Duct Leakage: Measured Magnitudes and Calculated Impacts

Mark Modera, PhD PE

Seminar 16

ASHRAE Winter Meeting, Chicago

January, 2012

Presentation Overview

- Leakage Area vs. Leakage Flow
  - Measurement techniques
- Are low-pressure system leaks important?
  - Light commercial systems – RTUs
  - Supply sections downstream of VAV boxes
  - Kitchen/bath exhaust systems
- Diagnostic Tools, Leakage Magnitudes, Energy Impacts

Duct Leakage Characterization

- **Leakage Area vs. Leakage Flow**
  - Leakage Area = size of hole
    - Sometimes expressed as cfm@1"H_2O or cfm@25Pa
    - Needs to be combined with leak pressures for performance analysis
      - Need to separate "low-pressure" and "high-pressure" sections (AT A MINIMUM)
  - Leakage Flow – cfm during normal operation
    - Performance impacts scale with leakage flow
    - % leakage is very useful – remains relatively constant with changes in system flow

Duct Leakage Measurement

- **"Standard" Fan Pressurization**
  - Measures leakage area
  - Small duct systems (e.g. RTUs)
  - Isolated duct sections in large systems
- **Test and Balance**
  - Measures leakage flow
  - Compares grille flows to fan flow or "design" flow
- **Simplified Leakage Diagnosis or Screening**
  - Kitchen and toilet exhaust
  - Leakage downstream of VAV boxes

Duct Leakage Magnitude – RTUs

- **Light Commercial Buildings – RTU Systems**
  - Leakage Area data from Fan Pressurization
  - No measured pressures during normal operation
  - 364 systems – all located in Southern California
  - System size: average 3.9 tons (Std Deviation 2.1 tons)
  - Sample: Customers of two Commercial Service Contractors

Duct Leakage Magnitude – RTUs

Parameter	Leakage Area [cfm@25/ ton]	Fractional Leakage (Supply and Return) assuming 25 Pa avg at leaks	Fractional Leakage (Supply and Return) assuming 40 Pa avg at leaks
Count [systems]	**364**	**364**	**364**
Average	**87**	**25%**	**33%**
Std Deviation [%]	50%	50%	50%
Std Error in Mean [%]	2.6%	2.6%	2.6%

