Cold Climate Housing Research Center
CCHRC

Final Report to
Alaska Housing Finance
Corporation

Fuel Use Monitoring Methods for Residential Oil Heating Appliances

September 31, 2012

Submitted to:
Alaska Housing Finance Corporation
4300 Boniface Parkway
Anchorage, AK 99504

Cold Climate Housing
Research Center

P.O. Box 82489
Fairbanks, AK 99708

Telephone: 907.457.3454
Fax: 907.457.3456

www.cchrc.org

Fuel Use Monitoring Methods for Residential Oil Heating Appliances

Cold Climate Housing Research Center

written by

Robbin Garber-Slaght

Vanessa Stevens

By Valentine

Liam Ryan

September 31, 2012

This document is a .pdf of a website. The full report and appendix for this project are available on the internet at http://137.229.65.15:8090/display/projects/Fuel+Use+Monitoring+Methods

Disclaimer: The research conducted or products tested used the methodologies described in this report. CCHRC cautions that different results might be obtained using different test methodologies. CCHRC suggests caution in drawing inferences regarding the research or products beyond the circumstances described in this report.

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Fuel Use Monitoring Methods

Introduction

There is a currently a need to monitor heating oil consumption in Alaska communities at the household level. Such monitoring would allow state agencies, such as the Alaska Housing Finance Corporation (AHFC), to identify current energy use levels and evaluate progress toward statewide energy efficiency targets. Monitoring fuel use can be as simple as using a dipstick to record the level in the tank or as complicated as measuring the weight of fuel passing through a small day tank. This report details a 2012 study done by the Cold Climate Housing Research Center, where several fuel-use measurement systems were tested on a residential-sized boiler and a Toyotomi oil-fired room heater. The study also allowed a platform for further testing of a run-time measurement system, BUDS-lite, developed by CCHRC. The project objectives were:

1. To determine the accuracy of the BUDS-lite measurement system;
2. To evaluate options for measuring fuel use in boilers, furnaces, and space heaters in terms of reliability, accuracy, cost, ease of install and maintenance, and required data analysis;
3. To compare the advantages and disadvantages of each option and make suggestions on measurement systems that would be appropriate for a large-scale study on fuel use in Alaska.

This project evaluated several systems to measure fuel use for residential heating systems, however the project was not an exhaustive review of all of the available fuel monitoring technologies. Measurements were taken of direct fuel flow, fuel level in the tank, or by estimating the run time of the heating appliance. Fuel oil is widely available in Alaska, and is used for household heating in most areas outside of Anchorage (see Figure 1). Diesel heating fuel comes in two types for residential heating: #1 and #2. Number 1 heating fuel is also known as kerosene and remains liquid to low temperatures. This type of fuel is used for Toyo type space heaters that require above-ground tanks. Diesel #1 is very common in Alaska, especially rural Alaska (Szumoniak, Fay, & Villalobos-Melendez 2010). Below-ground tanks can use Diesel #2, which is slightly less expensive. This study used diesel #1.

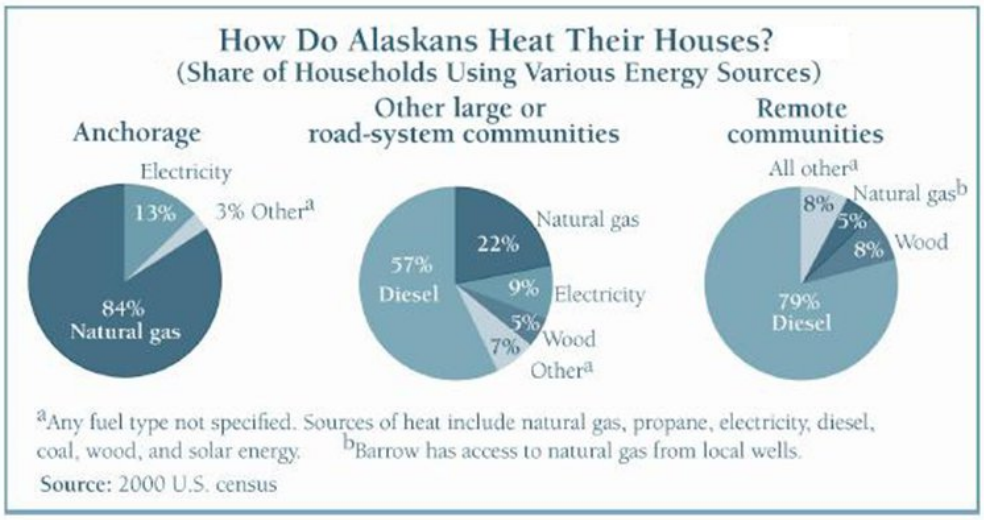


Figure 1. Many Alaskans use diesel fuel oil to heat their homes in the winter. (Figure from Saylor, B., Haley, S., & Szymoniak, N. (2008). *Estimated Household Costs for Home Energy Use.* Anchorage: Institute of Social and Economic Research.Retrieved from http://www.iser.uaa.alaska.edu/Publications/webnote/LLFuelcostupdatefinal.pdf)

The measurement systems were tested on two different heating appliances, chosen as representative of the heating appliances that might be found in an Alaska residence. The first was an oil-fired Viessmannn Vitola 200 hydronic boiler (Figure 2 left). This boiler is used as a central heating device with a radiant floor distribution system. The other appliance was a Toyotomi (Toyo) Laser 30, a small oil-fired space heater. It does not use a distribution system – a fan blows the heated air into the room (Figure 2 right). Many small cabins use a Toyo as a main heater, and larger houses can use Toyo stoves to supplement the primary heat source. Both of the

appliances used fuel oil #1 from an external tank. The fuel tank for the boiler was located above-ground outdoors on the west side of a building, and the fuel tank for the Toyo stove was located indoors next to the stove (it was installed specifically for this experiment). In Alaska, it is common for fuel tanks to be located outdoors, either above- or below-ground.

Figure 2. Studied heating appliances. The Viessmann (left) is a residential-sized boiler. The Toyo (right) is a small space heater.

Accurate monitoring of fuel use in residential heating systems is difficult. The low flows (as low as 0.04 gallons/hr) in the fuel line prevent the use of most flow meters. The simplest way to track fuel use is to monitor fuel delivery via utility bills, however this method is not necessarily the most most precise. Automatic physical monitoring of fuel requires special devices due to the hazardous and corrosive nature of the fuel and the low fuel flows. Simple monitoring of the heating device's run time requires an in-depth understanding of how the device uses fuel, which is not necessarily known from the device specifications. CCHRC found only one off-the-shelf monitoring system (the AMCO flow meter) for low-flow boilers in a search of available equipment. Most of the systems tested in this project require several parts; for example a system might require a sensor, a datalogger, a computer and a computer program for processing data.

As part of this study, CCHRC developed several fuel use monitoring systems and evaluated them based on the following criteria:

Reliability

The monitoring system should be universally reliable for monitoring fuel use for a variety of heating appliances in various climates. For example, it should be able to reliably monitor high-flow and low-flow fuel use on both boilers and room heaters. Some monitoring systems that need a constant power supply may not work in areas with variable power.

Accuracy

The monitoring system should provide an accurate estimate of fuel use, with a small uncertainty to a level that meets specific project objectives. It should be able to monitor fuel use in the range of 0.04 gallon/hr to 2 gallon/hr or a realistic change in tank level over a specified time range on both central heating appliances and room heaters.

Cost

The monitoring system should be cost-effective to use in large-scale fuel use studies. The researchers considered a range of hardware monitoring options that would be considered affordable for a study of more than 100 homes; the hardware in this study ranged from $12 to over $1500. The cost of a system includes the initial cost of the sensor and ancillary materials plus the cost of labor for set-up, data acquisition and analysis. In most cases the cost of labor and data analysis is far greater than the hardware costs.

