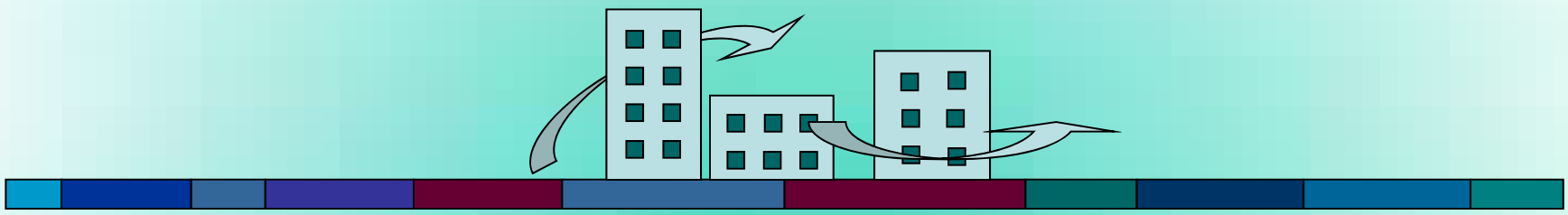

Opportunities and Challenges for Multi-Scale Modeling of Sustainable Buildings

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September 20, 2011

Built Environments

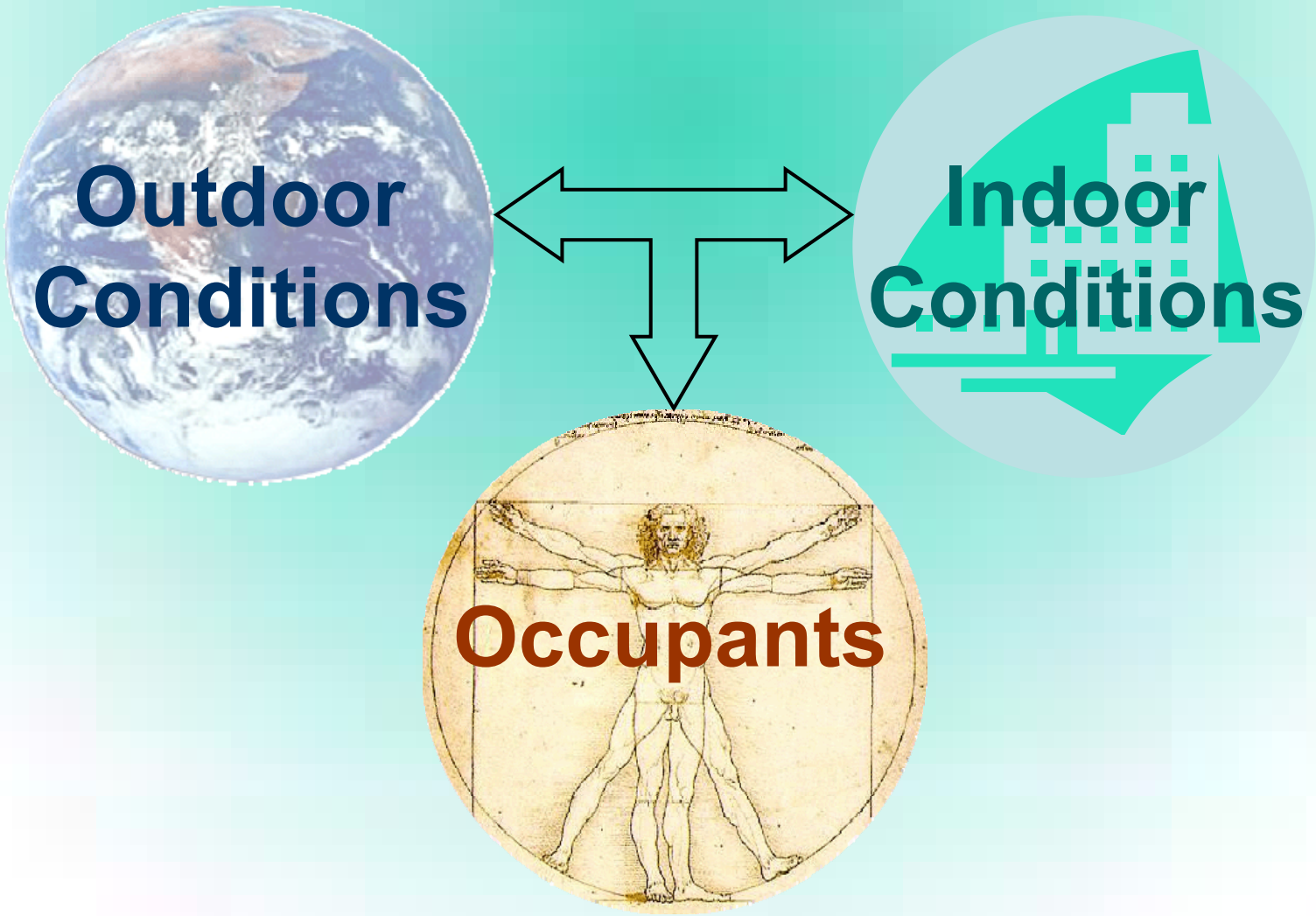
Humanity's Top Ten Problems for the next 50 years

(Smalley 2003)

- Energy
- Water
- Food
- Environment
- Poverty
- Terrorism & War
- Disease
- Education
- Democracy
- Population

Sustainable Technologies
In Built Environments

Built Environments



Built Environments

- Population migration from rural to urban areas during industrialization era
- Majority of world's population live in urban environments
- Buildings play a vital role in urban infrastructure and its energy demand
- Strong energy demand in residential and commercial buildings is to remain

Built Environments

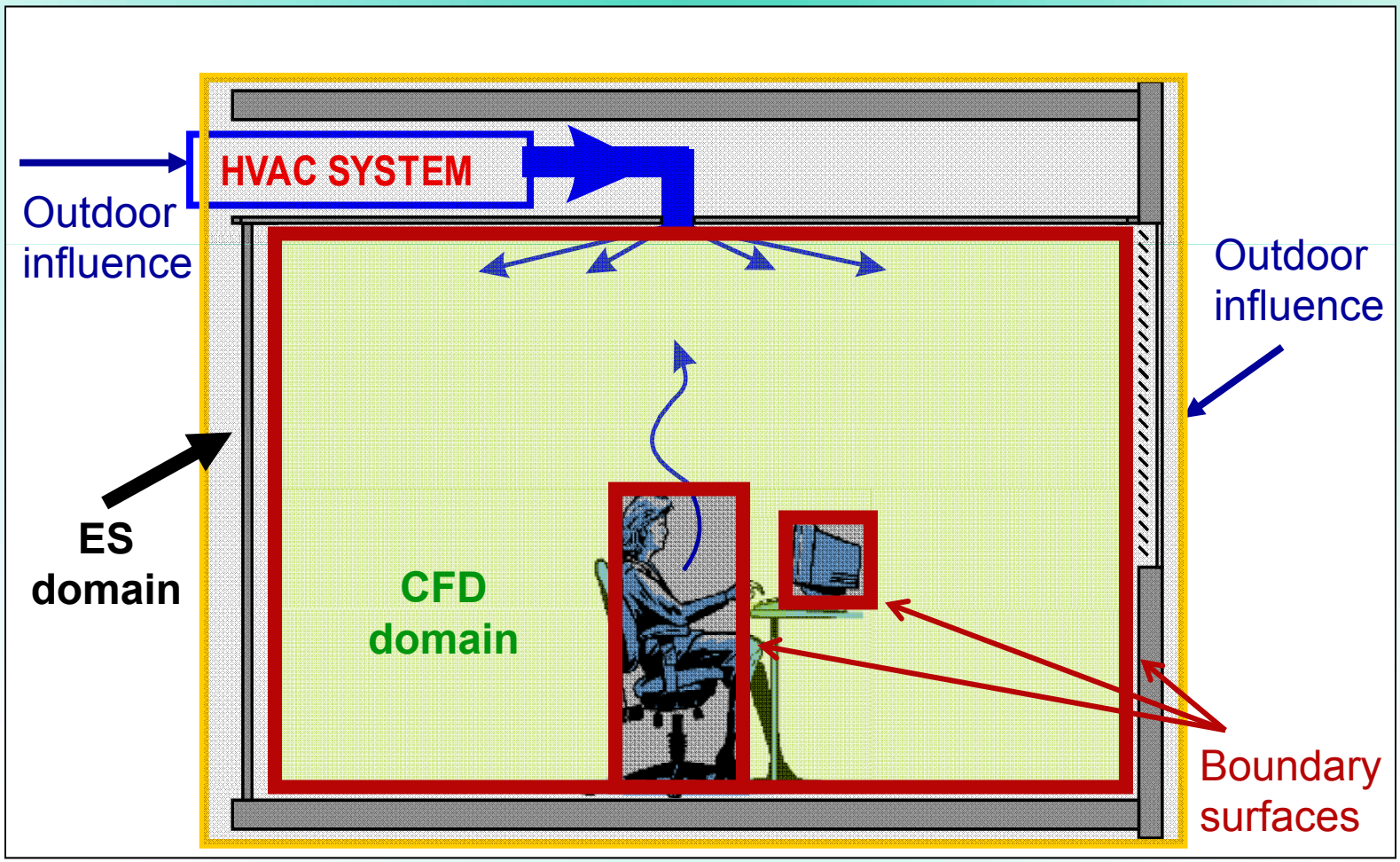
- Design paradigm shifts:
  - energy conservation
  - thermal comfort
  - health concerns
  - security issues
- Current trend: sustainable buildings
- Future trends to address stochastic nature of built environment associate with weather / climate change and its simultaneous impacts on energy and health

