the university campus or as a potted plant, but most measured	All species including conifers and angiosperms released monoterpenes (Catalpa speciosa, Cedrus libanii, Eucalyptus spp., Laurus nobilis, Magnolia grandiflora, Platanus hispanica,

				were conducted outdoors.	Robinia pseudoacacia, Tamarix gallica, Tamarix parviflora, Taxus baccuta, Viburnum lantana)
O'Donoghue, R. T. and B. M. Broderick (2007). "C-2-C-6 background hydrocarbon concentrations monitored at a roof top and green park site, in Dublin City centre." Environmental Monitoring and Assessment 132(1-3): 491-501.	Dublin	Ireland	VOC (Non-methane hydrocarbons)	3-5 week monitoring campaign in May and June was carried out in the city centre, comparing a roof-top, green-field and roadside site.	Hydrocarbon concentrations were usually lower in the park.
Streiling, S. and A. Matzarakis (2003). "Influence of single and small clusters of trees on the bioclimate of a city: A case study." Journal of Arboriculture 29(6): 309-316.	Freiburg	Germany	VOC (and temperature)	Measurements were taken inside tree crown of a single tree and a tree cluster of Horsechesnut, as well as nearby non-green sites, on 2 days in September (only one day presented on the article). Using an activated sorption material.	No VOCs were detected.
Stroud, C. A., J. M. Roberts, et al. (2002). "Nighttime isoprene trends at an urban forested site during the 1999 Southern Oxidant Study." Journal of Geophysical Research-Atmospheres 107(D16).	Nashville	USA	VOC	Measurements of isoprene and its oxidative products were taken over a period of a month between June and July at night within an urban forest.	The article focuses on the dynamics and chemistry of isoprene.
Takahashi, M., A. Higaki, et al. (2005). "Differential assimilation of nitrogen dioxide by 70 taxa of roadside trees at an urban pollution level." Chemosphere 61(5): 633-9.	greenhouse in Hiroshima	Japan	NO2	NO2 assimilation was measured for 70 species (1-3 individuals of each) of woody plants used as roadside trees, using isotope-labelled NO2 in a fumigation chamber.	The ability to assimilate NO2 differed by a factor of 122 between the highest (Prunus yedoensis) and the lowest (Cryptomeria japonica). There was some evidence that deciduous woody plants had a greater ability to assimilate NO2 in their leaves than evergreen species.
Weber, K., A. Ropertz, et al. (2004).	Dusseldorf	Germany	One large	Measurements were taken over a	The park tended to have lower

"Measurement and analysis of the air quality within the region of an urban green area using optical remote measurement techniques." Gefahrstoffe Reinhaltung Der Luft 64(6): 271-279.			green area and adjacent streets	year in the park and street.	concentrations of NO, NO2 but could have greater O3.
Xian & Crane (2006). The study of ozone variations in Las Vegas Metropolitan area using remote sensing and ground observations. Sixth Symposium on the Urban Environment AMS Forum: Managing our Physical and Natural Resources: Successes and Challenges. 1.5	Las Vegas Valley	USA	O3 and NO2/NO (and temperature)	Uses multi-year data collected from 10 monitoring stations that took measurements hourly. 8 stations selected to explore the relationship between average annual ozone concentration and NDVI.	Some indication that higher NDVI is linked with lower O3 concentrations. Highest ozone concentrations are associated with medium to low-density urban development.
Xiaoshan, Z., M. Yujing, et al. (2000). "Seasonal variations of isoprene emissions from deciduous trees." Atmospheric Environment 34(18): 3027-3032.	urban trees in Beijing	China	BVOC	Isoprene emissions from 12 tree species (1-13 measurements) in and around Beijing city using a bag-enclosure method.	Emissions were not detectable from some species (Paulownia tomentosa, Cedrus deodara, Firmiana simplex, Fraxinus chinesis, Duplex, Juglans regia) while; two species were negligible (Ginkgo, Magnolia denudata) but was greater for other species (Platanus orientalis, Pendula loud, Populus simonii, Salix matsudana koidz). Some support for effects of light, temperature and season.

Appendix O - Modelling studies on ozone

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Appendix P - UV studies

Citation	Urban area	Country	Comparison	Data collection	Key results
Gies, P., R. Elix, et al. (2007). "Assessment of the UVR protection provided by different tree species." Photochem Photobiol 83(6): 1465-70.	trees in Adelaide	Australia	6 tree species commonly used in urban Australia - in the shade and in the full sun.	The UV protection of 6 species (4 trees of each)was tested at solar noon during one day in 5 different months (Oct, January - April) by placing UVR sensitive polysulphone badges beneath, and compared to a full sunshine site.	All tree tested (White Cedar, Jacaranda, Kurrajong, Brush Box, Celtis (Nettle) and Golden Rain) provided some UV protection.
Grant, Heisler, Goa, Jenks 2003. Ultraviolet leaf reflectance of common urban trees and the prediction of reflectance from leaf surface characteristics. Agricultural and Forest Meterology vol 120:127-139.	trees in West Lafayette (Indiana)	USA	20 deciduous tree species	Measures the spectral reflectance and transmittance of leaves for 20 deciduous tree species (3 leaves for each). Reflectance measured with a spectrophotometer.	UV transmittance was small. Leaves can reflect UV, and this was suggested to be affected by epicuticular wax structures on the lead surface, which may vary between species.

