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
cunybpl.org

Measurement Guide: Boilers

By:
Daniel Jimenez, Peter Phung| M&V Interns
Phillip Chao, PhD | Applied Research Scientist
Duncan Prahl, RA, AIA | Sr. Applied Research Scientist

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

07/20/2020

The City University of New York

CUNY INSTITUTE FOR URBAN SYSTEMS

Table of Contents

Table of Figures

Table of Tables

Acronyms

AHU	Air handling unit
BAS	Building automation system
Btu	British thermal unit
CFD	Cubic feet per day
CUNY BPL	CUNY Building Performance Lab
DCAS DEM	NYC Department of Citywide Administrative Services Division of Energy Management
ECM	Energy conservation measure
FELL	CUNY BPL Field Equipment Lending Library
GHG	Greenhouse Gas
GPD	Gallons per day
kW	kilowatt
IPMVP	International Performance Measurement and Verification Protocol
OAT	Outdoor air temperature
M&V	Measurement and verification
MW	Megawatt
PV	Photovoltaic
RTU	Rooftop unit
true power	true RMS power
VAV	Variable air volume
VFD	Variable frequency drive
NOAA CNY	National Oceanic and Atmospheric Administration Climate Normal Year

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 expected 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 of 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 existing boiler systems with more efficient boilers.

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 boiler system. **If you are already familiar with the system, you may skip to the *Measurement Description for System* section.**

System Overview

A boiler system is comprised of a closed pressure vessel, exhaust vents for flue gases, a motor for air intake, and a burner to initiate combustion. Two examples of commercial boilers are shown in Figures 1[1] and 2.

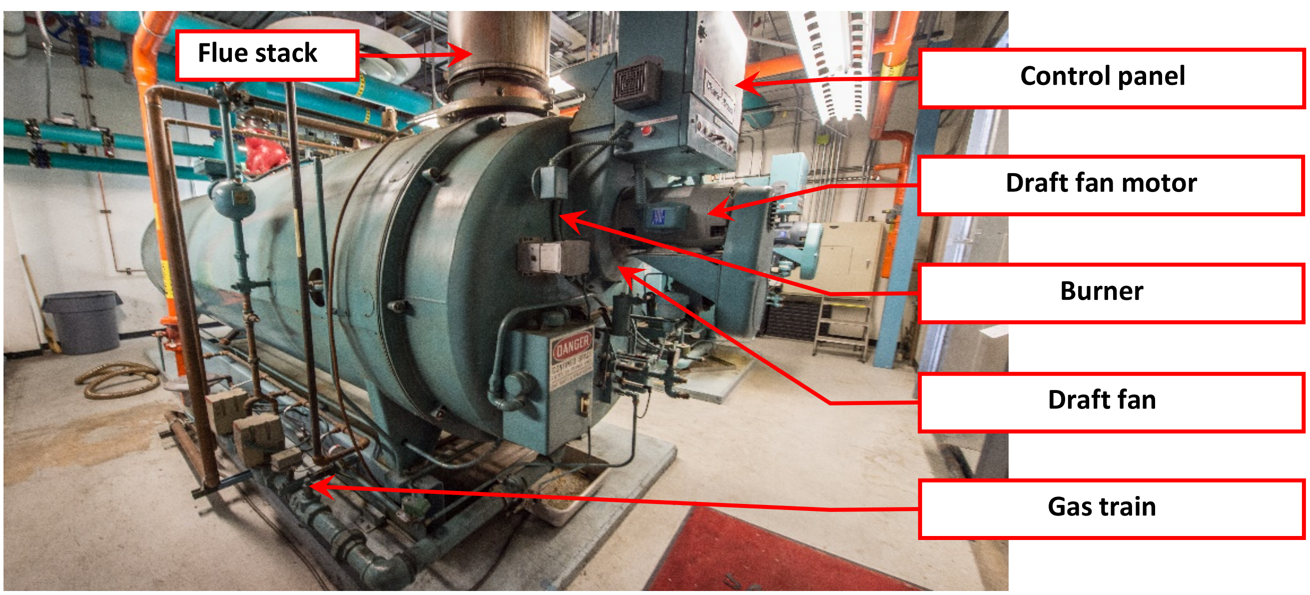


Figure 1. Components of a large boiler

[1] Image courtesy of NREL.

