# The EnergyPlus UFAD Module


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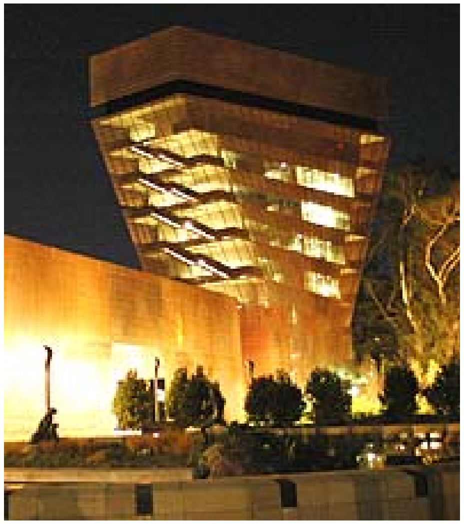
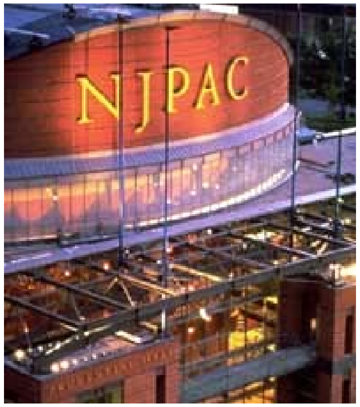
# The New de Young Museum



A three-level, 293,000 sq ft main building topped by a 144-foot spiralling tower with observation deck.

Arup proposed and designed a constant volume Underfloor Air Distribution (UFAD) system.

# New Jersey Performing Art Center




Start Date: 01 April 1991

Completion Date: 18 October 1997

The first underfloor air supply system for a North American theater.

# The New York Times Tower

Architect: Renzo Piano

52 stories high transparent glass tower

Floors (2-27) occupied by the New York Times utilize UFAD.

# One Bryant Park


54 stories high

Design for LEED Platinum rating

# OUTLINE

- Motivations
- Experimental modeling
  - Small-scale salt tank experiments
  - Full-scale room tests
- Implementation in EnergyPlus UFAD module
- Conclusions

# Environmental Impact of Buildings *

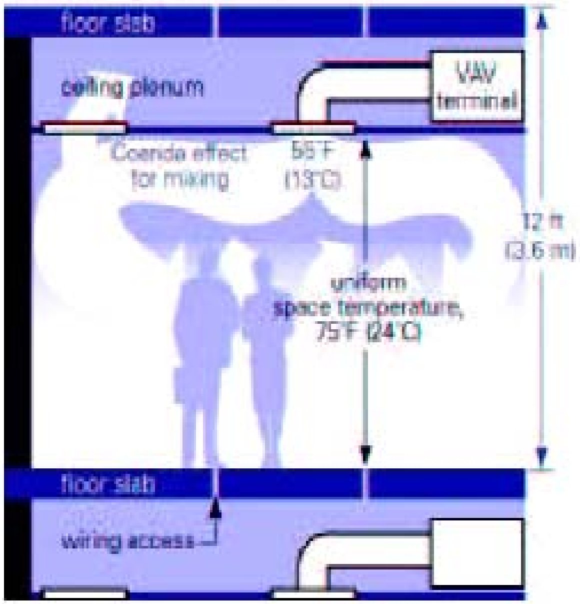
- 65.2% of total U.S. electricity consumption [1]
- > 36% of total U.S. primary energy use [2]
- 30% of total U.S. greenhouse gas emissions [3]
- 136 million tons of construction and demolition waste in the U.S. (approx. 2.8 lbs/person/day) [4]
- 12% of potable water in the U.S. [5]
- 40% (3 billion tons annually) of raw materials use globally [6]

- * Commercial and residential

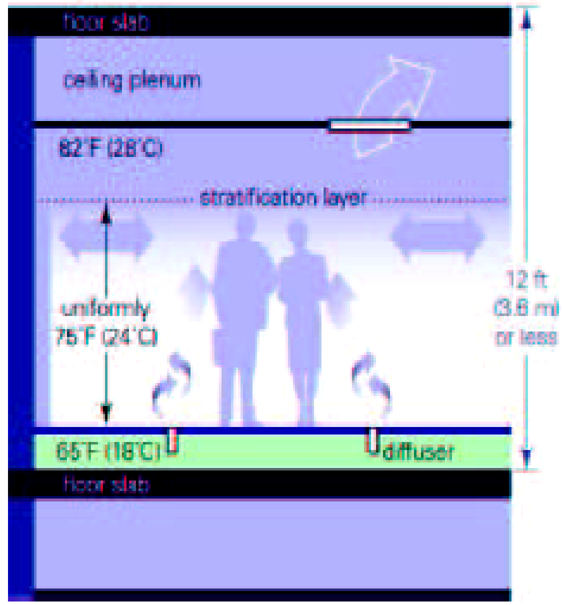
$$Q = \frac{\mathrm{H}}{\rho C_p (T_R - T_S)}$$