Heisler & Grant & Rao 2005. UV exposure in the shade.Bulletin of the American Meterological Society. 86(1):p29.	NA	NA	Compares different tree covers	Models the UVB irradiance for various levels of cloud and tree cover.	Increasing tree cover is predicted to decrease the mean erythemal irradiance (sunburn effectiveness).
Heisler, Grant & Gao (2003). Individual and scattered tree influences on UV irradiances. Agricultural and Forest Meterology. Vol. 120:113-126. See also Heisler, G. M., R. H. Grant, et al. (2002). Urban tree influences on ultraviolet irradiance. Ultraviolet Ground- and Space-Based Measurements, Models, and Effects. J. R. Slusser, J. R. Herman and W. Gao. Bellingham, Spie-Int Society Optical Engineering. 4482: 277-290.	trees in West Lafayette (Indiana)	USA	In and out the shade of a 3 trees sites (single tree, cluster of street trees and a park-like grove)	Irradiance measurements were taken with sensors in and out of the shade of trees at 3 sites at various times.	Shading provided by trees can reduce UVB but this can also be affected by sky diffuse radiance, reflectance from leaves and urban surfaces.
Heisler & Grant 1997.Ultraviolet radiation, human health and the urban forest. USDA Forest Service General Technical Report NE-268.	NA	NA	review paper	Reviews the effect of vegetation on UV, and presented data from the authors work and other studies.	

Appendix Q - Other language studies

The following summarisation is based on information only provided in the English abstract of the article.

Citation	Outcome	Place	Country	Greening intervention	Question/Methods	Results

Chen, I.-c. and S.-m. Pan (1998). "The Air-cleaning Capacity of Street Trees." Jour. Exp. For. Nat. Taiwan. Univ. 12(4):309:316.	Ozone and Nitrogen dioxide	street trees in Taipei	Taiwan	7 common tree species	Depletion rate of the gases by the trees was measured (also measured the stomatal conductance and anti-oxidant enzymes)	The results suggest that trees could deplete ozone and nitrogen dioxide.
Jiao, X. J., W. F. Zhao, et al. 2007. A Study on Reduction of the Heat Island Effect by Three Urban Tree Species. Journal of Jiangxi Agricultural University.	Temperature (and humidity, O2, CO2)	NA	Northern China	3 urban tree species, Sophora japonica, Acer mono, Platanus orientalis	Diurnal photosynthesis and transpiration were measured.	Effects of cooling and humidification differed among the tree species. P.orientalis cooled the most (0.31 ^{o}C)
Jin, W., Y. Yao, et al. (2002). "Microclimate effect of urban forest." Journal of Northeast Forestry University 30(3): 115-117.	Temperature (and humidity)	Shanghai City	China	"the representative urban forest"	Microclimate effects	"The results show that the urban forest has a much more influence on the temperature and humidity in the leeward of the forest than the windward".
Li, C., J. Yu, et al. (1997). "Evaluation of tree species for absorption and tolerance of ozone and nitrogen dioxide (II)." Quarterly Journal of the Experimental Forest of National Taiwan University 11(4): 31-47.	Ozone and Nitrogen dioxide	Taipei (lab or outdoors ?)	Taiwan	23 tree species (Diospyros ferrea, Antidesma japonicum, Neolitsea aciculata, Schima superba, Podocarpus macrophyllus, Pittosporum pentandrum, Clausena excavata, Daphniphyllum glaucescens, Ehretia thyrsiflora, Diospyros discolor, Scolopia oldhamii, Elaeocarpus sylvestris, Cyclobalanopsis gilva, Castanopsis cuspidata, Cyclobalanopsis morii, Pasania nantoensis, Cyclobalanopsis sessilifolia,	Rate of deposition and the lowest concentration of the gases causing damage were measured.	Absorption (deposition) varied among species, and this depended on the concentration of the gases. Trees also varied in their tolerance, which depended in gas concentration.

