Urban Heat Island (UHI) Mitigation Transfer Functions

Stephen Guerin
Harvard Visualization Lab, Earth and Planetary Sciences
stephenguerin@fas.harvard.edu

Alec Melkonian
Harvard Graduate School of Design
alec.melkonian@gsd.harvard.edu

Introduction

This document outlines basic transfer functions for modeling the mitigation of the Urban Heat Island (UHI) effect through rooftop design strategies. The framework is intended as a decision-support tool for community planning, particularly in urban environments where extreme heat poses risks to health, comfort, and sustainability. Communities, municipalities, and designers can use this tool to assess different rooftop intervention portfolios based on cost, time, available materials, community will, and sociopolitical feasibility.

The simulation goal is to reduce undesirable urban heat outcomes, tracked using **order parameters** such as:

- **Surface Temperature (°C)**: Rooftop surface temperature.
- **Air Temperature Near Surface (°C)**: Local microclimate effect near rooftops.
- **UHI Intensity (T)**: Difference in temperature between urban and rural zones.
- **Net Radiative Flux (W/m^2)**: Net heat retained.
- **Latent Heat Flux (W/m^2)**: Indicator of evaporative cooling.
- **Thermal Comfort Index**: Composite metric for human heat exposure.

To influence these outcomes, communities can adjust **control variables**, including:

- **Vegetation Cover Percentage** and **Type of Vegetation**: Affects evapotranspiration rate (ET).
- **Albedo (Reflectance)** of surfaces: Ranges from 0.1 (dark) to 0.9 (bright white).
- **Water Retention Capacity** and **Evaporation Rate** on roofs: Related to the concept of "sponginess" and evaporative cooling.

These control variables define a portfolio of experimental levers that can be simulated, iterated upon, and assessed by planners and stakeholders. The tradeoffs between them reflect real-world constraints—some changes are fast and inexpensive (e.g., painting roofs white), while others require time, community buy-in, or infrastructural investment (e.g., green roofs or stormwater systems).

1 Increasing Vegetation (Evapotranspiration Cooling)

Transfer Function:

$$Q_{ET} = \lambda \times ET$$

- Q_{ET} = Evapotranspiration cooling (W/m^2)
- λ = Latent heat of vaporization (2450 kJ/kg or 2.45 MJ/kg)
- ET = Evapotranspiration rate (kg/m^2·s), typically 0.05–0.2 mm/h

Practical Approximation:

- Grass and small plants: cooling ∼50–150 W/m^2
- Mature trees/shaded canopy: cooling ∼150–400 W/m^2 (peak daytime)

2 Increasing Surface Albedo (Reflectance)

Transfer Function:

$$\Delta Q_{abs} = I_{solar} \times \Delta\alpha$$

- ΔQ_{abs} = Change in absorbed solar radiation (W/m^2)
- I_{solar} = Incoming solar radiation (800–1000 W/m^2 at peak)
- $\Delta\alpha$ = Change in surface albedo (reflectance)

Practical Approximation:

- Every 0.1 increase in albedo reduces heat absorbed by ∼80–100 W/m^2

3 Increasing Roof Sponginess (Stormwater Evaporative Cooling)

Transfer Function:

$$Q_{evap} = m_{water} \times \frac{\lambda}{t}$$

- Q_{evap} = Evaporative cooling from water retention (W/m^2)
- m_{water} = Mass of water evaporated (kg/m^2)
- λ = Latent heat of evaporation (2.45 MJ/kg or 2450 kJ/kg)
- t = Time period of evaporation (s)

Practical Approximation:

- Each liter of water evaporated per m^2 yields ∼680 Wh of cooling
- 1 liter evaporated uniformly over 8 hrs ≈ 85 W/m^2 average cooling

Summary of Simplified Approximations

Mitigation Strategy	**Typical Cooling Impact**
Vegetation (Grass/Small Plants)	∼50–150 W/m^2
Vegetation (Trees/Canopy)	∼150–400 W/m^2
Albedo Increase ($\Delta\alpha = 0.1$)	∼80–100 W/m^2 reduction
Evaporating 1 liter/m^2 over 8 hrs	∼85 W/m^2