Modeling the Impacts of Filter Pressure on Energy Consumption

BERG Summer meeting

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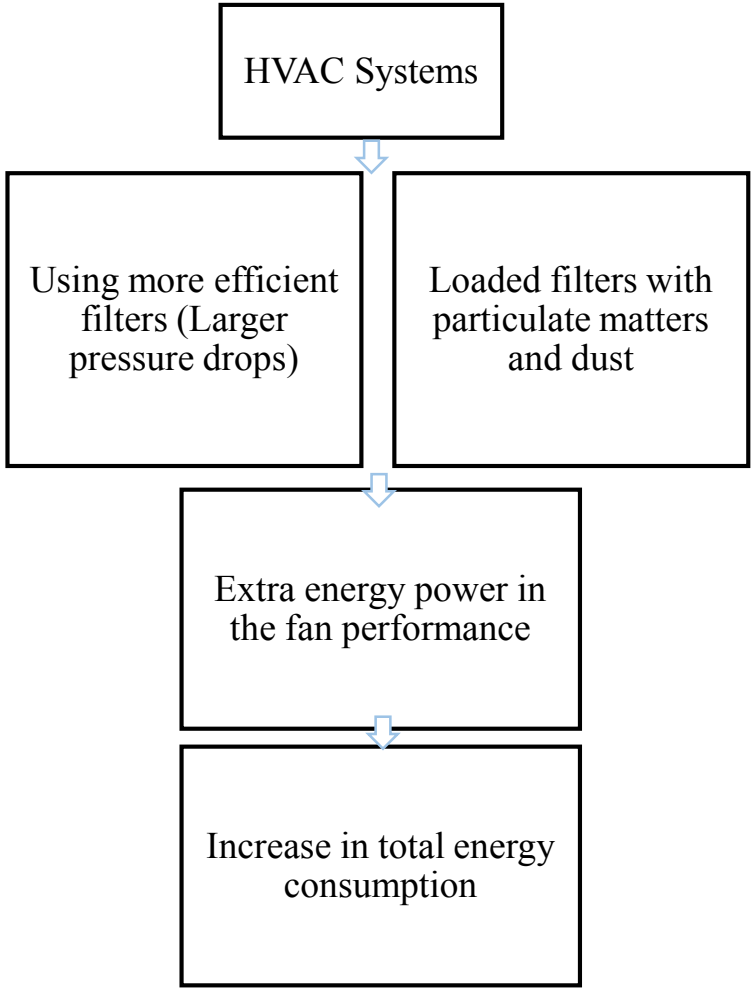
advancing energy, environmental, and sustainability
research within the built environment
at Illinois Institute of Technology

Introduction

Filters are used in heating, ventilating, and air-conditioning (HVAC) systems to protect the equipment and improve indoor air quality.



Filter Efficiency

Minimum Efficiency Reporting Value (MERV)

⇩

The most widely used measure of filter efficiency in the United States

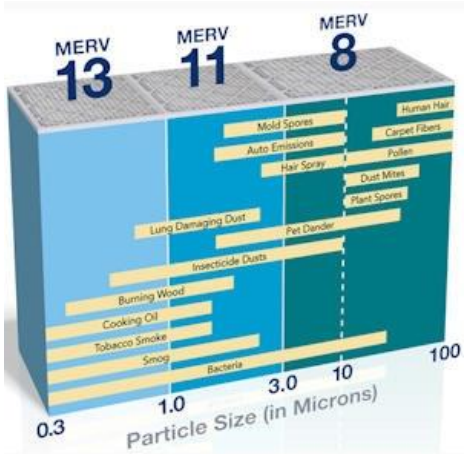
ASHRAE Standard 52.2 ⇨

1- Low-MERV filters (MERV <4) : remove 20% of of 3-10 µm particles

2- Mid-MERV filters (MERV 5-9) : remove at least 20-85% of 3-10 µm particles and up to 50% of 1-3 µm particles

3- Higher-MERV filters (MERV 10-12) : remove 85-90% 3-10 µm particles and up to 50-80% of 1-3 µm particles

4- Very-high-MERV (MERV >13) : remove submicron particles and have minimum efficiencies of 95% for all particle sizes



HVAC Systems' Fans

Permanent Split- Capacitor (PSC)

90% of residential buildings

Do not have flow control → Airflow rates change

Electronically Commuted Motors (ECM)

Generally use in commercial buildings

Have flow control → Maintain airflow rates

Objectives

Determine the impacts of filters pressure on energy consumption of prototypical homes

- ✓Find out the filter pressure drop and HVAC airflow rate according to different MERV rates
- ✓Calculate fan power draw to determine which kind of filters consume the most energy
- ✓Determine how a dirty filter effect amount of energy consumption

Methodology

The Methodology of this project is done in several steps by defining:

