A Green Roof Heat and Mass Transfer Model Coupled with a Finite Difference Method for Building Energy Simulations

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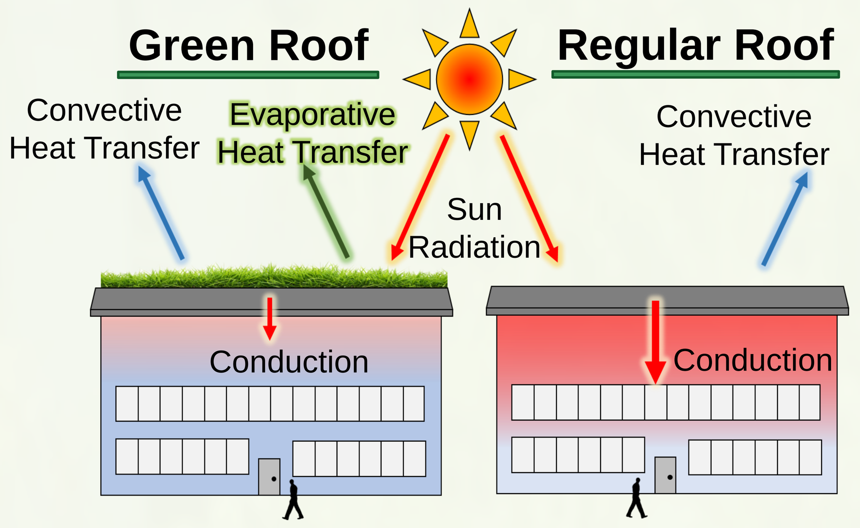
Introduction & Objectives

Introduction

- A green roof is a roofing system with substrate layer, covered by vegetation
- Green roof benefits:
  - Increase building sustainability
  - Decrease heat island effect
  - Decrease water runoff
  - Improve air quality
- Green roof cons:
  - High up front costs
  - More maintenance required
- Design requires careful analysis using a building energy simulation
- Model will provide a more accurate prediction of the heat fluxes during variable, real-life weather conditions.

Objective

Couple green roof model with a finite-difference conduction scheme



Green Roof Model Description

Model Description

- Finite-difference method
  - Discretizes substrate to approximate the conductive heat transfer
  - Better captures thermal inertia
- Gauss-Seidel iterative solver
- 15 minute time step
- MATLAB used for implementation

Assumptions

- 1-D conduction through the roof
- Roof fully covered by plants
- Plants and substrate horizontally homogenous
- Uniform substrate water content

Neglected components:

- Thermal mass of the plants
- Convective heat flux due to water runoff during precipitation

Governing Equations

Substrate Surface Energy Balance:

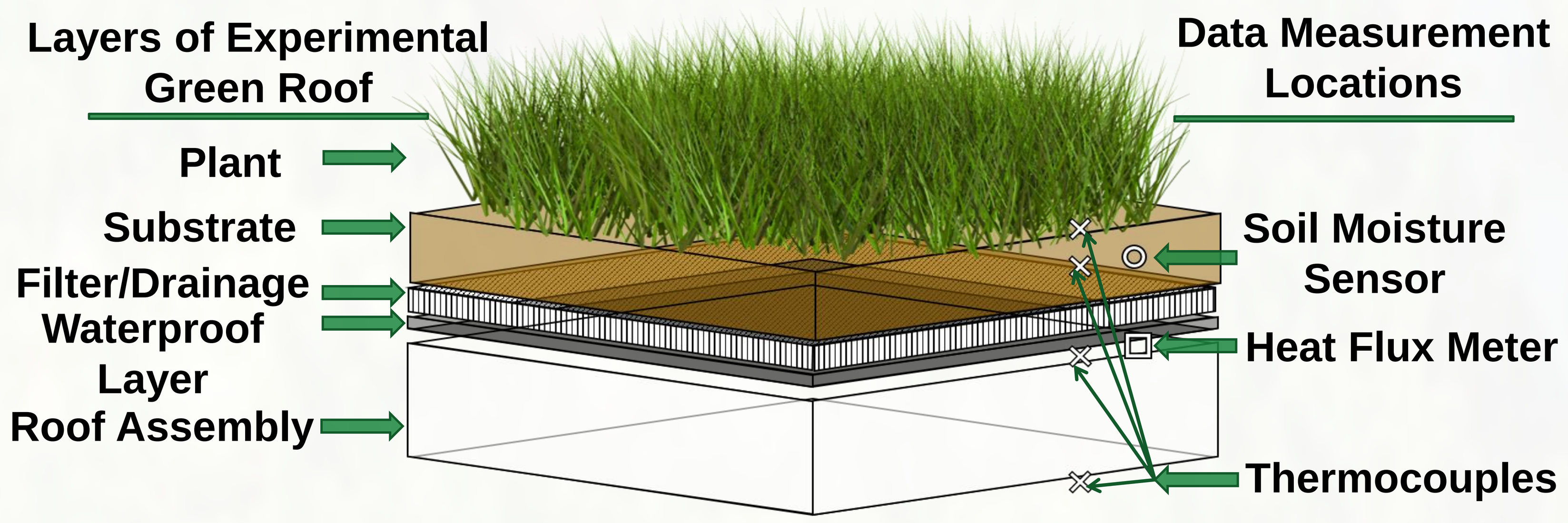
$$\rho c_p dx \frac{dT}{dt} = R_{N,Sub} + -Q_{conv,S} - Q_{cond} - Q_E$$

