Energy Performance Comparison of Fixed Speed, Danfoss VSH 088, and Mechanically Modulated Compressors When Cooling and Dehumidifying 100% Outdoor Air to 55 F for 8760 Hours per Year in 8 US Cities.

Prepared May 4, 2011

S. A. Mumma, Ph.D., P.E.

Executive Summary: VSH 088 vs. Fixed Speed annual energy consumption

Energy consumption necessary to cool and dehumidify 100% outdoor air (OA) to 55 F was modeled using hourly US weather data for eight (8) select cities. The three (3) compressor types simulated included: fixed speed, Danfoss VSH 088 variable speed, and mechanically modulated.

The VSH 088 performed much more energy efficiently than the fixed speed for all flow rates and US cities analyzed, and was relatively insensitive to over sizing or geographic location. Overall for all conditions analyzed, the VSH 088 used 37% less annual energy. Depending upon air flow rates and location, the energy savings ranged from about 56% to 19% compared to the fixed speed arrangement.

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Executive Summary:
VSH 088 vs. Mechanically Modulated annual energy consumption

Energy consumption necessary to cool and dehumidify 100% outdoor air (OA) to 55 F was modeled using hourly US weather data for eight (8) select cities. The three (3) compressor types simulated included: fixed speed, Danfoss VSH 088 variable speed, and mechanically modulated.

The VSH 088 performed more energy efficiently than the mechanically modulated for all flow rates and US cities analyzed. However the VSH displayed significantly better energy performance compared to the mechanically modulated for oversized applications, reducing energy use by as much as 50%. In the absence of over sizing, the VSH 088 used between about 10-20% less energy than the mechanical modulating arrangement. Overall for all conditions analyzed, VSH 088 used 21% less annual energy than the mechanically modulating.

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Objective

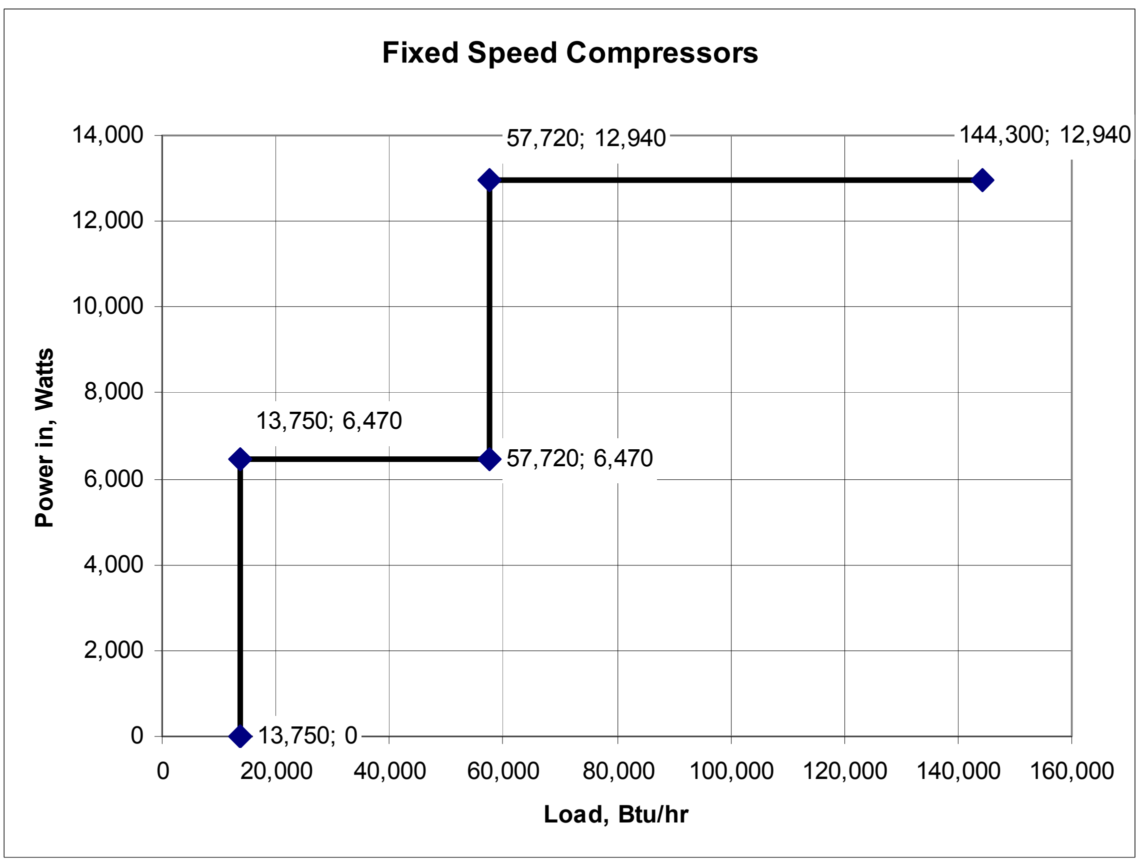
Compare the energy consumed by 3 compressor arrangements when cooling and dehumidifying 100% outdoor air (OA) for eight selected US cities. The 3 compressor arrangements included: fixed speed, Danfoss VSH 088 variable speed, and mechanically modulated.