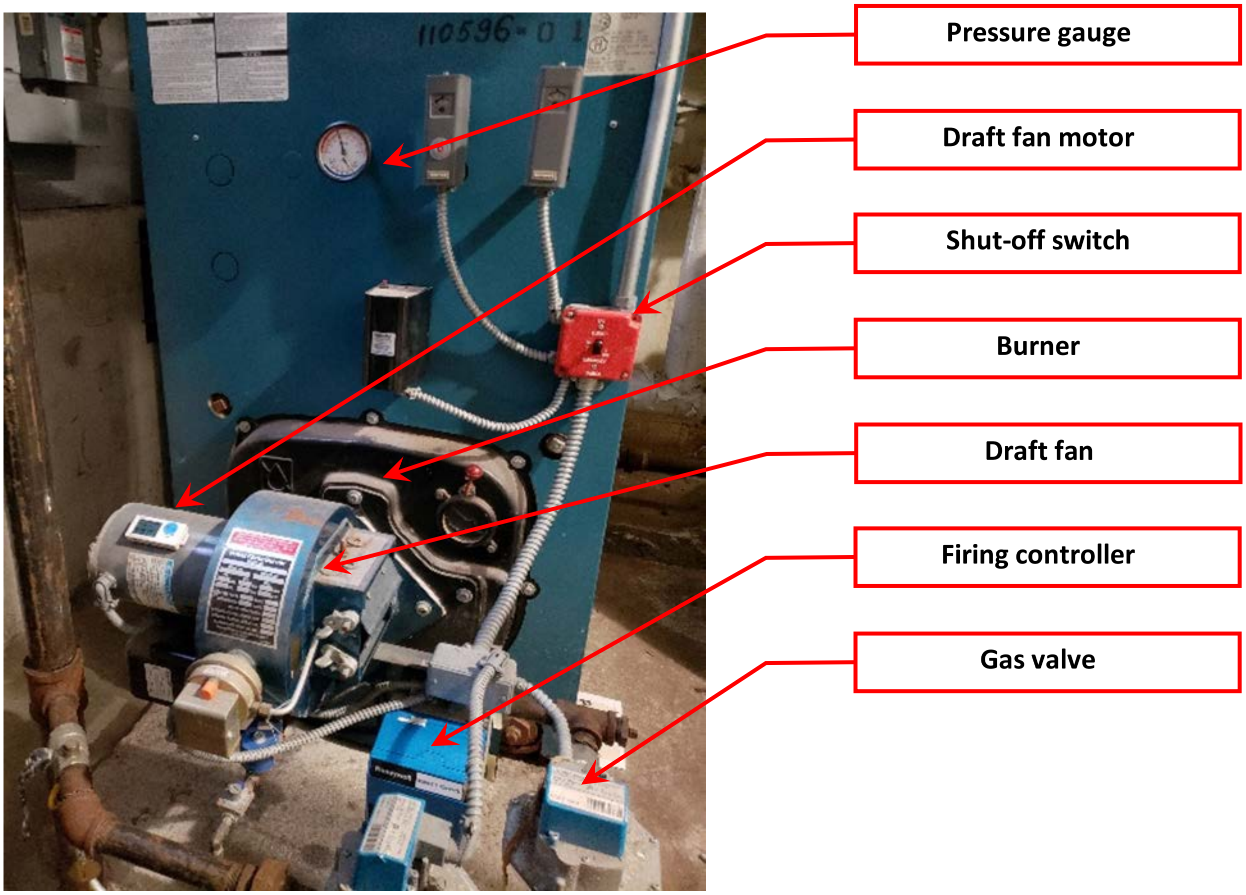


Figure 2. Components of a smaller boiler

Key Variables Associated with Calculating Energy Consumption of a Boiler System

The primary energy source for a boiler system is fuel, which is measured in the respective fuel unit type (e.g., gallons, cubic feet). The relevant variables used to characterize the fuel consumption of a boiler system are:

- Operating schedule
- Fuel type
- Fuel consumption
- OAT

Operating Characteristics

From the perspective of energy consumption, boiler systems have two operating modes – modulating and non-modulating. This guide is intended to measure boiler fuel use for a non-modulating boiler system. The approach for a modulating boiler system is a bit more complex, as the firing rate modulates to match the boiler output to the building heating load which results in changes in fuel and electricity consumption rate. Alternatively, a non-modulating boiler will turn on and off based on the system's internal pressure and control settings; this often leads to more on-off cycles.

It is important to discuss with the building operator the operating characteristics of the boiler to determine how the boiler is being run. Many buildings have multiple boilers and a variety of controllers that may include: OAT reset, modulating firing rate, fixed or staged firing rate, multiple modular boilers programmed to fire in sequence, differently sized boilers for use at different times of the year (e.g., summer boiler for DHW), dual fuel configurations, or other. It is important to characterize the type of system, any associated controllers, and the way in which boiler is actually operated, in order to reasonably quantify an estimate of annual consumption.