				Quercus championii, Pasania hancei, Pasania brevicaudata)		
Ma, J., D. Cui, et al. (2007). "Comparison of air-cooling effect of urban tree species in Jilin City." Journal of Northeast Forestry University 35(10): 90-91.	Temperature	Jilin City	China	27 urban tree species (Ulmus pumila, Taxus cuspidatea, Prunns mandshurica, Acer negundo, Picea koraiensis, Populus canadensis, Prunus davldiana, Forsythia suspensa, Sabina vulgaris, Salix matsudana, Koelreuteria paniculata, Prunus tomentosa, Picea crassifolia, Ligustrum suave, Abies holophlla, Crataegus pinnatifida, Spiraea trichocarpa, Acer mono, Syringa microphylla, Populus alba, Pinus tabulaeformis, Ulmus pumila, Prunus triloba, Sabina chinensis, Pinus sylvestris, Spiraea thunbergii, Syringa oblata).	Studied the air-cooling effects of trees by comparing the temperature within the vertical projection of tree crowns with the temperature of the control spot, without plants.	The air-cooling effect varied among species.
Mechkuev, R., M. Chuchkova, et al. (1979). "Kum khigienniia efekt na ozeleniavaneto v gradskite zoni." Probl Khig 4: 110-21.	Temperature (and humidity?)	Sofia	Bulgaria	2 blocks of flats with different degree of gardens and parks lain out and in a town park	Basic physical, chemical and physiologic parameters were measured and compared.	More greenery suggested a more 'favourable' temperature
Sung, C., Y. Wang, et al. (1998). "Evaluation of tree species for absorption and tolerance to ozone and nitrogen dioxide (III)." Quarterly Journal of the Experimental Forest of National Taiwan University 12(4): 269-	Ozone and Nitrogen dioxide	Taipei (lab or outdoors ?)	Taiwan	19 trees species (Alnus formosana, Cinnamomum camphora, Liquidambar formosana, Swietenia mahagoni, Bischoffia javanica, Melia azedarach, Acer rubescens, Pistacia chinensis, Fraxinus formosana, Sapindus mukorossi, Hibiscus mutabilis, Alstonia scholaris, Lagerstroemia speciosa, Camptotheca acuminata,	Rate of deposition and the lowest concentration of the gases causing damage were measured.	Absorption (deposition) varied among species, and this depended on the concentration of the gases. Trees also varied in their tolerance, which depended in gas concentration.

288.				Pittosporum pentandrum, Radermachera sinica, Ginkgo biloba, Juglans cathayensis, Samanea saman)		
Szumacher, I. (2005). Funkcje ekologiczne parków miejskich Translated Title: Ecological functions of urban parks. In: Integrated Landscape Studies and Their Application; 36/- (107-120): Poland Series: Prace i Studia Geograficzne.	Temperature (and others)	various	various [written in Polish but data from several countries]	Parks in various countries	Analysed the climate, biotic, soils, hydrological, pollution absorption and the dependence between parks' origin, position in the city and natural landscape components.	Not discussed in the abstract.
Wu, L. and F. Zhang (2003). "A study on the air temperature in the urban forest of Nanjing." Journal of Nanjing Forestry University 27(6): 31-34.	Temperature	Nanjing	China	"urban forest"	Temperature data measured at 2 stations (an urban site and an open site of the ecological station) from 1998 to 2001.	Means of the air temperature in an open sites of the urban forest are lower than the urban site. The cooling effect is greater at night than in the day.
Xu, L., Q.-G. Zhang, et al. (2008). "Analysis of spatial structure and microclimate effects of urban green space of Hefei City." Hefei Gongye Daxue Xuebao (Ziran Kexueban) / (Journal of Hefei University of Technology) (Natural Science) 31(2): 216-	Temperature	Hefei	China	woodland, lawn vs barren land	Analyses the microclimate effects of different landscapes	In the day, maximum temperature of the woodland was greater than the lawn, and maximum temperature of the lawn was greater than the barren land.

219.						
Zhang, Y., C. Jiang, et al. (2006). "Ecological effects of urban climbing plant Parthenocissus tricuspidata." Journal of Zhejiang Forestry College 23(6): 669-672.	Temperature (and humidity, O_2, CO_2)	NA	China	Climbing plant, Parthenocissus tricuspidata	Leaf photosynthesis and transpiration were measured.	Results shows that Parthenocissus tricuspidata absorbed CO_2 and released O_2 in the favourable soil moisture condition, which reduced air temperature and increased air humidity. With soil water stress increased, these effects decreased.
Zhu, N., M. Li, et al. (2002). "[Ecological functions of green land system in Harbin]." Ying Yong Sheng Tai Xue Bao 13(9): 1117-20.	Temperature (and humidity, PAR and CO_2)	Harbin	China	trees, shrubs, herbs and lawn	Outcomes were measured outside and inside each of the greening types.	Except lawn, green areas provided shading. Trees and shrubs lowered the temperature the most.