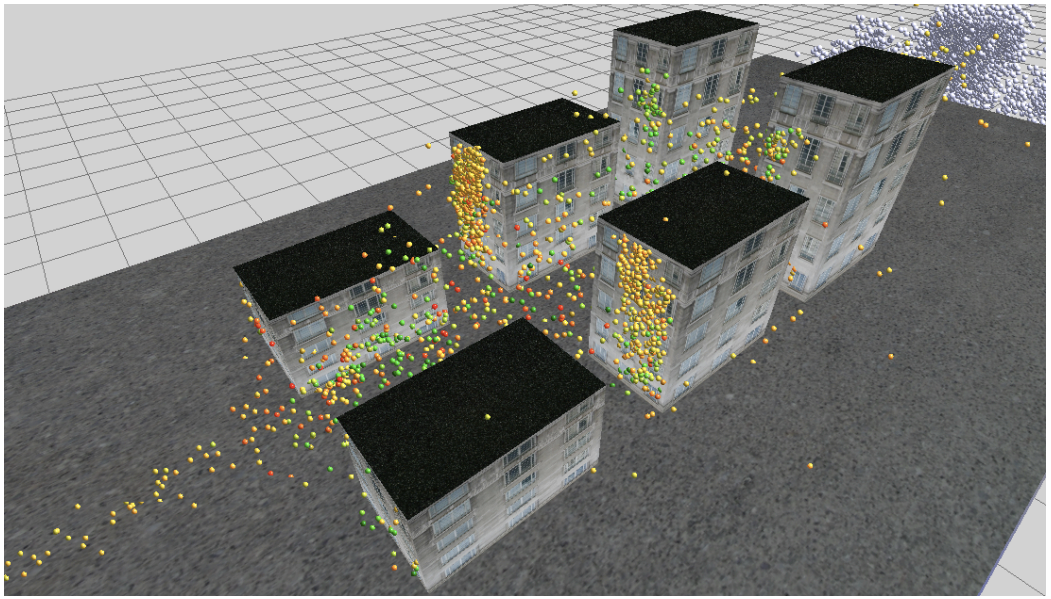
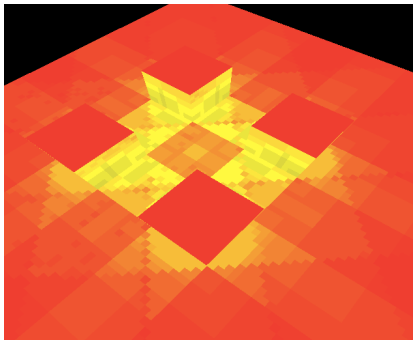
Impact of Green Infrastructure (GI) on Urban Microclimate & Air Quality



Peter Willemsen, PhD - UMD
Eric R. Pardyjak, PhD
University of Utah

University of Minnesota – Duluth
Bridge the Baccalaureate Degree Program
June 18-22, 2012



Why Different Urban Designs?

Global trend toward urbanization

- More walkable/healthy
- Better aesthetics
- More comfortable (microclimate)
- Builds community
- Better air & water quality
- Better "waste" management
- Consume fewer resources
- Better transportation
- Better building efficiencies
- More biodiversity

The incorporation of "green spaces and environmentally conscious construction in the built environment" Srinivasan et al. Am J Public Health. 2003

Examples of Green Infrastructure (GI)

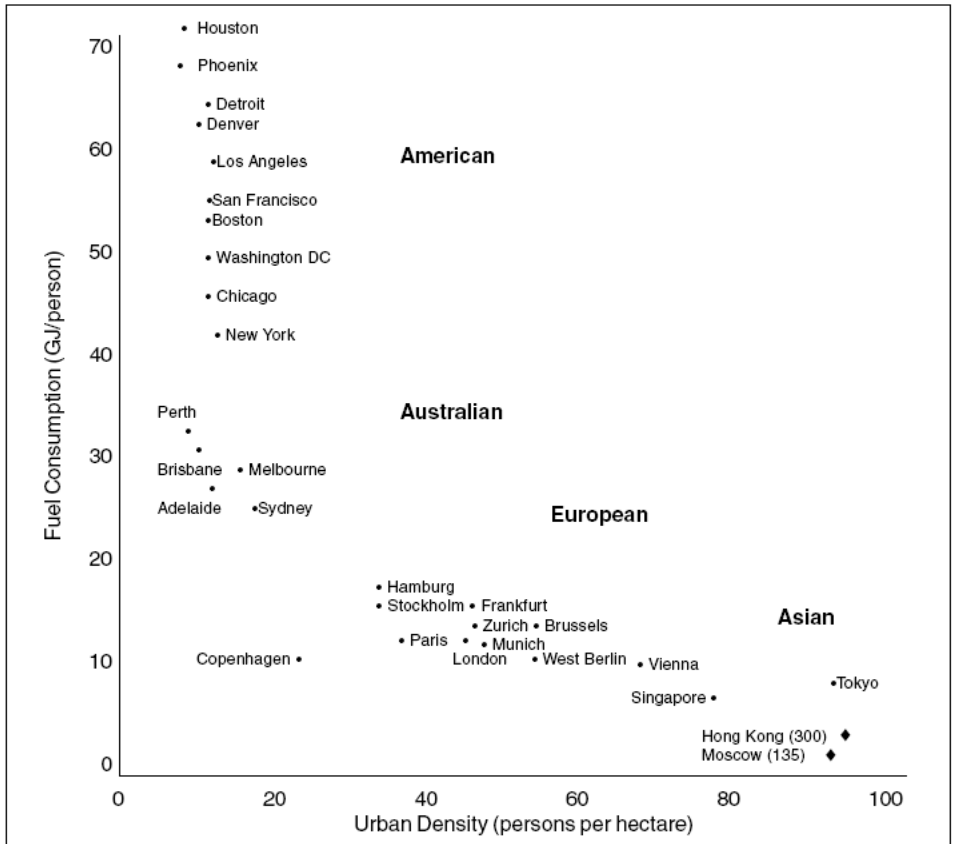
- Green space
  - Planting trees, developing parks, etc.
- Pervious parking lots
- Green rooftops
- Alternative colored/reflective surfaces
- Artificial water bodies

