The Road to Drive Savings

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ABSTRACT

Installations of variable speed drives (VSDs) are among the largest sources of energy reductions achieved by prescriptive commercial and industrial efficiency programs after lighting. Key uncertainties involved in estimating savings from VSDs include: (1) pre-installation operating conditions of the controlled equipment; and (2) the post-installation operation of VSDs to control equipment speed and reduce energy consumption. Program sponsors in the Northeast have conducted research to address both of these issues. In Massachusetts, program administrators (PAs) conducted a pre/post metering study to measure the energy and demand impacts for 26 VSD retrofit installations on various commercial building systems. The Northeast Energy Efficiency Partnerships conducted a metering study to characterize the operation of VSD-controlled equipment for more than 400 VSD retrofit projects across the Northeast, and will use the study results to estimate hourly savings profiles. Data from these studies have produced a wealth of knowledge regarding VSD retrofits, including information about pre-retrofit equipment power, post-retrofit equipment power, and typical VSD control methods.

The paper discusses the scope, methods, and findings from the two evaluation studies, including: a review of the types of VSD projects implemented through PA programs; an analysis of VSD operations in commercial facilities; and a comparison of equipment operations before and after VSD retrofit projects. In addition, the paper compares the evaluation processes for the pre/post and post-only metering efforts, discussing the benefits and challenges of each.

Introduction

A VSD is a motor controller that can be added to an existing drive system to control the operation and speed of connected equipment, such as fans or pumps. VSDs can run affected equipment at a constant speed or dynamically control the connected equipment based on monitored system conditions (such as duct static pressure for a supply fan, or loop differential pressure for a distribution pump in a hydronic heating/cooling system).

By reducing motor speeds, VSDs lower electric demand and energy consumption of existing fans and pumps. As described by the affinity laws, even small reductions in equipment speeds can elicit large reductions in equipment power and energy consumption.

Due to the proven savings potential and relative ease of installing VSDs, program administrators in the Northeast offer prescriptive incentives for VSD installations on a variety of equipment types in existing building systems. Eligible fan system equipment includes: supply fans, return fans, exhaust fans, make-up air fans, boiler draft fans, and cooling tower fans. Eligible pumps include: any pumps in hydronic heating and/or cooling systems, including boiler feedwater pumps and water source heat pump (WSHP) circulation pumps. The Northeast energy-efficiency programs typically provide prescriptive incentives for eligible equipment up to 200 horsepower in size and which serves space conditioning loads.[1]

After lighting, VSD installations provide one of the largest sources of energy reductions achieved by prescriptive commercial and industrial (C&I) efficiency programs. Program administrators (PAs) report energy and peak demand savings from VSD installations to state regulators and to regional capacity markets. Due to VSDs' increased importance in the regional PAs energy-efficiency portfolios, PAs in the Northeast have sponsored two impact evaluations, focusing on energy and demand savings achieved from VSD retrofit installations:

1. A study sponsored by Massachusetts PAs (the Massachusetts study) measured the energy and demand impacts of 26 VSD installations through pre- and post-retrofit metering of equipment power.
2. A regional study, sponsored by the Northeast Energy Efficiency Partnerships (NEEP), is measuring the post-retrofit power for 420 VSD installations, and developing weather-normalized hourly savings load shapes for VSDs on supply fans, return fans, chilled water pumps, hot water pumps, and water source heat pump circulation pumps. NEEP extended this study to monitor equipment performance through the summer of 2013, with final results expected at the end of 2013.

Background

Prescriptive VSDs typically account for 1% to 15% of PAs' Large C&I portfolio of measures, and contribute to their capacity market resources. Each PA collects a different set of project data and uses differing methods for estimating energy and demand savings from VSD installations. Most saving methods described in the PAs' various Technical Reference Manuals (TRMs) derive from theoretical models of equipment operation, based on building types, equipment types, and baseline configurations.

Table 1 shows VSD units installed and savings claimed in 2011 by PAs throughout the Northeast, including: Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, and Maryland. The data show the majority of energy savings is claimed for VSD installations on cooling water pumps, supply and other system fans, water source heat pump circulation pumps, and heating hot water pumps. The data also show more than a quarter of reported VSD installations have no recorded equipment type.

Table 1. VSD Claimed Savings in the Northeast, by Equipment Type (2011)

Equipment Type	Annual Energy Savings Claimed in 2011	Percentage Annual Energy Savings	Percentage of Annual Energy Savings (excluding unknowns)
UNKNOWN	24,695,866	27.83%	NA
Cooling Water Pump	16,711,456	18.83%	26.09%
Supply Air Fan	14,400,588	16.23%	22.48%
Fans, All Types	11,496,292	12.95%	17.95%
Water Source Heat Pump Circulation Pump	3,848,103	4.34%	6.01%
Hot Water Pump	3,674,750	4.14%	5.74%

[1] The programs typically provide incentives for VSDs on larger equipment and for industrial applications through custom programs.

