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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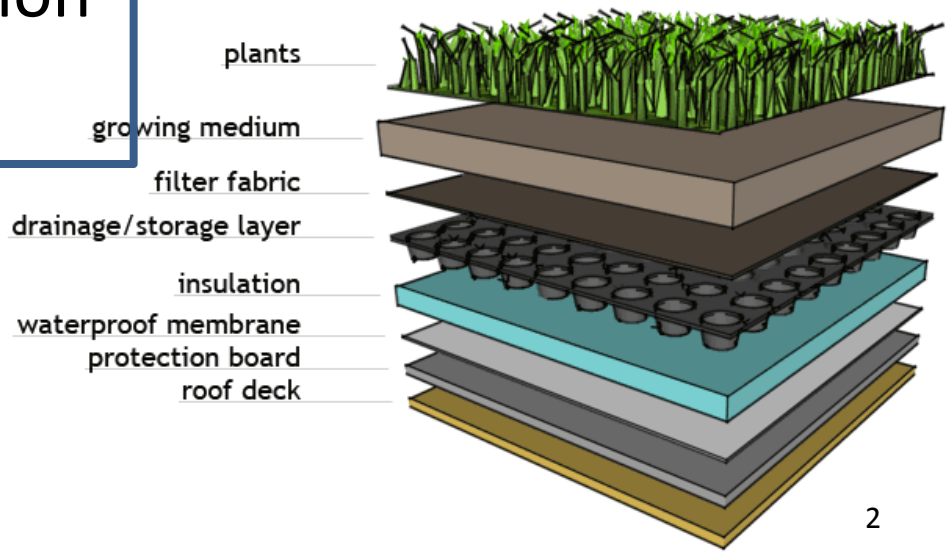
Why Green roofs?

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



The Building Sector

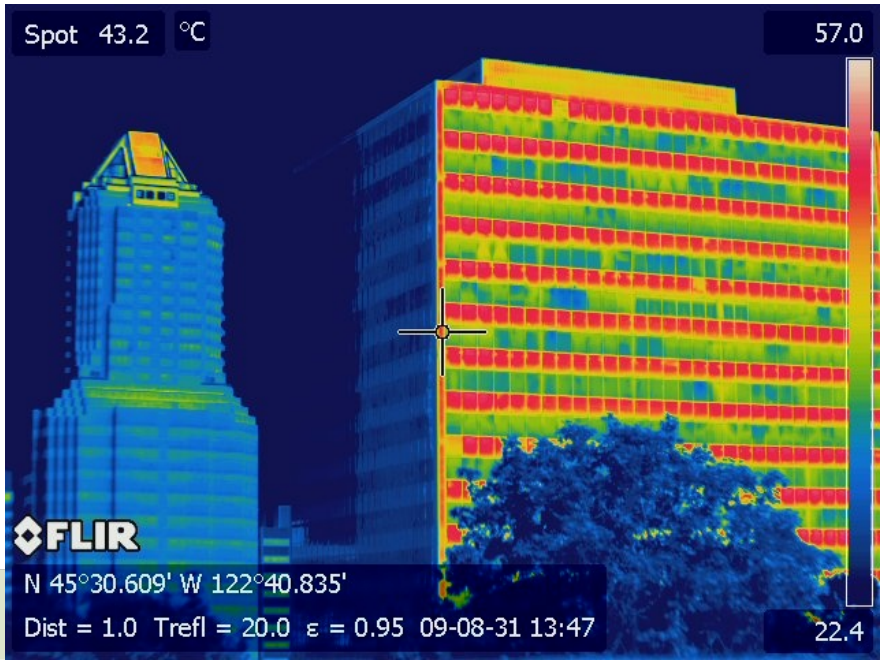
~ 40 % of all energy consumption and CO_2 emissions…

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

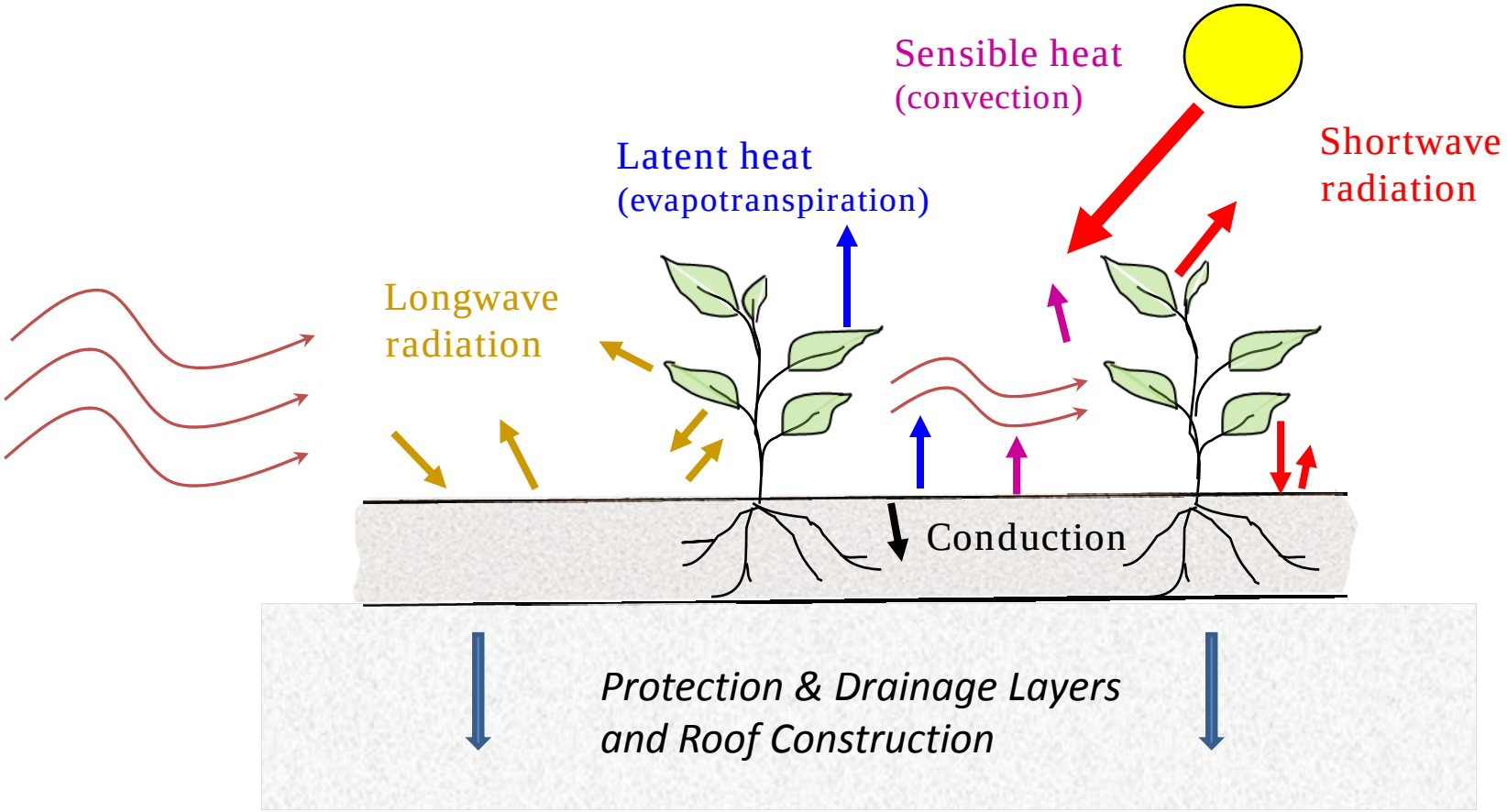
What role can green roofs play in reducing building energy use?