Plant Energy Balance:

$$0 = R_{N,Plant} - Q_T - Q_{conv,P} \quad [1]$$

ρ: substrate density (kg/m³)
c_p: substrate specific heat (J/kg K)
x: position from surface (m)
T: temperature (K)
$R_{N,Sub}$: Net radiation seen by Substrate
$Q_{conv,S}$: convective flux between substrate and surrounding air
Q_{cond}: conductive flux entering substrate substrate and sky
Q_E: evaporative flux from substrate
$R_{N,Plant}$: Net radiation seen by plant layer
Q_T: plant transpiration flux
$Q_{conv,P}$: convective flux between plants to surrounding air

Field Green Roof Data

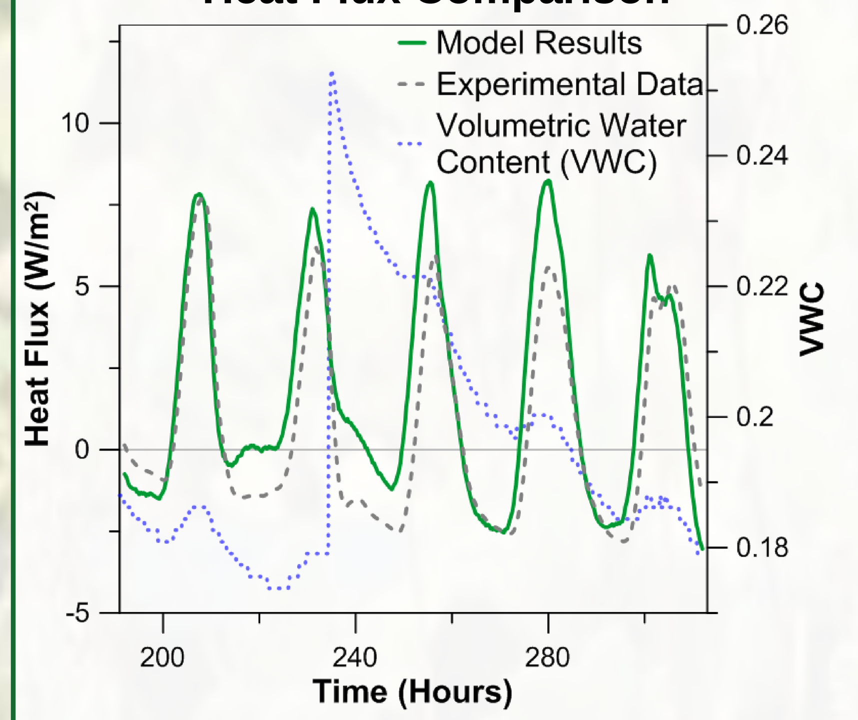


- Model validation uses data from a commercial roof in Chicago during summer (June)
- Schematic above describes the layers of green roof analyzed and the arrangement of sensors and was adapted from [2]
- Analyzed roof has 7000 m² of plant covered area [2]

