Basics of Urban Wind Sheltering and Infiltration

By:

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IBPSA-MD and BEC-Baltimore Joint Meeting

Energy Modeling in Research and Design

Research Presentation

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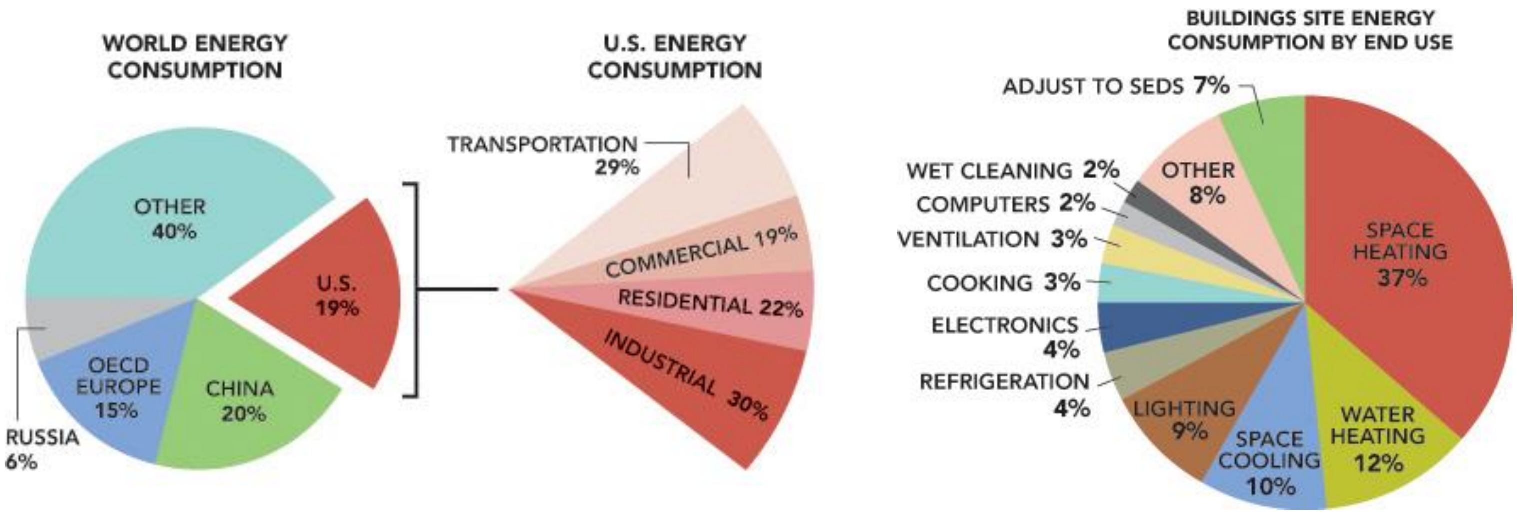
Preface

- Former graduate student at CITY@UMD under supervision of Dr. Jelena Srebric, Mechanical Engineering Department, University of Maryland, College Park
- Currently serving as a Building Performance Consultant at the Affiliated Engineers Inc./AEI, Rockville office
- This research is part of a sponsored National Science Foundation project. The results are published at:
  - S. Khoshdel Nikkho, M. Heidarinejad, J. Liu, and J. Srebric, *Quantifying the impact of urban wind sheltering on the building energy consumption*, Applied Thermal Engineering Journal, Volume 116, April 2017, Pages 850–865
- Degrees and certifications:
  - Master's, Mechanical Engineering, University of Maryland, 2016
  - Bachelor's, Mechanical Engineering, Sharif University of technology, 2014
  - LEED AP Building Design and Construction
  - Engineer-In-Training

