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# Effects of atmospheric stability and urban morphology on daytime intra-urban temperature variability for Glasgow, UK

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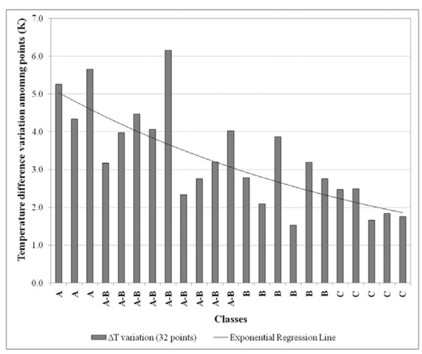
## HIGHLIGHTS

- Background atmospheric conditions contributes to explain daytime intra-urban temperature variability.
- Temperature variations tend to be more accentuated in less stable atmospheric classes.
- Variability in air temperature is mostly noticed in urban canyons and less so in open-air situations.

## GRAPHICAL ABSTRACT




Relative air-temperature difference variations to the reference weather station for varying atmospheric conditions – determined from the range of air-temperature differences for all 32 point locations

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## ABSTRACT

This study investigates the joint effect of atmospheric conditions and urban morphology, expressed as the Sky View Factor (SVF), on intra-urban variability. The study has been carried out in Glasgow, UK, a shrinking city with a maritime temperate climate type, and findings could guide future climate adaptation plans in terms of morphology and services provided by the municipality to overcome thermal discomfort in outdoor settings. In this case, SVF has been used as an indicator of urban morphology. The modified Pasquill-Gifford-Turner (PGT) classification system was adopted for classifying the temperature monitoring periods according to atmospheric stability conditions. Thirty two locations were selected on the basis of SVF with a wide variety of urban shapes (narrow streets, neighbourhood green spaces, urban parks, street canyons and public squares) and compared to a reference weather station during a total of twenty three transects during late spring and summer in 2013. Maximum daytime intra-urban temperature differences were found to be strongly correlated with atmospheric stability classes. Furthermore, differences in air temperature are noticeable in urban canyons, with a direct correlation to the site's SVF (or sky openness) and with an inverse trend under open-air conditions.


## 1. Introduction

Although the disadvantages of nocturnal overheating due to urbanization in warm climate locations are well recognised, Urban Heat Island (UHI) effects in cold climate cities can still be a matter of dispute. For

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example, London's UHI phenomenon had many advantageous connotations in the 1960s (e.g., longer growing season, lower heating requirements, less de-icing on railway tracks (Chandler, 1965)). Yet, after <40 years, overheating caused by UHIs was recognised as a problem (Kolokotroni & Giridharan, 2008; Kolokotroni et al., 2006; Oikonomou et al., 2012) and policies for mitigation and adaptation have been established (Davoudi et al., 2009; Carter, 2011).

In the context of climate change, the importance of tackling inadvertent UHI effects has been increasingly recognised. This is due to both current urbanization trends and to the growing intensity of risks facing cities, often affecting environmental conditions and the quality of urban life. Appropriate urban planning options could help ameliorate the UHI problem and urban microclimate, thereby reducing climate change-related risks (Kleerekoper et al., 2012). In addition to mitigating climate change by reducing greenhouse gas emissions, heat management is needed in cold climate cities in terms of using it as a resource in winter whereas ameliorating negative consequences in summer (Stone et al., 2012). However, the role of cities in climate change adaptation is only beginning to be addressed (Hebbert & Jankovic, 2013), with vague and uncertain city-specific urban climate change action plans. In particular, studies that relate urban form to climate change are still scarce (Shimoda, 2003).

To reduce the risk of overheating due to climate change and as a means of mitigating negative consequences of UHIs, the effectiveness of certain urban forms needs to be explored when accounting for seasonal changes and background atmospheric conditions. Given the increasing interest in climate change adaptation and the use of models to evaluate the efficacy of various adaptations (Tomlinson et al., 2012), such an assessment would further enhance their extent.

## 2. Background

The UHI effect in cold climate cities is well known. For example, comfort, energy and health implications of UHIs in cold climate cities (e.g., London) are well described by Mavrogianni et al. (2011). More interest in this subject is likely to arise in the coming years due to growing changes in global climate. In this sense, Kershaw et al. (2010) developed methods to predict the UHI effect in future climate projections for the UK.

Exploring land use and meteorological aspects of UHIs in Szeged, Hungary, Unger et al. (2001) reported strong relationships between urban thermal excess and distance from the city centre, and between urban thermal excess and the built-up ratio. However, the authors were not able to relate significant correlations between meteorological conditions and UHI intensity.

