Indoor-outdoor environmental coupling and exposure risk to extreme heat and poor air quality during heat waves

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Motivation by the numbers…

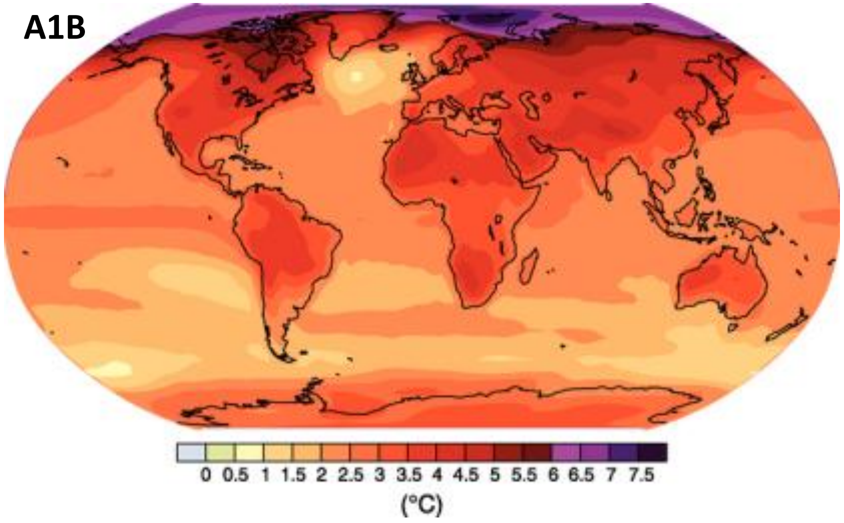
Climate

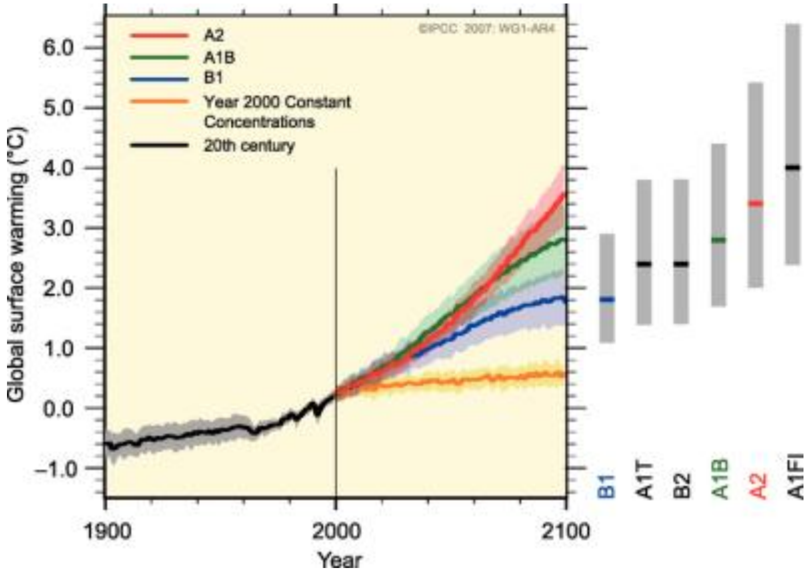
- 2 to 4 °C

- IPCC SRES-projected global temperature increase by 2100

ipcc.ch

A1B

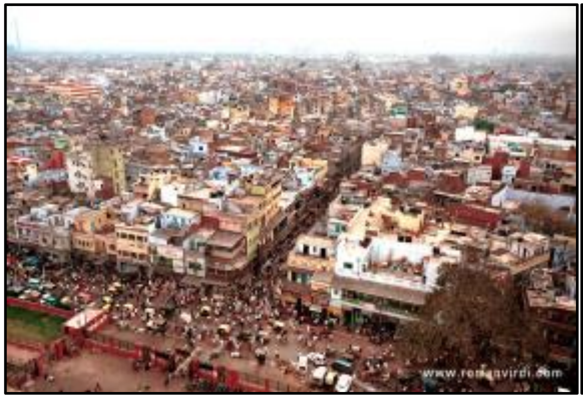




Urbanization

- 66%
- Urban fraction of world population by 2050

un.org


Exposure

- 89%, 6%, 5%
- Time spent indoors vs. in transit vs. outdoors (U.S. data)