Scope of This Guide

This guide describes how to measure and analyze the annual energy consumption of two ECMs that are relevant to boiler systems:

1. **Boiler Replacement:** Older low-efficiency or poorly operating boilers can be replaced with higher efficiency, more responsive equipment. This may include resizing boilers to enable the modulation to more closely match the heating load, or to provide domestic hot water more efficiently when heating is not needed.
2. **Boiler Tuning:** A boiler that is not tuned regularly will likely run less effectively than designed. Boiler tuning typically increases efficiency and thereby reduces fuel consumption and GHG emissions.

This guide is designed to assist in gathering both pre- and post-retrofit data for the fuel consumption of a boiler system used for space heating. As such, a primary goal is to describe the data that should be collected through measurements and the appropriate equipment to perform those measurements. Guidance is provided for measuring boiler system runtime and fuel consumption. Upgrades to hot water circulating pumps and draft fans are not covered in this guide.

In addition to facilities with large boilers, this guide may also be used at facilities that are equipped with many small boilers that are sequenced to fire individually as the heating load increases. These systems may have been modified over time and therefore not operating as originally intended. Boilers may be grouped to fire together instead of sequentially, non-operable boilers may be taken offline, or boilers sequence may be altered to rotate for even wear. A customized measurement strategy will likely be necessary for these situations.

The measurement strategies in this guide may be used on dual fuel boilers, however care must be taken to have proper recording equipment for measurements of both the natural gas and fuel oil consumption. This guide does not explicitly provide a methodology for measuring the aggregate fuel use of a dual fuel system; instead, each measurement technique should be individually applied and engineering judgement used in the interpretation of results.

Finally, if an estimate of boiler fuel consumption is needed for domestic hot water purposes, simply apply the measurement techniques in this guide for several weeks during the non-heating season, and derive an average daily or weekly fuel consumption amount, since domestic hot water consumption usually does not have any correlation to OAT.

Assumptions

Due to the difficulty of directly measuring fuel consumption at the boiler, a number of very broad assumptions are made when applying the measurement techniques in this guide:

1. **The boiler system is the dominant fuel use in the facility.** The boiler system must be using at least 80% of the daily fuel use. Other fuel-burning devices in the facility must have reasonably stable daily operating patterns that do not change between the pre- and post-retrofit periods.
2. **The primary function of the boiler system is to provide space heat for the facility**. This guide uses OAT as the independent variable for estimating fuel use; it should not be used for facilities that have large process loads that do not correlate to OAT. Though boiler systems may also generate domestic hot water for a facility, this guide assumes that there is no change in the daily hot water use patterns between the pre- and post-retrofit periods.
3. **The daily and weekly operation of the boiler system is reasonably consistent.** The techniques in this guide assume that facilities are operated on a regular schedule and that boiler operations are driven by that schedule. This applies to supervised boilers where facility staff start and stop the boilers, or a non-supervised system where an automatic controller (e.g., thermostat, time clock) operates the boiler.
4. **Manual fuel reading are logged at regular intervals.** The estimates of annual fuel use are driven by daily average OAT, which is derived from hourly temperatures between 12:00 a.m. to 11:59 p.m. Manual fuel readings that are not taken at midnight must be apportioned to allocate some fuel use to the previous day, and some to the day of the reading. Better annual estimates are derived when readings are taken at roughly the same time each day. The calculation tools that accompany this guide can apportion fuel use if readings are logged daily. A separate analysis is needed to apportion readings that span more than one day, taking into account aggregate boiler runtime and OAT. This analysis is beyond the scope of this guide.
5. **Days with fuel delivery are ignored.** On days when deliveries occur, fuel is both used by the boiler and added to the tank. There is no reasonable way to know when the fuel was delivered in the day and how to apportion fuel use for that day, so those days are removed from the analysis.
6. **Multiple boilers in a single facility are the same size.** Hourly boiler runtime is used to apportion daily fuel use in calculations where manual daily readings are taken. It is assumed that the firing rate of each boiler is roughly the same.
7. **Modulating boilers require automated readings.** Some modulating boilers use a constant speed draft fan, so the fuel use is not directly correlated to fan runtime. An automated reading system is needed to record fuel use at 12:00 a.m. each night for these systems. In rare cases where the boiler is supervised 24 hours-a-day, manual fuel readings may be a viable alternative.

