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Atmospheric Impacts on Daytime Urban Heat Island

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ABSTRACT: Daytime urban heat island effects can be weak compared to night time and even reversed (as in the case of cool islands, where urban locations display lower temperatures than at a rural site), mostly due to shading effects from buildings, vegetation, and other possible obstructions. The study of the relationship between the sky-view factor, an indicator of urban geometry in terms of sky openness, and urban heat island intensity generally focus on night time periods; only a few report on the daytime effect of the SVF. Such effect will also vary according to background atmospheric conditions of the period of measurements. This article is a commentary on a recent publication by the authors on a study of diurnal intra-urban temperature differences in a location with Koeppen's Cfb climate.

KEYWORDS: Urban climate, atmospheric stability, urban morphology

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COMMENT ON: Drach P, Krüger E, Emmanuel R. Effects of atmospheric stability and urban morphology on daytime intra-urban temperature variability for Glasgow, UK. *Sci Tot Environ.* 2018;627:782-791.

Introduction

The concept of urban heat island (UHI) applies to nighttime temperature differences between a given urban location and a rural counterpart. During the day, the UHI can be weakened and even reversed (as in the case of cool islands, where urban locations can display lower temperatures than at a rural site), mostly due to shading effects from buildings, vegetation, and other possible obstructions which will lower surface temperatures and air-temperature profiles in denser parts of the city when compared to an unobstructed rural location. The sky-view factor (SVF), an indicator of the complexity of the urban geometry in terms of sky openness, represents the amount of visible sky at a given point,¹ that is, the available sky for scattering of thermal energy. The value of SVF ranges from 0 to 1, with a value of 1 corresponding to an area without any obstacle between the chosen point and the sky. A number of studies are focused on the relationship between the SVF and the nocturnal heat island, but only a few report on the daytime effect of the SVF.

Depending on the background atmospheric conditions of the day when temperature measurements are carried out at both sites (urban versus rural), heat or cool islands may be verified in certain city locations. On a clear day, a highly shaded area can be cooler than an open-air site but such effect can drop enormously under cloudy conditions.

Indicators of atmospheric conditions can be as simple as the day's temperature fluctuation or follow a given stability classification scheme depending on the availability of meteorological parameters and related atmospheric processes in the lower part of the boundary layer.²

In a previous paper, we compared simultaneous meteorological measurements at two distinct urban locations in terms of SVF attributes in a subtropical city (Curitiba, Brazil, 25.5°S,

with Koeppen's Cfb climate type) and found out that the mean radiant temperature T_{MRT} , which is strongly affected by solar radiation, is more correlated to the SVF than air temperature.³ Furthermore, it was noticed that, on warmer days, locations with less obstruction of the sky, that is, with the highest value of SVF, yield greater discomfort due to heat. Yet, the same locations can provide comfort conditions on days with lower temperatures. Thus, if the focus of the analysis is the promotion of thermal comfort to pedestrians, it all depends on what target conditions are strived for.

A subsequent study was based on long-term microclimate data monitored simultaneously at two weather stations located in the same subtropical city during 2011–2013.⁴ Lower temperatures were observed at the rural or peri-urban location more consistently during night time with average temperatures in general slightly lower than in the downtown area. Diurnal temperature differences, however, did not show a clear trend, that is, daily maxima on the outskirts of the urban area were not always lower than downtown, which pointed to a cool island effect on given days.

This article is a commentary on a recent publication of the authors reporting on a study of diurnal intra-urban temperature differences in a location with similar Cfb climate but showing a temperate oceanic climate instead of subtropical patterns.⁵

UHI Studies in Glasgow, UK

An initial study was carried out in 2010–2011,⁶ investigating the changes in air temperature within the urbanized area of Glasgow relative to the surrounding Central Belt Region climate using historical data from several sources: UK Met Office (climate normals and running data for a 50-year period); MIDAS Surface Weather Stations network of the British Atmospheric Data Center (BADC); and Weather Underground



Table 1. Maximum air-temperature differences (in K) to “Group Mean” for different periods and atmospheric conditions—intra-urban T/RH stations.

