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U.S. DEPARTMENT OF ENERGY

Energy Impacts of Air-Handling System Leakage in Large Commercial Buildings: Measurements and Simulation

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Learning Objectives and Disclaimer

Session Objectives:

1. Understand need to determine leakage flows for entire air-handling system, and to understand impacts of leakage flows on zone heating and cooling loads and on whole-building energy use in commercial buildings.
2. Estimate energy impacts of system leakage downstream of VAV boxes, and in toilet/kitchen exhaust systems.
3. Become familiar with the necessary specifications for system leakage using industry accepted terminology.
4. Understand how various codes and standards address system air leakage.
5. Understand test protocols for cost-effectively measuring system leakage.
6. Recognize it is responsibility of design engineer to specify maximum allowable system leakage percentage.

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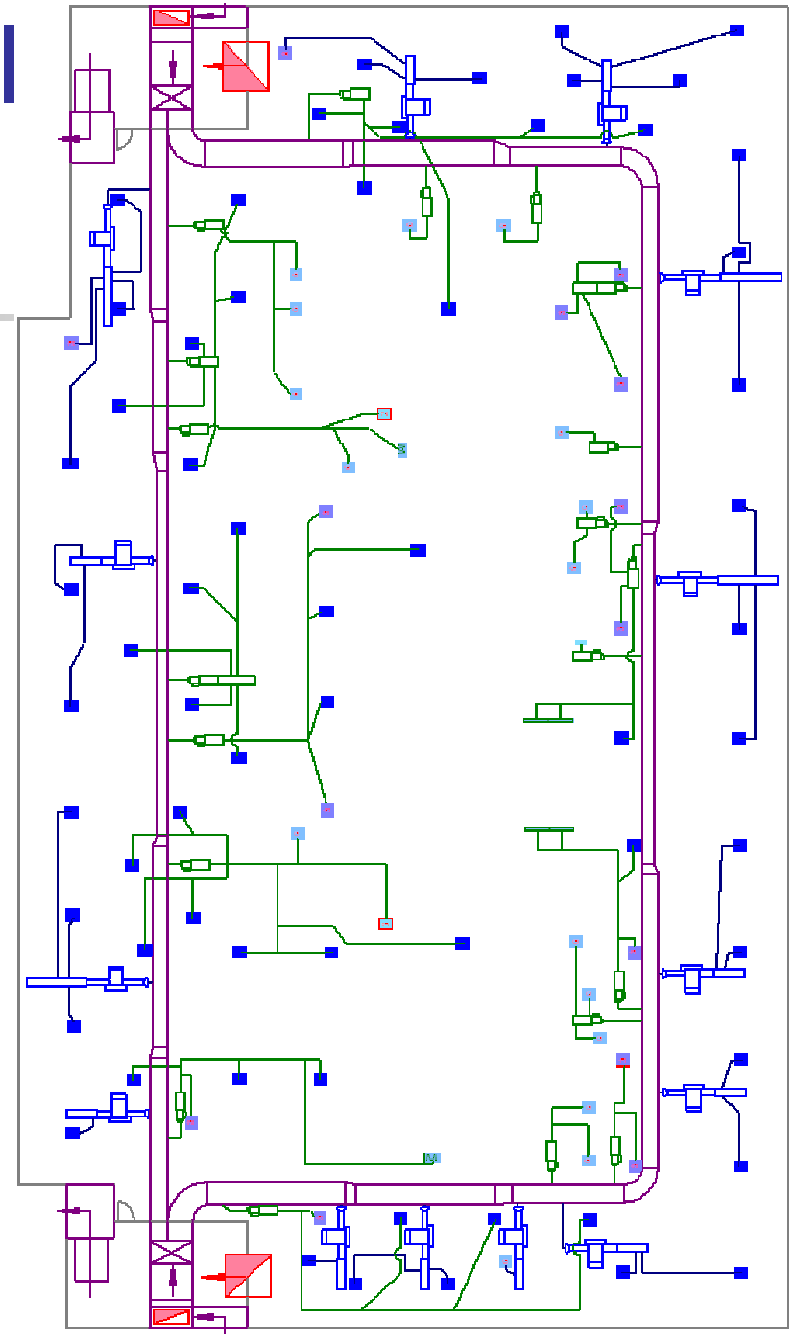
Presentation Outline

- U.S. system characteristics
- Common leakage metrics
- Leakage test methods
- Measurement and simulation results
- Next steps

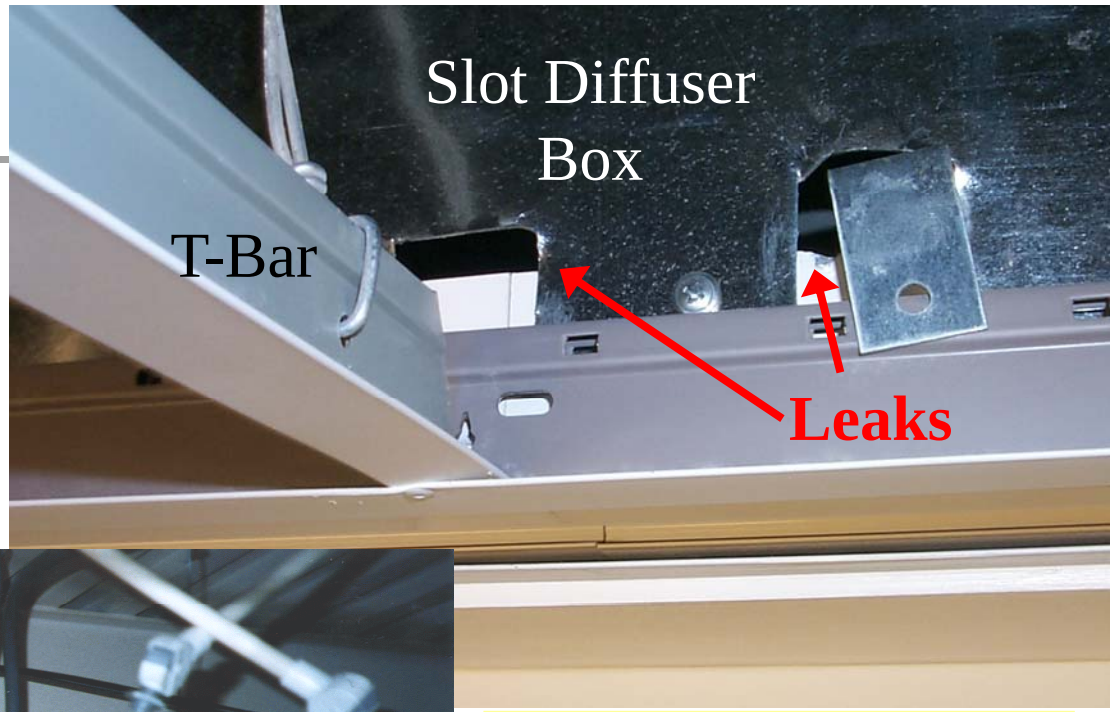
Large Commercial Systems

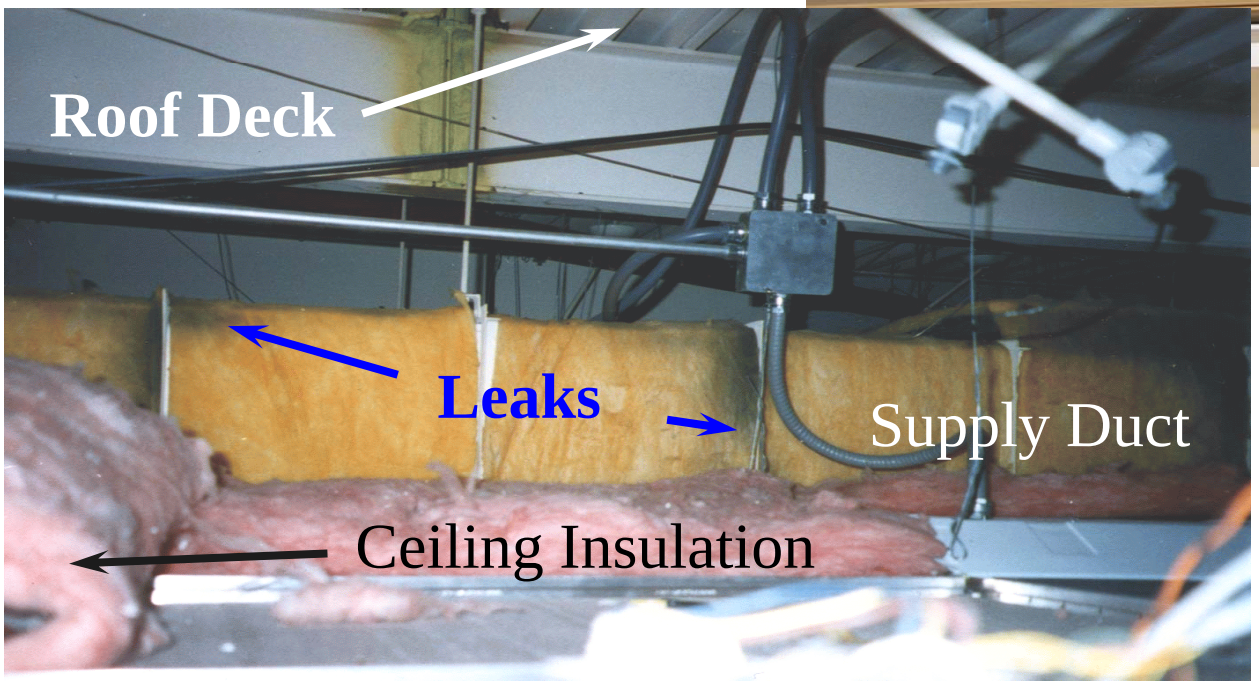
- Long, complex paths
- Large fan pressure rises and flows
- Fan-power dominated
- Sections often outside conditioned space
- Thermal losses create short circuit

