

BUILDING *performance* LAB

CUNY INSTITUTE FOR URBAN SYSTEMS
CITY UNIVERSITY OF NEW YORK

Dr. Robert E. Paaswell, Executive Director, CIUS
Michael Bobker, Executive Director, Building Performance Lab

96 Greenwich Street, New York, NY 10006
cunytpl.org

Measurement Guide: Secondary Chilled Water Pumps

By:

Phillip Chao, PhD | Applied Research Scientist

Linyuan Cui, Tom Lui | Interns

Duncan Prah, RA, AIA | Sr. Applied Research Scientist

Reviewed by:

Jillian Panagakos | Jr. Engineer

Honey Berk, LEED AP O&M, CMVP | Managing Director

June 16, 2020

Table of Contents

Acronyms	iii
Purpose of Guides	1
General Overview of NYC GHG Reduction Goals.....	1
Why Take Measurements?	1
Prioritizing Appropriate, Necessary Measurements	1
Application, Baseline, and Post-Retrofit Measurements.....	3
Direct and Proxy Measurements	3
Measurement Uncertainty.....	3
General System Overview	5
Safety	5
Description of System	5
System Overview	5
Key Variables Associated with Calculating Energy Consumption.....	7
Operating Characteristics.....	8
Scope of This Guide	9
Measurements	9
Measurement Approach	9
Sampling.....	11
Measure Motor On/Off Operation	11
Measure Directly at the Main Feed (Panel or Switchgear)	12
Measurement Tools and Equipment	13
Measurement Strategies.....	15
Measurement for Constant Speed Constant Volume Pumps – On/Off Operation	15
Measure Power Consumed at the Main Feed to the Motor Using a Data-logging Power Meter.....	16
Measure Current Supplied to the Motor at the Main Feed Using a Current Sensor	17
Alternate Strategy – Download Data from a BAS or a VFD.....	19
Calculation Methodology	20
Reporting Recommendations	21

Table of Figures

Figure 1. Secondary pumps with VFDs	5
Figure 2. Components of a constant speed pump system with constant pressure	6
Figure 3. Components of a variable speed pump system controlled by differential loop pressure	7
Figure 4. Measurement boundary of a constant speed pump	10
Figure 5. Measurement boundary of a secondary pump with a VFD	10
Figure 6. Decision tree to determine the measurement strategy for a secondary chilled water pump system.....	11
Figure 7. Measurement points for motor on /off operation	12
Figure 8. Measurement point at main feed.....	12
Figure 9. Example of Device Information Export from HOBOWare.....	21

Table of Tables

Table 1. List of measurements and associated tools.....	13
Table 2. Description of measurement tools.....	14

Acronyms

AHU	air handling unit
BAS	building automation system
Btu	British thermal unit
CUNY BPL	CUNY Building Performance Lab
DCAS DEM	NYC Department of Citywide Administrative Services Division of Energy Management
FELL	CUNY BPL Field Equipment Lending Library
kW	kilowatt
kWh	kilowatt hour
IPMVP	International Performance Measurement and Verification Protocol
NOAA CNY	National Oceanic and Atmospheric Administration Climate Normal Year
OAT	outdoor air temperature
M&V	measurement and verification
MW	megawatt
PNNL	Pacific Northwest National Lab
PV	photovoltaic
RTU	rooftop unit
true power	true RMS power
VAV	variable air volume
VFD	variable frequency drive

Purpose of Guides

This guide is one of a series developed with the goal of implementing consistent, simple, purpose-driven measurement processes to help quantify the impact of projects designed to further New York City's greenhouse gas (GHG) reduction goals. These guides are designed for use by internal and external stakeholders to facilitate comprehensive characterizations of building energy consumption and promote standardized and reasonable reporting of avoided energy use, through the collection of energy-related system data in buildings owned or operated by the City. Stakeholders include personnel at the NYC Department of Citywide Administrative Services Division of Energy Management (DCAS DEM), NYC Agency Energy Personnel, and third-party consulting engineers and/or other measurement and verification (M&V) providers. These measurement guides may also provide direction to other municipalities or private sector organizations that are looking to quantify avoided energy use for applicable energy conservation measures (ECMs).

General Overview of NYC GHG Reduction Goals

As the hub for energy management for the City's fixed infrastructure, DEM plays a critical role in supporting NYC agency partners' progress toward major emissions reduction and energy objectives. These goals include:

- **80x50**, focuses on achieving an 80% reduction in total economy-wide emissions in NYC by 2050 from a 2005 baseline. NYC also has an 80 x 50 goal relative to an FY06 baseline. OneNYC 2050 extended this goal by committing to net-zero greenhouse gas (GHG) emissions Citywide by 2050. This will require 100% clean energy and offsetting sources of irreducible emissions.
- **50x30**, a new target created by the Climate Mobilization Act (NYC Local Law 97 of 2019) that focuses on achieving a 50% reduction in emissions by 2030, relative to an FY06 baseline. This includes all operations, facilities, and assets that are owned or leased by the City and for which the City pays all or part of the annual energy bills.
- **40x25**, a new interim target on path to 50x30 that was also included in the Climate Mobilization Act and applies to all City government operations.
- **Solar Target of 100MWx25**, focuses on installing 100 Megawatts (MW) of solar photovoltaic (PV) at City government facilities by 2025.
- **Energy Storage Target of 100MWhx20**, focuses on installing 100 Megawatt hours (MWh) of energy storage at both private and public facilities by 2020.

Why Take Measurements?

Documenting consistent measurement techniques and reporting standards for DEM-funded energy efficiency projects is a vital step in facilitating judicious project selection and efficient program management. In agency applications for DEM project funding, the use of measurements (as opposed to general assumptions) yields more accurate estimates for baseline consumption and avoided energy use. Measurements promote a verifiable methodology that enhances the validity of the application and a best practice that is aligned with the City's goals.

Prioritizing Appropriate, Necessary Measurements

The primary goal of collecting measurements is to establish a reasonable characterization of the system before and after the retrofit in a simple, non-invasive, and replicable manner. This involves collecting

data that reasonably document the operational patterns and energy consumption using tools available from the [CUNY BPL Field Equipment Lending Library \(FELL\)](#). This guide is appropriate for a project where the International Performance Measurement and Verification Protocol (IPMVP) Option A or Option B for retrofit isolation is being used. Option A and B require direct or proxy measurements of some or all the key variables associated with the implementation of an ECM.

An engineering problem, such as measuring the amount of energy used by a piece of equipment or a system, can be solved using many different techniques. These guides provide a primary recommendation for direct or proxy measurements of key system variables. It is understood that other techniques may be more appropriate for specific situations and that the user can adjust these recommendations based on the specific details of the project they are undertaking.