| | | |
|---|---|---|
| $\mathrm{H}$ | — | Internal loads |
| $\rho$ | — | Air density at constant pressure |
| $C_p$ | — | Air specific heat at constant pressure |
| $T_S$ | — | Supply air temperature |
| $T_R$ | — | Return air temperature |
| $Q$ | — | Ventilation rate |

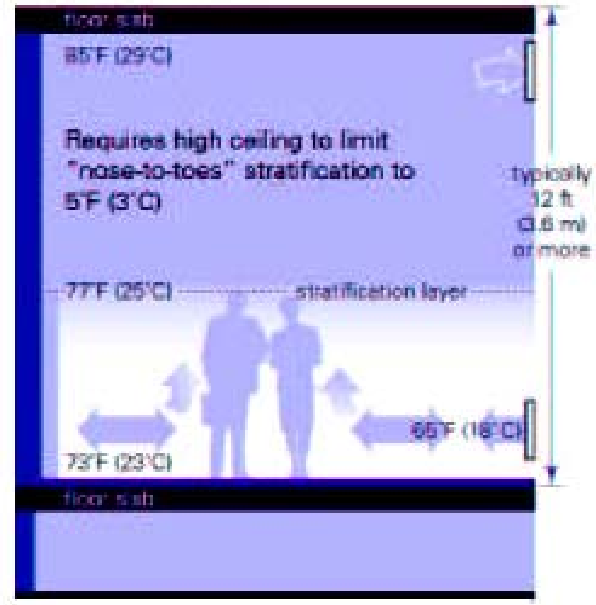
overhead




UFAD




displacement




Energy Efficiency

Indoor Air Quality

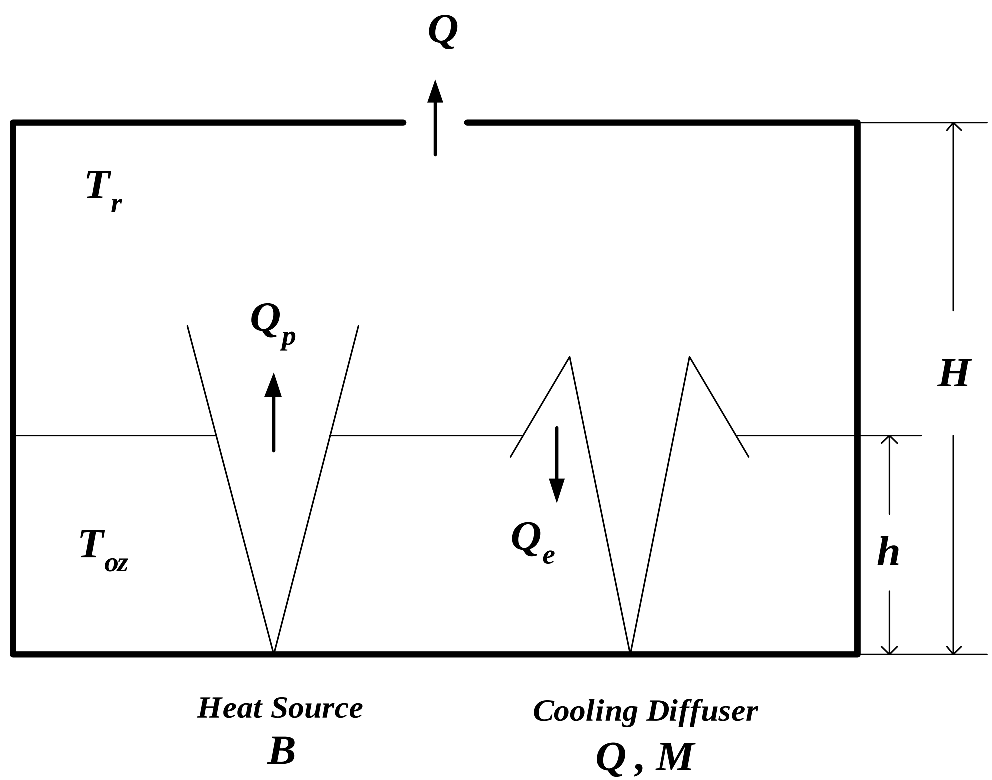
Thermal Comfort

# Motivation of This Study

- Stratification is difficult to model in building simulation programs.