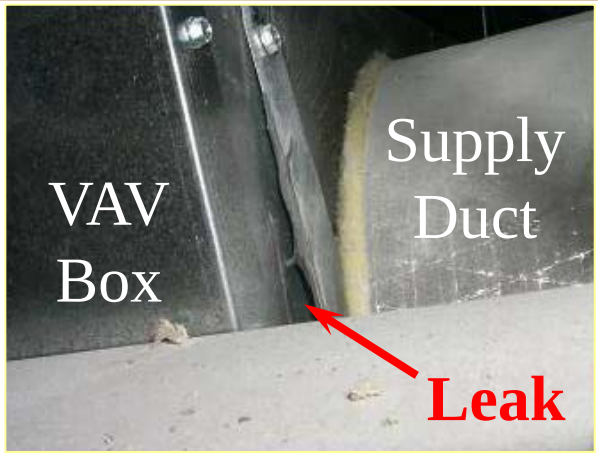


Numerous Leakage Opportunities

- Thousands of field assembled joints







System Pressures

- Pressures not uniform or constant
- High pressures upstream of box inlet (100 to 2,500 Pa)
- Low pressures downstream of box inlet (10 to 100 Pa)
- 50 to 75% of system might operate at “low” pressures
- Impossible to know location and pressure difference for each leak

Common Leakage Metrics

- Leakage Rate

$$= \frac{C\,(dP_{reference})^{n}}{A_{duct\ surface}}$$

- Reference pressure:
  - not necessarily operating pressure
  - no standard
- ASHRAE Handbook:
  - unsealed ducts 2.5 L/(s·m^2) at 250 Pa
  - tight ducts 5 to 10 times less

