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To green or not to green! That is the question. Does green infrastructure provide significant thermo-regulation in a maritime temperate climate?

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Abstract

The ecosystem service delivery of urban green infrastructure (UGI) is now manifest. Types and level of service provision, however, can alter radically, based on factors such as location, species choice, planting design and vegetation management. The value of vegetation to provide a cooling service is generally understood in hot climates, but the merit in temperate climates remains ambiguous. Indeed, policy makers within cooler countries (e.g. UK) remain to be convinced that expenditure on UGI is justified, at least from the point of view of city cooling alone. Occasional warm days do occur of course, and climate change models predict that heat wave events will become more frequent within the UK, including those that pose a risk to human health. To help UK policy makers make better-informed decisions around UGI, a number of our research programmes have targeted the role vegetation plays in regulating temperature, but specifically within the context of a maritime-temperate climate. Two examples of 'green interventions' are discussed here. The first documents the role of green façades to cool a wall system and the second illustrates the cooling influence conferred by roadside trees. Both experiments used a replicated sampling approach to ensure statistical robustness, and hence convince policy makers that data is representative of UK scenarios and results are reproducible. In the first experiment, 10 separate wall sections are used to investigate the cooling influence of two different plant genotypes (*Prunus* and *Phaseolus*) on both exterior and interior wall spaces. In the second study, road surface temperatures are documented with respect to both built and green infrastructure, i.e. we compare the influence of buildings and street trees on the surface temperatures across a road profile. Again replicate data are used to provide a 'generic' summer temperature profile for the city of Sheffield, rather than just specific locations at one point in time. Results show that green facades can reduce exterior and interior (cavity) wall air temperature by 3°C and 5°C respectively. Likewise, large street trees have a mean cooling influence of 4.5°C on road surfaces near their base compared to comparable sections adjacent to buildings. To maximise cooling, the data suggests that trees need to be provided on both sides of a roadway, i.e. a single tree did not manage to cool the pavement at the opposite side of the road. The implications of the results for temperate climates are discussed.

Keywords: Cooling, ecosystem services, road, street tree, urban, wall

INTRODUCTION

In a nation 'internationally renowned' for wind, rain and moderate temperatures, convincing politicians and policy makers that heat stress and human thermal discomfort may be significant problems in a future UK can be a 'hard sell'! Even to date the record official highest air temperature for the UK is only 38.5°C. The context is very different to some of the early work on thermal regulation via vegetation in the semi-arid regions of North America (Akbari et al., 1997). Nevertheless, more extreme weather events are predicted in line with climate change models, including increased frequency and severity of warm summer periods in the UK. Added to this, heat stress does occur within the British Isles albeit on an infrequent basis to date, and a number of cities are noticing more aggressive heat island effects. Although UK policy makers are beginning to embrace urban green infrastructure (UGI) for a range of ecosystem services (e.g. Cameron and Hitchmough, 2016, Cameron and Blanusa, 2016), the requirement, and indeed ability to provide localised cooling during summer remains to be largely accepted and adopted. Moreover, many policy makers remain sceptical of case studies (i.e. limited replication of site specific influences), and value strong empirical data before altering existing policies. The approach here, as well as elsewhere (e.g. Hunter et al., 2014), therefore, has been to use a high replication approach to determine if *generic* effects due to green infrastructure can be elicited. We provide some examples in this paper where this replicated approach has been used to determine the value of UGI both at a micro-climate scale (around a wall façade system in the first two experiments) and at the somewhat larger scale of urban streetscapes in the third experiment.

MATERIALS AND METHODS

Three separate experiments were conducted to determine the cooling influence of vegetation across three different scenarios. A key common theme in each case was to use a replicated treatment approach to provide data sets that represented generic findings, not site specific information. The first two experiments used an artificially created 'wall' scenario, whereas the third experiment used genuine street scenes, but categorised these in to broad profiles based on the presence of trees or buildings adjacent to the roadway.

