



Green infrastructure enhancement in Glasgow: A proposal based on Local Climate Zone evaluation of urban morphology in a shrinking city

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1. Introduction

In the face of growing consensus on the anthropogenic causes for global climate change and the lag-times involved in the mitigation of such changes, there is considerable focus on the enhancement of adaptive capacity of human systems to cope with climate change. Given the rapid rise in global urbanisation much of the adaptive action needs to occur in cities. World's shrinking cities face additional problems in managing climate change. For example, in Glasgow – one such 'shrinking city' – even when urban growth has subsided, the local warming that result from urban morphology (increased built cover, lack of vegetation, pollution, anthropogenic heat generation) continue to generate local heat islands (Emmanuel and Kruger, 2012; Kruger et al., 2013). Such heat islands are of the same order of magnitude as the predicted warming due to climate change by 2050. And the micro-scale variations are strongly related to local land cover/land use patterns. However, current climate change adaptation strategies are more focused on reducing carbon emission than managing the change via land use / land cover manipulations, even though the latter is relatively easier to manage in shrinking cities.

In this paper we present a relatively less data-intensive method to classify local climate zones (LCZ) and evaluate the effectiveness of green infrastructure options in tackling the likely overheating problem in cold climate urban agglomerations such as the Glasgow Clyde Valley (GCV) region. LCZ classification used LIDAR data available with local authorities, based on the typology developed by Stewart and Oke (2012). Built cover/green cover and land use classes were used to identify LCZ classes, which in turn were used to cluster areas likely to exhibit similar warming trends locally. This helped to identify likely problem areas ('hot spots'), a sub-set of which were then modelled to quantify the effect of green cover options (both increase and reduction in green cover) as well as building density options.

2. Glasgow's heat island

Based on a four-pronged approach to map the local climate variations in and around the city of Glasgow (historic climate trends in the city; fixed weather station data in and around the city; microclimate variations at the street canyon level within the city core, and thermal perception of street users in the heart of the city centre) Emmanuel and Kruger (2012) and Kruger et al., (2013) found the following:

Even when urban growth has subsided, the local warming that result from urban morphology (increased built cover, lack of vegetation, pollution, anthropogenic heat generation) continue to generate local heat islands;

Such heat islands are of the same order of magnitude as the predicted warming due to climate change to 2050;

Substantial variations within city neighbourhoods exist and these relate to land use/land cover attributes, pointing to planning possibilities to locally mitigate the negative consequences of overheating;

Strategies to tackle local overheating can lead to less carbon intensive enhancement of comfort, health and quality of life both within and outside buildings.

3. Method

The pursuit of green infrastructure strategies to tackle the overheating problem due to climate change enhanced by local warming in the GCV required the following steps:

Identification of localities where local warming is likely to be the most intense (the 'hot spots');

Evaluation of the sensitivity of green infrastructure-based adaptation options to reduce these 'hot spots';

Sense testing the feasibility of adaptation options.

We classified the GCV region into LCZ classes using Ordnance survey and LIDAR data to estimate surface characteristics such as building cover, building height, land cover and/or land use. Additional ground truth verification of selected representative areas using 'Google Earth' and site visits helped verify building height and other physical parameters. The evaluation of the effect of green infrastructure was carried out using ENVI-met simulations. Six scenarios were run as detailed below:

1. 2012 climate with current development pattern = 'Current Case;'
2. 2050 climate (using UKCIP'09 projections) with planned development patterns as planned by the relevant local authority – 'Base Case';
3. 2050 climate with 'loss' of green infrastructure ('m10 case')
- 4-6. 2050 climate with three levels of increased green cover (+10%, +20% and +100% – p10, p20 and p100 cases, respectively)

Based on the simulation results we estimated the minimum likely need for green cover to make a significant difference to likely local warming in the future. We then used the Green Area Ratio method (Keeley, 2011) to normalise the climatic effects of different types of green cover (urban parks, street trees, green roofs, green walls, etc).

3.1 Effect of land use / land cover and local climate

The key to understanding the local climatic effect of land cover/land use characteristics is to classify the settlement area according to their key climate-influencing features.

a Site selection using the LCZ approach

The following steps were performed to determine the dominant LCZ classes in the GCV region and thus select 'representative' sample locations where local warming is likely to be problematic.