| | T/RH STATIONS | | | | | | MAX. TEMP. DIFF. |
|-------------------|---------------|------|------|------|------|------|---------------------|
| | SUB2 | RES1 | SUB1 | GRN1 | COR1 | COR2 | |
| All data | -1.5 | -0.6 | -0.4 | 0.3 | 0.6 | 1.6 | 3.1 |
| Cold period | -1.4 | -0.5 | -0.4 | 0.2 | 0.5 | 1.5 | 3.0 |
| Warm period | -1.6 | -0.6 | -0.4 | 0.4 | 0.7 | 1.6 | 3.2 |
| Day type I | -2.7 | -0.9 | -0.5 | 0.7 | 1.2 | 2.1 | 4.9 |
| Day type II | -1.6 | -0.7 | -0.5 | 0.5 | 0.7 | 1.5 | 3.1 |
| Day type III | -1.4 | -0.6 | -0.4 | 0.3 | 0.6 | 1.6 | 3.0 |
| Unclassified days | -1.4 | -0.5 | -0.4 | 0.3 | 0.5 | 1.5 | 2.9 |

Table 2. Average UHI (ΔT_{u-r} in K) for different periods and atmospheric conditions.

| | DAYTIME (AVERAGE) | NIGHT TIME (AVERAGE) | NIGHT TIME (MINIMUM) |
|-------------------|----------------------|-------------------------|-------------------------|
| All data | 1.6 | 2.1 | 3.1 |
| Cold period | 1.6 | 2.2 | 3.2 |
| Warm period | 1.6 | 2.1 | 3.1 |
| Day type I | 1.6 | 2.2 | 3.4 |
| Day type II | 1.9 | 2.4 | 3.2 |
| Day type III | 1.7 | 2.6 | 3.9 |
| Unclassified days | 2.0 | 1.3 | 2.9 |

network. Our results suggested that the urban area superimposes a local warming effect over regional trends. Even though regional trends are accompanied by a similar decrease in heating degree days (HDDs) in Glasgow’s urban area over time—with local decrease in HDD possibly due to regional warming, a comparison between climate normals for Glasgow Airport and west of Scotland shows higher temperatures in Glasgow than regional averages. The number of days with night frost in the urban area drops significantly, from around 70 to 36 days per annum.

In a subsequent study,⁷ we evaluated the effect of atmospheric stability on seasonal ambient temperature differences after deploying two Davis VantagePro2 weather stations at an urban site (at Glasgow Caledonian University, GCU) and at a rural setting. Intra-urban temperature differences were concomitantly monitored with a string of T/RH Tinytag data loggers located across Glasgow on a N-S transect. The purpose was to estimate the effect of background atmospheric conditions on urban-versus-rural (UHI) as well as on intra-urban air-temperature differences to identify relationships between morphology and local climate. The monitoring period (from late February to early September 2011) was classified in terms of atmospheric classes according to the modified Pasquill–Gifford–Turner

(PGT) classification system.² A consistent warming pattern was observed both between the farthest T/RH station and the group mean with noticeable influence of atmospheric conditions, expressed as PGT Day Types, during the observation period (Table 1). The UHI, by its turn, was not particularly affected by the choice of more stable conditions for analysis according to the PGT scheme (Table 2).

We investigated the joint effect of atmospheric conditions and urban morphology, expressed as the SVF, on intra-urban variability in the city core.⁵ A total of 32 locations were selected on the basis of SVF, with a wide variety of urban shapes (narrow streets, neighborhood green spaces, urban parks, street canyons and public squares) and compared to a reference urban weather station during a total of 23 transects during late spring and summer periods. The locations used in this study differed from the ones used before, as they are located in the city core area. The method consisted of diurnal transects, covered on foot or by bicycle following designated routes (eastbound and westbound) as shown in Figure 1.

The urban area wherein traverses took place was selected according to a previous study by Emmanuel and Loconsole,⁸ where authors used the local climate zone “LCZ” classification for Glasgow from light detection and ranging (LIDAR) data available with local authorities to identify potential problem areas as regards overheating in summer. According to that study, the city center area (Glasgow City Center West and Glasgow City Center East) was categorized as the LCZ class “compact midrise.” Maximum daytime intra-urban temperature differences were found to be strongly correlated with atmospheric stability classes. Furthermore, significant intra-urban differences in air temperature are noticeable in urban canyons (e.g. in E-W street canyons), with a direct correlation to the site’s SVF (or sky openness) and with an indiscernible trend under open-air conditions (Figure 2).