"Given the unexpected lack of empirical data evaluating the effectiveness of specific, place-based green infrastructure, we wish to draw attention to the gap between the anticipated benefits of green infrastructure and the implementation and evaluation of its performance in specific contexts." Pataki et al. Front Ecol Environ 2011

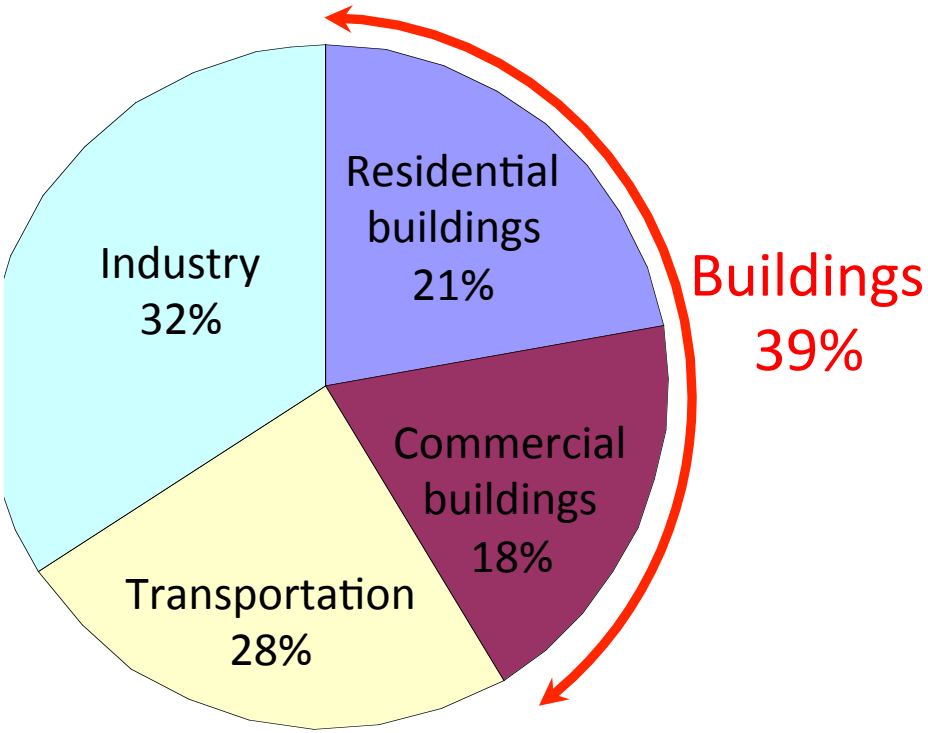
Example of a GI Dilemma

Energy Use

Transportation

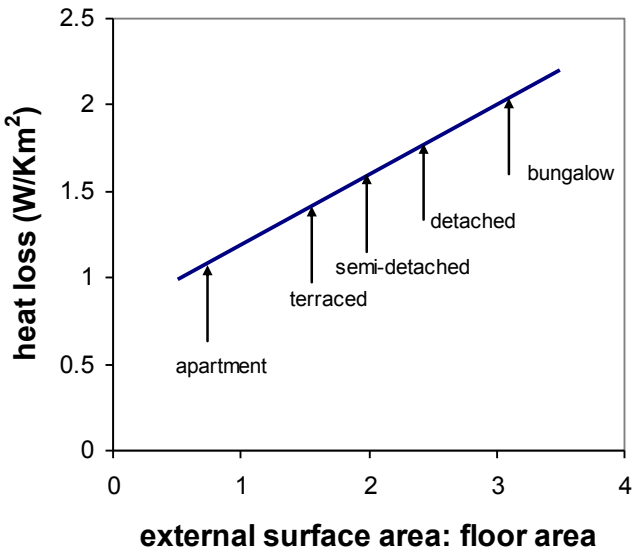


SOURCE: Newman, Peter W.G and Jeffrey R. Kenworthy, *Cities and Automobile Dependence: an International Sourcebook*, Gower Technical, Aldershot, 1989, 388 pages.