Measurements

Measurement Approach

This guide is focused on characterizing the annual fuel consumption for a boiler system based on OAT and day-of-week operating schedule. The measurement boundary of the system is defined simply as the fuel used by the boiler as reflected in the operational runtime and sequencing of one or more boilers in a facility. Figure 3 and Figure 4 illustrate the measurement boundaries used within the confines of this guide for a natural gas-fired boiler.

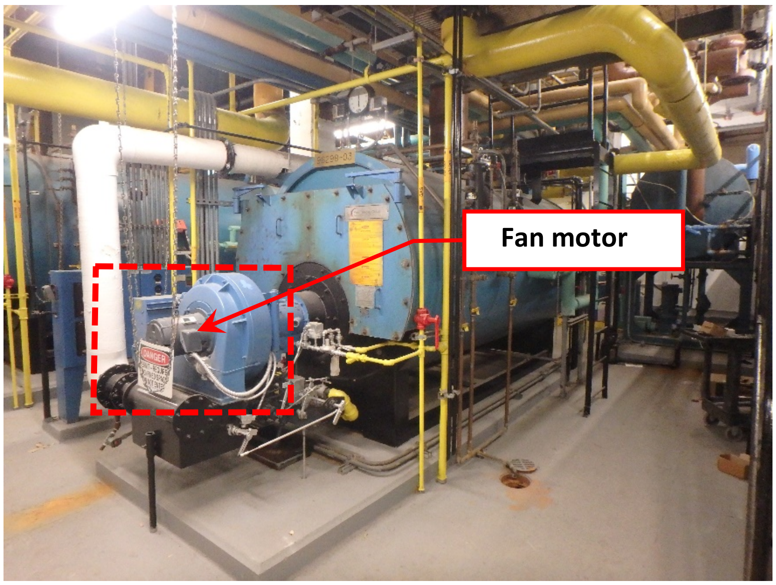


Figure 4. Measurement boundary of the boiler at the draft fan

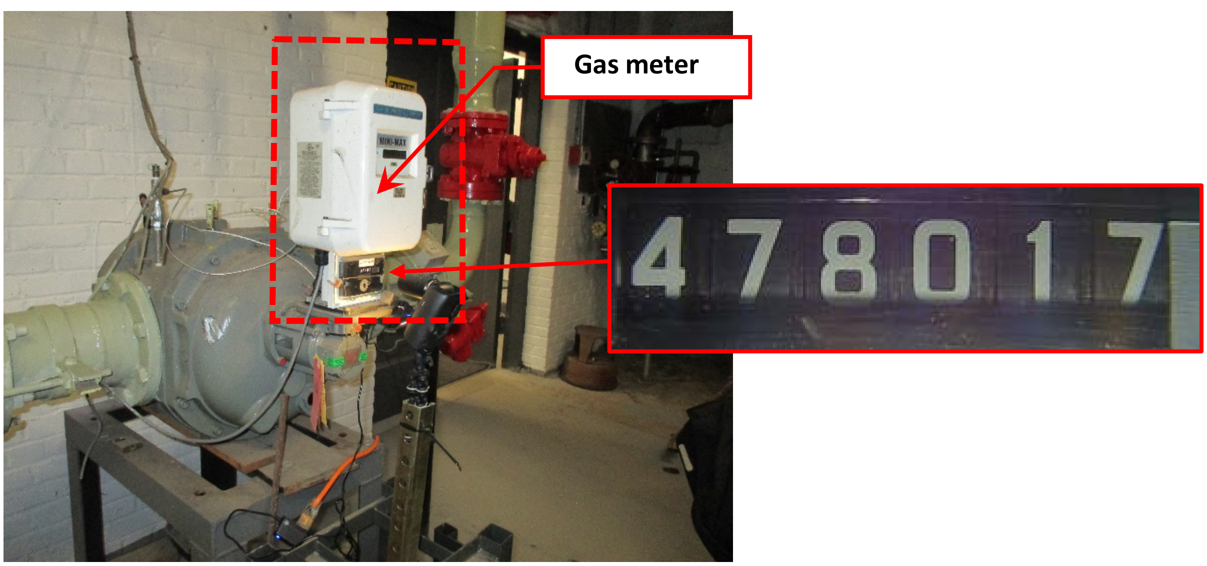


Figure 3. Measurement boundary of a boiler system at the gas meter

The first step is to determine how fuel measurements are to be taken. Figure 5 depicts a decision tree that can be used to evaluate options for fuel data collection. CUNY BPL has used a time lapse camera to record natural gas meter readings (where the camera can be set up in a secure location), and has also developed an automated method to read natural gas meters with digital readouts similar to the one shown in Figure 4.