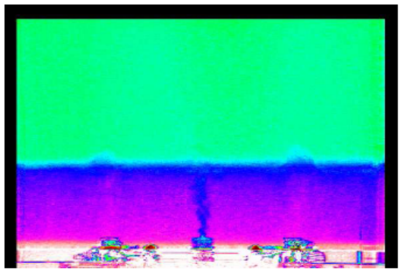
- Generate algorithms for the interface height and temperatures of the occupied zone and the upper zone for implementation in a UFAD module in EnergyPlus.

# Previous Research

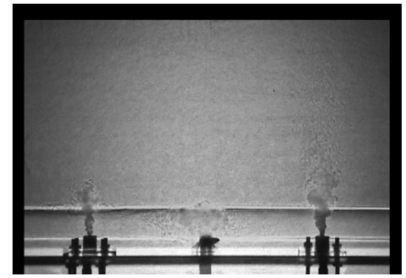



- Lin & Linden (2003)
  - two-layer stratification model;
  - the controlling parameters on the stratification – B, M;

# Our Extended Models

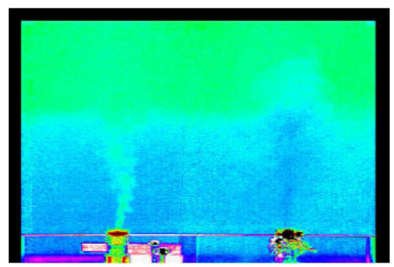


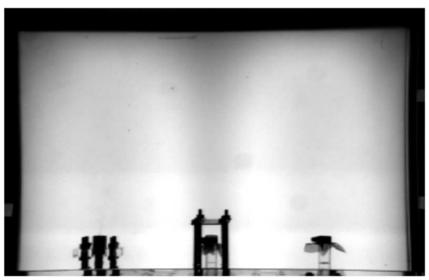
Multi-diffuser



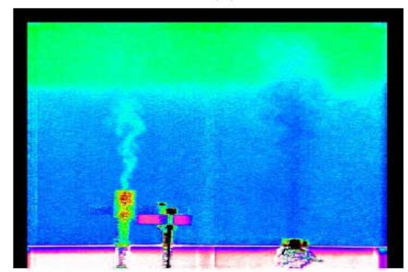
Multi-source

Basic model

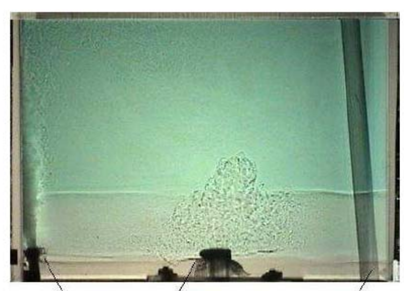




Floor leakage



Elevated source



Perimeter zone

# Laboratory Models

| Small-scale | Full-scale |
| --- | --- |
| water (salt, fresh) | air (warm, cold) |
| plume | heat source |
| fountain | cooling diffuser |
| buoyancy flux: B ($m^4s^{-3}$) | heat load: W (kw) |