In recent years, there has been more recognition of the need for more careful analysis of background atmospheric conditions (Lee et al., 2009; Holmer et al., 2012) and synoptic weather patterns (Kolokotsa et al., 2009; Lai & Cheng, 2009) when carrying out UHI measurements. As observed in a study on the shortcomings of UHI monitoring and simulation techniques (Mirzaei & Haghighat, 2010), UHIs develop from small-scale processes such as human metabolism and meso-scale interactions such as atmospheric forces. Kolokotsa et al. (2009) indicated that anticyclonic conditions greatly contribute to the development of UHIs during summer; they used a classification of synoptic conditions developed by Kassomenos (2003)) as a reference to investigate the UHI effect in Chania, Greece.

Krüger & Emmanuel (2013) estimated the effects of background atmospheric conditions on UHIs and intra-urban air temperature in Glasgow, UK. They found that the range of intra-urban air temperature variability and warming trends at specific urban locations relative to a rural condition were accentuated when atmospheric stability is taken into account during field observations. For understanding urban morphology effects on such relationship with a set of air temperature stations, authors used the Sky View Factor (SVF) as indicative of morphology attributes at each location surveyed. The relationship between the site's SVF and local warming was found to be more pronounced under given atmospheric conditions.

The effect of urban geometry, as expressed by the site's SVF, on microclimate is one of the most studied aspects of UHIs. An early attempt to statistically relate urban geometry and microclimate was first reported by Oke (1981)). Unger (2004) shows a detailed review of subsequent efforts.

A review of the relationship between SVF and urban air temperatures found it to be rather weak and contradictory (Unger, 2009). Strong relationships have been reported in specific parts of a city (such as downtown areas), in Gothenburg, Sweden ($R^2 = 0.78$) (Svensson, 2004). Long-term measurements encompassing larger areas showed, however, weaker relationships, as in a study analyzing the entire urban area of Szeged, Hungary ($R^2 = 0.47$) (Unger, 2004). A number of studies on the relationship between the SVF and daytime thermal effects show divergences, some suggesting a relationship between urban geometry, defined by the SVF, and ambient temperature (Unger, 2004; Svensson, 2004; Souza, 2007), others demonstrating negligible impacts of the SVF on local temperature (Eliasson, 1996; Upmanis & Chen, 1999).

Eliasson & Svensson (2003) showed intra-urban temperature variations reaching up to 9 °C based on data collected during an 18-month period at 30 sites in Göteborg, Sweden. Their work focused not only on nighttime variability but also on daytime differences (solar noon, or 12 pm, local time), thereby allowing comparisons between day and night conditions. Weather conditions at the times of the field observations followed a cloudiness/wind classification (clear, cloudy sky, windy, calm). Monitoring sites ranged between dense urban locations to green spaces, with SVF ranging 0.7–1.0. Results showed that, in general, temperature variations are more dependent on weather than season, the highest correlations (between air temperature and surface cover) were found for clear, calm conditions, irrespective of season. However, for daytime conditions, variability was more frequent during cloudy conditions, irrespective of wind speed. Authors concluded that statistically significant temperature differences do exist between densely built-up areas, large open areas and green areas during windy and cloudy situations, both during day and night. For clear sky conditions, the lack of statistical significance can be attributed to the small amount of clear days during the monitoring period.

Konarska et al. (2016) report findings from a field study involving long-term (two consecutive years) air temperature measurements in Göteborg, Sweden. Intra-urban thermal variations were analyzed at ten fixed park and street sites characterized by different types and density of vegetation, building geometry, openness and surface cover. The study showed the importance of such spatial characteristics in analyzing intra-urban variability in daytime and nighttime air temperature. Although most of the sites had some vegetation, with consequent foliage shading and evapotranspiration interfering effects (Park Cool Island 'PCI' effect), the relationship between openness and local air temperature during daytime in the warm half of the year (May–September) was positive i.e. followed a direct relationship.

Scott et al. (2017) deployed a network of low-cost sensors ('iButtons') to analyze the intra-urban temperature variability in Baltimore, United States. The amount of weather stations employed was quite significant (135+ sensors) in that study, though the variability in terms of landscape was low, most sites with significant presence of vegetation. Results showed small intra-urban temperature variability (as regards daily minima). Authors concluded, from linear regression analysis that the presence/absence of vegetation is the only reliable predictor of mean air temperature among the various aspects examined such as albedo, tree-canopy cover, and distance to the nearest park.

The aim of the present study is to understand the effect of background atmospheric patterns on intra-urban temperature variability under warm conditions in the maritime temperate climate city of Glasgow, UK. Previously published material on Glasgow's UHI (Emmanuel & Krüger, 2012) point to a warming trend during the last decades.