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Research Paper

# The potential of local climate zones maps as a heat stress assessment tool, supported by simulated air temperature data

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ABSTRACT

High population densities in cities and rapid urban growth increase the vulnerability of the urban environment to extreme weather events. Urban planning should account for these extreme events as efficiently as possible. One way is to locate hot spots in an urban environment by mapping cities into local climate zones (LCZ) and evaluate heat stress related to these zones. LCZs are likely to become a standard in urban climate modelling as they capture important urban morphological characteristics. For instance, temperature regimes linked to spatially explicit LCZ maps should be assessed for all LCZ zones derived from these maps. This study assesses the thermal behavior of mapped LCZs using simulated temperature data from the UrbClim model. Prior to temperature analysis, the model was validated with observational data. To evaluate the robustness of the analysis, we ran the model in three cities in Belgium: Antwerp, Brussels, and Ghent. The results show that temperature regimes are significantly different for all the built zones in the urban environment independent of the city. Second, the susceptibility to heat stress can differ greatly depending on the zone. The unique thermal behavior of the different LCZs provides indispensable information on the urban environment and its climatic conditions. This study shows that the LCZ scheme has a potential to help urban planners globally tackle adverse effects of extreme weather events.

## 1. Introduction

As Earth's climate continues to change over the coming decades, global warming will hit urban centers especially hard. This poses a major threat to the health and well-being of urban human populations (Hoag, 2015). At the same time, urban centers are facing problems associated with high levels of anthropogenic emissions, resulting from e.g. residential energy or increased traffic, potentially leading to premature mortality globally (Lelieveld, Evans, Fnais, Giannadaki, & Pozzer, 2015; Solberg et al., 2008) and are subject to an increase in impervious and built surfaces, which can significantly alter the local climate (Papalexiou, AghaKouchak, Trenberth, & Foufoula-Georgiou, 2018; Sundborg, 1951). Even though climate change and the alteration of local climate take place on different spatial scales, global warming can intensify the effects on local climate in the urban areas due to a phenomenon called urban heat islands (UHI), causing large air temperature differences between urban and surrounding rural sites (Oke, 1976). The higher frequency of severe heatwaves, in combination with the UHI effect, has a compounding effect on thermal conditions in urban areas. (Barriopedro, Fischer, Luterbacher, Trigo, & Garcia-Herrera, 2011; Grimm et al., 2008; Hoag, 2015; Lauwaet, Maiheu, Aertsens, & De Ridder, 2013; Maiheu, Van den Berghe, Boelens, De Ridder, & Lauwaet, 2013; Schär et al., 2004; Wouters et al., 2017).

Currently, 54% of the global population lives in cities, which cover only 3% of the Earth's land surface (Mills, 2007). Projections show that the proportion of global population living in urban areas will increase to 70% by 2050 (UN, 2014). The increasing urban population and quickly rising global temperatures will put additional pressure on cities, resulting in unhealthy living conditions (Aertsens et al., 2012; WMO, 2013). In the past decades more than 120,000 people have died due to extreme heat in Europe and Russia, 75% of which occurred in cities (WMO, 2013); Many thousands more were exposed to heat stress. Heat

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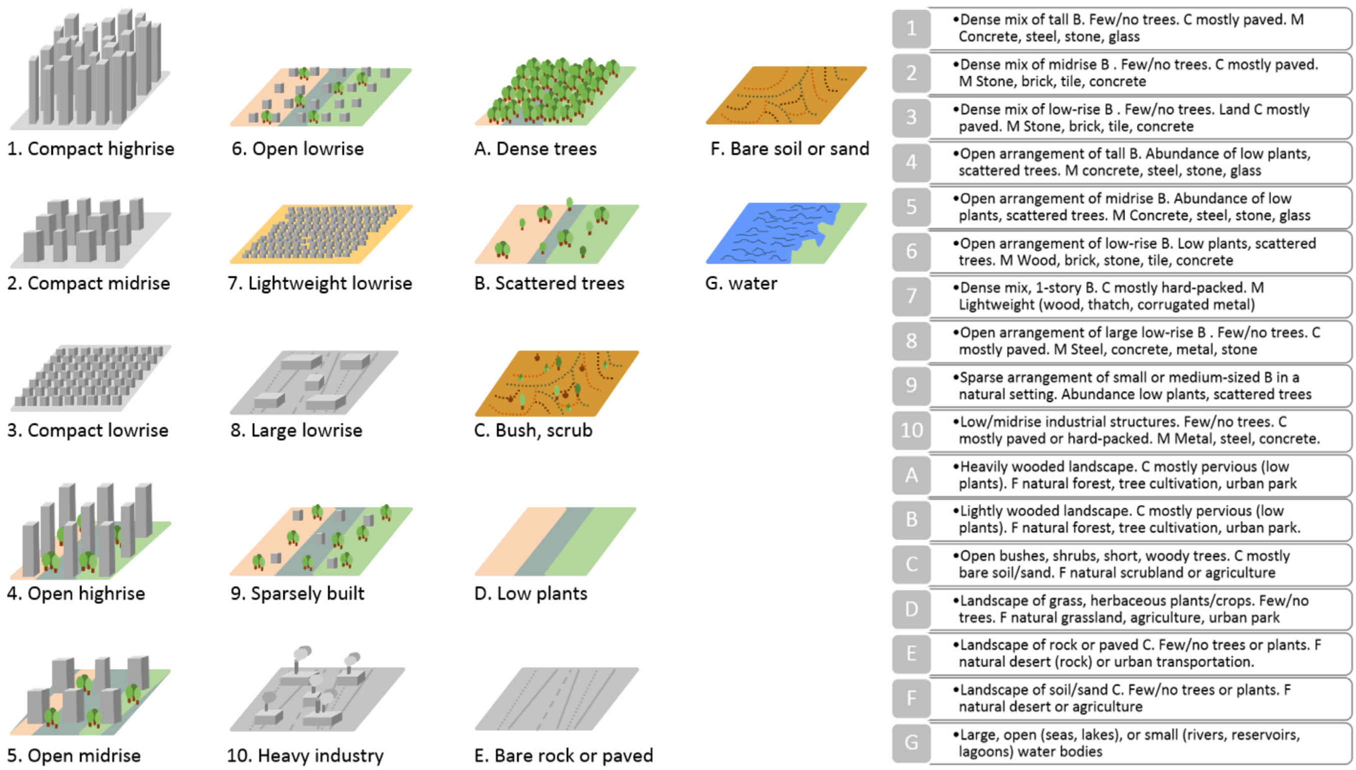