B = 0.0281 W

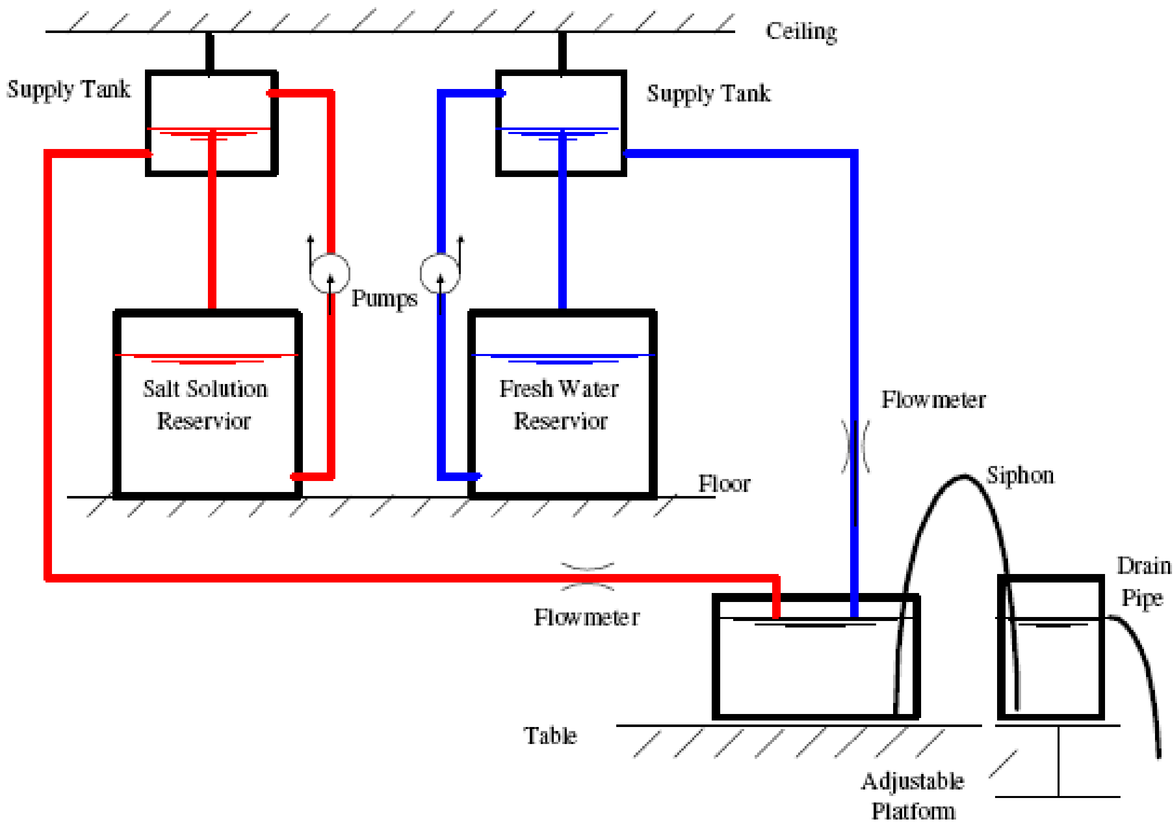
$$g' = g\frac{\rho - \rho_r}{\rho_r}$$

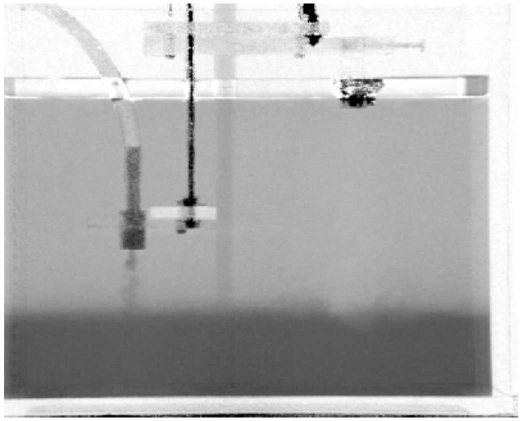
$\rho_r$ is the reference density

$$g' = g\frac{T - T_r}{T_r}$$

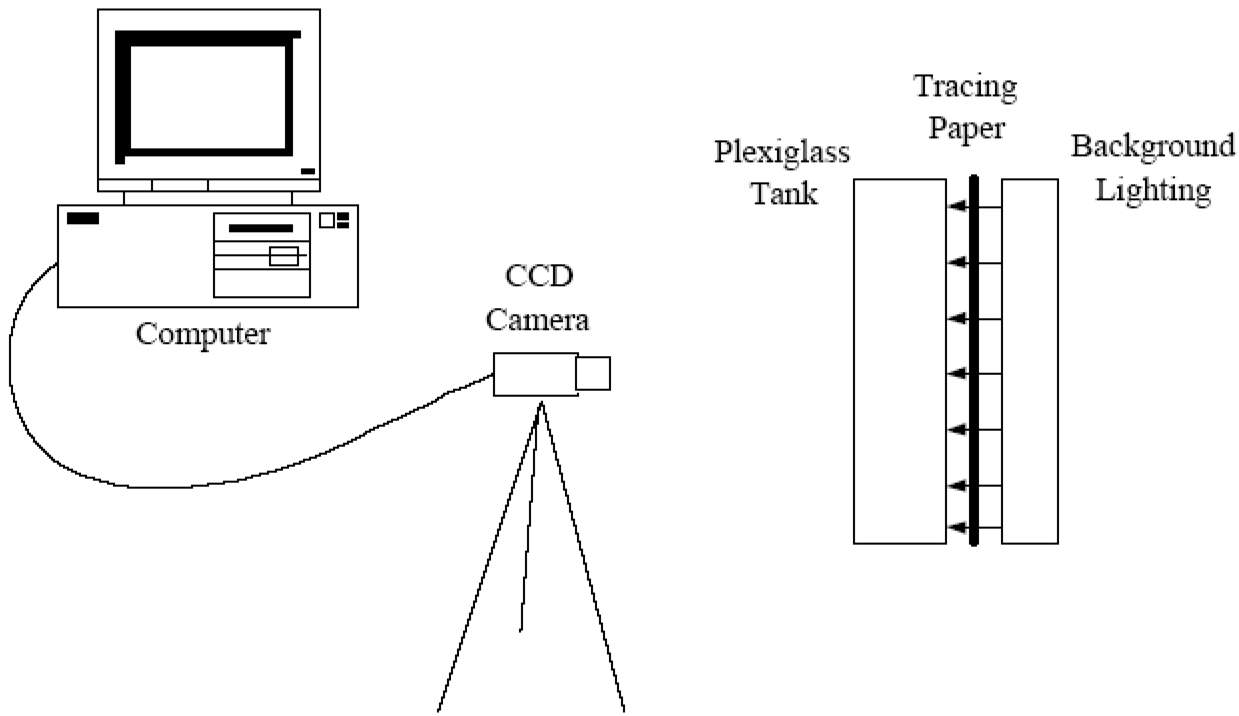
$T_r$ is the reference temperature