Energy Impact – RTUs

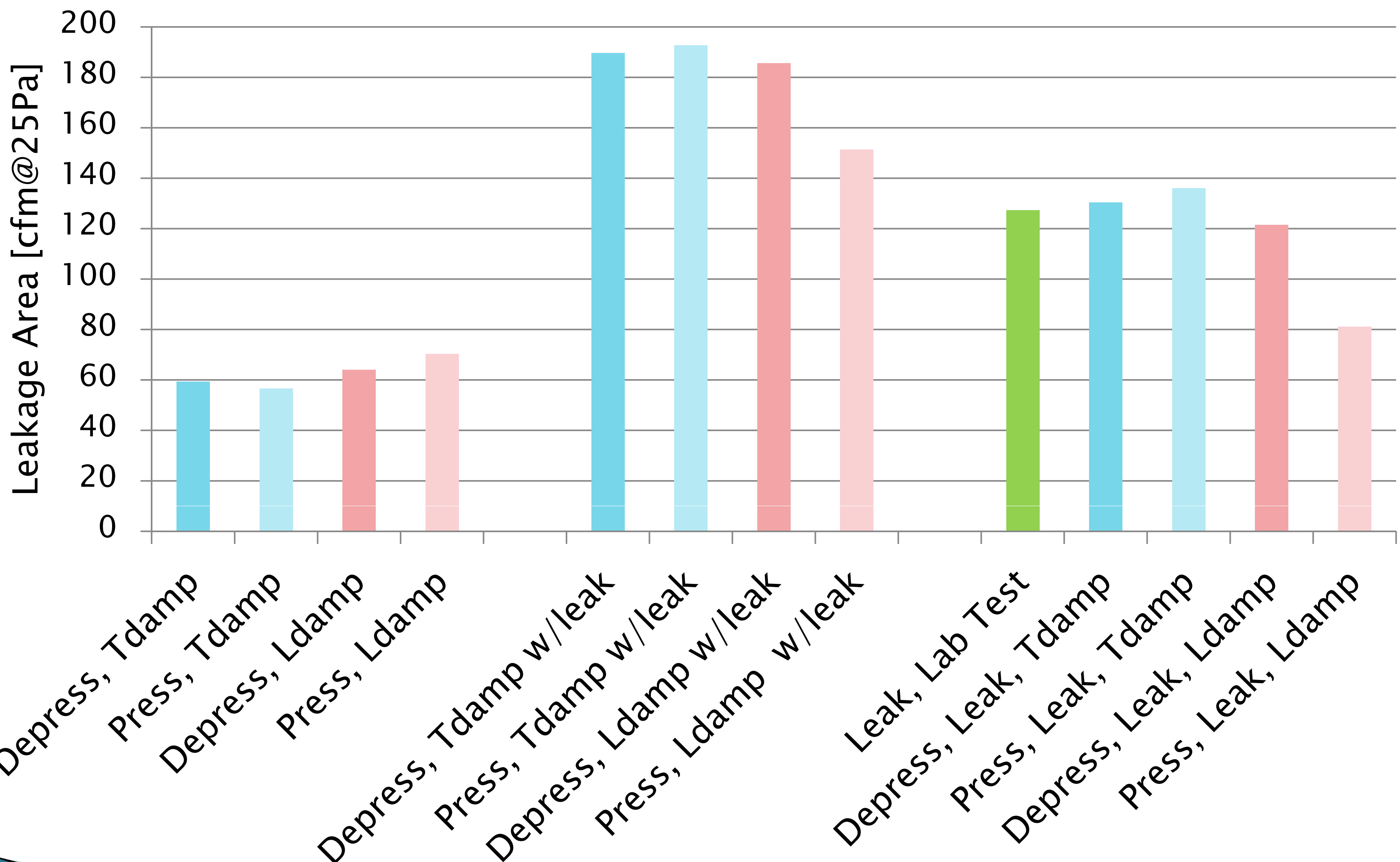
- **Approximate Analysis with ASHRAE Std 152**
  - Thermal losses are primary factor
  - Magnitude depends on location of ducts relative to insulation
  - For ducts above insulation, leakage split evenly between supply and return:

Duct Leakage	25%	33%
Heating Energy Increase	16%	23%
Cooling Energy Increase	28%	40%
Cooling Demand Increase	44%	68%

Leakage Diagnosis – VAV Supply

- **Leakage Downstream of VAV Boxes**
  - Standard fan pressurization
  - Test and Balance
  - Generally “low-pressure” ductwork and components
- **Simplified Diagnostic**
  - Leave fan running normally
  - Tape or block all grilles but one
  - VAV damper: close or set to minimum position
  - Pressurize/depressurize through open grille
  - Simultaneously calculate VAV damper opening and downstream leakage

Simplified Diagnostic – VAV Supply



Leakage Magnitude – VAV Supply

- **Supply Leakage Downstream of VAV Boxes**
  - Leakage Area data from Simplified Diagnostic
  - Measured/estimated average downstream pressures during normal operation
  - 9 systems, located California, Florida, Rhode Island, Texas, Washington
  - Vintage: 1980s, 1990s
  - Sample: Office buildings, mostly military and university

Leakage Magnitude –VAV Supply

Building	Flow Exponent	Best Estimate Leakage	Upstream ΔP [Pa]	Best Estimate ΔP leak [Pa]	Minimum (at grille) ΔP leak [Pa]	State
1	0.80	8%	250	25	8	CA
2	0.72	15%	375	25	10	WA
3	0.54	14%	300	25	20	RI
4	0.64	11%	108	25	15	RI
5	0.61	19%	550	50	50	FL
6	0.61	6%	155	40	10	TX
7	0.78	4%	155	40	10	TX
8	0.53	9%	375	67	9	CA
9	0.41	6%	488	50	20	CA
Average	**0.63**	**10%**	**306**	**39**	**17**	
Standard Dev [%]	**20%**	**47%**	**50%**	**39%**	**79%**	
Std Err in Mean [%]	**7%**	**16%**	**17%**	**13%**	**26%**	