The measurement processes outlined in this guide were established to meet four key criteria and to standardize GHG reduction reporting across City facilities and agencies. Measurements should be:

1. **Reasonable:** These measurements will not reflect the exact annual energy consumption of a device or system. Rather, they are expected to represent a reasonable characterization of the annual energy consumption and are generally normalized either by measured operation or weather-dependent variables such as outdoor air temperature (OAT). When measurements are being taken before and after a retrofit, the measurement techniques may change based upon the characteristics of the ECM, but both techniques are expected to provide equally reasonable results.
2. **Replicable and Consistent:** A key goal is to provide methodologies that are easily replicable by a wide range of users who have varying degrees of familiarity with the facility's operations and system configuration. This guide has multiple measurement strategies with differing levels of accuracy, however the results from any of these strategies are consistent enough to enable comparison across ECMs or facilities.
3. **Simple:** The measurement strategies and processes in this guide are intended to be as minimally invasive as possible, and relatively easy to set up. Setup time for most measurements should be less than an hour; however, in some cases, specialized personnel such as electricians or operating engineers should be engaged to assist with the installation of measurement equipment. This guide highlights methods of data collection that do not interfere with regular system operation and that are not excessively difficult to perform. All necessary tools used for measurements can be borrowed from FELL. The guides also provide standardized demonstrations for equipment setup, data collection protocols, and post-processing of the data to develop estimates of annual energy consumption.
4. **Purpose-driven:** While there may be different reasons for collecting these measurements (conducting full M&V, identifying preliminary avoided energy estimates, fault detection diagnostics, etc.), all methodologies represent the intent to estimate annual energy consumption and associated emissions.

Taking measurements provides verification of the two key variables associated with energy consumption in facilities: 1) operating schedule; and 2) energy used by the system when operating. Measuring operational variation in energy consumption over time, and other variables like OAT, allow for short term measurements to be extrapolated to a seasonal or annual estimate of energy consumption. For example, measuring a boiler can reveal the general time of day when the boiler is used in the facility, and how often it operates with respect to OAT. Given a range of measurements under varying

temperatures, a reasonable model of operation can be developed and applied to all times that the boiler is used over the course of an entire heating season.

Application, Baseline, and Post-Retrofit Measurements

Given the typical timeline of DEM-funded projects, measurements can be taken at three different stages:

1. **Project identification and scoping:** These measurements help to generally characterize the system operation and energy consumption and can be used with other engineering calculations to develop estimates of avoided energy use for a given ECM. Depending on the timing of the project development and the season, these measurements might only encompass several weeks of a year.
2. **Project approval and implementation:** Once the decision has been made to proceed with the project, a more comprehensive baseline measurement may be appropriate. The measurement technique and tools will likely be identical, but measurement duration is extended to verify the assumptions that went into the initial analysis. Longer measurement periods can provide more accurate estimates of annual energy consumption, especially in systems that vary due to changes in a key variable such as OAT.
3. **Post-implementation:** Post-retrofit measurements provide verification that the ECM is installed and operating as designed and are used to estimate avoided energy use. The measurement techniques may differ from the application or baseline measurements, especially if the ECM changed key system characteristics. For example, a lighting retrofit that added a lighting control system to some fixtures, yielding a change in their hours of operation, may require a different set of sensors to quantify this change compared to lighting fixtures without controls.

Direct and Proxy Measurements

There are two types of measurements used in this guide:

1. **Direct Measurement:** A direct measurement specifies a quantity of the exact item being measured. For example, a current transducer provides a direct measurement of the current through a wire. The coincident voltage and power factor can also be directly measured to calculate the true RMS power (kW) being used by the system or device.
2. **Proxy Measurement:** A proxy measurement provides an indication of the system operation but does not directly measure the quantity in question. For example, a motor runtime logger on the draft fan of a boiler provides a proxy measurement for the actual firing of the boiler. The draft fan motor typically runs before the fuel valve opens (for a series of internal safety checks), while the boiler is firing and for a short period after the fuel valve has shut off. By subtracting the pre- and post-firing runtime, a proxy measurement for the actual firing time can be calculated.

Measurement Uncertainty

Sources of measurement uncertainty can include the accuracy of measurement devices, translation of the measured data into models that are used to project longer term energy consumption, and measurement of a non-representative sample of ECMs.

Measurement accuracy is improved by using high quality and properly calibrated equipment. Typically, the recommended measurement equipment yields measurement errors of less than 2% and may often be significantly lower than 1%. As such, measurement error is typically negligible. CUNY BPL has worked to develop robust measurements and associated models that further reduce error. CUNY BPL has not developed tools to develop statistically valid sample sizes to achieve a desired error at a specific confidence interval; therefore, the recommended approach is to identify measurement points in the applicable system to capture the largest percentage of the total connected load as possible. This will allow for quantification of both the peak power draw of the system and operational variations that exist in the system.

General System Overview

This guide describes the measurement approach for quantifying avoided energy use associated with retrofitting pumps in the secondary loop of a chilled water pump system with VFDs and/or more efficient motors.

Safety

This guide does not cover health and safety aspects of the collection of measurements at facilities. There are many hazards that exist in facilities surrounding the collection of measurements, including but not limited to: electrical safety, fall protection, personal protective equipment, control of hazardous energy (lock out/ tag out), confined space, respiratory protection, and machine safeguarding. Part of the measurement planning process must include the identification and mitigation of these and other hazards. The implementation of a measurement strategy and installation of measurement equipment should be performed by qualified personnel.

Description of System

The following sections provide background information on the components of a primary-secondary chilled-water pump system. **If you are already familiar with the system, you may skip to the *Measurement Description for System* section.**

System Overview

In a primary-secondary chilled-water pump system, primary pumps circulate water returning from the building through the chiller and the secondary pumps circulate chilled water from the chiller to the cooling coils throughout the building. Centrifugal pumps are the most common type of pumps used.

The components of the system depend on the system configuration. There are two common configurations: 1) constant speed pumps with relatively constant pressure; and 2) pumps with variable frequency drives (VFDs) that maintain a constant pressure. An image of secondary pumps with VFDs is shown in Figure 1.