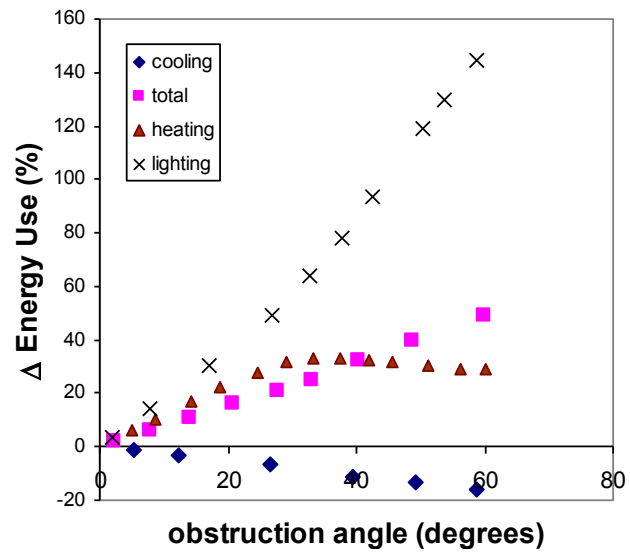


Adapted from *Energy Information Administration*, 2007: http://www.eia.doe.gov

Building Energy Consumption



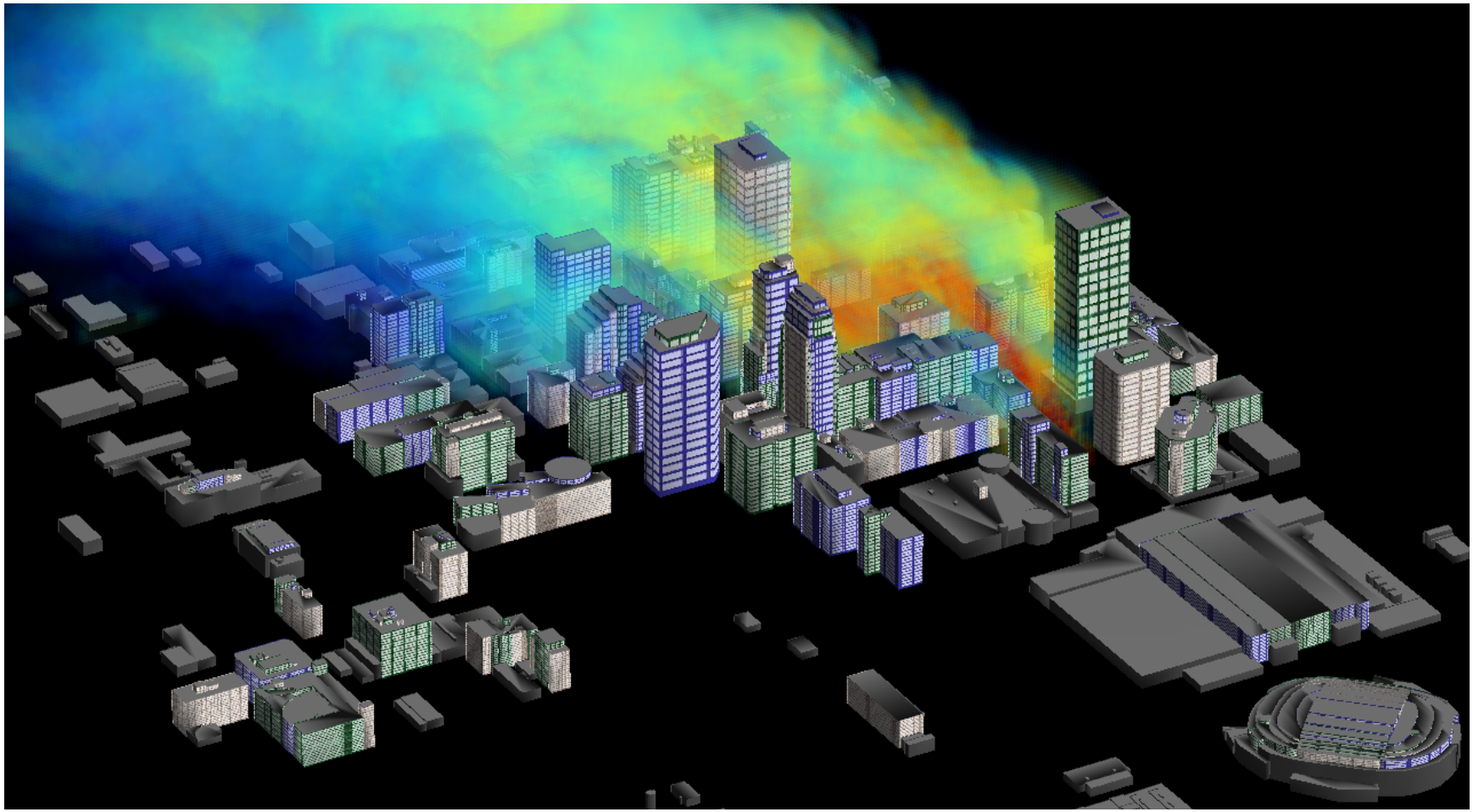
The effect of surface area to floor area & obstruction angle on energy use for buildings (plots reproduced from Steemers 2003)



Potential Problem: More dense cities may lead to less fuel consumption and reduced emissions, but does that translate into higher pollutant concentrations and more adverse health impacts?

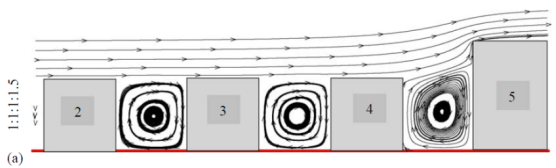
Complex Interaction between Energy Use and Air Quality

Physics of Different Environmental Transport Processes

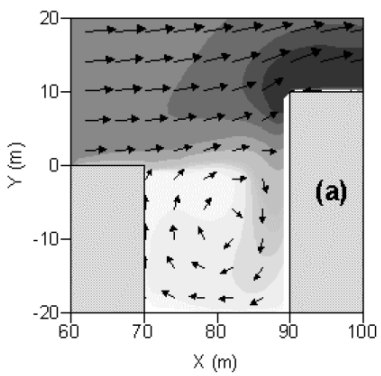


Air Flow in Cities

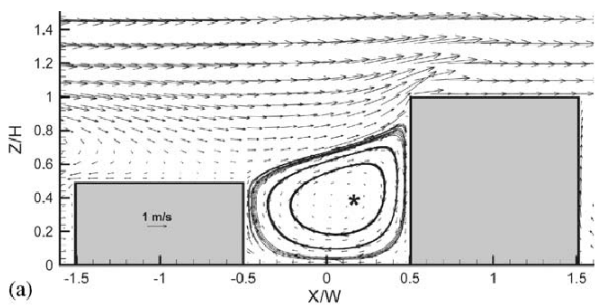
Vortices that Transport Mass, Heat, and Momentum