Ease of installation and maintenance

The monitoring system should be easy to install and to implement data collection. Ideally, the monitoring equipment could be set up by one person with minimal technical expertise. Also, there should be minimal disturbance to the heating appliance. After installation, the monitoring device should require little maintenance – for instance, would residents have to change out batteries? Does the device have to be protected from inclement weather? Can data be stored on the device, or does a separate data logger have to be used? Does the device have to be programmed for data collection? Also, researchers considered if the device had to be calibrated to provide accuracy. If calibration is required, the procedure should be easy to follow and guidelines specifying how often the calibration must occur should be supplied.

Data Analysis

Each monitoring system requires some data analysis to process the data collected by the measurement system. This might consist of simply reviewing measurements for errors, or it might involve several formulas to extract a fuel volume from the data collected. Calculations might require a computer with spreadsheet software and programming capabilities. The data analysis should be straightforward and include minimal requirements for a large-scale study.

Methodology

This study followed a specific procedure to identify and to test measurement systems. Researchers wanted to test as many systems as the project budget would allow so that there would be several options to compare to each other. Also, as much as possible, systems were tested on both heating appliances to evaluate their performance in both situations. The phases of the project are outlined below:

Phase 1: Research fuel use monitoring and measurement systems

Researchers gathered information about potential fuel use monitoring systems. Monitoring systems included systems that had been used in the past by CCHRC for other projects, new systems that had been developed recently, and systems that were suggested by experts in the industry. CCHRC sought input from scientists and programmers on possible measurement systems.

Phase 2: Instrument a Toyo Laser 30 space heater and Viessmann Vitola 200 hydronic boiler with sensors to gather and analyze fuel use data

During the second phase of the project, researchers tested the measurement systems on the two heating appliances. Seven monitoring systems were set up first on the boiler (Table 1, Figure 3). Trouble-shooting occurred during the first week of testing, during which all systems and data collection devices were tested. After it was established that all seven systems were gathering data, the boiler was run for approximately 2 weeks (from March 8 to March 26) while the measurement systems collected data continuously. At the end of this period all data was analyzed and compared.

On both the Toyo and the Viessmann boiler, the Sensirion flow meter was set up to be the control standard to which all other monitoring systems were compared. It was chosen mainly by process of elimination. The run-time monitors are all dependent on the fuel nozzle and its actual fuel use , which researchers did not measure accurately in this study. Instead, fuel use was obtained from appliance documents, which do not always contain the correct usage value. The dipstick measurement was not done on an exact time schedule, and the AMCO flow meter was not used as a control because it had been installed several years prior and its

accuracy and calibration were unknown. The Sensirion was calibrated in the lab at CCHRC and the look-up table from the calibration had uncertainties of less than 1%. While not an ideal control system, the Sensirion represented the most accurate measurement technique, and also took measurements frequently (every 10 to 15 seconds). Originally, it was hoped to compare the Sensirion data to the load cell on the Toyo to further assess its accuracy; however, this did not occur because the data from the load cell did not have the resolution for high accuracy.

Table 1. Boiler measurement systems
Sensirion Flow meter
AMCO flow meter
Dipstick
BUDS lite
HOBO motor on/off logger
Current transducer on the switch
Current transducer on the pump

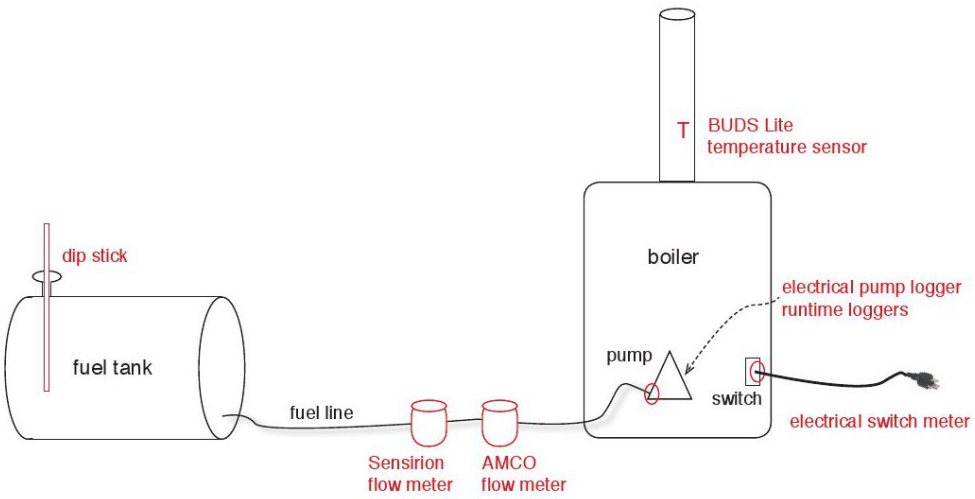


Figure 3. Measurement systems set up on the boiler. Seven monitoring systems were set up on the boiler and recorded fuel use for two weeks.

After the boiler test was concluded, eight measurement systems (Table 2, Figure 4) were then set up on the Toyo heater. The first phase of testing involved trouble-shooting the systems and checking that they were all running. Data collection occurred during two weeks in April while the Toyo was running continuously. Due to complications with the set point on the Toyo and some sensors, it was determined that the data collection period should be repeated. The second test ran from May 29 to June 11, but a power outage on June 1 shortened the data collection period for some sensors.

Table 2. Toyo measurement systems
Sensirion Flow meter
Omega load cell
Setra pressure transducer on the fuel tank
Scully Golden Gallon String Gauge
Dipstick
BUDS lite
HOBO motor on/off logger
Current transducer on the Toyo

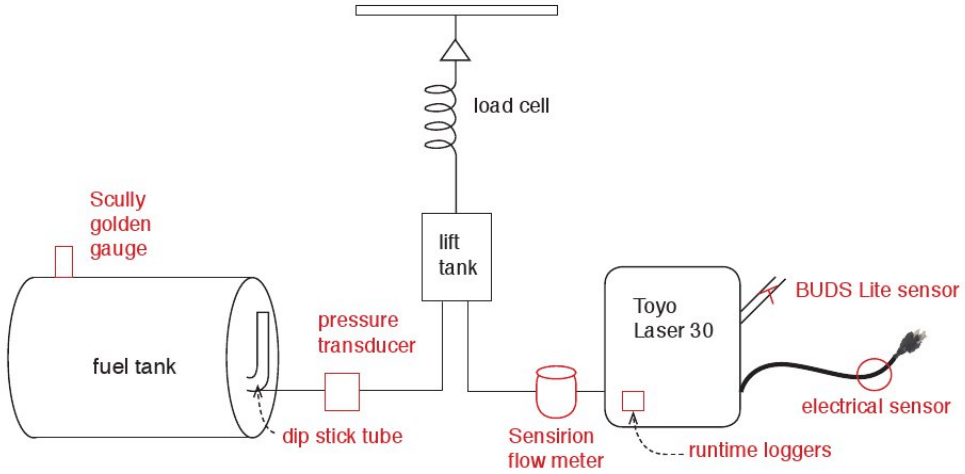


Figure 4. Measurement systems set up on the Toyo. Eight measurement systems recorded fuel use of the Toyo for two weeks.

Phase 3: Develop methods to calculate fuel use from data that was gathered

Researchers analyzed the data from each system to obtain a measurement for the fuel used during the testing period. For some systems, such as the dipstick and AMCO flow meter, researchers simply inspected the data for possible errors and then calculated the fuel use with basic arithmetic. Other systems required more complicated analysis to use the data collected to arrive at a fuel use measurement. In most cases, a spreadsheet program was used to organize and analyze the data. After analysis was performed, all measurements were compared to the Sensirion flow meter, which was the control system for both heating appliances.

Phase 4: Compare and contrast measurement systems

After analyzing the data to arrive at fuel use measurements, researchers compiled information about each measurement system. This information included quantitative information on the cost and accuracy of the systems, and qualitative observations on ease of use. Each fuel use system is discussed in the next section.

Fuel Use Measurement Systems

Table 3 contains an overview of each measurement system, and detailed descriptions of the systems follow. Th e systems are organized by the method of calculating the fuel use: in-line flow, tank level, or run-time. All systems with the exception of one were tested on at least one heating appliance.

