Cost-effectiveness Analysis of Pump VSD

DOE Proposal: C-5; ICC proposal: TBA
for 2018 IECC commercial code
Pacific Northwest National Laboratory
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PURPOSE

Investigate the cost-effectiveness of available VSD pump applications in commercial buildings.

BASIS

The current IECC pump threshold is 10 hp for cooling pumps with no requirement for VSDs on heating pumps. The cost-effectiveness analysis is conducted according to the DOE cost-effectiveness methodology.[1] In the DOE method, the long term economic impacts for two cases are determined:

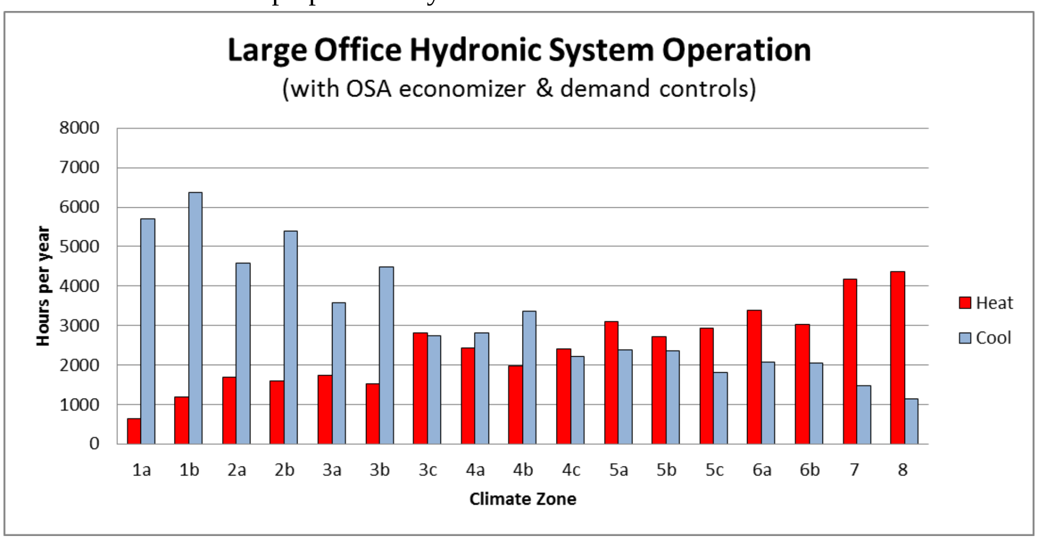
- Scenario 1 is for publicly-owned buildings and is based on a FEMP method. [2]
- Scenario 3 is for privately-owned buildings and is based on the 90.1-2016 scalar method.[3]

15.0 year measure life (Electronic controls)[4]

Scenario 1 electric UPW factor with 3% discount and EIA energy escalation:[5] 12.65

The Scenario 3 threshold for electric savings over a 15 year measure life is 10.8 years. In Scenario 3, measures are found cost-effective when the simple payback ≤ the scalar threshold.

Annual operation: Pump operation was estimated based on a large office prototype[6] with operation based on ASHRAE Standard 90.1-2010. Pump operation by climate zone is shown below:



[1] Hart, R., and Liu, B. (2015). *Methodology for Evaluating Cost-effectiveness of Commercial Energy Code Changes.* Pacific Northwest National Laboratories for U.S. Department of Energy; Energy Efficiency & Renewable Energy. PNNL-23923 Rev1. https://www.energycodes.gov/development/commercial/methodology.

[2] Fuller, Sieglinde, and Stephen Petersen. "LIFE-CYCLE COSTING MANUAL for the Federal Energy Management Program." NIST, U.S. Department of Commerce, 1995. http://fire.nist.gov/bfrlpubs/build96/PDF/b96121.pdf.

[3] Based on the approach and assumptions established by the ASHRAE Standard 90.1project committee for 90.1-2016.

[4] ASHRAE. (2015). *2015 ASHRAE Handbook Applications*. American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE], Atlanta, GA.

[5] Rushing, Amy S., Joshua D. Kneifel, and Priya Lavappa. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2014: Annual Supplement to NIST Handbook 135*, 2015. http://dx.doi.org/10.6028/NIST.IR.85-3273-29.

[6] Details on building prototypes available at: https://www.energycodes.gov/commercial-prototype-building-models.

Hours at low loads are removed to be conservative; with operation below 5% peak cooling load and below 2% peak heating load removed. Note that many pumps in commercial buildings operate longer hours to allow tenant schedule flexibility. Chilled water pumps often have longer hours because they must often serve equipment cabinets or server rooms that have 24/7 operation. The pump load profile is based on the large office building prototype with a VAV reheat system.

