Modeling Vegetative Heat Transfer in Urban Environments with OptiX

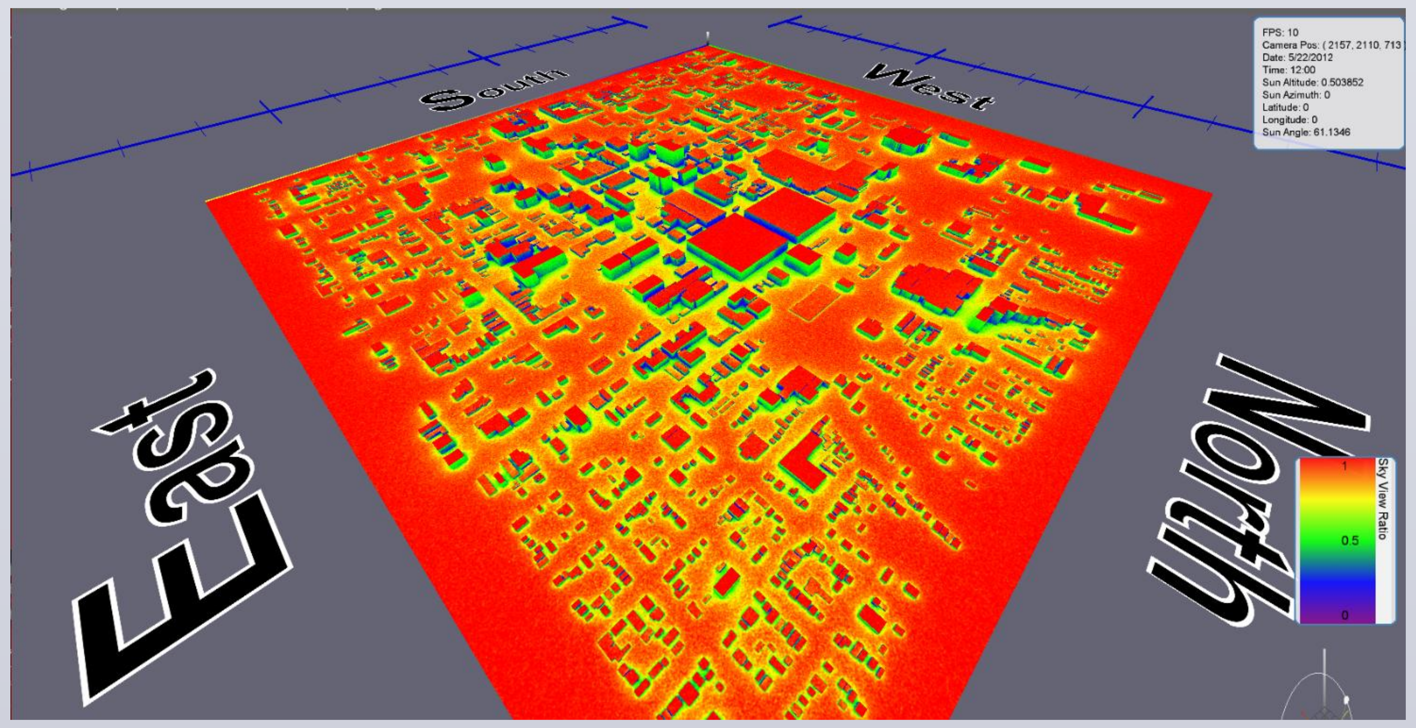
Matt Overby[1], Brian Bailey[2], Kevin Briggs[2], Aditya Vegesna[1], Eric Pardyjak[2], Rob Stoll[2], Peter Willemsen[1]