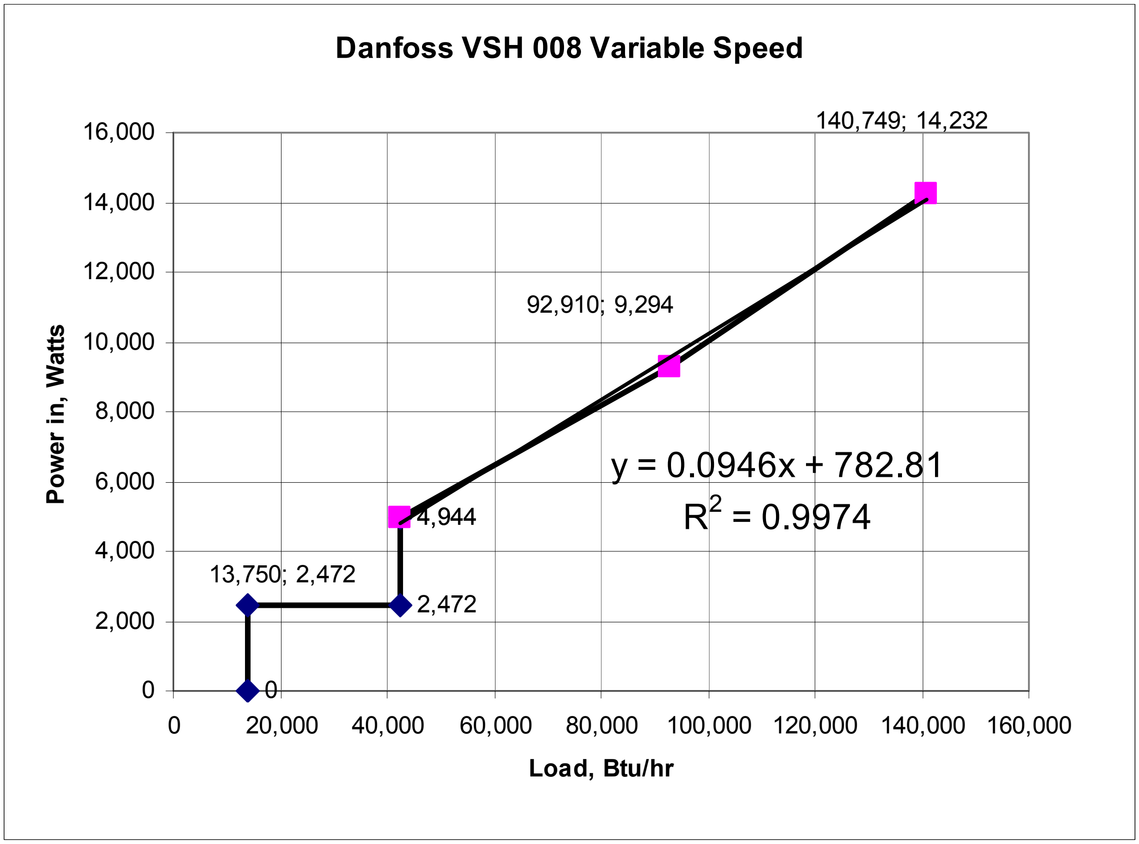
US Cities selected

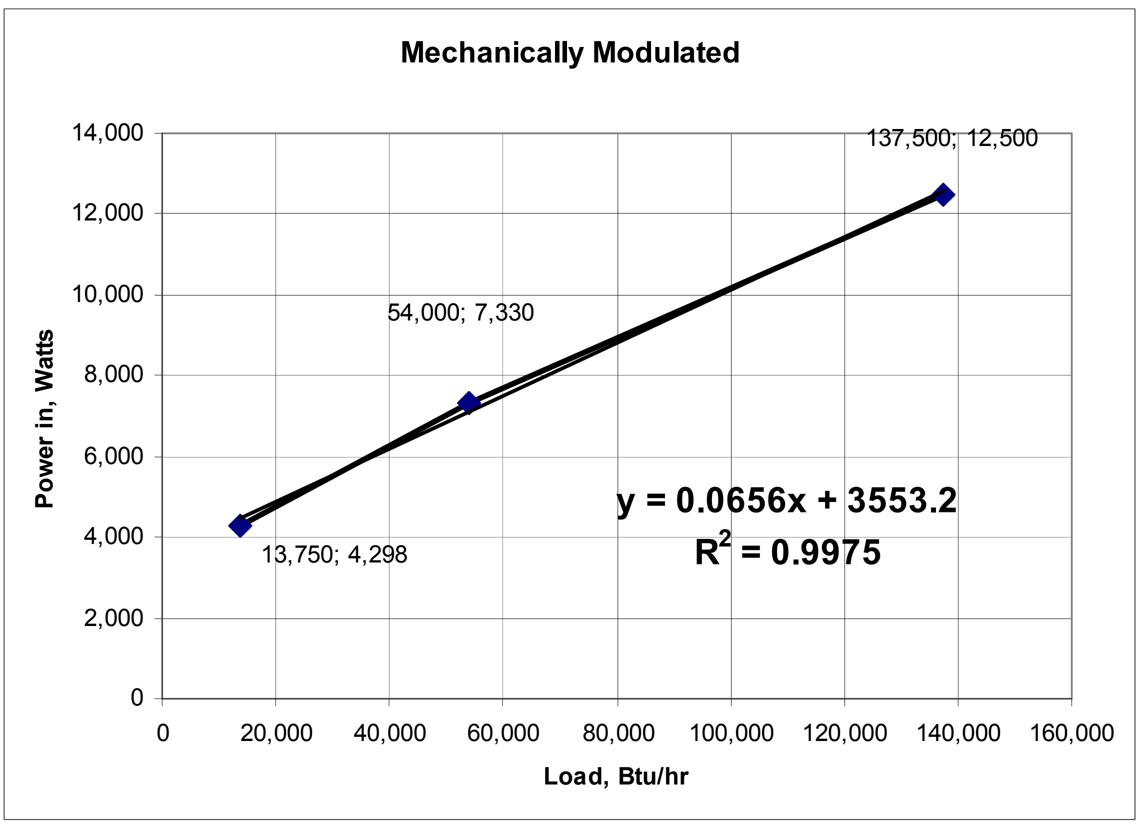
The 8 cities selected for analysis include: Chicago IL, Raleigh NC, Denver CO, Washington DC, Austin TX, Sacramento CA, Long Beach CA and Atlanta GA.

Compressor performance maps

The performance maps for the 3 arrangements are illustrated by the figures below:




Danfoss VSH 008 Variable Speed
Power in, Watts
Load, Btu/hr
140,749; 14,232
92,910; 9,294
4,944
13,750; 2,472
2,472
0
y = 0.0946x + 782.81
R2 = 0.9974
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000


Mechanically Modulated
Power in, Watts
Load, Btu/hr
137,500; 12,500
54,000; 7,330
13,750; 4,298
y = 0.0656x + 3553.2
R2 = 0.9975
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
20,000
40,000
60,000
80,000
100,000
120,000
140,000
160,000

The equations characterizing the compressor power input vs. load is reflected on the figures along with the degree of fit R^2. The equations were employed in the simulations.