Klepeis et al., 2001 JEAEE

89%

6%

5%

Heat-Related Mortality

- 15,000
- Heat-related deaths in France during Aug. 2003 heat wave

- x 4
- Increased risk of death for elderly by living on top floor

Poumadere et al., *Risk Analysis* 2005

Pollution

- 7 Million
- Global annual early deaths linked to air pollution*

- 175%
- Increase in mortality when ozone event simultaneous with heat wave**

* WHO, 2014
** Filleul et al., *Env. Health Persp.*, 2006



Interpreting the numbers…

The world is warming

…and becoming more urban

Heat and air pollution are deadly

… especially when they occur together

…and especially for the elderly

This is particularly important within the **indoor** urban climate.

Key Challenges for Indoor Environments

- Heat
  - Many vulnerable residents do not have access to (or choose not to use) AC
  - Those who have AC are particularly vulnerable to system failures

NE Blackout of Aug 14, 2003
Extreme heat, sagging power lines, alarm bug.
7 hours to 2days+, affecting 55M people

India Blackout of July 30-31, 2012
300-600M people affected for 1-2 days.
Likely caused by extreme heat and record power use.

- Ambient AQ affects Indoor AQ
  - Air exchange brings in outdoor pollutants (e.g. O_3)
  - Only a fraction of pollutants penetrate into building due to surface reactions
  - Concentrations of indoor pollutants such as O_3 decay due to reactions with constituents of indoor air
  - Indoor reaction products may be more harmful than the penetrating outdoor air pollutants (e.g., Weschler, *Atmos. Env.*, 2004)

HOME AIR project

Heat and Ozone in Metropolitan Environments: Assessing Indoor Risks

Houston TX

Team (Leads) –

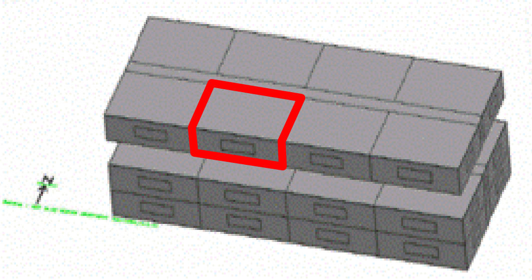
Sailor, Portland State → Arizona State University
Wilhelmi, NCAR
Banerjee, Houston Health Department

Objectives –

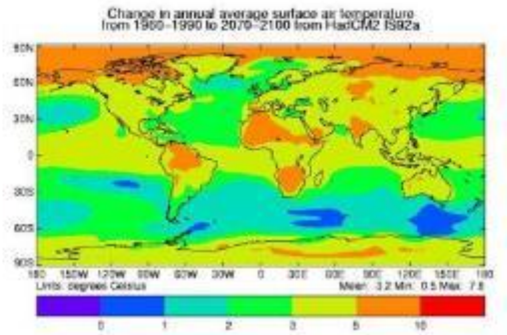
- Characterize current and future health risks of an older population to pollution and heat
- Understand how building design and management practices and occupant behavior affect indoor air quality and heat risks
- Build local capacity in reducing negative health outcomes

Initial Screening Simulations:

Indoor Air Temperature During Power Loss + Heat Wave



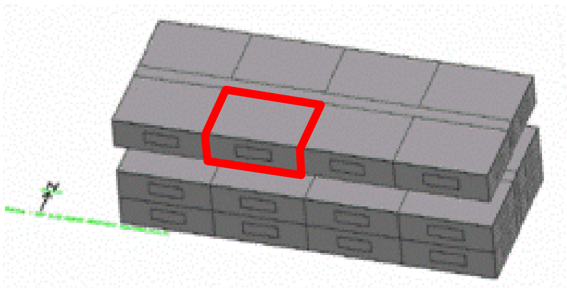
- Whole building simulations
  - Building energy simulation with EnergyPlus
  - Typical four story apartment building in Houston

