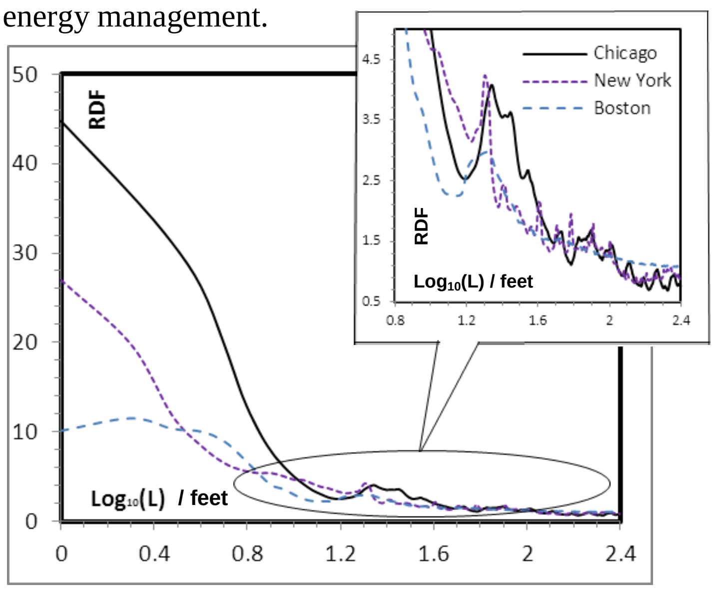
Energy Management: City Texture Matters

Problem

With more than 50% of the world's population (85% in the US) living in cities, one of the major societal challenges in the 21st century is the energy management of cities. The energy management of urban environments requires a realistic assessment of complex interactions amongst building envelopes and between buildings and the atmosphere. It suffices to consider the effect of solar radiation and its implications for thermal mass management of cities. In hot climates, the cooling energy is strongly affected by inter-building distances, due to shading and heat island effects. This is a contrast to cold climates, where the proximity of buildings determines the capacity of cities to receive solar energy. The total energy management of cities thus deviates greatly from the sum of the management of individual isolated buildings, and requires the consideration of other factors such as building density and city texture. Although, city planners consider these parameters in a qualitative fashion, a reliable quantitative assessment is complicated by the sheer complexity of cities, a complexity that is comparable to that of atoms and molecular structures. This motivates us to explore novel tools of Statistical Physics to quantitatively pin down city texture in major US cities required for energy management.



Normalized, to account for city's size and shape, radial distribution function applied to three different cities. Chicago, New York and Boston have glass-, crystalline- and liquid-like structures, respectively.

Approach

By analogy with molecular simulations, we consider each building in a city as an atom, and determine the radial distribution functions (RDF), which in Statistical Physics are used to measure the density variation from a reference atom. Applied to the building stock of a selected number of cities in the United States, we study the probability of finding a neighboring building at a distance L, away from a given reference building. The average density of buildings is then defined as the number of buildings divided by the area of a city, and the local density at distance L corresponds to the number of buildings within a circular ring of radius L divided by the area of the ring. While randomly distributed buildings will not exhibit any differences between the average and local density at any given distance, as soon as buildings present some kind of structural pattern, the local density deviates from average density presenting peaks in the RDF.

Findings

The RDF analysis shows distinctive patterns of city texture for major cities: for Boston, the two peaks are reminiscent of a liquid-type amorphous texture, which is illustrative of a weak structural order; for New York, the existence of sharp peaks is indicative of a crystal-type texture, which is associated with dense molecular order; in contrast, merging peaks of Chicago suggest a glassy, frozen liquid-type texture, characterized by a molecular structure less ordered than that of crystals.

Impact

The novel approach leverages Statistical Physics to describe the complexity of cities in terms of molecular structures. This provides city planners and developers with innovative texture information, which can be used for effective energy management, including heating, ventilation and air conditioning of buildings in the scale of neighborhood and cities.

More

Research presented by J.M. Sobstyl and M.J. Abdolhosseini Qomi, students in the CSHub, in collaboration with Dr. B. Coasne and Profs. R. Pellenq and F-J. Ulm.

This research was carried out by the CSHub@MIT with sponsorship provided by the Portland Cement Association (PCA) and the Ready Mixed Concrete (RMC) Research & Education Foundation. The CSHub@MIT is solely responsible for content. For more information, write to CSHub@mit.edu.