OA Flow Rate Basis for the Selected Cities

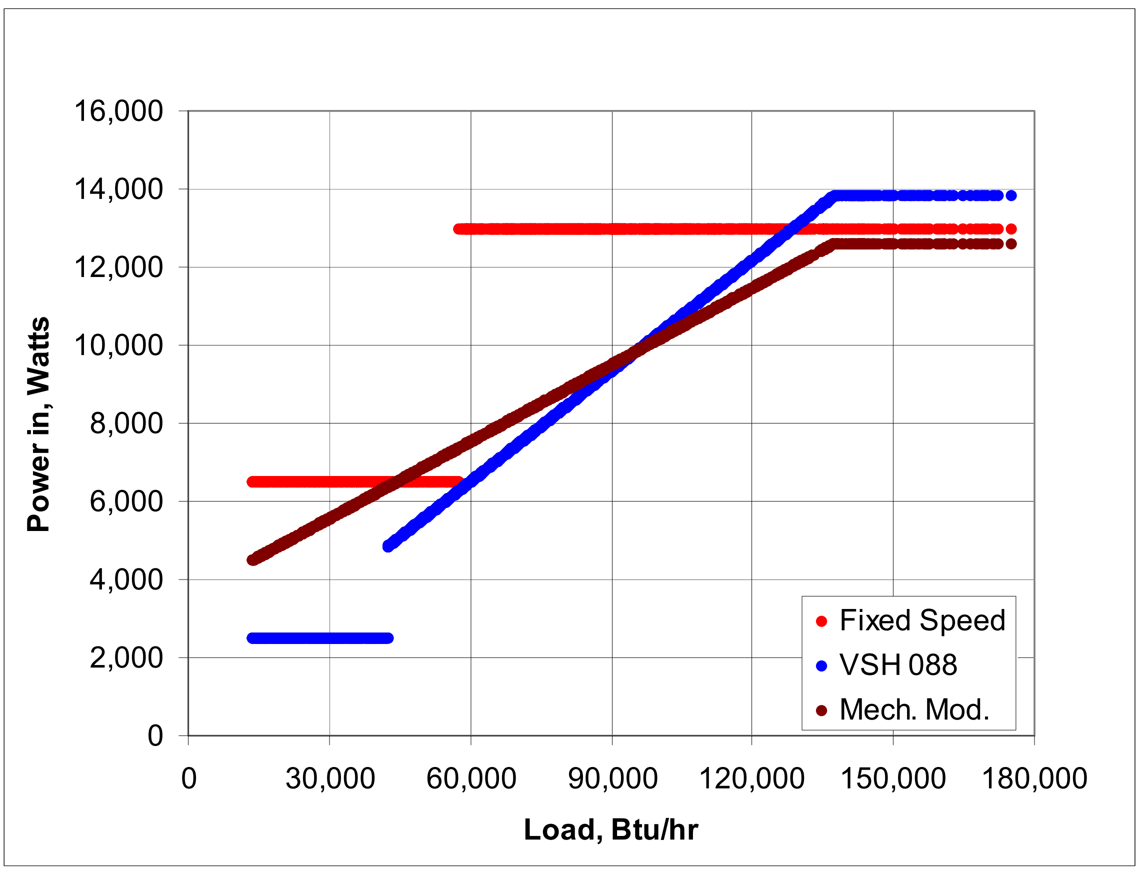
The ASHRAE published Dehumidification Design Conditions for the 8 US cities; listed in the table below, suggest that a common outdoor air (OA) flow rate of 2,000, 1,900, and 1,700 cfm would generally provide loads not exceeding the upper load boundary set by the mechanically modulated compressor of 137,500 Btu/hr. The exceptions to the flow range are the 3 dry climates of Denver, Sacramento, and Long Beach. A 4th OA cfm flow rate was analyzed as follows: Denver, 4,200 cfm, Sacramento and Long Beach each 3,200 cfm.