# Experimental Set-ups



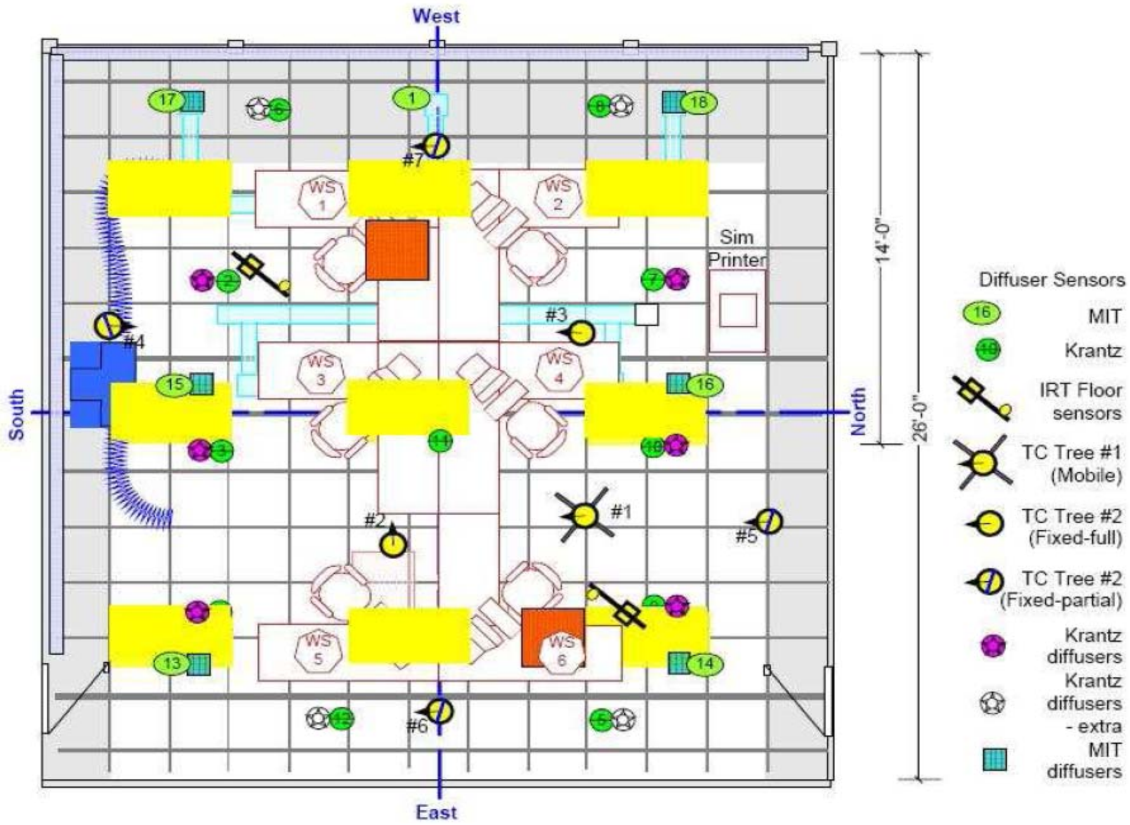



# Measurement Techniques



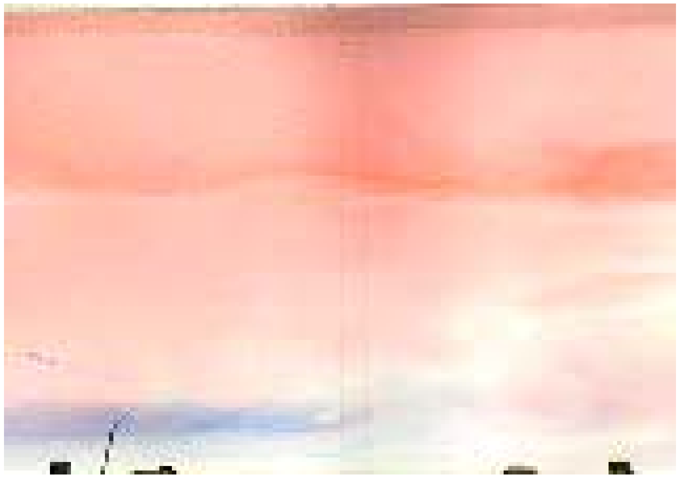

- The dye acts as a tracer for density because of a similar diffusion coefficient as the salt.
- The intensity attenuation of a tracer dye was analyzed by DigImage.