Sustainable Buildings

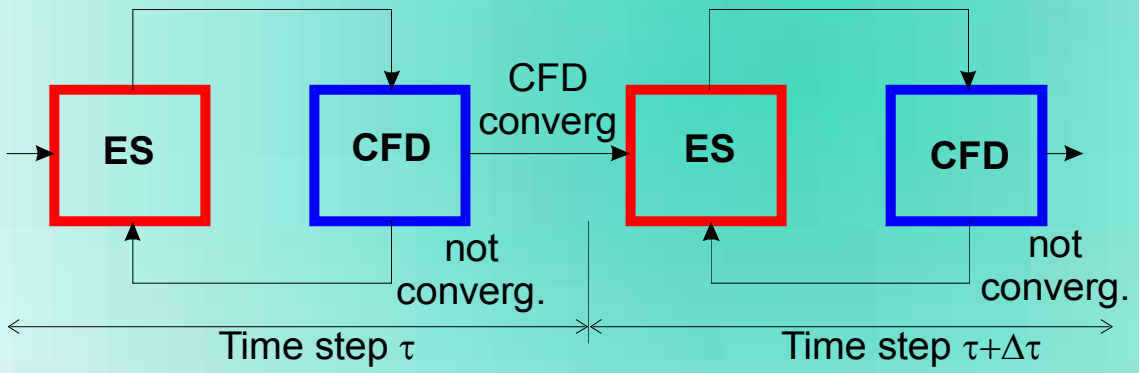
Ski Resort in Dubai Desert

The “Eden” Project in UK

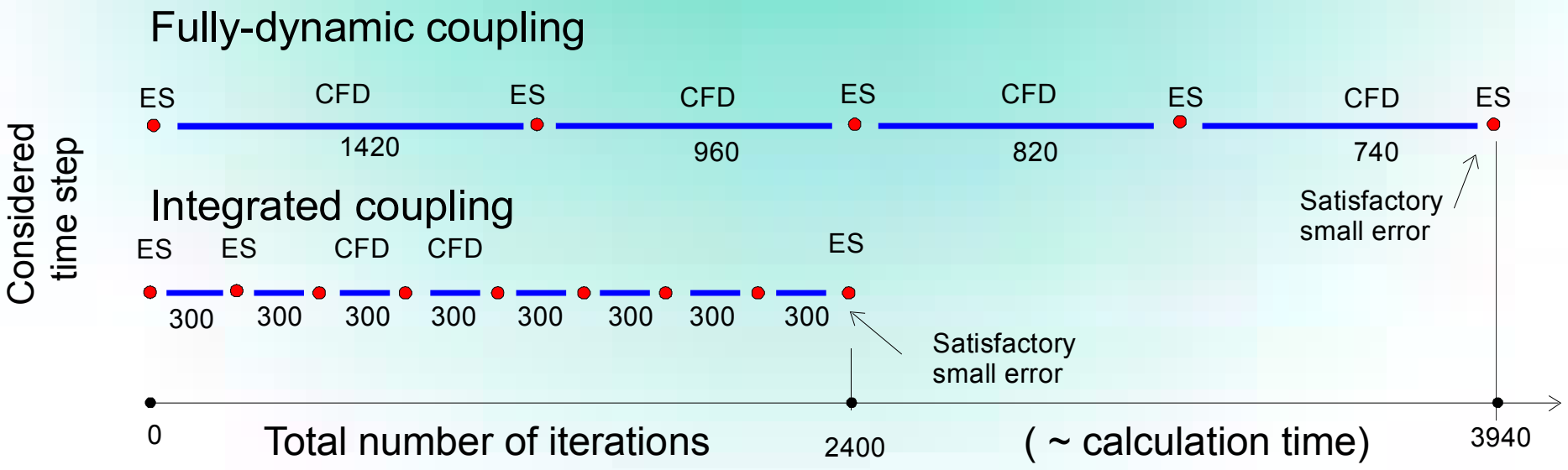
Energy and Indoor Air Quality



Energy and Indoor Air Quality



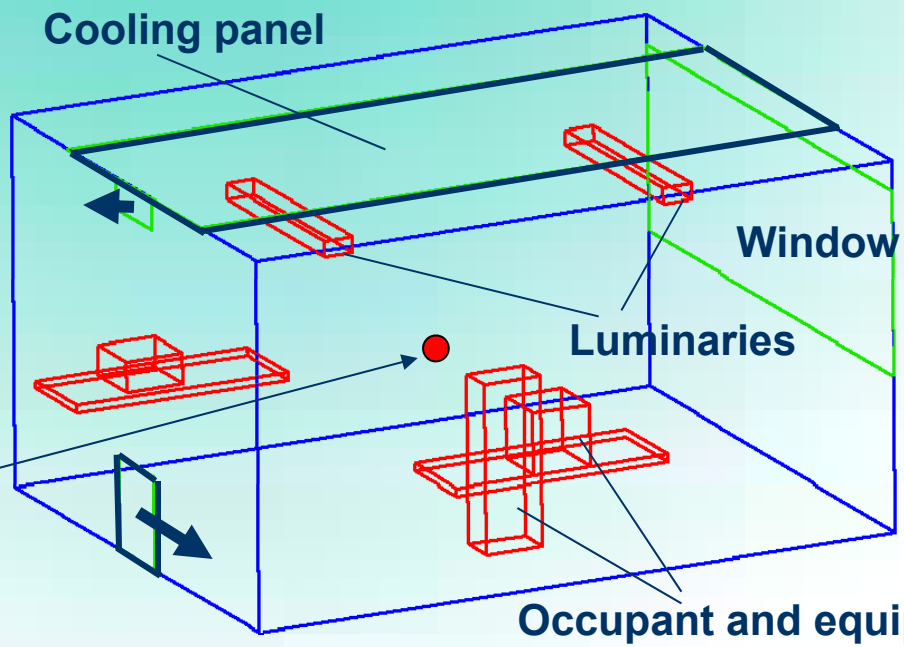
- Independent of $\Delta\tau$
- fast



Energy and Indoor Air Quality

Thermal comfort and energy consumption in an office with:

- Displacement Ventilation (DV)
- Displacement Ventilation with Chilled Ceiling (DV/CC)