Boiler Feedwater Pump	2,888,901	3.26%	4.51%
Cooling Tower Fan	2,520,766	2.84%	3.94%
Pump, All Types	2,443,487	2.75%	3.81%
Building Exhaust Fan	2,436,508	2.75%	3.80%
Return Air Fan	1,996,261	2.25%	3.12%
Make-Up Air Fan	1,559,276	1.76%	2.43%
Boiler Draft Fan	79,111	0.09%	0.12%
Grand Total	**88,751,365**	**100%**	**59,491**

Past impact evaluations conducted in the Northeast have not specifically covered prescriptive VSDs, given their relatively small amount of energy savings, compared to the PAs entire portfolios. Retrofit evaluations must depict pre-retrofit and post-retrofit energy consumption. Typical energy-efficiency projects do not require or include pre-retrofit metering data; project evaluations must estimate baseline consumption to assess VSD impacts. In an ideal evaluation, pre- and post-metering would be required to best represent actual energy consumption and savings. Unfortunately, this requires lengthy metering periods, due to uncertain, often delayed installation dates. Though only performing post-metering provides less accurate results, it allows collection of significantly more data over a comparable time period. The two Northeast VSD studies combine these methods to determine energy and demand impacts from VSD retrofit installations and to inform future TRM savings approaches for prescriptive VSD projects.

The Massachusetts Study

In 2010, Massachusetts developed a statewide TRM, which included common gross savings algorithms for prescriptive VSDs. These VSD savings assumptions drew upon theoretical models of baseline and VSD operations, and on assumed heating, cooling, and ventilation load profiles by building types. Between 2010 and 2013, independent evaluators performed an impact evaluation of Massachusetts' prescriptive VSD installations. Evaluation sponsors included all electric PAs in Massachusetts, including Cape Light Compact (CLC), National Grid, NSTAR, Unitil, and Western Massachusetts Electric (WMECO). The Massachusetts Energy Efficiency Advisory Council provided oversight and guidance for the impact evaluation.

The study quantified how well prescriptive VSD installations performed, and estimated energy and demand savings resulting from a sample of 2011 and 2012 VSD installations in Massachusetts, using pre- and post-installation metering.

The scope of work included analysis of 26 VSDs at 17 sites. Using pre- and post-installed case measurement and verification, the evaluation sought to calculate energy savings for each monitored drive. The study differed from similar efforts in that it selected its sample of VSDs on an ongoing basis, rather than drawing upon the prior year's completed installations; this allowed monitoring of pre-retrofit conditions.

The NEEP VSD Load Shape Study

In 2012, NEEP began a study to determine hourly savings load shapes from VSD installations across the Northeast. This study includes post-installation metering for VSD projects implemented by the following PAs: Efficiency Maine Trust, Baltimore Gas and Electric, Connecticut Light and Power, Consolidated Edison, NYSERDA, National Grid, NSTAR, Efficiency Vermont, PSNH, LIPA, PEPCO, and First Energy.

The study primarily seeks to: (1) estimate electric demand savings achieved for each hour of the year through the installation of a VSD on HVAC equipment; and (2) provide a tool for calculating energy and demand impacts for specific impact scenarios.

By the end of the study in 2013, the evaluation team will have completed more than nine months of post-retrofit power metering for over 420 VSD installations, collected detailed project information for each installation, and analyzed secondary data (including results from the Massachusetts study) to inform development of VSD and the baseline (pre-retrofit) load shapes. The study includes installations across eight states—Maine, Vermont, New Hampshire, Massachusetts, Rhode Island, Connecticut, New York, and Maryland—and focuses on the five equipment types with the highest savings in the PA programs: supply fans, return fans, cooling water pumps[2], heating hot water pumps, and water source heat pump circulation pumps.

Study Methods

Study methods—including sampling, recruitment, data collection, metering, and analysis—differ between the Massachusetts and NEEP studies, given each study's scope and objective. This section describes and compares the methods used.

Sampling. The Massachusetts study could not pursue a conventional stratified sample design as the program had not been evaluated previously on its own, and the population of projects could not be determined in advance. Thus, the study utilized an alternative approach, based on historical installation patterns. Researchers first looked at past VSD installations across the PAs' programs to determine their historical population characteristics. Adjustments removed all VSDs for measure types not included in the TRM. Due to the small number of VSDs installed by CLC, Unitil, and WMECO, the sample only included projects from National Grid and NSTAR.

