The Contribution of Anthropogenic Energy Use to Urban Heat Island: Combining Energy Consumption Data with Satellite Observation of Land Surface Temperature

CornellEngineering
Civil and Environmental Engineering

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1. Introduction

Anthropogenic energy use has been recognized as one of the factors contributing to urban heat island (UHI) effect (Oke. 1991; Gartland. 2008). The Earth skin temperature is a good indicator for the surface UHI (SUHI). However, effects of anthropogenic energy use on the skin temperature obtained from Earth observation are understudied. In this research, we use data from observations (space and ground measurements) and urban land surface characteristics (from local climate zone profiles) to investigate how indoor and outdoor air temperature increase caused by anthropogenic energy use leads to change in the skin temperature. Multiple North American cities are investigated to provide a new perspective to understand different heat transfer pathways in modulating the impacts of anthropogenic energy use.

2. Research sites and Datasets

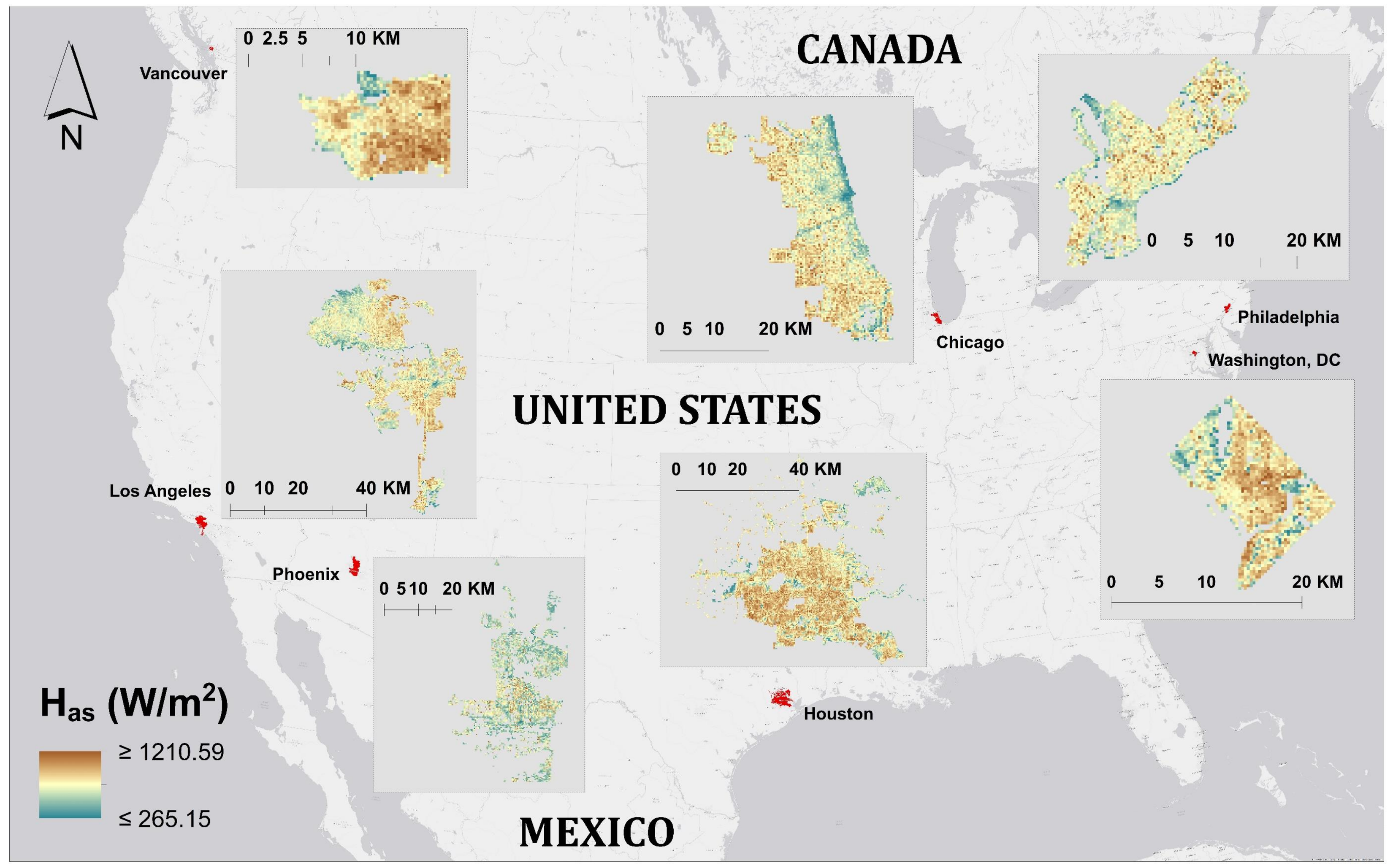


Fig. 1 Selection of cities and their increase in sensible heat flux due to anthropogenic energy use

- Seven cities over North America, including **Chicago (CHI), District of Columbia (DC), Houston (HOU), Philadelphia (PHL), Phoenix (PHX) and Vancouver (VAN)** are selected for a preliminary study of Surface Energy Balance (SEB) components. Residuals of SEB are shown as sensible heat increase (H_{as}) here (Kato et al. 2005), which is deterministic in affecting surface temperature growth.
- Many intermediary outputs in SEB are highly involved in the calculation of sub-city-level conductive temperature change. An application of **Landsat 8 products** (level 1 and level 2), together with **ASOS weather records** is necessary for the estimation of earth surface properties.
- Morphological and functional data of classified urban zones are derived from **LCZ parametric schemes**.