Pump Operating profiles:

	Time at flow	
Flow	Cooling	Heating
0%	0%	0%
10%	40%	41%
20%	15%	11%
30%	30%	6%
40%	7%	5%
50%	3%	17%

	Time at flow	
Flow	Cooling	Heating
60%	2%	14%
70%	1%	4%
80%	1%	1%
90%	1%	0.5%
100%	0%	0.5%

Motor efficiencies are from IECC for 1800 rpm general purpose open drip-proof motors.

Energy Prices

Energy rates for 2014 commercial annual average from July 2015 EIA STEO.

Energy escalation/present value rates from NIST 2015 annual supplement.[7]

Commercial Sector			2014	Annual Average		Most recent full year
			2015 July	EIA Short Term Energy Outlook		
Prices	$0.1075	$/kWh	$1.0555	$/therm	(2014 EIA average)	for Scenario 1 analysis
	$0.1013	$/kWh	$1.0000	$/therm	SSPC 90.1 for 2016	for Scenario 3 analysis

Cooling Cost-effectiveness

The cost-effectiveness threshold is evaluated using Scenario 1 for the public sector and Scenario 3 for the private sector.[8] The results are shown in the following table with results in the following columns:

- Motor horsepower (hp) rating.
- Operating hours per year at cost-effectiveness threshold. Any systems with operation longer than the hours shown will be cost-effective at or above the motor horsepower shown.
- Electric kWh savings per year for the given motor horsepower and hours of operation. Savings calculation method is the DOE VSD Calculator for Pumps.[9]
- Annual electric cost savings is shown at the prices for Scenario 1($0.1075) and Scenario 2 ($0.1013).
- The added or incremental cost for a VSD is shown, based on 2014 R. S. Means cost source with 25% General Contractor OH&P.[10] Added controls are included with a deduct for the motor starter replaced by the VSD. Pump controls cost includes a differential pressure sensor.
- The Scenario 1 present value of savings is calculated for a 15 year measure life with a 3% real discount rate and EIA energy escalation.

[7] Lavappa, Priya, and Joshua D. Kneifel. *Energy Price Indices and Discount Factors for Life-Cycle Cost Analysis-2015: Annual Supplement to NIST Handbook 135*, 2015. http://dx.doi.org/10.6028/NIST.IR.85-3273-30.

[8] Hart, Reid, and Bing Liu. "Methodology for Evaluating Cost-Effectiveness of Commercial Energy Code Changes." Pacific Northwest National Laboratories for U.S. Department of Energy; Energy Efficiency & Renewable Energy., August 2015. https://www.energycodes.gov/development/commercial/methodology.

[9] https://ecenter.ee.doe.gov/EM/tools/Pages/VSDPumps.aspx

[10] Means, R. S. *2014 Mechanical Cost Data*. R.S. Means Company, 2014. http://www.rsmeans.com/.

- For Scenario 1, the savings to investment ratio (SIR) indicates a measure is cost-effective when greater than or equal to 1.0.
- For Scenario 3, when the simple payback period (SPP) shown is less than or equal to the scalar threshold of 10.8 years, a measure is cost-effective.

Cooling Pump Cost-effectiveness

Motor HP	Operating hours/year	Annual Savings at Price Shown kWh/year	$0.1075	$0.1013	Added Cost	Scenario 1 PV Savings	SIR	Scenario 3 SPP
2	5,100	3,591	$386	$364	$3,920	$4,884	1.2	10.8
3	3,650	3,726	$401	$377	$4,026	$5,067	1.3	10.7
5	2,350	3,998	$430	$405	$4,274	$5,437	1.3	10.6
7.5	1,700	4,267	$459	$432	$4,650	$5,803	1.2	10.8
10	1,420	4,716	$507	$478	$5,101	$6,413	1.3	10.7
15	1,150	5,729	$616	$580	$6,224	$7,790	1.3	10.7

HEATING PUMP ANALYSIS:

Heating pump electric savings is same as cooling pump savings based on hours of operation; however, different operating hours are used to better match cost-effectiveness for heating pumps. Heating energy from pumping and hydronic friction must be made up at boiler, so there is a net savings that must be calculated. This can be estimated by determining a net price for electricity that accounts for the lost benefit of heating the water with pumping friction.

