Energy performance of UFAD systems

- **Goal/Significance**
  - Develop a version of the whole-building energy simulation program, EnergyPlus, capable of modeling UFAD systems
  - This will be the first validated UFAD energy simulation tool

- **Project details**
  - Project start: November 1, 2002
  - Final report and software: February 28, 2006
  - Ready for next release of EnergyPlus: April 15, 2006
  - Primary funding ($610K) from California Energy Commission (CEC) Public Interest Energy Research (PIER) program
  - Additional support from CBE, U.S. Department of Energy, and York International
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Energy performance of UFAD systems

- UFAD Version of EnergyPlus (LBNL)
- Plenum Model (CBE)
- RAS Model (UCSD)
- System Upgrades (LBNL)
- Plenum Testing (CBE)
- Full-scale Testing (CBE/York)
- Salt Tank Testing (UCSD)

Thermal performance of underfloor plenums

- CFD model
- Full-scale experiments
- Validate model vs. test facility
- Study thermal performance for range of design and operating conditions using CFD model
- Develop simplified plenum model for implementation in EnergyPlus
Thermal performance of underfloor plenums

Recent publications

- “Testing and Modeling Underfloor Air Supply Plenums”  
  Paper on CFD plenum model validation submitted to  
  ASHRAE Transactions in October 2005 (see handouts)
- “Heat Transfer Pathways in UFAD Systems”  
  Paper on simplified heat transfer analysis submitted to  
  ASHRAE Transactions in June 2005

Key findings – Underfloor plenums

- Airflow delivery and pressure distribution are very uniform  
  within same plenum zone.
- Air leakage from pressurized plenum can be significant and  
  must be controlled and accounted for.
- Heat gain into supply plenum (thermal decay) can be quite  
  high (30-40% of room load) in multi-story buildings.
- Plenum inlet conditions can have an important impact on the  
  velocity and temperature distribution in plenum.
- Overall energy balance of plenum varies by no more than 10%  
  for most practical plenum configurations
Energy performance of UFAD systems

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Room air stratification (RAS)

Approach

- Full-scale laboratory tests of commercially available floor diffusers in realistic office setting
- Study impact of various design and operating parameters on room air stratification (RAS)

Parameters investigated

- Type and number of diffusers
- Diffuser throw
- Supply volume
- Supply temperature
- Room load
- Plenum leakage
- Perimeter/interior zones
- Window blinds

York test lab
Sample room air stratification test results

<table>
<thead>
<tr>
<th>Height [ft]</th>
<th>Temperature [°F]</th>
<th>Temperature [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>70</td>
<td>20.0</td>
</tr>
<tr>
<td>2</td>
<td>70</td>
<td>21.1</td>
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<tr>
<td>3</td>
<td>70</td>
<td>22.2</td>
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<td>4</td>
<td>70</td>
<td>23.3</td>
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<td>5</td>
<td>70</td>
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<td>7</td>
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</tr>
<tr>
<td>14</td>
<td>72</td>
<td>26.7</td>
</tr>
</tbody>
</table>

6 workstations

6 SW, 0.6 cfm/sf, 81% DDR
8 SW, 0.6 cfm/sf, 64% DDR
10 SW, 0.6 cfm/sf, 48% DDR
12 SW, 0.6 cfm/sf, 39% DDR
14 SW, 0.6 cfm/sf, 36% DDR

Height [m]

Testing and modeling RAS in UFAD systems

Conducted by UC San Diego
Key findings – RAS testing

- Besides reducing airflow, lowering diffuser throw for a given load and setpoint increases stratification
- Diffuser throw characteristics depend on diffuser type and operating conditions
- Closing blinds in perimeter zones increases stratification and lowers airflow for given load and thermostat setting
- Plenum airflow leakage into the occupied zone will tend to increase stratification (cooler temperatures near floor), but is not detrimental if properly controlled
- Application of the CBE advanced thermal comfort model to a range of measured stratification levels (up to 7°F in occupied zone) for a constant load found only small differences in comfort
Current EnergyPlus model

Overhead system

- Ceiling plenum
- Conditioned space

Well-mixed, uniform temperature in conditioned space

New EnergyPlus UFAD model

Underfloor plenum

- Upper, stratified zone
- Lower, occupied zone

Room air stratification modeled as two zones separated at stratification height, h

SAT

Stratification height
Inputs and outputs for UFAD interior model

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supply conditions</strong></td>
<td><strong>Return temp.</strong> TR</td>
</tr>
<tr>
<td>▪ Supply temp. Ts</td>
<td><strong>Occupied zone temp.</strong> TL</td>
</tr>
<tr>
<td>▪ Total airflow rate Q</td>
<td><strong>Strat. height</strong> h</td>
</tr>
<tr>
<td><strong>Diffusers</strong></td>
<td></td>
</tr>
<tr>
<td>▪ Type (swirl, VA)</td>
<td></td>
</tr>
<tr>
<td>▪ Number n</td>
<td></td>
</tr>
<tr>
<td>▪ Area of each diffuser A</td>
<td></td>
</tr>
<tr>
<td><strong>Heat load and plumes</strong></td>
<td></td>
</tr>
<tr>
<td>▪ Total heat load W</td>
<td></td>
</tr>
<tr>
<td>▪ Number of plumes m</td>
<td></td>
</tr>
<tr>
<td>▪ Heat source height hs</td>
<td></td>
</tr>
</tbody>
</table>

Validation of EnergyPlus

- Comparison with full-scale RAS test data
- Interior zones – Allan Daly
- Perimeter zones – Ian Doebber
- Consideration of radiation is key to make sense out of heat flows in UFAD (stratified) systems
Energy balance – Testing and EPlus modeling

Full-scale laboratory measurements demonstrate good room energy balance. EPlus simulations match well.

% of Total Cooling Load Leaving Room

Chamber calibration test  EPlus simulation

Net room cooling load = 102%
Net room cooling load = 99%

Room extraction rate
Heat transfer into plenum
Conduction through walls

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E+ system upgrades: Variable speed fan coil

- Return Air Plenum
- Glazing
- Return Air Grille
- Heating Coil
- Linear Bar Diffuser
- Variable-speed fan coil
- Flex Duct
- No U/A diffusers in perimeter zones
- Raised Access Floor

E+ system upgrades: Return air bypass

- Exhaust outlet
- Return air fan
- Return air plenum
- Bypass air
- Mixed air plenum
- Cooling coil
- Outside air intake
- Supply air
- Mixed air plenum
- Mixed air outlet
Next steps

- Interior and perimeter zone RAS models into EPlus
- Validate RAS models in EPlus with full-scale data
- Complete validation of plenum model
- Draft final report due January 2006
- Final report and software due February 28, 2006
- Ready for next release of EnergyPlus (April 15, 2006)

Future directions with EnergyPlus/UFAD

- UFAD energy analysis study
- Comparison with field data
- Investigate demand response performance
- EnergyPlus in Title 24
- EnergyPlus/UFAD training seminars