1- 15 cities from different climate zones

2- Required climate data

3- Home geometries

4- Building codes

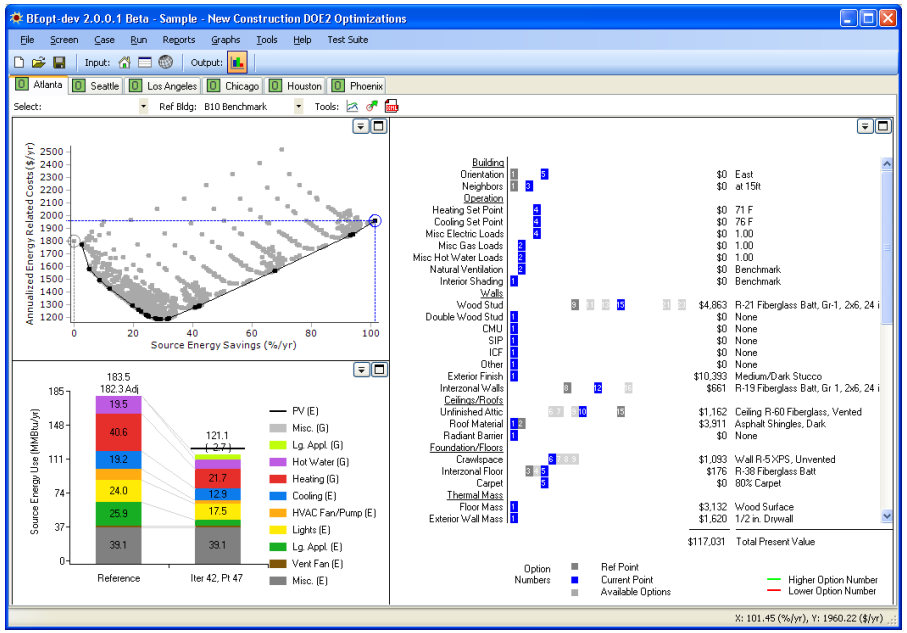
5- Required HVAC system data

Afterwards energy simulations of whole case study buildings are determined by using BEopt software.

Energy Simulation

- BEopt (Building Energy Optimization) is a software that is capable of evaluating residential building designs and identify cost-optimal efficiency at various levels.

- We use EnergyPlus as a simulation engine.



http://beopt.nrel.gov/sites/beopt.nrel.gov/files/help/prntdoc/printed.htm

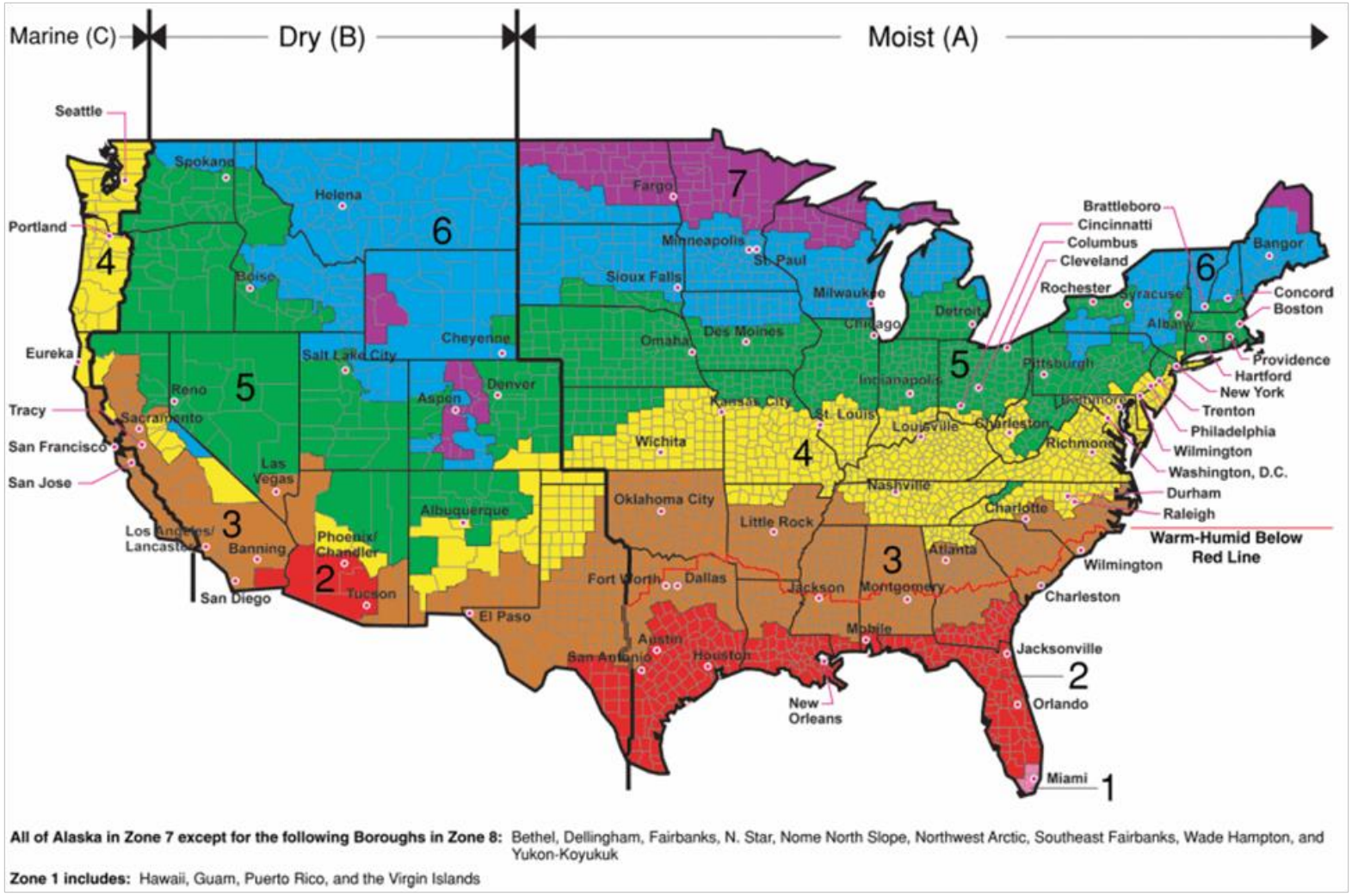
BEopt
Building Energy Optimization
with Hour-by-Hour Simulations