To calculate net savings for heating pumps, the following net electric price is used:

Item	Scenario 1	Scenario 3	Comment
Heating fossil price, $/therm	$1.0555	$1.0000	EIA Rate/ASHRAE Scalar rate (Blended Fossil Rate)
Fossil boiler efficiency	80%	80%	Boiler Et
Replace lost pump heat	$1.3194	$1.2500	Gas cost of delivered heat/Therm
Conversion factor	0.03413	0.03413	Therms/kWh
Convert to fossil $/kWh saved	$0.0450	$0.0427	Equivalent electric heating cost
Reduce for lost motor heat	91%	91%	Motor efficiency
Net lost heat benefit	**$0.0410**	**$0.0388**	**Replacement cost for heat not delivered to water**
Average Electric Price	$0.1075	$0.1013	ASHRAE Scalar price/EIA price; $/kWh at VSD
Net savings KWh price	**$0.0665**	**$0.0625**	Net Savings rate = Average rate - lost heat benefit
Ratio of net electric savings	61.9%	61.7%	

HEATING COST-EFFECTIVENESS

Similar to cooling pump VSDs, the cost-effectiveness is evaluated using Scenario 1 for the public sector and Scenario 3 for the private sector. For Scenario 1, the savings to investment ratio (SIR) indicates a measure is cost-effective when greater than or equal to 1.0. For Scenario 3, when the simple payback is less than or equal to the scalar threshold of 10.8 years, a measure is cost-effective. The results are shown in the table below, with the column contents similar to the cooling cost-effectiveness table. Here, a net electric price is used to account for the lost benefit of the pumping friction heating the water that must be made up at the boiler.

Heating Pump Cost-effectiveness

Motor	**Operating**	**Annual Savings at Price Shown**			Added	Scenario 1		Scenario 3
HP	**hours/year**	**kWh/year**	$0.0665	$0.0625	Cost	PV Savings	SIR	SPP
2	8,300	5,845	$389	$365	$3,920	$4,917	1.3	10.7
3	5,900	6,023	$401	$376	$4,026	$5,066	1.3	10.7
5	3,800	6,389	$425	$399	$4,274	$5,375	1.3	10.7
7.5	2,800	6,946	$462	$434	$4,650	$5,843	1.3	10.7
10	2,350	7,713	$513	$482	$5,101	$6,489	1.3	10.6
15	1,900	9,223	$613	$576	$6,224	$7,759	1.2	10.8
25	1510	12,138	$807	$759	$8,185	$10,211	1.2	10.8
50	1220	19,428	$1,292	$1,214	$12,966	$16,343	1.3	10.7
100	900	28,394	$1,888	$1,775	$18,904	$23,885	1.3	10.7
200	640	40,213	$2,674	$2,513	$27,029	$33,828	1.3	10.8

REQUIREMENTS BY CLIMATE ZONE:

Variable speed drives are cost-effective based on motor size, hours of operation and system type:

VSD Cost-effective at or above hours/year shown

Motor HP	**Cooling Systems**	**Heating Systems**
2	5100	8300
3	3650	5900
5	2350	3800
7.5	1700	2800
10	1420	2350
15	1150	1900
25		1510
50		1220
100		900
200		640

When this cost-effectiveness information is combined with the hours of operation for cooling and heating systems by climate zone, the following proposal is developed:

> Automatically vary pump flow on heating-water systems, chilled-water systems and heat rejection loops serving watercooled unitary air conditioners as follows:

- Where pumps have continuous operation or operation based on a time schedule, pumps with nominal output motor power of 2 hp or more shall have a variable speed drive.
- Where pumps have automatic direct digital control configured to operate pumps only when zone heating or cooling is required, a variable speed drive shall be provided for pumps with motors having at least the nominal output power shown in the following table based on the climate zone and system served.

Variable Speed Drive Requirements for Demand-controlled Pumps

Chilled Water and heat rejection loop pumps in these climate zones	Heating Water pumps in these climate zones	VSD required for motors with rated output of
0, 1a, 1b, 2b		≥2 HP
2a, 3b		≥3 HP
3a, 3c, 4a, 4b	7, 8	≥5 HP
4c, 5a, 5b, 5c, 6a, 6b	3c, 5a, 5c, 6a, 6b	≥7.5 HP
	4a, 4c, 5b	≥10 HP
7, 8	4b	≥15 HP
	2a, 2b, 3a, 3b	≥25 HP
	1b	≥100 HP
	0, 1a	≥200 HP

Conclusion

VSDs on heating and cooling hydronic pumps are cost effective at different motor sizes based on climate zone.