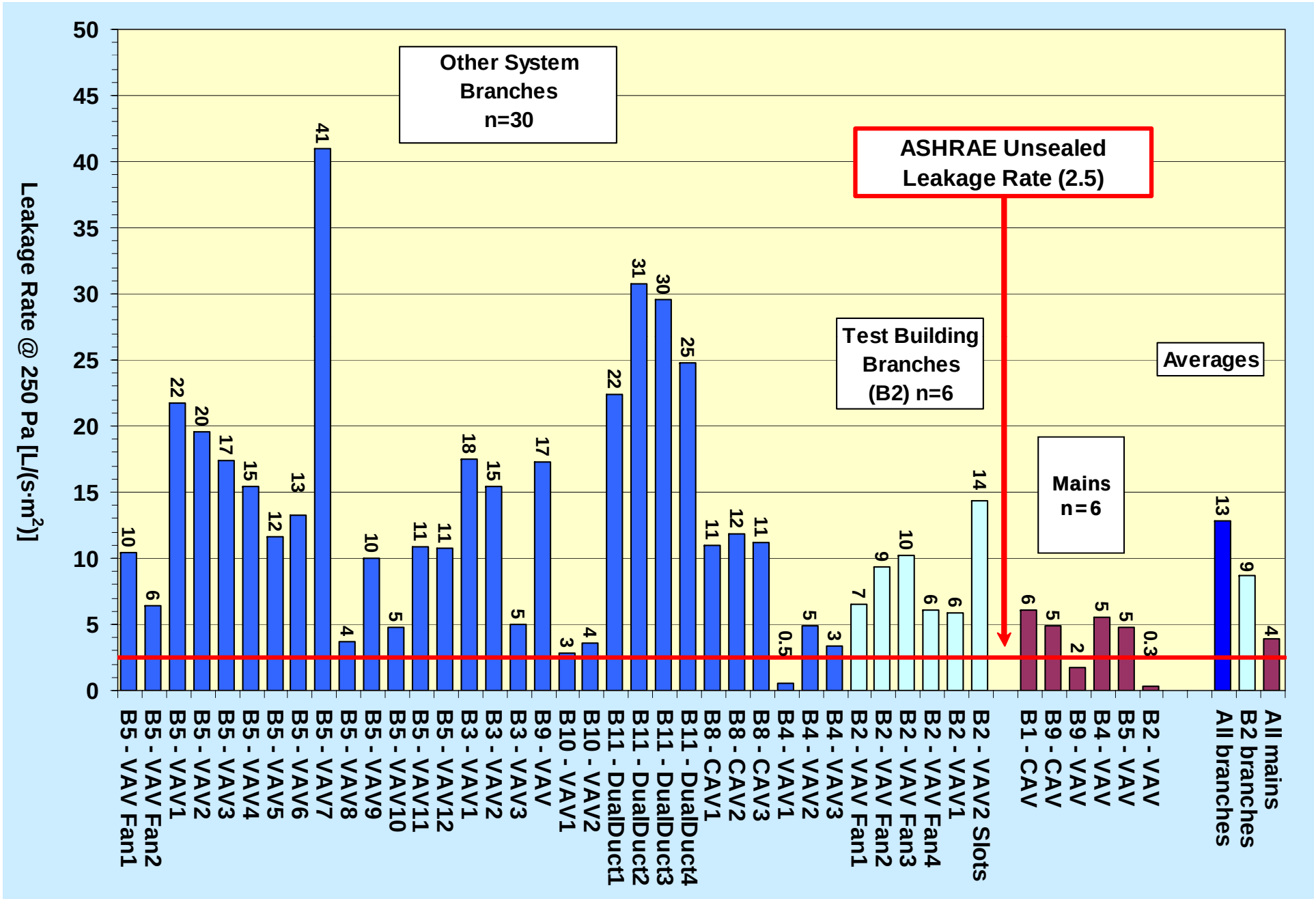
- Leakage Flow Fraction

$$= \frac{Q_{leaks}}{Q_{reference}}$$

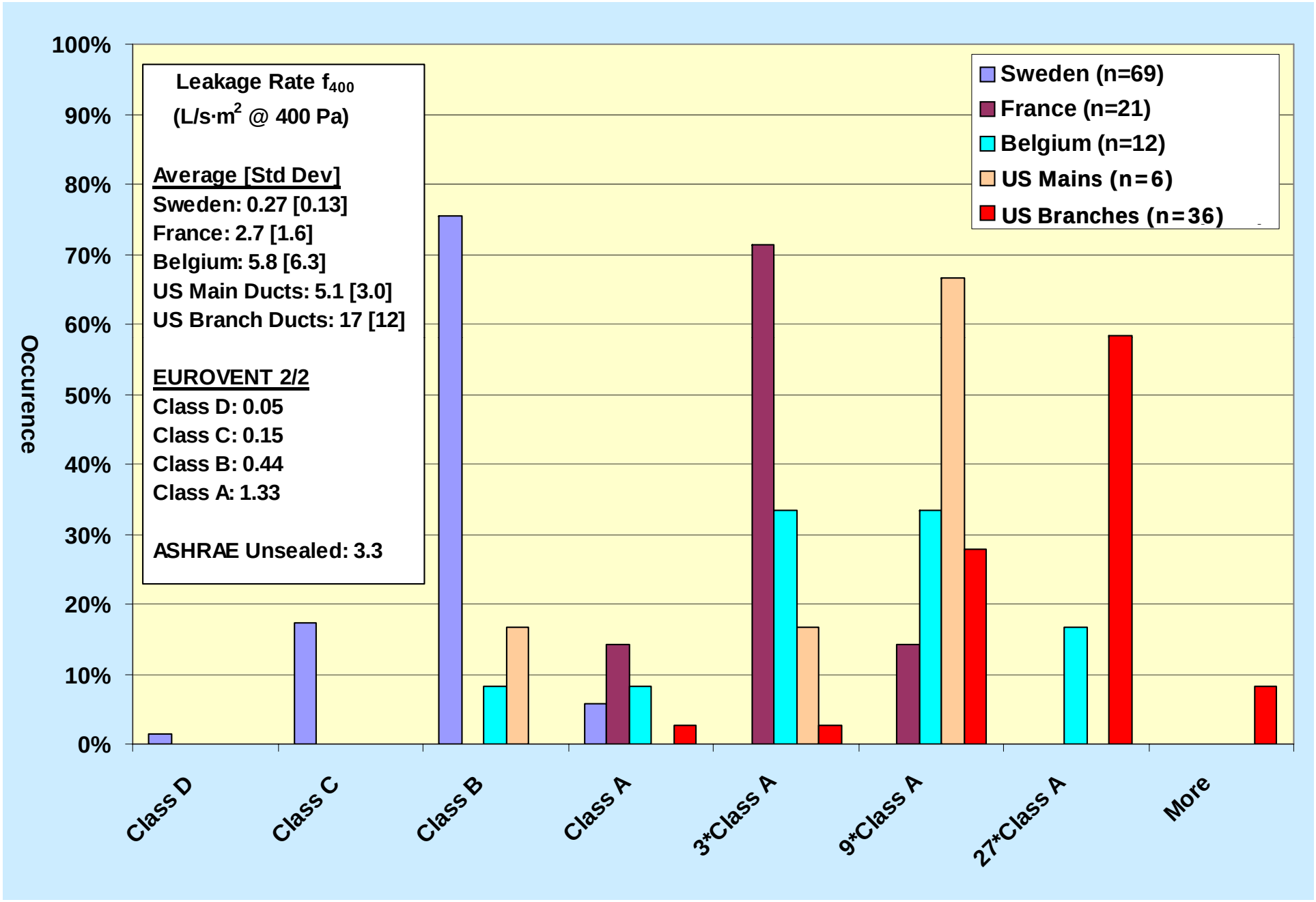
- Leakage flow:
  - estimated from leakage area and average pressure OR
  - measured directly
- Reference flow:
  - fan flow for upstream sections
  - VAV box inlet flow for downstream sections

System Pressurization Tests

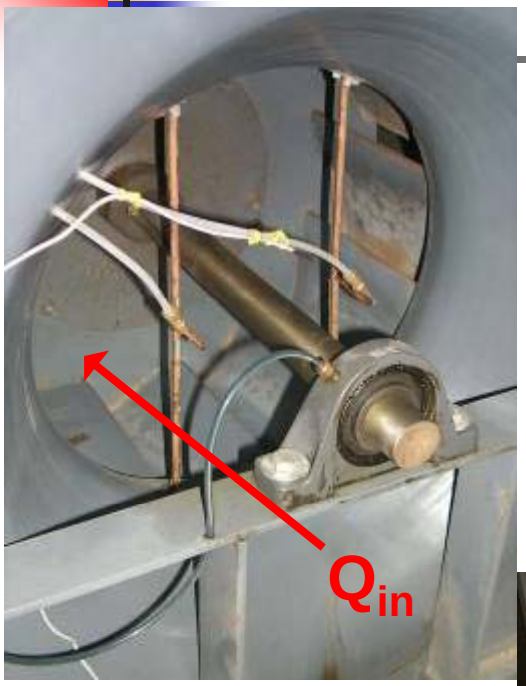
System Pressurization Results



System Pressurization Results



Measuring Leakage Airflows



$$Q_{leak} = Q_{in} - \Sigma Q_{out,i}$$

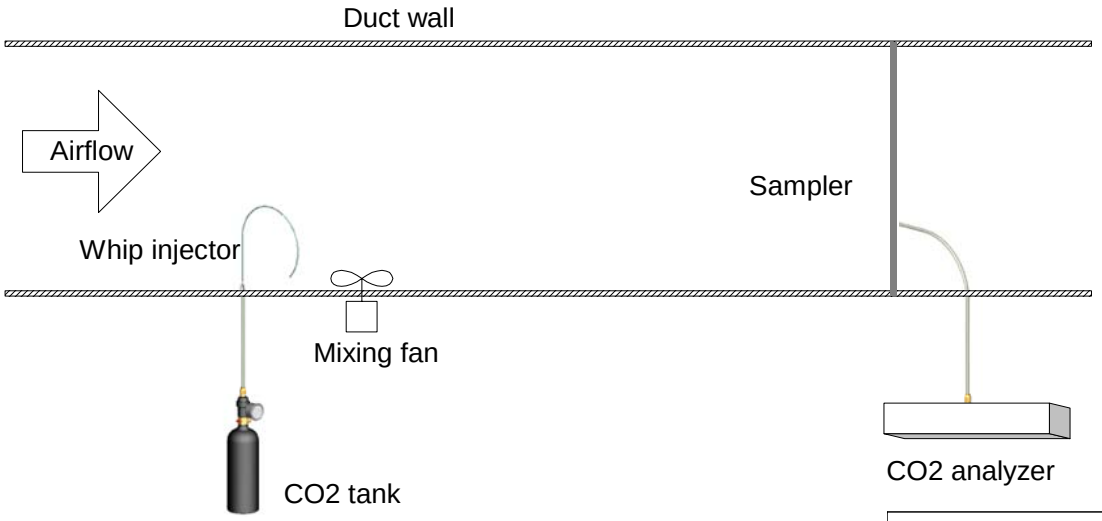
$Q_{out,i}$

Airflow Measurement Technology

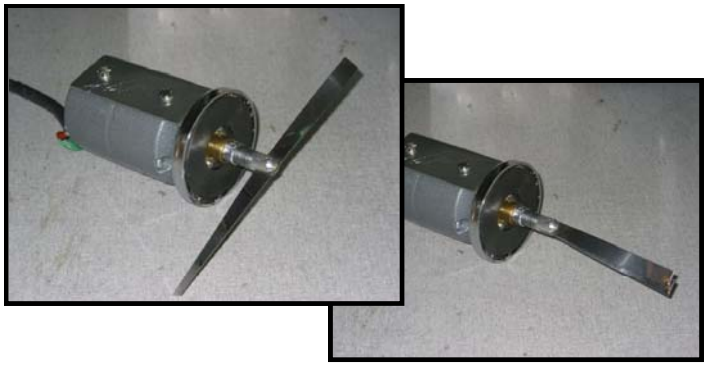
Status:

- Rapid response CO_2 tracer gas system developed (better than 2% accuracy)
- CA, MN, & FL pilot field tests well received (pitot-static tube traverses within 4%)
- Five flow hoods tested in lab & field, more than 1000 lab tests over wide range of flows and grille types, found one suitable hood (3% accuracy)

