Energy Performance of Green Roofs:  
the role of the roof in affecting building energy and the urban atmospheric environment

EPA Heat Island Reduction Program Webcast  
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Why Green roofs?

• Roof life
• Aesthetics and recreation
• Biodiversity and habitat
• Storm water quality and quantity
• Air Quality
  • Building Energy Consumption
  • Urban Heat Island
The Building Sector

~ 40 % of all energy consumption and CO₂ emissions...

~ 1/3 of building energy use is for heating and cooling...

What role can green roofs play in reducing building energy use?
Causes of Heating/Cooling Loads in Buildings

- Indoor energy use (lighting & plug loads)
- Ventilation and infiltration of outdoor air
- Solar heat gain through windows
- Conduction through walls
- Conduction through roof
Heat Transfer on a Green Roof

- Longwave radiation
- Latent heat (evapotranspiration)
- Conduction
- Protection & Drainage Layers and Roof Construction
- Sensible heat (convection)
- Shortwave radiation
Conventional Roof – Day

$T_{surf} = T_{membrane} \approx 120-150 \, ^{\circ}F$

Heats up rapidly during summer day...

Conventional Roof -- Night

...but cools off rapidly at night.
“Cool” White Roof -- Day

\[ T_{\text{surf}} = T_{\text{membrane}} \sim 90-110 \, ^\circ \text{F} \]

Doesn’t heat up as much during summer day...

“Cool” White Roof -- Night

...and cools off significantly at night.
Green Roof-- Day

\[ T_{\text{surf}} \sim 90-110 \degree F \]
\[ T_{\text{membrane}} \sim 80 – 100 \degree F \]

Doesn’t heat up much during summer day...

Green Roof- Night

...but remains warm at night due to stored heat.
Many studies have measured green roof impacts on roof temperatures...

... some studies have measured heat flux...
Average rooftop surface temperatures for a standard and a green roof.

Green roof is ~30-40 °F cooler during a summer day.

Green roof is warmer by ~10 °F at night.

Green roof is ~30-40 °F cooler during a summer day.

Green roof is warmer by ~20 °F at night.

Student Union, Univ. Central Florida.

J. Sonne, FSEC
...but we are interested in **whole building energy use**...

**Rooftop heat flux interacts with...**

* time-varying internal loads
* thermostat schedules and occupancy
* infiltration and ventilation
* seasonal weather
\[ F_f = \sigma_f \left[ I_s^{\downarrow} (1 - \alpha_f) + \varepsilon_f I_{ir}^{\downarrow} - \varepsilon_f \sigma T_f^4 \right] + \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} (T_g^4 - T_f^4) + H_f + L_f \]

\[ F_g = (1 - \sigma_f) \left[ I_s^{\downarrow} (1 - \alpha_g) + \varepsilon_g I_{ir}^{\downarrow} - \varepsilon_g T_g^4 \right] - \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} (T_g^4 - T_f^4) + H_g + L_g + K \frac{\partial T_g}{\partial z} \]
Green Roof Energy Model Summary

- **Standard in EnergyPlus**
  - Starting with v 2.1 in April 2007

- **Model inputs include:**
  - Green roof design parameters
  - Building details & schedules
  - Weather file, precipitation, irrigation

- **Model outputs include**
  - Hourly building electricity and natural gas use

**Sailor, D.J., 2008, Energy and Buildings 40 (8), 1466-1478.**
Example Simulation

- Monthly heating/cooling savings compared with a conventional darker roof
  - Residential
  - Located in London, UK
  - 2 story
  - 45 m by 45 m footprint

- Results depend on...
  - Building type
  - Location/climate
  - Construction details
A Green Roof Energy Calculator
*Sailor, Spolek, Bass, Peck*

- **Goal:** Create a simplified green roof energy savings calculator.
- **Compare** green roof design options with a “conventional” membrane roof and a “cool” white membrane alternative.
- A tool for developers, architects, and designers to investigate the building energy (& cost) implications of green roof design decisions.
The Urban Heat Island

Solar radiation

Sensible heat (S)

Waste heat ($Q_f$)

Long-wave radiation (LW)

Thermal storage (G)

Evaporative cooling
Green Roofs and the UHI – Portland Oregon

- Central eastside roofs developed over time to 100% green by 2050?
- Use atmospheric modeling to estimate air temperature impacts

Results: Heat Island Reduction

\[ \Delta T_{\text{air}} \approx 0.8^\circ C \quad (1.5^\circ F) \]

Contours by 0.2 °C
Green Roofs and the UHI – New York City

- Researchers at Columbia University:
  - Satellite thermal images, land use data...
  - Green roofs “could reduce average surface temperatures...by as much as $0.8 \degree C$ ($1.4 \degree F$) if 50% of the city’s flat roofs are greened.”

$\Delta T_{surface} \approx 0.8 \degree C$

$\Delta T_{air} \rightarrow ???$

Solecki, Rosenzweig, et al., 2006
Toronto, Canada – Control Simulation

Toronto
Lake Ontario
Temperature change with green roofs & urban vegetation
1300 Hrs, June 29, 2001

$\Delta T_{air} \approx 1 - 2^\circ C$
PV and Green Roof Integration

- Green roof – PV interactions
  - PV efficiency = f(T)
  - Vegetation health/diversity & shading
  - UHI implications (counteracting effects)
- NSF project at Portland State
  - Wamser, Sailor, Rosenstiel
  - 16 panels & 4 test roof sections
Diagram showing the components of a green roof system: solar panels, growing medium, drainage layer, and rooftop slab. The diagram includes labels for incoming light (I_s), reflected light (I_r), and transmitted light (I_a). It also indicates the power output to the metering device and grid.
Roof design affects sensible heating of the urban environment.
Some final thoughts...

• Energy performance of green roofs varies with:
  – growing media composition, depth, and moisture
  – plant coverage/function
  – building characteristics, loads, and schedules
  – weather conditions

• Green roofs impact air conditioning and heating energy

• Evaluation of green roof energy performance requires definition of a “baseline” for comparison

• Green roofs can contribute to UHI mitigation, but this is complicated by thermal storage issues.
Questions?
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