Energy Consequences of Filtration

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Central Question

- Does higher pressure drop filter mean more energy?
  - Conventional wisdom: **Yes**
  - What I hope to convince you of: **Maybe not**
- Challenging subject
  - Going against conventional wisdom, burden of proof required is higher.
  - Very complex problem
- Focus on smaller systems

What happens to constant-speed fan energy when you add pressure drop?

A. Fan energy use goes up
B. Fan energy use goes down
C. Fan energy use stays the same

What happens to flow when you add pressure drop?

A. Flow goes up
B. Flow goes down
C. Flow stays the same

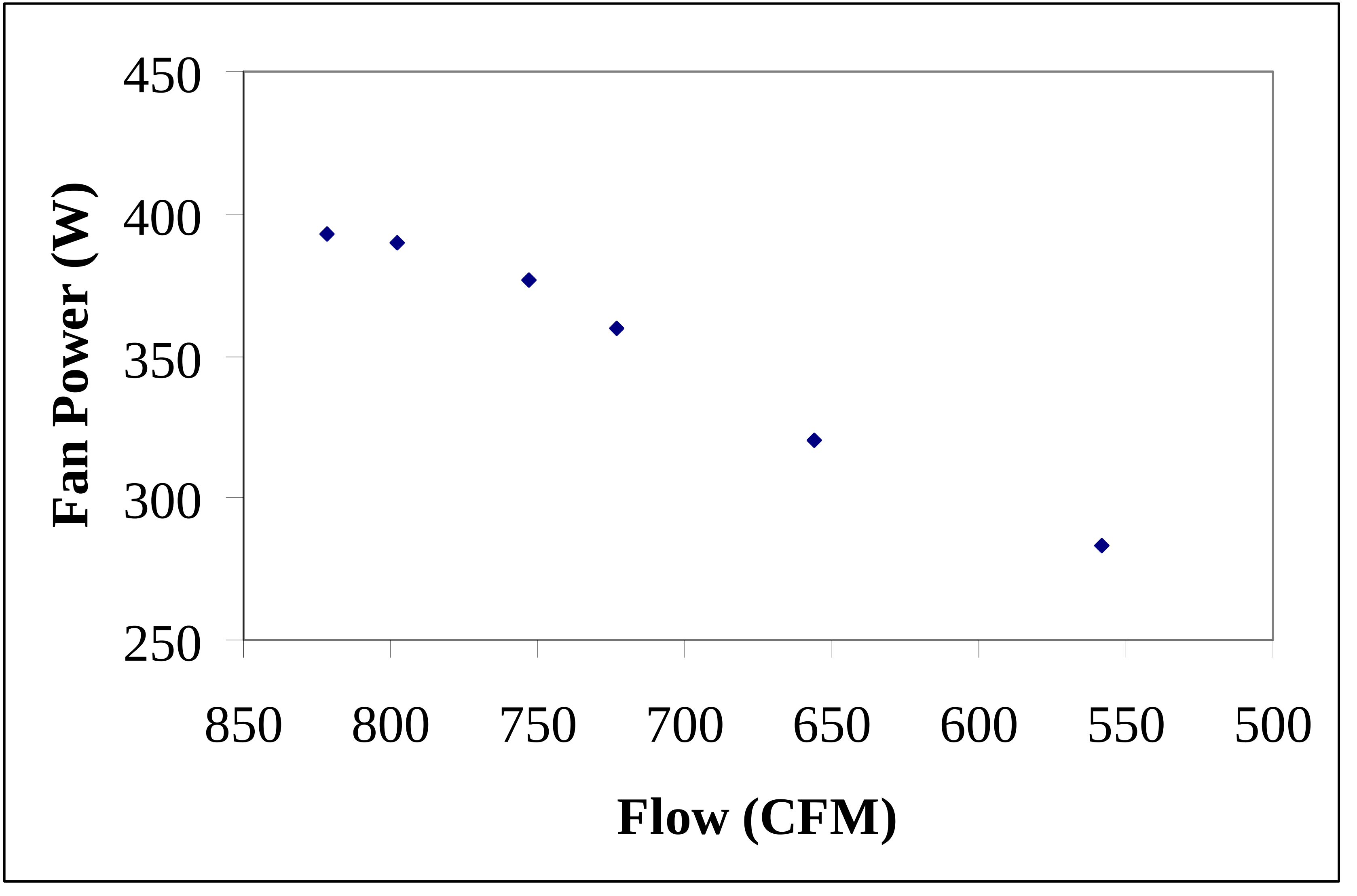
What happens to fan efficiency (watts/CFM) when you add pressure drop?