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

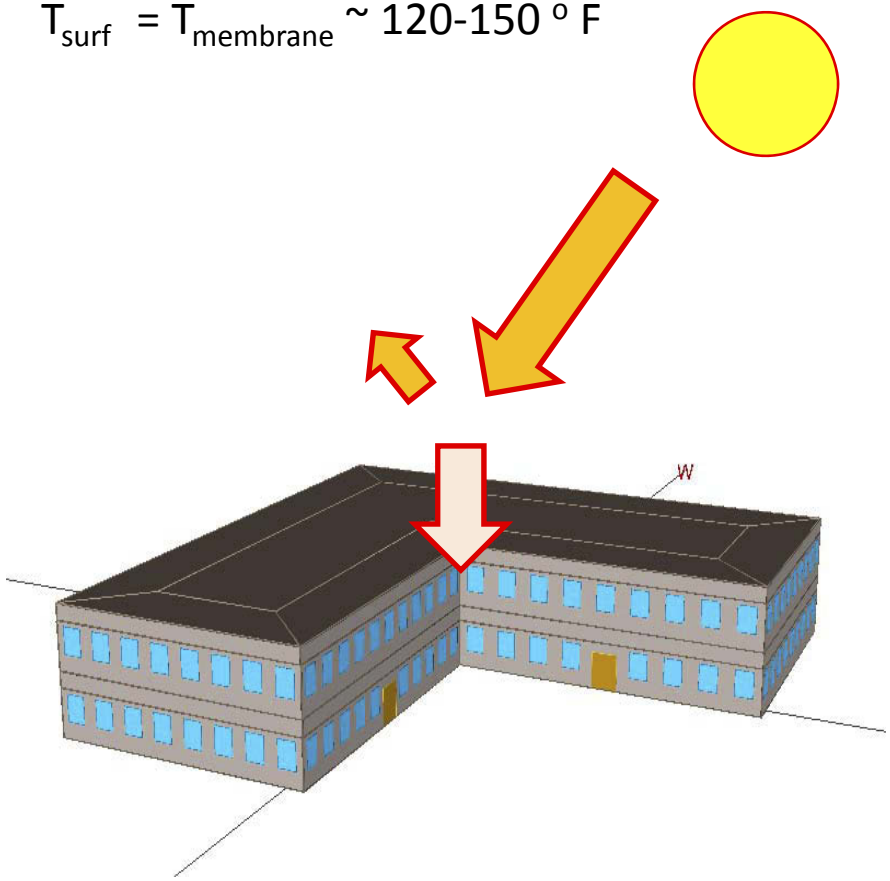


Heat Transfer on a Green Roof



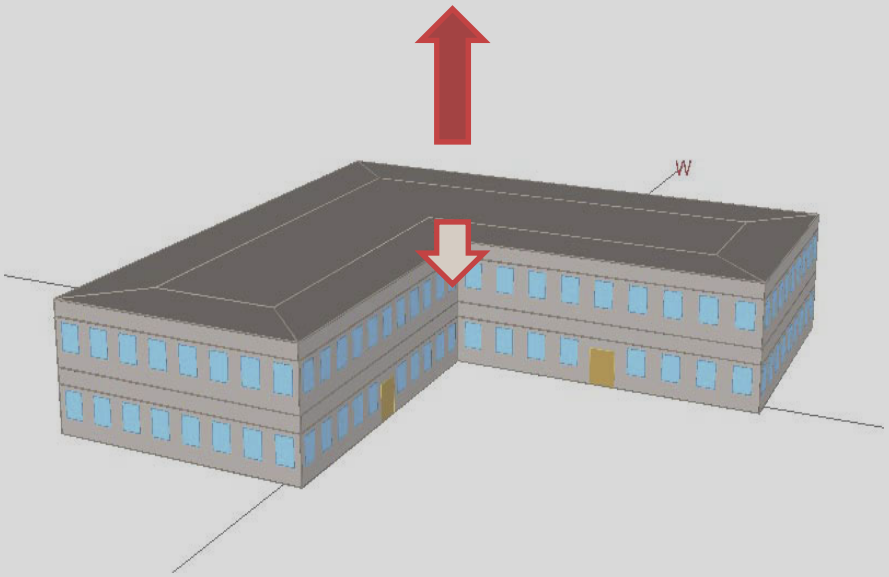
Conventional Roof – Day

$T_{surf} = T_{membrane} \sim 120\text{-}150\ ^{o}F$



Heats up rapidly during summer day…

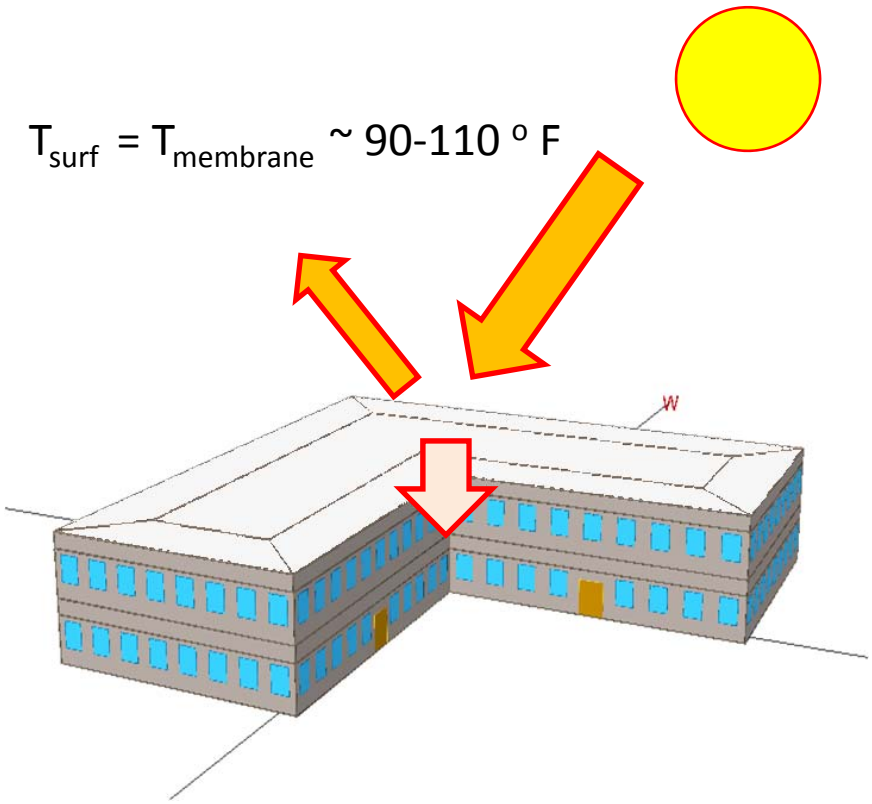
Conventional Roof -- Night



…but cools off rapidly at night.

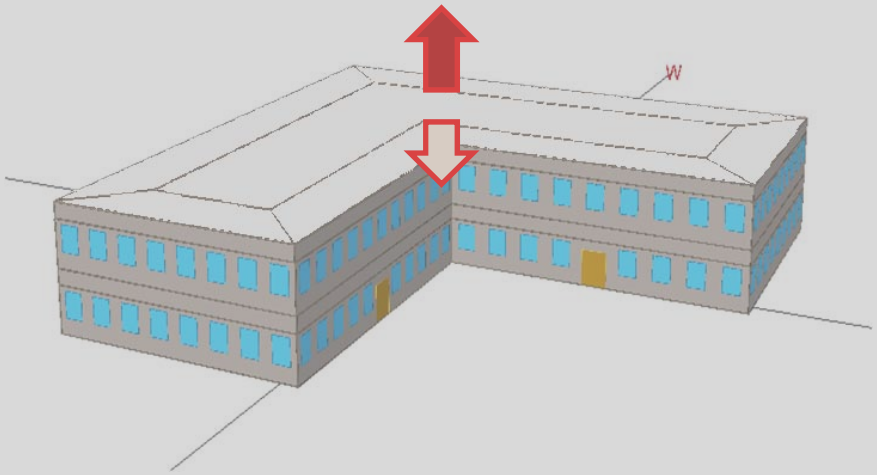
“Cool” White Roof -- Day

$T_{surf} = T_{membrane} \sim 90\text{-}110\ ^{o}F$



Doesn’t heat up as much during summer day…

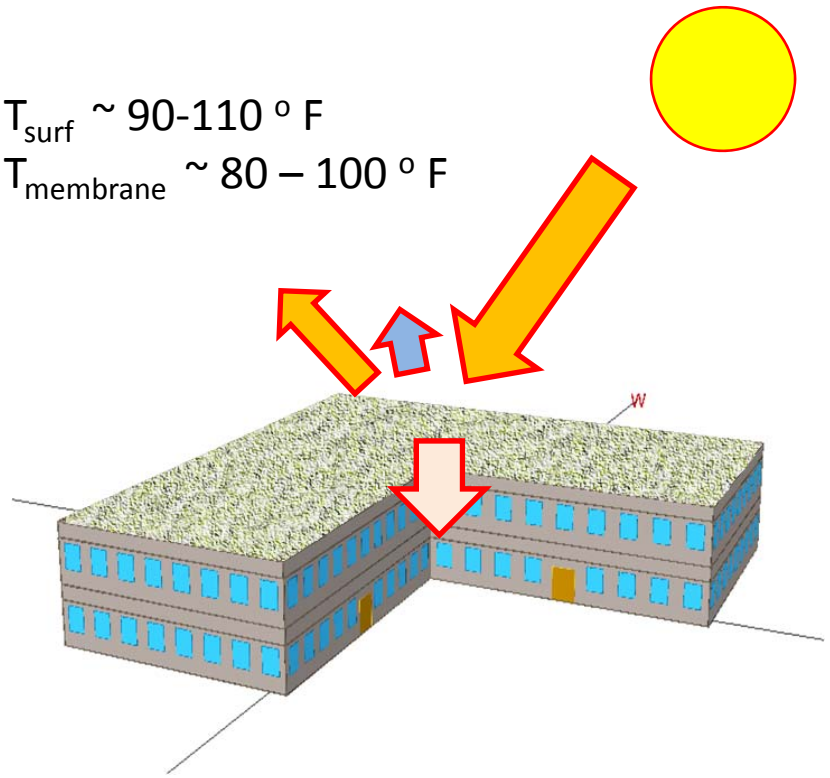
“Cool” White Roof -- Night



…and cools off significantly at night.