Experiment 1. Green facades with *Prunus laurocerasus*: Air and surface temperatures

A set of ten vertical cavity brick walls were constructed at the University of Reading, UK using a standard house brick. Wall sections were 2.4 m long x 1.2 m high with a cavity space of 60 mm. Two lines of walls were constructed on an east-west axis, with wall sections isolated from each other in each block by a polystyrene infill. The two lines were constructed, set 4.7 m apart, with 5 separate wall sections in each row. Air temperature (Hobo Pro V2 External Temperature Sensors within Stevenson's screens) was recorded 80 mm from the exterior skin of each wall and 1 m in front of each wall, and data compared to that recorded in a mini-met station located in the centre of the wall site. Temperature sensors were accurate to +/- 0.2^{o}C and calibrated every 3 weeks. In addition to air temperatures, wall surface temperatures were recorded at specified times and under a range of climatic conditions (temporarily lifting plant foliage away from the walls as required) using a thermal camera (NEC Thermo Tracer TH7800; 0.1^{o}C resolution and emissivity set to 0.95).

Plants of *Prunus laurocerasus* (*Prunus* treatment) grown in 20 L pots were placed around 4 walls (4 plants for the north and 4 plants for the south aspect of each wall). For 3 additional walls, pots containing growing media alone (60% John Innes compost, 20% peat, and 20% perlite), were placed in equivalent locations (*Pot+media*), to ascertain thermal effects due to the pot/damp media. Finally, 3 other walls had nothing placed in front of them (*Control*). To avoid bias due to specific locations, the three treatments were re-randomised across the walls every 10 days. All locations irrespective of the presence of plants or not, were irrigated with 4 L of water per day. Air temperatures at the central weather station (ambient) and within the vicinity of the wall (wall) were recorded from 18th Aug until 19th Sep, 2011. Values for 10 min before, on and 10 min after each half-hour interval were used to provide mean values for each wall/location, and data are depicted for diurnal trends between 8.00 and 23.30 (inclusive).

Experiment 2. Green facades with *Phaseolus vulgaris* 'Cobra': Exterior air and interior air (cavity) temperatures

Similar approaches to Experiment 1 were employed, although in this case a leafy annual climbing plant *Phaseolus vulgaris* 'Cobra' was used to screen the walls. In addition Hobo thermacouples were inserted and sealed into the wall cavities of each wall. Data was recorded one year later than Experiment 1, but slightly earlier in the season than, i.e. June 28th to August 16th 2012.

Experiment 3. Street morphology and thermal profiles

Road locations with contrasting street morphology were identified in western Sheffield, using Google maps, and stratified to compare cross sectional transects of roads that composed *building – building, tree-tree* or *building-tree* profiles (designated street scenarios). Each scenario was represented by 15 separate locations. The buildings in all cases were terraced housing with small front gardens (2-4 m wide), and trees were pavement planted and approx. 4-10 m in height (some trees were relatively old 80-100 years, but had been pollarded in the recent past). All scenarios were restricted to inner suburban landscapes, with low traffic use, i.e. not major arterial roads. Otherwise, there were site specific variables peculiar to each site, including variations on street orientation, street furniture (e.g. presence of lamp posts etc.) and predominant tree species. In each location (45 in total), surface temperatures were recorded at approx. 0.75 m intervals across the profile of each pavement and at 1.0 intervals across the road itself (giving 12 readings per transect). Surface temperatures were recoding using a digital laser infrared thermometer (model GM320, Benetech). Data was recorded in the morning (10.00 - 11.30) and the afternoon (14.00-15.30) for each site. Recording was restricted to days within June- Aug 2015 with air temperatures > 16°C, and in the absence of any precipitation during the recording period. Recording of sites were randomised in an attempt to avoid any inadvertent correlations treatments / times or weather.

Statistical approaches

Analysis of variance (ANOVA) was carried out taking account of the unbalanced design in Experiments 1 and 2 (e.g. in Exp. 1, 4 reps for one treatment, 3 reps for the others) and ensuring the variance in the data was homogenously distributed. Where mean temperatures are depicted as time course data, least significant difference LSD values (P = 0.05) are depicted hourly for clarity. In the case of road transects each of the 12 points in the transect (a-l) were compared with each other to provide an LSD for each point.