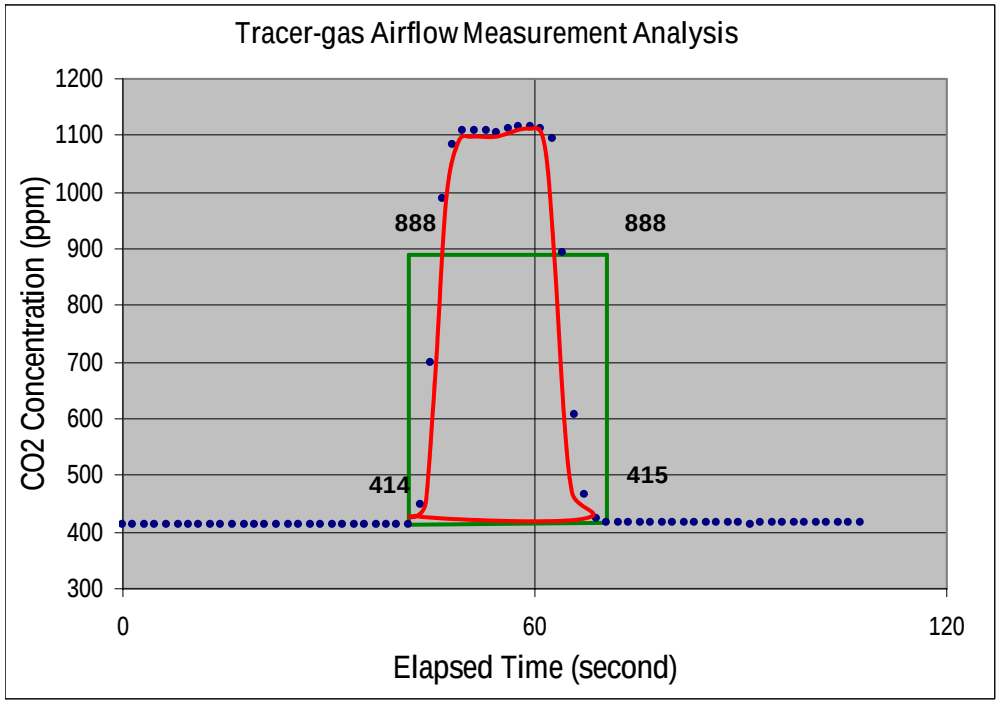
Tracer Gas System



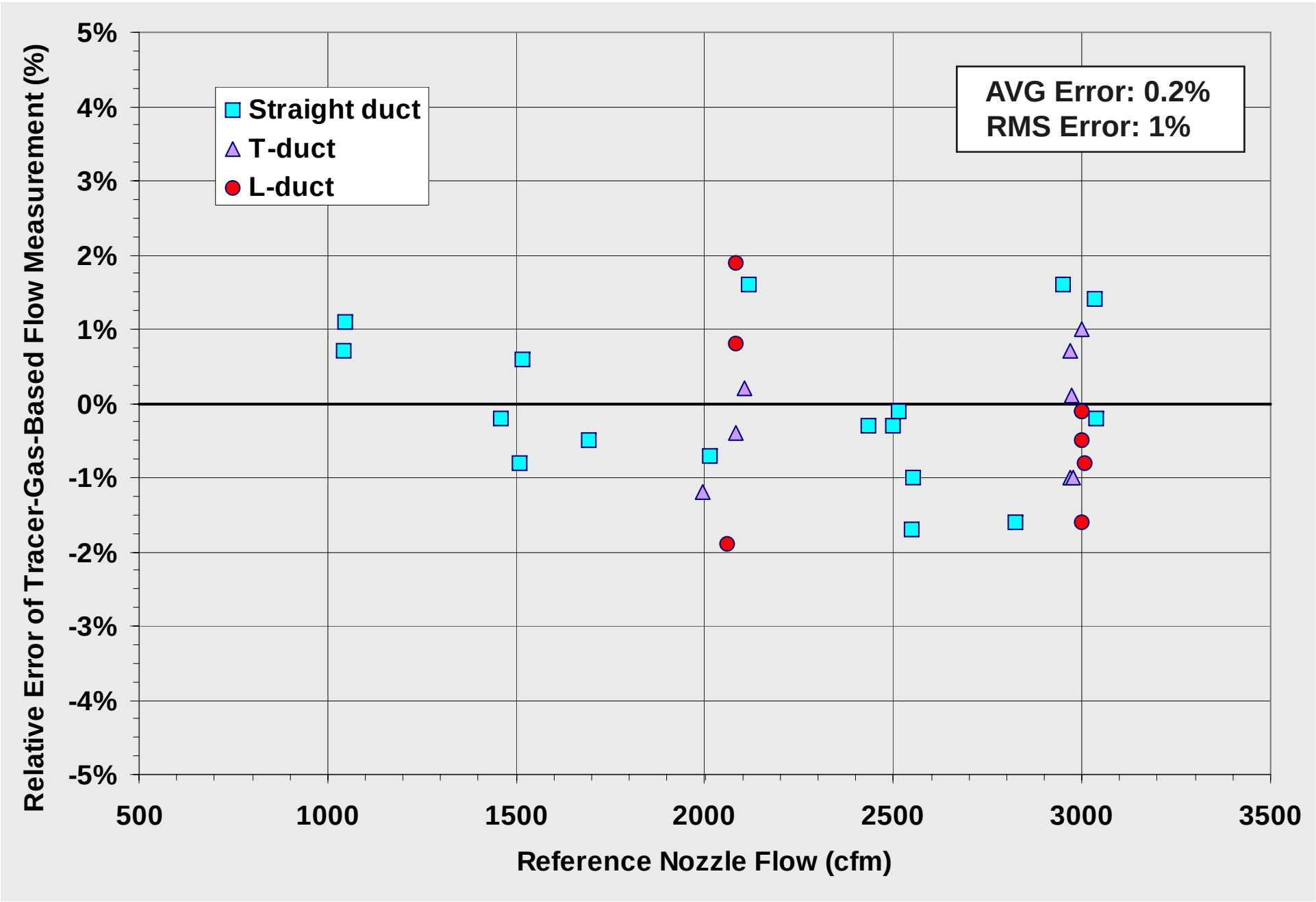
High Pressure CO_2 Injector Detail



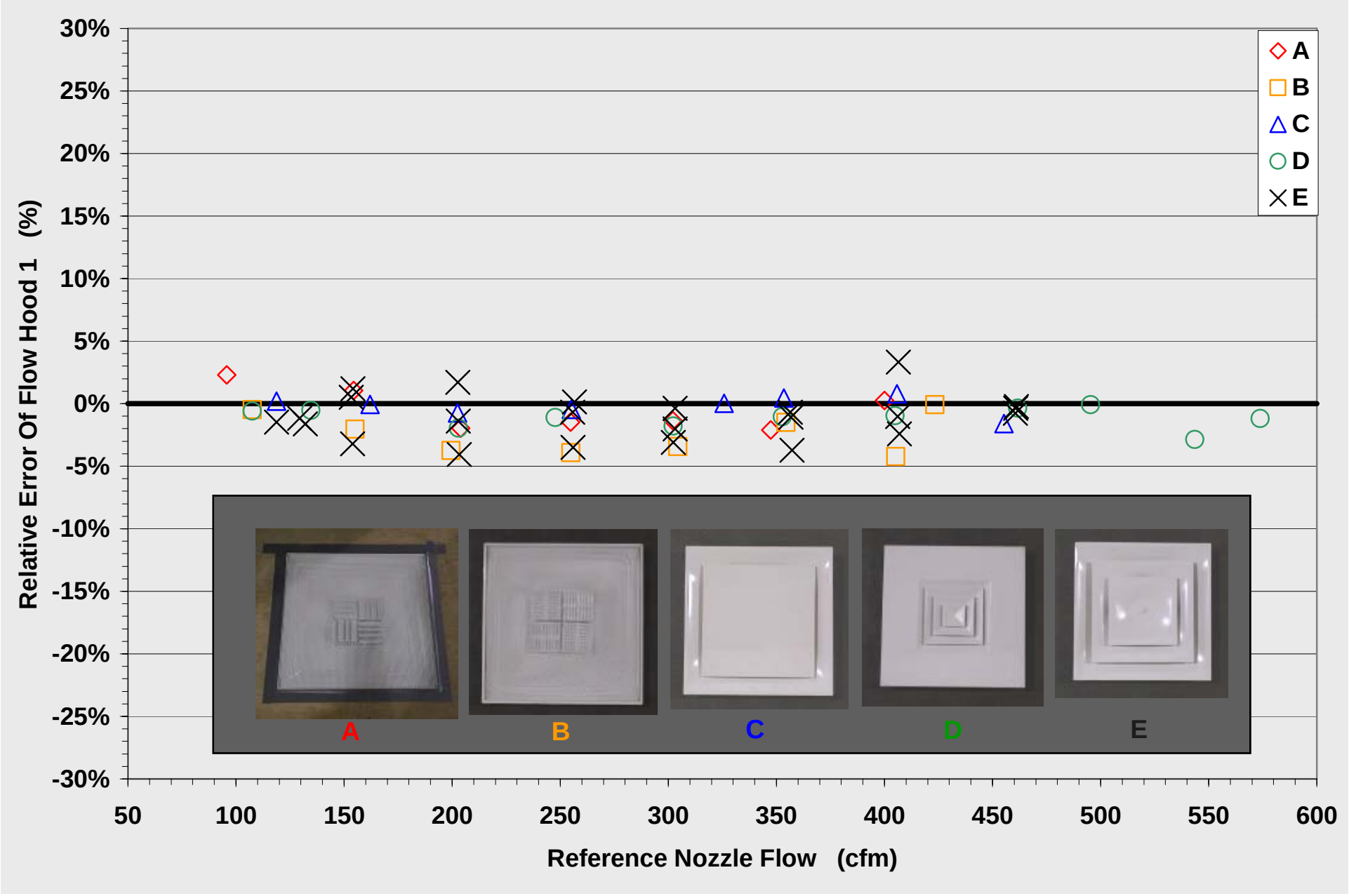
$$Q_{air}^{ave} = \frac{m_{CO_2}}{\rho_{CO_2} \int_0^T \left(C^{down} - C^{up} \right) dt}$$