The UHI intensity in Glasgow can reach almost 4°C under certain atmospheric conditions, yet such temperature differences are not solely determined by atmospheric stability classes, that is, such are not determining factors for explaining local

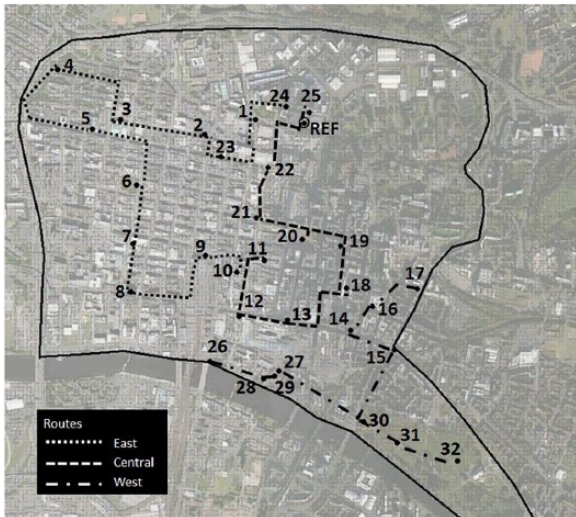


Figure 1. Study area with monitoring points and traverses in Glasgow's city core (as by Drach et al⁵).

daytime periods) will bring stronger temperature differentiation within urban core locations. By identifying the dominant atmospheric classes in summer for Glasgow, it may be assumed that such conditions favor strong differences in air temperature within urban canyons, impacting to a greater or lesser extent the thermal comfort of pedestrians.

Policy Implications

Our urban climate studies in Glasgow have had considerable traction within the climate change adaptation policy community. In particular, our work in partnership with the Glasgow Clyde Valley Green Network Partnership (GCVGNP) has been influential in pushing the “green infrastructure” agenda as a potential adaptation option for both flood prevention at the regional scale as well as overheating mitigation at local scale.⁹

We have thus attempted to embed urban climate studies within the wider (and potentially more popular) attempts to adapt to climate change. This might provide a template for engagement with the policy development community, not just in the cold climate regions.

Author Contributions

Conceived and designed the experiments: EK, RE, PD. Analyzed the data: EK, PD. Wrote the first draft of the manuscript: EK. Contributed to the writing of the manuscript: RE, PD. Agree with manuscript results and conclusions: EK, RE, PD. Jointly developed the structure and arguments for the paper: EK, RE, PD. Made critical revisions and approved final version: EK, RE, PD. All authors reviewed and approved of the final manuscript.

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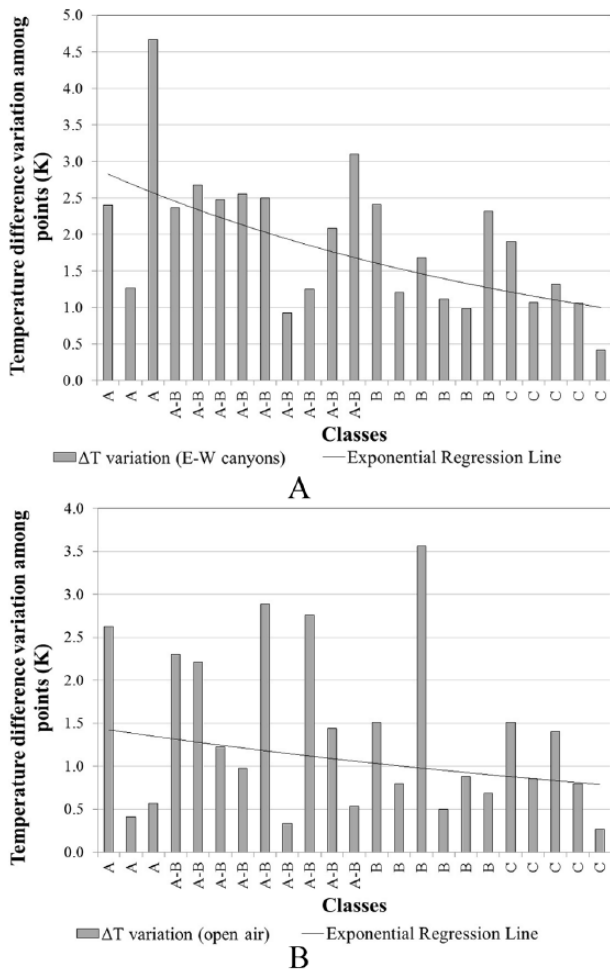


Figure 2. Relative variations in air-temperature differences for varying atmospheric conditions: (A) for E-W street canyons and (B) for open-air locations (Drach et al⁵).

UHI. On the other hand, daytime intra-urban temperature differences tend to be affected by PGT patterns with increasing urban density. Particular day types (resulting PGT class for

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