RESULTS

Experiment 1. Green facades with *Prunus laurocerasus*: Air and surface temperatures

The placement of *Prunus* plants cooled the air immediately adjacent to the wall by approximately 1.2°C on average over the late summer period (data meaned across all weather conditions and daylight hours). Differences in mean air temperature between blank walls and vegetated walls were significant, albeit by a relatively small overall magnitude (Fig. 1). Interestingly, even placing plants on the north side of walls improved the localised cooling on this façade. Comparing air and surface temperatures on a typically warm afternoon revealed greater magnitudes of difference, with 3°C differences noted in air temperatures (blank 23.6°C, *Prunus* 20.6°C; LSD 1.89) and 8.7°C difference on surface temperatures (blank 33.5°C, *Prunus* 24.8°C; LSD 1.42) on the south aspect. Overall, there were no significant differences between blank walls and those where pots with moist media were placed; in effect all the cooling was due to the presence of the foliage.

Experiment 2. Green facades with *Phaseolus vulgaris* 'Cobra': Exterior air and interior air (cavity) temperatures

Air temperatures adjacent to walls in the second year (*Phaeseolus*) showed similar trends to the *Prunus*, but a much greater margin in temperatures was noted in the interior air of the wall cavity (Fig. 2). For example, around mid-afternoon mean temperatures in the wall cavity of the vegetated walls was 5°C cooler than the non-vegetated. Overall, all daylight hours the temperature difference was a significant 2.8°C cooler in the cavities of the *Phaseolus* covered walls compared to the un-vegetated cavity walls (22.9 vs 25.7°C, LSD=0.26).

Experiment 3. Street morphology and thermal profiles

Surface temperatures in the middle of the road tended to be higher than pavements at the side of the road, for both morning and afternoon scenarios (Fig. 3). Roads that had trees placed at either side of the road had significantly lower surface temperatures compared to those roads with buildings adjacent to the road, both for the central part of the road (by about 3 to 4°C), as well as the pavements. In tree-lined avenues, locations nearest the trees could have surface temperatures approximately 4°C cooler than the central location of the road. In situations where only one side of the road was vegetated, then surface temperatures below the trees were comparable to roads with two lines of trees, but there was a decreasing cooling effect as the position moved away from the trees towards the build infrastructure (Fig. 3, B-G treatment). These data represent mean values; for any specific one location with a building-tree transect the maximum temperature gradient recorded was 7.2^{o}C.

DISCUSSION

Despite the rather temperate summer weather conditions experienced during these studies, the provision of green facades and street trees significantly reduced average air and surface temperatures in all three experimental studies. These replicated experiments reinforce previous observations about the value of green facades and walls to building cooling in other countries (e.g. Jim, 2015). The most dramatic decreases, were associated with the more extreme scenarios presented within the experimental periods, i.e. the benefits of vegetative cooling were manifest when solar irradiance and ambient air temperatures were highest, for example, an 8.7^{o}C reduction in wall surface (Exp. 1) and a 5^{o}C decrease in cavity temperatures (Exp. 2). The former wall surface cooling being comparable to that found in studies in warmer climates such as Greece (Eumorfopoulou and Kontoleon, 2009).

Similarly, by measuring temperature profiles over numerous streets, it is evident that the presence of trees is on average reducing surface temperature by approx. 4^{o}C. Further work is required by our group to assess air temperature below the tree canopies (and adjacent to buildings), but 4^{o}C surface temperature reduction has been correlated with reduction in air temperature of 1.2 and 2^{o}C, depending on species and scenarios being studied (e.g. Lin and Lin, 2010). Such temperatures reductions are in line in with improving human thermal comfort, and UK policy makers should consider such interventions when designing future cityscapes.

Possibly the most notable aspect of the work outlined here, is the consistent cooling effect on the cavity air temperatures. Previous work (Cameron et al., 2014) demonstrated that vegetation acts as a screen to cool surface temperature and affect interior air temperatures of single wall structures, but it was unclear how much an additional exterior layer of vegetation would actually impact on a thermally buffered pocket of air within a 'double skin' cavity wall system, i.e. the more common double walled system used in UK residential properties. Although not directly analogous, previous work has shown the advantage of green facades and walls on thermal fluxes to interior walls (Cheng et al., 2010). Clearly, the addition of vegetation was having a positive effect, and this has implications for the use of vegetated facades with modern buildings where the wall cavity is used. Further work is required to determine how vegetation interacts with other thermal screens (physical materials) and cavity insulation systems, but this research widens the opportunities where green walls might be employed.