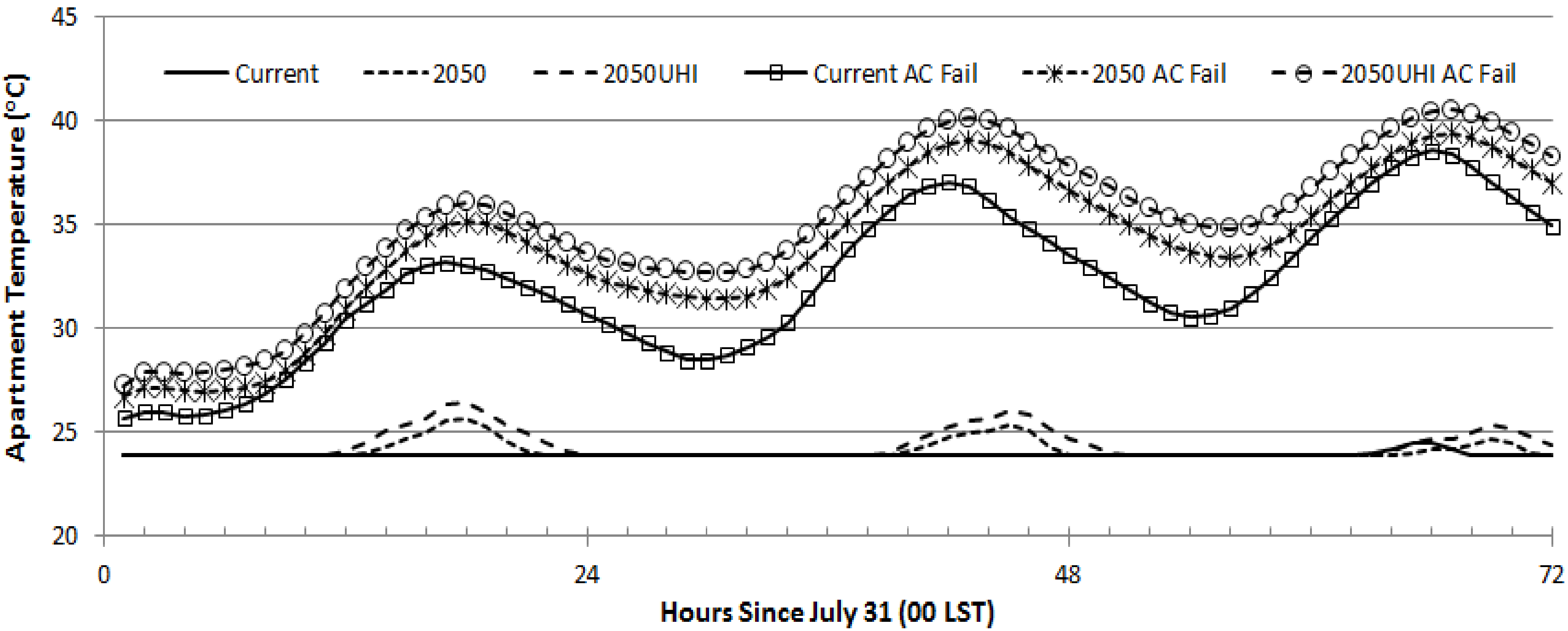


- Climate scenarios
  - Future, 2050 climate (RCP4.5, 27 runs, screened for current climate performance, with variant of imposed offset method used for diurnal ΔT (Sailor, B&E 2014)
- Equipment operation scenarios
  - Normal operation
  - AC system failure
  - Complete power outage

Results – Indoor Air Temperature

(hottest 3-day period)