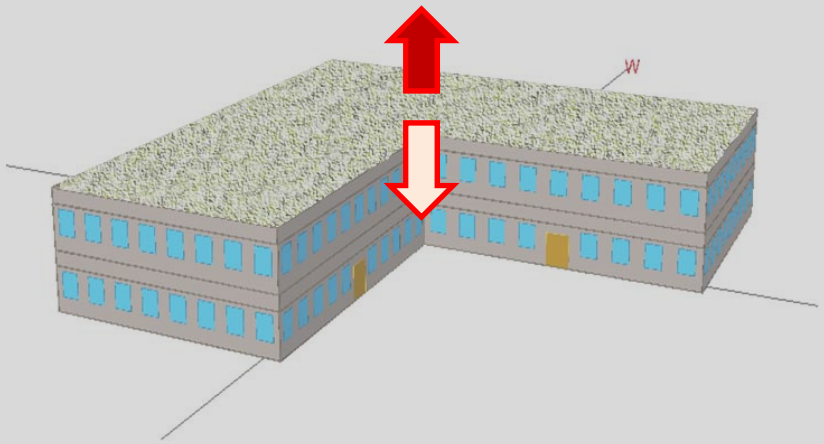
Green Roof-- Day

T_{surf} ~ 90-110 ° F
$T_{membrane}$ ~ 80 – 100 ° F



Doesn't heat up much during summer day…

Green Roof- Night

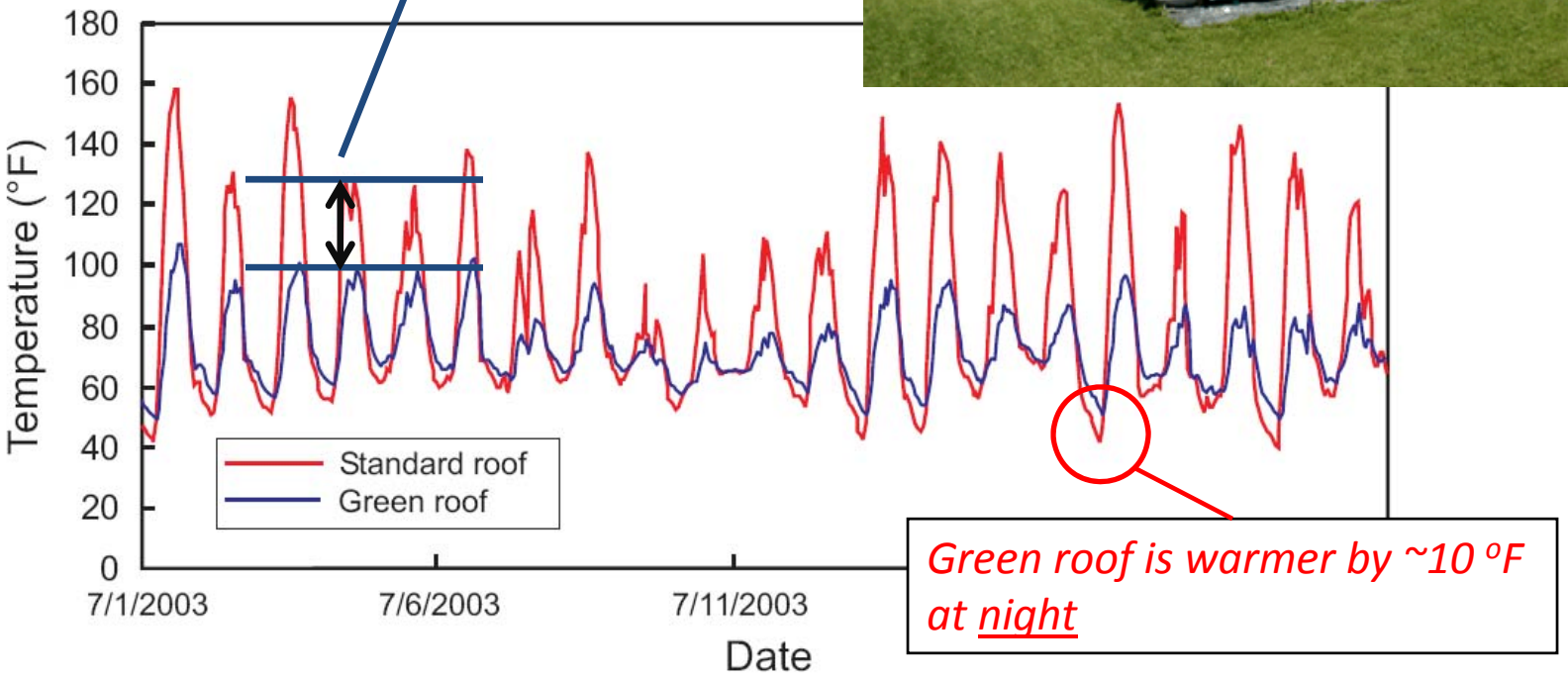


…but remains warm at night due to stored heat.

Many studies have measured green roof impacts on roof temperatures…

… some studies have measured heat flux…

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

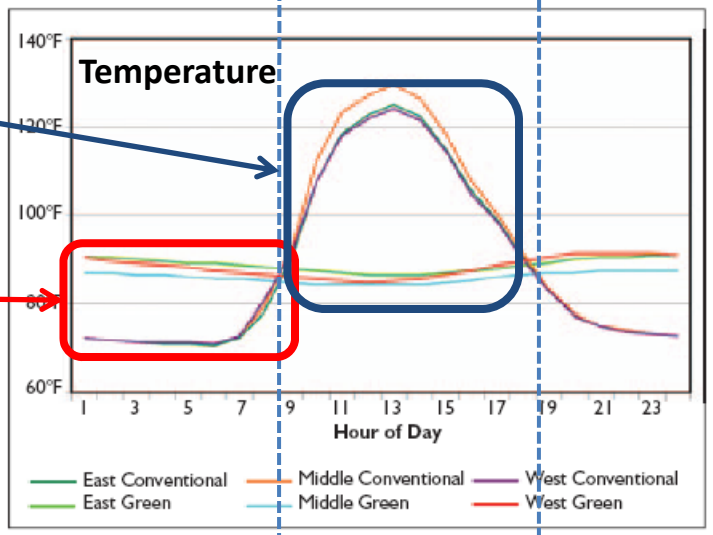


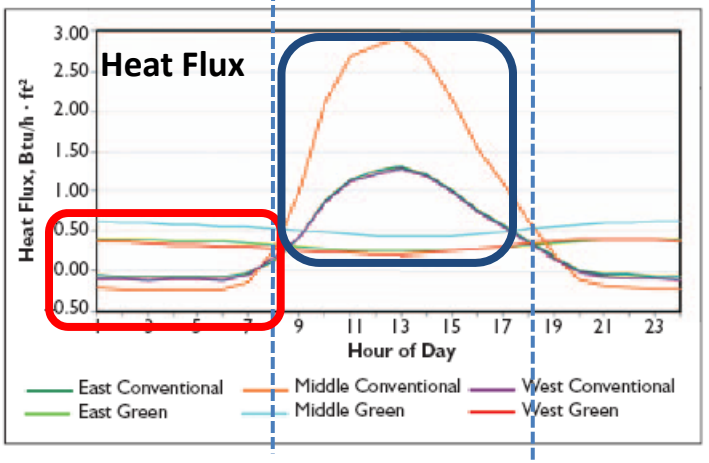
Green roof is warmer by ~10 °F at night

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 ~20 °F at night



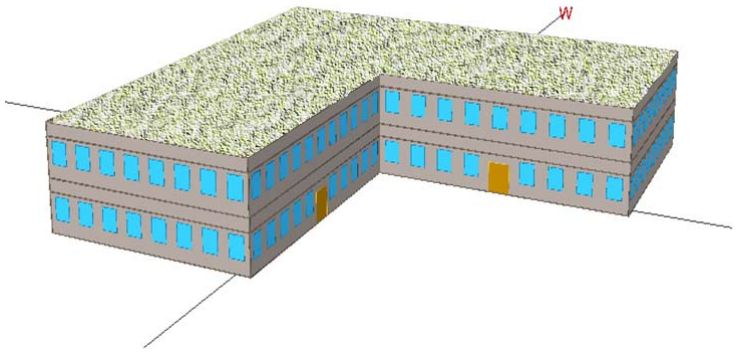


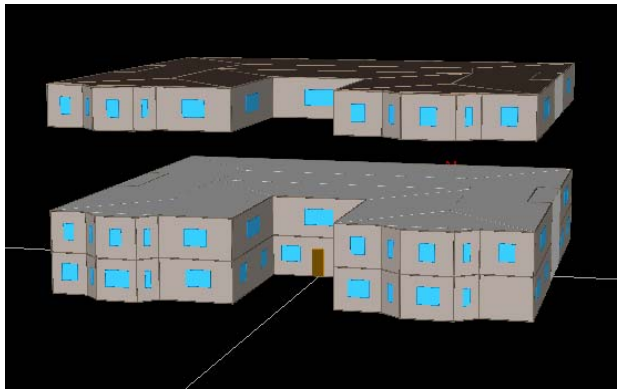
Student Union,
Univ. Central Florida.