location	Dehumidification Design conditions, ASHRAE HOF Climate Design Info											
	0.4% HR Gr	**MDB**	**h**	**cfm**	**1% HR Gr**	**MDB**	**h**	**cfm**	**2% HR Gr**	**MDB**	**h**	**cfm**
Chicago	130	84	40.57	1,763	123	82	38.97	1,941	115	80	37.22	2,184
Raleigh	134	82	40.70	1,749	130	81	39.82	1,842	135	80	38.79	1,964
Denver/Boulder	96	69	31.54	3,677	90	68	30.36	4,285	85	68	29.58	4,812
DC/Baltimore	132	83	40.63	1,756	125	81	39.04	1,933	120	80	38.00	2,069
Austin	137	81	40.92	1,727	134	80	40.20	1,801	130	80	39.57	1,870
Sacramento	85	84	33.51	2,972	80	81	31.99	3,488	77	79	31.03	3,917
Long Beach	101	76	34.04	2,827	96	75	33.02	3,121	92	75	32.39	3,336
Atlanta	133	82	40.54	1,765	128	81	39.50	1,878	124	80	38.63	1,984

Note: the cfm OA flow rates presented in the table above are based on a load of 137,500 Btu/hr

Basis for Uniform Performance Comparisons

In order to make the energy use comparisons uniformly based, the upper load allowed for each configuration was 137,500 Btu/hr (mechanically modulated upper limit) even though both the Danfoss VSH 088 and the fixed speed arrangements had greater peak capacities. So in the simulations, when a load exceeding 137,500 Btu/hr was encountered, the load was limited and the power input for 137,500 Btu/hr was used as the power consumed. To illustrate the limiting load and associated power input, the figure below shows a case where there were some hours when the required OA load exceeded 137,500 Btu/hr. The simulated load used in the energy analysis was limited; thus limiting the power input for such high OA enthalpy hours. The figure also shows that the occurrences of excess load decreased as it approached the worst TMY weather data hour. By the same token, when the OA flow rate was low for the dry locations of these simulations, the full capacity of the compressors was never utilized. To correct this, the additional elevated flow rates for the dry locations were simulated. These events will be pointed out in the results.



Weather Data Used in the Analysis
Typical Meteorological Year (TMY) weather data was used for each of the 8 US cities analyzed.

Results
The results of the energy simulation are presented in the table below. Columns 2 and 3 present the maximum TMY cooling condition for each location. It should be noted that the maximum TMY enthalpy (h) for Chicago of 44.03 Btu/lbmDA is noticeably above even the 0.4% ASHRAE dehumidification Design conditions enthalpy (h) of 40.57 Btu/lbmDA. This difference between the extreme TMY data enthalpy and the ASHRAE Design conditions occurred for all US Cities. As a result, for all but the 3 dry locations, even at the 1,700 cfm OA air flow required load (column 7) exceeded the actual load (column 8) when the capacity limit of 137,500 Btu/hr was imposed. In the 3 dry US locations, 2,000 cfm was not enough air flow to fully load the compressors. So as noted above an air flow in excess of 2,000 cfm was simulated and presented. The actual hours of cooling for the various cities and flow rates are presented in Column 6.

Columns 9, 10, and 11 contain the annual energy consumption for each compressor arrangement. And columns 12, 13, and 14 present the kW/T performance metric for each compressor arrangement. The Danfoss VSH 088 compressor energy consumption as a percentage of the mechanically modulated arrangement is displayed in column 15. Finally, the energy used by the Danfoss VSH 088 compressor as a percentage of that used by the fixed speed compressors is presented in column 16.

To facilitate reading the results table, rows for alternate US cities was highlighted. There is no other significance to the highlighting.