Sailor, Building and Environment, 2014

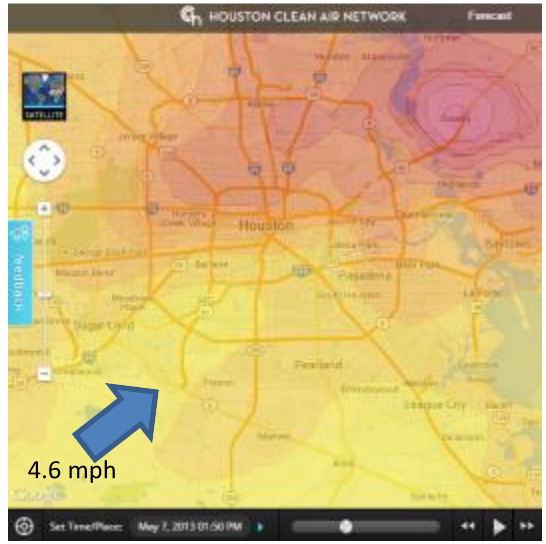
Next Steps: HOME AIR Project

Phase 1: Assisted Living Facilities

Phase 2: Individual homes/apartments

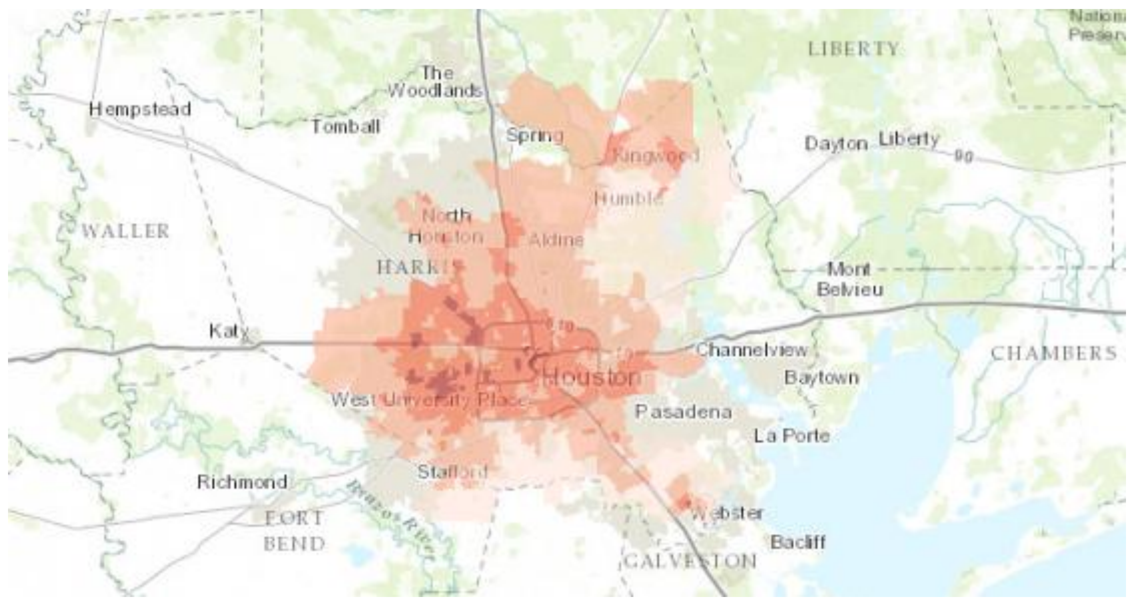
Ozone and Temperature Vary across the City