NREL
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
www.nrel.gov

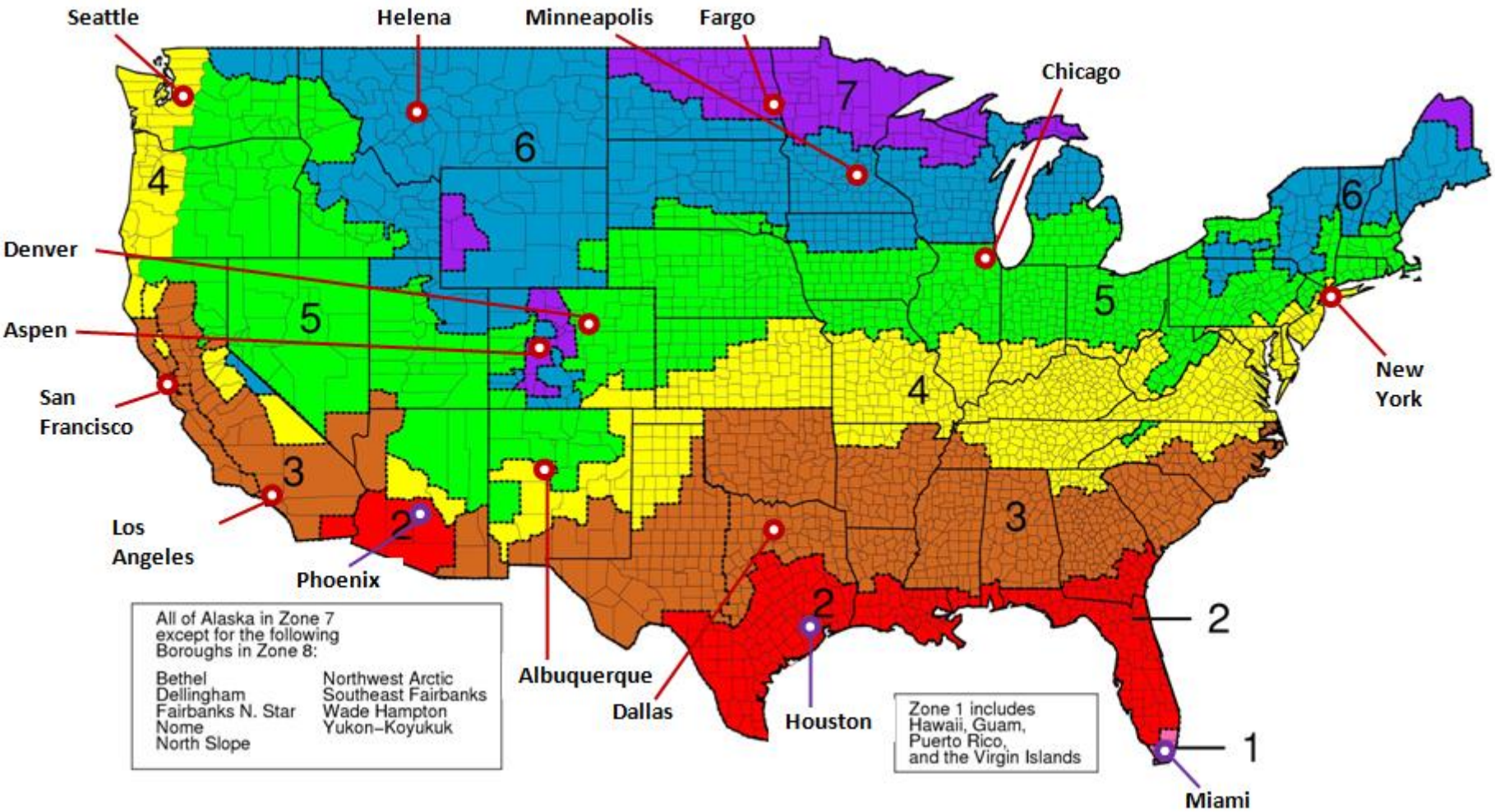
EnergyPlus

1- 15 cities from different climate zones

According to ASHRAE Standard climate zones



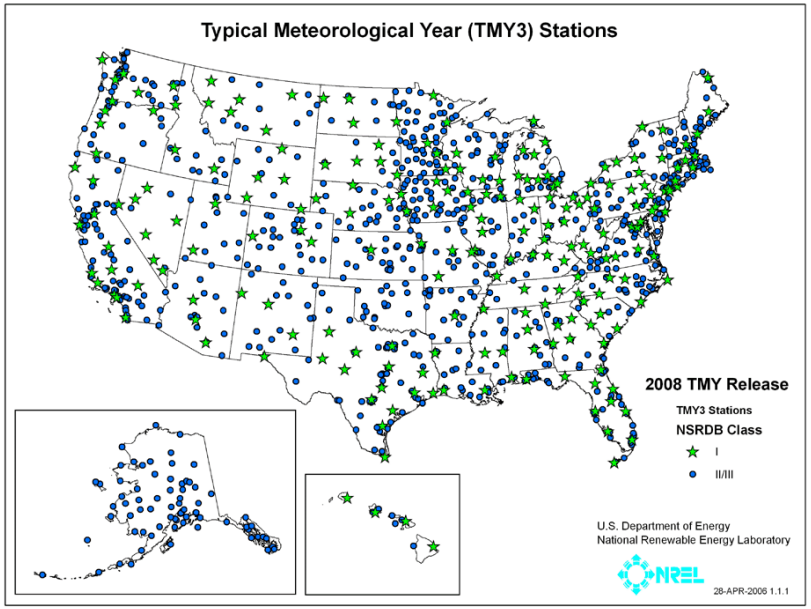
1- 15 cities from different climate zones



2- Climate Data

National Solar Radiation Data Base

- ✓Data files for the typical meteorological year (TMY)
- ✓Data sets derived from the 1961-1990 and 1991-2005
- ✓Data sets are hourly values of solar radiation and meteorological elements for a 1-year period
- ✓TMY3 data set contains data for 1020 locations



http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/usTMYmaps3medium.gif

3- General home geometries

According to US Census Bureau

- ✓Floor Area: 2025 ft^2 (1800-2400 ft^2)
- ✓No. of stories: 1
- ✓No. of bedrooms: 3
- ✓No. of bathrooms: 2
- ✓Exterior Wall Materials: Vinyl, Light
- ✓Type of foundation: Slab on ground

4- Building codes

- New energy efficient homes
- Existing homes
- Old homes

4- Building codes

✓New energy efficient homes

According to International Energy Conservation Code 2009 in order to meet or exceed most minimum energy code requirement.