Table 3. Fuel Use Measurement Systems

	Heating System	Reliability	Accuracy	Cost	Ease of use	Data Analysis	Restriction
In-line Flow Monitoring Systems							
Sensirion Flow meter	Toyo & Viessmann	High	High	Expensive	Medium	Medium	
AMCO flow meter	Viessmann	High	High	Mid-range	Medium	Easy	Boilers/Furnaces only
Omega load cell/day tank	Toyo	Medium	Medium	Mid-range	Difficult	Difficult	Requires a lift station
Tank Level Systems							
Setra pressure transducer	Toyo	Medium	High	Expensive	Medium	Medium	Above-ground tanks only
Scully Golden String Gauge	Toyo	Medium	Medium	Cheap	Easy	Easy	Requires tank dimensions
Dipstick	Toyo and Viessman	High	High	Cheap	Easy	Easy	Requires tank dimensions
Fuel Level Sensors	Neither	Low	Unknown	Mid-range	Difficult	Difficult	Requires tank dimensions
Run-time Systems							
BUDS lite	Toyo & Viessmann	High	High for Toyo Low for Viessmann	Mid-range	Easy	Easy	
HOBO motor on/off logger	Toyo & Viessmann	High	Low	Mid-range	Easy	Easy	Boilers/Furnaces only
Electricity Monitoring System	Toyo & Viessmann	Medium	High for Toyo Low for Viessmann	Mid-range	Medium	Medium	

In-line Flow Monitoring Systems

In-line flow monitoring systems are used to determine the flow through the intake line of the heating appliance. They can calculate the fuel volume directly, or a spreadsheet can be used to calculate the fuel volume using the flow rate and period of time. The following three systems require cutting into the fuel supply line in order to install sensors. Clamp on ultrasonic sensors were looked into but none were found in the range of flow residential appliances use at a reasonable price.

Sensirion flow meter

Tested on

Toyo and Viessmann

Materials and Price

- Sensirion SLQ-HC60 Flow meter ($1500)
- DC power supply (variable price)
- Data acquisition system (for example a Labjack U6 ($299))
- Computer (variable price)

Supporting Documents

- Sensirion datasheet (Sensirion)
- Labjack Logger user guide
- Labjack program- Sensirion
- Sensirion Calibration information (Sensirion)
- Calibration report
- Calculation worksheet - Sensirion (Excel file)

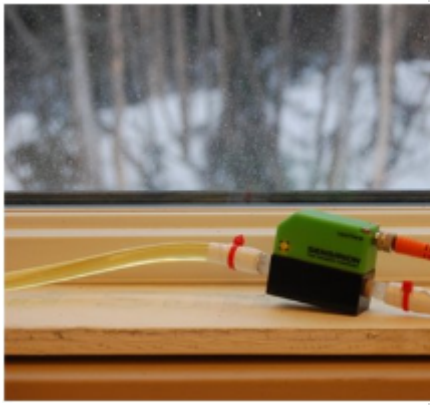


Figure 5. The Sensirion connected to the intake fuel line of a Toyo stove.

How it works

This flow meter measures the mass of the fuel that flows through it. It contains two temperature sensors. As fuel flows past the first sensor, a known amount of heat is added to the fuel. The fuel then passes by a second temperature sensor and the temperature difference of the fuel before and after the heat is added is used to calculate the mass. The sensor outputs a voltage which corresponds to a fuel flow.

Data storage

Data must be stored on an external data logger, such as a Labjack and computer or a Campbell Scientific data logger.

Data analysis

A computer program should be used to perform data analysis. The flow meter outputs a voltage which corresponds to a given fuel flow. The formula for this calculation is given by Sensirion, but the constants in the formula are specific to isopropyl alcohol. For use with other fuels, each Sensirion must be calibrated to obtain a “look-up table” of flow rates. Flow can then be calculated for other fuels using a linear interpolation technique. The procedure used to calibrate the flowmeter at CCHRC is in the Appendices , along with the program for linear interpolation and the calibration report for this project. After the flow is obtained, it must be summed over time to obtain a fuel volume.

Pros	Cons

• Reliable and accurate when calibrated and used correctly • Capable of logging data independently	• Expensive • Must be calibrated before use • Requires a break in the fuel line during install

AMCO flow meter

Tested on Viessmann **Materials and Price** AMCO 4 USG RE flow meter (approximately $330)	**Supporting Documents** • AMCO datasheet (AMCO) • Calculation worksheet - AMCO (Excel file)	 Figure 6. The AMCO flow meter connected to the intake fuel line of the boiler.

How it works

This flow meter was installed with the boiler at the time of the boiler install in the building, prior to this study. The flowmeter has an oscillating piston which turns a counter visible on the flow meter face. The flow meter is designed for oil flows of 0.25 to 20 gallons/hour. The flow meter is calibrated by AMCO to an accuracy of ±1%. AMCO tests this accuracy in the factory with fuel oil #2 at 70°F. However, AMCO states that the flow meter can be used with light heating oils, diesel, and gasoline.

Data storage

Data storage is a matter of user preference, as the data is collected by an individual. For instance, date, time and fuel level might simply be written in a notebook or on a calendar. Other people might choose to enter data into a computer spreadsheet program. AMCO (now Elster) also makes this meter with a pulse output (not studied as part of this project) which would allow for automatic logging of fuel use with a data logger.

Data analysis

Because the flow meter gives a reading in gallons, to find the total gallons used in a given time period, only subtraction is necessary. A spreadsheet program on a computer can be used to track fuel usage over time.

Pros	Cons
• Reliable and can be accurate • Easy to read fuel volume • Simple data analysis	• Requires a break in the fuel line during install • Relies on a person to record data

Omega Load Cell/Day Tank

Tested on	Supporting Documents	
Toyo **Materials and Price** • Omega S-beam load cell ($305) • Data acquisition system (for example a Labjack U6 ($299)) • Computer (variable) • Bracketing to suspend lift tank	• Omega datasheet (Omega) • Labjack Logger user guide • Labjack program - load cell • Fuel density information • Calculation worksheet - load cell (Excel file)	 Figure 7. The holding tank hangs from a load cell.

How it works

The load cell will only work on heating appliances with a lift tank. A day tank/lift station pumps fuel into a small holding tank until the holding tank is full. The fuel is then fed to the Toyo slowly as it is needed. When the level in the tank falls below a set point the pump fills the tank again. The holding tank is suspended from a load cell, which records the deflection in its shape. The deflection is sent to the LabJack in the form of a differential voltage. The LabJack program on the computer translates the voltage to a weight. Using a graph of the weight the fills can be calculated. The weight of each fill is used to calculate the amount of fuel flowing to the Toyo.

Data storage

Data must be stored on an external data logger, such as a Labjack/computer or Campbell Scientific.

Data analysis

A computer program should be used to perform data analysis. The program outputs a weight over time which corresponds to a given amount of flow. The data analysis portion of this system is complex and will require more time than some of the other systems. The attached calculation worksheet demonstrates how to convert the raw data into meaningful data.

Pros	Cons
• If a day tank is already in use, this method requires minimal set-up.	• Requires a suspended day tank/lift station • Requires a break in the fuel line during install • Not as reliable or accurate as other options • Complex data analysis

Tank Level Systems

Tank level systems measure fuel use by recording data on the level of the fuel in the tank. The level of the fuel is converted to a tank volume using the tank dimensions (see Appendix). The fuel used will be equal to the difference in fuel volumes between measurements.

Setra In-line Pressure Transducer

Tested on	Supporting Documents	
Toyo **Materials and Price** • Setra Model 256 Pressure Transducer ($470) • Data acquisition system (for example a Labjack U6 is $299) • Computer (variable)	• Setra datasheet (Setra) • Labjack Logger user guide • Labjack program - Setra • Fuel volume from fuel height • Fuel density information • Calculation worksheet - Setra (Excel file)	 Figure 8. The Setra pressure transducer is the blue cylinder appearing to the right of the filter.