May 2, 2013



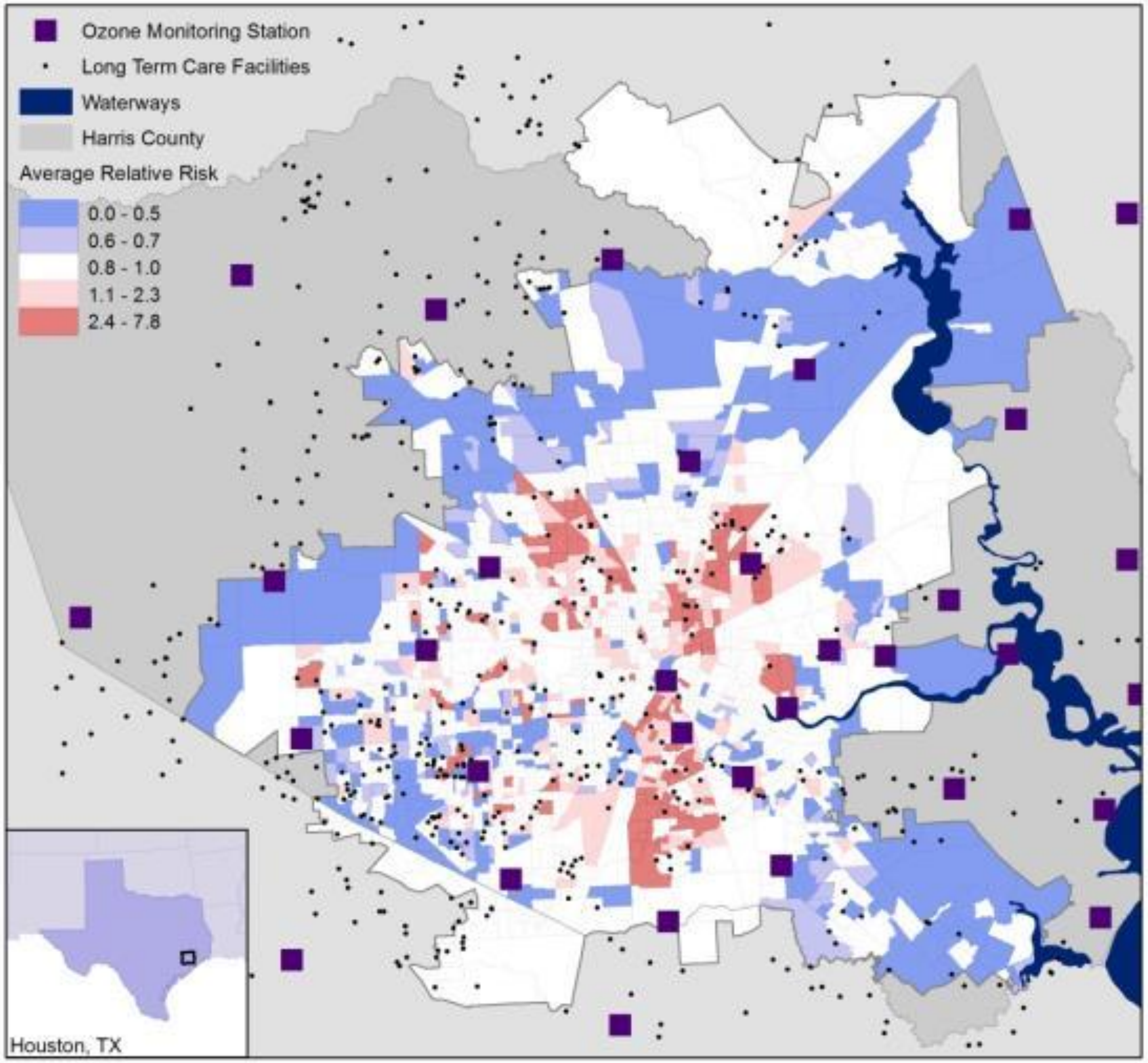
Sept. 8, 2014

http://houstoncleanairnetwork.com/



gis.ucar.edu/projects/simmer

Locations of ozone monitoring stations and Long Term Care Facilities overlaid on a map of <u>average relative risk of heat-related mortality</u> in Houston