New Energy Efficiency Home

	Walls// Wood Stud	Walls// Wall Sheathing	Ceilings/ Roofs// Unfinished Attic	Foundation/ Floors// Slab	Windows & Doors// Windows// U-value
1A-Miami	R-13 Fiberglass Batt, Gr-1	OSB	R-30 Fiberglass, Vented	Uninsulated	1.2
2A-Houston	R-13 Fiberglass Batt, Gr-1	OSB	R-30 Fiberglass, Vented	Uninsulated	0.65
2B-Phoenix	R-13 Fiberglass Batt, Gr-1	OSB	R-30 Fiberglass, Vented	Uninsulated	0.65
3A-Dallas	R-13 Fiberglass Batt, Gr-1	OSB	R-30 Fiberglass, Vented	Uninsulated	0.5
3B-Los Angeles	R-13 Fiberglass Batt, Gr-1	OSB	R-30 Fiberglass, Vented	Uninsulated	0.5
3C-San Francisco	R-13 Fiberglass Batt, Gr-1	OSB	R-30 Fiberglass, Vented	Uninsulated	0.5
4A-New York	R-13 Fiberglass Batt, Gr-1	OSB	R-38 Fiberglass, Vented	2ft R10 Exterior XPS	0.35
4B-Albuquerque	R-13 Fiberglass Batt, Gr-1	OSB	R-38 Fiberglass, Vented	2ft R10 Exterior XPS	0.35
4C-Seattle	R-13 Fiberglass Batt, Gr-1	R-5 XPS	R-38 Fiberglass, Vented	2ft R10 Exterior XPS	0.35
5A-Chicago	R-13 Fiberglass Batt, Gr-1	R-5 XPS	R-38 Fiberglass, Vented	2ft R10 Exterior XPS	0.35
5B-Denver	R-13 Fiberglass Batt, Gr-1	R-5 XPS	R-38 Fiberglass, Vented	2ft R10 Exterior XPS	0.35
6A-Minneapolis	R-13 Fiberglass Batt, Gr-1	R-5 XPS	R-49 Fiberglass, Vented	4ft R10 Exterior XPS	0.35
6B-Helena	R-13 Fiberglass Batt, Gr-1	R-5 XPS	R-49 Fiberglass, Vented	4ft R10 Exterior XPS	0.35
7A-Fargo	R-21 Fiberglass Batt, Gr-1	OSB	R-49 Fiberglass, Vented	4ft R10 Exterior XPS	0.35
7B-Aspen	R-21 Fiberglass Batt, Gr-1	OSB	R-49 Fiberglass, Vented	4ft R10 Exterior XPS	0.35

4- Building Codes - Cont'd

New Energy Efficiency Home

	Windows & Doors// Windows// SHGC	Airflow// Air Leakage	Airflow// Mechanical Ventilation	Space Conditioning// Central Air Conditioner	Space Conditioning// Furnace	Space Conditioning// Ducts
1A-Miami	0.3	3ACH50	ERV, 72%	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
2A-Houston	0.3	3ACH50	ERV, 72%	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
2B-Phoenix	0.3	3ACH50	ERV, 72%	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
3A-Dallas	0.3	3ACH50	Supply	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
3B-Los Angeles	0.3	3ACH50	ERV, 72%	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
3C-San Francisco	0.3	3ACH50	Supply	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
4A-New York	0.3	3ACH50	Supply	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
4B-Albuquerque	0.3	3ACH50	Supply	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
4C-Seattle	0.3	3ACH50	Supply	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
5A-Chicago	0.3	3ACH50	Supply	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
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7A-Fargo	0.3	3ACH50	ERV, 72%	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8
7B-Aspen	0.3	3ACH50	ERV, 72%	SEER 16	Gas, 98% AFUE	7.5% Leakage, R-8

5- Required HVAC system data

$$W_{fan} = \frac{\Delta P_{system} \times Q_{fan}}{\eta_{fan} \times \eta_{motor}}$$

W_{fan}: Fan power draw (W)

ΔP_{system}: External system pressure (Pa)

Q_{fan}: Air flow rate (m^3/h)