How it works

The pressure transducer is placed at the base of the fuel storage tank along the fuel line. The pressure of the fuel at the base of the tank is recorded as a current output measured in milliamps from the transducer. The milliamp output is read at the Labjack and converted to a pressure using the calibrated data from Setra.

Data storage

The data must be stored on an external data logger, such as a Labjack and computer or a Campbell Scientific datalogger.

Data analysis

The pressure readings can be converted to height of fuel using the fuel density and calibrated data from the manufacturer. The volume of fuel in the tank can then be calculated using the height of fuel in the tank (see Appendix).

Pros	Cons
• Reliable and accurate • Capable of logging data independently • Can tolerate low temperatures to -40°F	• Requires a break in the fuel line during install • Only as accurate as the dimension measurements of the fuel tank • Only useable for above-ground tank

Scully Golden Gallon String Gauge

Tested on	Supporting Documents	
Toyo **Materials and Price** Scully Golden Float Gauge ($153)	• Scully Golden Gauge Data Sheet • Fuel volume from fuel height • Calculation worksheet - Scully (Excel file)	 Figure 9. The user simply reads the fuel height (in inches) from a counter at the top of the tank.

How it works

The Scully floating gauge is a commercial product that measures fuel height from the bottom of a fuel tank. It consists of a float that is inserted into a fuel tank, a string connected to the float, and a counter that appears at the entrance to the fuel tank. As the fuel level sinks or rises, the float stays on top of the fuel, causing the string to either lengthen or to scroll up. As the string moves, it rotates a counter so that the user can read the fuel height.

Data storage

Data storage is a matter of user preference, as the data is collected by an individual. For instance, date, time and fuel level might simply be written in a notebook or on a calendar. Other people might choose to enter data into a computer spreadsheet program. This might be helpful because calculations are necessary for converting a fuel height into a volume (formulas to convert fuel height to volume for a cylindrical tank on its side appear in the Appendix).

Data analysis

Since the float gauge gives a fuel height, analysis is necessary to convert the fuel height into a volume. The Appendix contains calculations for a cylindrical tank on its side. Computer programs are useful for this data analysis as they can apply the formula to several readings at the same time.

Pros	Cons

• The floating gauge is a fairly inexpensive way to measure fuel use • There is no risk of fuel spillage • The readings are simple to take	• Relies on individual to measure fuel level and record data • The accuracy is limited by the markings on the height counter • Calibration of the floating gauge can take half an hour and must be done correctly • A computer or calculator may be needed for data analysis

Dipstick

Tested on Toyo and Viessmann **Materials and Price** Dipstick (dipsticks with pre-marked fuel volumes for a specific tank size are available for $12.50)	**Supporting Documents** • Fuel volume from fuel height • Calculation worksheet - Dipstick (Excel file)	 Figure 10. A researcher inserts a dipstick into a fuel tank.

How it works

A dipstick simply refers to a rod that is inserted into a fuel tank through a vent or fill cap on the top. To use it, insert the dipstick into the tank, keeping it vertical, until it touches the bottom of the tank. Then the dipstick is pulled back out, and the user can see on it the level of the fuel oil – this procedure is the same as for finding out the level of oil in a car.

Some dipsticks are simply unmarked rods. In this case, a measuring tape can be used to measure the height of the fuel as indicated by the dipstick. Other dipsticks have markings for depth of fuel, or have readings in gallons. Those that have markings for gallons are designed for a specific volume of a tank, and it is important to make sure that the dipstick is meant for the correct size of tank.

Data storage

Data storage is a matter of user preference, as the data is collected by an individual. For instance, date, time and fuel level might simply be written in a notebook or on a calendar. Other people might choose to enter data into a computer spreadsheet program. This might be helpful if calculations are necessary for converting a fuel height into a volume (formulas to convert fuel height to volume for a cylindrical tank on its side appear in the Appendix).

Data analysis

The data analysis for a dipstick depends on the dipstick. If the dipstick already has gallon markings on it, the data analysis simply consists of simple subtraction to measure fuel use. If instead the dipstick measures fuel height, other calculations will be necessary to calculate the volume of fuel that corresponds to a particular

height. Sample calculations appear in the Appendix for a cylindrical tank lying on its side. Spreadsheet programs on computers are useful in this case for data storage and analysis because they allow one formula to be applied to several measurements.

Pros	Cons
• A dipstick is very inexpensive way to measure fuel use • The dipstick is reliable and accurate when used properly • Certain dipsticks have gallon markings for specific tank sizes, eliminating the need for data analysis	• Relies on individual to measure fuel level and record data • There is a possibility of small amounts of fuel spills when oil drips off of the dipstick • It is important to use a dipstick that matches the fuel tank size, or to correctly calculate fuel volume from fuel level • A computer or calculator may be needed for data analysis

Infrared and Ultrasonic Fuel Level Sensors

Tested on

Not tested on heating appliance as the reliability and accuracy of the sensors was not satisfactory when tested outside of the fuel tank during system assembly.

Materials and Price

Ultrasonic Proximity Sensor XL-Maxsonar WR1 ($104.95)

Infrared Proximity Sensor Sharp GP2YoA21YK ($13.95)

Arduino Uno R3 Circuit Board ($29.95)
Arduino Data-Logging Shield and SD card ($19.50)

9-volt batteries or power supply (variable)

Supporting Documents

- Ultrasonic sensor datasheet (MaxBotic)
- Ultrasonic sensor online tutorials (outside site)
- Infrared sensor datasheet (Sharp)

Figure 11. The Arduino circuit board appears with the ultrasonic sensor

How it works

These proximity sensors measure distance by sending a signal (either ultrasonic or infrared) from the sensor and measuring the time that it takes to return. In theory, they could measure the distance from where they were placed at the top of a fuel tank to the fuel height. From this data, a fuel volume can be calculated. This particular study did not test these sensors on the boiler or on the Toyo. While the sensors do represent an inexpensive do it yourself option, the amount of time necessary to bring these sensors to operation with fuel oil was considered impractical for this study. However, as the online tutorials for sensors such as these are improving, they may prove to be a valuable option in the future.

Data storage

The sensors must be attached to a small programmable circuit board (researchers chose the Arduino circuit board). The Arduino was programmed to attach proximity data to a time stamp that was then stored on a SD card located on a data-logging shield purchased independently of the Arduino.

Data analysis

Data analysis can be performed on fuel height data after data has been logged. Alternatively, it is possible to program the Arduino to convert fuel height to volume before storing it on the data-logging shield. See the Appendix for calculations on how to convert fuel height to volume for a cylindrical tank with its long axis in the horizontal plane.

Pros	Cons
• Sensors are inexpensive • System is capable of logging data independently • System can be programmed to perform data analysis	• System requires significant set-up and trouble-shooting • SD card has limited amount of storage • System is not able to work in cold or wet conditions • Reliability and accuracy of sensors are unknown -

Run-time Systems

Run time sensors measure the length of time that the heating appliance is on or running. Some systems measure this directly through electrical use, while others measure it indirectly, for example, by inferring that the appliance is on and producing heat when the stack temperature rises to a certain level. Fuel use is then calculated by multiplying the 'on time' by the burn rate, or the rate of fuel use by the appliance when it is running. For an accurate fuel use measurement, it is imperative to obtain the burn rate for the heater. Unfortunately, this quantity is not available for all appliances, and may vary significantly from manufacturer specifications depending on cleanliness and tuning of the fuel nozzle and pressure in the supply lines.

BUDS Lite

Tested on	Supporting Documents	
Toyo and Viessmann **Materials and Price** • Extech SD200 3-channel thermocouple datalogger ($230) • High-temperature K-type thermocouple (such as XC-24-K-24 from Omega, $25) • K-type thermocouple extension wire, if needed (such as GEC-K-10-9 from Omega, $15) • Male thermocouple wire mini-connector (such as SMPW-K-M from Omega, $2)	• BUDS lite user guide • Calculation worksheet - BUDS lite (Excel file)	 Figure 12. The BUDS lite data logger and sensors are located on the right side of the Toyo.