A. Efficiency goes up
B. Efficiency goes down
C. Efficiency stays the same

Mini-Experiment

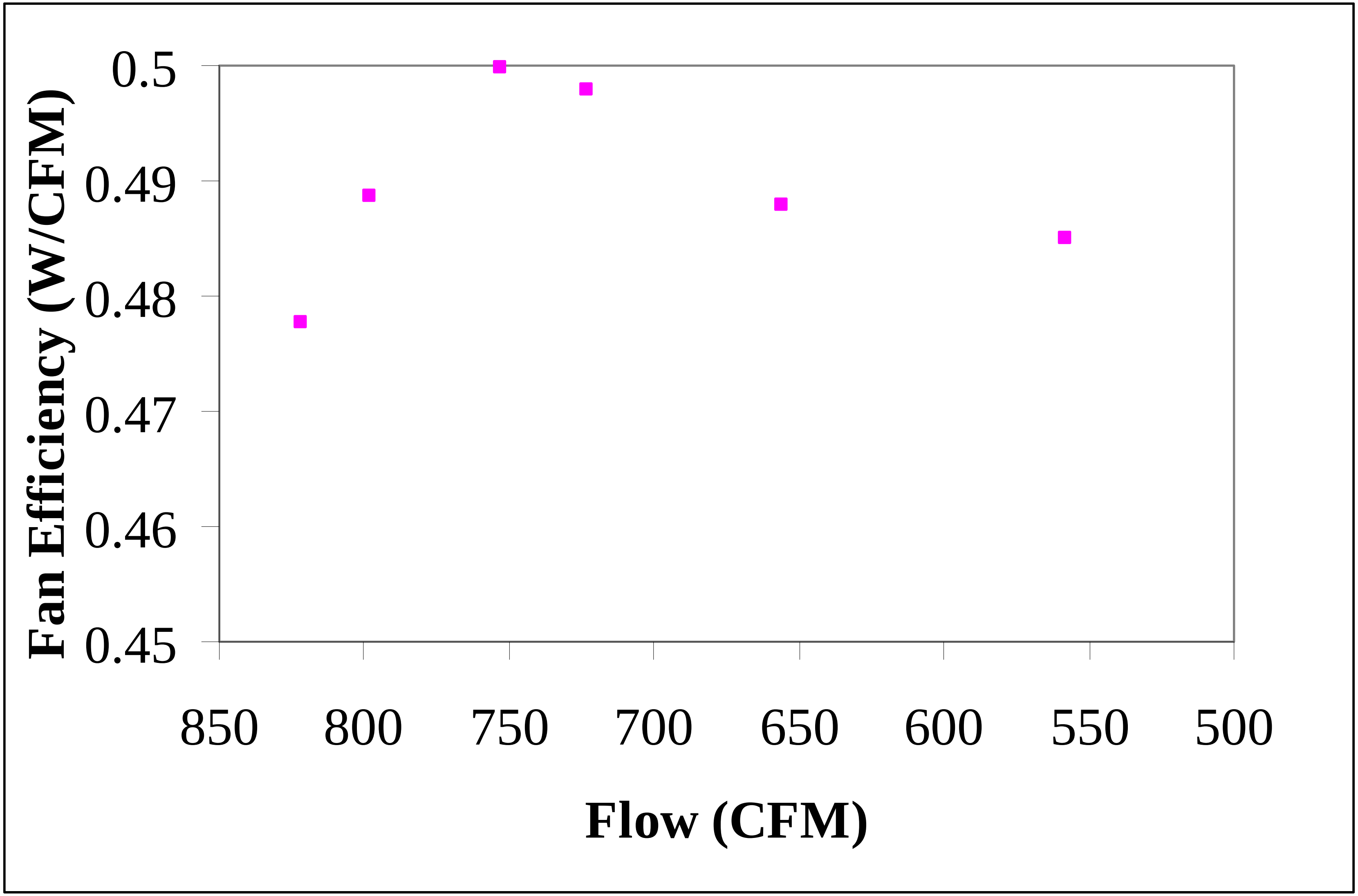
- Residential air-conditioner in fan-only mode
- Measuring power draw of fan & air flow rate
- Slowly taping off return grille

Fan Power



Fan Power (W)
450
400
350
300
250
850
800
750
700
650
600
550
500
Flow (CFM)

Fan Efficiency



Energy Implications of Filtration

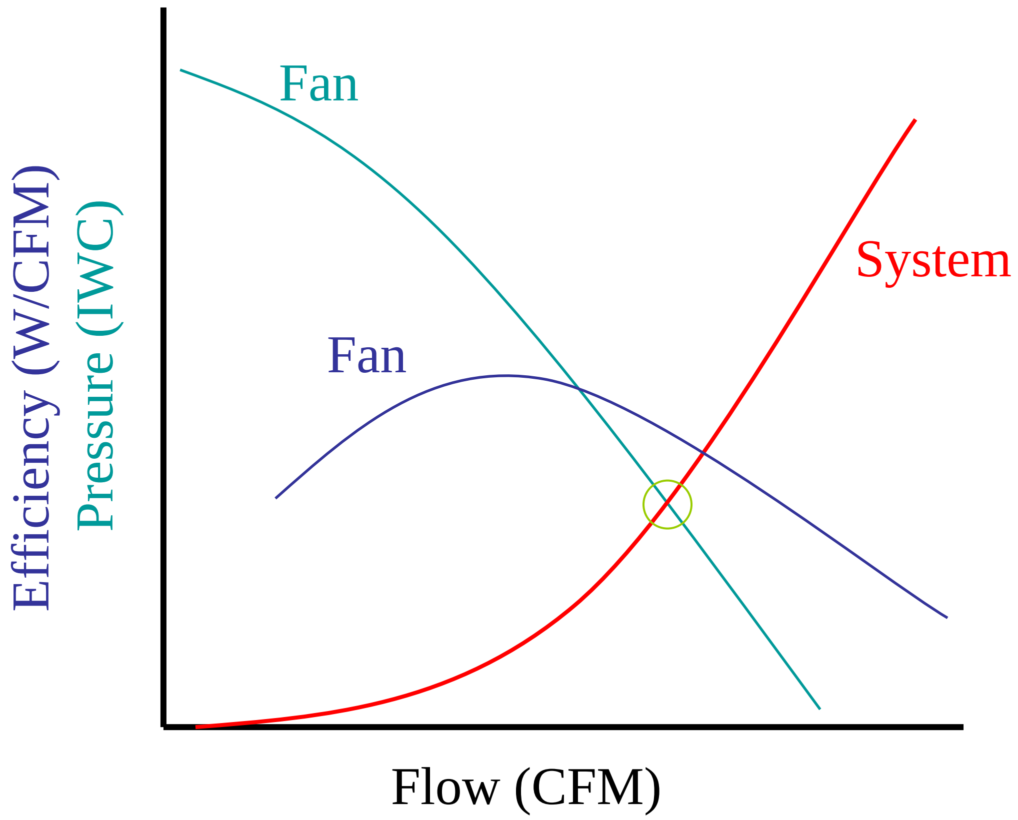
- Primary effects
  - Less flow, less fan energy
  - AC capacity and efficiency degradation
- Secondary effects
  - Changes in duct leakage
  - Changes in coil/component fouling
- Tertiary effects
  - Changes in sensible/latent balance
  - Changes in comfort/thermostat setting