3. Anthropogenically induced heating rate

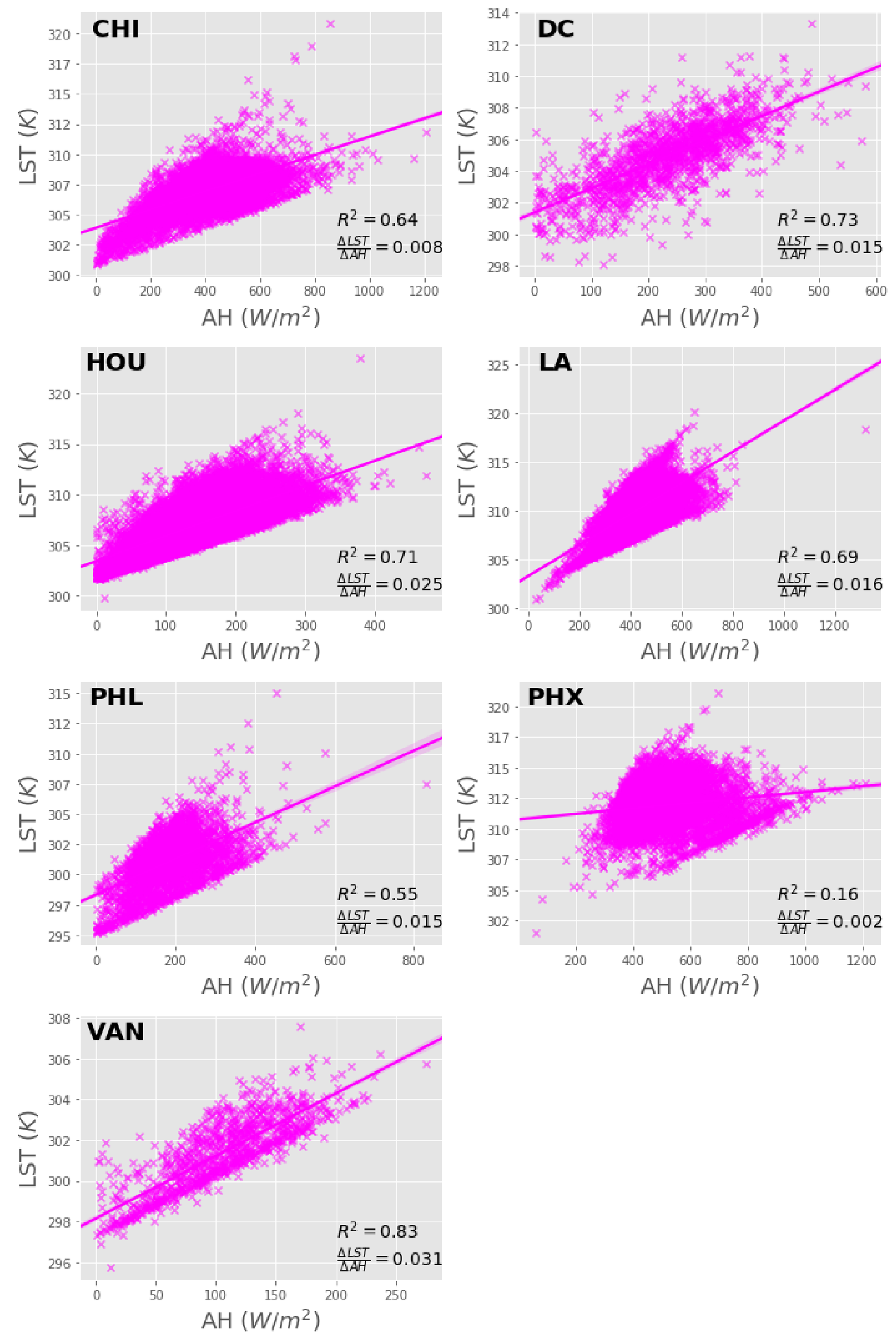


Fig. 2 Scatter plots of AH versus LST

- Indoor air temperature (T_{in}) and outdoor air temperature (T_{out}) are accountable for the change of observational SUHI (T_s) after a linearization on the SEB equation with respect to T_s (See Eq.1).
- Assuming that the indoor and outdoor air temperature are enhanced by anthropogenic energy use, two research questions are proposed: **1) Which one is more dominant in its efficiency to elevate the skin temperature, T_{in} or T_{out}? 2) How does the efficiency vary across urban land use types (i.e. LCZs) and across cities?**
- Preliminary results (Fig. 2) show different trends in the response of surface temperature to anthropogenic energy consumption across cities.