# Full-scale Testing Room




# Qualitative Comparisons --

## Stratification observation

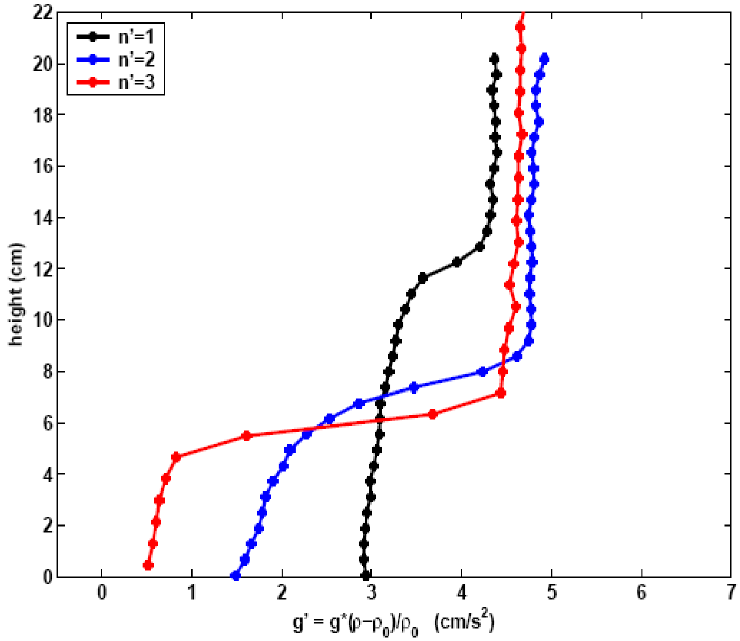


Small-scale

Full-scale

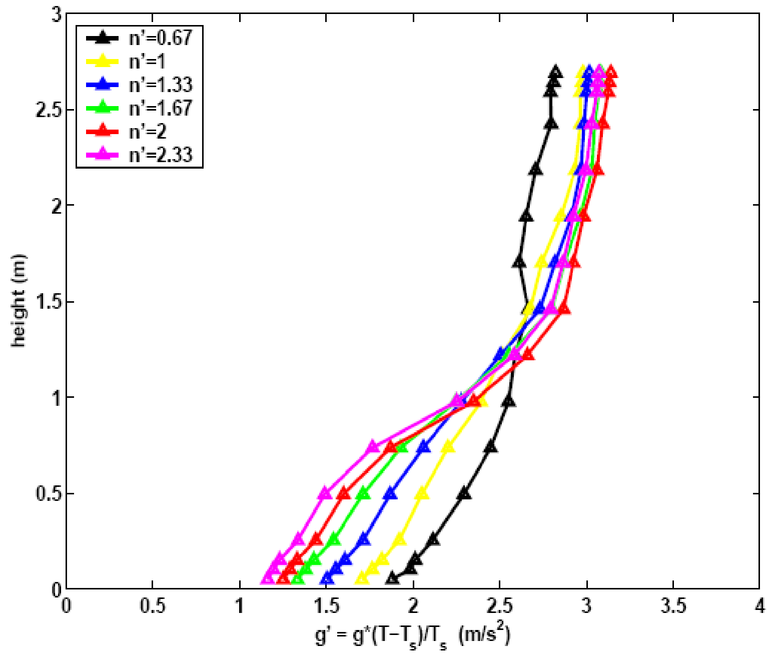
# Qualitative Comparisons --

## Effects of multiple diffusers




(a)

Small-scale




(b)