Determine the 'built-up' areas of the GCV

Calculate built fraction / green cover / natural cover within 1km dia circles placed in an array covering the entire 'built-up' area in the GCV identified in step 1

Classify each circle into relevant LCZ class, depending on built/green fraction and building height closely matching the urban morphological parameters as defined by Stewart and Oke (2012)

Determine the dominant LCZ class in closest proximity to an official weather station

The aim of the first step was to reduce the area of enquiry to few urban agglomerates to limit the computational time needed. We first downloaded the data for the area of interest from the Ordnance Survey Open Database. The GCV Region covers only a small part of the 100x100km NS square using the British National Grid reference system, for this reason a rectangular vector was created with ArcGIS to delimitate the area of the enquiry. 1519 equally distributed points were positioned within the rectangular area and a circular buffer of 500m in radius was added to each point. We then removed the building footprints from each buffer area and calculated the built up area ratios. The building cover were divided into categories (depending on their three dimensional properties) and each category was assigned a unique colour. This step enabled us to identify five locations with distinct urbanisation patterns: Glasgow City Centre, Glasgow eastside, Paisley, Wishaw and Hamilton. The choice was made taking into account the following criteria: percentages of buildings, closeness to the weather stations, importance of the area considering the population and political and economic factors.

The aim of the second step was to associate each of the above mentioned unique urban areas with an LCZ class and to select the precise area to model within each location. Five circumferences of 1km in radius were created. Four other circumferences of 500m in radius were created within each of the former circle. These smaller circles had their centre 500m north, south, east and west from the centre of each bigger circle, respectively. The percentages of building-, road-, roadside-, inland water-, green-, etc. area were calculated for all the circumferences using ArcGIS (v.10.1) and averaged to represent the coverage in each of the 1km radius circles. Figure 1 shows the results of these steps.

It could be seen from Figure 1 that the GCV region largely composes of two classes of 'semi-dense' urban morphology (LCZ 2 and 3 – Compact midrise, mainly Glasgow City centre) and three classes of 'sparse' settlement morphology (LCZ 5 – Open midrise: Paisley; LCZ 6 – Open lowrise: Clyde Gateway area; and LCZ 9 – Sparsely built: Wishaw and Hamilton).

Based on these results six sites were selected as follows. Each site has a domain area of 400m x 400m (See Figure 2 for locations):

- 1-2. LCZ 2 – Compact midrise two locations characterising this class: Glasgow City Centre West (Gla CCW) centred on the intersection of W Campbell Street & Bath Street (Coordinates – British National Grid; map projection: transverse Mercator; datum: OSGB: 36258595.665 – 665800.603 Meters) and Glasgow City Centre East (Gla CCE) comprising an area surrounding the George Square area, centred on the intersection of John Street & Ingram Street (259339.524 – 665260.852 Meters);
3. LCZ 6 – Open lowrise: Clyde Gateway area (London Road & Springfield Road) (260683.157 – 663742.061 Meters);
4. LCZ 5 – Open midrise: Paisley area (High Street & New Street) (248146.997 – 663988.741 Meters)
- 5-6. LCZ 9 – Sparsely built (or extensive lowrise): two locations characterising this class Wishaw (Caledonia Rd. and Main St.) (279691.562 – 655018.654 Meters), and Hamilton (Brandon St. and Quarry St.) (272438.576 – 655517.511 Meters)