…but we are interested in <u>whole building</u> energy use…

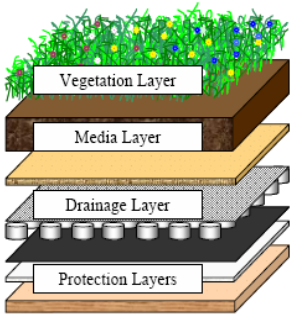
<u>Rooftop heat flux interacts with…</u>

* time-varying internal loads
* thermostat schedules and occupancy
* infiltration and ventilation
* seasonal weather





Sailor, 2008

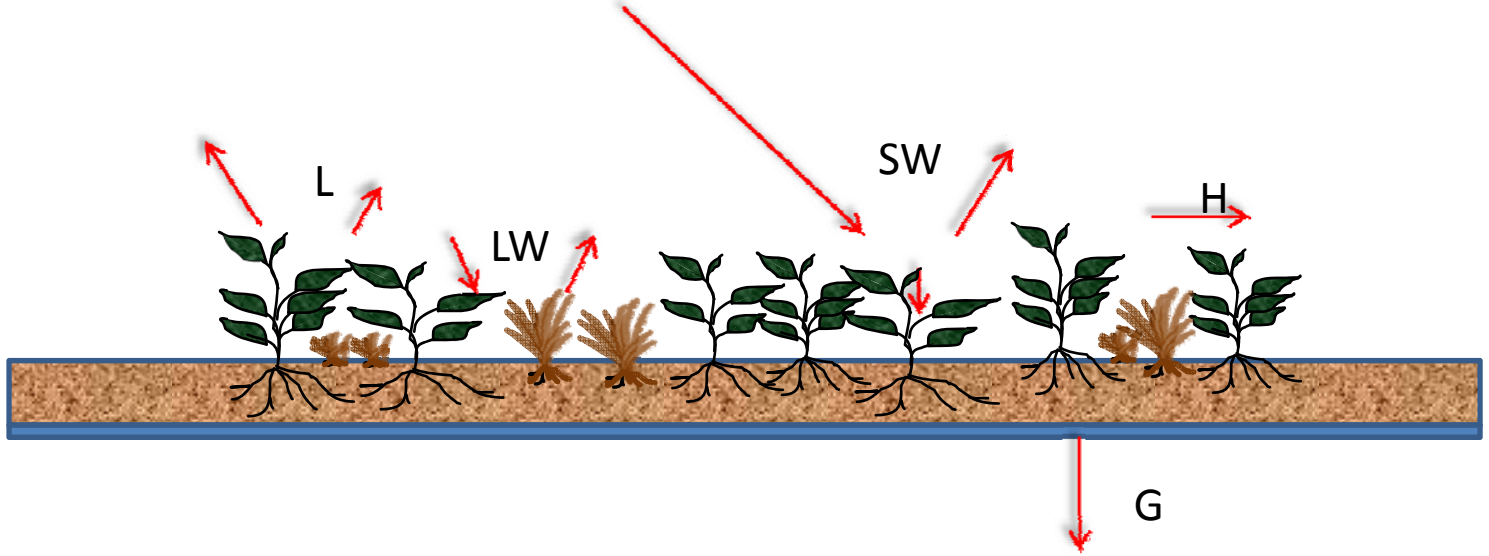


FOLIAGE

$$F_f = \sigma_f \left[I_S^{\downarrow}(1-\alpha_f) + \varepsilon_f I_{ir}^{\downarrow} - \varepsilon_f \sigma T_f^{\,4} \right] + \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} \left(T_g^{\,4} - T_f^{\,4} \right) + H_f + L_f$$

GROUND SURFACE

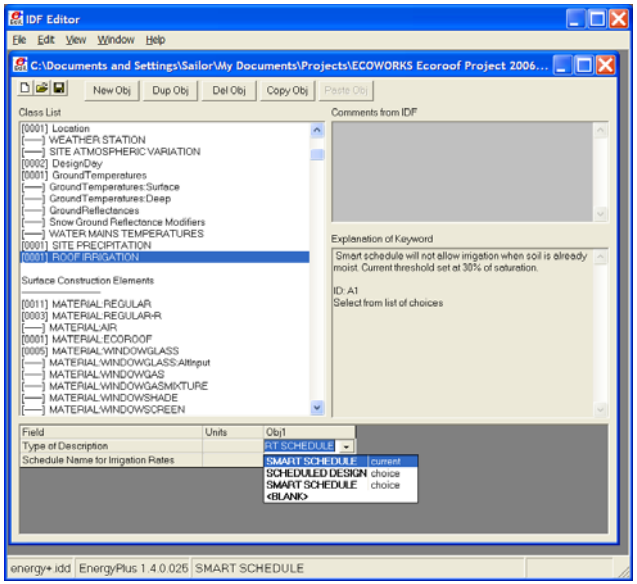
$$F_g = (1-\sigma_f)\left[I_s^{\downarrow}(1-\alpha_g) + \varepsilon_g I_{ir}^{\downarrow} - \varepsilon_g T_g^{4} \right] - \frac{\sigma_f \varepsilon_g \varepsilon_f \sigma}{\varepsilon_f + \varepsilon_g - \varepsilon_f \varepsilon_g} \left(T_g^{4} - T_f^{4} \right) + H_g + L_g + K * \frac{\partial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

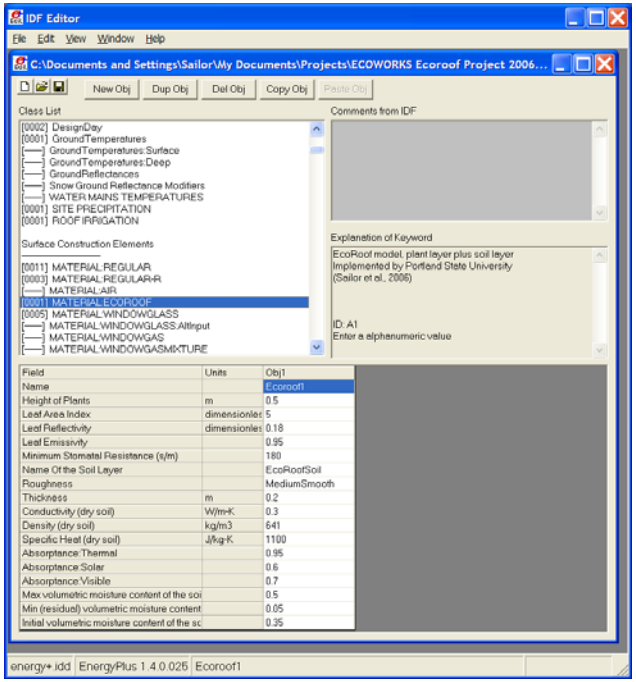


Sailor, D.J., 2008, *Energy and Buildings* **40** (8), 1466-1478.

