Flow Exponent Values and Implications for Air Leakage Testing

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ROBIN URQUHART, MBSC, MA NRES, RDH BUILDING ENGINEERING
DR. RUSSELL RICHMAN, P.ENG, RYERSON UNIVERSITY
Outline

→ Introduction to air leakage testing
→ Relationship between flow and pressure
→ Case study building
→ Abnormal flow exponents
→ Data extrapolation to operating pressures
→ Conclusions/Implications
→ Further study
Air leakage testing

- Air leakage = Uncontrolled air movement through the building enclosure
  - Can account for up to 50% of a building's heat loss/gain
  - Affects assembly durability
Fan induced pressure

→ Induced pressure differentials using fans
  → Mechanical
  → Blower door

→ ASTM E779-10 (10-60 Pa)
  → multi-point

→ ASTM 1827-12 (50 Pa)
  → single point

→ USACE (75 Pa)
  → single point
Why test?

→ Evaluate performance and determine retrofit options
  → Single building
  → Building stock

→ Determine leakage rates for energy models
  → 4 Pa – 10 Pa

→ Code or other
  specification compliance
  → LEED, Energuide, etc.
The Relationship between Flow and Pressure

Power Law Equation (Bernoulli):

\[ Q = C(\Delta P)^n \]

Where,
- \( Q \) = flow
- \( C \) = flow coefficient
- \( P \) = pressure
- \( n \) = flow exponent (dimensionless).
Flow exponent \( (n) \)

**Power Law Equation:**

\[
Q = C (\Delta P)^n
\]

\[
(\log Q) = n (\log P) + (\log C)
\]

\[
y = mx + b
\]

- **0.5 = Turbulent**
  - flow resistance varies with the square of velocity

- **1.0 = Laminar flow**
  - flow resistance proportional to velocity

**Slope =** \( n > 0.5 \) and < 1.0
Case study building

→ 13-story MURB
→ Enclosure retrofit 2012
  → focus on air tightness
→ Air leakage tested
  → Pre-retrofit
  → Post-retrofit
Guarded-zone method
### Flow exponent values – Case study building

<table>
<thead>
<tr>
<th>Suite 1101</th>
<th>Suite 1102</th>
<th>Suite 1103</th>
<th>Suite 1301</th>
<th>Suite 1302</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-press</td>
<td>0.52</td>
<td>0.49</td>
<td>0.53</td>
<td>0.74</td>
</tr>
<tr>
<td>Post-press</td>
<td>0.71</td>
<td>0.56</td>
<td>0.64</td>
<td>0.77</td>
</tr>
<tr>
<td><strong>Change</strong></td>
<td><strong>+0.19</strong></td>
<td><strong>+0.07</strong></td>
<td><strong>+0.11</strong></td>
<td><strong>+0.03</strong></td>
</tr>
</tbody>
</table>

| Pre-depress | 0.47       | 0.46       | 0.78       | 0.57       | 0.63       |
| Post-depress| 0.61       | 0.43       | 0.59       | 0.57       | 0.47       |
| **Change**  | **+0.14**  | **-0.03**  | **-0.19**  | **0.00**   | **-0.16**  |

1. pre-press = pre-retrofit pressurization, post-press = post-retrofit depressurization, pre-depress = pre-retrofit depressurization, post-depress = post-retrofit depressurization
2. positive change indicates a move towards laminar flow (smaller cracks), negative change indicates a move towards turbulent flow (larger cracks)
“...blower door tests occasionally yield exponents less than the Bernoulli limit of 0.5. In fact, it is physically impossible for such low exponents to occur.”

Sherman, Wilson and Kiel. 1986

So why do we get them?
## Flow Exponents <0.5

<table>
<thead>
<tr>
<th></th>
<th>Series 1: n=0.5-1.0</th>
<th></th>
<th>Series 2: n&lt;0.5</th>
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<tbody>
<tr>
<td>Q</td>
<td>P</td>
<td>Q</td>
<td>P</td>
</tr>
<tr>
<td>800</td>
<td>10</td>
<td>800</td>
<td>10</td>
</tr>
<tr>
<td>1600</td>
<td>30</td>
<td>1300</td>
<td>30</td>
</tr>
<tr>
<td>2200</td>
<td>50</td>
<td>1590</td>
<td>50</td>
</tr>
<tr>
<td>2500</td>
<td>60</td>
<td>1710</td>
<td>60</td>
</tr>
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</table>
Flow exponents <0.5

- $R^2 = 0.9999$
- $R^2 = 0.9993$

Graph showing log flow versus log pressure with $R^2 = 0.9999$ and $R^2 = 0.9993$ for $n = 0.63$ and $n = 0.42$, respectively.
Geometry of the Enclosure

→ Higher pressure differentials change leakage path geometry

→ Resulting in abnormal flow exponent (n) values.

→ What effect on the data does a changing $n$ value cause?
Extrapolating to lower pressure differentials

Difference of ~35%

40 L/s
Enclosure change at high pressure

\[ N = 0.68, \quad \text{Rsq} = 0.99 \]

\[ N = 0.62, \quad \text{Rsq} = 0.99 \]

<table>
<thead>
<tr>
<th>Q</th>
<th>P</th>
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<tbody>
<tr>
<td>650</td>
<td>30</td>
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<tr>
<td>865</td>
<td>50</td>
</tr>
<tr>
<td>1100</td>
<td>70</td>
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<tr>
<td>1180</td>
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<tr>
<td>1250</td>
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<tr>
<td>1375</td>
<td>90</td>
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<tr>
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Enclosure change at higher pressures

![Graph showing flow against pressure with two lines: one for static enclosure and another for enclosure changes. The graph illustrates an increase in flow as pressure increases.]
Adjusted values using $n$

![Graph showing flow and pressure for static and changing enclosures, with a 25 l/s flow and 14% difference highlighted.](image)
Conclusions

→ The enclosure may not remain static throughout the test

→ The linear relationship may not be accurate at operating pressure

→ Substituting $n$ values can have magnified impacts at lower/higher pressure differentials

→ R-squared values not perfect indicators
Implications for the industry

→ Energy models using extrapolated flow rates may be inaccurate

→ Sizing mechanical systems for predicted in operation flow rates

→ Retrofit options
→ Multi-point testing still important
→ Order of magnitude for comparison purposes
→ Flow exponents tell us something, we might not know exactly what it is
→ Standards at higher pressures can be used for compliance purposes
Flow exponent corrections

In-test corrections
- Check R-squared values during testing
- Check $n$ values at the termination of each test

Post-test corrections
- Review data points and remove lowest pressure differential point(s)
- If not reconciled, single point test at 50 Pa
Further study

- Sensitivity analysis: R-value threshold
- The use of flow exponent values in forensics
- Standardized leakage metric and pressure differential for comparison purposes
- Effect on flow exponent of enclosure geometry changes
Questions

ROBIN URQUHART
RURQUHART@RDH.COM