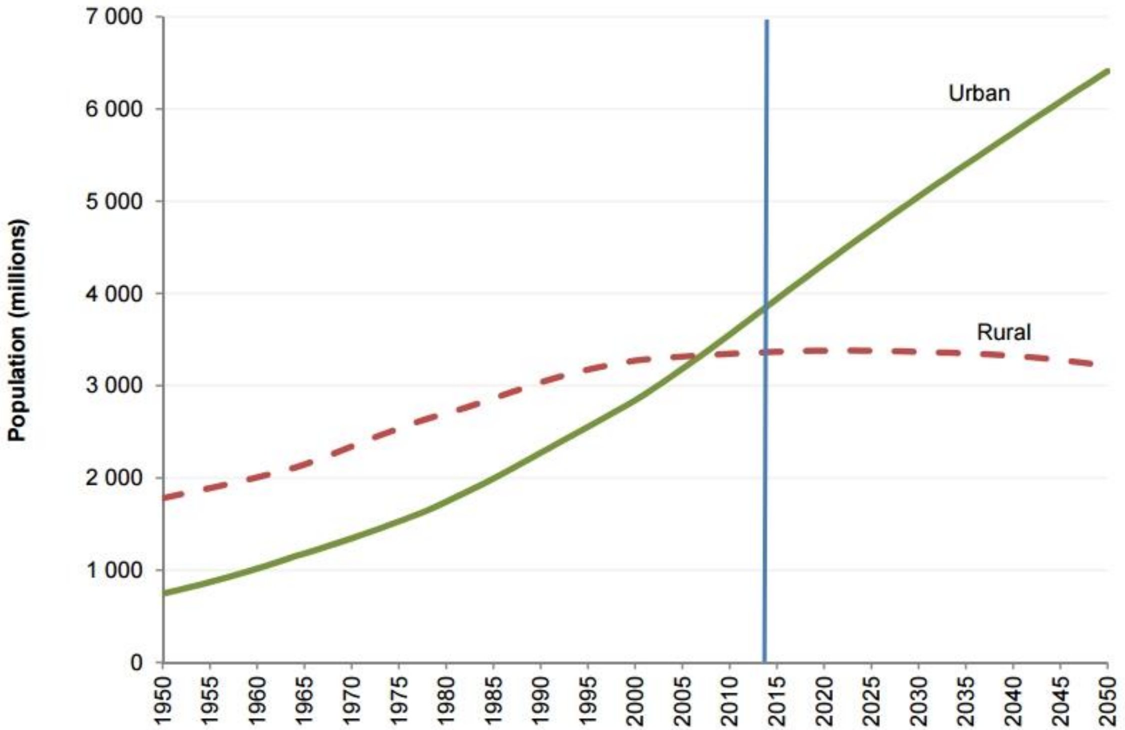
Building Energy Consumption in the US

- Buildings consume 41% of total primary energy in the US
- About half of this energy is consumed for Heating, Ventilation, and Air Conditioning (HVAC)



World Urbanization

- The world is rapidly urbanizing



The world’s urban and rural population, 1950-2050 (United Nations Report, 2014)

Building Energy Models and Urban Environment

- Building Energy Modeling (BEM): Physics-based calculation of building energy consumption

- Common approaches of BEM have limited functionality to take surrounding urban environment into account

Problem Statement:

Currently, the common approaches of building energy modeling do

not consider urban neighborhoods

Research Gap

- Local wind flow have multiple impacts on building energy consumption
  - Convective Heat Transfer Coefficient (CHTC)

$$Q_c = h_{c,ext} A \left(T_{surf} - T_{air}\right)$$

$$h_{c,ext} = D + EV_z + FV_z^{\,2}$$

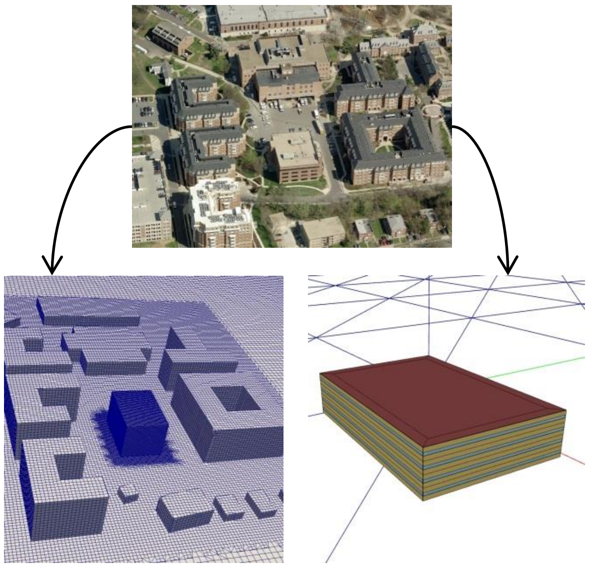
  - Infiltration

$$Infiltration$$
$$= \left(I_{design}\right)\left(F_{Schedule}\right)[A + B|\Delta T| + C(WindSpeed) + D(WindSpeed^2)]$$

- The wind speeds used in the energy models are based on input weather data files derived from weather stations mainly located at airports

Thesis Objectives

Objective 1

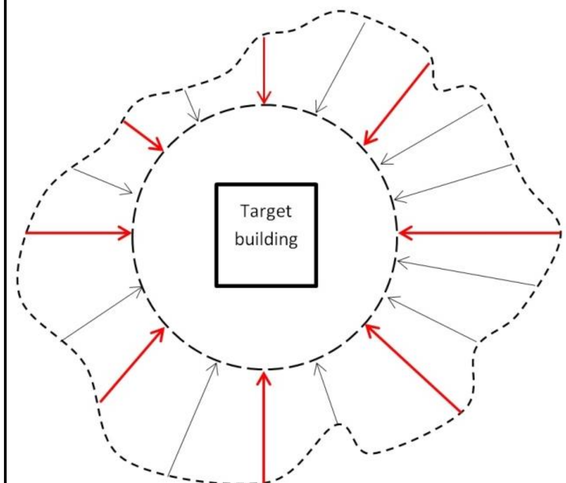


- Develop the framework
- Create CFD airflow model
- Create energy model

Objective 2

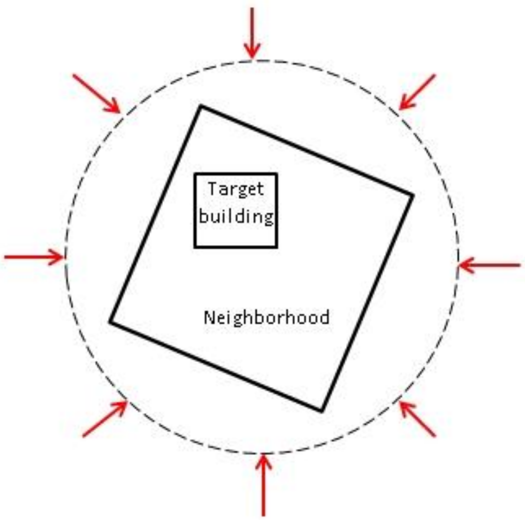
- On-site temperature measurements
  Comparison with CFD
- Validation with temperature