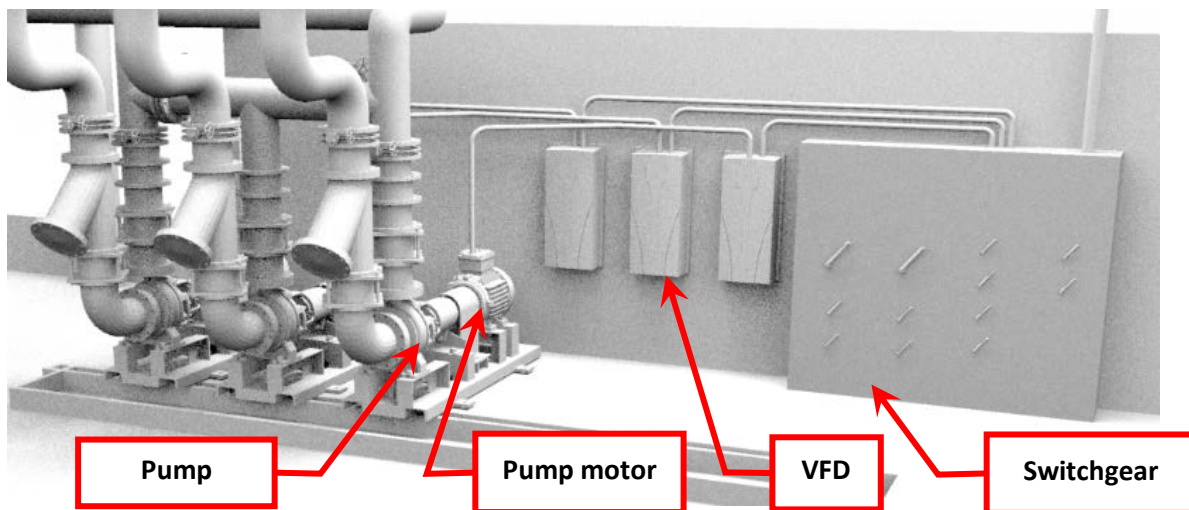


Figure 1. Secondary pumps with VFDs

Constant Speed, Constant Pressure

In this configuration, the secondary pump speed is constant regardless of cooling load. As shown in Figure 2, each coil has a three-way valve and a bypass pipe. Chilled water is sent through the coil based on the cooling load and the excess flow is distributed through the bypass pipe. The pressure drop across each coil and bypass pipe remains relatively constant in the secondary loop. This system is the typical pre-retrofit condition for older systems.

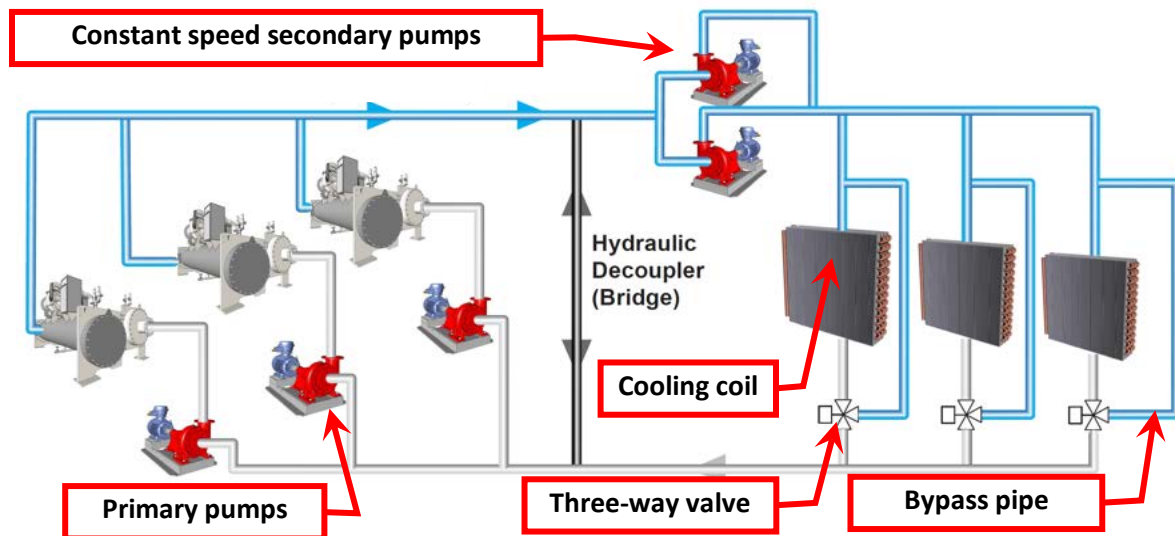


Figure 2. Components of a constant speed pump system with constant pressure

Variable Speed, Variable Flow, Constant Differential Pressure

In this configuration, pump speed and flow are controlled by maintaining constant differential pressure in the secondary loop. This is measured at the point where the maximum pressure drop exists in the system (usually after the coil farthest from the secondary pumps) where a three-way valve and bypass pipe is installed. As shown in Figure 3, the remaining coils have two-way valves that modulate chilled water flow based on the cooling load and bypass piping has been removed or disabled. The three-way valve at the farthest coil keeps the bypass open when all coils are off. The speed of the secondary pumps is varied to maintain a constant pressure throughout the secondary loop regardless of the total flow needed, which is based on the valve position of all coils. This system is the typical post-retrofit condition.

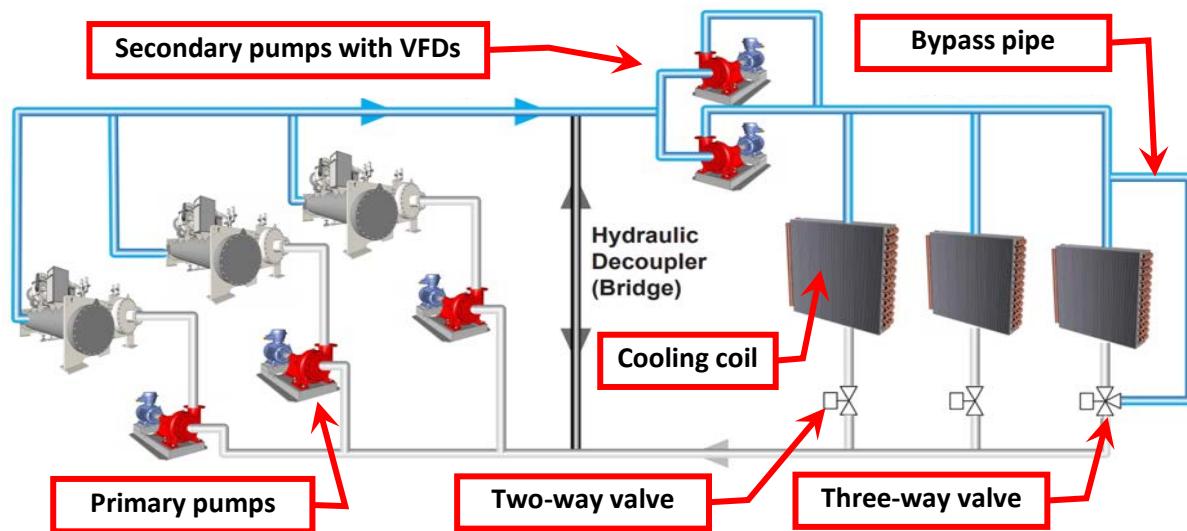


Figure 3. Components of a variable speed pump system controlled by differential loop pressure

There are two general arrangements of the pumps within the secondary loop: 1) a headered set of pumps at the start of a loop, as shown in Figure 2 and Figure 3; or 2) individual pumps that operate for different zones or subloops in the facility. For headered pumps, two sizes of secondary pumps may be also be installed: 1) a smaller pump for spring and fall operation when the cooling loads are lower; or 2) a larger pump for operation during the hotter summer months.