Energy Impact – VAV Supply

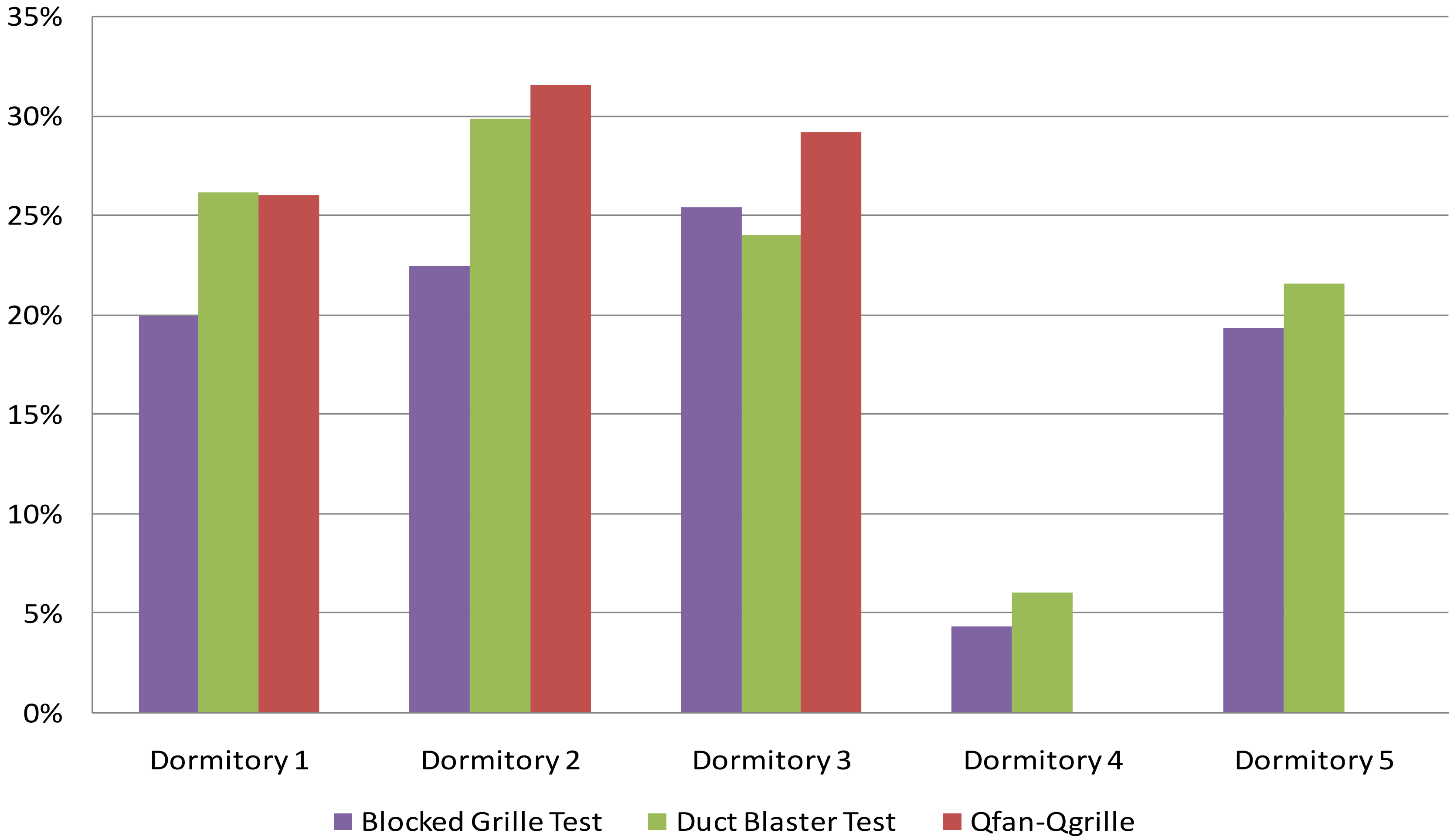
- **Fan Power**
  - Varies with flow rate raised to power 2.4 for typical supply systems
  - Duct leaks ⇨ short circuit of supply air to the return plenum ⇨ excess air flow through fan to meet loads
- **Heating/Cooling Energy**
  - Cooling load due to extra fan heat
  - Heating/cooling loads due to excess outdoor air
  - Ceiling loads during simultaneous heating and cooling
- **Implication of 10% supply leakage:**
  - **29%** excess fan power
  - **39%** including heating/cooling impact