Furthermore, the data at a larger scale on street trees suggest these too are positively influencing temperature profiles within a temperate climate and have role to play in cooling buildings / roadways and indeed, future proofing northern cities against heat island effects (Aguiar et al., 2014). These data sets representing different scales and scenarios demonstrate that much more emphasis needs to be placed on integrated green space design to maximise the opportunities for building / streetscape cooling (and indeed other urban ecosystem service provision).

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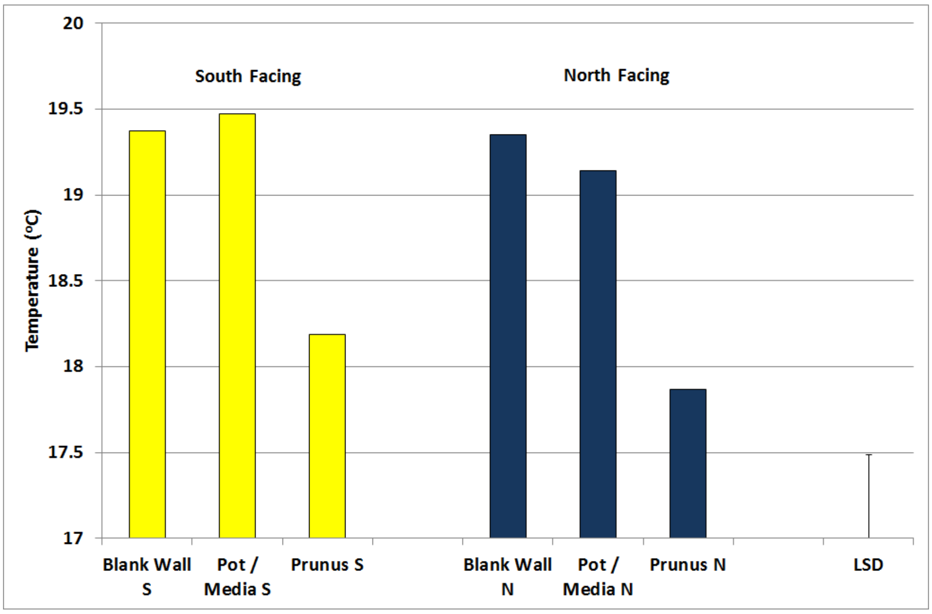

Figure 1. Air temperature at wall surface, with blank controls, pots and moist media or pot plant of *Prunus*. Data are meaned values for diurnal hours (8.00-23.30) for south (S – pale bars) and north facing (N – dark bars) aspects.

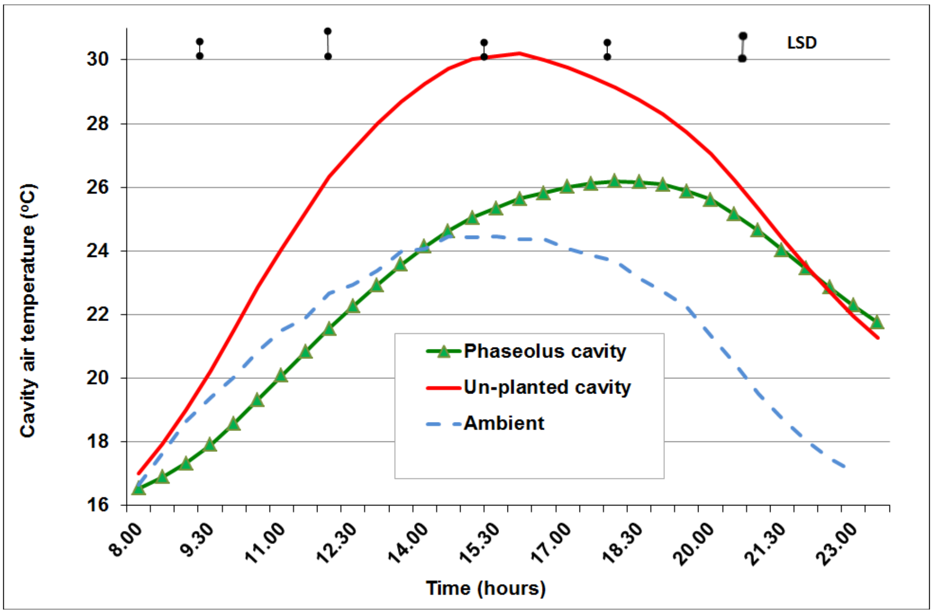

Figure 2. Mean half hourly air temperature inside wall cavity flanked by *Phaseolus* compared to unplanted Controls and ambient temperatures; 26 days: June 28th to August 16th. LSD 5%, df. 25 for selected times.