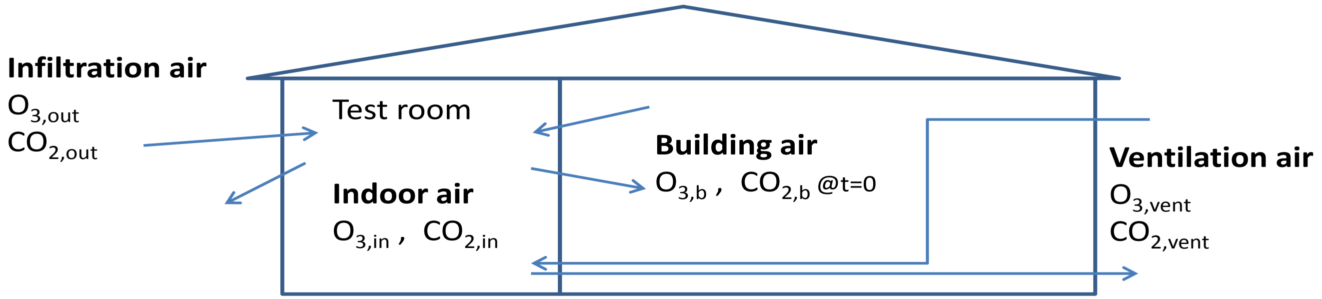
Sources: HDHHS, 2014; TCEQ, 2014; Heaton et al., 2014

Enroll and Characterize Facilities

- Construction, HVAC, and management characteristics
- Routine cleaning procedures and inter-occupancy maintenance
- Leakage and ozone penetration/decay tests

$$\frac{dCO_{2,in}}{dt} = \lambda_{i,in}\, CO_{2,out} + \lambda_{b,in}\, CO_{2,b} + \lambda_{v,in}\, CO_{2,v} - (\lambda_{i,out} + \lambda_{b,out} + \lambda_{v,out}) * CO_{2,in}$$

$$\frac{dO_{3,in}}{dt} = \lambda_{i,in}\, P_i * O_{3,out} + \lambda_{b,in}\, P_b * O_{3,b} + \lambda_{v,in} P_v * O_{3v} - (\lambda_{i,out} + \lambda_{b,out} + \lambda_{v,out} + \beta) * O_{3,in}$$