Leakage Diagnosis – Exhaust

- **Kitchen and Toilet Exhaust Systems**
  - Standard fan pressurization
  - Test and Balance
  - Generally “low-pressure”

- **Simplified Diagnostic**
  - Leave fan running normally
  - Tape or block all grilles
  - Measure duct pressure at mid-point of shaft
  - Measure flow leaving roof cap

Bath Exhaust Leakage – Simplified Diagnostic



Kitchen/Bath Exhaust Leakage – "Standard" Fan Pressurization

Building	Fan Flow [cfm]	Leakage [%]	Notes
Condominium (40-Story)	950	74%	Building-Cavity Bathroom Exhaust
NYS University Dorm (10-story)	2,300	70%	Bath/Shower Exhaust
NYS University Dorm (7-story)	2,050	54%	Bath/Shower Exhaust
Navy BEQ (10-story dorm)	6,470	54%	Building-Cavity Exhaust w/heat wheel
Barracks (eight 3-story buildings)	20,000	20%	Bath/Shower Exhaust
Office Toilet Exhaust (3-story)	8,700	9%	No pre-diagnosis of leakage
Seven NYC Apartment Exhausts	2,450	36%	Kitchen/Bath Exhausts
Flow-Weighted AVERAGE for 20 Buildings		**29%**	**Based upon leakage area and average pressure differential**

