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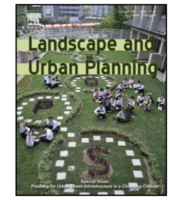

Research Paper

Green infrastructure as an adaptation approach to tackling urban overheating in the Glasgow Clyde Valley Region, UK

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HIGHLIGHTS

- Classification of urban areas into local climate zones (LCZ).
- CFD simulation of green cover in mitigating climate change and heat island effects.
- 20% increase in green cover could reduce surface temperatures by 2 °C in 2050.
- Green infrastructure option to achieve 20% increase in greenery is presented.

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ABSTRACT

Although urban growth in the city of Glasgow, UK, has subsided, urban morphology continues to generate local heat islands. We present a relatively less data-intense 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 uses LIDAR data available with local authorities, based on the typology developed by Stewart and Oke (2012). LCZ classes were then used cluster areas likely to exhibit similar warming trends locally. This helped to identify likely problem areas, a sub-set of which were then modelled for the effect of green cover options (both increase and reduction in green cover) as well as building density options. Results indicate green infrastructure could play a significant role in mitigating the urban overheating expected under a warming climate in the GCV Region. 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. 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. The process adopted here could be used to estimate the overheating problem as well as the effectiveness green infrastructure strategies to overcome them.

1. Introduction

In the face of growing consensus on the anthropogenic causes for global climate change (see IPCC, 2013) 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. However, research on the augmentation of climate change effects by local urban warming (characterised by urban heat islands) remains weak. A key difficulty in untangling the urban warming from global climate change is the computational and parametric difficulties associated with representing urban areas in climate models (Grawe, Thompson, Salmond, Cai, & Schlünzen, 2013; Jin, Dickinson, & Zhang, 2005). Additionally, translating future climate change projections at finer spatial scales relevant to cities typically use statistical downscaling techniques to global climate models without modelling the urban areas themselves (Lemonsu, Kounkou-Arnaud, Desplat, Salagnac, & Masson, 2013) a technique not without problems. Although the situation is continuing to improve (cf. Hebbert & Jankovic, 2013) much more still need to be done to (a) ameliorate the urban heat island (UHI) effect and (b) use UHI mitigation as part of climate change adaptation.

World's shrinking cities face additional problems in managing climate change. Previous work in Glasgow (Emmanuel & Krüger, 2012; Krüger, Drach, Emmanuel, & Corbella, 2013) – one such

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'shrinking city' – indicates that 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 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 focussed 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.

Given these realities, it is necessary to explore the role of land cover changes especially green infrastructure changes, as potential climate change adaptation options. Specifically, it is necessary to quantify the scale of green infrastructure changes needed in specific cities and explore ways to accomplish them. It in this light the present paper explores the role of green cover in areas of different urban density within the Glasgow Clyde Valley (GCV) Region in the central belt of Scotland. It characterises the urban pattern within the GCV in terms of their local warming attributes, using a classification system known as the local climate zones (LCZ) (Stewart & Oke, 2012). Such classification could help identify areas most likely to experience significant overheating problem in the future (cf. Lelovics, Unger, & Gal, 2013). Computational fluid dynamics (CFD) simulations are then carried out to test the applicability of green infrastructure approaches. Alternative strategies to enhance the green cover in a Glasgow city centre neighbourhood are presented.

The rest of the paper is structured in five sections: Section 2 presents background evidence to the presence of the heat island phenomenon in Glasgow and the two techniques commonly used to study it (local climate zones to classify urban areas and ENVI-met, a CFD model commonly used to study the effectiveness of mitigation strategies). Sections 3 and 4 detail the land cover/land use classification employed in the present study. Section 5 presents the results of the simulation exercise and Section 6 explores the implications of the results. It is hoped that the method of classifying LCZ using relatively easily available data as well as the exploration of green infrastructure in ameliorating the likely overheating problem could be applicable to other cold climate cities.