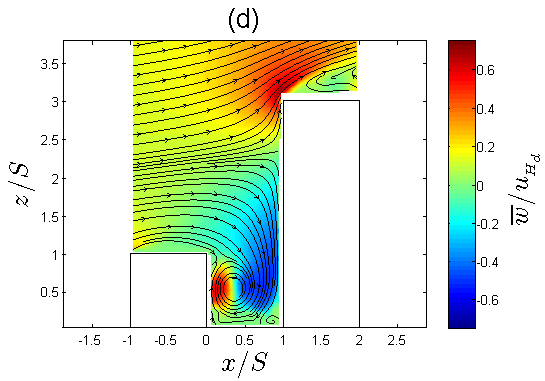
Xie, et al., 2005



Santiago & Martin, 2005



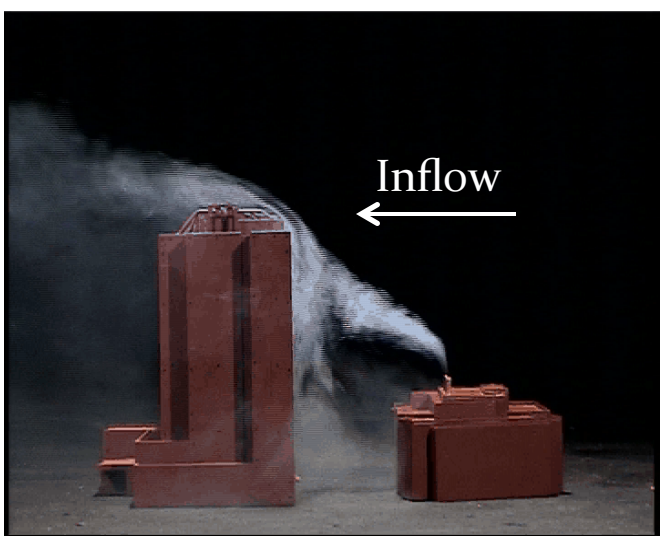
Assimakopoulos et al., 2003

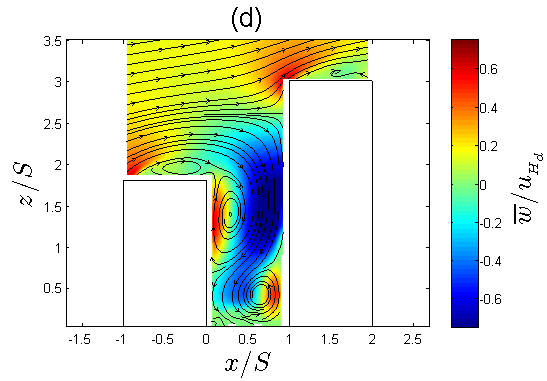


2D PIV data

$H_d / H_u \approx 3$; $W / S \approx 4$

Smoke Visualization - Courtesy : CPP, Inc – Fort Collins



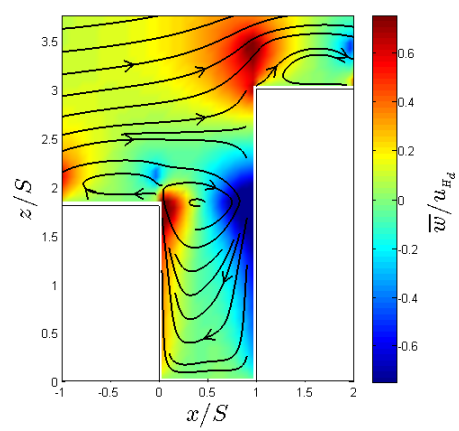


2D PIV data

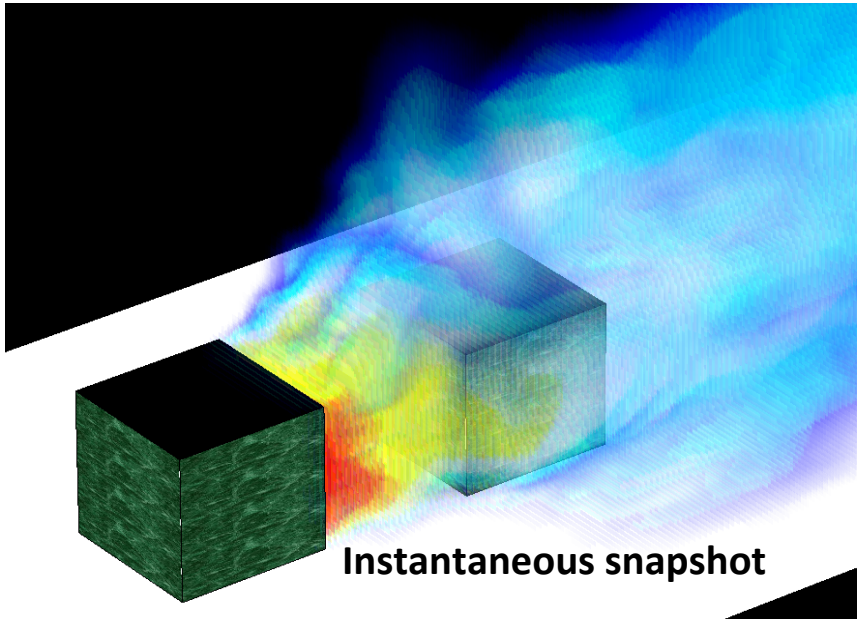
$H_d / H_u \approx 1.67$; $W / S \approx 4$

QUIC

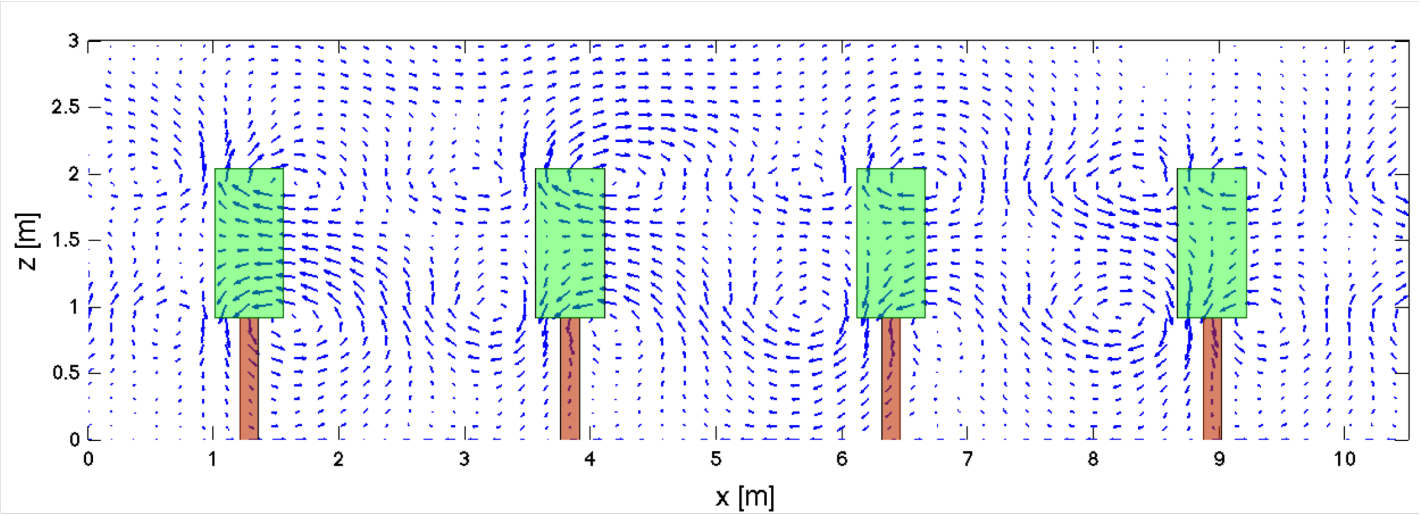
$H_d / H_u \approx 1.8$; $W / S \approx 4$