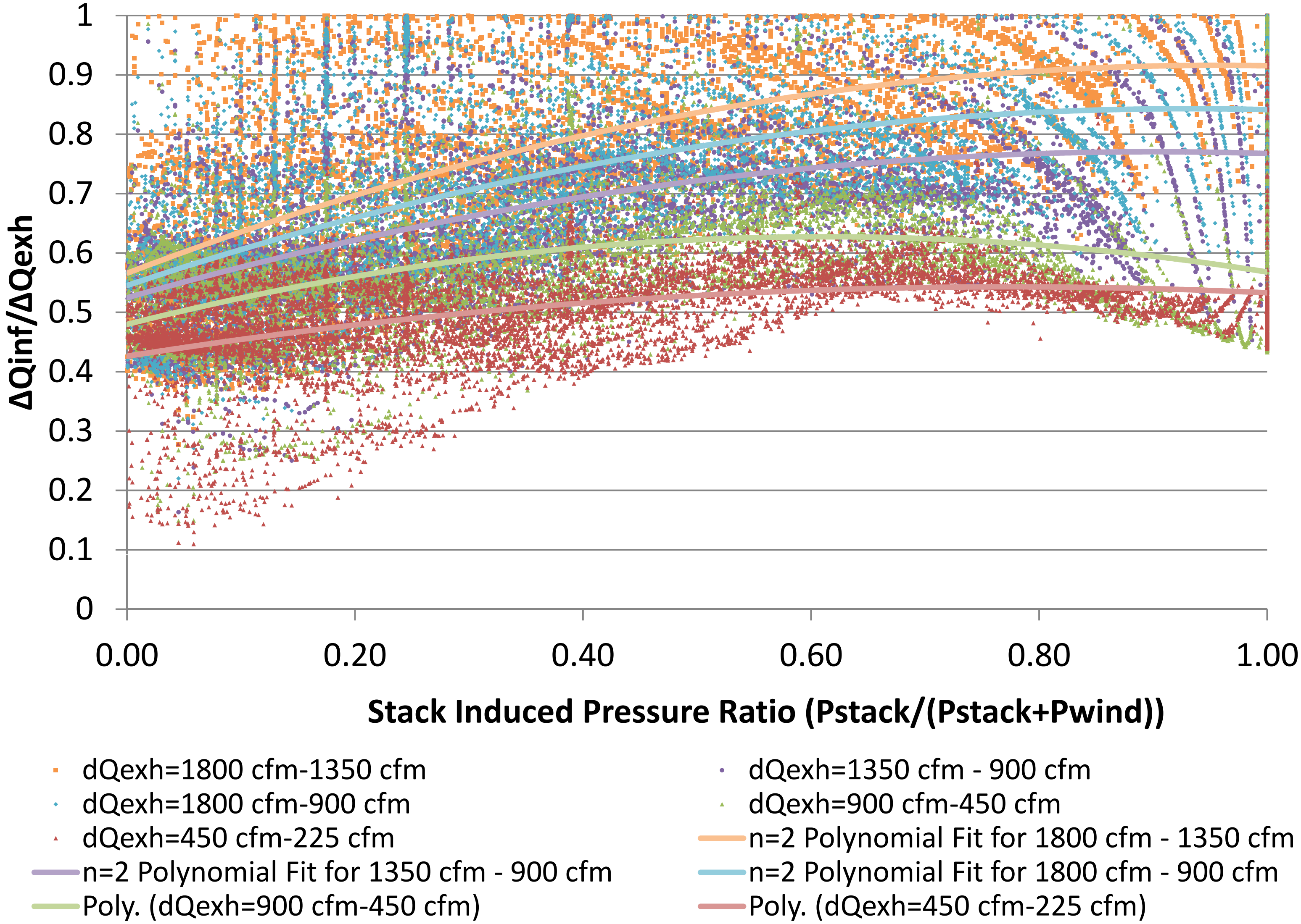
Energy Impacts: Kitchen/Bath Exhaust

- **Fan Power**
  - Scales with Cube of Flow
  - **29%** Leakage Increases Fan Power by **179%** to Produce Design Flow at Grilles

- **Heating and Cooling Loads**
  - Scale with Excess Air Infiltration
  - Change in infiltration is not equal to reduction in exhaust flow

$$\frac{\Delta Q_{\text{inf}}}{\Delta Q_{exh}} = \frac{Q_{\text{inf}}^{initial} - Q_{\text{inf}}^{final}}{Q_{exh}^{initial} - Q_{exh}^{final}}$$

Exhaust Model Results: 6-Story Building



Energy Impact – Kitchen/Bath Exhaust

- **Heating/Cooling Energy**
  - Assumptions
    - 75 cfm nominal kitchen plus bath exhaust for 1000 ft^2 apartment
    - 0.2 ACH natural infiltration
- **Implication of 29% exhaust leakage:**
  - **179%** excess fan power
  - **23%** increase in ventilation heating/cooling load

Energy Impact Summary

- **Light Commercial RTUs**
  - **15%-70%** increase in heating and cooling loads for ducts above ceiling insulation
- **Supply leakage downstream of VAVs**
  - **30%-40%** increase in system fan power
- **Kitchen and bath exhaust leakage**
  - **>150%** increase in fan power
  - **>20%** increase in infiltration load

Conclusions

- Low-pressure duct leakage is common and substantial
- Simplified techniques exist for measuring/diagnosing low-pressure leakage
- Energy impacts and analysis depend on type of system
  - Light Commercial RTUs
  - Supply leakage downstream of VAVs
  - Kitchen and bath exhaust leakage
- Importance of testing should be based upon leakage percentage of flow, not operating pressure