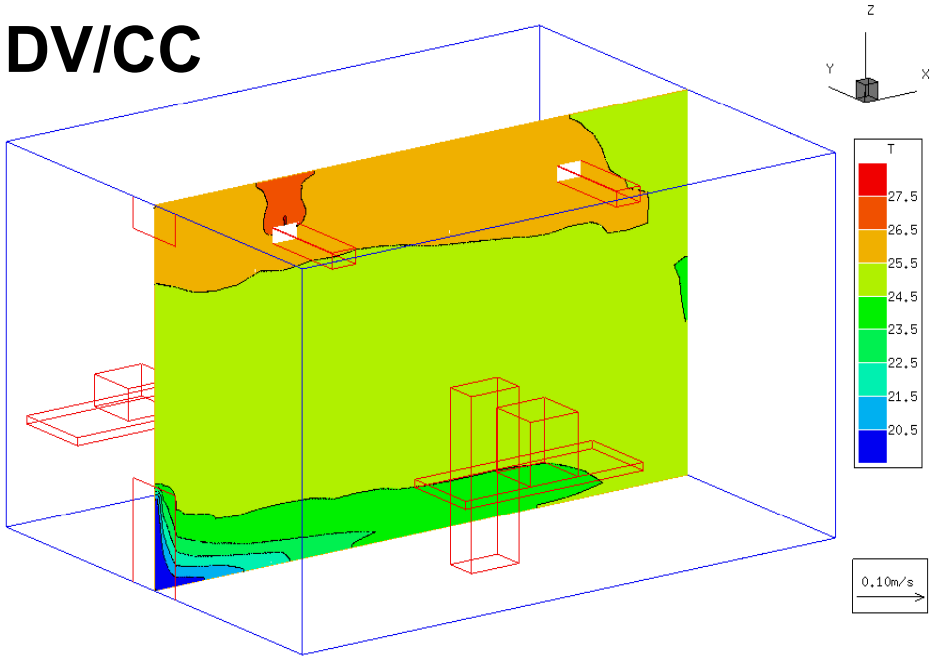


Temperature control:

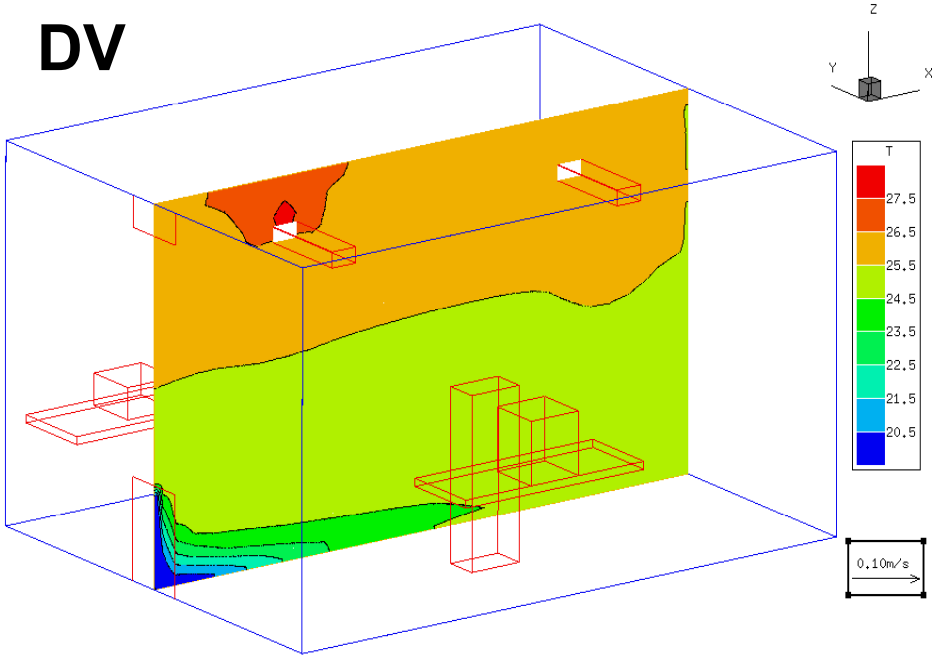
Set Point T = 25°C

Energy and Indoor Air Quality

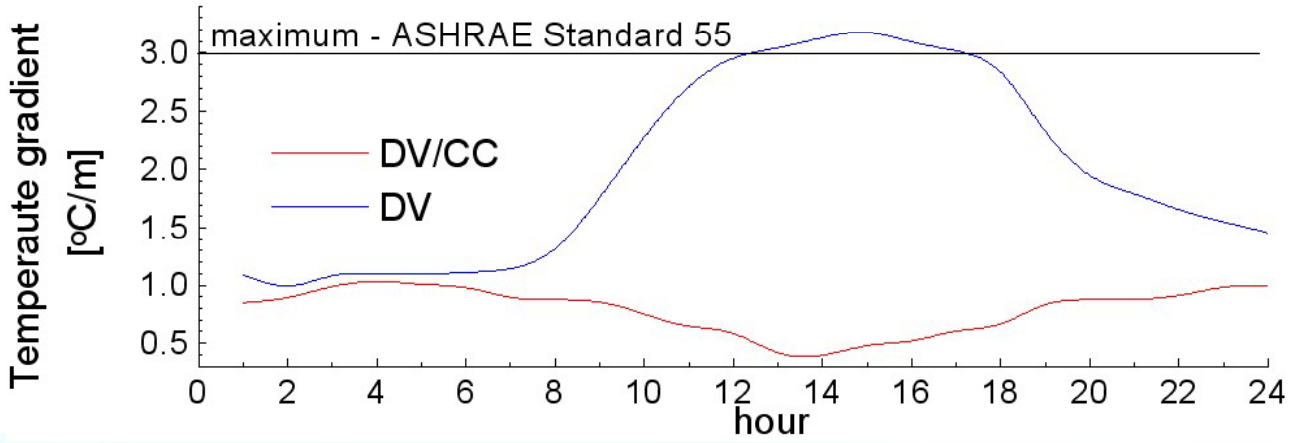
DV/CC



DV

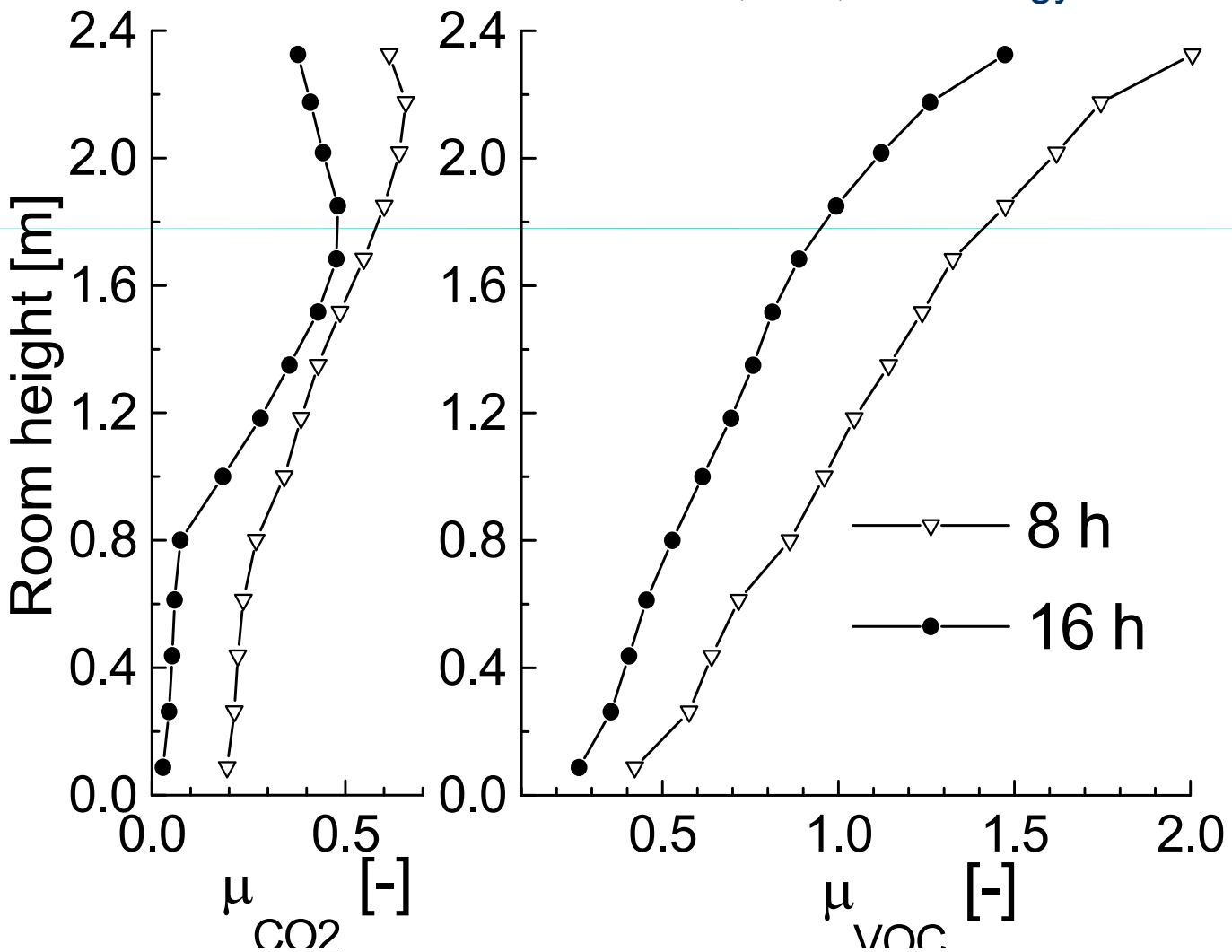


Hour 0.5

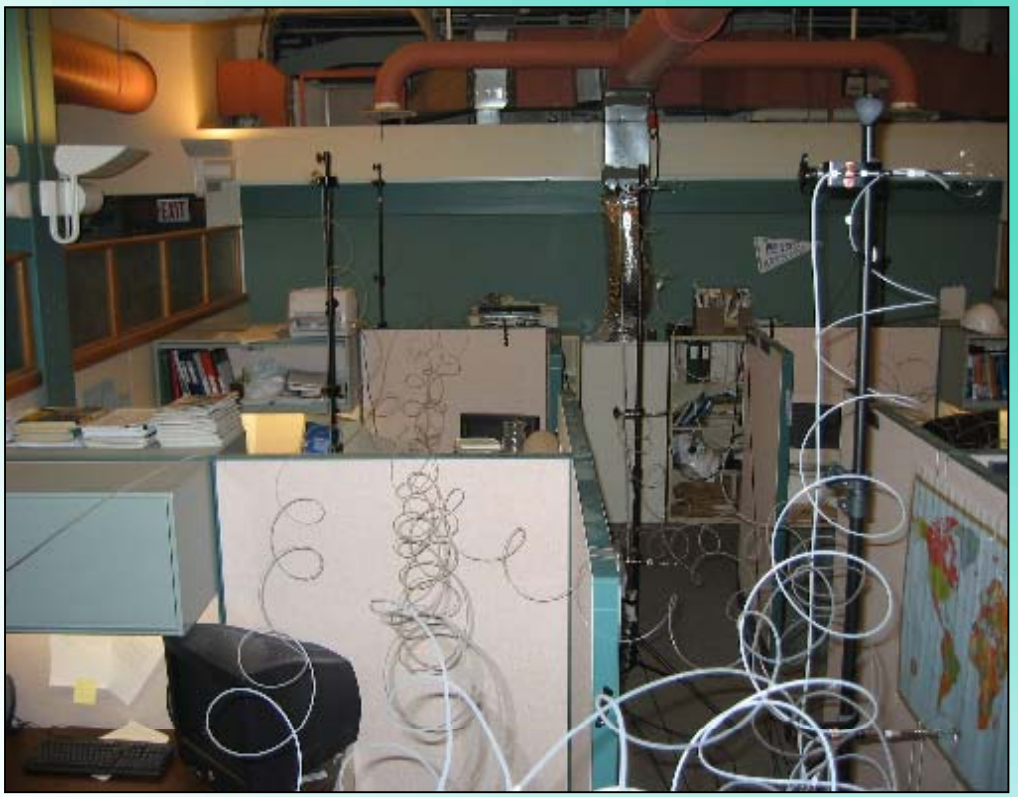


Energy and Indoor Air Quality

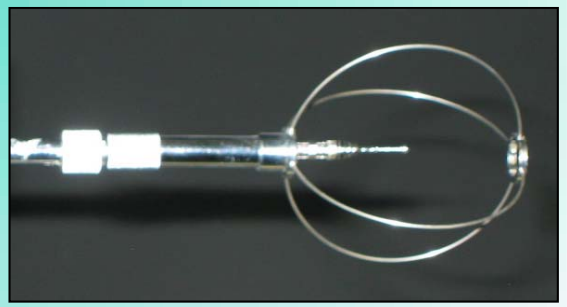
Clear connection between thermal comfort, IAQ, and energy consumption



Energy and Indoor Air Quality



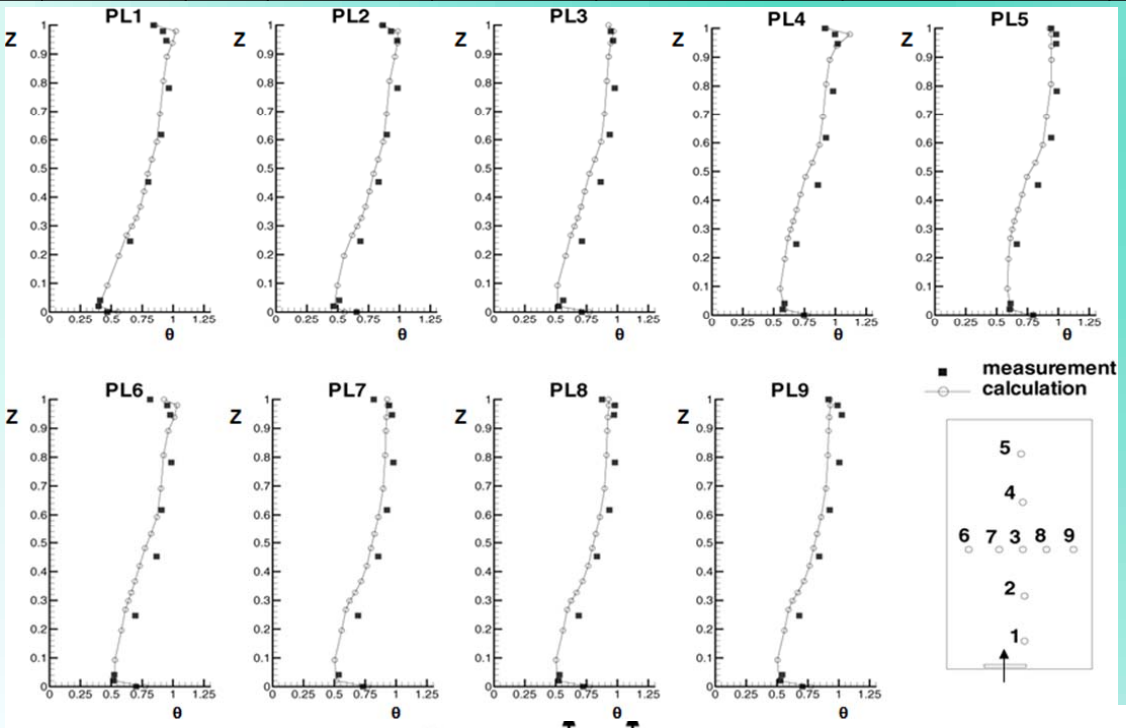
Tracer gas monitor system



Omni directional air velocity and temperature sensor

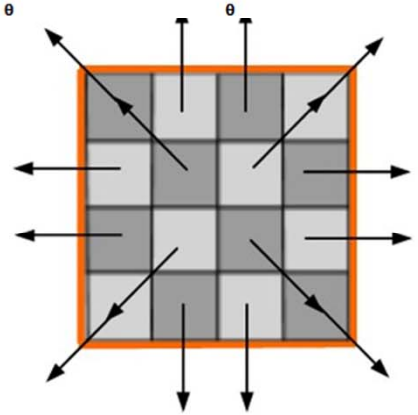
Small packaged board with multiple sensors for autonomous data collection