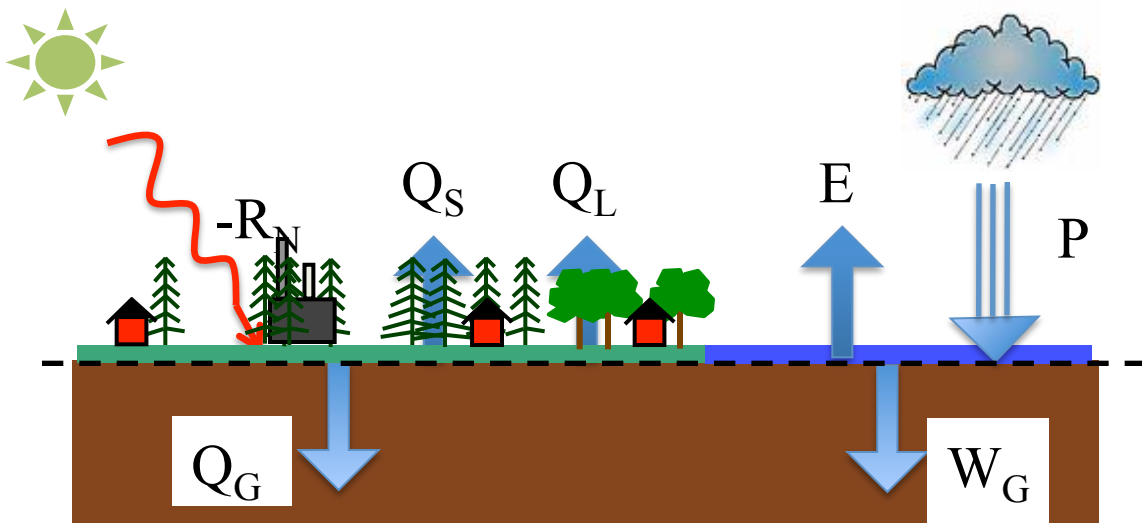
Air Flow in Cities



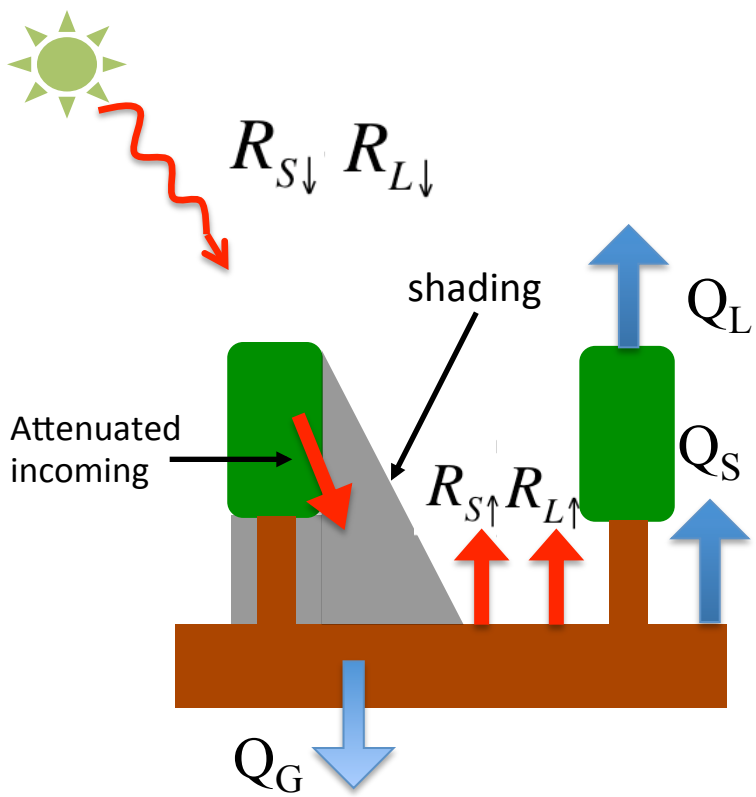
Flow in and Around Vegetation



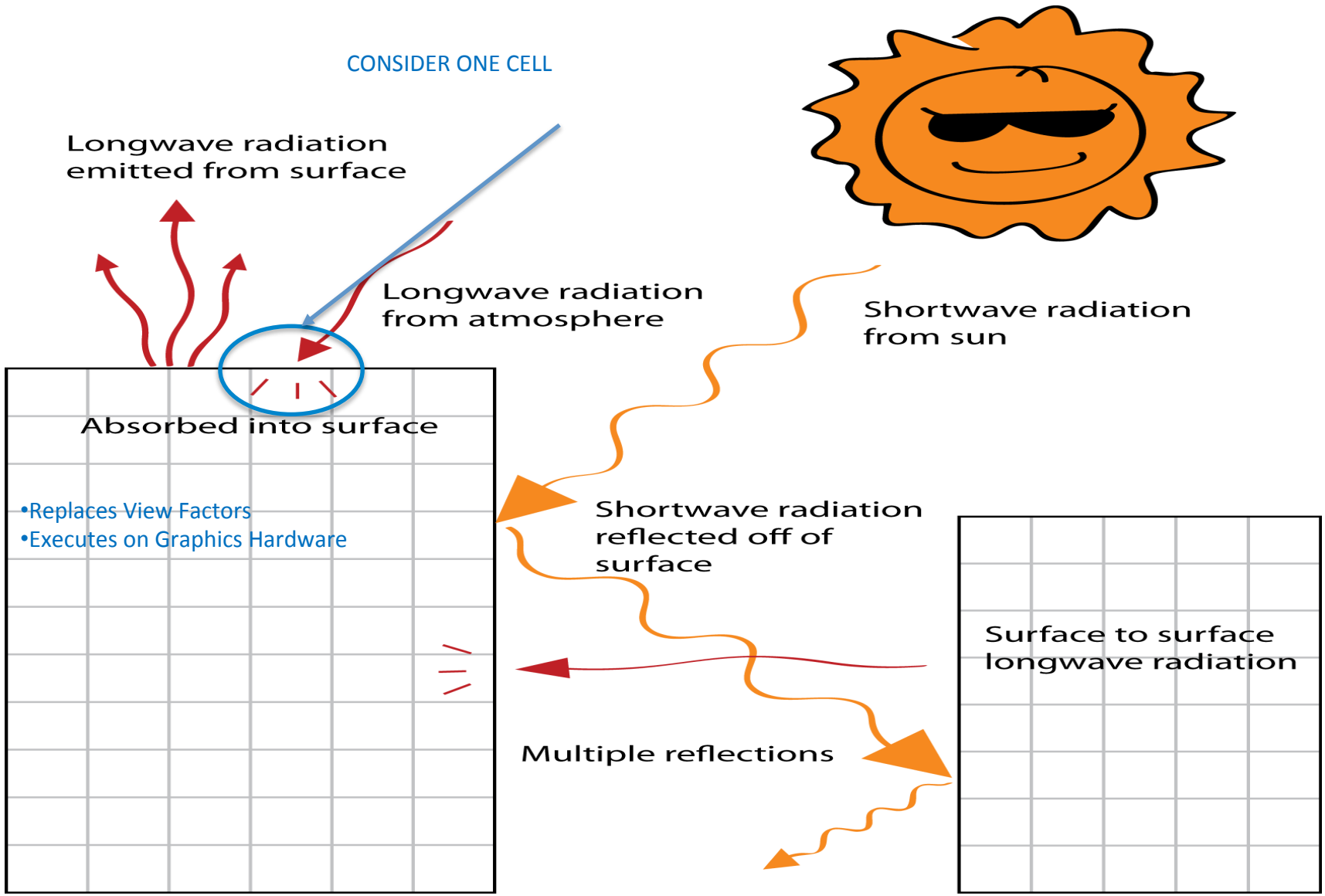