Physics Part I

- As flow ↑, electricity required ↑
- Precise relationship is complicated
- Remember "work"
  - Force over a distance = work
  - If distance = 0, work = 0

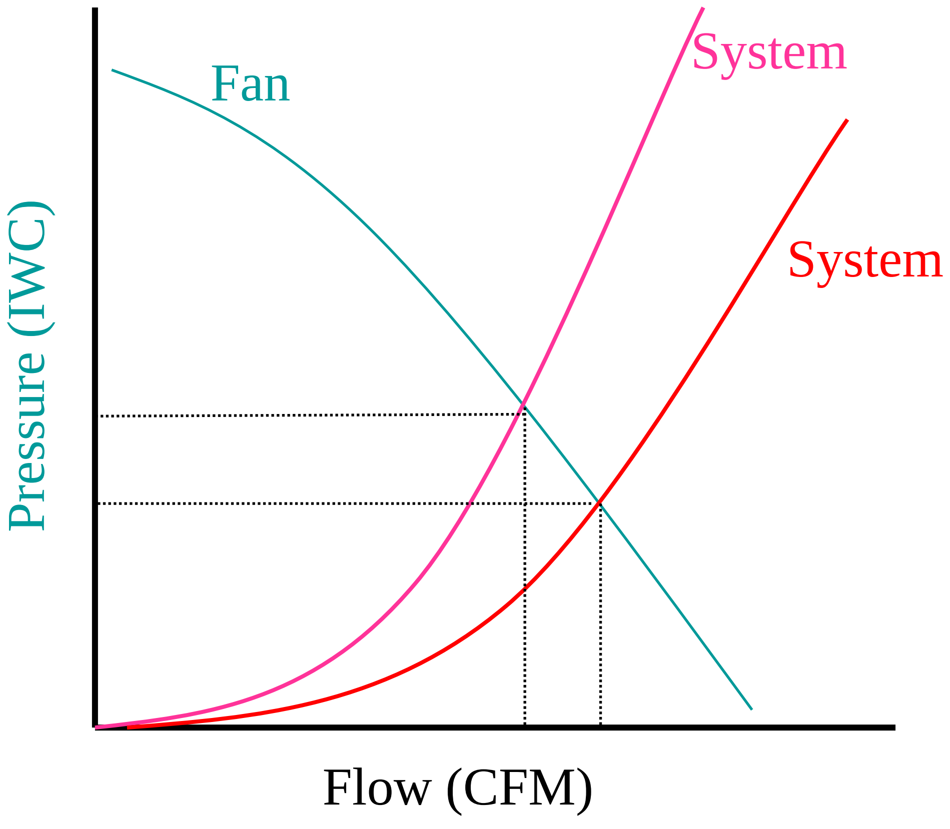
Physics Part II

- Every fan has curves, every system has curves



Physics Part III

- Intersection of fan and system curve gives actual flow and pressure



- If you add a pressure drop
  - $\Delta P_{fan} \uparrow$
  - Flow$\downarrow$
- Amounts depend on fan and system curve

Primary Implications

- If fan energy goes down
  - Less heat is dumped into air stream
    - Typical fan raises temperature 2 – 5 °F
  - Less cooling is required
- Typical residential fan energy:
  - 0.44 - 0.57 W/CFM
  - Assuming 400 CFM/ton (recommended)
- For a 3 ton AC
  - Fan is approximately **1/5** ton **heater**
- Adding a higher pressure drop filter: less fan energy and less air conditioning required

Reducing Flow – AC System Effects

- Air conditioner capacity goes down
- Air conditioner efficiency goes down
- For small changes in flow
  - Degradation in efficiency and capacity is larger than decrease in fan energy (but not by much)
  - Very limited data (Parker *et al.*, 1997 *ASHRAE Transactions)*

- Adding a higher pressure drop filter
  - More AC energy, but less fan energy
  - Overall, small consequences