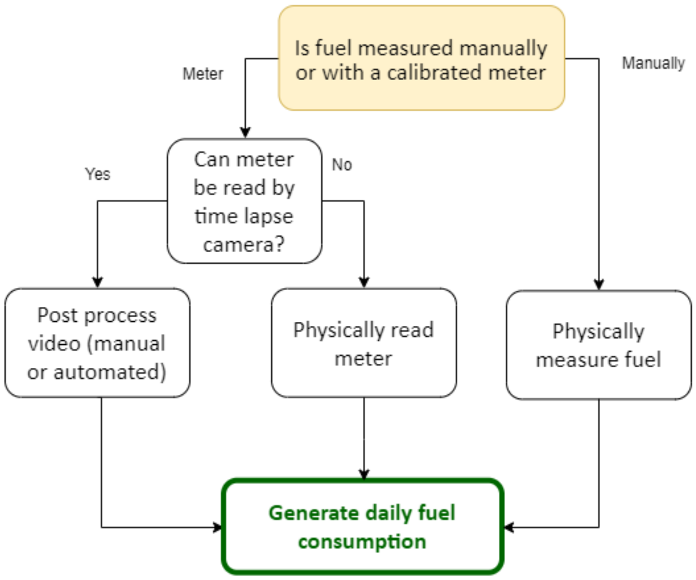


Figure 5. Decision tree to determine method to use to gather fuel data.

Figure 6 depicts a decision tree that can be used to determine which measurement strategy to apply to a specific system based on system configuration and components.

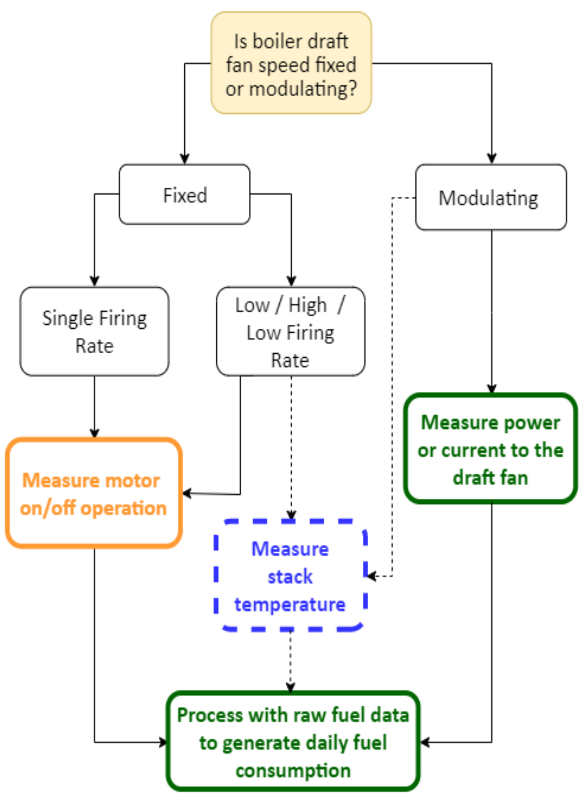


Figure 6. Decision tree to determine the measurement strategy for a boiler system.

The measurements are designed to quantify fuel use per day using boiler runtime per day as a proxy for boiler firing; boiler start and stop times per day (if the boiler is set back or manually operated by a building operator); and if there are multiple boilers, which one is running as the "lead" or primary boiler and which is the "lag" or second-stage firing boiler.

Ideally, fuel consumption is measured using a calibrated meter. Inline meters that directly measure the flow of the fuel being used are best, however in many cases these are impractical to add on to individual or multiple boilers. Ultrasonic meters are available for non-intrusive measurement; however, many fuel oil systems continuously circulate, so direct measurement of the oil flow through the pipe is not representative of the actual consumption of the boiler. Natural gas is typically metered by the utility, and in most facilities there is either a dedicated meter for the boilers or the boilers are the dominant use of natural gas. Meter location will influence the ability to implement some of the measurement techniques listed below.

Given the number of variables, a number of strategies are listed below. These are based on either taking manual direct measurements or recording utility meter operation over time and translating that into a data file.

It is strongly recommended, in the implementation of boiler ECMs in this guide, to specify a system that enables trend-logging of the firing rate, runtime, and fuel consumption as part of the retrofit. The boiler control system or a building automation system (BAS) can then be used to record long-term measurement of post-retrofit operation to estimate annual consumption.