Objective 3

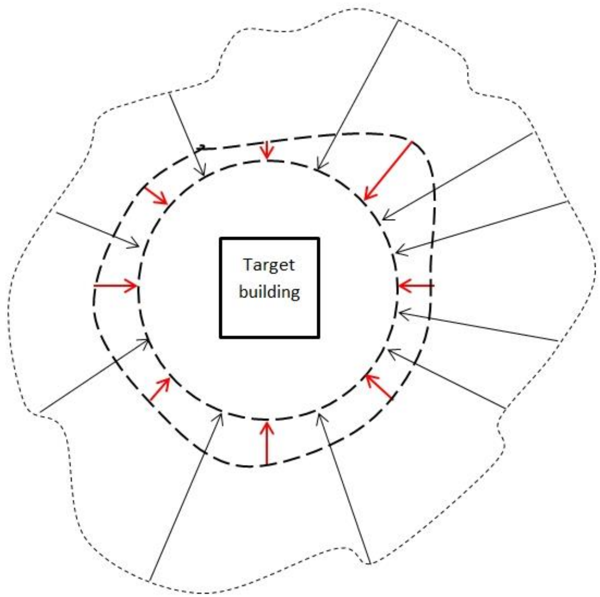


- Adjusting weather data by local wind
- Energy model calibration
- Local wind effects

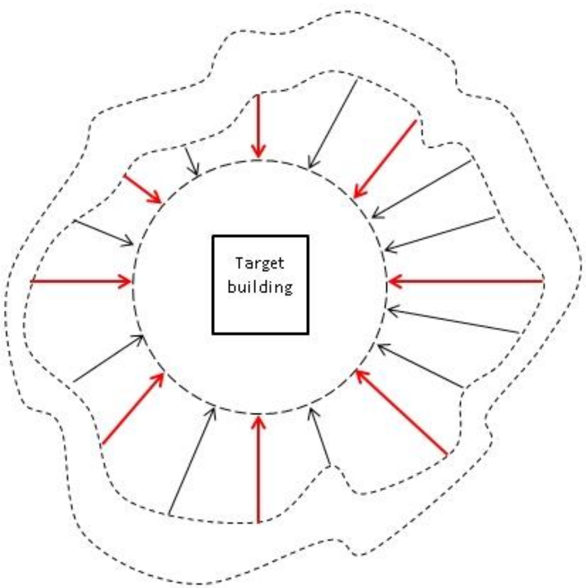
Combining CFD and Energy Model



- 8 CFD cases for main principal directions
- 1m/s inlet velocity
- Measurement at windward facade, target building



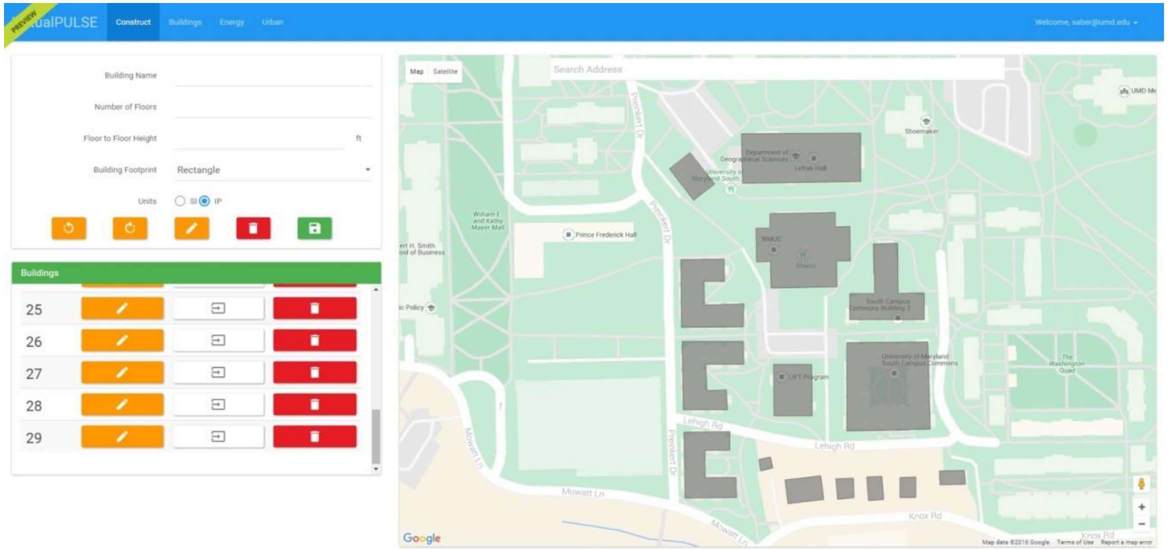
- Wind multiplier calculation
- Taking hourly weather data (energy model input)



- Adjusting the wind velocity in weather data by wind multipliers
- Effects of adjusted wind in energy model

Software Packages

- Open Source software packages are preferred to advance state of urban environment simulations
- Building energy balance: **EnergyPlus**
- CFD: **OpenFOAM**
- **Virtual PULSE**