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

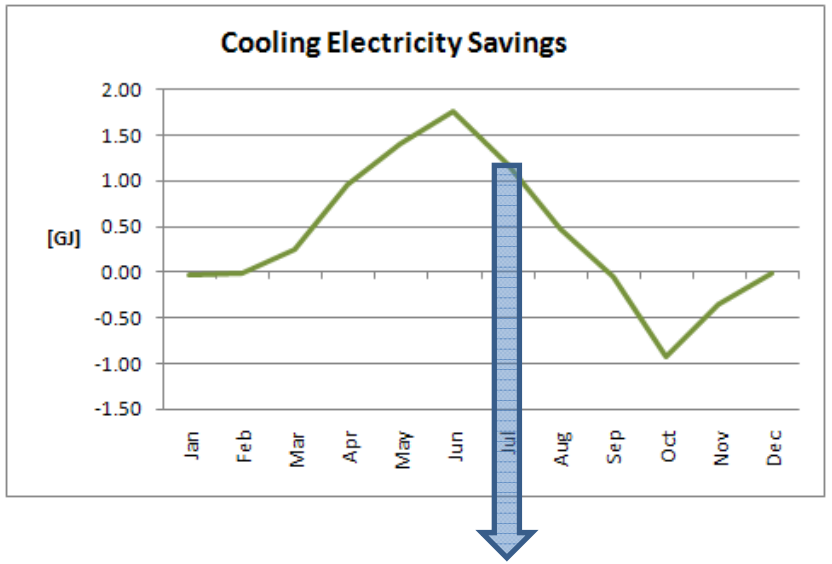


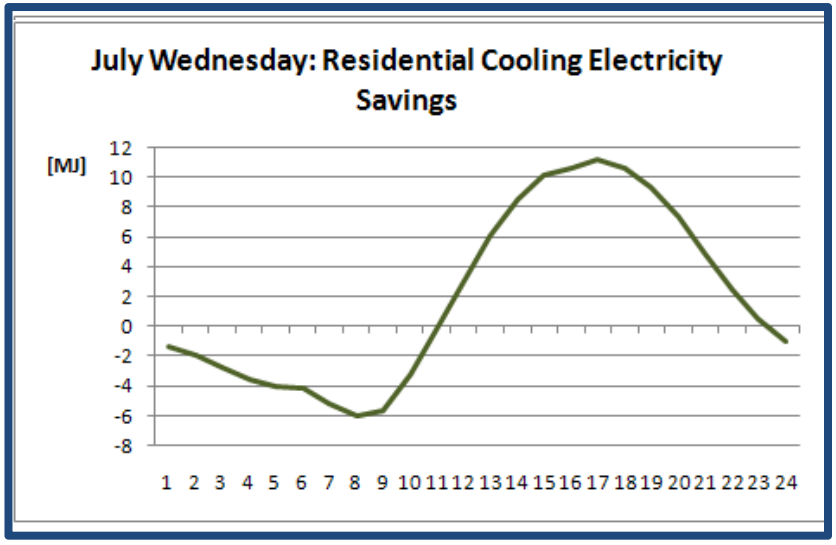


Sailor, D.J., 2008, *Energy and Buildings* **40** (8), 1466-1478.

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

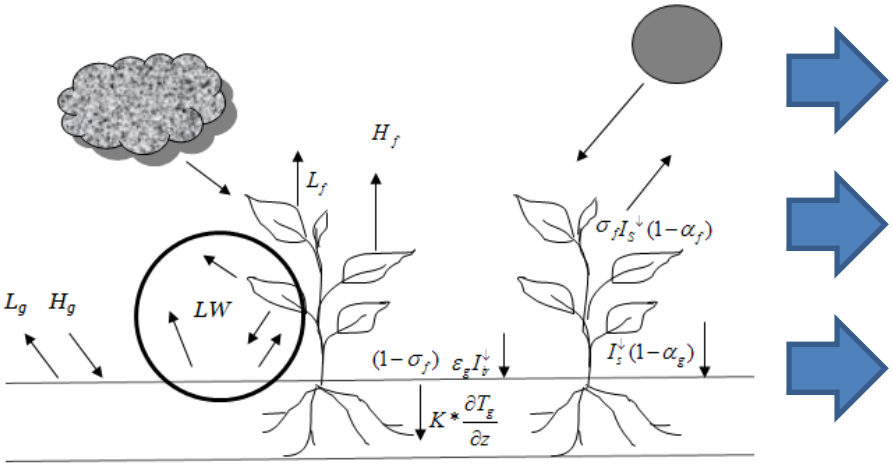


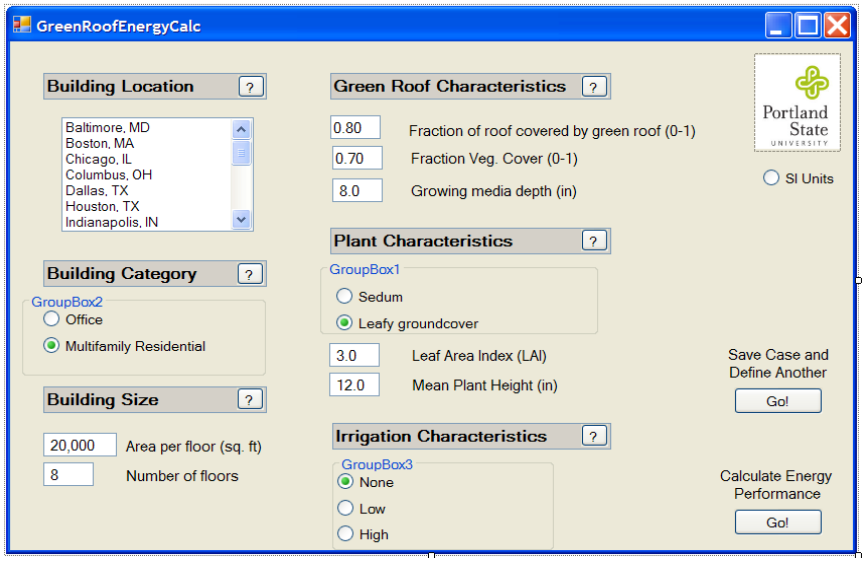


A Green Roof Energy Calculator

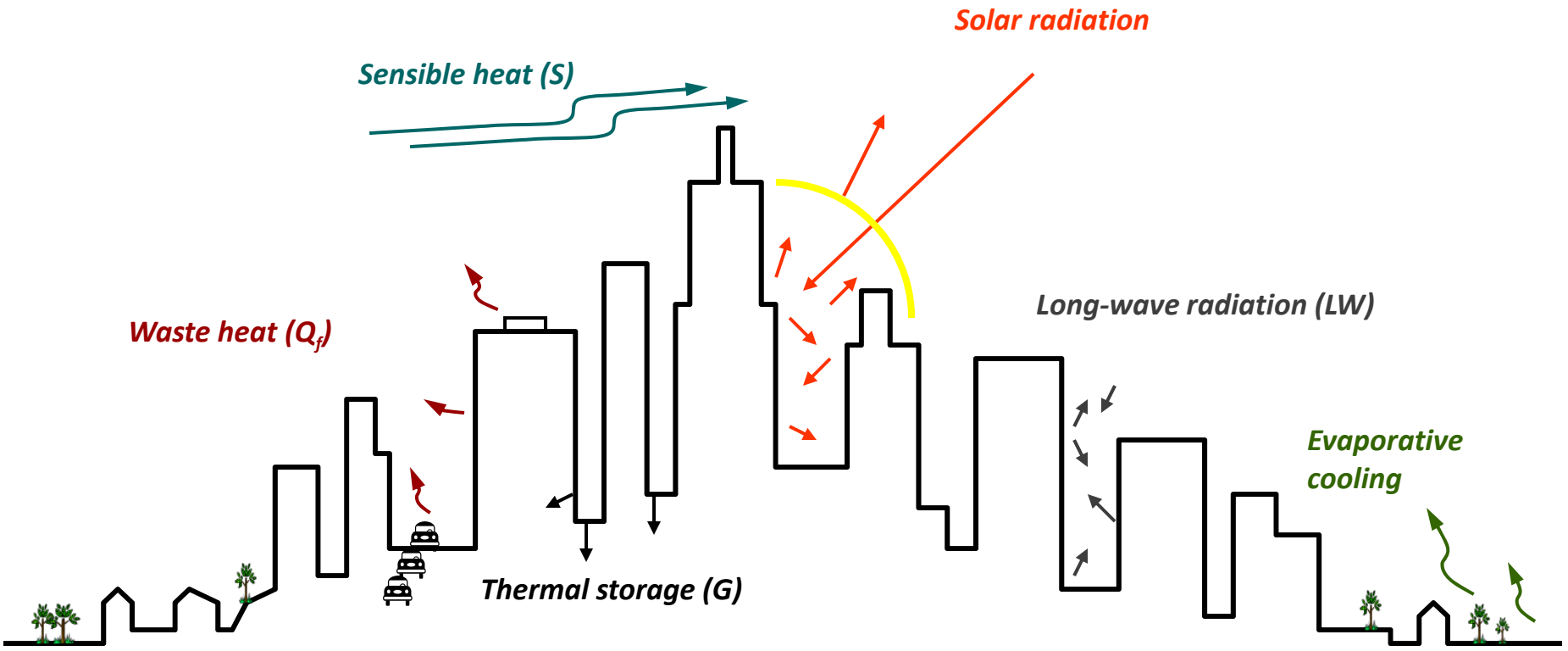
Sailor, Spolek, Bass, Peck

- 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.