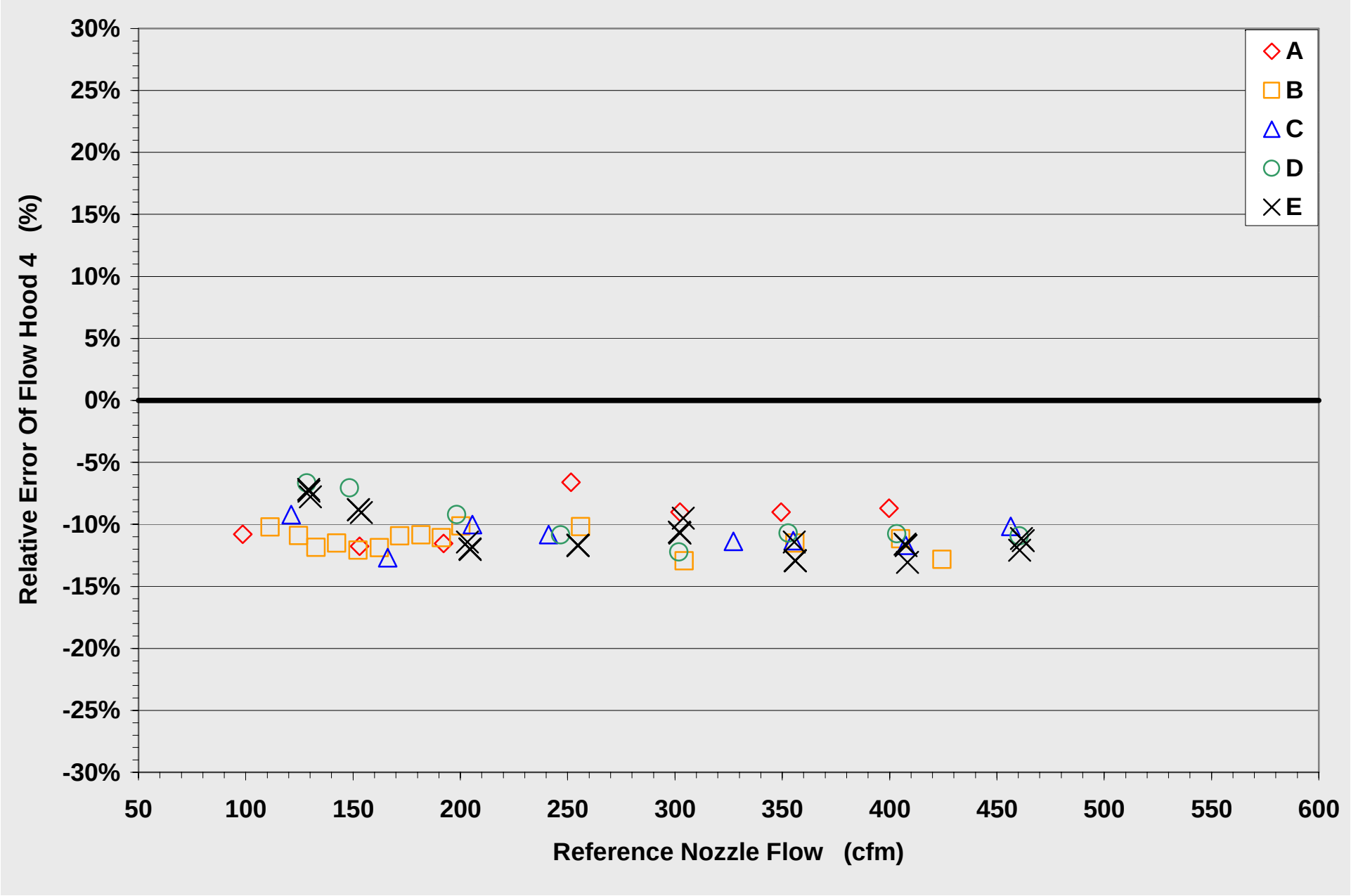
Tracer Gas System - Lab Test Results



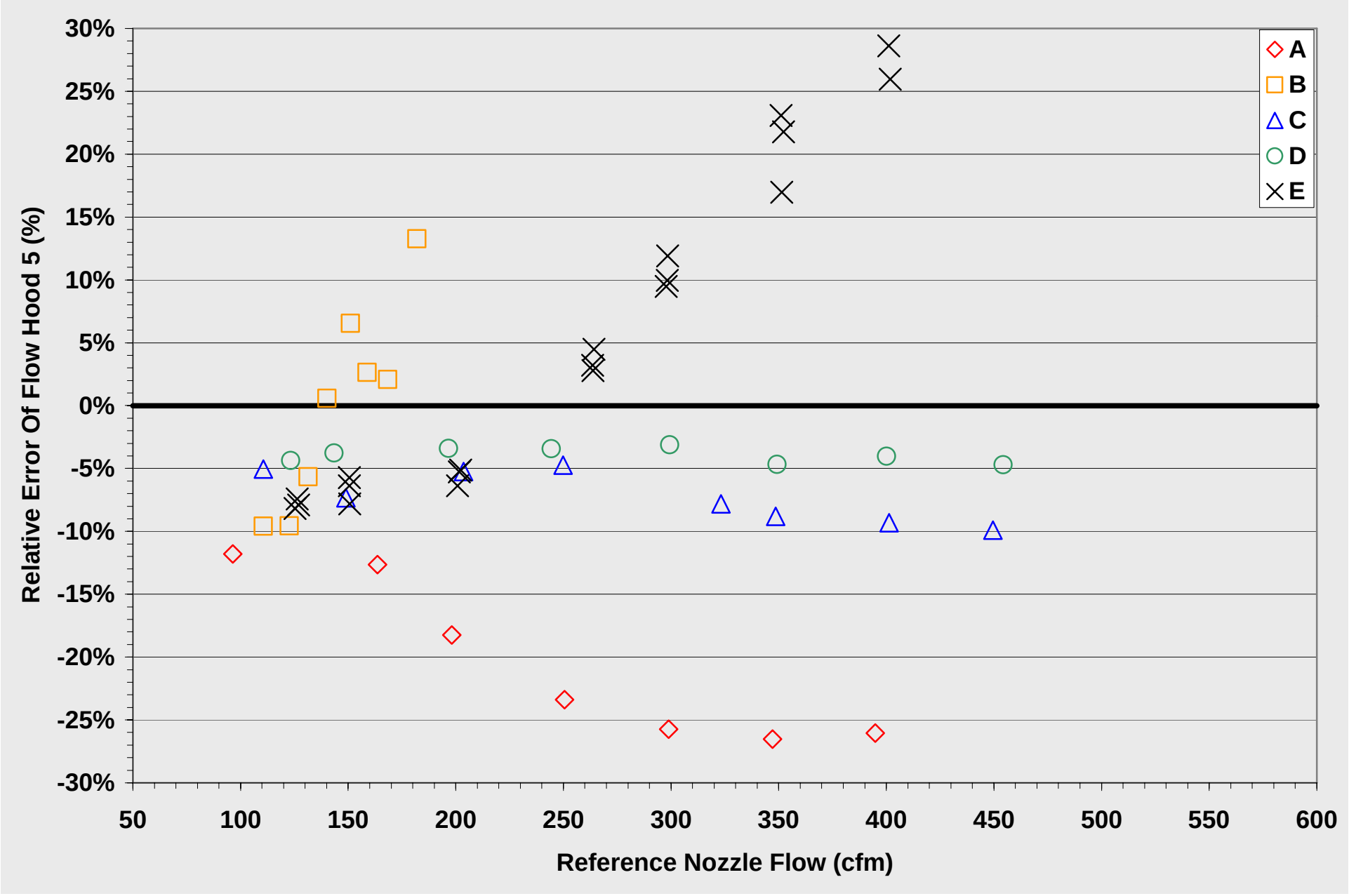
Flow Hood Test: Good Results



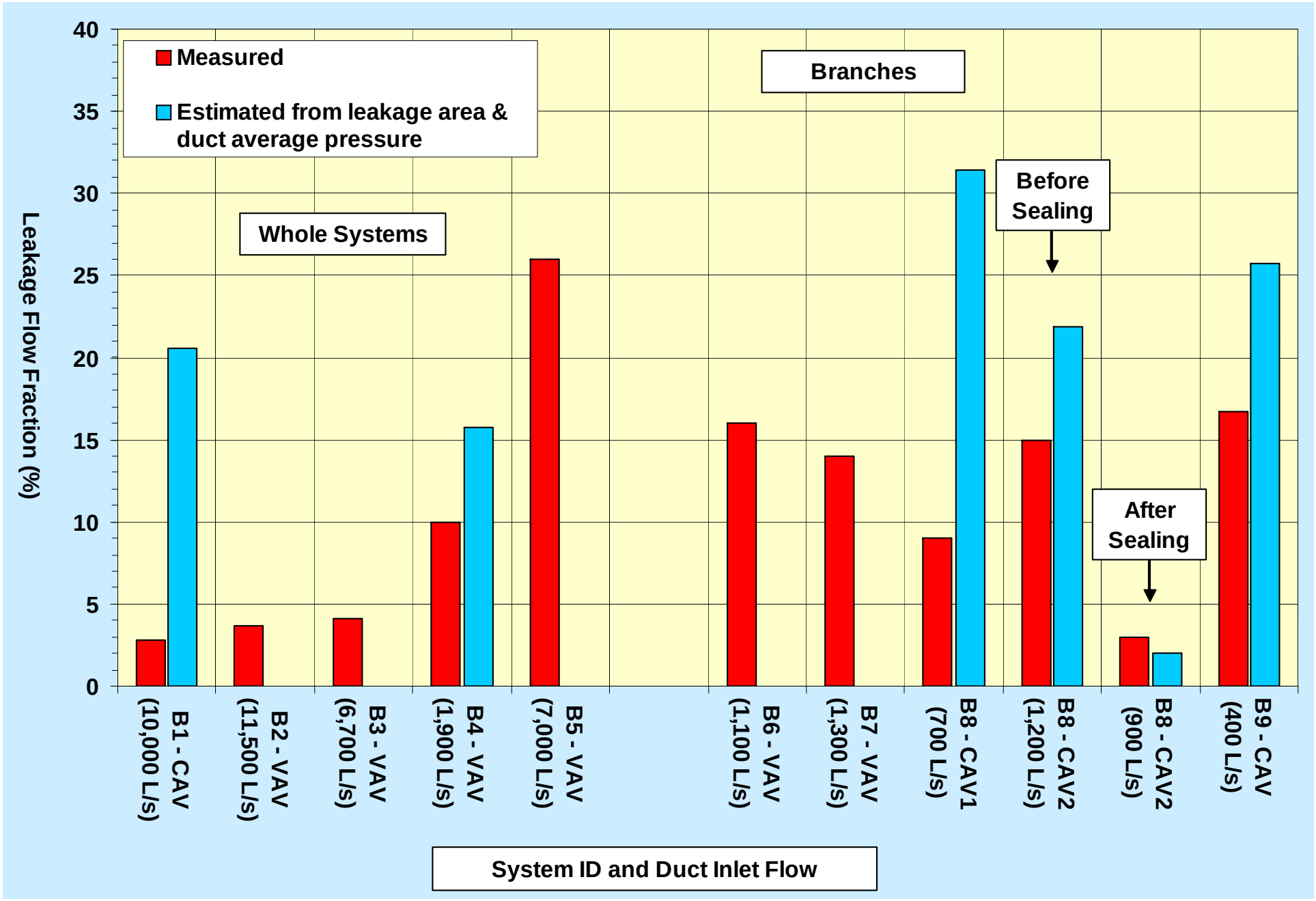
Flow Hood Test: Biased Results



Flow Hood Test: Scattered Results



Leakage Flow Fractions – 10 Systems