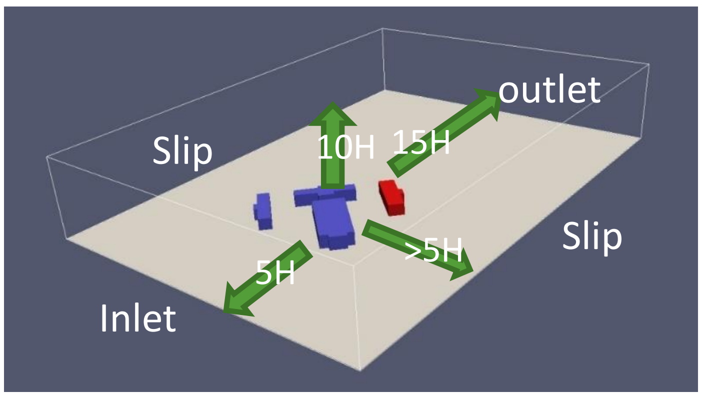


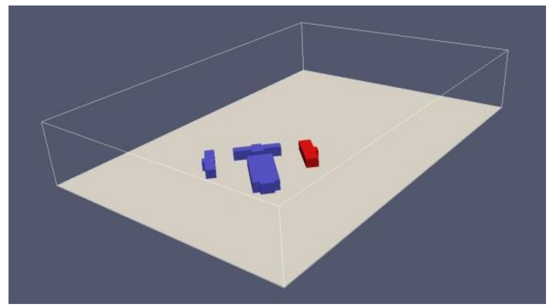
CFD Validation, OpenFOAM

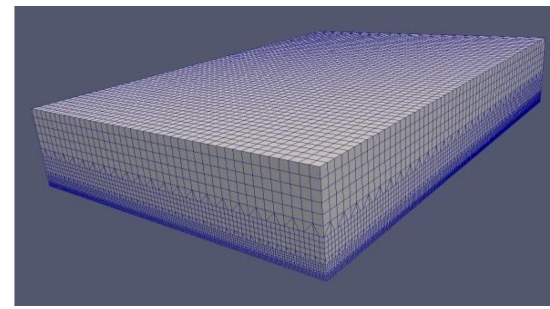
- Case setup for 6/24/2014 at 1pm

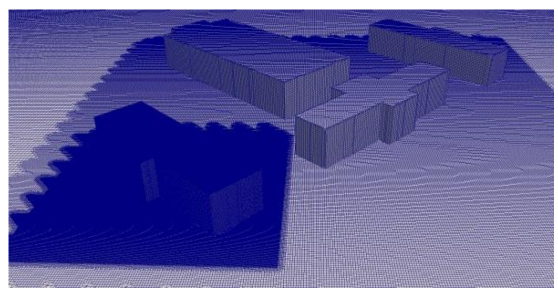
    Inlet temperature: 28.2ºC (82.8ºF) buoyantBousinesqSimpleFoam solver

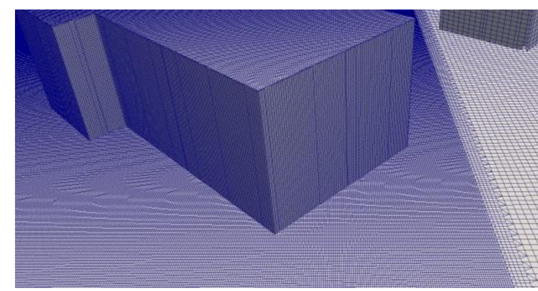
    Inlet wind velocity: 5 m/s (3.3 ft/s)





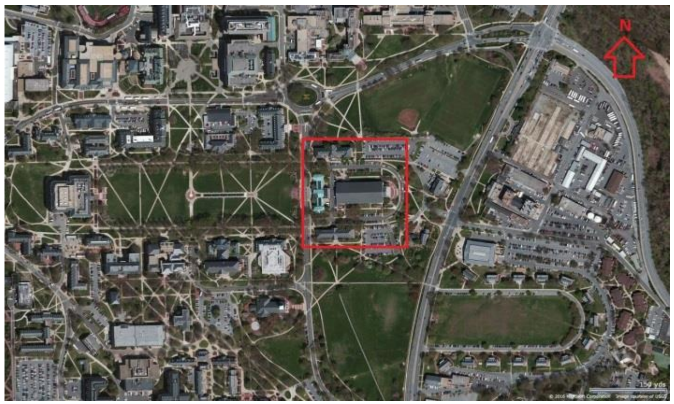






CFD Validation, Instrumentation

- Temperature measurements around Mitchell building on UMD campus
- iButton sensors, accuracy ±0.5°C
- IR Photos using FLIR E40 camera