Given the unknown distribution of future project applications, and the lack of information regarding the variability of estimated savings, anticipating the evaluation's precision and accuracy proved difficult. Still, the evaluation's design sought to estimate a statewide savings realization rate with ±20% relative precision at an 80% confidence level. The study faced an additional challenge in representing a range of projects across PAs, measure types, and complexities (in terms of numbers of drives). As a project site could include one or more measure types, and measure types could include one or more VSD installations, the number of site visits and meters required to achieve these goals could vary by the types of project applications received during the selection process. Based on historical data, and assuming an estimated error ratio of 1.0, the study selected a target sample size of 44 drives.

A traditional sample design would have stratified the population, allocating the 44 sample points to PAs and measure categories to result in the best overall precision. In this case, however, the population of measure category characteristics only provided a very rough indicator of units installed in coming years. In addition, requiring sample selection in real time, based on applications received by the PAs, necessitated building additional flexibility into the design. The study's limited structure could not realistically support applying standard statistical formulas to determine the number of sample points in each stratum and then determining the case weight for each point. Therefore, study developers recommended a simple proportional allocation by measure category and PA, as shown in Table 2.

[2] The cooling water pump category included both chilled water pumps and condenser water pumps.

Table 2. Planned and Final Sample Allocations for Metering

Equipment Type	Massachusetts Pre/Post		NEEP VSD Load Shape	
	Planned	**Actual**	**Planned**	**Actual**
Boiler Feedwater Pump	1	0	n/a	n/a
Building Exhaust Fan	3	1	n/a	n/a
Cooling Water Pump	4	4	102	119
Cooling Tower Fan	4	1	n/a	n/a
Hot Water Distribution Pump	4	3	72	79
Make-up Air Fan	2	1	n/a	n/a
Return Fan	5	0	72	64
Supply Fan	19	13	102	141
Water Source Heat Pump Distribution Pump	2	3	72	18
Total	**44**	**26**	**420**	**421**

The study developers recognized the recommended allocations might not be achievable, depending on the schedule of upcoming VSD installations and the conditions encountered at each site. Ideally, the drive in each application would be considered against the numbers completed in the cell it represents. If the required number had not been reached, the drive would be metered; if the number had been reached, it would be rejected as a sample point.

Table 2 also shows the final sample allocation of actual metered drives. Though the targeted number of sample points could not be achieved for several reasons, pre-approved installations of VSDs posed the primary problem, with units already installed by the time the evaluation team learned of them; this usually precluded pre-installation metering.

For the NEEP study, the evaluation team developed a unique sampling strategy: to account for varying levels of tracking data, provided by the study's sponsors, and limited information about the equipment types in the population of projects; and to ensure adequate representation across all participating PAs and weather regions. After reviewing available tracking data, the evaluation team narrowed the focus to the five equipment types accounting for the majority of tracked program energy savings.

This led to development of a multiphase, multistage sampling framework, with both sampling *phases* and *stages* required as project equipment types often remained unknown until: reviewing the sampled project details; initiating communication with the participant site; or, in some cases, the initial site visit. Multiple stages provided a method for sampling projects using a known parameter (total project kWh savings), and multiple sampling phases allowed the sample to be balanced across equipment types without bias.

The first sampling phase examined the complete population of VSD installation projects provided by the PAs. The first sampling *stage* focused on the population of projects, stratified by project size (annual kWh savings) and weather region. Once a project sample had been selected, the second *stage* involved sampling equipment installations within each sampled project. If a sampled project had four or fewer VSD installations for the selected equipment type, all installations were selected for metering. If a sampled project had more than four VSD installations, up to four VSDs were selected for metering, while maximizing the number of equipment types metered.

The second phase of sampling followed the identification of equipment types achieved in Phase 1. As the Phase 1 sample met the planned sample size for supply fans, the Phase 2 sample frame eliminated supply fans from the eligible equipment type list, along with projects without any of the remaining four eligible equipment types. The first sampling stage in Phase 2 drew additional projects from the adjusted VSD project population. The second sampling stage in Phase 2 analyzed the VSD installations within each Phase 2 project, selecting VSD installations as before (up to four installations per project), but eliminating supply fans from metering.

A third sampling phase followed, once the sample target for cooling water pumps had been reached for the Phase 1 and Phase 2 projects. Phase 3 eliminated supply fans and cooling water pumps from the eligible population; so Phase 3 projects only provided VSD installations on return fans, heating water pumps, and water source heat pump circulation pumps.

As shown in Table 2, the NEEP regional study completed post-retrofit metering on over 420 VSD installations for the five targeted equipment types.