Energy Balance



The of Effect of Green Infrastructure on the Urban Energy Balance

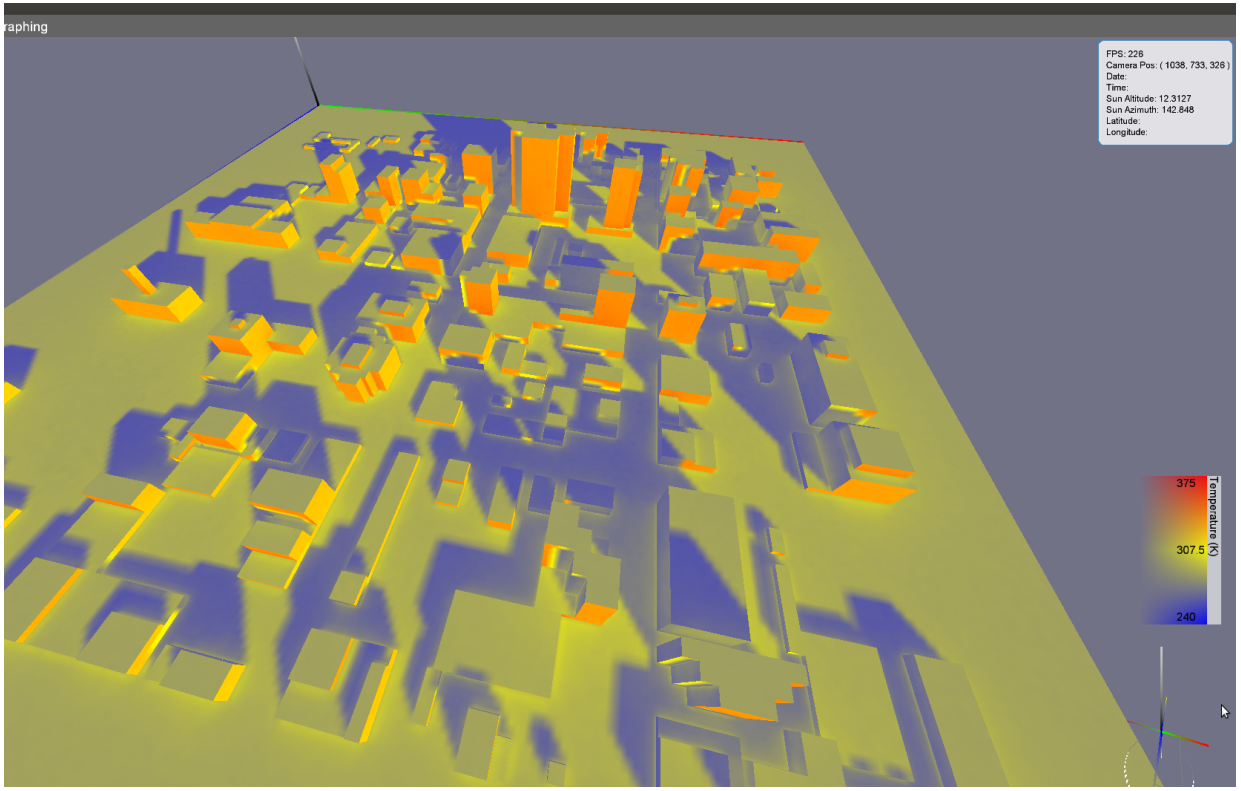


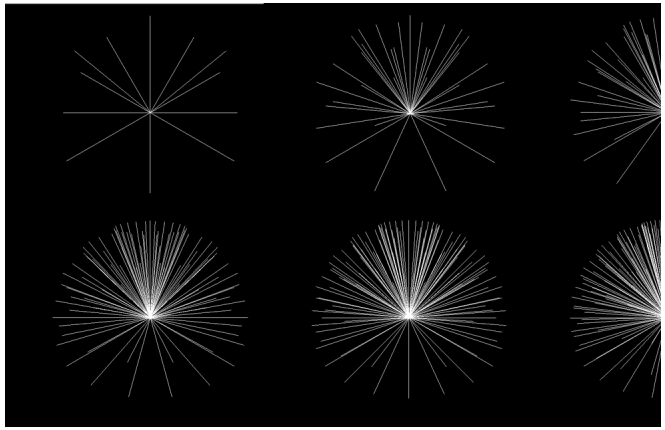
QUIC-GPU[continued]