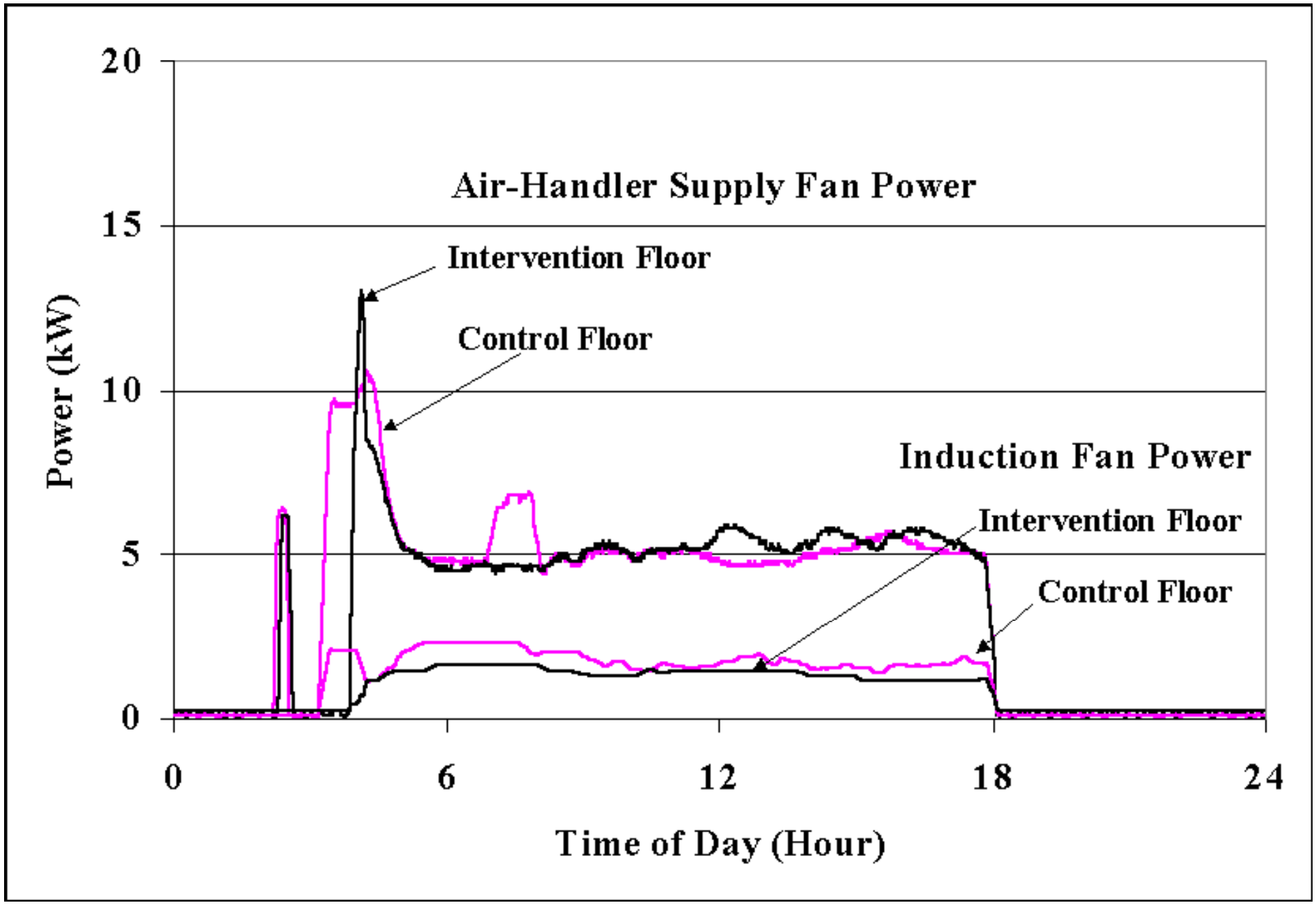
Measured Leakage Flows

- Ten systems:
  - Three “tight” (<5%)
  - Seven “leaky” (10% and more)
- Potentially a substantial duct leakage problem in U.S. buildings
- Need to train installers to use industry best practices and to test for system leakage