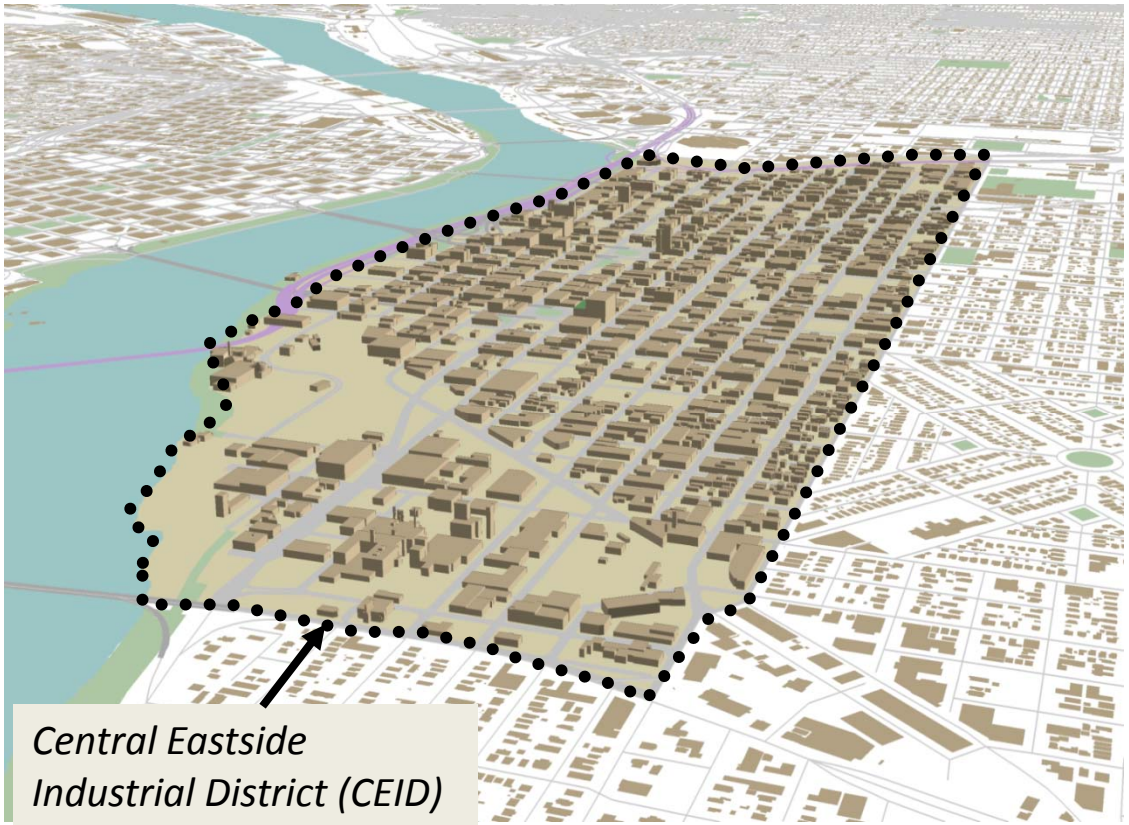


The Urban Heat Island



Green Roofs and the UHI – Portland Oregon

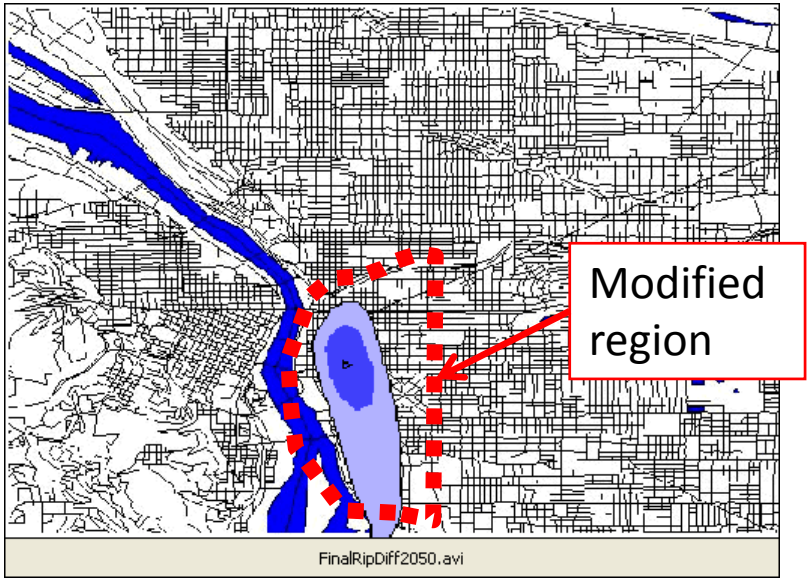
- Central eastside roofs developed over time to 100% green by 2050 ?
- Use atmospheric modeling to estimate air temperature impacts



Sailor, 2004.

Results: Heat Island Reduction

$$\Delta T_{air} \approx 0.8^{o} C \quad (1.5^{o} F)$$



Contours by 0.2 ° C

Green Roofs and the UHI – New York City

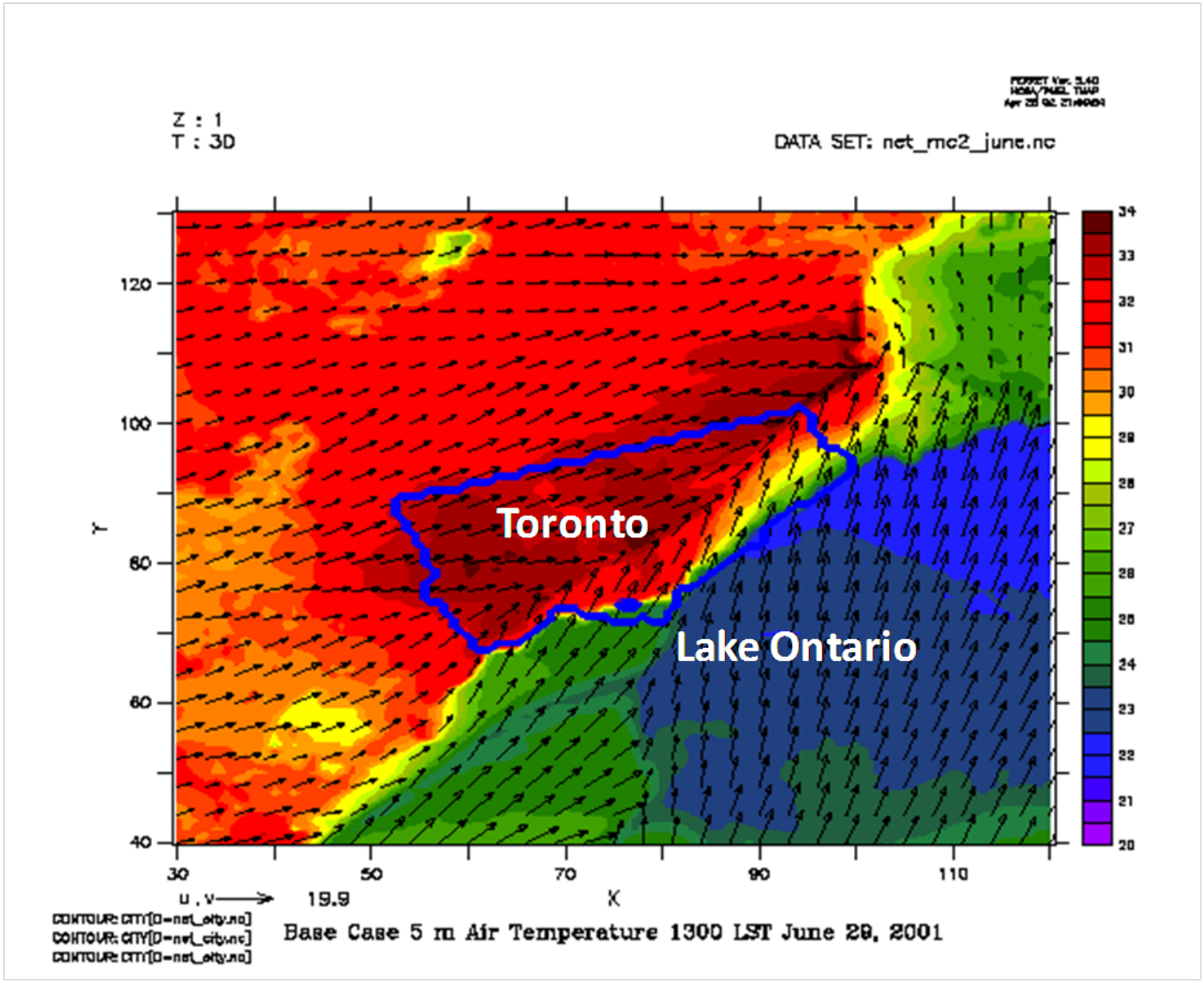
- Researchers at Columbia University:
  - Satellite thermal images, land use data…
  - Green roofs "could reduce average surface temperatures …by as much as **0.8 º C** (1.4º F) if 50% of the city's flat roofs are greened."