Recruitment. Though for different reasons, both studies experienced difficulties in recruiting participants. The Massachusetts study—to collect pre-retrofit data—had to identify, recruit, and install metering for sites before VSD installations. The NEEP study had to recruit projects with specific equipment types, using limited tracking data and competing with recruitment for concurrent PA-specific evaluation studies.

The evaluation team for the Massachusetts study relied on Massachusetts PAs to notify them as potential VSD retrofit projects emerged. With permission, the evaluation team contacted an individual in charge of the potential project at the site. Ensuing discussions determined the project status, including the likelihood of a VSD installation and expected installation data.

For projects with an expected VSD installation date more than one week away, the evaluation team traveled to the site to observe the equipment, speak with facility personnel about operations, and set up kW monitoring equipment. The sample did not use projects less than one week from installation, as these would not have produced sufficient pre-installation data. Licensed electricians were provided by the site, or a third party electrical contractor assisted with the physical metering installation. In all instances, use of three-phase kW meters allowed for power factor corrections.

In four cases, a VSD had already been installed, but the evaluation determined that the pre-retrofit system could be re-created by controlling the VSD to bypass. In these cases, the site agreed to operate in bypass mode to simulate pre-retrofit conditions for evaluation purposes.

For the NEEP study, the evaluation team developed the participant sample using program tracking data from each PA, and the sample design described above. As tracking data for several PAs did not include information on equipment types, the evaluation team overdrew the sample, knowing many projects would be disqualified, based on their actual equipment type. Once the sample had been drawn, the evaluation team requested contact information, detailed project information, and any specific contact instructions from each participating PA. Based on instructions from the PAs, the study dropped several sample projects during this data request. Reasons for this included: the PA notified the evaluation team that the project had an inappropriate equipment type; the PA requested dropping the customer from the sample due to participation in another evaluation; or the PA requested the customer not be included in the evaluation for other reasons.

To facilitate recruitment and to improve customer uptake, the evaluation team developed a recruitment letter to precede recruitment phone calls. This letter described the project and participation process, was customized for each of the 12 PAs, and included the PA logo and PA contact information, as most of the customers were unfamiliar with NEEP.

During the recruitment and scheduling phone call, the evaluation team attempted to verify the equipment type on which a VSD had been installed, but this often proved difficult as: the PA tracking data lacked information on the project; or site contacts did not know or could not remember the project. This recruitment step eliminated a number of projects due to inappropriate equipment types, customer refusals to participate, or inability to contact the customer.

The final step in the recruitment process used an on-site visit to collect project information and to install the metering equipment. Even this step eliminated a number of sample projects due to identification of inappropriate equipment types.

Data Collection and Metering. Though the Massachusetts study sought to collect operational data before and after VSD installations (ideally consisting of one month of pre-retrofit and post-retrofit data), various site factors often affected data sampling periods. The site contact was asked to inform the evaluation team when the installation had been completed; so metering equipment could be removed in a timely matter. To avoid influencing the project, however, the evaluation team would not contact the sites for six months after the installation date; anticipating repeated phone calls from the evaluator regarding the installation status might impact the installation status. For example, repeated inquiries from the evaluator about the status of controls programming could result in completion of a job that otherwise would be left unfinished. If the site contact did not inform the evaluation team of an installation after six months, the metering equipment would be uninstalled, and the data collected would be considered representative of the post-retrofit case.

For the NEEP study, the evaluation team collected up to 12 months of post-retrofit data for VSD installations completed in 2010 and 2011. Based on early feedback from the Massachusetts study, the evaluation team limited the sample frame to projects completed by December 2011 to provide a buffer period for commissioning after VSD installations. The evaluation team began installing meters in August 2012, a minimum of eight months after the completion of VSD installations for the eligible project population. This provided adequate time for customers to completely integrate the VSDs with energy management or other control systems.

Given the multistaged sampling approach, meter installations continued through December 2012. To capture operational data during the summer, the evaluation extended the metering period through the summer of 2013.

To supplement meter data and to assist in developing of baseline load shapes for each installation, the evaluation team conducted a detailed survey for each site and VSD, including information such as: building type, equipment type, building and equipment operating schedules, pre-retrofit conditions, pre- and post-retrofit control strategies, drive control settings, motor nameplate information, and space served by the equipment. An additional study will be performed during the meter removal process to collect data on VSD control strategies and reasons for installing VSDs.

Analysis. The Massachusetts study developed an Excel-based spreadsheet analysis template for analyzing all installations. Metered data was first entered into the template in a continuous column. Raw data could then be graphed with respect to time, providing an overview of the metering effort. This graph also was used in conjunction with known installation and operation information to specify dates used for pre- and post-installation analysis. Weather data, specific to the site location, also were added to the spreadsheet for use in analysis, and included hourly temperature observations from National Oceanic and Atmospheric Administration weather stations.