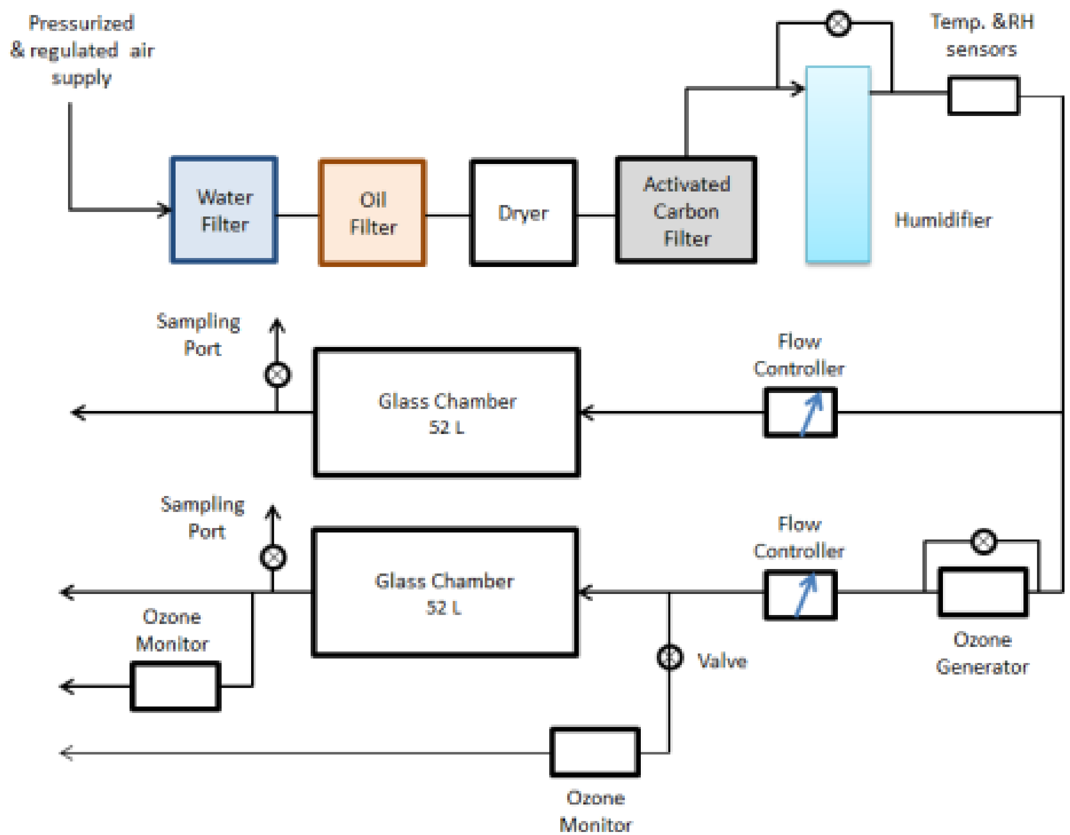


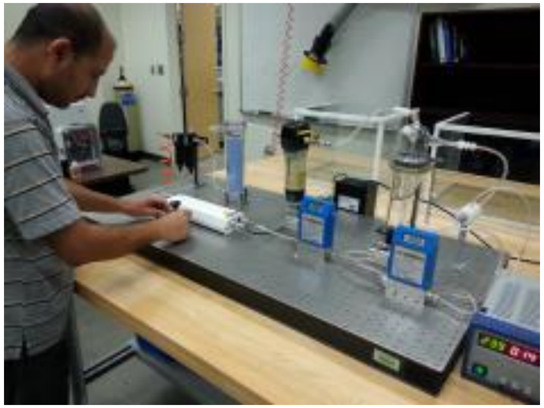
Establish indoor/outdoor monitoring

- Establish local weather stations (e.g. in courtyards)
- Occupancy and indoor environment (T,RH, CO_2, O_3) sensors
  - Indoor common areas (entertainment, dining)
  - Apartments
- Rotate extensive short-term (~2-3 week) monitoring for IAQ measurements (Ozone, VOC)

Conduct laboratory measurements

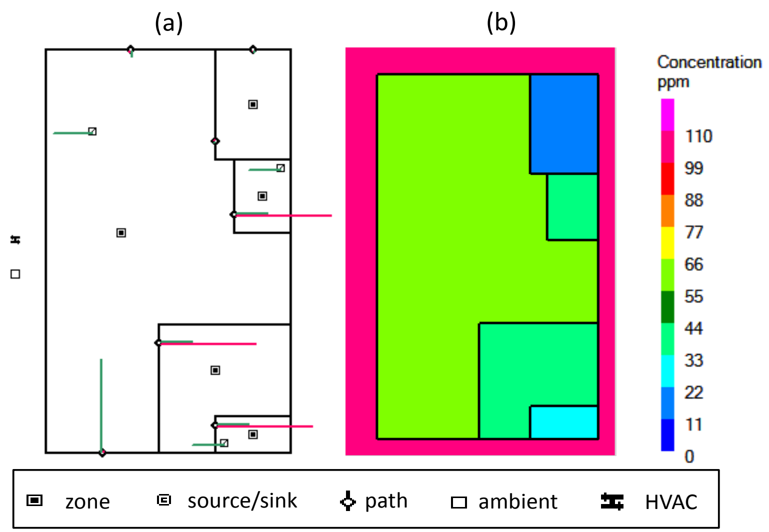
- Understand how management practices and building materials affect indoor air quality





Modeling to explore key controls on IAQ

- Use indoor transport models to estimate indoor air quality and thermal conditions
  - Develop/validate using intensive monitoring periods and laboratory data
  - Vary key factors to explore management practices that may improve IAQ and thermal conditions (e.g. equipment failure during heat waves)



Conclusions

- While the outdoor urban climate is a key driver, ultimately we must understand the indoor environment and the roles of the building and occupants in mediating interactions
- Indoor air temperatures can rise 10 to 14 ^{o}C above ambient conditions when AC fails
- Existing building management practices ranging from air filter replacements to inter-occupant maintenance and routine cleaning may play a significant role in contributing to poor indoor air quality

Thanks…

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