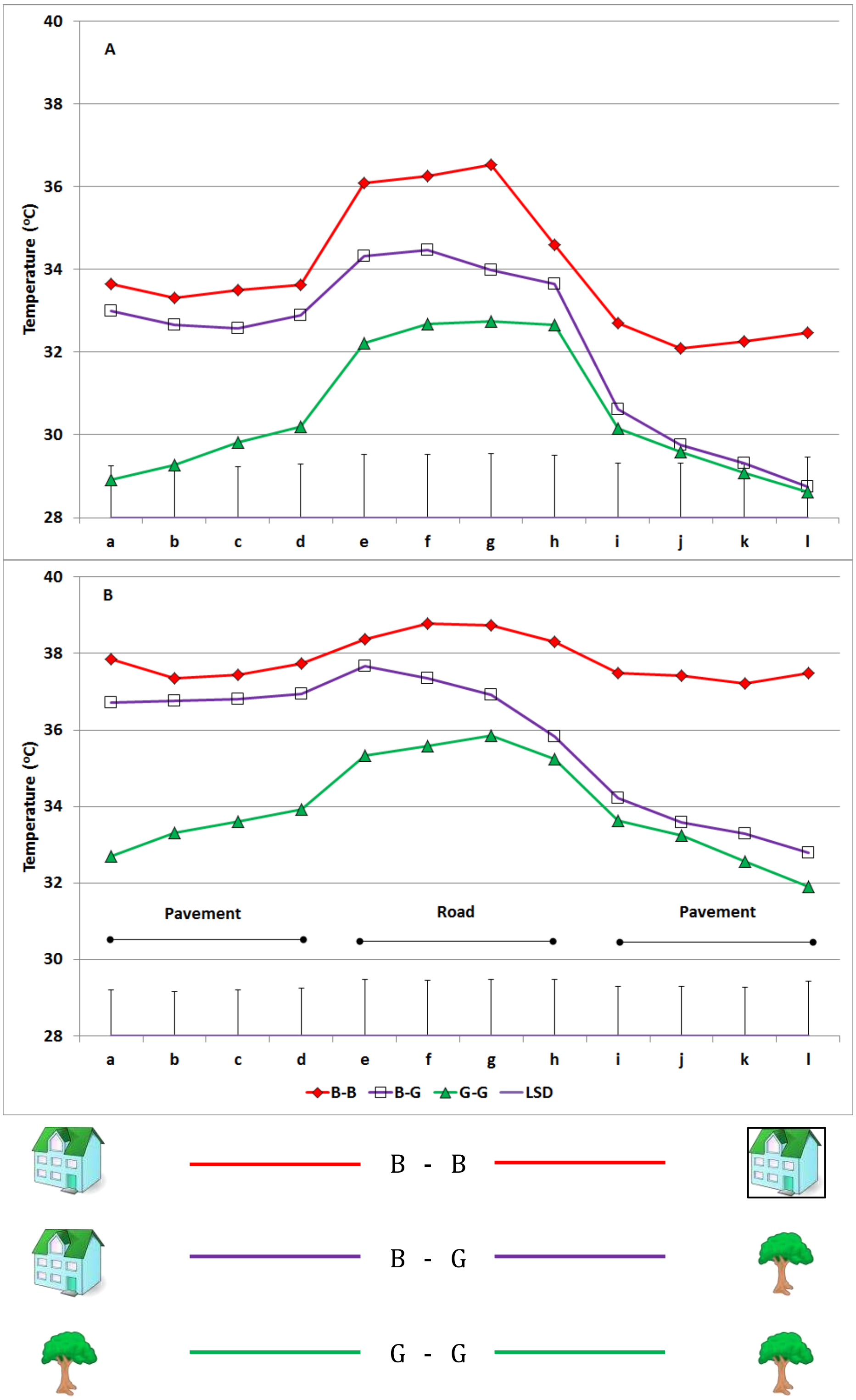

Figure 3. Surface temperature profiles across roadways in morning (A) and afternoon (B), as characterised by buildings either side of road (B-B), trees either side of road (G-G), or buildings on one side and trees on other.