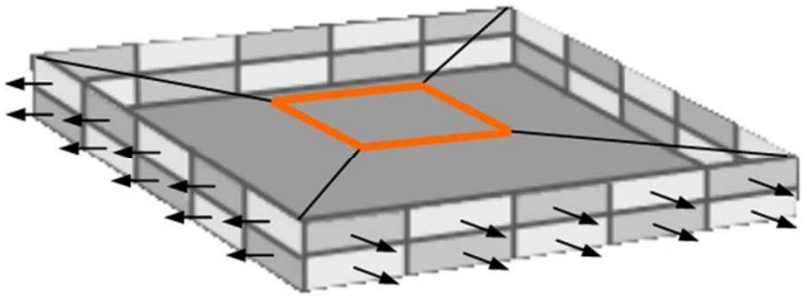
Energy and Indoor Air Quality



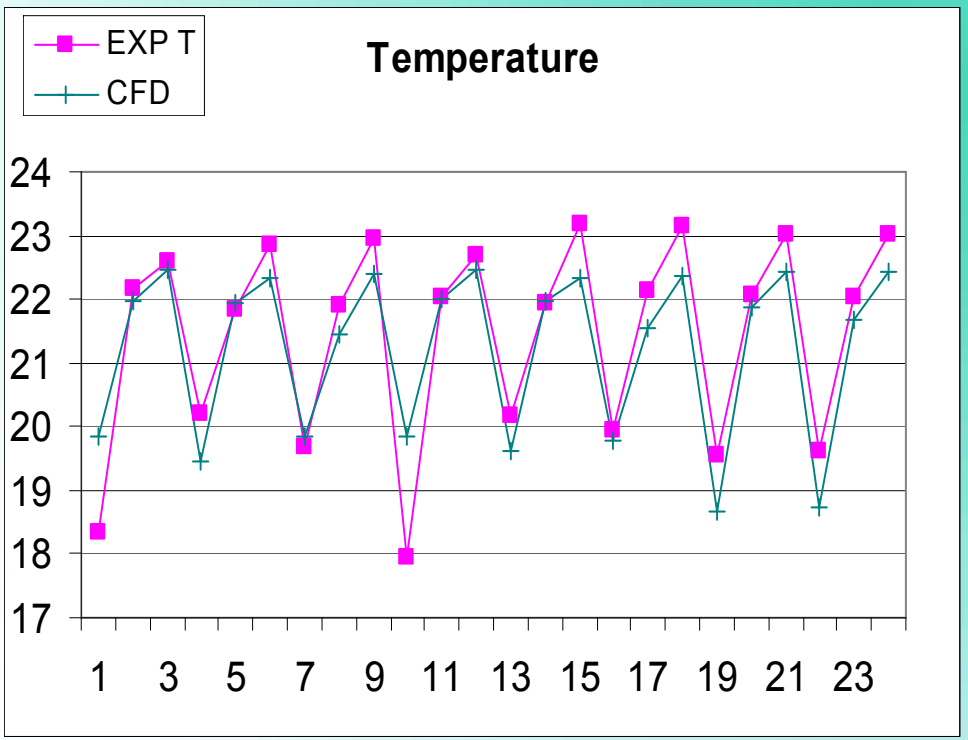
Critical simulation parameters:

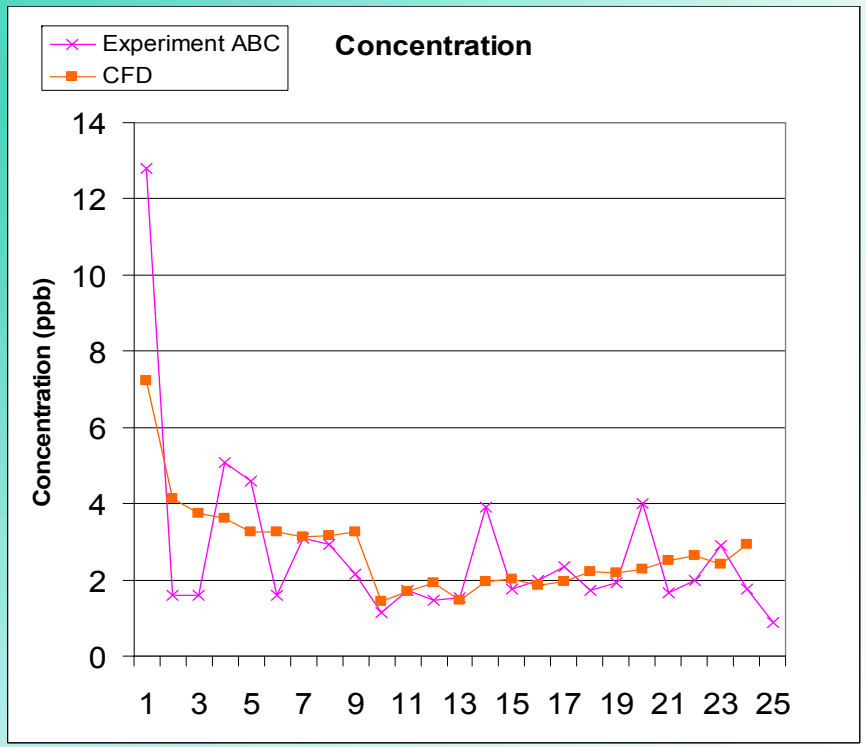
- Diffuser airflow conditions
- Thermal boundary conditions
- Contamination sources





Energy and Indoor Air Quality





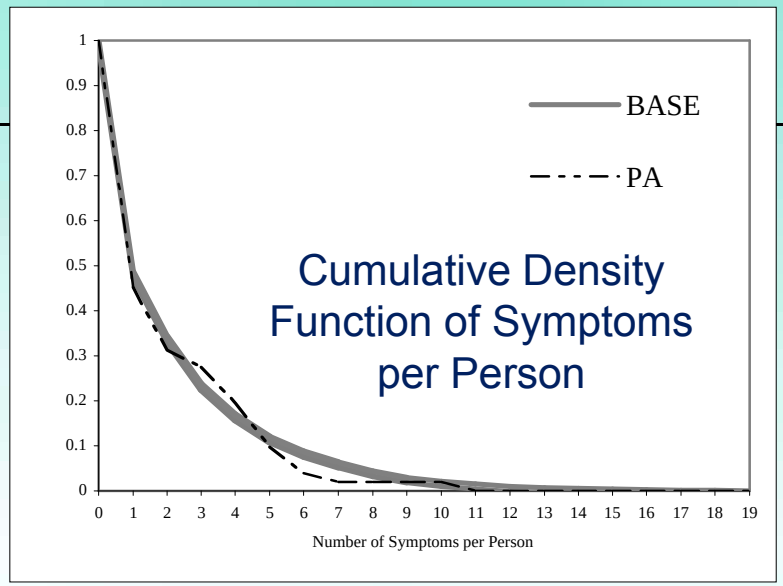
Predictions of temperature and concentrations agree well with measured results in real environments

Applications

- Datacenter cooling systems
- Hospital ventilation systems
- Atria and other interesting architectural design solutions
- Natural ventilation
- Smoke and fire suppression systems
- Laboratory ventilation

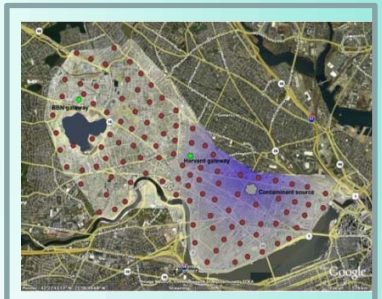
Energy and Indoor Air Quality

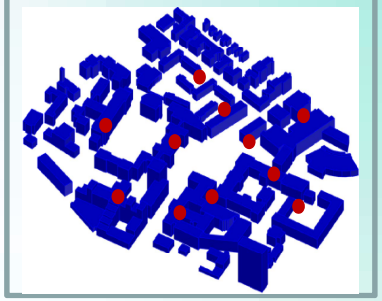
Negative Environmental Perception	PA %	BASE %
Too dry	27.45	25
Too little air	11.76	31
Too cold	11.76	26
Too hot	9.8	27
Other odor	9.8	16
Too much air movement	0	8
Too humid	0	6
Smoke odor	0	5
Chemical odor	0	26