How it works

The datalogger records temperature from a thermocouple inserted in or attached to the heater exhaust. The temperature data are analyzed to detect 'on time', and, in the case of direct-vent heaters, on time at various burn levels. 'On time' is converted to fuel usage using the fuel burn rate for the heater.

Data storage

Data is stored on a removable SD-card. A 2-GB card comes with the logger, but a larger capacity card could be substituted. Several months of data can be stored before the need for download to a computer using a standard USB-SD card reader.

Data analysis

Data downloaded from the SD card are imported into a spreadsheet program such as MS-Excel or Open Office Spreadsheet. Some facility with spreadsheet formulas is needed to determine the 'on' condition based on the temperature regime and then to sum the 'on time' for multiplying by the burn rate. Please see the supporting calculation worksheet to understand how these data are used for variable burn rate appliances.

Pros	Cons

• System is inexpensive • System is easy to install, with no fuel line plumbing • Reliable • Data is logged independently	• Accuracy of the measurement is greatly determined by accuracy of the 'burn rate' used • A computer and spreadsheet calculations are necessary for data analysis • Computation of fuel use is significantly more complicated for heaters with multiple burn levels

Run Time Logger – HOBO

Tested on	Supporting Documents	
Toyo and Viessmann **Materials and Price** • HOBO U9 Motor On/Off datalogger – U9-004 (this model is no longer available, however Onset recommends the UX90-004 for $85 instead) • HOBOware Lite ($45)	• HOBO datasheet (HOBO) • HOBOware screen shot • Calculation worksheet - HOBO (Excel file)	 Figure 13. A HOBO data logger

How it works

When the fuel pump is running the U9 senses that the pump is on and record the time on, and when the pump goes off the sensor records the time off. A sum of all the time the unit was on is used to determine the amount of fuel the unit burned, based on the specified fuel flow of the unit.

Data storage

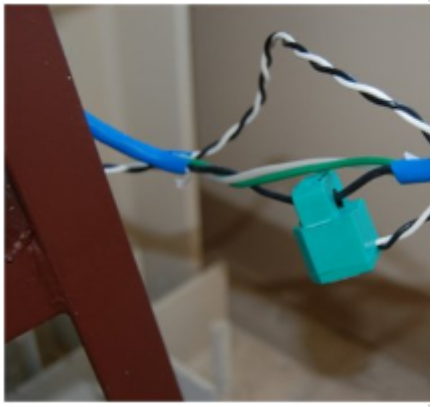
The HOBO stores its own data up to a certain number of state changes, 43,000 for the U9.

Data analysis

HOBOware tallies the run time of the unit. The sum can be multiplied by the rated fuel flow for units with one flow rate to give a total fuel use. For units with more than on flow rate (the Toyo for example) this logger does not work. The accuracy of the unit depends on the accuracy of the fuel flow rate of the appliance. While this may be given in the appliance manual, it can be affected by nozzle cleanliness and fuel temperature among other things.

Pros	Cons
• Reliable • Capable of logging data independently • Inexpensive	• Only works on units with one fuel flow rate • Depends on the accuracy of the rated flow rate, can over and under estimate • Since fuel use is measured indirectly, there is the possibility that results may vary with individual heater units, or with the age or condition of the unit

Electricity Monitoring System

Tested on	Supporting Documents	
Toyo and Viessmann **Materials and Price** • Data acquisition system (for example a Labjack U6 ($299)) • Computer (variable) • Current Transducer ($35) • Voltage Transformer ($55) • Extension cord (variable)	• Labjack Logger user guide • Labjack program - Measuring Power • Current transducer - How it works • Current transformer -How it works • Calculation worksheet - Power (Excel file)	 Figure 14. A current transducer installed on an extension cord.

How it works

Labjack records electrical power usage data from the voltage and current sensors onto the computer, which is used to infer if the appliance is on or off. From the data on the electrical use, the run time of the appliance can be calculated. In order to use these sensors a "hot" wire for the appliance must be accessible. If the unit has a power cord (like a Toyo) a stripped extension cord can be used to attach the sensors (see Figure 14). The Labjack program link provides a more detailed guide to monitoring electricity.

Data storage

A datalogger is required to store the data from the electrical sensors. Examples include a Labjack paired with a computer, or a Campbell Scientific datalogger.

Data analysis

Based on power consumption estimates in the heater's manual, the electrical power usage of the unit with the amount of fuel consumed can be correlated. Fuel usage is calculated for every 10-second interval and then summed together to determine overall fuel usage. The manual's power usage estimates were higher than what was actually consumed, which complicates the task of accurately correlating these values, and suggests that the actual power usage might vary. This means that the accuracy of this method may change as the unit ages, and might also change if applied to a different unit of the same model. Since the power usage of the heater unit is already measured directly, it can be converted to kilowatt-hours with minimal effort.

Pros	Cons
• Accurate when calibrated and used correctly • This method allows one to measure electrical power usage in addition to fuel usage at no additional cost	• The measurements tended to be a bit higher than most other measuring systems • Since fuel use is measured indirectly, there is the possibility that results may vary with individual heater units, or with the age or condition of the unit • Variable power can cause problems with the data collection • Data analysis is complex

Results

The fuel use for the monitoring period was summed and the results across all the monitoring systems compared. The Sensirion flow meter data was used as the baseline data of how much fuel was actually consumed. Prior to the study the flow meter was calibrated using heating oil from the Toyo tank. Short of manually filling a tank with a specified amount of fuel and then draining that tank completely, the Sensirion is the most accurate fuel measurement system.

The boiler was monitored from March 8, 2012 through March 26, 2012. The gallons of fuel used during this time that were calculated for each of the seven measurement systems appear in Table 4. The dipstick measurements of the tank level were the closest to the actual fuel use. The slight variation in the dipstick measurements most likely has to do with the precision of the tank and fluid level measuring devices (tape measure and dipstick). The AMCO flow meter was not as accurate, which may have something to do with its initial calibration, which was not done as part of this study.The percentage error also appears in Table 4, however the percentage error is based on one measurement and may be misleading.

Table 4. Boiler Fuel Use

	gallons	% error
In-line flow systems		
Sensirion flow meter	**100.7**	**--**
AMCO flow meter	123.0	22
Run-time systems		
BUDS Lite	142.7	42
Electrical monitoring of the switch	139.8	39
Electrical monitoring of the pump	144.0	43
HOBO motor on/off logger	144.3	43
Tank Level systems		
Dipstick	108.0	7

The run time estimates of boiler fuel use relied on the fuel flow specification that is printed on the boiler to determine fuel use. The running time of the boiler was summed based on the various monitoring schemes, and the hours running were then multiplied by 1.21 gallons/hour (the boiler spec) to determine total fuel use. All of the run time systems provided very similar fuel use estimates. However, they all overestimate the fuel use of just two weeks by approximately 40 gallons. This demonstrates gross inaccuracy in the run time systems, probably resulting from relying on the printed specifications for the boiler nozzle. The average flow rate determined from averaging the instantaneous readings of the Sensirion flow meter was 0.88 gallons/hour. Using the run time data and the measured fuel rate yields more accurate fuel use numbers for the run time systems: BUDS Lite 103.8

gallons (3% error), Motor on/off 104.7 gallons (4% error), switch 101.7 gallons (1% error), and the HOBO 104.9 gallons (4% error).

In a boiler the nozzle delivers the fuel to the combustion chamber in a very precise pattern and amount. However, the nozzles are tested with a particular type of fuel at a certain temperature. Diesel #1 is a not the standard fuel oil for most boilers in the United States; instead nozzles are tested with diesel #2, which has a different viscosity than #1. Additionally, in very cold temperatures the viscosity of fuel rises (Olson n.d.). The viscosity of #2 fuel oil increases steeply from approximately 6 centistokes to 13 as the temperature drops from 40 and 20 F, and the curve steepens as the temperature drops further (it is assumed that #1 follows a similar curve) (Olson n.d.). In addition to viscosity, the boiler fuel pressure setting is easily changeable and will change the flow of the nozzle (Olson n.d.). The fuel pressure of the Viessmann was tested as part of this study and was found to be 180 psig, which is the exact pressure it is specified for. The pressure is easily tested in most boilers (see Appendix D) and the flow can be calculated if the different pressure is known (this number can still be off based on the fuel viscosity). Low temperature fuel, different viscosity and varying pressures can combine to make the flow through the boiler nozzle different than the flow specified by the sticker.