In addition to metered and weather data, the analysis relied on a specified occupancy schedule, a list of holidays, and peak demand periods to make calculations. Though usually not used, entering a known occupancy schedule allowed a more detailed analysis to be performed. The holiday list included federal holidays for the years spanned by the metered data, but could be changed to be site specific. The spreadsheet defined summer and winter on-peak and seasonal demand periods.

Finally, the user selected the building type and the motor type controlled by the VSD, and entered the motor horsepower. The building types and motor types drew upon lists of possibilities stipulated in the TRM. The evaluation team used these selections to look up the annual energy savings factor (kWh/HP), the summer demand savings factor (kW/HP), and the winter demand savings factor (kW/HP) expected for the VSD application.

In the fall of 2013, the NEEP study will develop a tool to estimate the hourly electric impact of various VSD retrofit scenarios by comparing measured VSD load shapes to baseline load shapes. VSD load shapes will be based on power measurements from the 420 VSD installations across the Northeast, drawn between Summer 2012 and Summer 2013, and combined with weather data and other VSD-specific details, such as seasonal operations and control methods. At a minimum, the load shape tool will require inputs for connected horsepower and the weather region, and will vary based on inputs such as equipment types, building types or schedules, and VSD control modes.

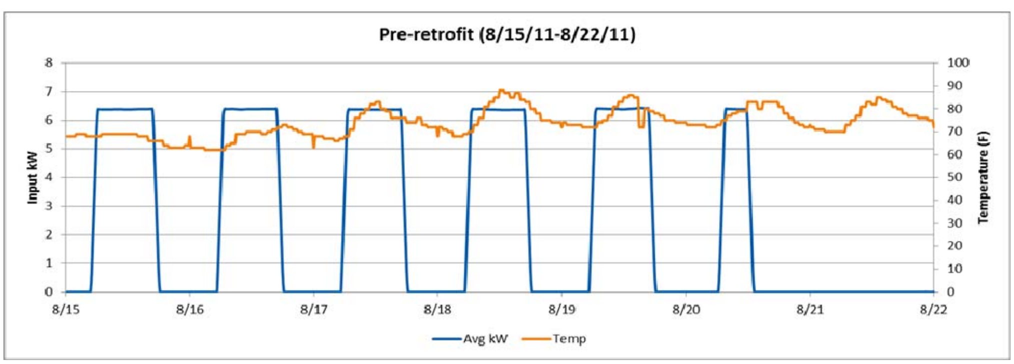
Baseline load shapes will be based on: results from the Massachusetts study, theoretical models for various baseline configurations, and VSD-specific information, such as pre-retrofit configurations and controls, the connected equipment horsepower, and operating schedules.

The tool will calculate the savings load shape as the difference between the baseline load shape and the VSD loadshape for each selected scenario. These savings profiles will be used by regional PAs to determine annual energy savings, seasonal period energy savings, and peak period demand savings for various VSD project types.

Findings

Pre-Retrofit Operations. The Massachusetts TRM for the baseline efficiency case assumes the evaluation addresses all motor types, with either constant-speed or two-speed motors, and with controls provided using valves or dampers. Using such control methods on a constant-speed motor can significantly impact input kW. For example, a forward-curved fan, throttled with inlet guide vanes, may operate at approximately 50% of full load power when throttled to just 75% of maximum airflow. The evaluation team expected this would result in baseline profiles with significant variations; however, the collected baseline data did not support this. The majority of pre-retrofit motors operated at a relatively constant input kW (<20% variation), with the most significant exception a cooling tower fan, equipped with a two-speed motor.

Figure 1 shows a sample of the pre- and post-retrofit metering for a 7.5-hp chilled water pump for a week during August, when the outside air temperature varied between 60 and 90 degrees Fahrenheit. In the pre-retrofit case, the metered pump operated at a relatively constant power and a regular schedule. In the post-retrofit case, the pump power significantly reduced, but still exhibited relatively little fluctuation in pump power, even during a very hot week.



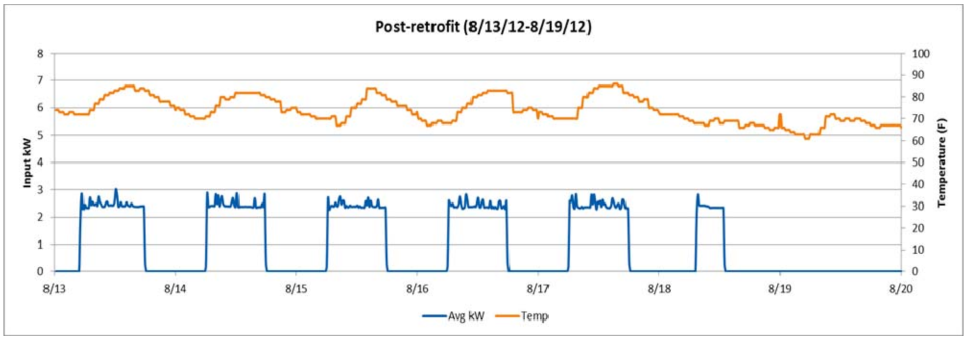


Figure 1. Sample of Pre/Post Metering for a 7.5-hp CHWP

For many installations in the Massachusetts study, the post-retrofit VSD operated at a fixed speed, without automatic controls. Consistent operation could result in the baseline demand profile having a constant shape.