Built cover and LCZ classes

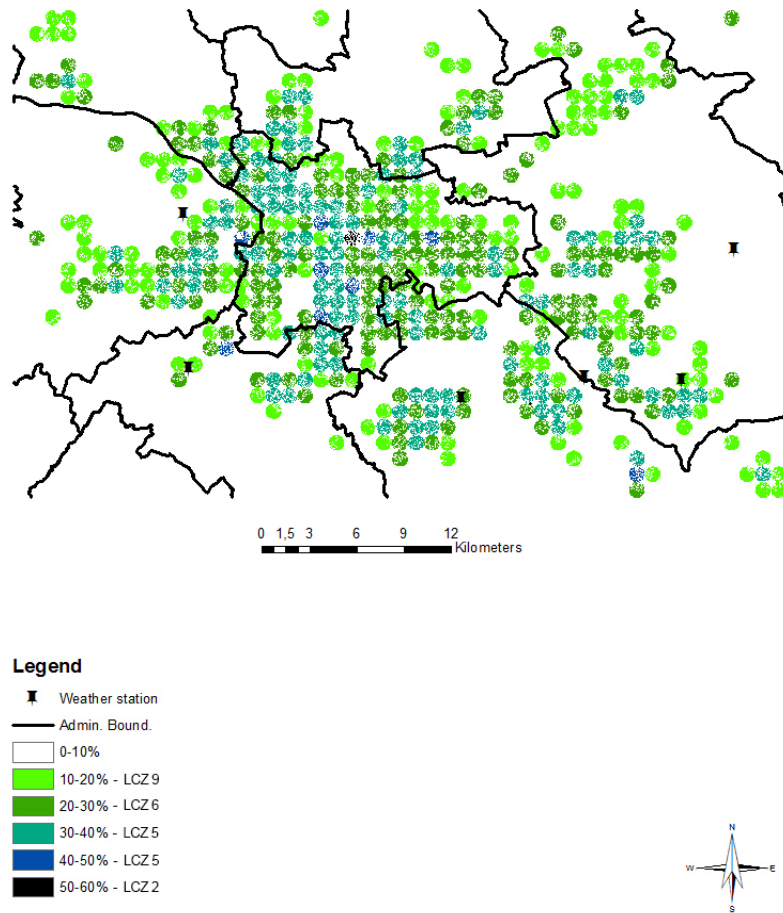


Figure 1: Detailed view of LCZ classes with built cover categories



Figure 2: Selected locations for model simulations

4. Results

The performance of ENVI-met was validated for Glasgow, using a process described by Loconsole (2013). We used data from a weather station set up on the city campus of Glasgow Caledonian University for this purpose. Emmanuel and Loconsole (2015) show a comparison of results of simulated and measured temperatures in the city of Glasgow on 30 April 2011 (Root Mean Square Error [RMSE] = 0.83 and R2 = 0.94), thus giving confidence with regard to the performance of the model and its assumptions in the context of Glasgow.

During the daytime city centre locations exhibit minimal changes to air temperature while the suburban/rural sites have marked decrease in air temperature at increased levels of green cover (Figure 3). Increased shading (tall buildings) and/or increased shading with green roofs however lead to significant cooling in the city centre. The situation at nighttime (not shown) is different, in that there is a consistent pattern of cooling at all sites.