η_{fan}: efficiency of the fan

η_{motor}: efficiency of the fan motor

Department of Energy Document

Fan curve for PSC blowers

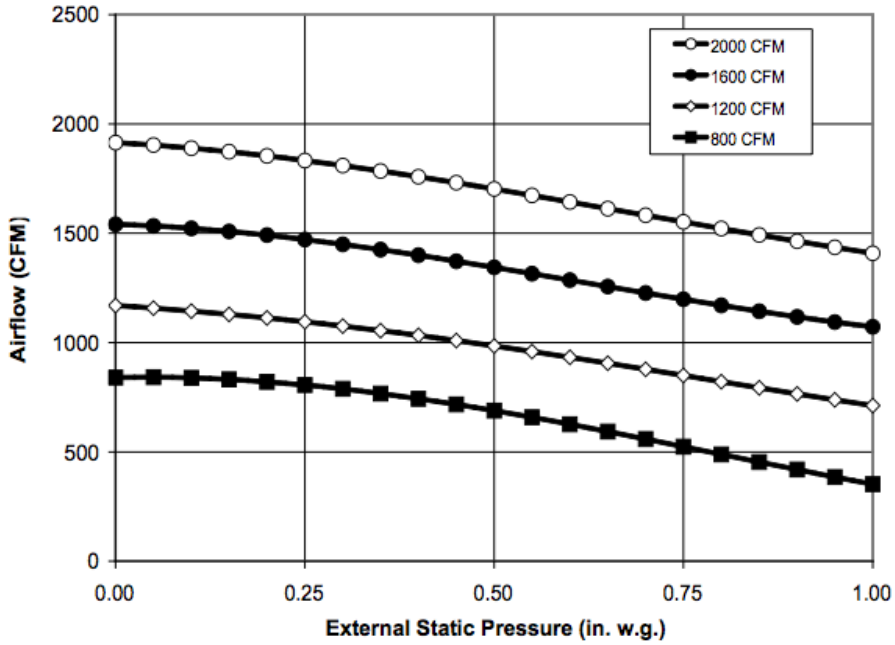


Figure 7-F.3.3 Fan Curves for Single-Stage Virtual Model Furnaces

Fan curve for ECM blowers

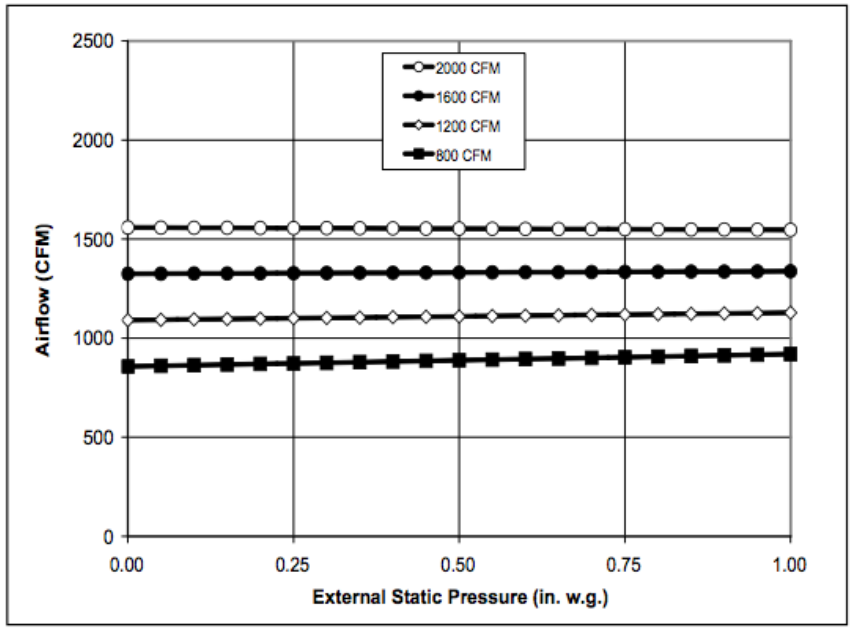
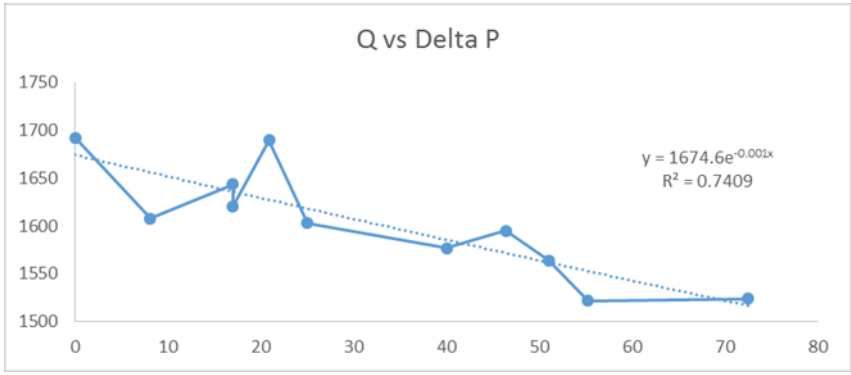


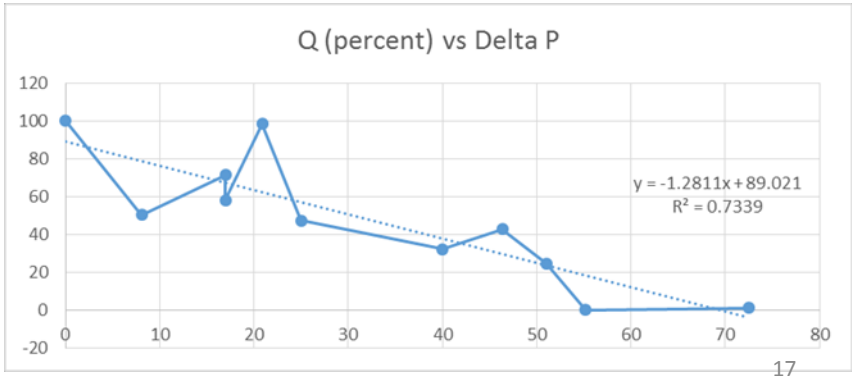
Figure 7-F.3.4 Fan Curves for Two-Stage Virtual Model Furnaces – High Fire

