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Unveiling an underground climate change in the Chicago Loop with a district-wide sensing network

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The subsurface temperatures of many urban areas are significantly rising, causing an emerging underground climate change, also known as subsurface urban heat islands (SUHIs) [3,11]. SUHIs result from two types of heat sources in the underground: large-scale drivers at the surface and localized drivers in the subsurface. Large-scale drivers consist of infrastructure at the surface that generate heat in the atmosphere, which eventually diffuses into the subsurface. Localized drivers consist of underground infrastructures that directly reject heat in the subsurface [8, 11]. The impacts of SUHIs lead to globally concerning issues that have detrimental effects on the biodiversity of subsurface ecosystems, public health, and subsurface transportation infrastructure [2, 5, 9]. Considering these impacts, it is crucial to understand the key variables and fundamental mechanisms that govern this silent hazard. The current literature mostly focuses on the intensity and effects of SUHIs that show highly heterogeneous temperatures around localized SUHI drivers [1, 4, 6-8]. However, limited information is available about the intensity and features of the sources (i.e., the localized drivers) of SUHIs. To explore this problem, this study summarizes the features and measurements of a unique subsurface sensing network deployed in the Chicago Loop district by Rotta Loria et al. [10] to monitor the temperature across a myriad of underground built environments and the ground. This facility enables to understand the inherent characteristics of the sources of SUHIs and underpin future studies devoted to the spatial and temporal evolution of SUHIs.

The sensing network includes >150 HOBO temperature sensors deployed in various underground structures (e.g., building basements, parking garages, train lines, pedways, tunnels, underground streets) as well as surface parks and streets. Figure 1 shows the relationship between the daily average subsurface and surface air temperature for the monitored parking garages, building basements, and metro tunnels. An analysis of the monitoring data reveals that the temperature in underground built environments is generally warmer than the surface air temperature during winter and cooler during summer. Furthermore, the temperature in such environments is markedly heterogeneous, with maximum values of up to 36°C. Temperatures within the same level of a considered environment (e.g., lower level x of environment X) can vary up to 15°C, and temperatures across different levels of the same environment (e.g., lower levels x and y of environment X) can vary up to 10.8 °C. The differences in air temperatures among the monitored environments can be attributed to the influence of different architectural and operational features, such as the materials constituting the envelope, the number of distribution channels and apertures, and the presence of ventilation systems and sources of waste heat, including human activity, underground transport, and operating utility equipment. An analysis of the hourly average temperatures in parking garages and building basements further reveals a surge in temperature during the working hours of the day. This rise in temperature during daytime hours was observed to be more prominent starting from March 2021, when COVID-19 restrictions started to become less stringent in Chicago, and people transitioned to a new normality. Such a surge in temperature was more evident in parking garages indicating a correlation between increased air temperatures and human and vehicular activity. Monitoring data referring to a depth of 4 m in the subsurface underneath Grant Park in the Loop and a depth of about 12 m in the heart of such a district underneath its buildings reveal that the ground temperature at such locations reads 11°C and 18°C, respectively. The significant difference between such results is attributed to the fact that the ground in the monitored park does not appear

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to be affected by sources of waste heat, whereas the ground in the heart of the Loop is indeed influenced by sources of waste heat. Specifically, with a temperature differential that can be as high as 25 °C compared to the ground temperature in Grant Park, the monitored underground environments in the Loop appear to be the key cause for the observed underground climate change.

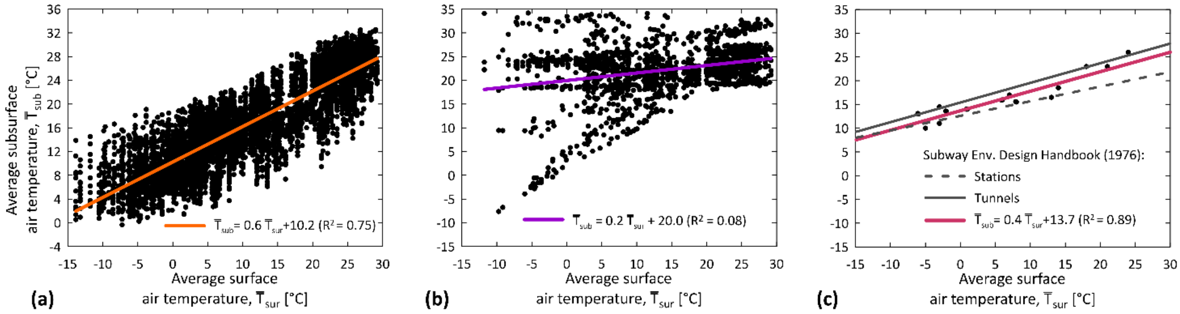

Figure 1: Comparison between subsurface and surface air temperatures for underground built environments: (a) parking garages, (b) building basements, and (c) metro tunnels.

This study yields two significant outcomes: on the one hand, a severe SUHI for the Chicago Loop district; on the other hand, an inherently heterogenous nature of temperatures within underground built environments, which arguably characterize the Loop and many other cities worldwide. Waste heat is continuously rejected into the ground as the temperatures of the localized drivers significantly exceed the undisturbed ground temperatures. A temperature variability characterizes localized drivers belonging not only to different categories (e.g., building basements and parking garages), but also to the same category (e.g., parking garages), with temperatures varying across the same level or different levels of a given environment. Therefore, the heterogeneous nature of localized drivers in SUHIs warrants consideration in robust modeling efforts and the data presented in this study serve as a resource for future simulations. Specifically, this study can foster a better understanding, utilization and management of subsurface energy resources. Understanding these aspects is crucial for the assessment of the geothermal energy potential of urban areas, the study of the variation in the thermal properties of geomaterials, and the optimization of the design and performance of geotechnical systems.

Contributor statement

Anjali N. Thota: Writing, Data curation, Formal analysis, Investigation and Visualization. Alessandro F. Rotta Loria: Writing, Conceptualization, Formal analysis, Project administration

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