VSD Installations. A summary of evaluation findings includes the following:

- ***VSD controls are not immediately implemented by the customer***. The Massachusetts study found that although prescriptive VSD applications required automatic controls, they were used infrequently during the data collection period. The NEEP study found the opposite result, suggesting VSD control implementation may occur six months to a year *after* equipment installation. Data found in the studies include:
  - The Massachusetts study, which conducted post-retrofit metering as soon as possible after VSD installation and up to six months after installation, found only one-third of the installed VSDs set in "auto" mode, with the majority of the drives set in "manual" mode and to a constant (though reduced) speed.
  - The NEEP study (which conducted post-retrofit metering no less than eight months after VSD installation, and typically continued well over a year after the installation) found only one-third of VSD installations in "manual" mode and the majority in "auto" mode.
- ***Manually set fixed VSD speeds are common***. This results in constant post-retrofit power demand, and very high summer demand reduction realization ratios.
- ***VSDs are used to solve airflow balancing issues***. In some cases, comparable energy savings could have been achieved through proper balancing and without installing a VSD, a less costly approach achieving faster payback periods.
- ***VSDs may replace failed VSDs***. Both studies found new VSD installations, incented by the PA programs, replacing existing and failed VSDs.
- ***Tracking data frequently misrepresented equipment types***. Both studies found equipment types miscategorized in the program tracking data. For example, a swimming pool circulation pump was categorized as a hot water circulating pump. This resulted in misapplication of savings estimates designed for specific equipment types.

VSD Savings. A summary of savings from the Massachusetts study includes the following:

- ***Energy and demand savings from VSD installations vary widely***. Figure 2 shows evaluated annual energy savings for the 26 Massachusetts sites, normalized by connected horsepower.
  - Two of 26 projects (a supply fan and cooling tower fan) showed negative energy impacts.
  - Annual energy savings for supply fans in schools ranged from -21 kWh/hp/year to 1,611 kWh/hp/year.

- As expected, the WSHP project had the highest energy savings, at 4,308 kWh/hp/year.

- ***Energy savings realization rates vary widely***. While the Massachusetts study exhibited an overall realization ratio close to 100%, significant variation occurred at the motor level, with many motors either close to 0% or much higher than 100%. Figure 3 shows the annual energy savings realization rates for the 26 Massachusetts projects, which ranged from -10% to 407%.
  - Failure to install controls or configure manual VSD speeds most commonly resulted in a poor realization ratio.
- ***Constant speed settings resulted in higher-than-expected summer peak savings***. The evaluation found summer peak kW reductions significantly higher than predicted by the TRM due to post-retrofit motors operating with manual controls at a constant input kW. Figure 4 and Figure 5 show evaluated results for summer peak demand savings.[3]

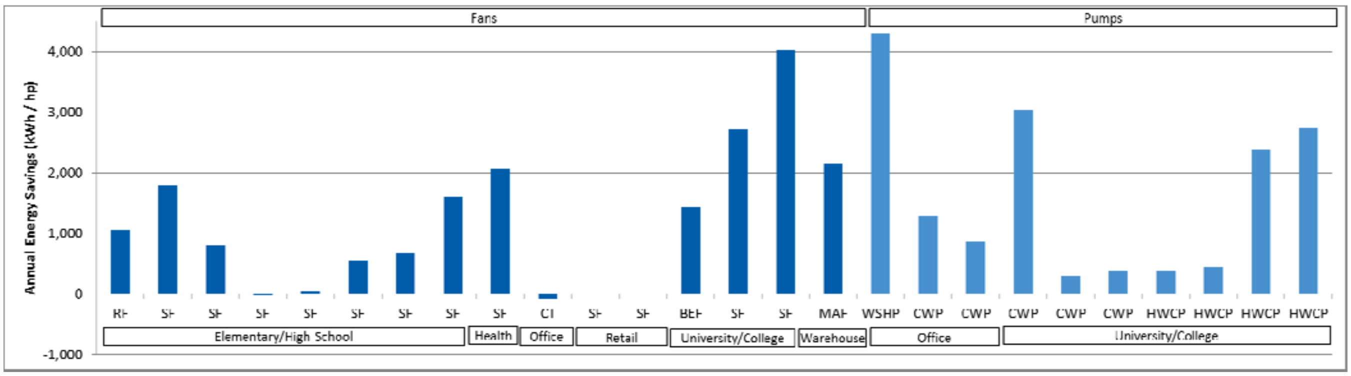


Figure 2. Evaluated Annual Energy Savings (kWh/hp)