Caveats on Reducing Flow

- When flow gets really low, AC and fan efficiency drop significantly
- Coil can ice up
- Much sadness
- Interaction with refrigerant charge

http://webcon.ca/~rhardy/gallery2/v/ACFreezeup/cimg0248.jpg.html

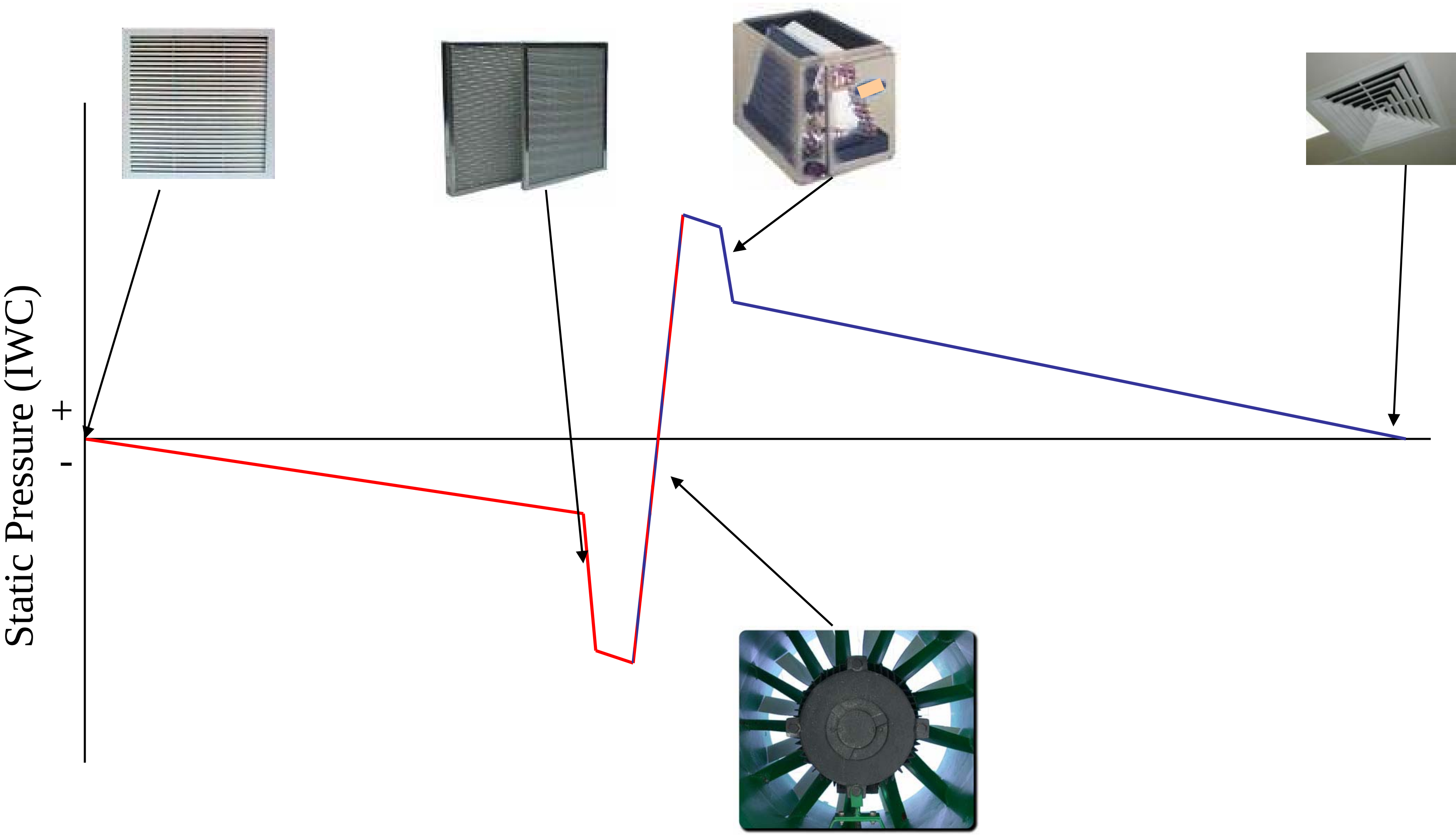
Secondary Impacts

- Duct leakage is enormous problem
  - 10 – 20% of fan flow in **typical** home
  - Similar data for commercial buildings (limited data)
- How can a filter affect duct leakage?

