Using CFD to Wring Out Energy Efficiency in Laboratory Settings
Energy Conservation Strategies for Cornell University Laboratories

- Primary focus is on controls to reduce outside air use
- Occupancy sensors to index occupied/unoccupied air flow rates
  - Air flows currently are 8/4 ACH occupied/unoccupied typical
- Use proven numerical methods to demonstrate that reduced air flow in labs can be safely achieved
- Perform smoke testing to validate numerical methods on early projects
CFD Chosen as the Numerical Method for conservation projects

- Scientific way to safely push toward lower airflows
- Virtual technique to demonstrate “ventilation effectiveness” and ensure laboratory safety without human exposure.
- CFD allows tests of existing and new design strategies to quantitatively demonstrate ventilation effectiveness.
Three Pilot Conservation Projects Chosen

- Wing Hall
- Morrison Hall
- Biotechnology Building

Decided to evaluate three energy intensive labs at Cornell using CFD @ 8/4 ACH and 6/3 ACH
  - Wing Hall
  - Morrison Hall
  - Biotechnology Building
Project Considerations

- As a result of multiple conservation projects and creation of a climate neutrality “Climate Action Plan”, a push was implemented to evaluate 6/3 ACH vs 8/4 ACH occupied/unoccupied
- EH&S engaged as a partner to OK 6/3 evaluation
- Decision to check current ECI projects (Wing/Morrison) and one older project (Biotechnology) – signed off by all.
- M/E Engineering contracted for CFD models, identify issues and provide design solutions.
- Results of CFD modeling:
  - *Wing/Morrison* – no issues at 6/3 ACH
  - *Biotechnology* – needs help!
Project Results

- CFD modeling revealed that:
  - Wing Hall has no issues at 6/3 ACH – Control solution implemented.
  - Morrison Hall has no issues at 6/3 ACH – Control solution implemented.
  - Biotechnology Building ventilation performance was very poor at all flow rates – A mechanical design change was implemented as a solution.
Biotechnology Evaluation & Design Scope

- Create a full 3D model in Star-CCM+ software
- Evaluate existing ventilation effectiveness - compare 8/4 ACH and 6/3 ACH occupied/unoccupied airflows
- Findings: even 8-10 ACH was not adequate!
- Redesigned supply and general exhaust based on CFD
- Reran cases and found 6/3 ACH is possible with much better ventilation effectiveness
Biotechnology existing ductwork design

Adjacent Computer Room

Open Passage Between Labs

Lab #1

Lab #2

Existing 8” round perforated supply

Existing general exhaust grille

Five foot VAV fume hood
6 ACH Smoke Test – Existing Design

Smoke hangs low in lab as predicted with the CFD modeling.

Smoke permeates adjacent computer room – floor to ceiling as predicted with CFD modeling.
6 ACH Smoke Test – Existing Design

6 ACH or 1 Air Change Every 10 minutes
8 ACH CFD Model – Existing Design
8 ACH CFD Model – Existing Design
Biotechnology new ductwork design
6 ACH Smoke Test - Redesign

Smoke does not permeate into other lab room and adjacent computer room as predicted with the CFD modeling
6 ACH Smoke Test - Redesign

$t = 0 \text{ min}$

$t = 1 \text{ min}$

$t = 4 \text{ min}$

$t = 7 \text{ min}$

$t = 9 \text{ min}$

$t = 10 \text{ min}$

$t = 11 \text{ min}$

$t = 12 \text{ min}$

No visible Smoke
6 ACH CFD Model - Redesign
6 ACH CFD Model - Redesign
Vertex Average Parts Per Million of Acetone at 0.5ft. above Floor

- Puddle evaporation phase (30 min)
- Vapor Purge Phase (> 60 min)

Existing Design (8ACH)
Redesign (6ACH)
Biotechnology Return on Investment

- Pilot installation cost determined at ~ $2,000/lab zone
- 90 lab zones = ~ $180,000
- Calculated energy savings ~ $1200/year/lab, or less than a 2 year simple payback!
Conservation & Cost Implications For Cornell University

• Laboratory ventilation creates about half of all energy use on campus or ~ $35 million per year at billed rates

• Using CFD on all new and renovated laboratory spaces (with administrative controls) could allow flow rates of 6/3 ACH occupied/unoccupied in most labs
  – The cost of CFD analysis is miniscule compared to the potential overall savings.

• Recommissioning all laboratory spaces on campus from their current airflows down to 6/3 ACH occupied/unoccupied represents a very large potential savings
  - $ millions/year
Using CFD to Wring Out Energy Efficiency in Laboratory Animal Facilities
HVAC – LAB ANIMAL ROOM AIR FLOW

• Guide for the Care and Use of Laboratory Animals, 1996
  – Suggested “guideline of 10-15 fresh air changes per hour”
  – “…other factors-such as odor control, allergen control, particle generation, and control of metabolically generated gases-might necessitate ventilation beyond the calculated minimum.”