The Toyo was monitored from May 29, 2012 through June 11, 2012. There was a power outage on June 1, so there are two sets of data. Some of the sensors shut off with the power outage and did not turn back on. This was not realized by researchers until the data was analyzed. Results (in gallons) from both periods of time appear in Table 5. The percentage error also appears in the table, however the percentage error is from one measurement and is based on the Sensiron flow meter as the true measurement, therefore the error measurements have limited applicability.

The Toyo fuel flow rate is so low that several of the data systems did not register the amount of fuel used. For example, the volume calculated from the Scully Golden Gauge does not appear because the inherent uncertainty of the device is on the same order as the fuel volume measured during the testing period. There is no data for the dipstick for the first period because the researcher did not dip the tank on June 1.

The run-time loggers overestimated the fuel use again, but the overestimation is much smaller than for the boiler. This is due to several factors: the lower flow, the fact that the Toyo does not rely on a pressure nozzle, and that the fuel was stored inside at a constant temperature. The Toyo has a small fuel storage tank attached to a pump that meters the fuel to the burner. Additionally, the fuel for the Toyo was stored inside the lab so it was at a more consistent temperature and thus more consistent viscosity. The Toyo runs at three different burn rates that are specified in its manual. The run-time data needed to be analyzed to determine the temperature or electrical draw at each burn rate and then the run-time at each level tallied and multiplied by the burn rate for each level (see Appendix D). The HOBO run-time logger did not register any run-time data, and is not a useable choice to monitor a Toyo.

The tank level sensors tended to be more accurate with larger amounts of fuel use. The 100-gallon storage tank did not have a measurable change in fuel depth at an accurate level for the first time period studied. As the fuel use increased, the change in the level of the tank was larger and thus more apparent to the monitoring systems. When monitoring fuel use for a Toyo, enough time is needed to produce a noticeable change in the fuel tank level.

In the case of both heating appliance tests, the run-time estimates of fuel use were larger than the control system, the Sensirion flow meter. For the boiler test, the dipstick and the AMCO flow meter measured the closest amounts of fuel used. All the run-time estimates for the boiler were within 5 gallons of each other with estimates that were approximately 40% higher than the actual fuel consumption. This led researchers to believe that the actual fuel use rate of the boiler nozzle was lower than quoted in the appliance's manual. In a large-scale study, relying on run time to estimate fuel use for a large number of different appliances will likely produce an overestimate of fuel use. The run-time measurement systems on the Toyo were also too high. For the Toyo test, the Setra pressure transducer and the dipstick had the closest measurements to the Sensirion flow meter.

Table 5. Toyo Fuel Use				
	5/29/2012 to 6/1/2012		5/29/2012 to 6/11/2112	
In-line flow systems				
	gallons	% error	gallons	% error
Sensirion flow meter	**1.5**	**--**	**7.8**	**--**
Omega Load Cell	1.4	7%	lost power	--
Run-time systems				
BUDS lite	1.7	13%	8.97	15%
Current transducer	1.9	27%	lost power	--
HOBO motor on/off logger	0.0	--	0.0	--
Tank Level systems				
Dipstick	insufficient data	--	7.5	4%
Setra pressure transducer	2.5	67%	7.2	8%
Scully Golden Gallon String Gauge	insufficient data	--	insufficient data	-

Conclusions

This project did not study all of the available technologies to measure fuel use, but instead provides a general overview of several options in three general categories: flow meters, run-time loggers, and tank level sensors. In general, commercial flow meters designed to measure low flow of diesel fuel are accurate and reliable when used correctly. However, the small market for these flow meters and the precision needed makes the cost of the flow meters quite high. Run-time loggers are an inexpensive option but are not as accurate as flow meters or tank level sensors. Also, run-time loggers depend on an accurate statement of fuel use rate by a heating appliance. This can be difficult to obtain, since the rate of fuel use is dependent on factors that can change daily, such as the temperature of the fuel. The final option, tank level systems, can be the least expensive and fall between run-time systems and flow meters for accuracy.

The best way to choose a fuel use monitoring system is to first evaluate the heating system(s) to be monitored. The choice will depend on the heating appliance, the location of the tank (above or below ground), the users of the system, and power supply availability. It will also depend on the budget and time available. Cutting the fuel line and installing a Sensirion flow meter is the most accurate, however it has the most expensive hardware. The two other in-line flow meters are less expensive, but also less accurate. The run-time systems have the advantage of being inexpensive and versatile, however they are more difficult to use for heating appliances with variable flow rates. Low temperature fuel from above-ground tanks can cause an over-estimate of fuel use with the run-time systems. The tank level measuring systems require a good knowledge of the dimensions of the tank

and they are best used with above-ground tanks. In most cases the evaluation of the data will require more time and expertise than the collection of the data. Evaluating each option together with the appliance to be monitored will ensure that a proper measurement system is chosen.

Works Cited

Olson, E. (n.d.). Fuel nozzles for oil burners; technical aspects of applications. Retrieved from http://www.delavaninc.com/pdf/Fuel_Nozzles_for_Burners.PDF

Saylor, B., Haley, S., & Szymoniak, N. (2008). *Estimated Household Costs for Home Energy Use.* Anchorage: Institute of Social and Economic Research.Retrieved from http://www.iser.uaa.alaska.edu/Publications/webnote/LLFuelcostupdatefinal.pdf

Szymoniak, N., Fay, G., & Villalobos-Melendez, A. (2010). Components of Alaska Fuel Costs: An Analysis of the Market Factors and Characteristics that Influence Rural Fuel Prices Anchorage: Institute of Social and Economic Research. http://www.iser.uaa.alaska.edu/Publications/componentsoffuel3.pdf

Appendices

The following appendices contain calculations used for different monitoring techniques, information on sensors, and other peripheral topics related to fuel use monitoring. The authors hope that this information can be useful to people who are trying to choose a monitoring technique for fuel use.

A. In-line flow monitoring systems

In-line flow monitoring systems are used to determine the flow directly through the intake line of the heating appliance. Summing the flow to the appliance over time will provide the fuel use for that time.

Sensirion flow meter	• Sensirion datasheet (Sensirion) • Labjack Logger user guide • Labjack program- Sensirion • Sensirion Calibration information (Sensirion) • Calibration report • Calculation worksheet - Sensirion (Excel file)
AMCO flow meter	• AMCO datasheet (AMCO) • Calculation worksheet - AMCO (Excel file)
Omega load cell/day tank	• Omega datasheet (Omega) • Labjack Logger user guide • Labjack program - load cell • Fuel density information • Calculation worksheet - load cell (Excel file)

B. Tank level systems

Tank level systems measure fuel use by recording data on the level of the fuel in the tank. The level of the fuel is converted to a tank volume using the tank dimensions. The fuel used will be equal to the difference in fuel volumes between measurements.