Key Variables Associated with Calculating Energy Consumption

The primary energy source for a secondary chilled water pump system is electricity, which is measured in kWh. The electricity consumption of a water pump motor is a function of the pump's operating hours and the speed, where the pump affinity laws define power as proportional to the cube of speed. The relevant variables used to characterize the electricity consumption of secondary chilled water pumps are:

- True RMS Power input to the VFD or motor for all pumps in the secondary chiller loop
- Operating schedule
- OAT (if pump speed is temperature-dependent)

There are two operating modes described in this guide. The first is for constant speed systems where no VFD has been installed. True RMS power draw (kW) is multiplied by operating time (hours) to compute electricity consumption (kWh). The model assumes that the power draw is relatively constant at any operating condition and combination of three-way valve positions. The primary measurements, taken over several weeks, confirm the power draw and operating schedule.

The second mode is for secondary pumps equipped with a VFD. The secondary pump speed is varied based on the overall differential pressure in the secondary loop, which is a function of the number of coils that are calling for chilled water, which is assumed to vary with OAT. A regression model can be created for the hourly average true RMS power as a function of hourly average OAT. The annual electrical consumption is then the true RMS power (kW) drawn by the pump motor at a given OAT for each hour multiplied by the hours of operation of the pump at that given OAT.

Operating Characteristics

The secondary chilled water pumps are one component in the larger chiller plant system. An overall operational strategy is needed for the chiller plant that varies by the overall components in the chiller system, the type of building and occupancy, and the building operations staff. It is important to interview the operations staff to understand how the secondary pumps are operated, and to develop a measurement strategy that will appropriately capture all modes of operation. Chiller operation typically takes place during the cooling season, generally from April to October. Chillers are most commonly either turned off or have temperature setbacks overnight, unless the building has a 24-hour occupancy (e.g., hospital). Regardless of setbacks or scheduled operation, a minimum flow needs to be maintained through the chillers when they are operating.

Pressure and flow are controlled by a combination of the pump characteristics and the operation of the cooling coil valves. Generally, the pump is selected for a peak flow rate (gpm) with all coils open. In a fixed speed pumping system, the three-way cooling coil valves and bypass piping are designed to allow the peak flow rate through the secondary loop regardless of the valve position. A key to successful VFD implementation is to disable most of the bypass piping so that the total flow rate in the secondary loop is driven by the flow through the cooling coils based on cooling demand. Furthermore, the three-way valves should be replaced as needed to ensure efficient operation of the system post-retrofit. This flow rate varies by control of the pump speed to maintain a constant differential pressure in the secondary loop.

Scope of This Guide

The profile of energy consumption and avoided energy use associated with two types of ECMs can be characterized using this guide:

1. **High Efficiency Motor replacement** – Replacing an existing motor with a premium efficiency motor can yield avoided energy use by increasing the useful work output per unit of electricity consumed. It is important to make sure the RPM of the pump is the same after the retrofit. High-efficiency motors sometimes run at a slightly higher shaft RPM per HP, and the increased RPM can negate any savings from the improved efficiency. The pump impeller may need to be replaced as part of the motor replacement to maintain pump RPM.
2. **VFD installation** – Because VFDs control the relative speed of the pump, significant avoided energy use can result from implementing variable speed controls on constant volume systems, depending on the type of motor and pump involved. VFDs must be compatible with the motor that is to be upgraded.

This document is designed to assist in gathering both pre- and post-retrofit data for the electricity consumption of secondary chilled water loop pumps. As such, a primary goal is to describe the measurements and the appropriate equipment to perform those measurements. Guidance is provided for measuring both constant and variable speed motors for the secondary pumps in each of the configurations detailed above.

The guidance provided assumes the chiller is either air-cooled or water-cooled, however secondary pumping systems are most common on larger water-cooled chillers. It also assumes that the operation of the chiller and cooling tower are not substantially modified as part of this retrofit. If a change in the facility's hours of operation is detected between the pre- and post-retrofit measurements, further investigation should be undertaken to determine if a routine or non-routine event took place and needs to be accounted for in the savings calculations. Routine events include holidays or vacation weeks that may occur during the measurement period; non-routine events include unscheduled shutdowns or emergency 24-hour operations.

The primary chilled-water pumping system is not covered in this guide, although the measurement techniques for a primary pumping system would be similar. Interactive effects with whole-facility heating and cooling loads due to the upgrade of the pump motors are similarly not addressed.

Measurements

Measurement Approach

This guide is focused on characterizing the avoided electricity use associated with changes to the pump motor efficiency, speed, and operating schedule. As such, the measurement boundary of the system, per this guide, is defined as the secondary pump motors plus their associated VFDs, if installed. Figures 4 and 5 illustrate the measurement boundary defined for the measurement approaches presented in this guide.

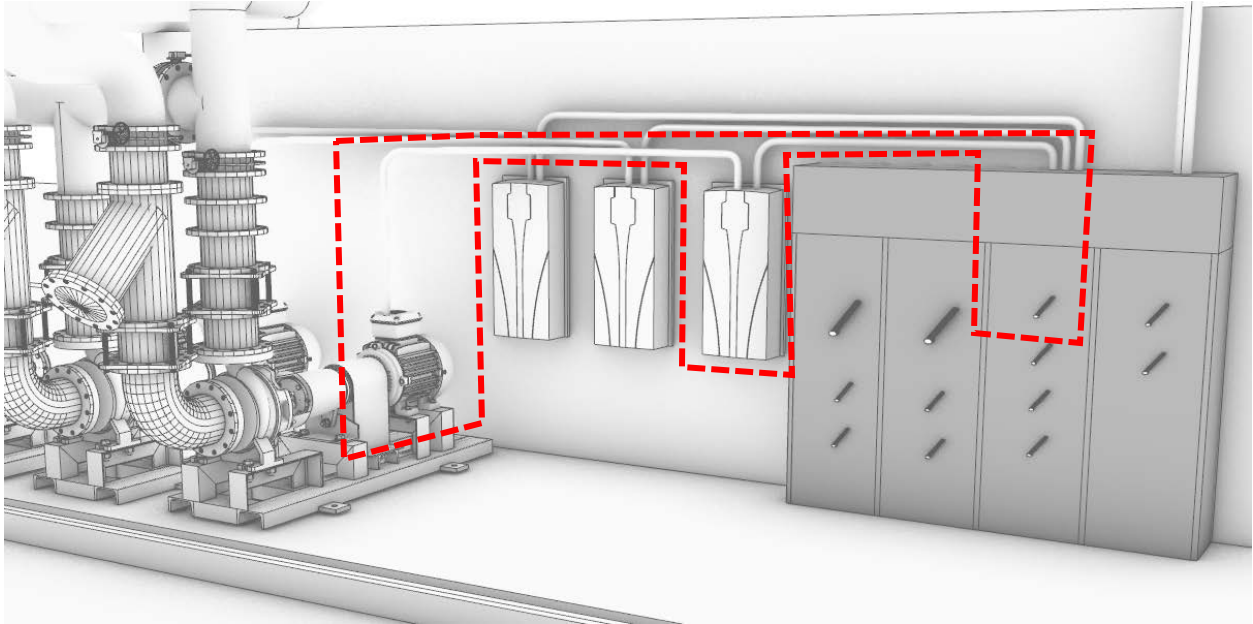


Figure 4. Measurement boundary of a constant speed pump

The measurement strategy for this system is determined by the true RMS power of the 3-phase power supply either at the power main for the motor (outlined in red in Figure 4) or at the three-phase input to the VFD (outlined in red Figure 5).