• Industry Practice
  – Standard Room: 20 fresh air changes per hour
  – Room with Ventilated Caging: 10 ACH ?!

• Not a solution if the room (and facility) have odor and contamination issues.
VENTILATION WINDOW
OPTIMAL
HVAC – CASE STUDY OBJECTIVES

• New Room and Existing Room Design Goals:
  – Minimize odor levels (approach non-detectable)
  – Suitable for all species and rack configurations
  – Reduce energy consumption
3 high radial supplies, 6 soffit mounted exhausts, 15ACH
3 high radial supplies, 6 soffit mounted exhausts, 15ACH
Isosurfaces of 7 ppm NH$_3$ – Virtually odor free
STUDY 1
NEW CONSTRUCTION BENCHMARK

3 high radial supplies, 6 soffit mounted exhausts, 15ACH NH₃ Concentrations, 5 ft Above Floor
3 high radial supplies, 6 soffit mounted exhausts, 15ACH

Through Supply

Through Room Center
STUDY 1
NEW CONSTRUCTION BENCHMARK
2 high supplies, 1 low corner exhaust, 20 ACH
2 high supplies, 1 low corner exhaust, 20 ACH
Isosurfaces of 15 ppm NH$_3$
2 high supplies, 1 low corner exhaust, 20 ACH
NH₃ Concentrations, 5 ft Above Floor
2 high supplies, 1 low corner exhaust, 20 ACH

Through Supply

Through Room Center
2 high supplies, 1 low corner exhaust, 15 ACH
2 high supplies, 1 low corner exhaust, 15 ACH
Isosurfaces of 15 ppm NH₃
2 high supplies, 1 low corner exhaust, 15 ACH
NH₃ Concentrations, 5 ft Above Floor
STUDY 2
RENOVATED EXISTING ROOM

2 high supplies, 1 low corner exhaust, 15 ACH

Through Supply

Through Room Center
HOLDING ROOM
RENOVATED
SUMMARY OF CASE STUDY 2 - Renovation

• The redesigned room performed well at both 15 and 20 ACH for multiple species

• Reduced air flow of 15 ACH resulted in:
  – NH3 concentrations at or below 7 ppm in most of the breathing zone
  – Temperature uniformity within 2F in the occupied zone
  – Consistent air flow through cages

• Ventilation performance is much better than the pre-renovation ventilation design, and reasonably close to the benchmark case (Study 1)

• 25% reduction in airflow (20 ACH → 15 ACH)

• In reality, even greater savings: 22 to 25 ACH → 15 ACH
MODIFIED ASHRAE CALCULATION OF VENTILATION EFFECTIVENESS

• Transient CFD techniques are used to assess ventilation effectiveness in virtual space
  
  1. Use CFD (steady state) to solve the flow dynamics of room
  2. The room is then “charged up” with a neutrally buoyant tracer gas to a known concentration (say 100 ppm)
  3. Run the analysis in a transient state where all supplies are treated as fresh air and all returns are exhausts
  4. The decay in volume average concentration is monitored over time and is recorded
  5. An exponential or polynomial curve is fitted to the results and its equation is integrated over the time for one air change (and more recently a 90% drop in concentration)
  6. A 2nd linear curve is plotted for a perfect case with all room air expelled in 1 air change, then its equation is also integrated
  7. The ratio between the actual integrated concentration & the perfect integrated concentration is the ventilation effectiveness
EXISTING ROOM VENTILATION

Pre-Renovation Ventilation

Tracer Gas Decay vs Time

Old Design

59.05% Effective
(based on 1 Air Change)

New Design

78.72% Effective
(Based on 1 Air Change)

Post-Renovation Ventilation

Tracer Gas Decay vs Time

Old Design

21.64% Effective
(based on 90% reduction)

New Design

61.79% Effective
(Based on 90% reduction)
Other Criteria to Consider

- Planar averages at various levels may provide additional insight about the room’s behavior.
  - Breathing zone (Human Safety)
  - Floor level (explosion hazard)
- Perform decay method and spill method simultaneously
- Tie ventilation effectiveness with energy consumption – units of % effectiveness per ACH
IMPROVEMENT IN EFFECTIVENESS & ENERGY

Energy & Ventilation Effectiveness

Old System: 59.1% (D₁) at 25 ACH
Old System: 55.0% (D₁) at 20 ACH
New System: 78.7% (D₂) at 15 ACH

\[
\frac{D_2}{D_1} = \frac{78.7\%}{59.1\%} \approx 2.22 = 2.22 \text{ x More Bang for the Buck}
\]

MODIFIED ASHRAE CALCULATIONS
STUDY 2 - VENTILATION EFFECTIVENESS
LAST SLIDE