Sampling

Since there are usually no more than three boilers associated with any given project, sampling is not recommended. In addition, multiple boiler systems are typically cycled by building operations staff to even out overall runtime and the lead/lag use of the boilers. If a rigorous sampling plan is needed, Bonneville Power Administration[2] has developed an excellent reference for guidance.

Measurement Strategies

To develop a reasonable estimate for the annual consumption of a boiler system, daily fuel use must be quantified and correlated to the operational schedule of the facility and OAT. This requires measurement of the daily operation of the boiler draft fan(s), daily fuel consumption of the boiler(s), and average daily OAT.

Measure Draft Fan Motor On/Off Operation

This strategy is for single-speed fans. Single-speed fans may be installed on modulating boilers, where the air mixture is controlled by the relative position of the air damper at less than high fire. Draft fans are typically turned on shortly before a boiler fires (pre-purge) and turned off slightly after the burner has stopped firing (post-purge). The draft fan on-off cycle is not an exact measure of the firing time, however the duration of the pre- and post-purge cycles are usually the same regardless of the length of time the boiler fires. A motor on/off data logger is used to track the operating schedule, and identifies the lead and lag boiler, the sequence of boiler rotation over time (if boiler operations are rotated), and if the boiler is frequently turning on and off (i.e., short-cycling).

---

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

For each single-speed draft fan motor, the following parameter should be measured:

- Fan motor runtime

Motor on/off loggers only sense the magnetic field of motors running at 60Hz. If it is not possible to determine whether the draft fan has a single-speed 60Hz motor (e.g., through physical observation of the system, an interview with the building operator, or review of as-built drawings) it is best to derive runtime by using the next measurement strategy.

Measure Draft Fan Motor Current or Power

When the power draw of the draft fan motor is varied (i.e., modulating or running at multiple fixed speeds) the measurement approach needs to characterize the range of operation and how it varies over time. While motor on/off loggers do not sense the magnetic field of motors running below 60 Hz, measuring the power or current to the motor captures both the runtime of the boiler and the relative speed of the motor, which is an indication of the firing rate.

Measure Stack Temperature

If a more detailed evaluation of the relative firing rate of a low/high/low or modulating firing rate boiler with a single-speed fan is needed, measuring the flue stack temperature in conjunction with the motor runtime can provide insight into the hourly firing rate of the boiler system. However, it is not necessary for estimating annual fuel consumption.

Measure Daily Fuel Consumption

Given the difficulty of installing equipment to directly measure fuel consumption, two general strategies are recommended. First, CUNY BPL has been successful processing time lapse video from a gas meter digital readout into a time-stamped data file. The video can also be manually translated into a spreadsheet. If this is not achievable, the second strategy is the time-honored tradition of “dipping the tank” for oil or manually logging a daily reading of the gas meter.

Measurement Tools and Equipment

The measurements in this guide can be performed with the equipment listed in Table 1; more detailed descriptions have been provide in Table 2. NYC agency employees can borrow the recommended equipment from the CUNY BPL 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.

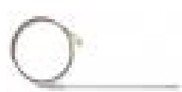
Table 1. List of measurements and associated tools

Measurement	Units	Tool	FELL Equipment
Burner Motor On/Off & Runtime	Seconds/Hour and %	Motor On/Off Data Logger	Onset HOBO Motor On/Off Data Logger (UX9- or UX90-004)

Measurement	Units	Tool	FELL Equipment
True RMS Energy	kWh	Data-logging Power Meter and Current Transformers	DENT ELITEpro XC Portable Power Data Logger (EXCUNC) Dent 16” RoCoil Flexible Rope Current Transformers (CT-R16-A4-U)
OAT	°F	Weatherproof Temperature/Relative Humidity Data Logger	Onset HOBO Temperature/RH Data Logger (MX2301)
Fuel flow rate (GPM/CFM)	GPD/CFD	Time Lapse Camera	Brinno TLC200 Pro
Flue Stack Temperature (not required, but may be useful)	°F	Data Logger and Stack Tempoerature Sensohermocouple	Onset HOBO 4-Channel Thermocouple Logger (UX120-014M) Onset HOBO Type K 12" Probe Thermocouple Sensor

Table 2. Detailed descriptions of measurement tools

Tool Image	Tool Name	Description
	Onset HOBO Motor On/Off Data Logger (UX90-004)	Records when a motor is on and off, as well as runtime. Requires HOBOware software and a USB connection cable for programming and downloading data files.
	DENT ELITEpro XC Portable Power Data Logger (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) measurements. Requires ELOG19 software and a USB connection cable for programming and downloading data files.
	Onset HOBO Temperature/RH Data Logger (MX2301)	Records outdoor air temperature and relative humidity using internal sensors. Requires HOBOware software and a USB connection cable for programming and downloading data files.