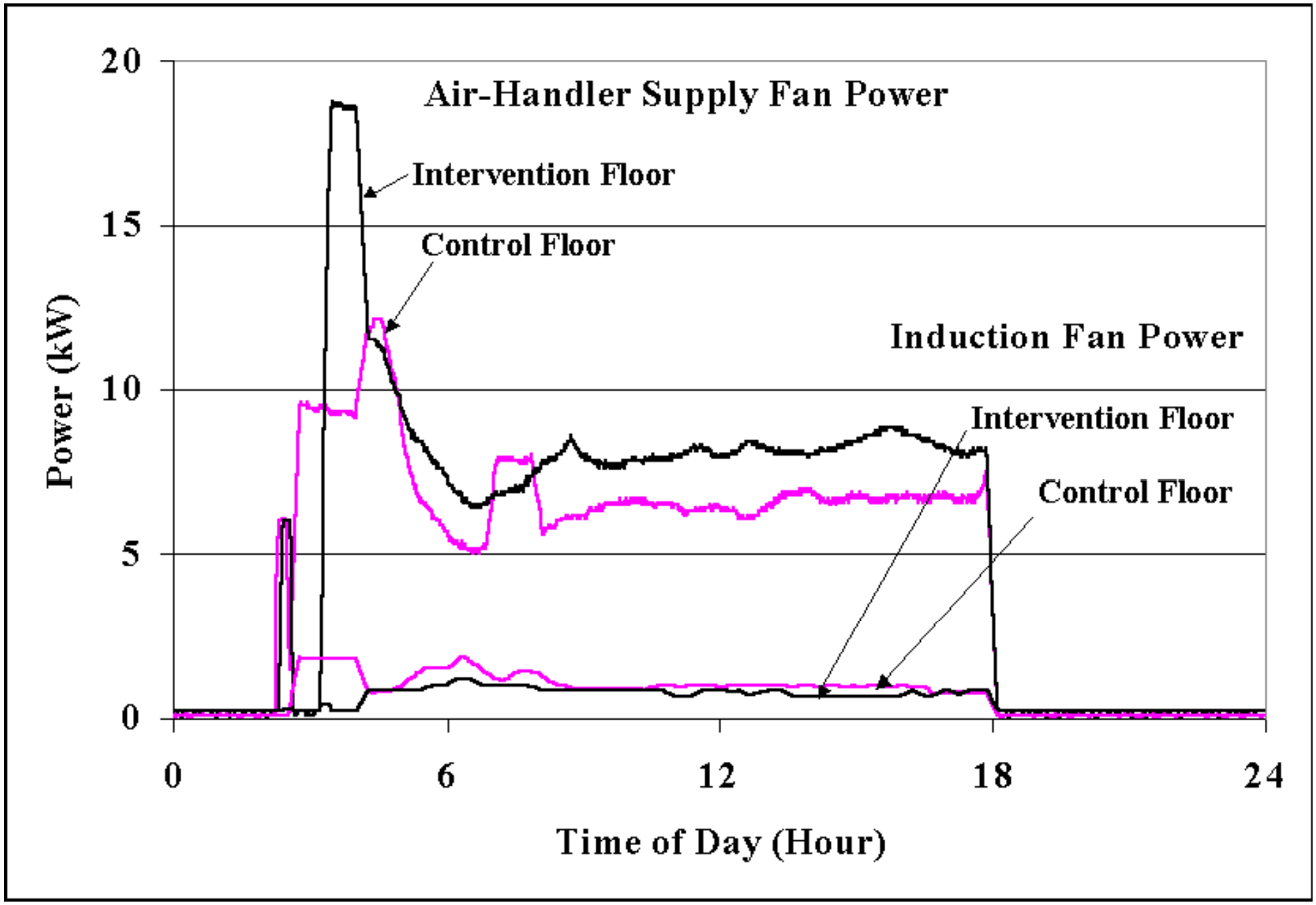
Measured Leakage Impacts

- LEED Platinum building in Sacramento, CA
  - Two identical floors: intervention and control
  - VAV single-duct reheat systems
  - Parallel fan-powered boxes for perimeter zones
  - Summer 2002 cooling season tests
- Supply leakage increased from:
  - 5% to 20% (operating conditions: 14,000 cfm)
  - 4% to 13% (design conditions: 24,400 cfm)
- 35% supply fan energy increase
- 25% net effect due to reduced box fan operation