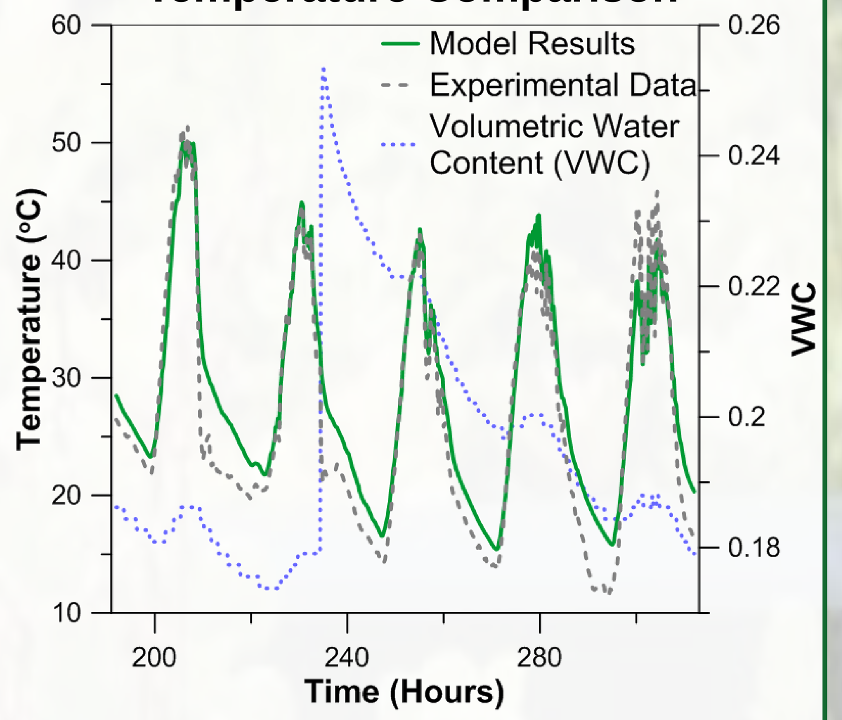
Validation

Model Results Compared to Week 2 Experimental Results

Heat Flux Comparison



Temperature Comparison

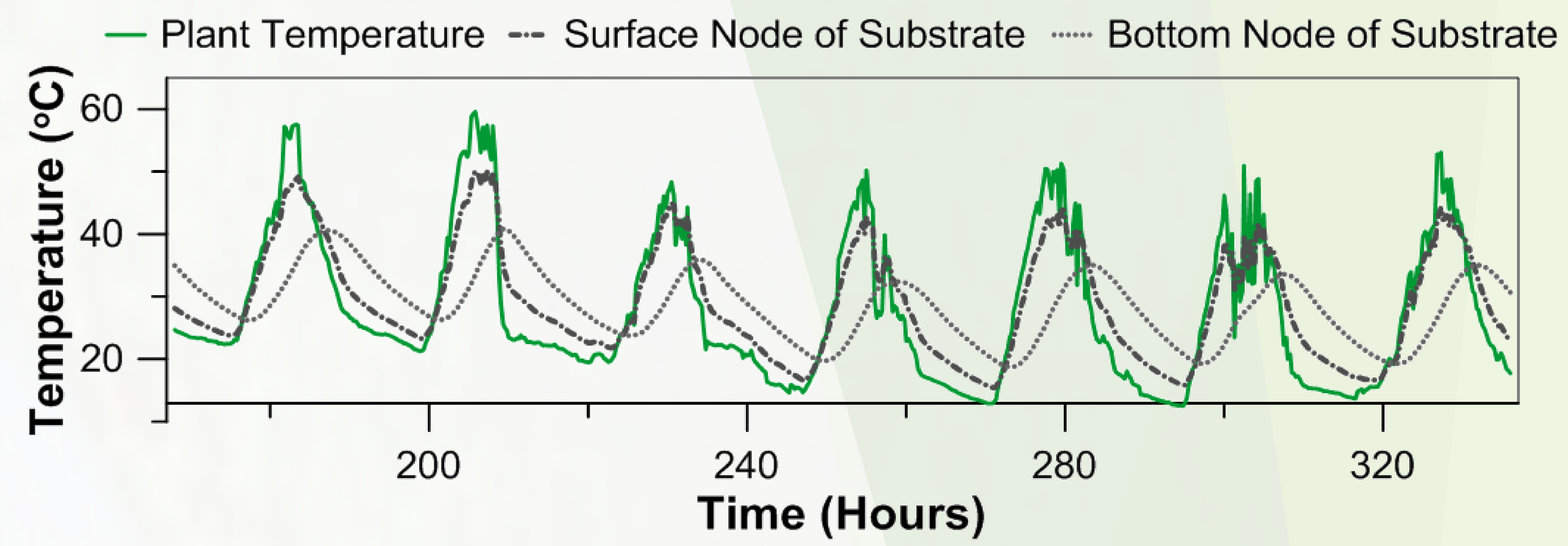


Root Mean Squared Error (RMSE) Comparison

	Model Results	Tabares and Srebic [2]
Temperature (°C)	2.72	2.36
Net Radiation (W/m²)	63.7	67.07
Heat Flux (W/m²)	1.43	1.44

- Approximately 2000 time steps were used for RMSE calculations
- Data during precipitation was not used in RMSE calculations for either model
- Substrate volumetric water content is displayed on plots to show precipitation event

Model Results



Conclusion

Summary

- Model accurately predicts substrate temperatures and heat fluxes under transient conditions
- Results compare both with the experimental data and with previous models
- Finite-difference conduction scheme accurately captures the thermal inertia of the substrate

Future Work

- Continue validation in different climates via collaboration with a University in Chile
- Add moisture equations to capture water movement through the substrate
- Use a faster, more robust solver
- Implement into building energy simulation program (EnergyPlus) to predict energy fluxes of buildings with green roofs
- Implement into large scale climate models

References

[1] P. C. Tabares-Velasco and J. Srebric, "A heat transfer model for assessment of plant based roofing systems in summer conditions," *Build. Environ.*, vol. 49, pp. 310–323, 2012.

[2] P. C. Tabares-Velasco, M. Zhao, N. Peterson, J. Srebric, and R. Berghage, "Validation of predictive heat and mass transfer green roof model with extensive green roof field data," *Ecol. Eng.*, vol. 47, pp. 165–173, 2012.

Acknowledgments

The authors would like to thank Colorado School of Mines for providing work study funding, and giving the opportunity to work as an undergraduate researcher