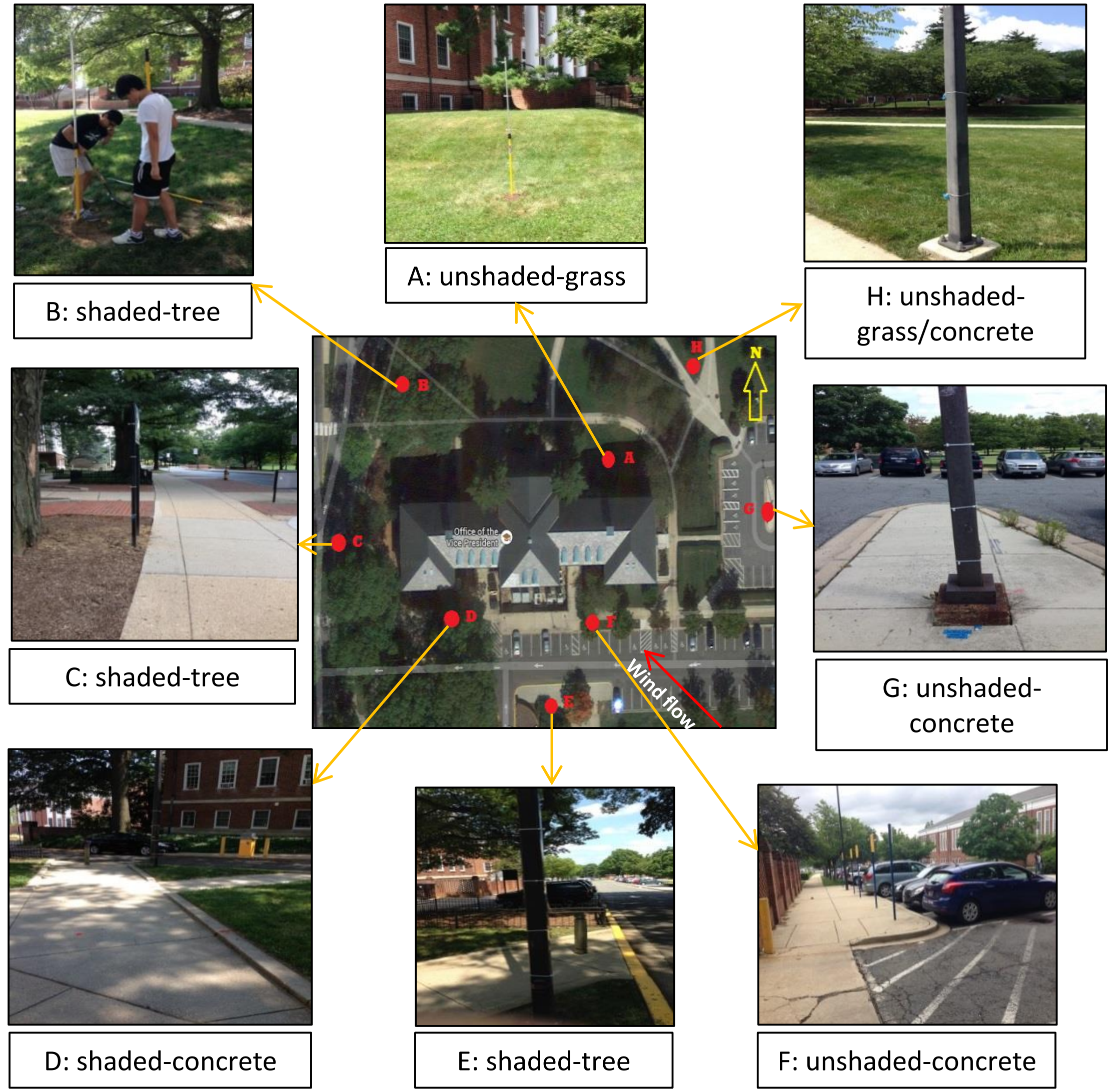
CFD Validation, On-site measurements

Location of iButton sensors

Temperature measurements

8 locations at 1m, 1.5m, 2m

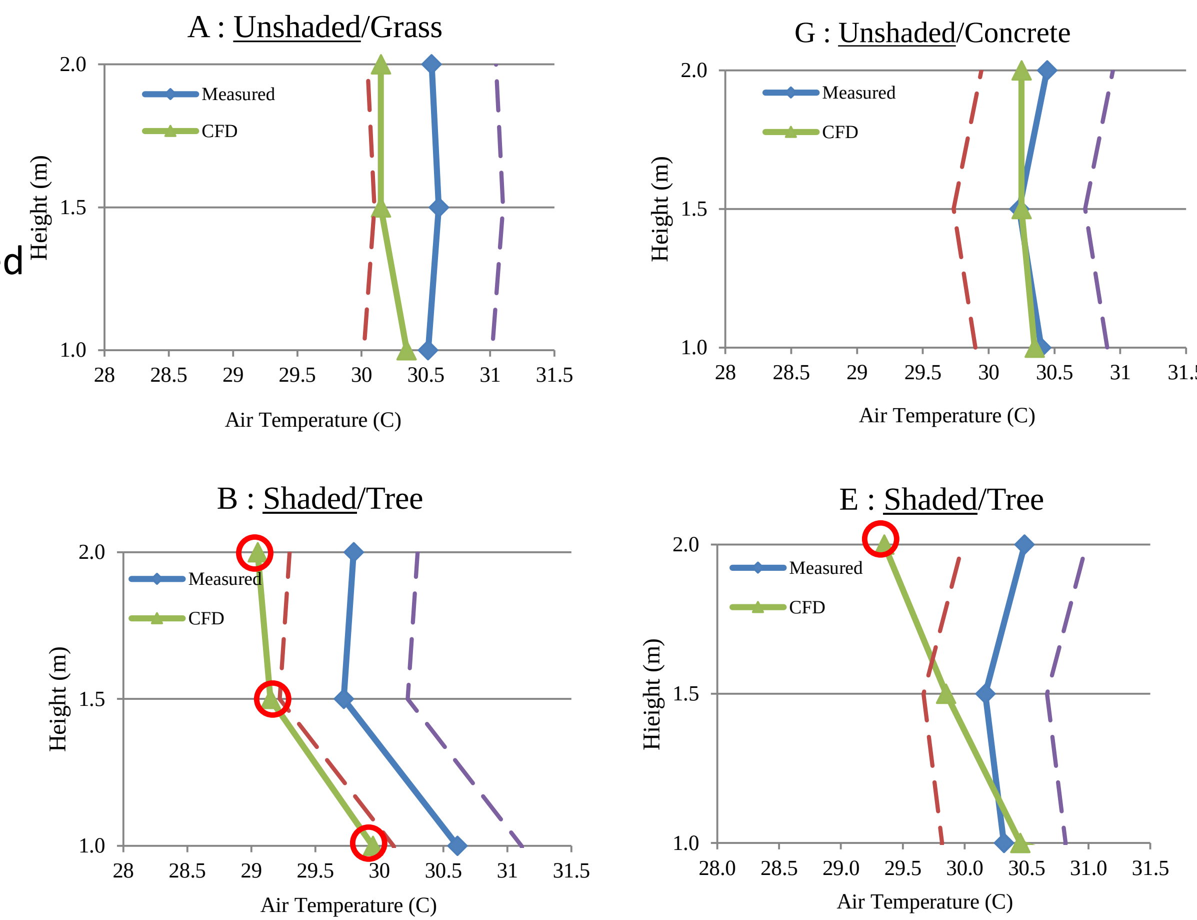
June 2014



CFD Validation, Comparison, Air Temperature

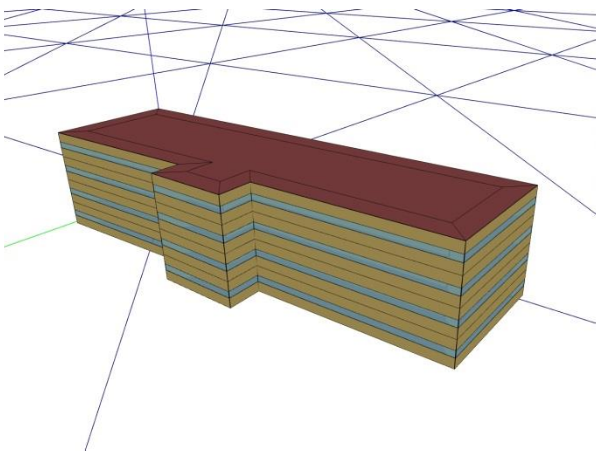
- Accuracy: dash-lines
- Shaded vs. unshaded
- Lower accuracy in shaded areas