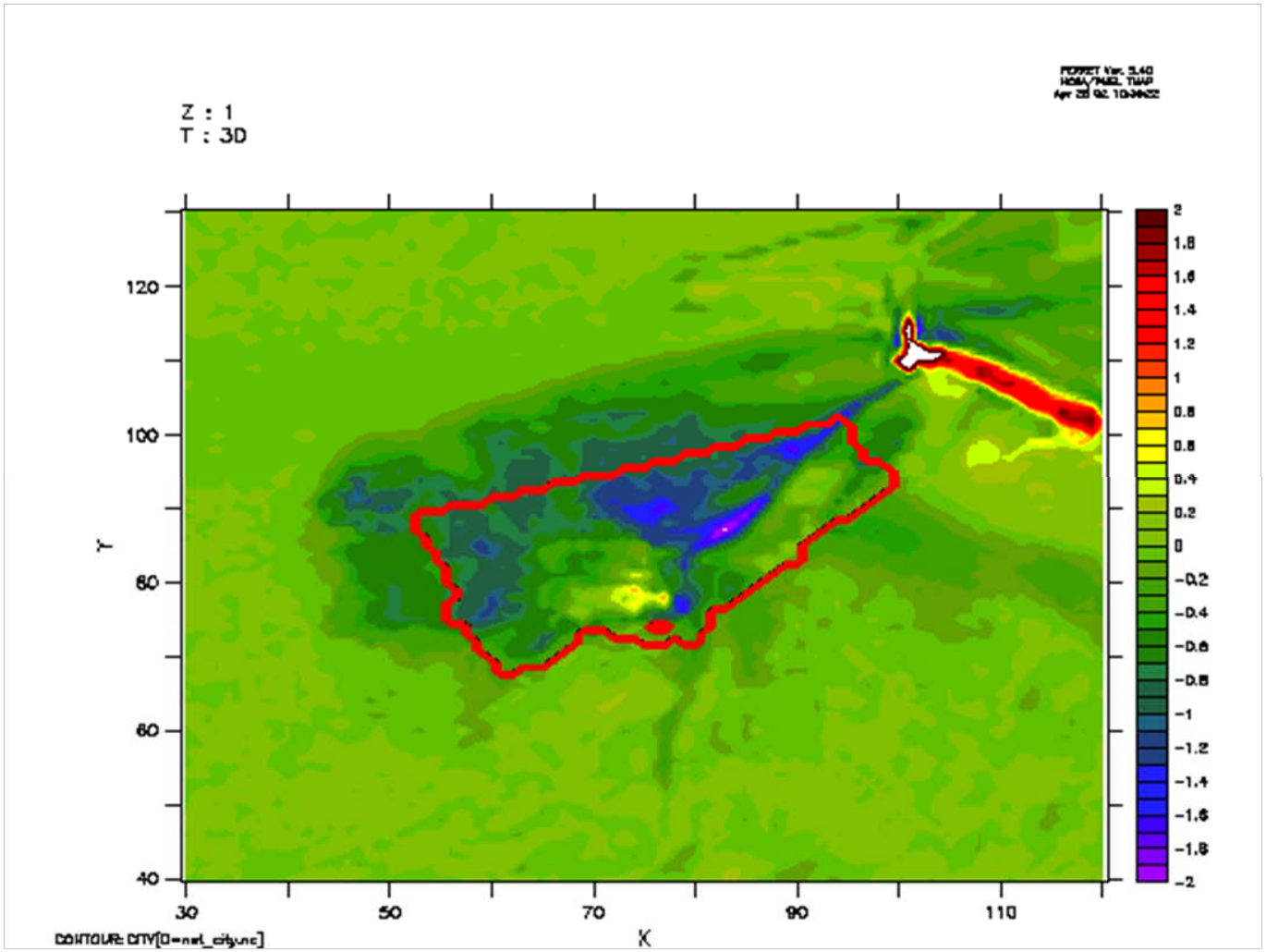
$$\Delta T_{surface} \approx 0.8^{o} C$$