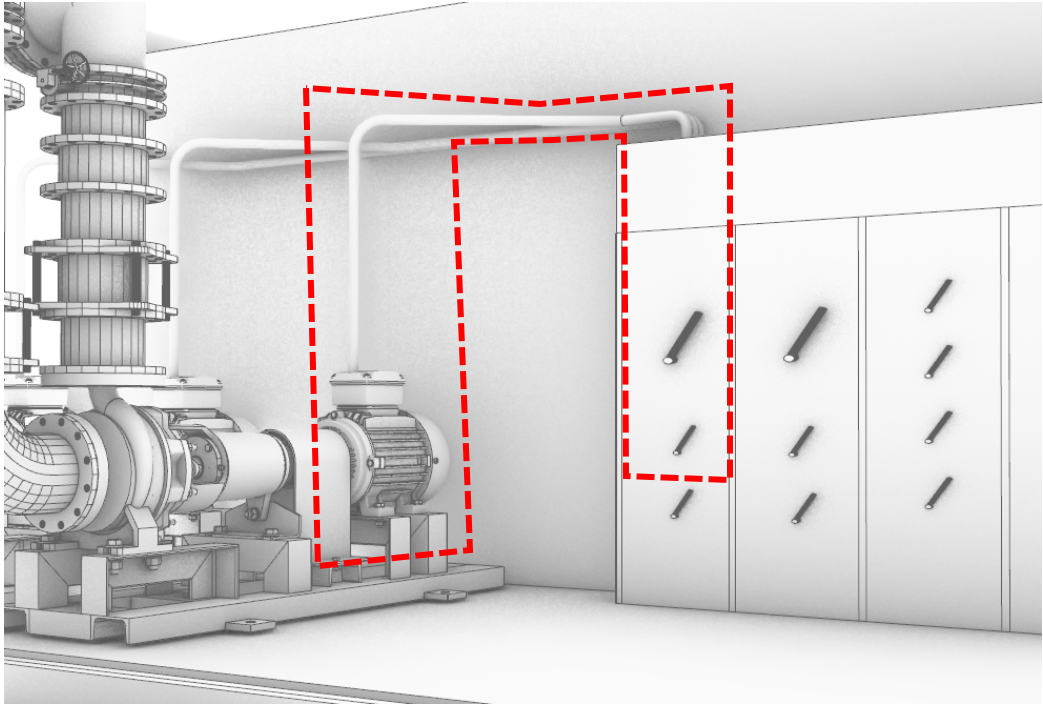


Figure 5. Measurement boundary of a secondary pump with a VFD

The appropriate measurement strategy is determined by whether the pump is operated at constant or variable speed. Figure 6 depicts a decision tree that can be used to determine which measurement strategy to apply to a specific system, based on its configuration and components.

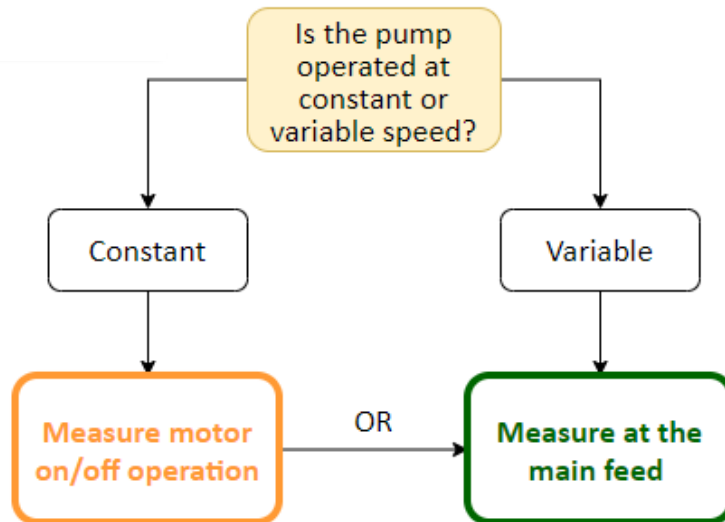


Figure 6. Decision tree to determine the measurement strategy for a secondary chilled water pump system

Sampling

The measurement plan should include all pump motors in the secondary chiller circuit. As discussed earlier, different size pumps may be operated at different times of the year, in which case both pump motors should be measured. In most cases there is also a standby pump that is used as part of regular operations, to keep uniform wear on all pumps in the system. If a standby pump is used, or if pumps are regularly cycled, those pump motors should also be measured. If a more rigorous sampling plan is needed, Bonneville Power Administration¹ has developed an excellent reference for guidance.

Measure Motor On/Off Operation

This strategy, represented in Figure 7, is for the pre-retrofit condition for a constant speed system and for the post-retrofit condition when replacing a constant speed system with a higher efficiency motor. The approach assumes that the power draw stays constant throughout the measurement period. Because the motor runs at constant speed, it is either operating at full power (when on) or it is drawing no power (when off). As such, a motor on/off data logger is used to record the operating schedule.

The following parameters should be measured:

- True RMS power of the motor that drives the pump (kW)
- Pump motor runtime

¹ https://www.bpa.gov/EE/Policy/IManual/Documents/2_BPA_MV_Sampling_Reference_Guide.pdf

If it is not possible to determine whether the pump motor has a constant power draw (e.g., through physical observation of the system, an interview with the building operator, or review of as-built drawings), it is best to use the alternative measurement approach described below.

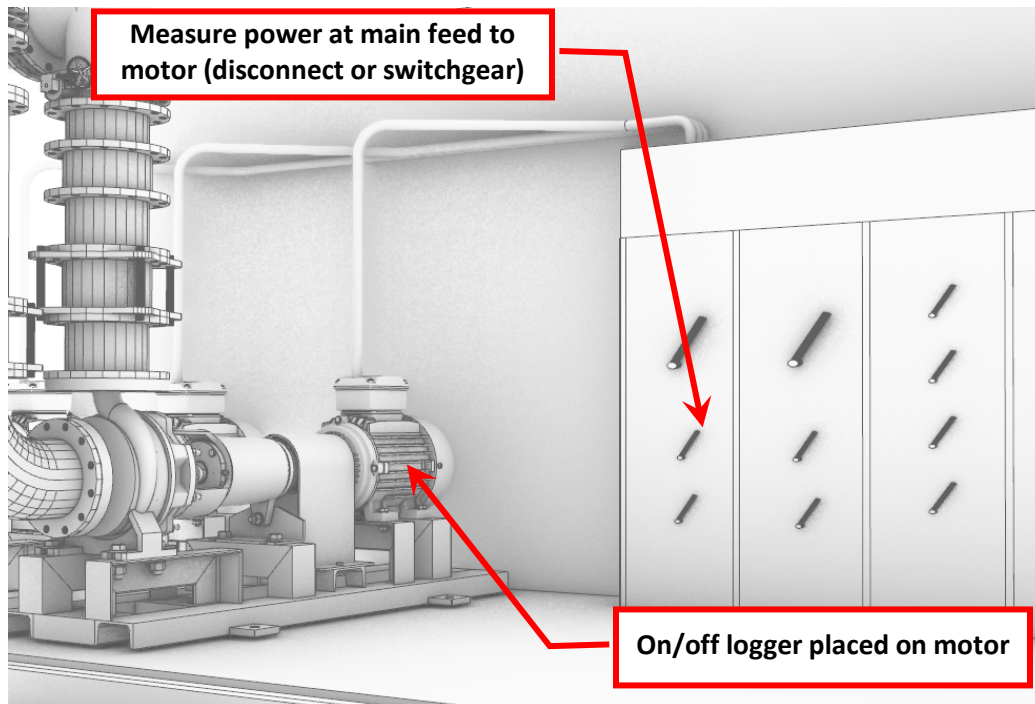


Figure 7. Measurement points for motor on /off operation

Measure Directly at the Main Feed (Panel or Switchgear)