Tool Image	Tool Name	Description
	Brinno TLC200 Pro	Takes pictures with respect to a time interval set by the user. Stores all of the pictures that the camera has taken in a video file that can be used to obtain measurement data for whatever the camera was pointed at. Should only be used in a secure location.
	4-Channel Thermocouple Logger (UX120-014M)	Used to record flue gas temperatures to assess firing rate of a modulating boiler. Can accept up to four J, K, T, E, R, S, B, or N type probes. In addition the logger features an internal sensor for logging ambient temperatures. Not a required measurement.
	Onset HOBO Type K 12" Probe Thermocouple Sensor	Used to measure flue gas temperature if needed. Converts the measurement to a signal that the 4-Channel Thermocouple Logger (UX120-014M) can record. Not a required measurement.

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.3: DENT ELITEproXC Portable Power Data Logger*
- *A.7: Onset HOBO Temperature/RH Data Logger (MX2301)*
- *A.11: Brinno TLC200 Pro Time Lapse Camera*

Measure Draft Fan Motor On/Off Operation

This measurement approach is intended for single-speed, fixed firing rate boiler system configurations.

STEP 1: Preparation for Data Acquisition

a. Confirm site conditions and locations where data acquisition equipment will be placed.
b. Obtain measurement equipment from FELL:

    a. Onset HOBO Motor On/Off Data Logger (UX90-004)

c. Refer to *A.1: Onset HOBO Motor On/Off Data Logger (UX-90-004)*
    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 *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.
3. 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 A1.6. **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.**
    b. Once data acquisition has been confirmed, stop the logger per the instructions in section A.1.7.
3. Remove the data logger and return to FELL.

Measure Draft Fan Motor Power

This approach should be used in a boiler with a variable speed fan and burner. Post processing of data is needed to convert hourly power as a percentage of full fire operation to an equivalent gross daily firing rate. Workbooks for this conversion have not been fully developed.

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed.
    a. Obtain measurement equipment from FELL:
        i. DENT ELITEproXC Portable Power Data Logger – (EXCUNC) with 16” Flexible Current Transformers (CTs) (DENT CT-R16-A4-U)
2. Refer to *Appendix A.3: DENT ELITEproXC Portable Power Data Logger*
    a. Set up and initialize the DENT logger per the instructions in section A.3.1.
3. Refer to *Appendix A.3: DENT ELITEproXC Portable Power Data Logger*
    a. Set up and initialize the DENT logger per the instructions in sections A.3.1.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. *Appendix A.3: DENT ELITEproXC Portable Power Data Logger*
    a. Install the DENT ELITEproXC Portable Power Data Logger using sections A.3.2 to A.3.3 as guidance. Keep the computer connected to the logger so readings can be seen in real time.
    b. Ask the facility representative to operate the boiler at four or five known firing rates (e.g. minimum, ~30%, ~60% maximum) for three to five minutes at each rate.
    c. Confirm the readings have been recorded by the DENT ELITEproXC Portable Power Data Logger
3. 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 ELITEproXC Portable Power Data Logger*
    a. Confirm that the DENT ELITEproXC Portable Power Data Logger is collecting data and that system operation is being recorded per the instructions in section A.3.4. **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. Refer to *Appendix A.3: DENT ELITEproXC Portable Power Data Logger*
    a. Confirm that the DENT ELITEproXC Portable Power Data Logger has collected the required 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. Remove the data logger and return to FELL.

Measure Daily Fuel Consumption with Time Lapse Camera

This measurement approach provides a non-intrusive method of obtaining the natural gas consumption of a boiler with the use of a Brinno TLC200 Pro Time Lapse Camera. The camera records time-lapse photos of the natural gas meter, which are stored in an AVI file from which meter readings can be extracted and analyzed for the purposes of this M&V guide.

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. Brinno TLC200 Pro Time Lapse Camera
3. Refer to *Appendix A.11 Brinno TLC200 Pro Time Lapse Camera*
    a. Set up and deploy camera per the instructions in section A.11.1.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
2. Refer to *Appendix A.11 Brinno TLC200 Pro Time Lapse Camera*
    a. Install the camera at the field site by following the steps outlined in section A.11.2.
3. Initial field setup is now complete.