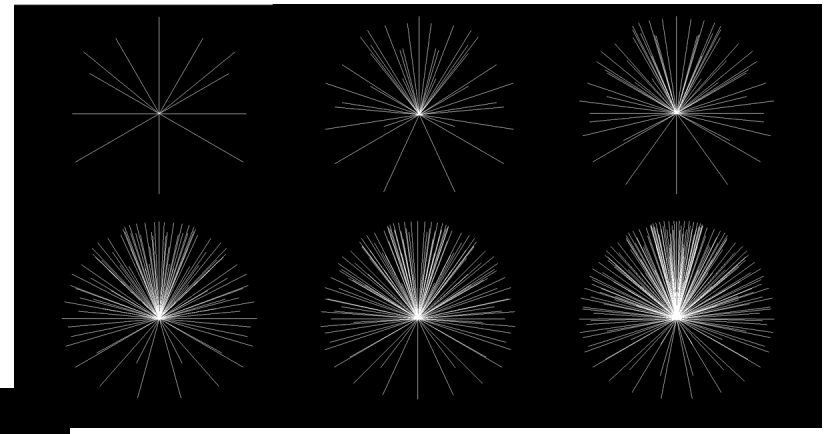
QUIC-Energy (GPU)

Surface Temperatures Salt Lake City

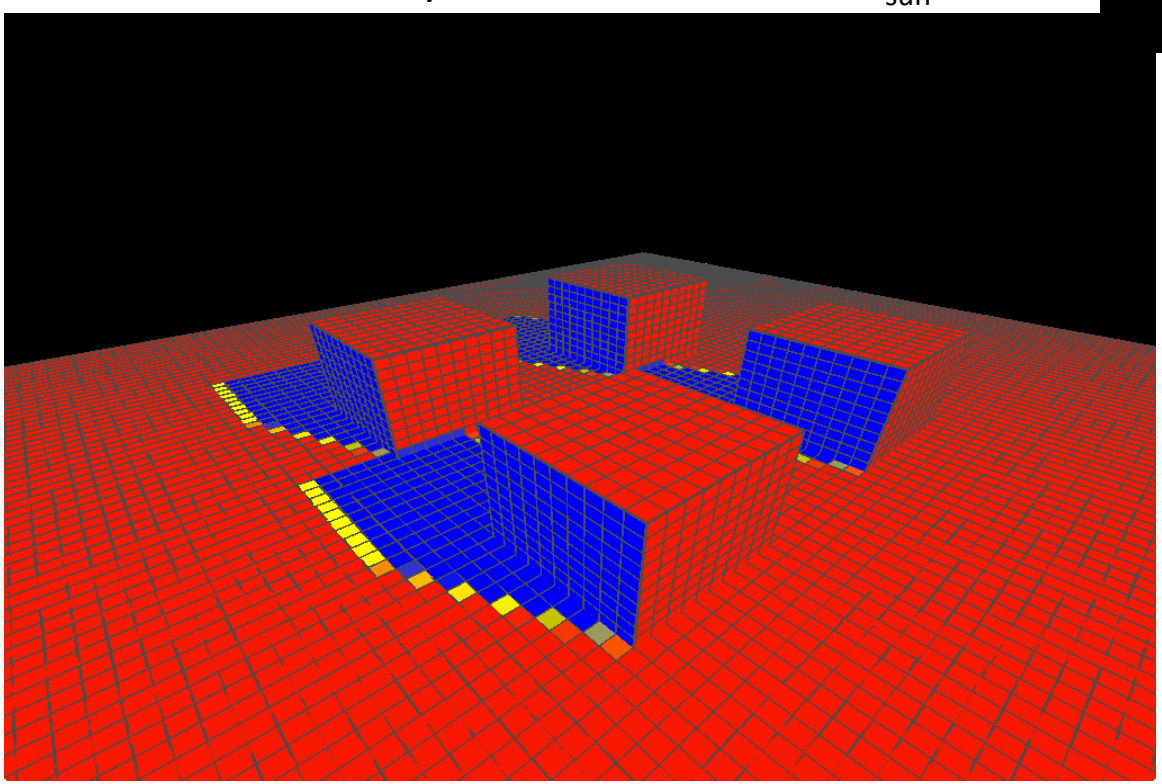




QUIC-Energy (GPU)



Fraction of Rays that “see” the sun - F_{sun}



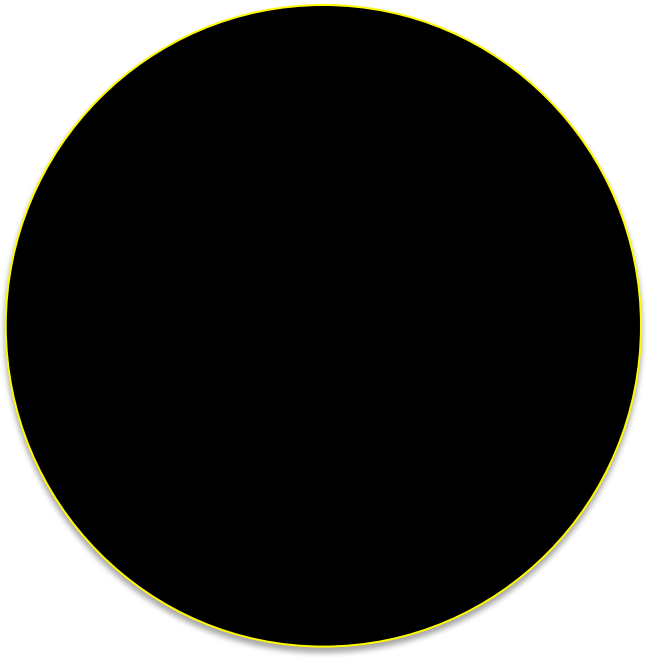
Solar Constant?

Types of radiation:
Direct vs. Diffuse

Sky View Factor

Ψsky = 0 The sky is completely obstructed by obstacles and all outgoing radiation would be intercepted by the obstacles (such a situation would occur in a tunnel).

Ψsky = 1 There are no obstructions and all outgoing radiation would radiate freely to the sky (e.g. a wide open field.



