City geometry and Urban Heat Island

PROBLEM

The urban heat island (UHI) effect is defined as a temperature difference between urban areas and their rural surroundings where the city temperature is higher. UHI has increased with the urbanization and industrialization of human civilization resulting in negative socioeconomic and health impacts. The majority of current UHI modeling practices focus on vertical heat flow, or the idea that some heat bounces back while other heat is absorbed by surfaces and structures, within a given urban boundary layer (UBL)[i] or urban canopy layer (UCL)[ii]. While the existing approaches can provide accurate results, they are generally only applicable to individual cities and, since they cannot be used universally, their practical application is limited. Further, these approaches fail to take into account the horizontal movement of heat. This brief presents research that looks at the horizontal movement of heat through a method that groups and characterizes cities by their urban surface geometry[iii] using a novel approach typically applied in the field of statistical physics.

APPROACH

A geographic information system (GIS) analysis of the UCL of 33 cities from the US and Europe revealed a striking resemblance between the cities and the molecular structure of materials. As a result, researchers were able to simplify complicated city conditions by using radial distribution function (RDF), a tool that describes how atoms in a system are packed around each other in relation to distance from a reference particle, to capture the variation between local and average building density. Based on their distinct geometries, as captured by RDF, the researchers categorized the cities as: **crystals** (e.g., Chicago, New York), which present regular patterns in their UCL; **liquids** (e.g., Los Angeles, Houston), which offer more sporadic and chaotic distributions; and **gases** (e.g., London, Paris), where the local density of building is almost the same as the average, suggesting almost no order. Since there was not much variation in building heights in a given city sample, defined by the global minimum of RDF distance became a crucial component for analyzing the local heat flow simulation used to compute a view factor (VF)—a portion of emitted heat-—in the horizontal direction.

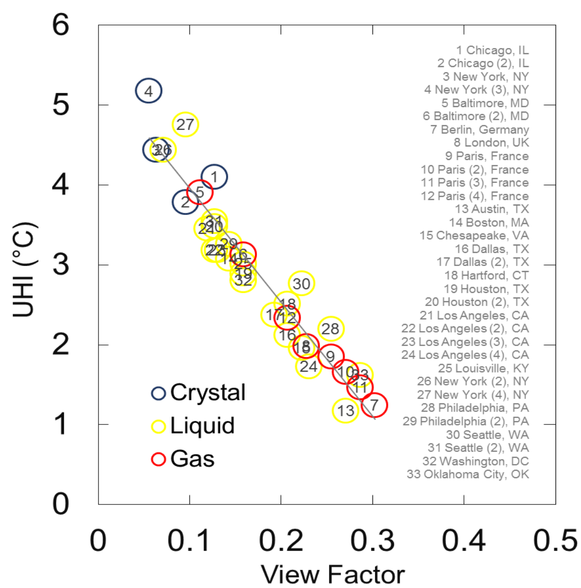

Figure. 1. The correlation between UHI and normalized dimensionless View Factor.

FINDINGS

The researchers found that the global minimum of RDF could be used to define an average length of a street in each city, which acts as a boundary for the heat flow analysis through the local UCL. VF computed using this method is negatively correlated with UHI (as shown in Figure 1).[iv] The researchers expected that lower VF cities retain a greater fraction of heat and thus experience higher UHI. They were able to conclude that for parts of cities with similar building heights, VF is an easily obtainable parameter. Being able to identify VF will allow those planning cityscapes to better understand, quantify, and mitigate UHI.

IMPACT

Urban geometry defined by the sizes and shapes of buildings, and the distances between them, has an impact on heat flow within a cityscape. Using a simplistic tool, like RDF, offers researchers and planners a reliable depiction of the horizontal flow of heat through an urban canopy layer for any major city in the world. This simplified calculation may allow developers to plan more energy efficient cities and, for existing urban landscapes, prioritize the neighborhoods where taking steps to mitigate UHI can have the biggest impact. These models also eliminate the need for detailed surface or air temperature data.

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[i] **Urban boundary layer:** the layer of air directly above the city, which stretches to the defined city limits
[ii] **Urban canopy layer:** The layer of air interspersed between the buildings, trees, and other objects of which a city is composed, and extending upward to the average height of the buildings and trees. ("Weather Word," Chicago Tribune, August 5 2002)
[iii] **Urban surface geometry**: the shape and size of buildings along with the distance between buildings and other physical characteristics of the city.
[iv] While there were some uncontrollable climatic variables in the study (e.g., wind, cloud coverage), through extensive hourly temperature analysis taken between 2006-2015, the researchers found that non-cloudy days with little or no wind are in fact correlated with average temperatures obtained from analysis of all days.

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