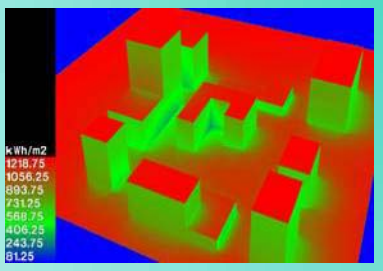


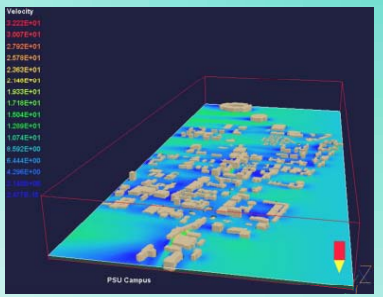
Predictive Modeling

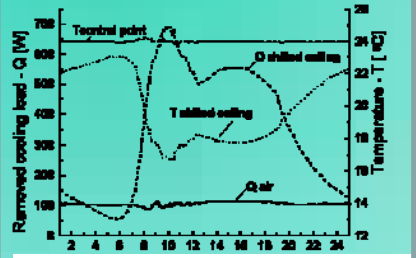
Creating Opportunities for Adaptation Based on PULSE (Population in Urban Landscape for Sustainable Built Environments) – NSF EFRI -1038264

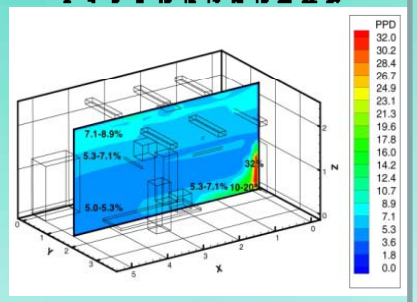


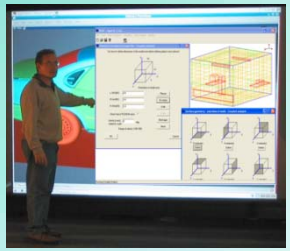












Urban Building Design Performance Matrices & Adaptation Strategies

Neighborhood Wireless Data & ArcGIS Files

Neighborhood Simulations of Solar and Wind

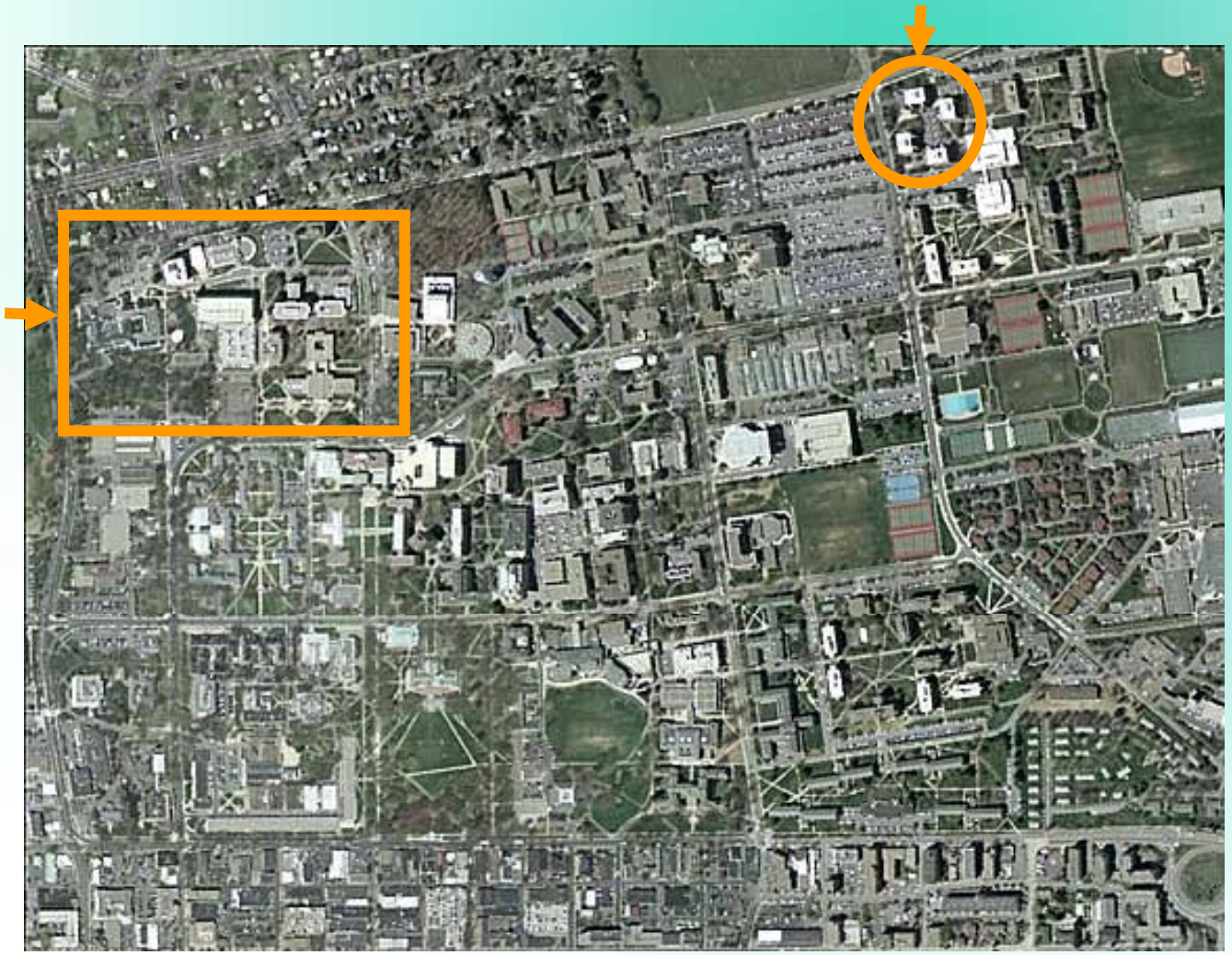
Building Energy Consumption and Occupant Perception

Occupant Input to Controls & Visual Interface

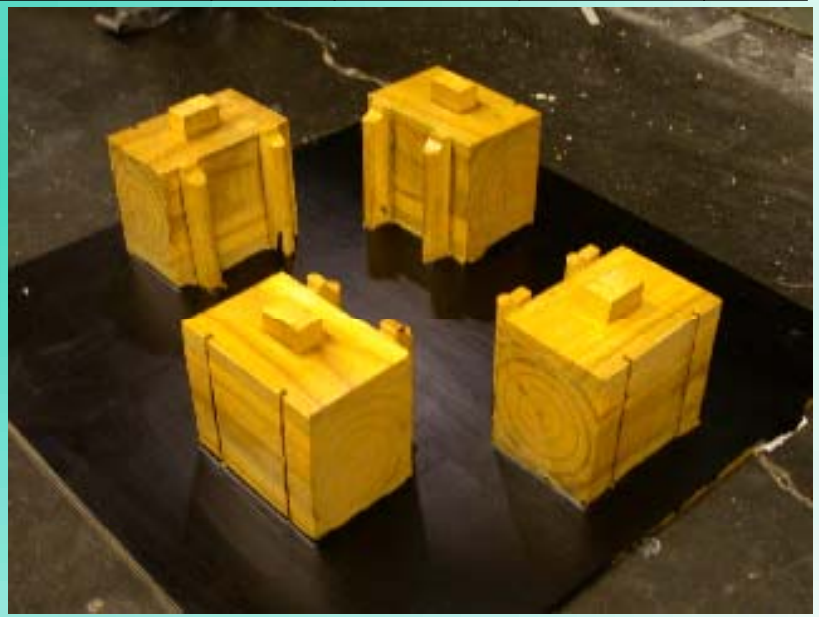
Refine wireless network

Refine building controls

Outdoor Airflow



Outdoor Airflow



Outdoor Airflow

$$\mu_t = 0.2 \cdot (\frac{10^5}{\mathrm{Re}_b}) \cdot \rho \cdot T_{i\_\mathrm{inflow}} \cdot U \cdot l$$