Ψsky = 0

Ψsky = 1

From Brown and Grimmond (2001) LA-UR-01-1424

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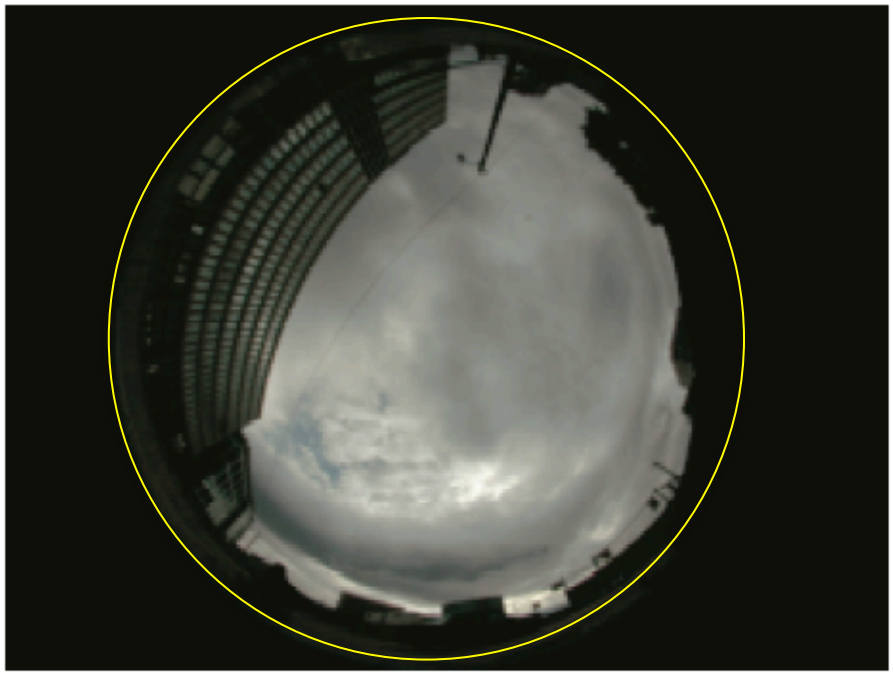
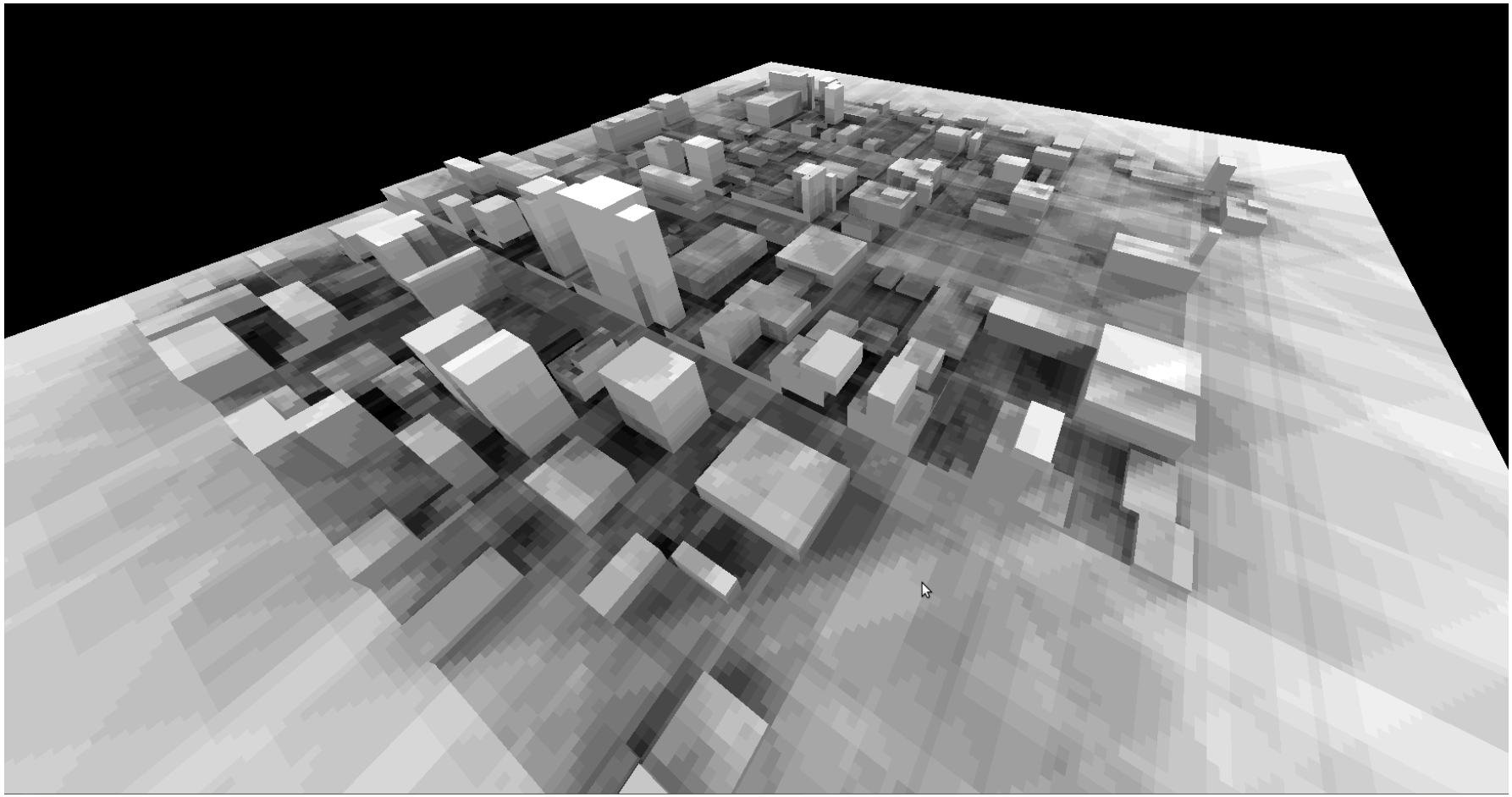


From Brown and Grimmond (2001) LA-UR-01-1424

QUIC-Energy (GPU)

Sky View Factor Calculations Salt Lake City



QUIC-GPU[continued]

- GPU-URB: diagnostic wind model
- GPU-PLUME: random-walk dispersion model
- GPU-ENERGY: urban energy use model
  - Prognostic Heat Transport sub-model

- Reynolds Averaged Enthalpy Equation

From QUIC Dispersion modeling system

$$\frac{\partial \theta}{\partial t} + U_i \frac{\partial \theta}{\partial x_i} = (\alpha + K_H)\frac{\partial^2 \theta}{\partial {x_i}^2} - \cancel{\frac{1}{\rho c_P}\frac{\partial Q_j}{\partial x_j}} - \cancel{\frac{L_V E}{\rho c_P}}$$

I II III IV V

- Term I: mean storage of heat
- Term II: advection of heat by the mean wind
- Term III: molecular and turbulent diffusion of heat
- Term IV: mean net body source associated with radiation divergence
- Term V: body source term associated with latent heat release