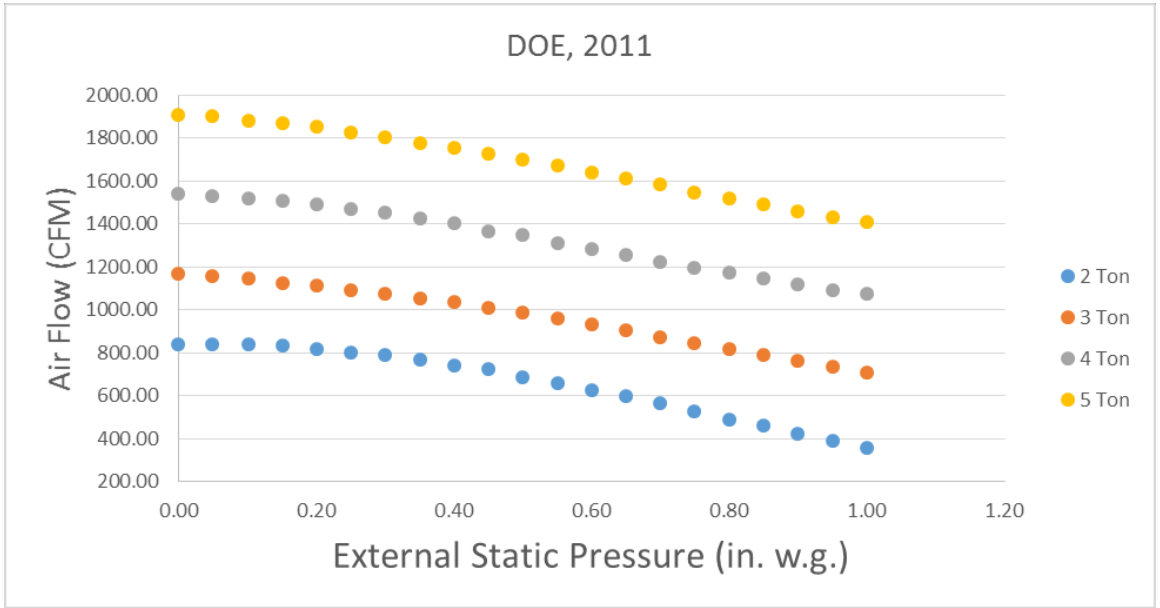
DOE, 2011

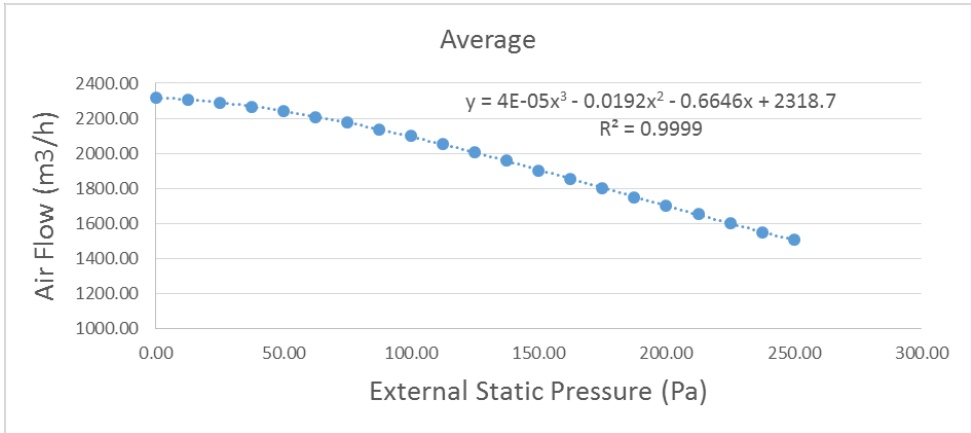
Finding the relation between ΔP_{filter} and ΔP_{system} (1st way)

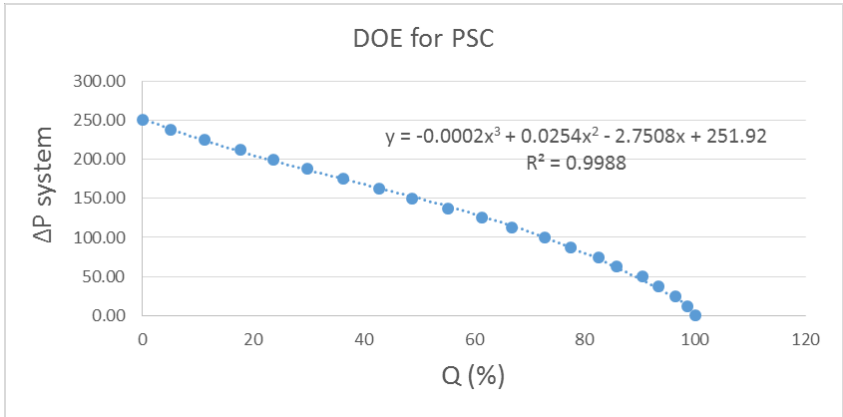
MERV Rate	Stephens et al, 2010		Stephens & Siegel, 2012		Stephens & Siegel, 2013	
	ΔP_{filter} (Pa)	Q ($\frac{m^3}{h}$)	ΔP_{filter} (Pa)	Q ($\frac{m^3}{h}$)	ΔP_{filter} (Pa)	Q ($\frac{m^3}{h}$)
No Filter	0	-	0	1673	0	1712
2	-	-	-	-	-	-
3	-	-	-	-	-	-
<4	20.9	1690	-	-	-	-
4	-	-	-	-	17	1644
<5	-	-	8.1	1608	-	-
6	-	-	-	-	51	1564
7	-	-	55.2	1522	-	-
8	46.35	1595	-	-	-	-
10	-	-	-	-	17	1621
11	82.25	1540	89.2	1460	46	1572
13	-	-	-	-	40	1577
16	-	-	-	-	25	1603



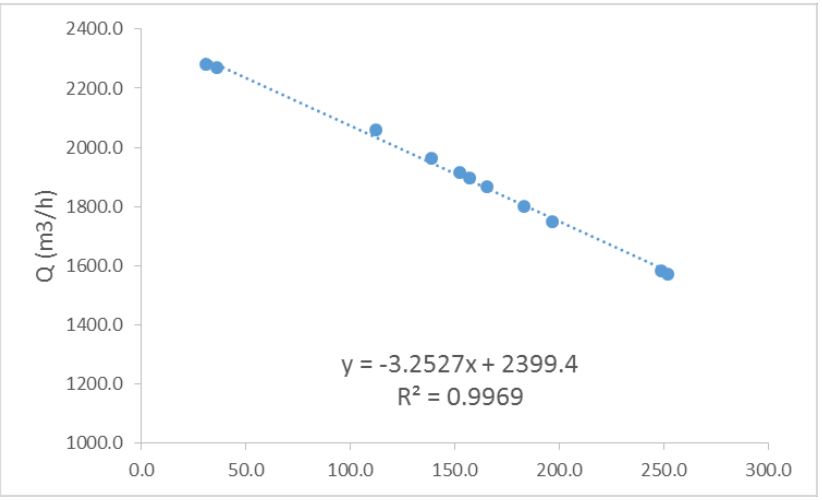



DOE, 2011
Air Flow (CFM)
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
External Static Pressure (in. w.g.)
2 Ton
3 Ton
4 Ton
5 Ton