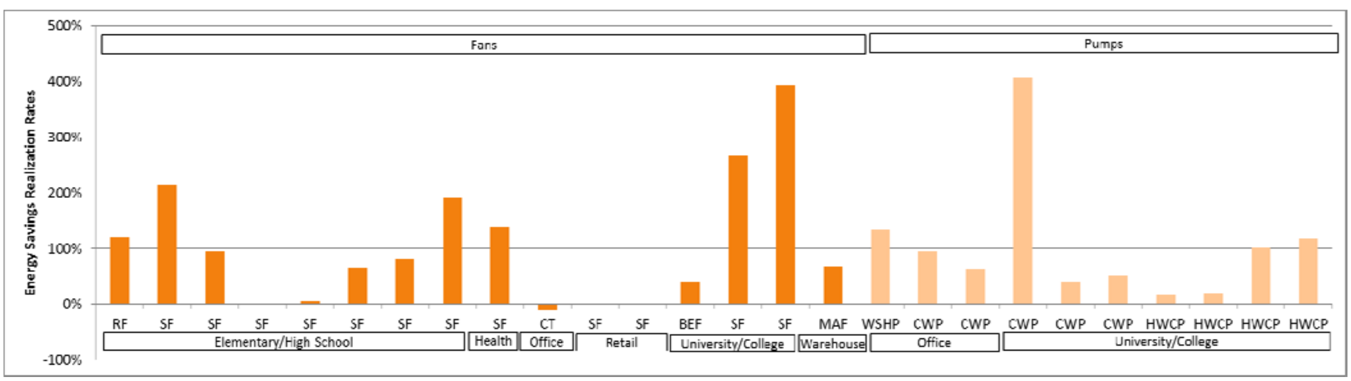


Figure 3. Annual Energy Savings Realization Rates (%)

[3] In Massachusetts, summer peak demand savings equals: average demand savings between 1:00 p.m. and 5:00 p.m., non-holiday weekdays in June, July, and August.

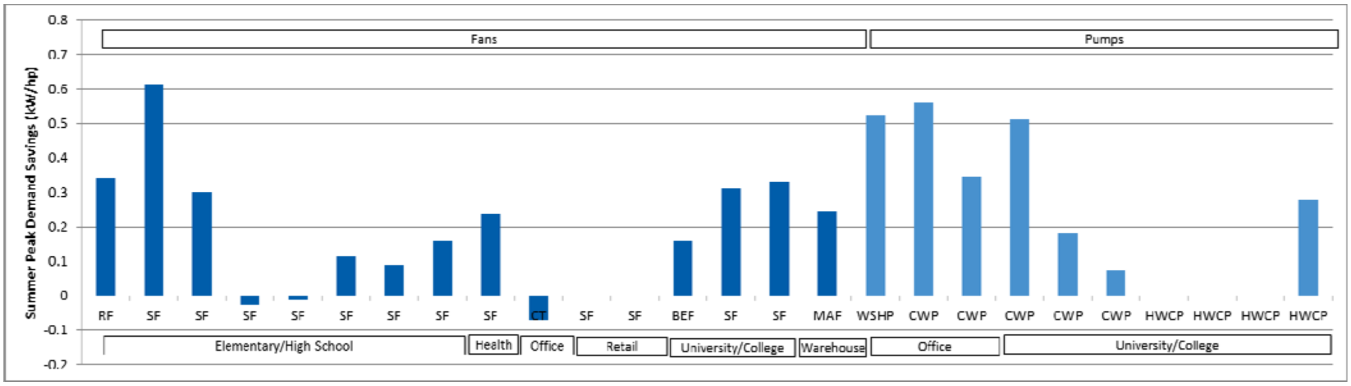


Figure 4. Evaluated Summer Peak Savings (kW/hp)