Setra in-line pressure transducer	• Setra datasheet (Setra) • Labjack Logger user guide • Labjack program - Setra • Fuel volume from fuel height • Fuel density information • Calculation worksheet - Setra (Excel file)
Scully floating gauge	• Scully Golden Gauge Data Sheet • Fuel volume from fuel height • Calculation worksheet - Scully (Excel file)

Dipstick	• Fuel volume from fuel height • Calculation worksheet - Dipstick (Excel file)
Infrared and ultrasonic fuel level sensors	• Ultrasonic sensor datasheet (MaxBotic) • Ultrasonic sensor online tutorials (outside site) • Infrared sensor datasheet (Sharp)

C. Run-time systems

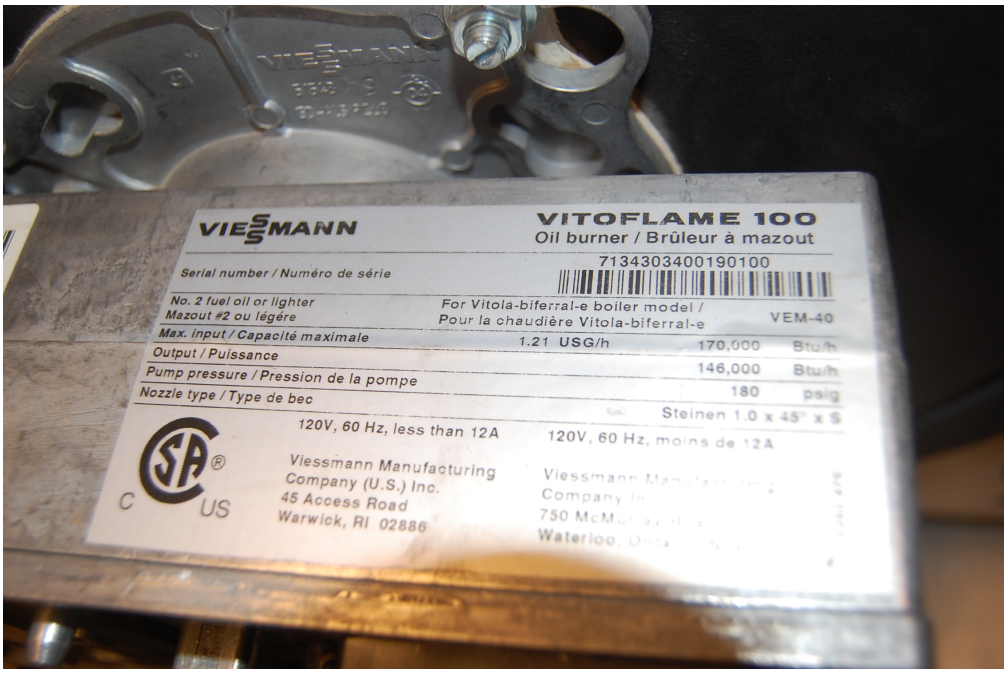
Run time sensors measure the length of time that the heating appliance is on or running. Some systems measure this directly through electrical use, while others measure it indirectly, for example, by inferring that the appliance is on and producing heat when the stack temperature rises to a certain level. Fuel use is then calculated by multiplying the 'on time' by the burn rate, or the rate of fuel use by the appliance when it is running.

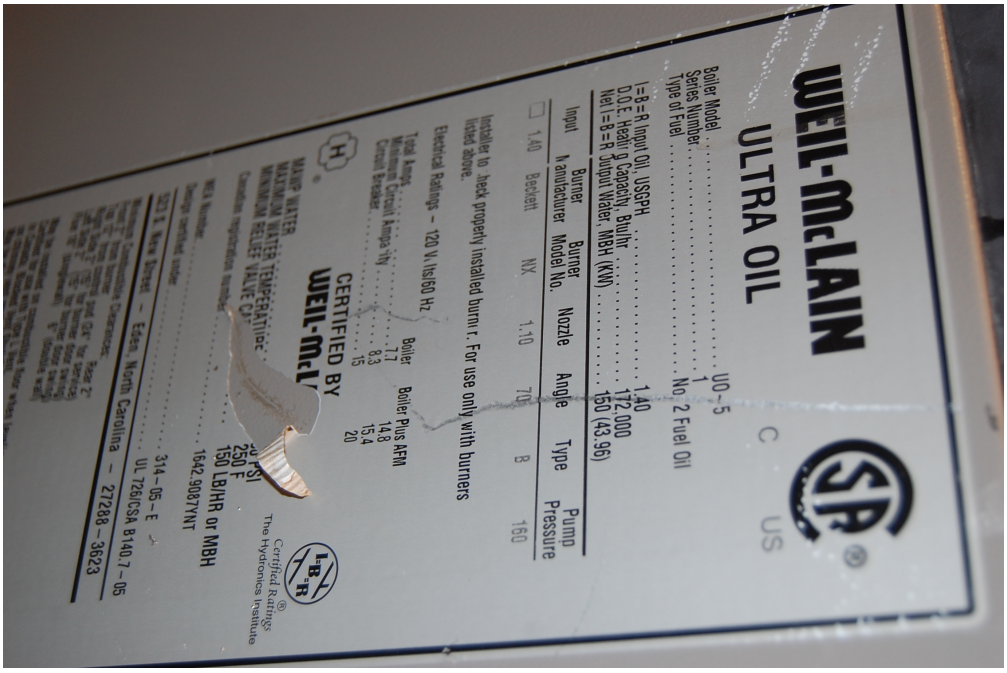
BUDS lite	• BUDS lite user guide • Calculation worksheet - BUDS lite (Excel file)
HOBO logger	• HOBO datasheet (HOBO) • HOBOware screen shot • Calculation worksheet - HOBO (Excel file)
Electrical monitoring	• Labjack Logger user guide • Labjack program - Measuring Power • Current transducer - How it works • Current transformer -How it works • Calculation worksheet - Power (Excel file)

D.Miscellaneous

Boiler Pressure Analysis (CCHRC.pdf)

Examples of fuel use specifications from two boilers and a Toyo Laser 30


VIESMANN
VITOFLAME 100
Oil burner / Brûleur à mazout
Serial number / Numéro de série
7134303400190100
No. 2 fuel oil or lighter
Mazout #2 ou légère
For Vitola-biferral-e boiler model /
Pour la chaudière Vitola-biferral-e
VEM-40
Max. input / Capacité maximale
1.21 USG/h
170,000 Btu/h
Output / Puissance
146,000 Btu/h
Pump pressure / Pression de la pompe
180 psig
Nozzle type / Type de bec
Steinen 1.0 x 45° x S
120V, 60 Hz, less than 12A
120V, 60 Hz, moins de 12A
Viessmann Manufacturing
Company (U.S.) Inc.
45 Access Road
Warwick, RI 02886
C US


WEIL-McLAIN
ULTRA OIL
C US
Boiler Model UO-5
Series Number 1
Type of Fuel ..... No. 2 Fuel Oil
I=B=R Input Oil, USGPH 1.40
D.O.E. Heating Capacity, Btu/hr 172,000
Net I=B=R Output Water, MBH (KW) 160 (43.96)
Input
Burner Manufacturer
Burner Model No.
Nozzle
Angle
Type
Pump Pressure
1.40
Beckett
NX
1.10
70
B
160
Installer to check properly installed burner. For use only with burners listed above.
Electrical Ratings – 120 V, 1ph/60 Hz.
Total Amps
Minimum Circuit Amps (Hz)
Circuit Breaker
Boiler
7.7
8.3
15
Boiler Plus AFM
14.8
15.4
20
CERTIFIED BY
WEIL-McL
MAWP WATER
MAXIMUM WATER TEMPERATURE
MINIMUM RELIEF VALVE C
250 F
150 LB/HR or MBH
1642.9087YNT
314-05-E
UL 726/CSA B140.7-05
Eden, North Carolina – 27288-3623
Certified Ratings
The Hydronics Institute

SECTION A: SPECIFICATIONS

Model:	Laser 30
Heater Efficiency:	90% (1)
Heat Rating:	High - 15,000 BTU/h Med - 10,000 BTU/h Low - 5,000 BTU/h
Fuel Consumption:	High - 0.108 gal/h Med - 0.076 gal/h Low - 0.040 gal/h
Fuel system:	External tank (2)
Fuel Type:	ASTM D3699 1-K Kerosene, ASTM D396 Low Sulfur No.1 Fuel Oil, or ASTM D975 Ultra Low Sulfur Diesel (ULSD)
Dimensions (W × H × D):	16-15/16" × 21-3/4" × 13-9/16"
Weight:	31 lbs. Empty
Vent Pipe Hole:	2-3/4" ~ 3" diameter
Maximum Length of Vent Pipe System:	10 ft., 3 bends or less
Electrical Rating:	120 Volts AC, 60 Hz Preheat - 260W Burning - 26W
Typical Room Size (3):	600 square feet (0°F) 720 square feet (20°F)

(1) Heat and vaporized water are produced by the combustion process of this heater. This rating does not take into account heat loss due to condensation of water vapor.