[1] University of Minnesota Duluth, [2] University of Utah

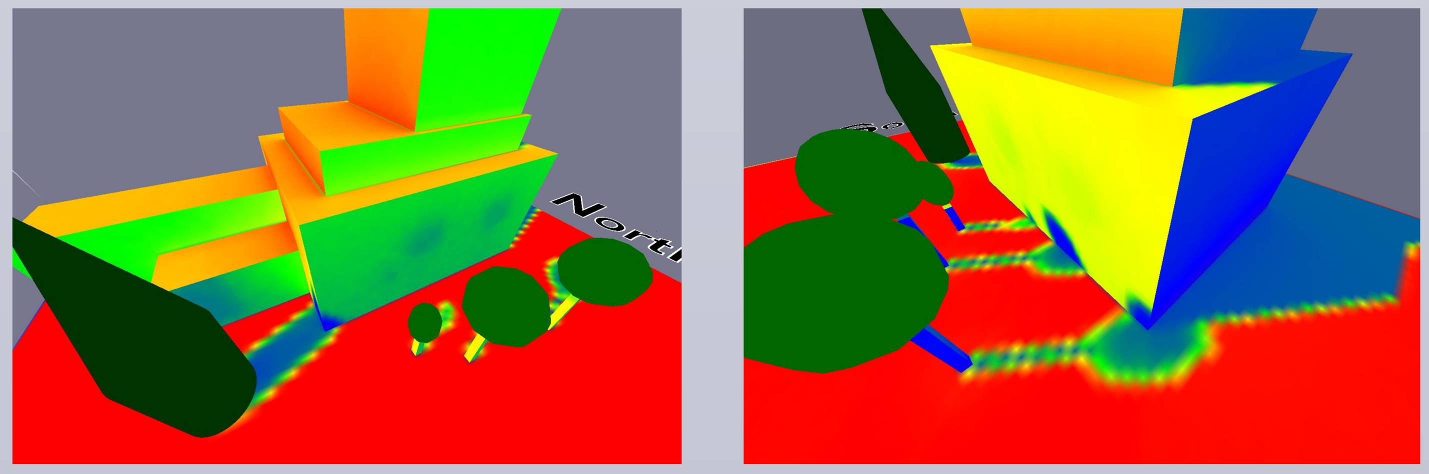
INTRODUCTION

For many years urban planners have attempted to design buildings and city infrastructure to be more environmentally sustainable. Trees, vegetative roofing, and other green infrastructure have the potential to reduce heat load in urban environments and lower power consumption required for heating and cooling buildings. Certain building materials, shapes, and urban layouts can mitigate trapped heat and air pollutants. However, the interactions between the environment and urban landscapes are complex and difficult to quantify. Modeling these interactions can be useful to urban planners so that they are able to find optimal locations of vegetation, buildings, and other infrastructure.

Our research group is developing **QUIC Energy**, a software tool that models radiative heat transfer in three dimensional urban environments. By taking advantage of parallel computation on the GPU using NVIDIA's OptiX ray tracing engine, we are able to model urban domains upwards of five square kilometers, containing thousands of trees and buildings. Current efforts are aimed at incorporating vegetation, as well as interactions between air and surfaces using a land surface model [3].



Sky view factor values of a 5 km^2 model of Salt Lake City with over 2000 buildings.



Effects of the absorption of solar irradiation by vegetation on building surface temperature.

PROGRAM OVERVIEW

Preprocess

Create Geometry

- Surfaces of buildings and the ground are stored as groups of axis-aligned 2D quads, called patches.
- Vegetation is stored as meshes of axis-aligned 3D boxes.
- Both patch and vegetation dimensions are user defined. Buildings can be made up of any number of patches, and trees can be made up of any number of boxes.

Longwave Exchange

Launch Rays from Geometry → Calculate Longwave Exchange Factor → Calculate Sky View Factor

- Patches emit rays in a hemisphere about their surface, and boxes emit rays in a sphere around their volume.
- If the ray reached the sky, longwave exchange with the sky is calculated.
- If the ray hit something, longwave energy is absorbed from the object hit.

Shortwave Exchange

Calculate Sun Direction → Launch Rays to the Sun → Calculate Solar Irradiation

- The sun direction is calculated from user-inputted latitude, longitude, date, and time.
- Rays are launched toward the sun. If they hit vegetation, they are reversed and re-launched toward the surface and potentially scattered along the way.

Transport Model

Run Transport Model

- Using data from the velocity field generated by QUIC-URB [2], a turbulent transfer model is run to determine the advection and distribution of heat, moisture, and pollutants in the air.

Land Surface Model

Run Land Surface Model

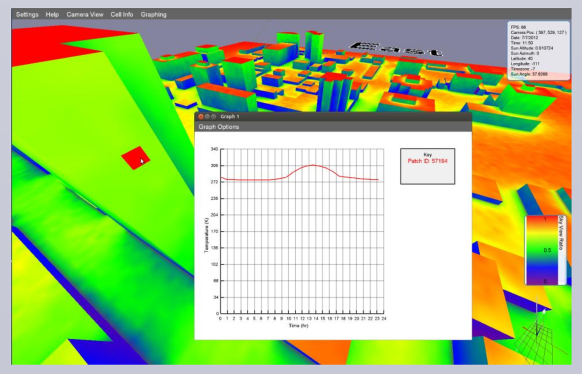
- The exchange/transport of heat and moisture between air and surfaces are determined using corresponding air values.
- Using terms that were calculated in previous steps, the energy balance equation is solved with the Newton-Raphson Method. This provides a distribution of temperature and moisture over all surfaces.