Column # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
				Cell # @		Req'd	Actual							VSH 088	VSH 088
location	max TMY	max h	SA	13,750	Hrs of	Cooling	cooling	Fixed speed	VSH 088	Mech. mod.	Fixed speed	VSH 088	Mech. mod.	energy as %.	energy as %..
	DB/WB		cfm	Btu/hr	cooling	TH	TH	kWh	kWh	kWh	kW/T	kW/T	kW/T	Mech mod	Fixed speed
Chicago	88/80.3	44.03	2,000	2,621	2,616	13,705	13,594	25,362	16,557	20,000	1.87	1.22	1.47	82.79	65.28
Chicago			1,900	2,598	2,593	12,994	12,932	24,644	15,722	19,397	1.91	1.22	1.50	81.05	63.8
Chicago			1,700	2,556	2,551	11,581	11,566	23,053	14,106	18,172	1.99	1.22	1.57	77.62	61.19
Raleigh	90/79.9	43.56	2,000	3,931	3,926	25,037	24,784	41,861	30,380	33,463	1.69	1.23	1.35	90.79	72.57
Raleigh			1,900	3,908	3,903	23,759	23,637	41,059	29,008	32,479	1.74	1.23	1.37	89.31	70.65
Raleigh			1,700	3,850	3,845	21,195	21,179	39,085	26,066	30,378	1.85	1.23	1.43	85.81	66.69
Denver	75.9/71.9	35.77	4,200	1,173	1,163	5,853	5,760	10,980	7,018	8,670	1.91	1.22	1.51	80.95	63.92
Denver			2,000	919	914	2,580	2,580	6,405	3,071	5,282	2.48	1.19	2.05	58.14	47.95
Denver			1,900	903	898	2,433	2,433	6,218	2,874	5,109	2.56	1.18	2.10	56.25	46.22
Denver			1,700	837	832	2,105	2,105	5,648	2,480	4,817	2.68	1.18	2.29	51.48	43.91
DC/Baltimore	91.9/82.1	46.03	2,000	3,255	3,250	20,517	20,106	33,955	24,631	27,379	1.69	1.23	1.36	89.96	72.54
DC/Baltimore			1,900	3,244	3,239	19,479	19,225	33,333	23,572	26,646	1.73	1.23	1.39	88.46	70.72
DC/Baltimore			1,700	3,180	3,175	17,359	17,290	31,694	21,190	24,896	1.83	1.23	1.44	85.11	66.86
Austin	90/80.1	43.79	2,000	5,743	5,738	44,535	44,041	65,231	53,659	55,061	1.48	1.22	1.25	97.45	82.26
Austin			1,900	5,723	5,718	42,308	42,108	64,273	51,382	53,539	1.53	1.22	1.27	95.97	79.94
Austin			1,700	5,680	5,675	37,855	37,833	62,481	46,401	50,174	1.65	1.23	1.33	92.48	74.26
Sacramento	104/73.8	37.37	3,200	2,674	2,664	14,085	13,948	25,395	17,055	20,442	1.82	1.22	1.47	83.43	67.16
Sacramento			2,000	2,309	2,304	8,472	8,472	19,080	10,444	14,860	2.25	1.23	1.75	70.28	54.74
Sacramento			1,900	2,261	2,256	8,049	8,049	18,614	9,974	14,526	2.31	1.24	1.80	68.66	53.58
Sacramento			1,700	2,173	2,168	7,202	7,202	17,553	9,044	13,859	2.44	1.26	1.92	65.26	51.52
Long Beach	87.1/73.5	37.12	3,200	4,276	4,266	22,483	22,380	41,919	27,480	32,783	1.87	1.23	1.46	83.82	65.55
Long Beach			2,000	3,871	3,866	13,682	13,682	30,525	16,545	24,511	2.23	1.21	1.79	67.50	54.2
Long Beach			1,900	3,814	3,809	12,998	12,998	29,613	15,579	23,972	2.28	1.20	1.84	64.99	52.61
Long Beach			1,700	3,721	3,716	11,630	11,630	27,789	14,030	22,895	2.39	1.21	1.97	61.28	50.49
Atlanta	84/79.4	43.10	2,000	4,282	4,277	27,018	26,887	46,383	33,019	36,366	1.73	1.23	1.35	90.80	71.19
Atlanta			1,900	4,268	4,263	25,652	25,589	45,633	31,467	35,295	1.78	1.23	1.38	89.15	68.96
Atlanta			1,700	4,219	4,214	22,898	22,891	43,782	28,243	32,996	1.91	1.23	1.44	85.60	64.51