(2) External tank to be purchased from local suppliers.

(3) 0° F Heat Load = 24 BTU/ft²/hr
20° F Heat Load = 20 BTU/ft²/hr
Room size for which this heater is suitable will vary depending on outside temperature, house insulation, window size, and other factors.

Density of Fuel Oil #1

The volume, and thus the density, of liquids changes with temperature. The density of fuel oil #1 at several temperatures was investigated for the fuel use monitoring project. The density was required to determine the fuel volume in the tank via the Setra pressure transducer as well as the volume of fuel moving through the day tank.

To investigate the change in density, researchers measured the mass and volume of a quantity of fuel oil in a graduated cylinder at different temperatures. The graduated cylinder was covered with plastic wrap to minimize evaporation of the fuel oil. The graduated cylinder had a maximum volume of 10 mL and an uncertainty in measurement of 0.1 mL. The scale used for measuring the mass has an uncertainty in measurement of 0.0001. The uncertainty in the temperature measurement in the temperature sensor is 0.1°F.

Temperature	Mass of the fuel oil	Volume of the fuel oil	Density	Uncertainty in density
°F	g	mL	g/mL	g/mL
5.4	5.4756	6.9	0.79	0.011
14.0	5.4663	6.9	0.79	0.011
24.5	5.461	7.0	0.78	0.011
33.9	5.4568	7.1	0.76	0.011
69.2	5.4418	7.1	0.76	0.011

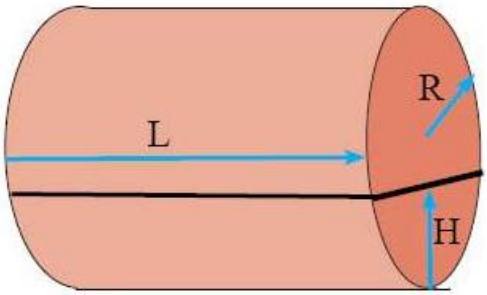
These measurements can be used to calculate beta, the volumetric expansion coefficient for fuel oil. Each pair of measurements can be used to calculate beta (temperature must first be converted to °C). An average of all of the possible results for beta gives a value of 0.0018 /°C for the volumetric expansion coefficient. The standard beta from the Engineering Toolbox is 0.001001 /°C for kerosene, http://www.engineeringtoolbox.com/cubical-expansion-coefficients-d_1262.html.

Fuel Volume from Fuel Height in a Cylindrical Tank

The following calculations can be used to obtain a fuel volume from a fuel height in a cylindrical tank. The cylindrical tank is assumed to be on its side, so that the long axis of the tank is in the horizontal plane.

The following variables must be measured:

R = radius of the tank
L = length of the tank
H = measured height of the fuel



The first step is to calculate the area of the end of the tank that is covered in fuel – in the figure, this is the area below the black line on the end of the cylinder. Then, this area can be multiplied by the length of the tank to get the fuel volume. The area is given by the formula:

$$Area = R^2 \times ACOS\left(\frac{R-H}{R}\right) - (R-H)\sqrt{2RH - H^2}$$

Then the volume in the tank is given by the formula:

$$Volume = Area \times L$$

It is important to remember that all units in both formulas should be the same. After calculating the volume, it also may be necessary to convert the unit into gallons.

Boiler Fuel Pressure

Each boiler comes with a specified fuel pressure that is usually listed on the sticker (Figure 1). The fuel pressure is used to determine the fuel flow for the nozzle. Nozzles can have different flows based on the pressure of the fuel. A nozzle will come with a data curve that relates pressure to flow.

Figure 1. Boiler specification sticker. The pressure on this sticker is specified to 180 pisg.

The pressure is important to understanding the amount of fuel flowing through the nozzle. The pressure is very easy to change on many boiler models. In order to check the pressure, a pressure gauge with the correct pressure fitting is needed (Figure 2). Attach the gauge to the pressure port of the boiler; check your manual to find this. When the unit is running the pressure can be read on the gauge. It should correspond to the posted sticker unless the unit has been tuned to a different pressure. If the pressure does not correspond you'll need to find a pressure curve for the nozzle (also listed on the sticker) to determine the fuel flow rate.

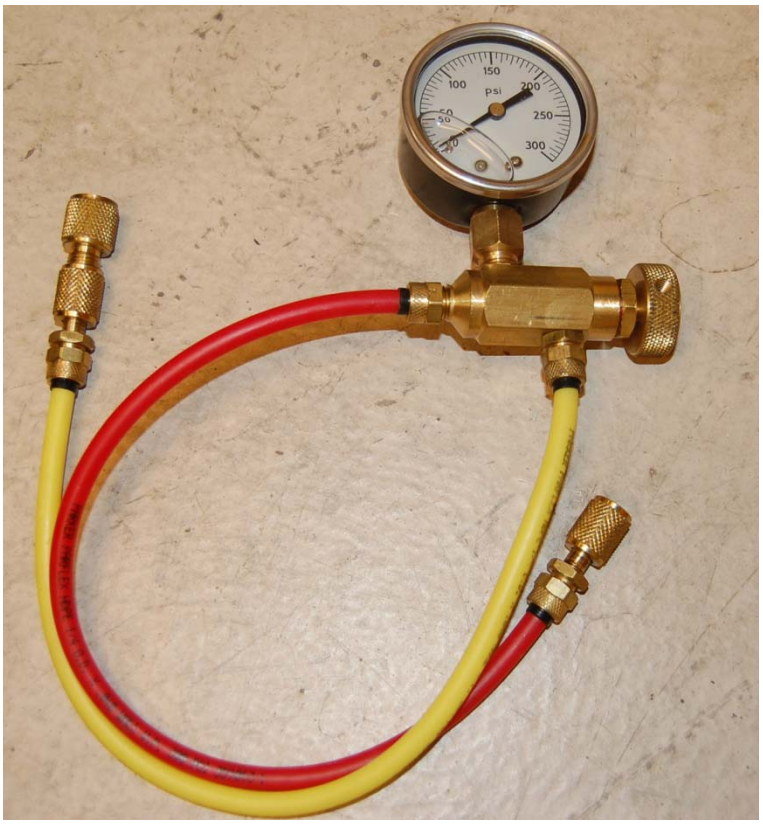


Figure 2. Pressure gauge. The fittings are adaptable for different boiler ports.

Some boilers have an integrated fuel pressure sensor (Figure 3).

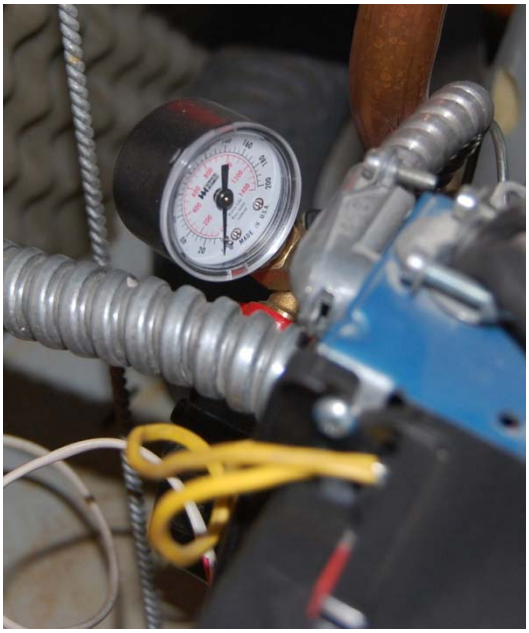


Figure 3. Integrated pressure gauge. This gauge is easily viewable inside this condensing boiler.