**Fig. 1.** Urban (1–10) and natural (A–G) LCZ types and their characteristics (adapted from Table 2 in (Stewart & Oke, 2012), text shortened, icons reworked) B: Buildings; C: cover; M: materials; F: function; Tall: > 10 stories, Midrise: 3–9 stories, Low: 1–3 stories (Adapted from Stewart & Oke, 2012).

stress occurs when the human body's means of regulating its internal temperature starts to fail (Werder, 2010). This failure can affect physiological processes and result in various strains on the body (e.g. dehydration). A 3 °C increase in internal temperatures within the human body can be lethal (Simon, Niiro, & Gwinn, 1993). Recently, Mora et al. (2017) argued that 30% of the world's population is exposed to climate conditions that lead to lethal heat events, a number that is expected to increase to 74% under the projected growing greenhouse gas emissions. In the face of these threats, knowledge of critical areas should be made available and urban planners should consider the health issues arising from the urban climate when developing new projects (Koppe, Kovats, Jendritzky, & Menne, 2004). It is therefore necessary to introduce supporting research on areas most susceptible to heat stress (Koppe et al., 2004; Pickett, Cadenasso, & McGrath, 2013).

There are three primary ways to counteract the unwanted effects of urban heat (Rizwan, Dennis, & Liu, 2008): (1) reducing anthropogenic heat release; (2) climate sensitive roof design; (3) other design factors. The first method mainly focusses on reducing air conditioning and other urban or building design factors (Kikegawa, Genchi, Kondo, & Hanaki, 2006; Urano, Ichinose, & Hanaki, 1999; Yamamoto, 2005). Climate sensitive roof design includes measures such as green and reflective roofs as well as roof spray-cooling (Jain & Rao, 1974; Rosenfeld, Akbari, & Romm, 1998; Takebayashi & Moriyama, 2007). Finally, other design factors can include the introduction of more vegetation and water, urban ventilation, the use of high reflective building materials, and the general increase in albedo (Aertsens et al., 2012; Bowler, Buyung-Ali, Knight, & Pullin, 2010; Coutts, Tapper, Beringer, Loughnan, & Demuzere, 2012; Demuzere et al., 2014; Feyisa, Dons, & Meilby, 2014; Rizwan et al., 2008; Salmond et al., 2016; Sun & Chen, 2012; Weng, Lu, & Schbring, 2004). In addition to these well-known adaptation and mitigation strategies, adjusting urban morphology can have a major effect on the thermal behaviour of a city due to better ventilation, lower heat absorption, and increased evaporation. Simple tools for relating urban morphology to possible heat stress are thus of high interest for urban planners (Heldens, Taubenböck, Esch, Heiden, & Wurm, 2013; IPCC., 2018; Kleerekoper, Van Esch, & Salcedo, 2012; Shahmohamadi, Che-Ani, Maulud, Tawil, & Abdullah, 2011).

Various models, operating on different scales, can be used to assess the urban climate depending on the aim of the study and the surface of the study area (Best & Grimmond, 2015; Mirzaei, 2015; Toparlar, Blocken, Maiheu, & van Heijst, 2017). As this study focuses on neighborhood-scale urban heat island dynamics, the UrbClim model is used; a simple urban surface energy balance model designed to target the spatial scale of an urban agglomeration yet fast enough to allow integrations over multiple summer seasons while maintaining a satisfactory level of accuracy (De Ridder, Lauwaet, & Maiheu, 2015; García-Díez et al., 2016). The scheme was developed from an existing land-surface scheme adapted to urban surfaces (De Ridder, 2006; Demuzere, De Ridder, & Van Lipzig, 2008), and can be classified as a slab surface (type L1) land surface model (Grimmond et al., 2011). Similar to most other urban land surface schemes (for a non-comprehensive overview see e.g. Best and Grimmond (2015)), one need to accurately describe the urban land surface, as modelled temperatures and urban energy balance components are known to be sensitive to the urban canopy parameters used (Demuzere et al., 2017; Grimmond et al., 2011; Wouters et al., 2016). Ideally, spatial site-specific information is available, yet often generalized global values are used to describe the morphological, radiative and thermal properties of the impervious surfaces, such as the Jackson, Feddema, Oleson, Bonan, and Bauer (2010) database and the ECOCLIMAP data (Champeaux, Masson, & Chauvin, 2005; Faroux et al., 2013). Since the introduction of 'Local Climate Zone' concept by Stewart and Oke (2012), progress has been made to integrate these structural and land cover classes and related generic urban canopy properties into urban canopy schemes (Alexander, Fealy, & Mills, 2016; Brousse, Martilli, Foley, Mills, & Bechtel, 2016; Hammerberg, Brousse, Martilli, & Mahdavi, 2018; Stewart, Oke, & Krayenhoff, 2014; Wouters et al., 2016). The Local Climate Zone classification scheme was originally developed to ease comparison of observational urban heat island (UHI) studies and to provide an objective protocol for measuring the UHI intensity. The