Re_b = inflow Reynolds number at the building height

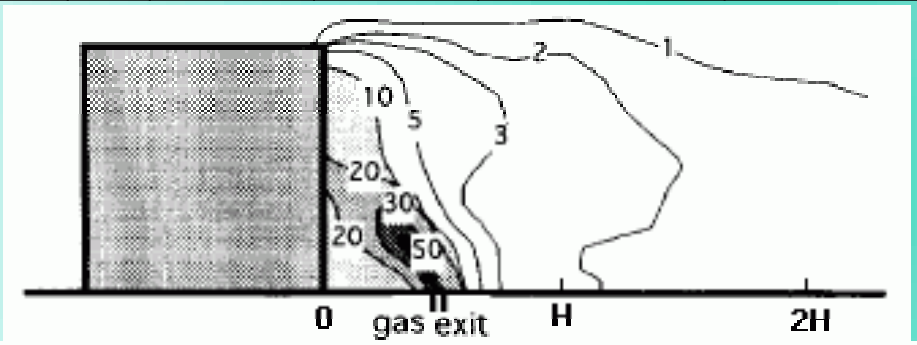
$T_{i\_\mathrm{inf}\,low}$ = inflow turbulence intensity at the building height

U = local mean velocity

l = length scale (the nearest distance to the building surface)

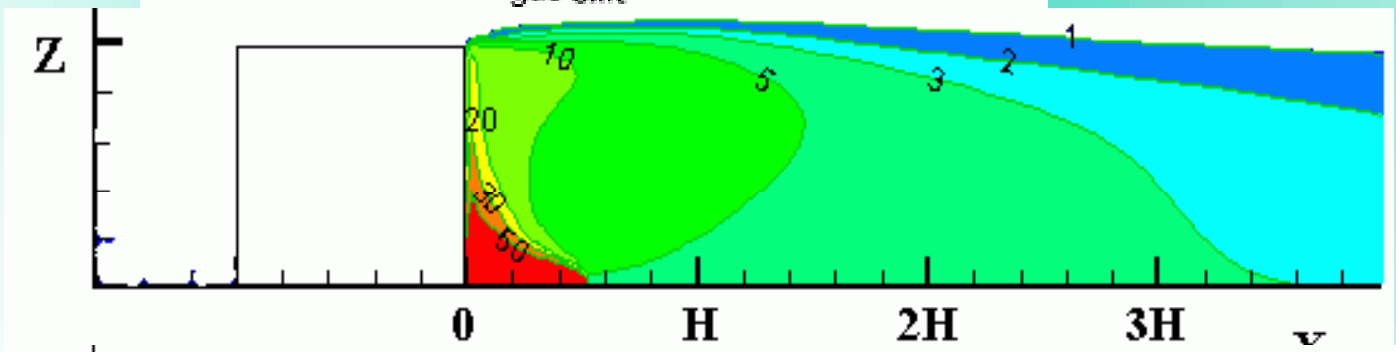
ρ = air density

Outdoor Airflow

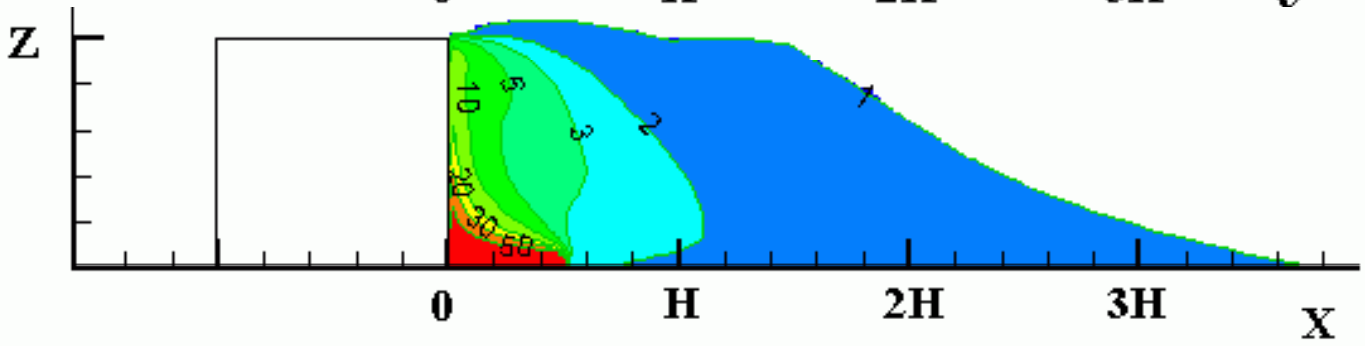


Experiment

(Stathopoulos at al. 2002)