Average
Air Flow (m3/h)
2400.00
2200.00
2000.00
1800.00
1600.00
1400.00
1200.00
1000.00
y = 4E-05x³ - 0.0192x² - 0.6646x + 2318.7
R² = 0.9999
0.00
50.00
100.00
150.00
200.00
250.00
300.00
External Static Pressure (Pa)

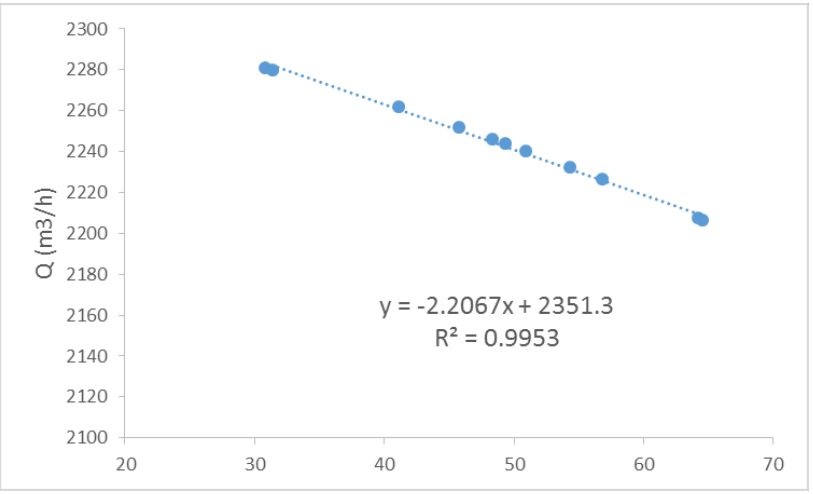

DOE for PSC
ΔP system
300.00
250.00
200.00
150.00
100.00
50.00
0.00
y = -0.0002x³ + 0.0254x² - 2.7508x + 251.92
R² = 0.9988
0
20
40
60
80
100
120
Q (%)

	ΔP	Q	Q %	ESP (DOE)	Q (DOE)
No Filter	0	1692.5	100.0	30.8	2281.1
MERV<5	8.1	1608	50.4	152.1	1914.1
MERV 4	17	1644	71.6	111.9	2060.1
MERV 10	17	1621	58.1	138.7	1964.0
MERV<4	20.9	1690	98.5	36.1	2271.5
MERV 16	25	1603	47.5	157.1	1895.4
MERV 13	40	1577	32.3	182.9	1799.6
MERV 8	46.35	1595	42.8	165.0	1866.0
MERV 6	51	1564	24.6	196.6	1750.0
MERV 7	55.2	1522	0.0	251.9	1572.3
MERV 11	72.48	1524	1.2	248.7	1581.1



Changing the minimum value for airflow rate to 0

	ΔP	Q	Q %	ESP (DOE)	Q (DOE)
No Filter	0	1692.5	100	31	2281
MERV<5	8.1	1608	95	48	2246
MERV 4	17	1644	97	41	2262
MERV 10	17	1621	96	46	2252
MERV<4	20.9	1690	100	31	2280
MERV 16	25	1603	95	49	2244
MERV 13	40	1577	93	54	2232
MERV 8	46.35	1595	94	51	2240
MERV 6	51	1564	92	57	2226
MERV 7	55.2	1522	90	65	2207
MERV 11	72.48	1524	90	64	2208
Full Loaded		0	0		



Finding the relation between ΔP_{filter} and ΔP_{system} (2nd way)

Using collected data for 17 sites and 4 different MERV rates from Stephens, et al, 2010, ASHRAE research project.

In 8 sites filters play an important role

In 2 sites filters are not important at all

	ΔP	Filter Pressure Drop Fraction of Return Plenum Pressure Drop	ESP
Site 11 MERV 2	26.8	99	27.1
	27.6	96	28.8
	33.6	100	33.6
	34.5	93	37.1
Site 11 MERV 6	49	98	50.0
	50.7	97	52.3
	48	86	55.8
	55.5	100	55.5
	53.1	100	53.1
	67	100	67.0
	78.3	100	78.3
Site 11 MERV 11	50.1	100	50.1
	48	100	48.0
	54	100	54.0
	63.5	100	63.5

	ΔP	Filter Pressure Drop Fraction of Return Plenum Pressure Drop	ESP
Site 10 MERV 2	15.7	15	104.6667
	15.6	15	104
	16	14	114.2857
	36.6	29	126.2069
Site 10 MERV 6	36.8	29	126.8966
	37.8	30	126
	37.2	30	124
	37.3	30	124.3333
Site 10 MERV 11	37.3	30	124.3333
	36.5	29	125.8621
	37.5	30	125
	40.2	32	125.625
Site 10 MERV 7	40.1	31	129.3548
	41.7	31	134.5161
	42.6	33	129.0909

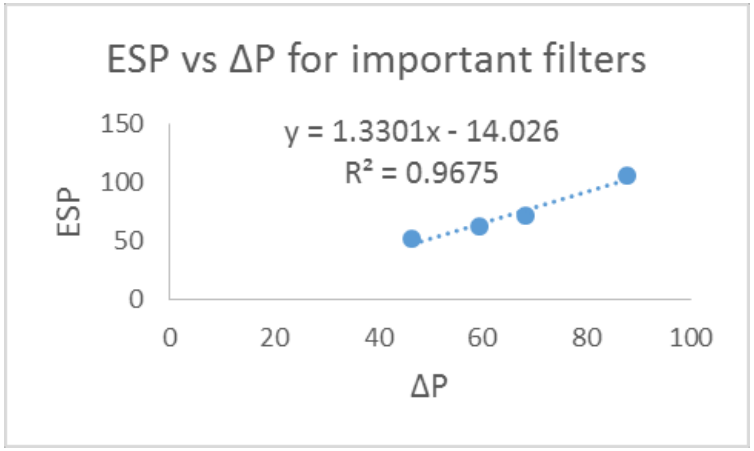
Average values for filter pressure and external static pressure