This strategy, represented in Figure 8, is used to directly measure the power consumed by a constant or variable speed system. When power draw varies, a direct or proxy measurement of power is needed to characterize how it is affected by operational schedule or OAT. Because pump power is proportional to

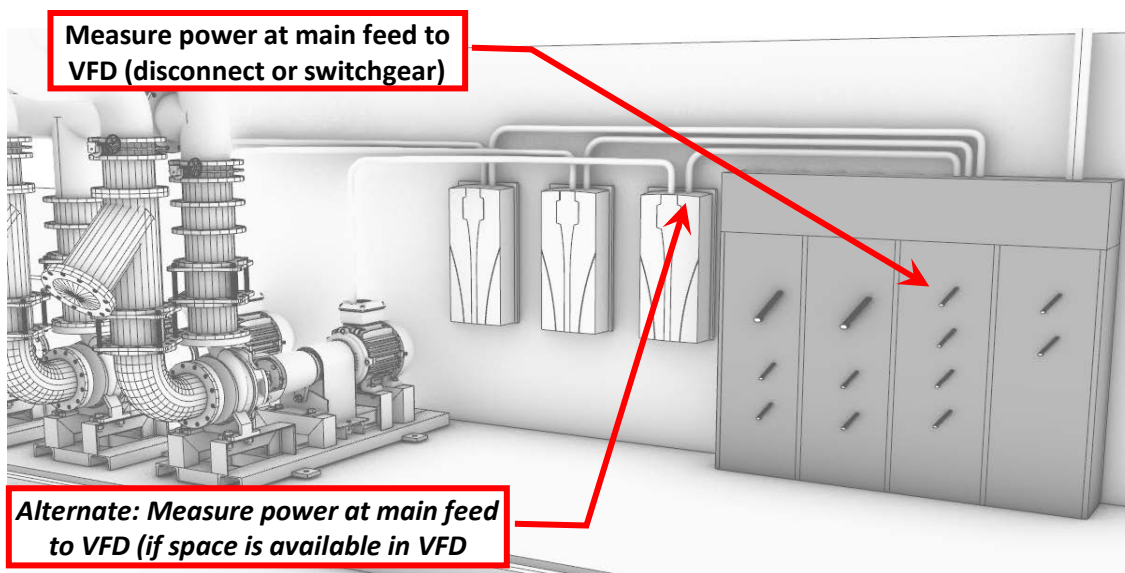


Figure 8. Measurement point at main feed.

the cube of the pump speed, it is important to measure the power draw over the full range of loading conditions. For variable speed pumps, at least four to six weeks during the hottest time of summer and a few weeks during spring or fall should be sufficient to capture the operation of the system with respect to OAT².

The following parameters should be measured:

- Continuous energy consumption of the motor that drives the pump, kWh
- OAT, °F

Measurement Tools and Equipment







The measurements in this guide can be performed with the equipment listed in Table 1; more detailed descriptions have been provided in Table 2. NYC agency employees can borrow recommended equipment from CUNY BPL’s FELL, and have it delivered to their facility. Third-party M&V consultants and others can use this equipment list as guidance, recognizing that many manufacturers make comparable equipment. Inclusion on the list in Table 1 or Table 2 should not be construed as an endorsement of these manufacturers.

Table 1. List of measurements and associated tools

Measurement	Units	Tool	FELL Equipment
True RMS Power	kW	Clamp Meter	Fluke 345 Power Quality Clamp Meter
Apparent Current	Amperes	Current Sensor and Data Logger	Onset Split-core AC Current Sensor (CTV-A, CTV-B or CTV-C) Onset HOBO 4-channel Analog Data Logger (UX120-006M)
True RMS Energy	kWh	Data-Logging Power Meter and Current Transformers	DENT ELITEpro XC Power Meter (EXCUNC) Dent 16” RoCoil Flexible Rope Current Transformers (CT-R16-A4-U)
Motor Runtime	Seconds per hour	Motor On/Off Logger	Onset HOBO Motor On/Off Data Logger (UX9-004 or UX90-004)
OAT	°F	Weatherproof Temperature/Relative Humidity Logger	Onset HOBO Temperature/RH Data Logger (MX2301)

² While OAT data can be measured directly with tools available through FELL, it can also be downloaded directly from the closest available weather station from the National Oceanic and Atmospheric Administration: <https://www.ncdc.noaa.gov/cdo-web/datasets>.

Table 2. Description of measurement tools

Tool Image	Tool Name	Description
	Fluke 345 Power Quality Clamp Meter (Fluke 345)	Multi-purpose electrical measurement tool used to take true RMS power readings over a short period of time.
	Onset HOB0 4-Channel Analog Logger (UX120-006M)	Used in conjunction with the CTV series of sensors. Records measurements from up to four CTV sensors. Requires HOBOWare software and a USB connection cable for programming and downloading data files.
	Split Core AC Current Sensor (CTV-A, CTV-B, or CTV-C)	Provides a measurement of the current flowing through a conductor and converts to a signal the U12- or UX120-series data logger can record. Rated for specific amperage ranges (CTV-A: 2-20 amps, CTV-B: 5-50 amps, or CTV-C: 10-100 amps). Sensor should be selected based on the maximum or minimum amperage anticipated to be measured, to avoid out of range readings.
	Onset HOB0 Motor On/Off Data Logger (UX90-004)	Records when a motor is operational, as well as runtime. Requires HOBOWare software and a USB connection cable for programming and downloading data files.
	DENT ELITEpro XC Power Meter (EXCUNC) Dent 16" RoCoil Flexible Rope Current Transformers (CT-R16-A4-U)	Provides a measurement of true RMS power from voltage and current inputs and records long-term power (kW) and energy (kWh). Requires ELOG software and a USB connection cable for programming and downloading data files.
	Onset HOB0 Temperature/RH Data Logger (MX2301)	Data logger and sensors in a waterproof enclosure that measure and record OAT. Requires HOBOWare software and a USB connection cable for programming and downloading data files.