  (No trees in the model)



Wind-focused Study, Baseline Energy Model

- Virtual PULSE, EnergyPlus model inputs for Mitchell building



Building parameters	Baseline energy model inputs
Geometry and shape	T shape 4 floors Floor to floor height: 3m (10 ft)
Information	Year built: 1958 Type: office Weather: AMY College Park, MD 2014
Construction	DOE Ref Pre-1980
Spaces	Window to wall ratio: 33% Thermal zones : perimeter and core zoning with single space type Perimeter zone depth: 3m (9.8 ft)
Loads	Lighting: 20 W/m^2 Electric equipment: 10 W/m^2 Infiltration: 0.002 m^3/m^2s of exterior surface area (0.4 cfm/ft.min)
HVAC	Rooftop VAV with reheat DX for cooling District heating Fan efficiency: 70% Ventilation: 0.06 cfm/ft^2 + 5 cfm/person
Simulation result	Area: 4217 m^2 (45400 ft^2) Actual area: 4200 m^2 (45212 ft^2) **EUI: 1135 MJ/m^2 (100 $kBtu/ft^2$)** **Actual EUI: 854 MJ/m^2 (75.2 $kBtu/ft^2$)**

Wind-focused Study- Energy Model Calibration

- Calibrating main parameters: Schedules + Infiltration

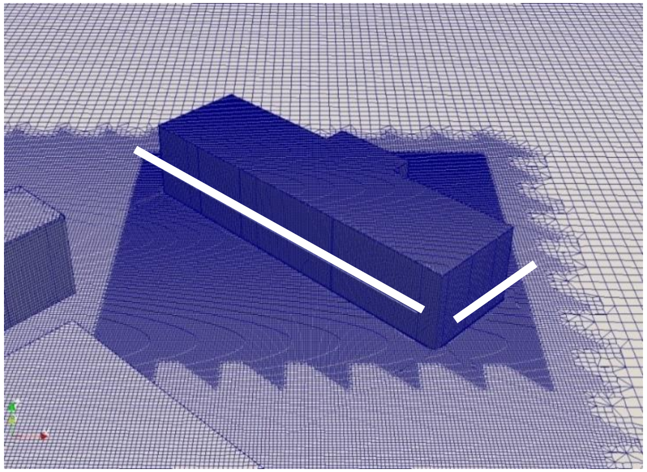
Calibration modification	Parameters
People	0.04 people/m^2 0.3 fraction radiant 120 W/person, level of activity
Schedules	Shorter working hours based on heat maps Modified temperature setbacks
Infiltration	Design Flow Rate Model by medium office coefficients: 0.002 m^3/m^2s per exterior surface area (0.4 cfm/ft.min) Coefficients (Lisa C. Ng, 2015): Constant term: 0.0 Temperature term: 0.0138 Wind velocity term: 0 Wind velocity squared term: 0.0315