Duct Leaks

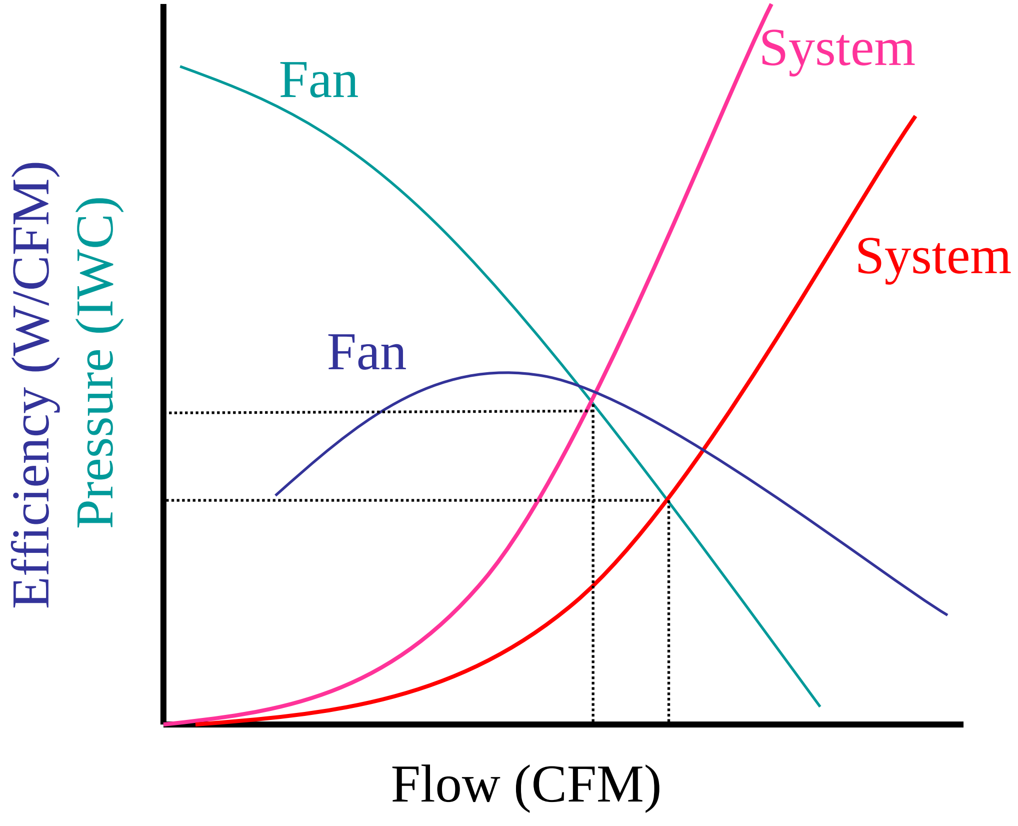
- Need
  - Hole
  - Pressure difference
- Return leaks
  - Negative pressure, air sucked in, adds to cooling load (sensible and latent)
- Supply leaks
  - Air leaks out, diminishes delivered capacity