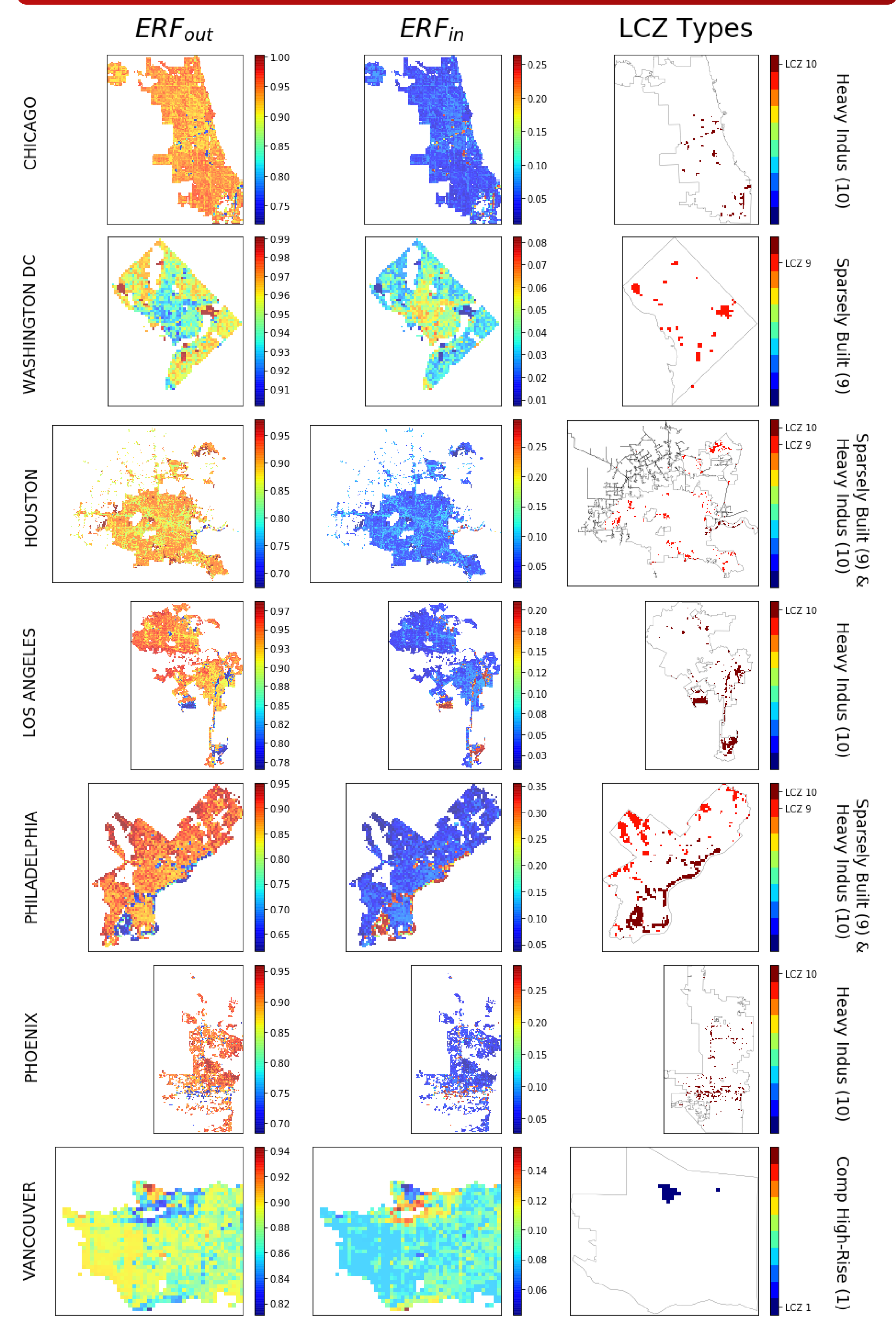
4. Energy redistribution factors (ERF)

Relations between T_{in}, T_{out} and T_s can be obtained from a linearized SEB:

$$\Delta T_s = \frac{f_a}{f_s + f}\Delta \mathrm{T}_{out} + \frac{f}{f_s + f}\Delta T_{in} = ERF_{out}\Delta \mathrm{T}_{out} + ERF_{in}\Delta T_{in} \quad (1)$$

$\frac{f_a}{f_s+f}$ and $\frac{f}{f_s+f}$ are considered as two energy redistribution factors ($\boldsymbol{ERF_{out}}$ and $\boldsymbol{ERF_{in}}$, respectively). f_a and f_s are functions of parameters like emissivity, surface/air temperature, Bowen ratio, aerodynamic resistance, etc, in the energy budget closure (Manoli et al. 2019; Sun et al. 2017; Zeng et al. 2017). $f = \frac{k}{\Delta x}$ is due to the storage heat flux computed following a similar approach in (Offerle et al. 2005), where k is thermal conductivity and Δx is thickness of the 'effective' urban surface, reference values are retrieved from the look-up tables of LCZ available from The World Urban Database and Access Portal Tools (WUDAPT).

5. Results



6. Conclusions

- Urban skin temperature is distinctively influenced by waste energy discharge: efficiency of the external heat sources generally exceed that of the internal ones for its contribution to LST. Their efficiencies show an opposite trend.
- Two ERFs slightly differ among cities, suggesting different responses to anthropogenic energy consumptions and different contributions to LST.
- Certain LCZ types (industry and sparsely built) show strong spatial correspondence with the extreme values of ERFs in all cities investigated here.