Full-scale

# Quantitative Comparisons –

## Non-dimensional Scaling Comparisons

- Competition between stratification and mixing

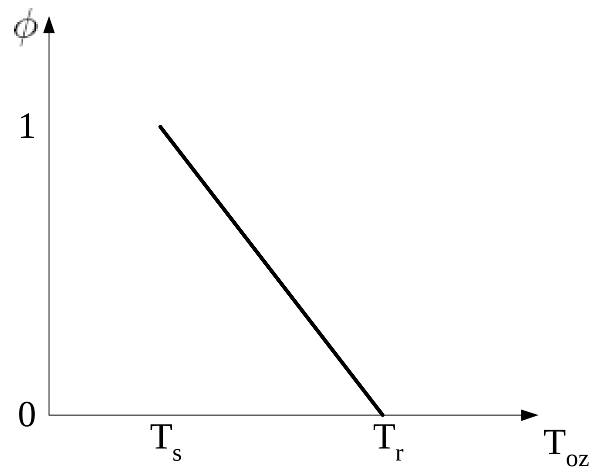
Small-scale: $$\Gamma = \frac{(n' M_d)^{3/4}}{B'^{1/2}\sqrt{n' A_d}} = \frac{Q'^{3/2}}{(n' A_d)^{5/4} B'^{1/2}} = \frac{Q^{3/2}}{m(n' A_d)^{5/4} B^{1/2}}.$$

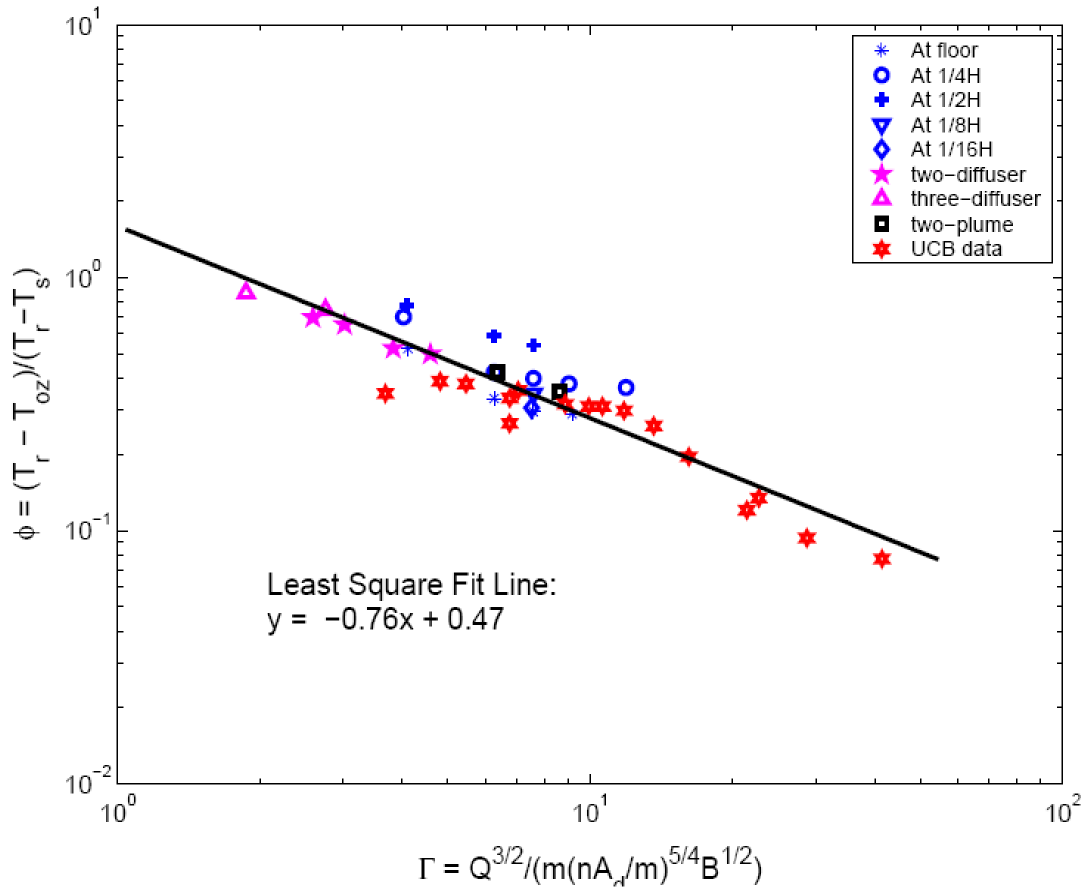
Full-scale: $$\Gamma = \frac{(Q \cos\theta)^{3/2}}{m(n' A_d)^{5/4}(0.0281W)^{1/2}}$$