Simple Duct System



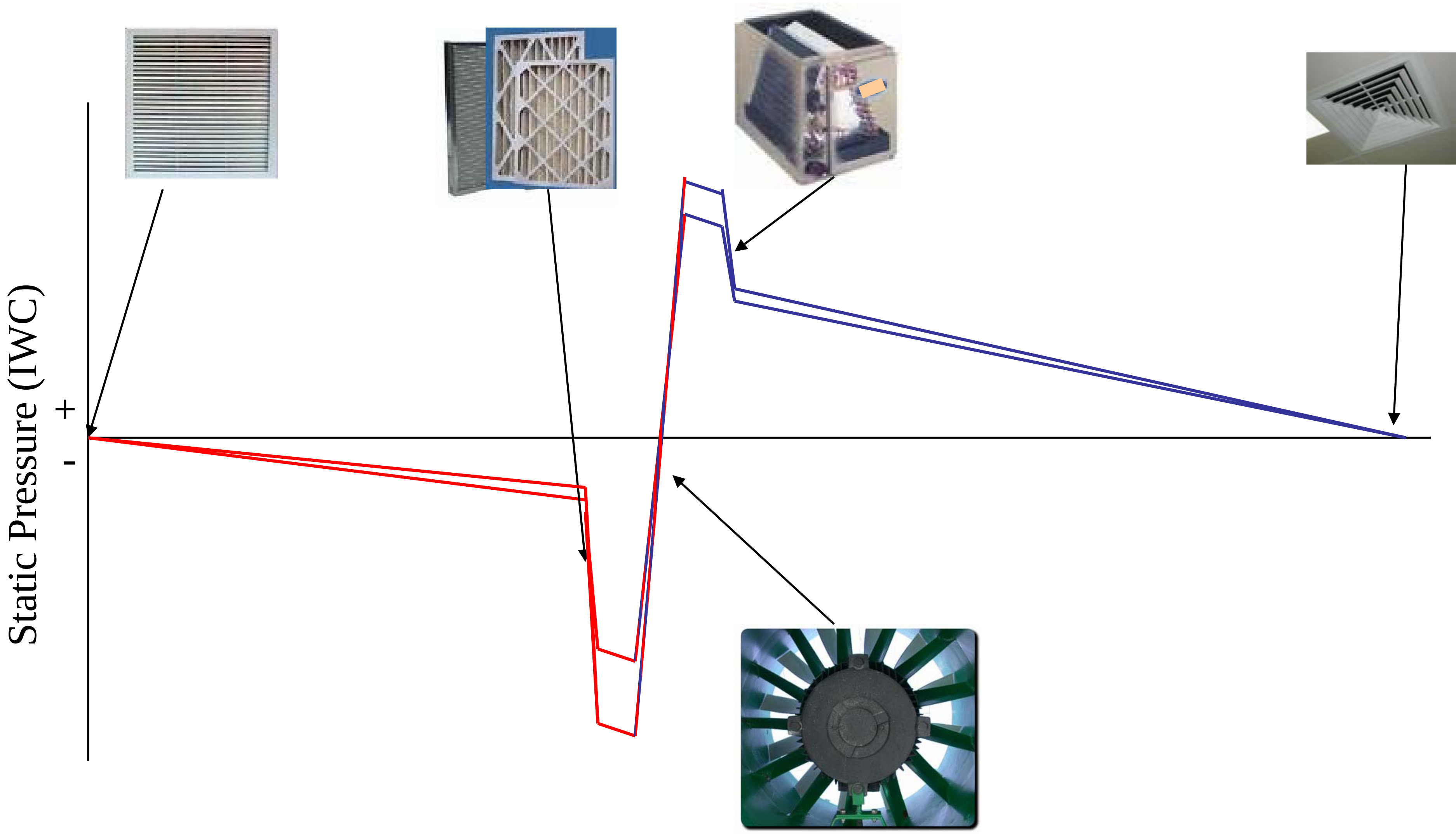
Filter with a Higher pressure Drop

- Intersection of fan and system curve gives actual flow and pressure

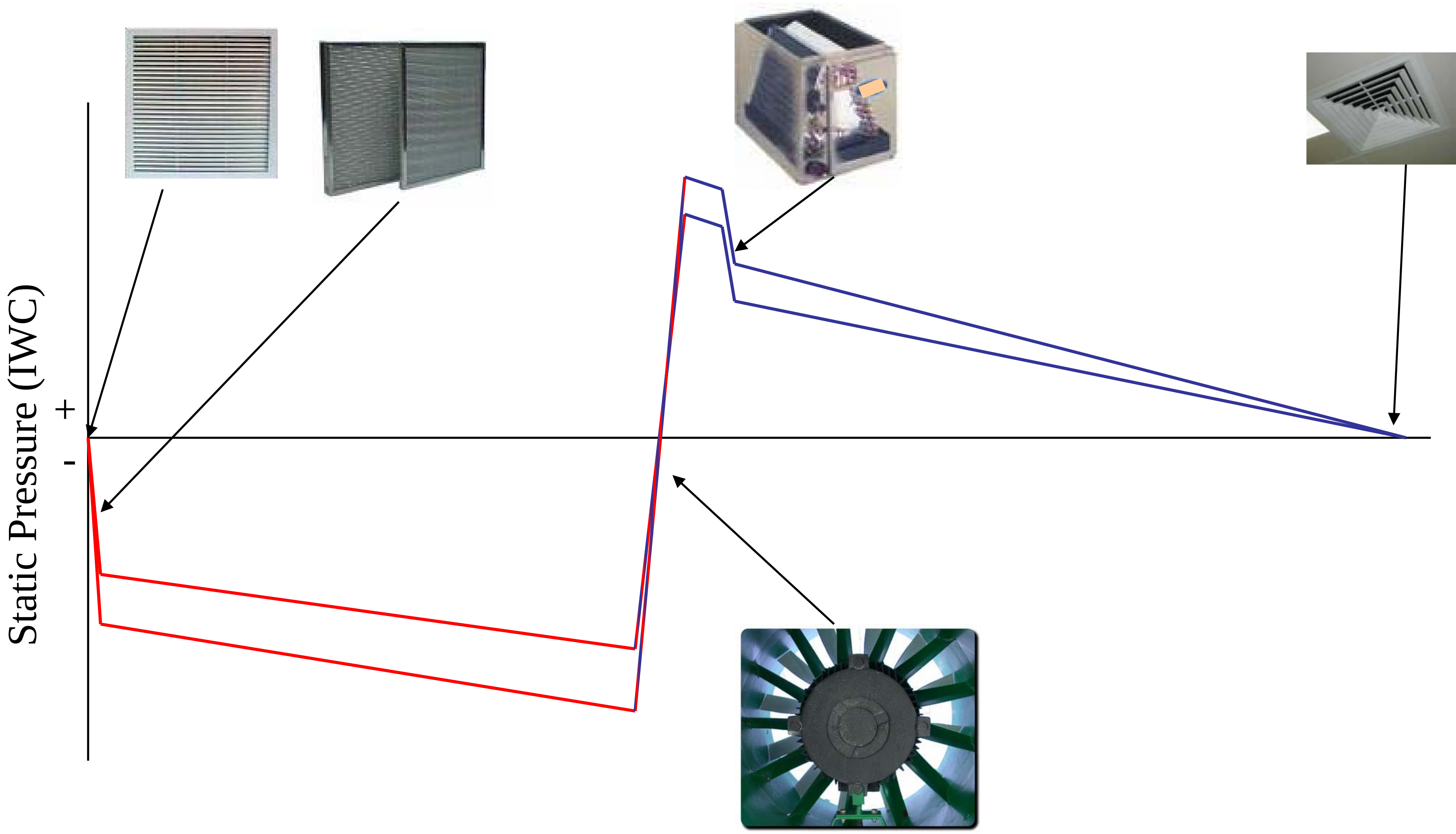


- If you add a pressure drop
  - $\Delta P_{fan}\uparrow$
  - Flow↓

Higher Pressure Drop Filter



Duct System With Grille Filter

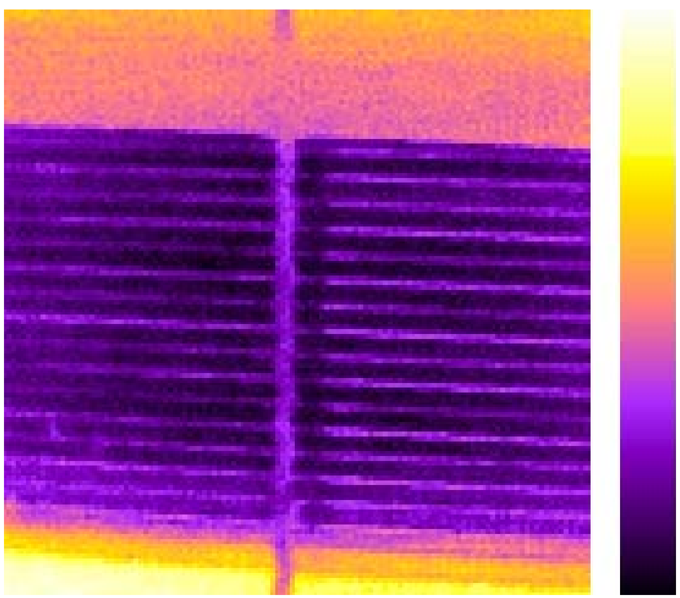


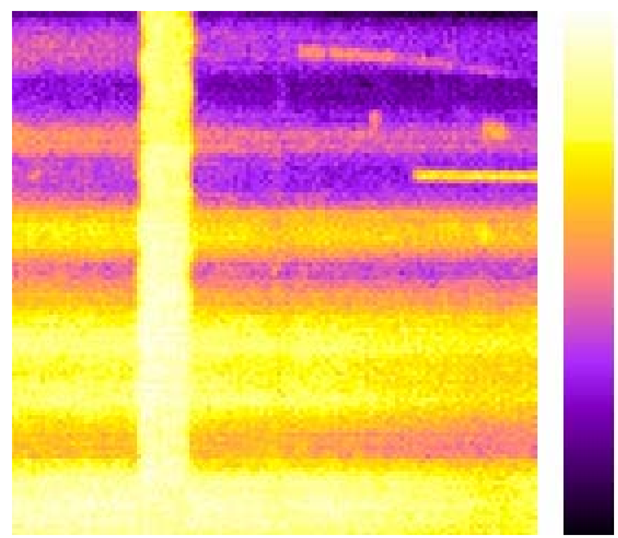
Filter Pressure Drop and Duct Leakage

- Impact on duct leakage depends on
  - Location and size of leaks
  - Size of filter pressure drop relative to rest of system
  - Location of filter

Secondary Impact – Coil Fouling

- Higher efficiency filter better protects coils
- Good anecdotal and experimental evidence





Coil Fouling in Smaller Systems

- Pressure drop goes up
  - Air flow, capacity, power consumption, system efficiency, fan energy decrease
- Heat transfer decreases (small impact)
- Surface area increases
  - Heat transfer increases (small impact)

Krafthefter *et al.* (1986, 1987) *ASHRAE Trans.*, Siegel and Nazaroff (2003) *Atmos. Environ.*, Yang *et al.* (2004) ARTI Report

Tertiary Effects

- Air conditioners are supposed to cool (sensible) and dehumidify (latent)
- Most air conditioners are oversized (1.5 - 2×)
  - Cold and clammy feeling (not enough dehumidification)
- **Primary**: If flow ↓, latent fraction ↑, sensible ↓
- Secondary: Reduced fan energy reduces sensible load
- Secondary: Duct leakage also effects sensible/latent balance

Tertiary Effects II

- Speculative
- People turn down the thermostat temperature to get dehumidification
- Filter impacts on sensible/latent balance could affect this behavior