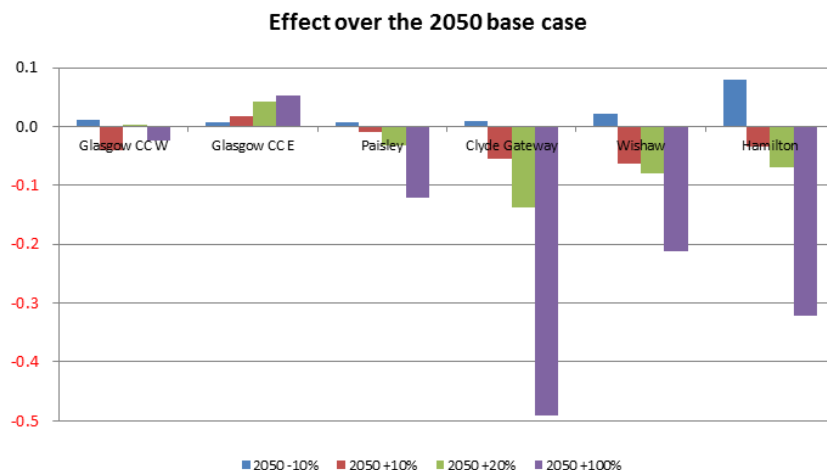


Figure 3: Air temperature effect of green infrastructure – daytime

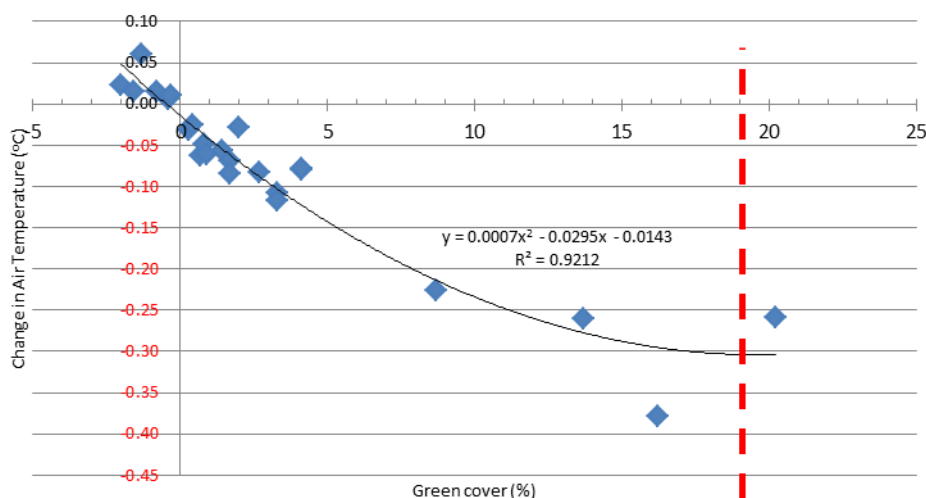


Figure 4: Average daily summertime temperature effect of green cover

Figure 4 shows the level at which green cover makes the most impact is approx. 20% above the current level, with diminishing returns thereafter. At this level of green cover a net cooling of 0.3°C can be expected in 2050, equaling about a third of the extra heat island effect predicted for Glasgow (Kershaw et al., 2010).

5. Implications

Thus green infrastructure could play a significant role in mitigating the urban overheating expected under a warming climate in the GCV Region. Our work also indicates that a green cover increase of approximately 20% over the present level could eliminate a third to a half of the expected extra urban heat island effect in 2050. This level of increase in green cover could also lead to local reductions in surface temperature by up to 2°C. Furthermore, over half of the street users would consider a 20% increase in green cover in the city centre to be thermally acceptable, even under a warm 2050 scenario (Emmanuel and Loconsole, 2015).

5.1 Achieving green cover increase – an example

In practical terms a 20% increase in green cover could be achieved in a number of different ways: mini-parks, street trees, grass areas, roof gardens, green walls or even urban forests. Not all green areas contribute equally

to local cooling nor are they equal in their other environmental and sustainability benefits. Recognising this, planners have begun to develop weighting systems that captures the relative environmental performance of different types of green cover. The most widely used among these is the Green Area Ratio (GAR) method (Keeley, 2011). GAR is currently implemented in Berlin and has been adapted in Malmo (Sweden), several cities in South Korea and Seattle (USA).

Table 1 shows some options to achieve 20% green cover increase at the Glasgow city centre west (Gla. CC-W) site using the weightings shown in Keeley (2011). These range from a 1,056m² (32.5m x 32.5m) park to 528 new street trees or extensive roof gardens up to 1,056m² or 1,268m² of green façade at this site.

Table 1: Alternative approaches to increasing green cover by 20% in Gla. CC-W

| Scenario | Permeable vegetated area (m ²) | Street trees (Nos.) | Intensive Roof Garden (m ²) | Extensive Roof Garden (m ²) | Green façade |
|---|--|---------------------|---|---|--------------|
| 1. A large park only | 1,056 | | | | |
| 2. Street trees only | | 528 | | | |
| 3. 50% of additional greenery in street tree, balance intensive roof garden | | 264 | 755 | | |
| 4. 50% of additional greenery in street tree, balance extensive roof garden | | 264 | | 1,056 | |
| 5. Mix of intensive (50%) and extensive (50%) roof garden | | | 755 | 1,056 | |
| 6. 50% of all 'sun facing' (i.e. South & West) façade covered façade green | | | | | 1,268 |

The amelioration of urban heat island has a long pedigree and cities have adapted to local warming for a very long time (cf. Hebbert and Jankovic, 2013). Green infrastructure is long known to have a positive impact on the minimisation of the UHI effect (Gill et al., 2007). The present work indicates that green cover increase could play a vital role in partially eliminating the expected urban overheating problem in the more urbanised regions of the GCV. The extent of green cover necessary to make a cooling impact is modest, and there are several options to achieve this. More work will be needed to evaluate the relative merits of specific green infrastructure interventions at specific urban sites, however, the present work indicates green cover could be a future adaptation strategy to at least partially overcome the urban overheating problem likely to be made worse by global warming.

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