User Interaction

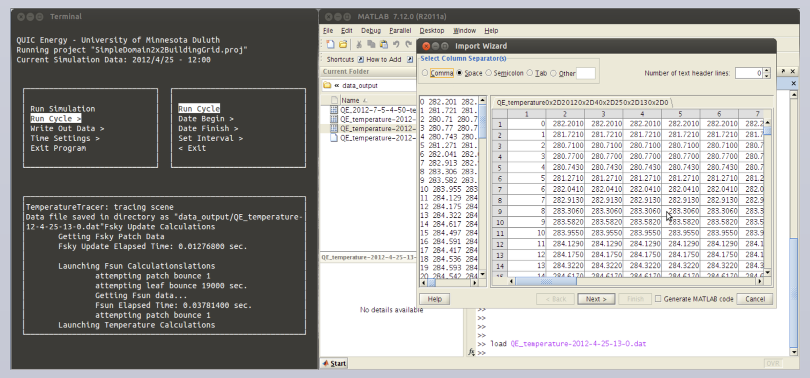
Update Visuals or Output Data → Change Date/Time

- The output is rendered in 3D using OpenGL.
- The program will wait for the user to change the latitude, longitude, date, or time.
- Alternatively, QUIC Energy can be run in headless mode. By specifying a beginning and end date, as well as the iteration time step, QUIC Energy will run the cycle and output the results of each iteration to a text file.

USER INTERFACE

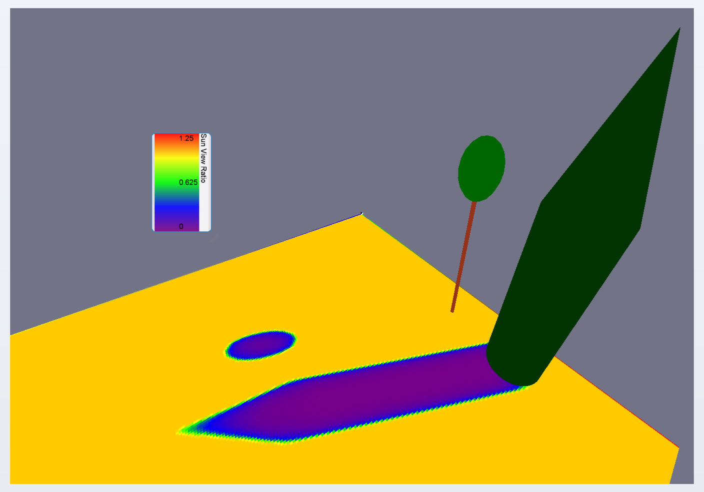


A user selects a patch in interactive mode and plots its temperature over a diurnal cycle using QUIC Energy.



A user simulates a diurnal cycle using QUIC Energy in headless mode and loads the output into MATLAB.

VALIDATION



The initial vegetation model was validated using field data reported by Constabel [1].

Overstory Aspen

θ	LAD	G(θ)	τ (model)	τ (data)
33°	0.92	0.55	0.161	0.17
51°	0.92	0.54	0.194	0.19
65°	0.92	0.45	0.260	0.34

Overstory White Spruce

θ	LAD	G(θ)	τ (model)	τ (data)
33°	1.06	0.50	0.077	0.04
51°	1.06	0.50	0.108	0.07
65°	1.06	0.50	0.124	0.12

θ: Solar zenith angle
LAD: Leaf Area Density; the surface area of leaves per unit volume of vegetation
G(θ): Projection of leaves in the direction of propagation
τ: Transmissivity; the ratio of flux on the ground to incoming flux

REFERENCES & ACKNOWLEDGEMENTS

[1] Constabel, A.C., 1995. *Light transmission through boreal mixedwood stands*. M.S. Thesis, University of Alberta, Edmonton, AB.

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[3] Shingleton, N., 2010. *Coupling a land-surface model to large-eddy simulation to study the nocturnal boundary layer*. M.S. Thesis, University of Utah.

QUIC Energy is part of the GEnUSiS Project. For more information, visit *http://envsim.d.umn.edu/*

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