What About Heating?

- (Other than heat pump systems)
- Effects on heating capacity are very small
  - No sensible/latent issues
- Still have fan energy impacts
  - But, fan energy adds to heating
  - Overall much smaller impact
- Generally, less of a concern

Just Tell Us the &#%*@ Answer

- Do higher efficiency filters cause systems to use more energy?
  - I do not know
  - It depends
  - Maybe
- We are conducting a study to answer this
  - ASHRAE RP-1299
  - Can not present any data until final report has been approved by ASHRAE

Summary

- Sample (Central Texas)
  - 8 residential buildings
  - 8 light-commercial buildings
- Study design
  - 1 day a month for 1 year
  - 3 months each with high, medium, low efficiency filters
  - 3 months for
    - Repetition
    - Changing non-filtration parameter (i.e. duct leakage, filter location, coil cleaning, etc.)

Monitoring

- Power draw of fan and AC (or heating) system
- Pressure drop of filter and coil
- Capacity of system (temp & RH upstream and downstream)
- Outdoor temp. and RH
- 10 second time resolution
- Initial and periodic measurement
  - Duct leakage, fan flow rate, duct pressures

Analysis

- Many factors affect AC capacity and efficiency, not just flow and fan energy
  - Entering wet-bulb temperature
  - Outside temperature
- So, have to compare data at similar conditions

Additional Monitoring

- Manufactured home
  - UTest House
- Continuous 30 second data for 1 year
  - Fan is running continuously
- Change parameters every month

So, I will have an answer

- Presentations at ASHRAE TC 2.4 Research Committee
- Final report to ASHRAE by April **31**st, 2009
  - All measurements
  - Quasi-empirical model