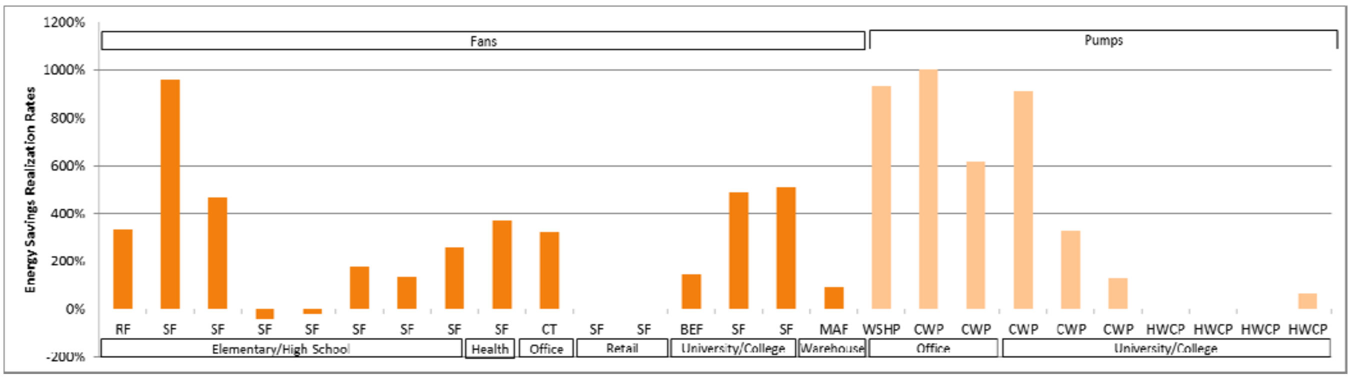


Figure 5. Summer Peak Savings Realization Rates (%)

Conclusions and Recommendations

Evaluation Protocol

The Massachusetts study often found VSD installations completed upon making initial contacts. Unless a VSD bypass option had been installed and the customer agreed to operate using it to recreate pre-retrofit conditions, the project could not be evaluated. In such cases, the evaluation could not determine if the installation had been completed prior to a participant receiving an incentive.

Seasonal equipment operations significantly delayed the evaluation. Many VSD categories involved seasonal equipment, such as cooling tower fans or hot water pumps shut down for several months per year. Consequently, data could not be collected during off seasons, and data collected during shoulder seasons often proved insufficient for analysis.

In several instances, VSD retrofits had been categorized incorrectly, which became apparent during the initial phone call contact or upon metering setup site visits. The evaluation did not include such cases as metering data would not be representative of the desired motor type.

VSD Operational Characteristics

The Massachusetts study found that many installed VSDs are never utilized. After installation, motors operated at 60 Hz. Post-inspections should be performed to ensure automatic controls have been installed, as required by prescriptive applications.

VSD installation dates varied significantly from the installation of control sequences. A majority of installations had VSDs installed several weeks or months before implementation of control sequences. During this period, VSDs typically operated at 60 Hz. This evaluation's standard protocol required awaiting confirmation of control installations (rather than encouraging installations by calling for updates). In some cases, the evaluation team installed kW meters for pre-retrofit conditions, but VSDs were never installed. To confirm proper operations, a six-month follow-up should be performed before paying a full incentive.

Both studies found that, upon implementation of control setting, VSDs commonly operated at fixed speeds rather than modulating to maintain set points. Such operations resulted in a constant motor input kW, causing a very high summer demand peak realization ratio. It remains unknown whether these sites consequently experienced operational issues during extreme conditions.

Both studies also found multiple instances where VSD retrofits replaced an existing drive. In all such cases, facility operators reported existing drives were failing and had operational issues. Failing VSDs averaged 15 years old or more. The prescriptive VSD application states that incentives cannot be applied to replace existing VSDs. Evaluated savings for these installations were found to be small (or even zero).

In one case, energy savings primarily resulted from proper balancing rather than VSD motor controls. Prior to the VSD retrofit, a chilled water pump provided excess water to end users, and the motor operated at over a 100% load. The VSD installation essentially sought to balance the chilled water flow. Though this resulted in significant energy savings, some of these could have been achieved through balancing. A pre-inspection should be conducted to identify cases where VSDs might not provide the most economical solution.

Demand Impacts

The Massachusetts TRM claims summer kW reductions for hot water pumps and winter kW reductions for chilled water pumps. In most cases, hot water pumps shut down for summer months, and chilled water pumps shut down for winter months. Though this was not expected to apply to all motor types, it appears, based on the sample observed in this evaluation, that the TRM should be adjusted downwards. Currently, the TRM assumes 100% of these motors operate during off-seasons. The Massachusetts TRM should be reviewed, and appropriate adjustments should be made to ensure realistic demand savings for certain measure types.

The TRM generally indicates summer kW reductions very close to zero for motor types not related to heating. This seems a reasonable assumption for motors with automatic controls, as an appropriately-sized motor likely would operate near full load on a design day. However, the evaluation revealed significantly more motors with manual controls than expected; with motors operating below full-load input kW. As the TRM predicts very low summer kW reductions, this results in very high realization ratios.

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