2. Background

2.1. Glasgow's heat island phenomenon

Based on a four-pronged approach to map the local climate variations in and around the city of Glasgow in 2011 (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 Krüger (2012) and Krüger et al. (2013) found the following:

1. 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.
2. Such heat islands are of the same order of magnitude as the predicted warming due to climate change to 2050.
3. 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.
4. Strategies to tackle local overheating can lead to less carbon intensive enhancement of comfort, health and quality of life both within and outside buildings.

Given the geographic and urban growth similarities of the GCV Region to that of the city of Glasgow, the overheating problem in the GCV area is likely to be similar. Carefully planned development of urban morphological variables such as the green infrastructure offers possibilities to enhance outdoor livability and reduced building energy use in the immediate future when the regional climate remains relatively similar to current conditions, but also provides an adaptive mechanism when the background climate continues to warm (Kleerekoper, van Esch, & Salcedo, 2012), thus lending itself to be a useful strategy to adapt to climate change in the GCV Region, both in the immediate- and long-term.

2.2. Local climate zone classification

In order to characterise the land use/land cover patterns in areas of interest, we used the 'local climate zone' (LCZ) system developed by Stewart and Oke (2012). LCZs are defined as 'regions of uniform surface-air temperature distribution at horizontal scales of 102–104 m (Stewart & Oke, 2012). Their definition is based on characteristic geometry and land cover that is expected to generate a unique near-surface climate under calm, clear skies. These include vegetative fraction, building/tree height and spacing, soil moisture, and anthropogenic heat flux. LCZ has 16 climate zones and the classification system has been validated in Sweden, Japan and Canada (Stewart and Oke, 2009) and widely used in other contexts (for example, Lelovics et al., 2013; Middel, Häb, Brazel, Martin, & Guhathakurta, 2014; Villadiego & Velay-Dabat, 2014).

Although the LCZ classification system was not developed for mapping the UHI effect but to assist in the selection of locations for local weather stations and to report heat island effect in a standardised manner, it is a useful system to identify microclimatically distinguishable areas within an urban agglomeration, and this aspect of the LCZ is useful in identifying the likely local warming effects of urban development. This was indeed shown to be true in Glasgow (see Fig. 12 in Emmanuel & Krüger, 2012).

2.3. CFD simulations in UHI studies

The non-linearity of the UHI problem lends itself to numerical simulations and is therefore increasingly popular in urban climatology (Saneinejad, Moonen, & Carmeliet, 2014). Urban microclimate models vary widely with regard to their physical basis and spatial/temporal resolution. Ali-Toudert & Mayer (2006) provide a detailed critique of contemporary models at the micro-scale with fine temporal resolutions. They inferred that ENVI-met (Bruse, 2011) is perhaps the only micro-scale computational fluid dynamic model that is capable of analysing the thermal comfort regime within the street canyon at fine resolutions (down to $0.5 \text{ m} \times 0.5 \text{ m}$). ENVI-met is increasingly being used to assess the effectiveness of urban planning measures to tackle the UHI problem in a variety of climate contexts (for example, Ketterer & Andreas Matzarakis, 2014 – Stuttgart, Germany; Chen & Ng, 2013 – Hongkong SAR; Emmanuel et al., 2007 – Colombo, Sri Lanka; Middell et al., 2014 – Phoenix, USA; Skelhorn, Lindley, & Levermore, 2014, Manchester, UK).

ENVI-met is a three-dimensional non-hydrostatic model for the simulation of surface–plant–air interactions, especially within the urban canopy layer. It is designed for the micro-scale with a typical horizontal resolution from 0.5 to 10 m and a typical time frame of 24–48 h with a time step of 10 s. This resolution allows the investigation of small-scale interactions between individual buildings, surfaces and plants (Bruse, 2011).

Input meteorological data required to initiate ENVI-met simulations are: wind speed and direction at 10 m above ground, roughness length (Zo), initial temperature of the atmosphere, specific humidity at 2500 m and relative humidity at 2 m. The model calculation includes surface and wall temperatures for each grid