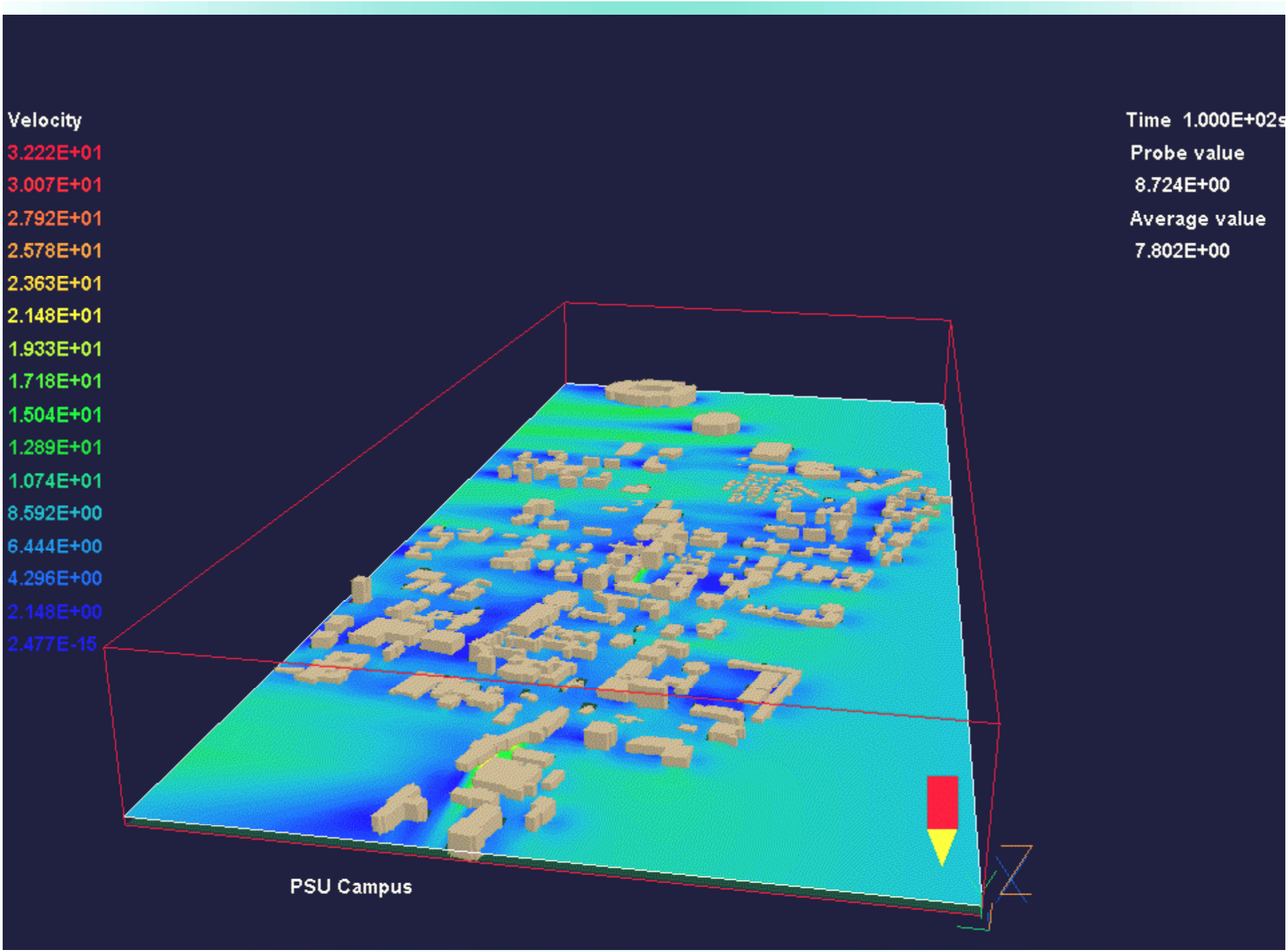


Standard k-ε Model

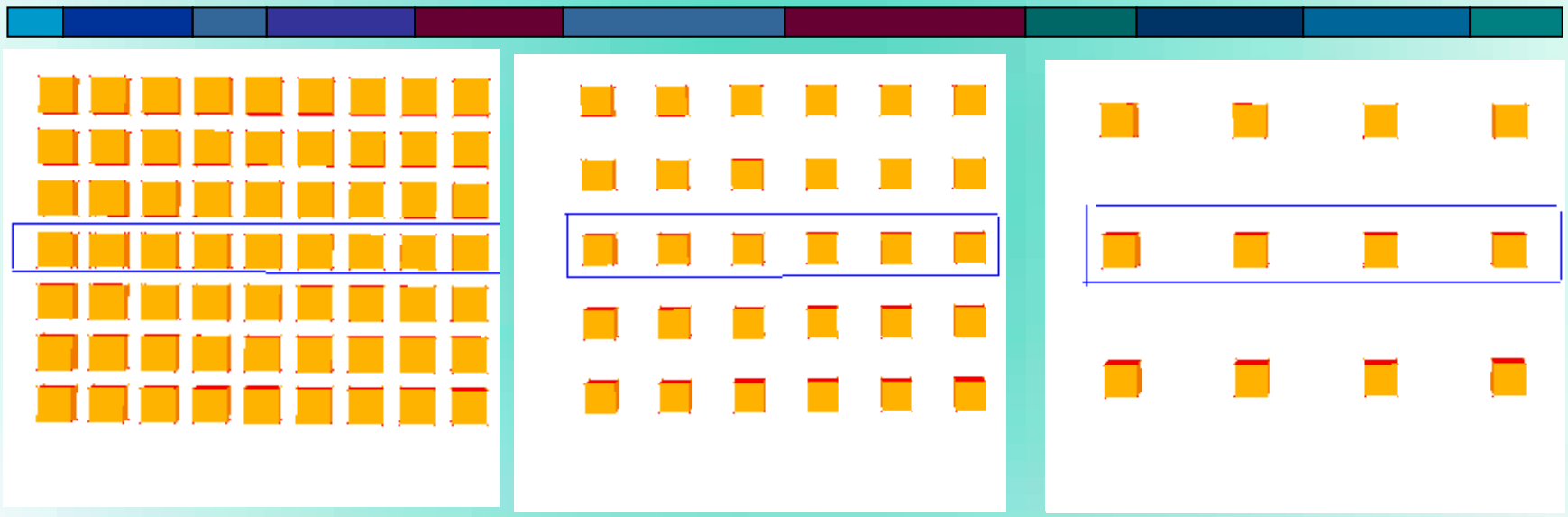


New Algebraic Model

New turbulence model better predicts concentration field than the standard k- ε model

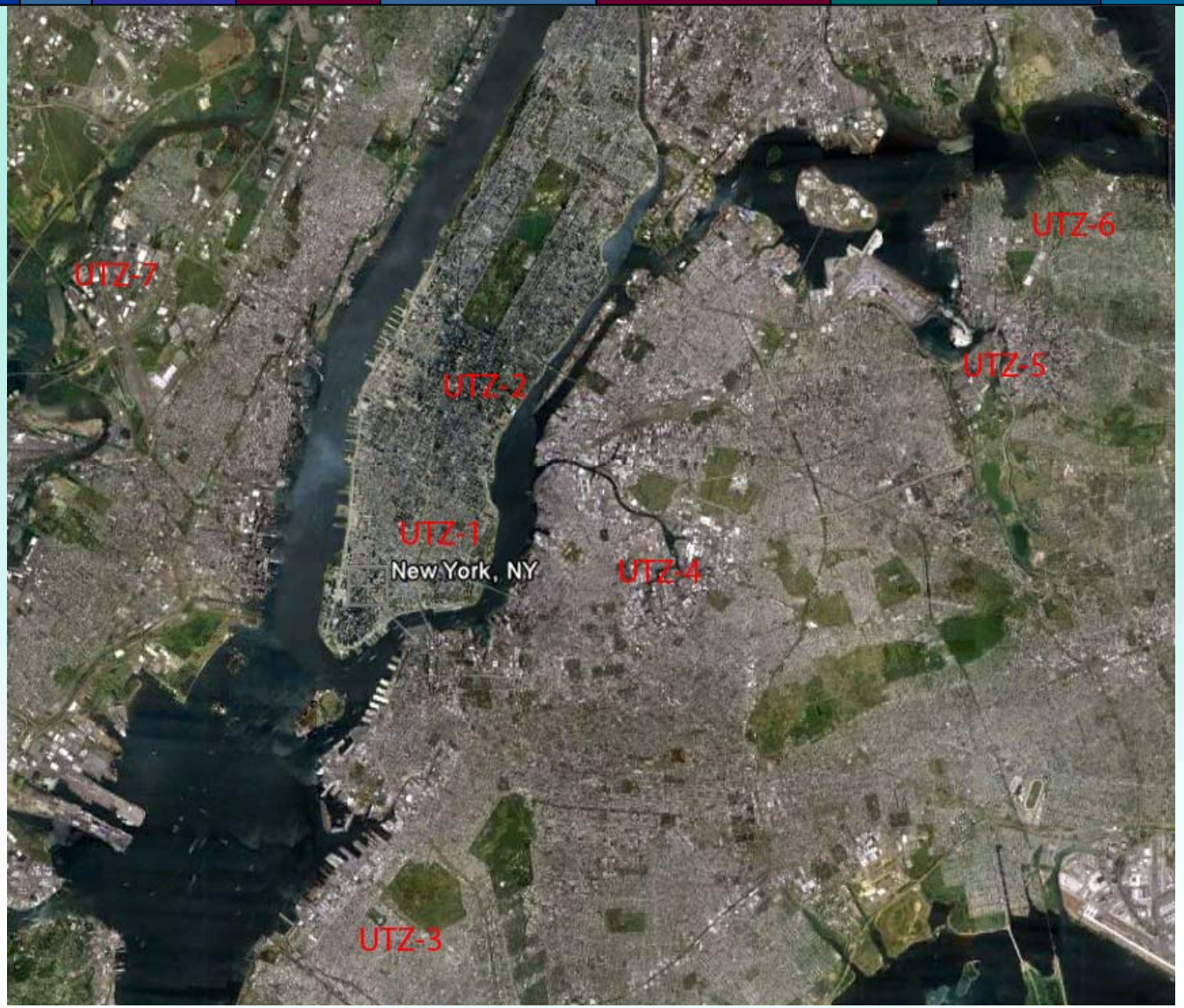

Velocity
3.222E+01
3.007E+01
2.792E+01
2.578E+01
2.363E+01
2.148E+01
1.933E+01
1.718E+01
1.504E+01
1.289E+01
1.074E+01
8.592E+00
6.444E+00
4.296E+00
2.148E+00
2.477E-15
Time 1.000E+02s
Probe value
8.724E+00
Average value
7.802E+00
PSU Campus

Outdoor Airflow



- Different urban densities result in different local temperatures
- Cooling equipment efficiency can be significantly reduced due to increased local temperatures

Built Environments



Built Environments

- Need for distributed sensor networks
- Need for reliable predictive modeling
- Need for novel enclosure materials
- Need for more efficient power distribution
- Need for local power generation
- Need for novel hybrid cooling equipment

Improved energy footprint and air quality

Built Environments