Measurement Strategies

The following instructions have been developed for each measurement strategy discussed in this guide. While these instructions are reasonably detailed, certain aspects of each strategy may need to be modified based on the specific system configuration at each facility. Early surveying of the facility is useful when tailoring each strategy to unique site conditions.

The measurement recommendations reference supplementary equipment guides, which can be found in Appendix A.

- *A.1: Onset HOBO Motor On/Off Data Logger (UX90-004)*
- *A.2: Fluke 345 Clamp Meter*
- *A.3: DENT ELITEpro XC Power Meter*
- *A.4: Onset HOBO 4-Channel Analog Logger (UX120-006M) & Onset Split-Core AC Current Sensor*
- *A.7: Onset HOBO Temperature/Relative Humidity Data Logger (MX2301)*

Measurement for Constant Speed Constant Volume Pumps – On/Off Operation

This measurement approach is intended to be used for a constant speed, constant volume system configuration.

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations to place data acquisition equipment and take spot measurements.
2. Obtain measurement equipment from FELL:
 - a. HOBO Motor On/Off Data Logger (UX90-004)
 - b. Fluke 345 Power Quality Clamp Meter (Fluke 345)
3. Refer to *Appendix A.1: Onset HOBO Motor On/Off Data Logger (UX90-004)*
 - a. Set up and deploy data logger per the instructions in sections A.1.1 to A.1.3.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.2: Fluke 345 Clamp Meter*
 - a. Take a one-time measurement of true RMS power draw of the motor per the instructions in section A.2.1.
 - b. Take a screenshot of the reading per the instructions in section A.2.2 (or, alternatively, a photograph using a cell phone).
3. Refer to *Appendix A.1: Onset HOBO Motor On/Off Data Logger (UX90-004)*
 - a. Install the motor on/off logger in the selected location and be sure the logger passes the calibration with the motor running per the instructions in sections A.1.4 and A.1.5.
4. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the logger to verify data collection. **Do not remove the logger from the equipment.**
3. Refer to *Appendix A.1: Onset HOBO Motor On/Off Data Logger (UX90-004)*
 - a. Confirm that the logger is collecting data and that system operation is being recorded per the instructions in section A.1.6. **Be careful not to stop the logger when downloading data.**
4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.1: Onset HOBO Motor On/Off Data Logger (UX90-004)*
 - a. Confirm that the logger has collected the required operational data per the instructions in section A.1.6. **Do not yet remove the logger from the equipment. Be careful not to stop the logger when downloading data.**
3. Once data acquisition has been confirmed, stop the logger per the instructions in section A.1.6.
4. Remove the data logger and return to FELL.

Measure Power Consumed at the Main Feed to the Motor Using a Data-logging Power Meter

This measurement approach is the preferred method for a variable speed system. A data-logging power meter is attached at the feed to the VFD. It can also be used for a constant speed, constant volume system configuration, in which case the measurement is taken at the switch panel to the motor.

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed.
2. Obtain measurement equipment from FELL:
 - a. For all systems:
 - i. DENT ELITEpro XC Power Meter (EXCUNC) with 16" Flexible CTs (Current Transformers) (DENT CT-R16-A4-U)
 - b. For a system that is continuously variable with OAT:
 - i. Onset HOBO Temperature/RH Data Logger (MX2301)
3. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter* and, as necessary, *Appendix A.7: Onset HOBO Temperature/ RH Data Logger (MX2301)*
 - a. Set up and deploy data loggers per the instructions in sections A.3.1 and A.7.1 to A.7.3, respectively.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. For all systems, refer to *Appendix A.3: DENT ELITEpro XC Power Meter*
 - a. Install the ELITEpro XC power meter using sections A.3.2 and A.3.3 as guidance.
3. For a system that is continuously variable with OAT, also refer to *Appendix A.7: Onset HOBO Temperature/ RH Data Logger (MX2301)*
 - a. Install the Temperature/RH logger using section A.7.4 as guidance.
4. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the logger to verify data collection. **Do not remove the logger from the equipment.**
3. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter* and, as necessary, *Appendix A.7: Onset HOBO Temperature/ RH Data Logger (MX2301)*
 - a. Confirm that the ELITEpro XC power meter and Temperature/RH logger are collecting data and that system operation is being recorded per the instructions in sections A.3.4 and A.7.5, respectively. **Be careful not to stop the meter when downloading data.**
4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. For a single or dual-speed system:
 - a. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter*
 - i. Confirm that the ELITEpro XC power meter has collected the required operational data per the instructions in section A.3.4. **Do not yet remove the meter from the equipment. Be careful not to stop the meter when downloading data.**
 - b. Once data acquisition has been confirmed, stop the logger per the instructions in section A.3.5
3. For a continuously variable system with OAT:
 - a. Refer to *Appendix A.3: DENT ELITEpro XC Power Meter* and *Appendix A.7: Onset HOBO Temperature/ RH Data Logger (MX2301)*
 - i. Confirm that the ELITEpro XC power meter and Temperature/RH logger have collected the required operational data per the instructions in section A.3.4 and A.7.5. **Do not yet remove the loggers from the equipment. Be careful not to stop the loggers when downloading data.**
 - b. Once data acquisition has been confirmed, stop the loggers per the instructions in section A.3.4 and A.7.6, respectively.
4. Remove the data logger(s) and return to FELL.

Measure Current Supplied to the Motor at the Main Feed Using a Current Sensor

This measurement approach is intended as an alternative method for a VFD system. It can also be used for a constant speed, constant volume system configuration, where the measurement is taken at the switch panel to the motor instead of at the VFD. A one-time measurements of true RMS power and apparent current at known pump speed are recorded and used to create a correlation between true power and apparent current. Long-term measurements of apparent current are used to derive true RMS power over time.

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed
2. Obtain measurement equipment from FELL:
 - a. Fluke 345 Power Quality Clamp Meter (Fluke 345)
 - b. ONSET 4-Channel Analog Logger (UX120-006M)
 - c. ONSET Amp Split Core AC Current Sensors (CTV-A, B, or C)

3. Refer to *Appendix A.4: Onset HOBO 4-Channel Analog Logger (EX120-006M) & Onset Split Core AC Current Sensor*
 - a. Set up and deploy data logger per the instructions in sections A.4.1 to A.4.3.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.4: Onset HOBO 4-Channel Analog Logger (EX120-006M) & Onset Split Core AC Current Sensor*
 - a. Install the current sensors and analog logger using section A.4.4 as guidance.
3. Working with the appropriate facility personnel, run the VFD at a five equal steps starting at the minimum VFD speed recommended by the operator (e.g. 20%, 40%, 60%, 80% and 100%), waiting long enough between ramping for the clamp meter to get stable true RMS power, apparent current, power factor, and voltage. This may require overriding two-way valves with the BAS system to maintain the setpoint pressure differential in the system.
 - a. For each speed of the VFD, refer to *Appendix A.2: Fluke 345 Clamp Meter*:
 - i. Take a one-time measurement of true RMS power draw of the motor, apparent current, power factor, and voltage per the instructions in section A.2.1.
 - ii. Take a screenshot of the reading per the instructions in section A.2.2 (or, alternatively, a photograph using a cell phone).
4. If the pump is constant speed and constant volume, only one true power reading is needed.
5. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the logger to verify data collection. **Do not remove the logger from the equipment.**
3. Refer to *Appendix A.4: Onset HOBO 4-Channel Analog Logger (EX120-006M) & Onset Split Core AC Current Sensor*
 - a. Confirm that the logger is collecting data and that system operation is being recorded per the instructions in section A.4.5. **Be careful not to stop the logger when downloading data.**
4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.4: Onset HOBO 4-Channel Analog Logger (EX120-006M) & Onset Split Core AC Current Sensor*
 - a. Confirm that the logger has collected the required operational data per the instructions in section A.4.5. **Do not yet remove the logger from the equipment. Be careful not to stop the logger when downloading data.**
3. Once data acquisition has been confirmed, stop the logger per the instructions in section A.4.6.
4. Remove the data logger and return to FELL.