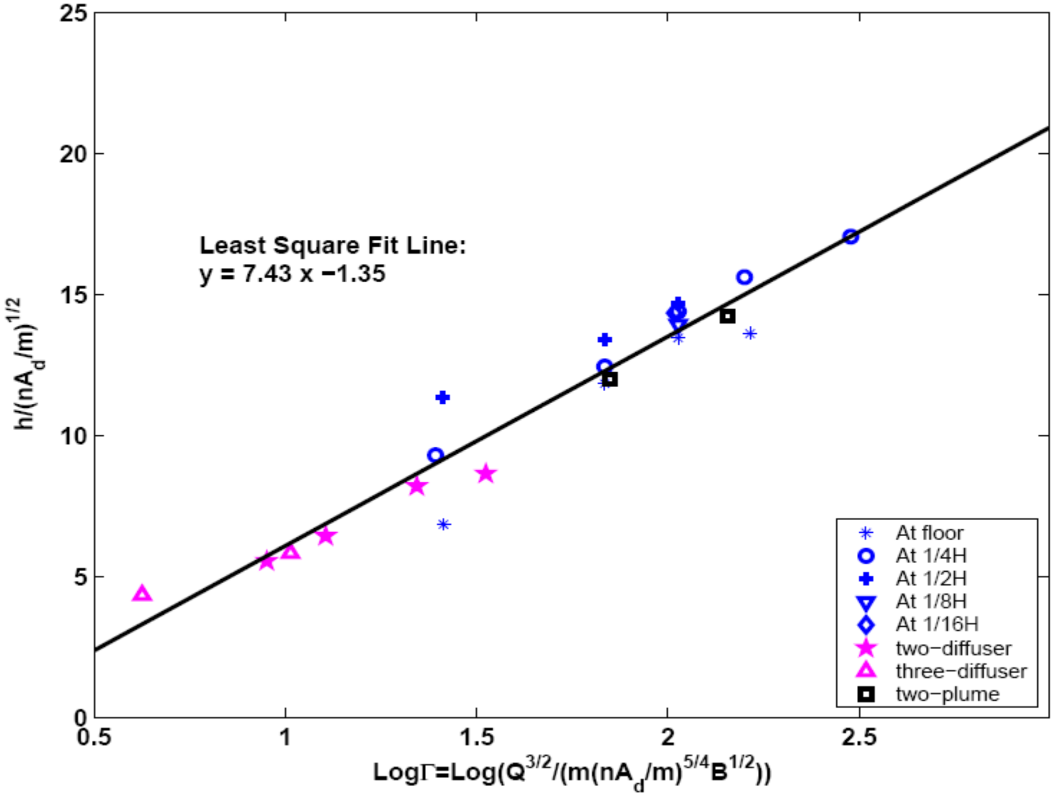
- Strength of stratification

Small-scale: $$\phi = \frac{\rho_u - \rho_l}{\rho_u - \rho_o},$$

Full-scale: $$\phi = \frac{T_r - T_{oz}}{T_r - T_s}$$




$10^{1}$
$10^{0}$
$10^{-1}$
$10^{-2}$
$10^{0}$
$10^{1}$
$10^{2}$
$\phi = (T_r - T_{oz})/(T_r - T_s)$
$\Gamma = Q^{3/2}/(m(nA_d/m)^{5/4}B^{1/2})$
At floor
At 1/4H
At 1/2H
At 1/8H
At 1/16H
two−diffuser
three−diffuser
two−plume
UCB data
Least Square Fit Line:
y = −0.76x + 0.47



Least Square Fit Line:
y = 7.43 x −1.35
25
20
15
10
5
0
0.5
1
1.5
2
2.5
h/(nA_d/m)^1/2
LogΓ=Log(Q^3/2/(m(nA_d/m)^5/4 B^1/2))
At floor
At 1/4H
At 1/2H
At 1/8H
At 1/16H
two−diffuser
three−diffuser
two−plume

## Implementation for EnergyPlus

the return air temperature $T_r$(K):

$$T_r = \frac{0.0281W}{Qg} T_s + T_s;$$

the occupied zone temperature $T_{oz}$ (K):

$$T_{oz} = T_r - 1.6\Gamma^{-0.76}(T_r - T_s);$$

and the interface height $h$ (m):

$$h = \sqrt{\frac{n}{m} A_d} \, [7.43\ln(\Gamma) - 1.35] + \frac{1}{2}h_s - \frac{1}{2}Z_v,$$

**Modeling of Underfloor Air Distribution Systems**


Tom Webster, Fred Bauman, *CBE*

Fred Buhl, *LBL*

Allan Daly, *Taylor Engineering*

# Conclusions

- A two-layer stratification has captured the most important characters of UFAD systems.
- Algorithms for the temperature stratification and the occupied zone depths in terms of the external parameters, have been implemented in EnergyPlus.