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

Solecki, Rosenzweig, et al., 2006

Toronto, Canada – Control Simulation



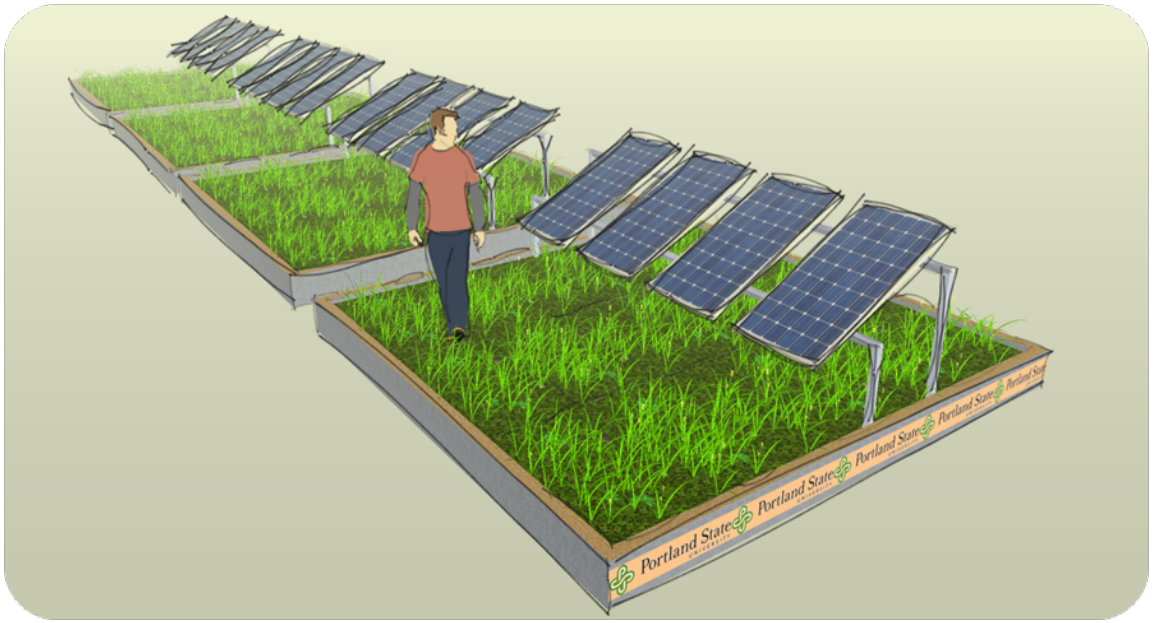


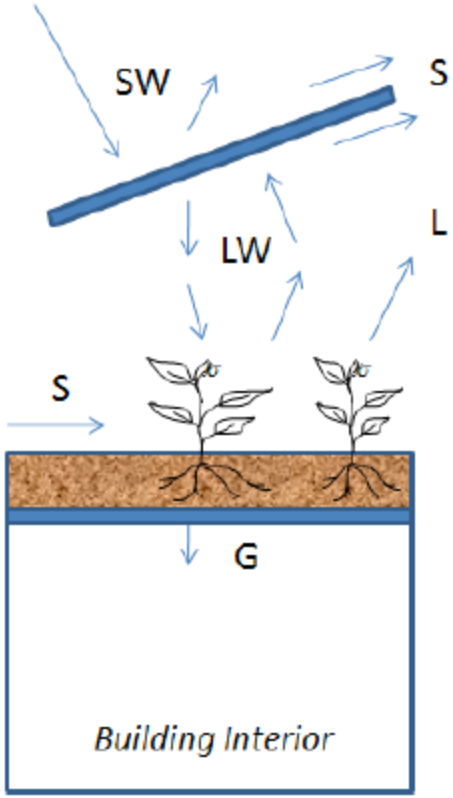
$$\Delta T_{air} \approx 1-2^{o}C$$

Temperature change with green roofs & urban vegetation

1300 Hrs, June 29, 2001

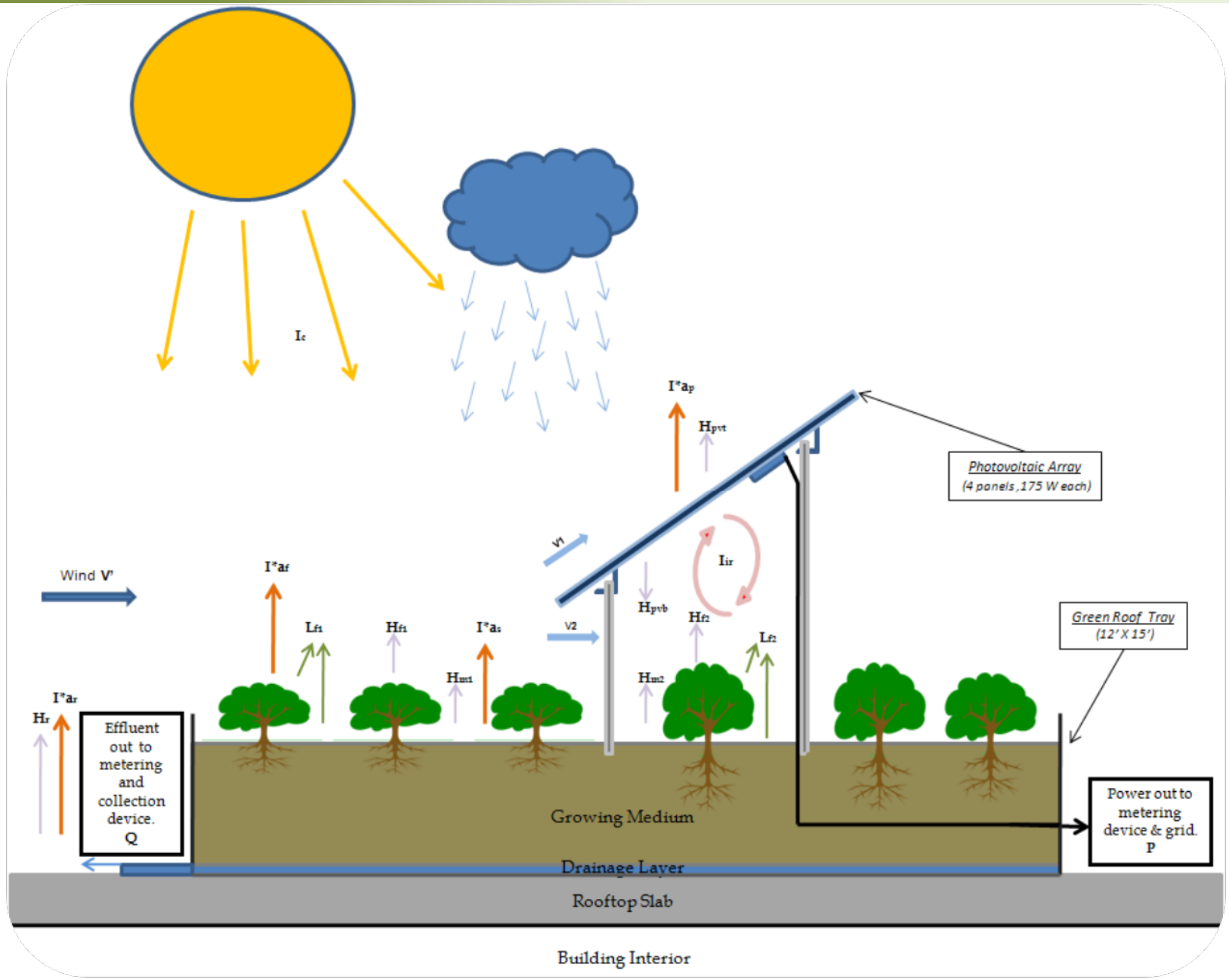
PV and Green Roof Integration



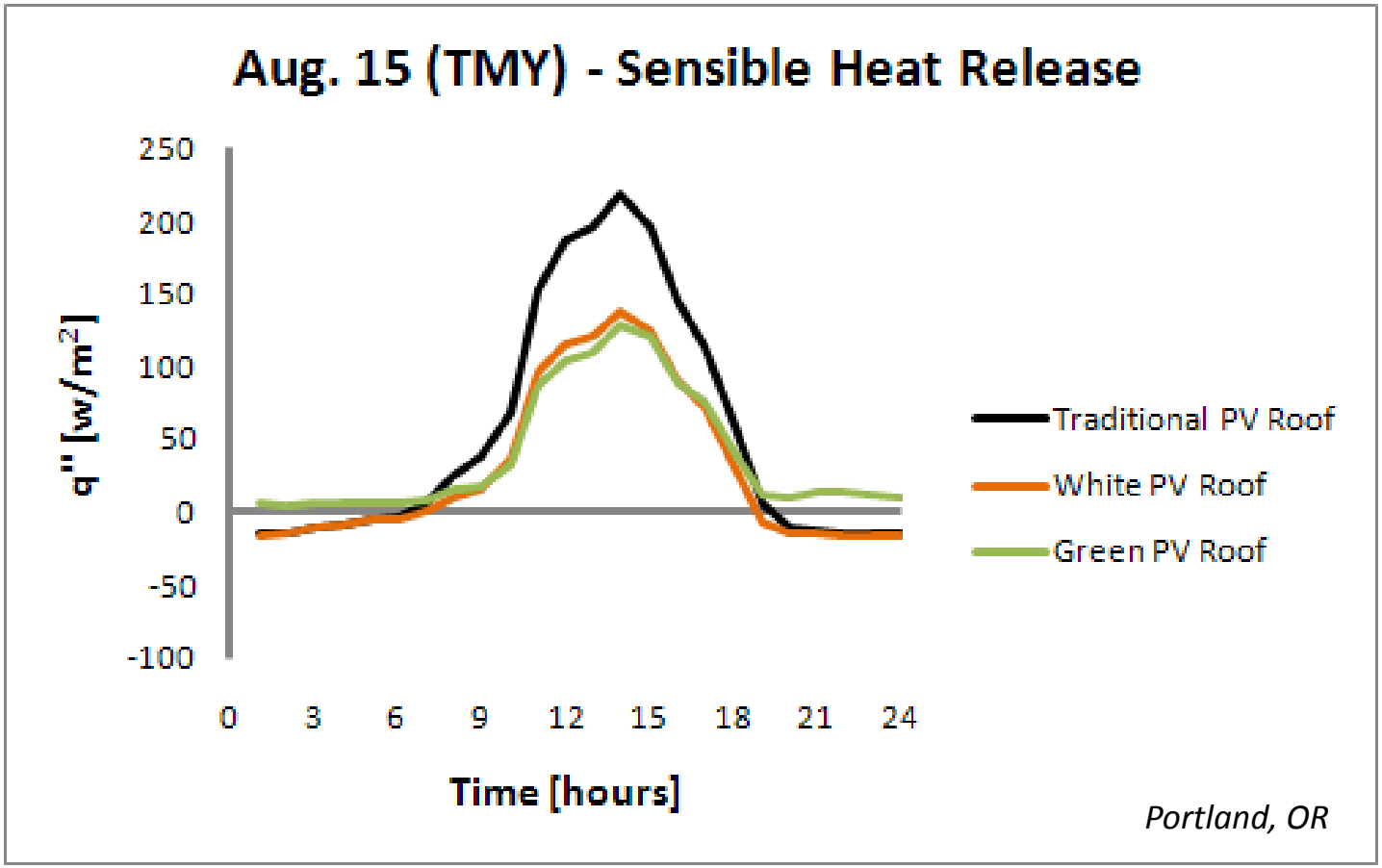


- Green roof – PV interactions
  - PV efficiency = f(T)
  - Vegetation health/diversity & shading
  - UHI implications (counteracting effects)
- NSF project at Portland State
  - Wamser, Sailor, Rosenstiel
  - 16 panels & 4 test roof sections

Environmental Services City of Portland working for clean rivers | PGE | best Oregon Built Environment & Sustainable Technologies Center An Oregon BEST Signature Research Facility | NSF


Ic
I*ap
Hpvt
Photovoltaic Array
(4 panels, 175 W each)
V1
Iir
Hpvb
Wind V'
I*af
Lf1
Hf1
I*as
V2
Hf2
Lf2
Hm1
Hm2
Green Roof Tray
(12' X 15')
I*ar
Hr
Effluent out to metering and collection device. Q
Growing Medium
Power out to metering device & grid. P
Drainage Layer
Rooftop Slab
Building Interior

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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Brad Bass, U. Toronto
Tim Elley, PSU MME student
Seth Moody, PSU MME student
Stephen Peck, GRHC
Todd Rosenstiel, PSU Biology
Adam Scherba, PSU MME student
Graig Spolek, PSU MME
Carl Wamser, PSU Chemistry