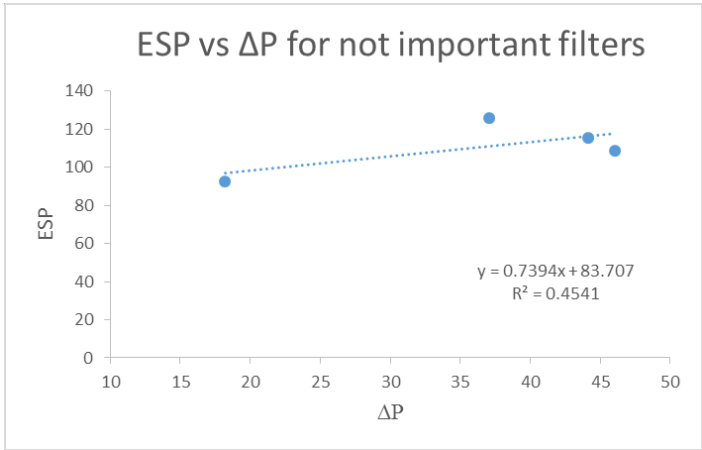
For the sites that Filter is important

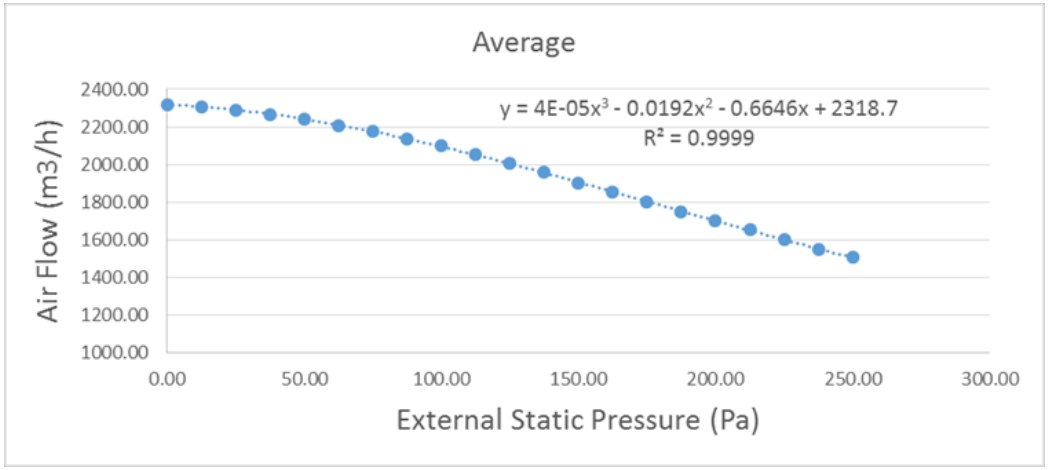
	ΔP	%	ESP
MERV 2	46.54286	90.8	51.80373
MERV 6	59.32222	96.03704	62.36609
MERV 7	87.825	80.75	106.0287
MERV 11	68.39388	94.5102	72.29952

For the sites that filter is not important

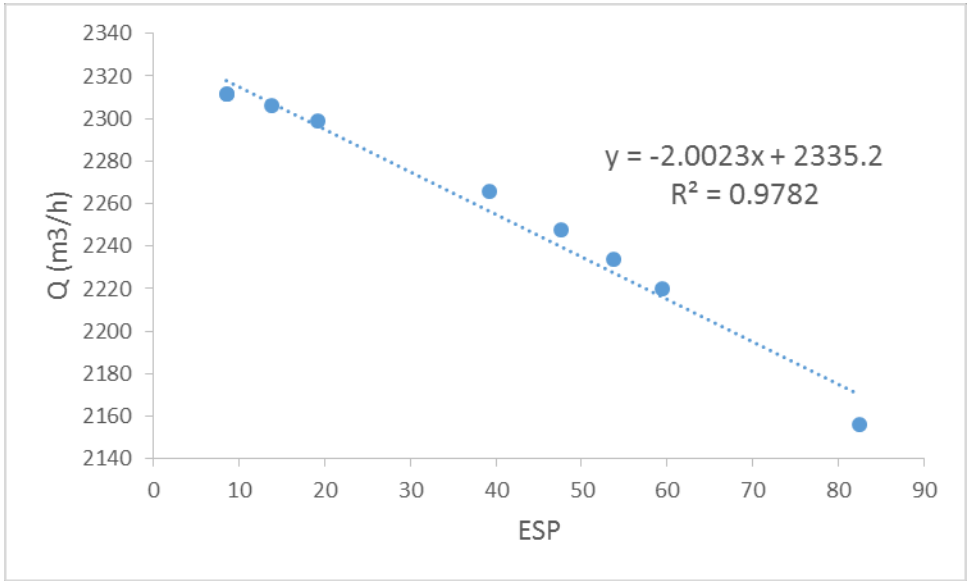
	ΔP	%	ESP
MERV 2	18.2	20.28571	92.51662
MERV 6	37.1	29.5	125.7759
MERV 7	44.1125	39.125	115.3813
MERV 11	46.075	43.41667	108.7233







	ΔP	ESP	Q (DOE)
No Filter	0	-14.03	2324.13
MERV<5	8.1	-3.25	2320.66
MERV 4	17	8.59	2311.60
MERV 10	17	8.59	2311.60
MERV<4	20.9	13.77	2306.01
MERV 16	25	19.23	2299.11
MERV 13	40	39.18	2265.60
MERV 8	46.35	47.62	2247.82
MERV 6	51	53.81	2233.58
MERV 7	55.2	59.40	2219.87
MERV 11	72.48	82.38	2156.01



Thank You!

Questions?