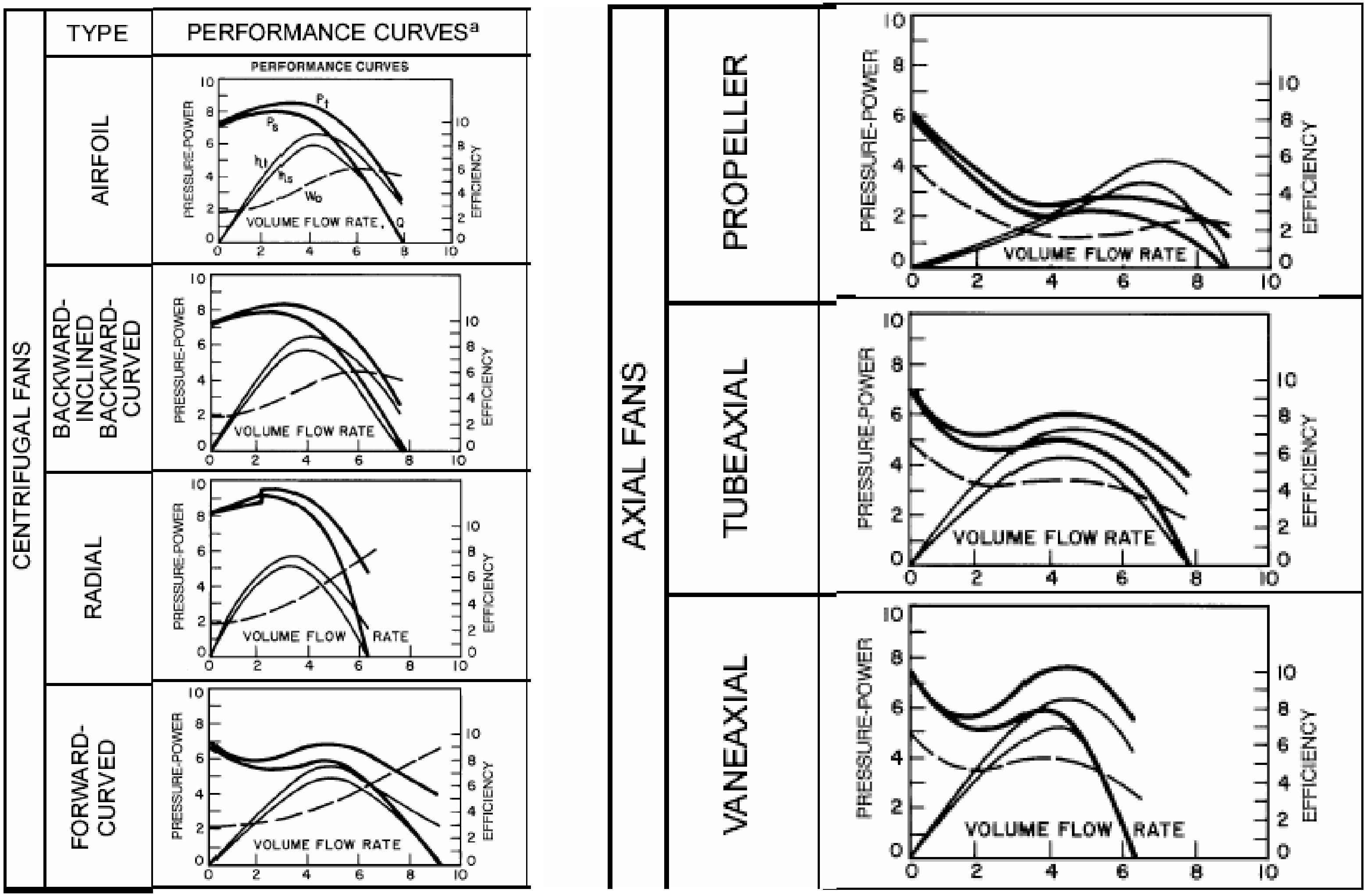
Partial Summary

- Adding a higher pressure drop filter, has a variety of implications
  - Some lead to more energy use, others to less
- Very dependant on system and its installation and maintenance
- We will know more of answer in 1.5 years

What About Commercial Systems?

- Bigger buildings do not typically have constant speed fans
  - Fan increases speed (RPM) to deliver correct flow
- Energy consequences are much clearer and can be significant Fisk (2002) *Indoor Air*, Matela (2006) *Facilities Engineering Journal*
- But…

Fan Curves



ASHRAE Handbook of HVAC Systems and Equipment (2004)

Impacts in Commercial Buildings

- Shapes of fan and system curves are critical
  - Efficiency curve
    - Change in intersection can result in higher or lower efficiency
  - In steeper portions of fan curve
    - Change in filter pressure will result in a small change in fan speed (but a big change in pressure)
  - In flatter portions of fan curve
    - Change in filter pressure may result in a big change in fan speed (but a small change in pressure)
- How important is filter to overall system pressure drop?

Big Picture

- Energy consequences of filtration are important, but poorly understood
  - I hope that I have raised a reasonable doubt about the connection between higher efficiency filters and increased energy use

The Elephants in the Closet

- Duct/system design is really terrible
  - If it is designed at all
- Fans rarely operate at peak efficiency
- Returns are often undersized
  - Return pressures are very high
- Users change filters
- Air conditioning is not well-maintained