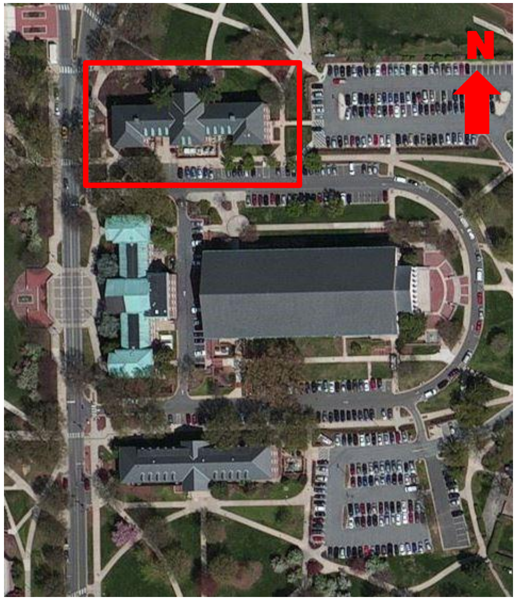
Need for wind multipliers to calibrate

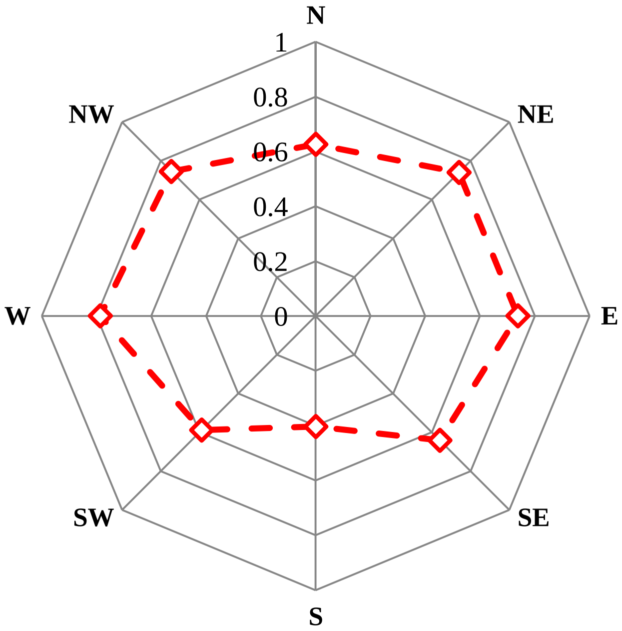
the building energy model

Wind-focused Study, Wind Multipliers

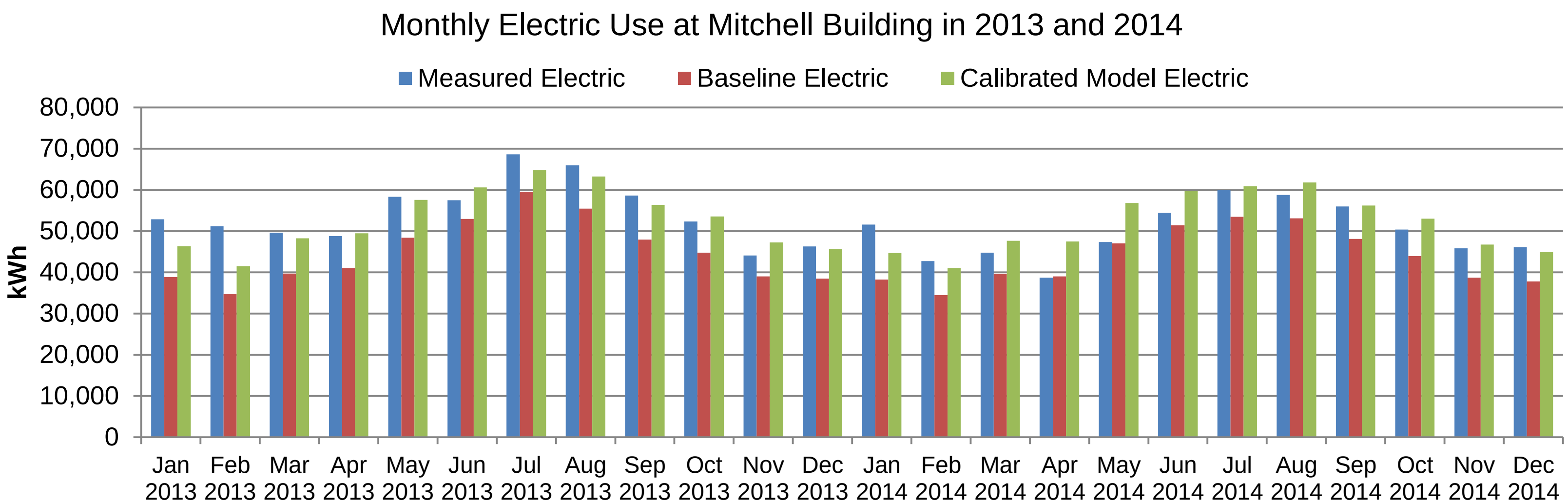
- Rotating Mitchell neighborhood in 8 main principal wind directions
- OpenFOAM CFD cases
- Iso-thermal, simpleFOAM solver
- Measurement at windward facade of Mitchell building
- 10m height, 5m away from the facade