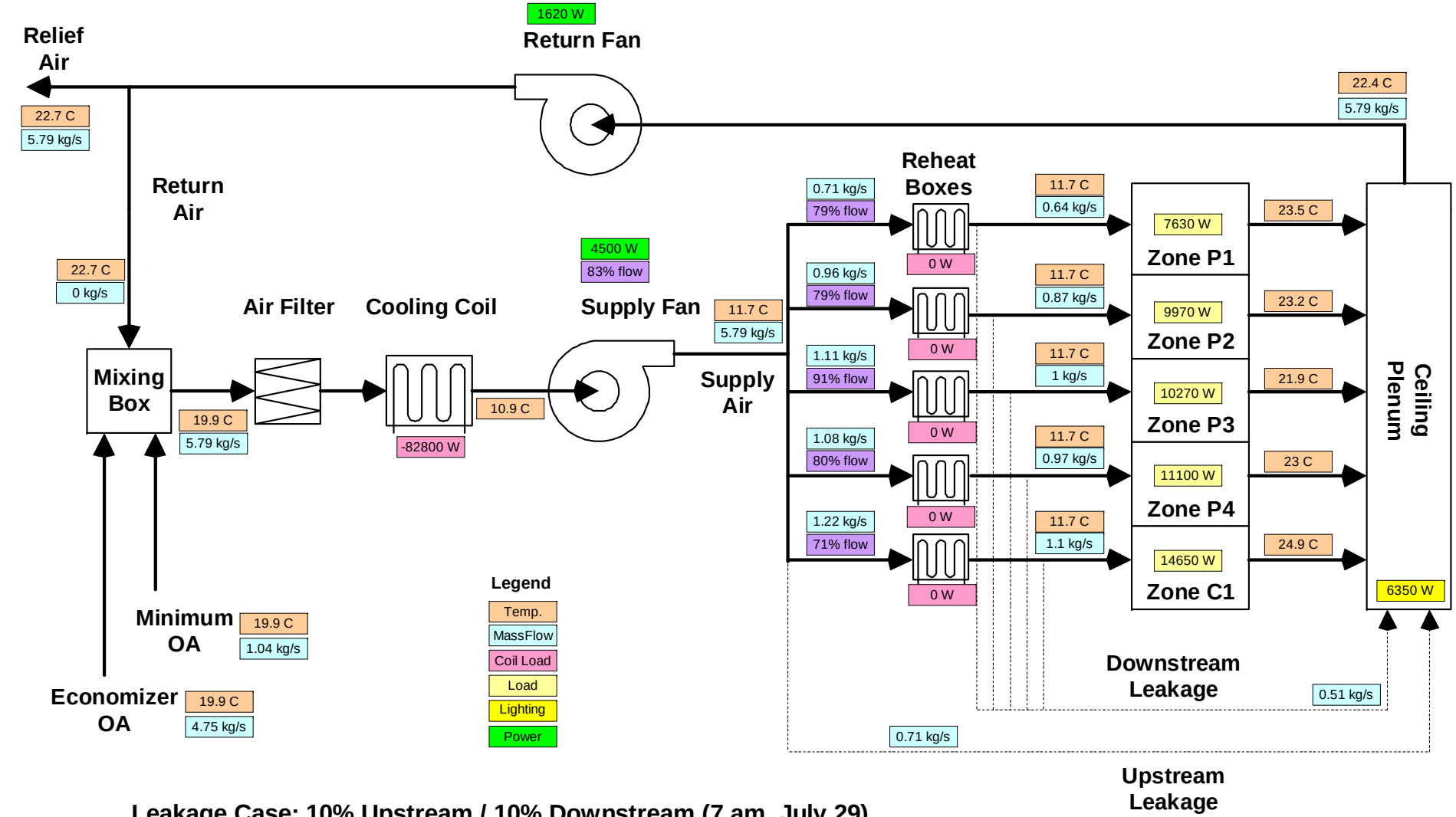
Measured Fan Power: “5%” Leakage



Measured Fan Power: “20%” Leakage



Air Distribution System Model

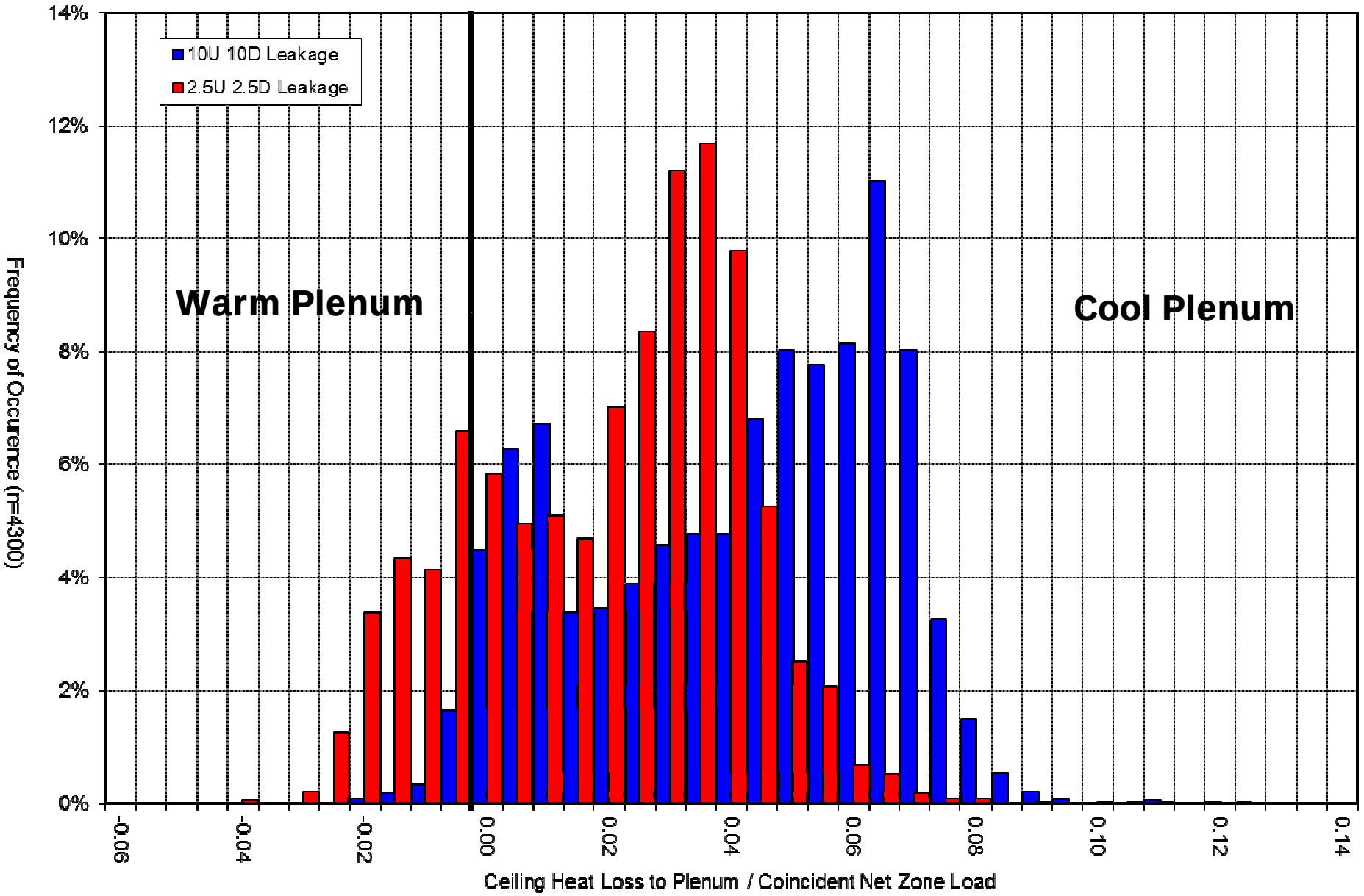


Leakage Case: 10% Upstream / 10% Downstream (7 am, July 29)

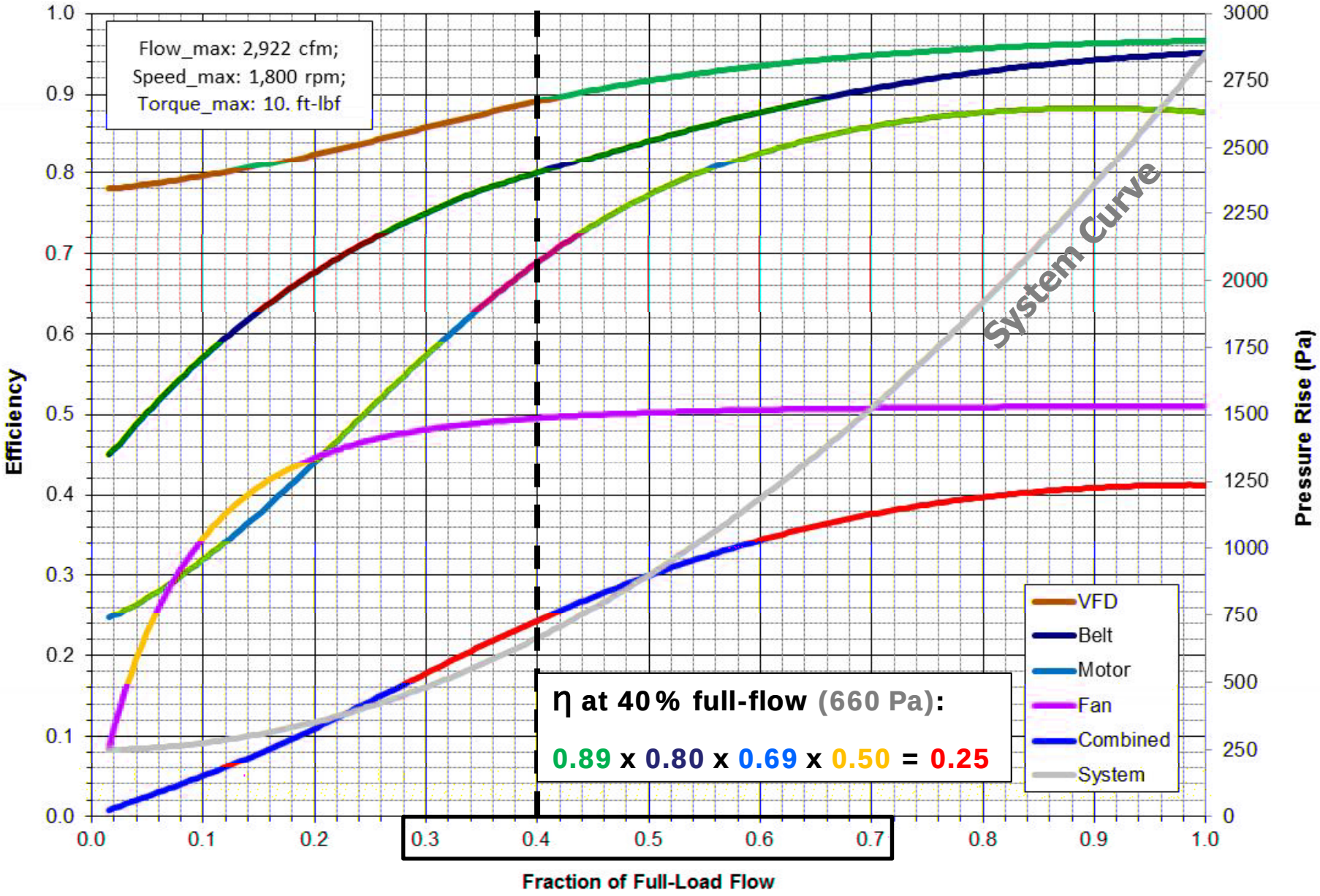
Modeling Results

- Single-duct VAV reheat system; unpowered VAV boxes
- California Title 24 VSD fan models
- Supply leakage increased from 5% to 20% at design conditions
- Annual energy consumption impacts (Sacramento, Oakland, Pasadena):
  - Supply & return fan electricity up 40 to 50%
  - Chiller & cooling tower electricity up 7 to 10%
  - Boiler (reheat) natural gas down 3 to 10%
  - Total HVAC site energy up 2 to 14%

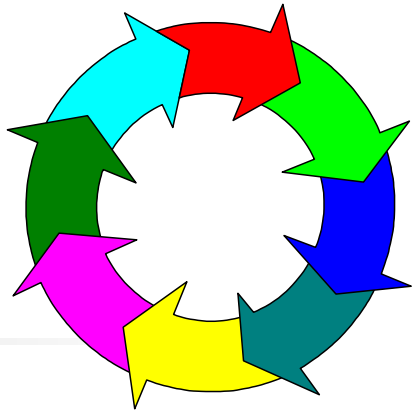
Ceiling Conduction Effects



Fan Component Models



Next Steps



- Further evaluation of diagnostic tools
- Flow measurement device calibration standards
- System commissioning guidelines
- Identify “tight system” installation procedures (ultimately eliminate leakage testing?)
- Validate new models and simulate impacts
- Evaluate combined retrofit opportunities
  - Reduce system leaks/flows/pressures
  - Improve component efficiencies and sizing

Questions ?

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