STEP 3: Verify Data is Being Collected

1. Implement appropriate safety procedures.
2. Refer to the last step of Appendix A.11.2 and Appendix A.11.3.
    b. Confirm that the logger is collecting data. The LCD screen of the Brinno TLC200 Pro Time Lapse camera should have the word "REC" right under the preview screen, which means the camera is taking time-lapse photos.
3. It is recommended that this step be repeated periodically during the measurement period.
    a. Ensure that the meter window is free of any dirt or obstructions during the periodic checkup.

STEP 4: Retrieve Data Acquisition Equipment and Download Data

1. Implement appropriate safety procedures.
2. Refer to Appendix A.11.4
    a. Confirm that the logger has collected the required operational data per the instructions in section A.11.4. Follow that section to view the contents of the SD card on your computer. **Do not yet remove the camera from the equipment.**
3. Once data acquisition has been confirmed, shut off the camera.
4. Process video file manually or request CUNY BPL support in translation of the video to a data file.
5. Remove the camera and return to FELL.

Manually Measure Daily Fuel Consumption

Tools from FELL are usually not needed in the case of obtaining the fuel consumption from dipstick readings or manual meter readings. Dipstick or meter readings should be conducted daily by the building personnel and the fuel levels recorded in a log.

1. Three headings are needed for the log:
    a. Calendar date
    b. Time in hours (0 – 23, where 0 = 12:00 a.m. to 12:59 a.m.)
    c. Fuel consumed since last reading in gallons or cubic feet

Measure Outdoor Air Temperature

STEP 1: Preparation for Data Acquisition

1. Confirm site conditions and locations where data acquisition equipment will be placed.
    a. Obtain measurement equipment from FELL:
        i. Onset HOBO Temperature/Relative Humidity Weatherproof Data Logger (MX2301)
2. Refer to *Appendix A.7: Onset HOBO Temperature/Relative Humidity Weatherproof Data Logger (MX2301)*
    a. Set up and initialize the Temperature/Relative Humidity Weatherproof Data Logger, per the instructions in sections A.7.1 through A.7.3.

STEP 2: Installation at the Site

1. Implement appropriate safety procedures.
    a. Install the Temperature/Relative Humidity Weatherproof Data Logger using section A.7.4 as guidance.
2. 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.7: Onset HOBO Temperature/Relative Humidity Weatherproof Logger (MXX2301)*
    a. Confirm that the Onset HOBO Temperature/Relative Humidity Weatherproof Data Logger (MX2301) is collecting data and that system operation is being recorded per the instructions in sections A.7.5, respectively. **Be careful not to stop the loggers 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.7: Onset HOBO Temperature/Relative Humidity Weatherproof Logger (MX2301)*
    a. Confirm that the Temperature/Relative Humidity Weatherproof Data Logger has collected the required data per the instructions in section 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.7.6.
3. Remove the data logger and return to FELL.

Calculation Methodology

Total heating season energy is calculated using the general equation, below:

$$E = \sum_{n}^{365} a_n * X_n + b \tag{1}$$

Where,

E_{ann} = annual normalized fuel usage of boiler
a_n = regression coefficient in fuel use/average daily OAT in °F for n day of year
X_n = NOAA CNY OAT for n day of year, in °F
b = y-intercept of regression equation

One Microsoft Excel workbook has been developed along with this guide to facilitate the calculation of total annual energy consumption from the measured data:

1. **2002_0720_boiler.** This workbook assumes that boiler operation for space heating begins when the daily OAT is below 65°F. Fuel consumption readings that are not taken at 12:00 a.m. each day are apportioned by boiler runtime. Measurements of fuel consumption are needed, as is the time the reading was taken, the motor runtime for all operating boilers, and the corresponding average OAT for that day. If the boiler makes both space heat and domestic hot water, this workbook calculates the fuel consumption for both. To calculate only the space heating consumption, separate measurements must be taken during the non-heating season, an average daily fuel consumption for domestic hot water must be derived, and that consumption must then be subtracted from the fuel consumption calculated in the workbook for the number of days the boiler is providing space heat.

Instructions are included in the boiler calculation 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.14: Boiler Calculations and are captured in the workbook.

This calculation is based on the daily fuel consumption of the boiler (i.e., from 12:00 a.m. to 11:59 p.m.). Daily fuel readings must be aligned with this time period; if readings cannot be taken at 12:00 a.m. each day, then the following calculations can be used to apportion fuel use per day.

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 7. 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 7. Example of device information export from HOBOware

2. If a 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) containing 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.