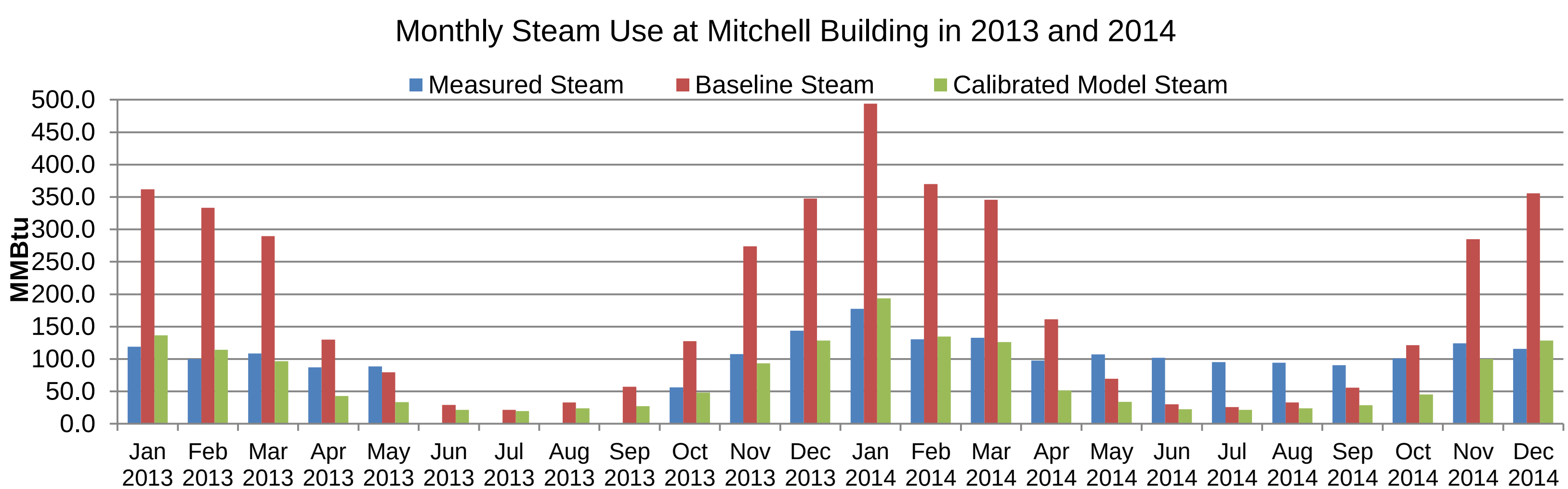




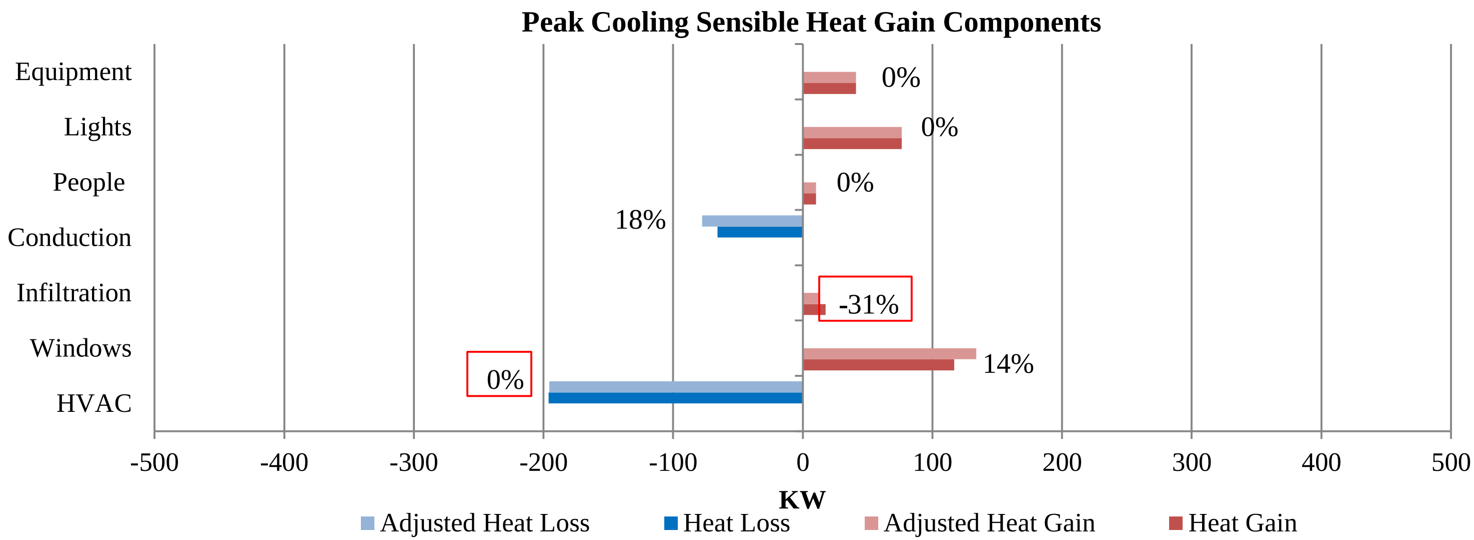


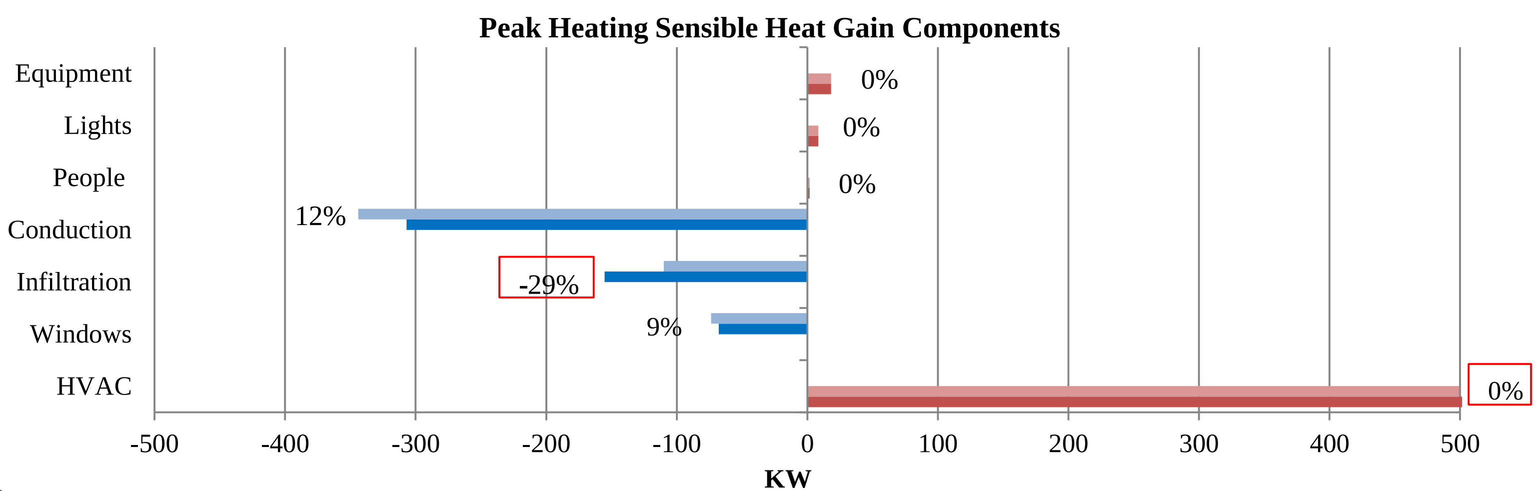
Wind-focused Study- Energy Model Calibration





Local Wind Effect on Peak Cooling and Sensible Gains





Conclusions

- In the case study, considering adjusted wind velocity in energy model using wind multipliers led to:
  - 5% decrease in total building EUI
  - No significant effect on HVAC design
  - Considerable effect in calibration of end-uses
- Direct effect of the local wind on infiltration
- Indirect effect of local wind on convection due to the conduction
- Lower wind speeds in urban areas results in less infiltration

Questions?