Alternate Strategy – Download Data from a BAS or a VFD

This measurement approach is intended to be used for a variable speed system that is controlled by a BAS or by a VFD with data trending and exporting capability.

STEP 1: Preparation for Data Acquisition

1. Confirm that the system can record either motor speed (in RPM) or percentage of full speed (in percentage). If possible, also record true RMS power. In lieu of true RMS power, current, voltage and power factor may still be available. In this case, true RMS power can be calculated.
2. Work with the building operator to program the VFD to record hourly average RPM or percent of full speed, as well as true RMS power (where possible).
3. If the system cannot record true RMS power, obtain the following from FELL:
 - a. Fluke 345 Power Quality Clamp Meter (Fluke 345)

STEP 2: Installation at the Site

1. Note that, for this measurement approach, installation at the site will only be required if the system cannot record true RMS power.
2. Implement appropriate safety procedures.
3. Working with the appropriate facility personnel, run the VFD to various speeds at which the VFD is programmed to operate. This may require overriding two-way valves with the BAS system to maintain the setpoint pressure differential in the system.
 - a. For each speed of the VFD, refer to *Appendix A.2: Fluke 345 Clamp Meter*
 - i. Take a one-time measurement of true RMS power draw of the motor, apparent current, power factor, and voltage per the instructions in section A.2.1.
 - ii. Take a screenshot of the reading per the instructions in section A.2.2. (or, alternatively, a photograph using a cell phone).
4. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. If possible, wait for the first recording period to pass during the installation at site; if not, return to the site as soon as possible to retrieve data from the system. **Do not stop the data recording process when downloading the data.**
3. Confirm that the data is being collected in the proper format, as required by the calculation spreadsheet.
4. It is recommended that this step be repeated periodically during the measurement period.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. Download data from the system for the duration of the measurement period.
3. Format the data into a Microsoft Excel spreadsheet in the appropriate format for the calculation spreadsheet.

Calculation Methodology

Total annual energy (in kWh) is calculated using the general equation, below:

$$E \left[\frac{kWh}{year} \right] = \sum_{i=1}^N T_i [Hours] * P_i [kW] \quad (1)$$

Where,

E = Electricity use of the pump motor, in kWh/year

T_i = Total amount of time that the pump is operational for a given operational bin, in hours/year

(Note that the operational bin could be defined by temperature ranges or scheduling characteristics.)

P_i = Average motor power draw for each operational bin, in kW

N = Number of operational bins

Five Microsoft Excel workbooks have been developed along with this guide to facilitate the calculation of total annual energy consumption from the measured data:

1. **Constant speed, constant volume pumps using motor on/off loggers** – This workbook calculates annual consumption of pumps using spot measurements for true power and motor operational time per hour, as measured by motor on/off data loggers.
2. **Constant speed, constant volume pumps using data logging power meters** – This workbook calculates annual consumption using average hourly power draw in kW.
3. **Constant speed, constant volume pumps using current sensors** – This workbook calculates annual consumption using hourly average current (in Amps) as directly measured by current sensors, and spot measurements for true power at both high and low speed operation.
4. **Variable speed, variable volume pumps using data logging power meters** – This worksheet calculates annual consumption using the average hourly power draw (kW) and the average hourly OAT as measured by a temperature/RH logger.
5. **Variable speed, variable volume pumps using speed data from BAS or VFD** – This workbook calculates annual consumption using hourly average motor speed (in RPM), as downloaded from a BAS or a VFD, and spot measurements for true power at both high and low speeds.

Instructions are included in each workbook that detail how to input data and how to interpret and make use of the results. Specific calculation methodologies can be found in Appendix A.18: Secondary Chilled Water Pump Calculations and are captured in the workbooks.

Reporting Recommendations

As part of the documentation of expected avoided energy use, the integration of measurements and calculation methodology discussed in this guide will serve to enhance these projections. To facilitate transparency and data quality control, the following pieces of information should be documented to accompany expected savings calculations:

1. Measurement tool information and dates of measurement. The HOBOWare software records logger information (such as product, serial number, and version number) as well as deployment and measurement dates. To export this information, use the software to open the logger data file, then select “Export Details” from the File menu; this will produce a text file like the one shown in Figure 9. Repeat for all data loggers that were deployed and include all files with the funding application.

```
Details
Series: FAn
  Devices
    Device Info
      • Product: HOBO UX90-004M Motor On/Off
      • Serial Number: 10939612
      • Version Number: 3.07
      • Manufacturer: Onset Computer Corp.
      • Device Memory: 524288
      • Header Created: 11/30/11 01:37:05 PM GMT-07:00
    Deployment Info
      • Full Series Name: FAn
      • Launch Name: AC-1-07_Fan
      • Deployment Number: 11
      • Wrap Enabled: Yes
      • Wrap Count: 0
      • Launch Time: 05/24/18 09:37:51 AM GMT-07:00
      • Launch GMT Offset: -7 Hr 0 Min
      • Battery at Launch: 2.87 Volts
      • Launching Program: HOBOWare Pro-3.7.13_0928_1253_Windows
    Series Statistics
      • Samples: 16
      • Total time on: 31:30:23 HMS
      • Total time off: 329:20:35 HMS
      • Percent time on: 8.73
      • Percent time off: 91.27
      • Number of transitions to on: 7
      • Number of transitions to off: 7
      • First Sample Time: 05/24/18 11:00:00 AM GMT-07:00
      • Last Sample Time: 06/08/18 11:50:58 AM GMT-07:00
```

Figure 9. Example of Device Information Export from HOBOWare

2. If a building automation system (BAS) was used to collect any of the information discussed in this guide, submit a brief description of the system, including:
 - a. BAS manufacturer and model
 - b. BAS software and version number
 - c. Measurement dates
 - d. Most recent date of sensor calibration (if a sensor was used)
3. The completed workbook(s) with measured data.

It is expected that the user will be responsible for measuring the system of interest and compiling the data input to the calculation tools. The output of these tools can be directly used to satisfy reporting requirements.