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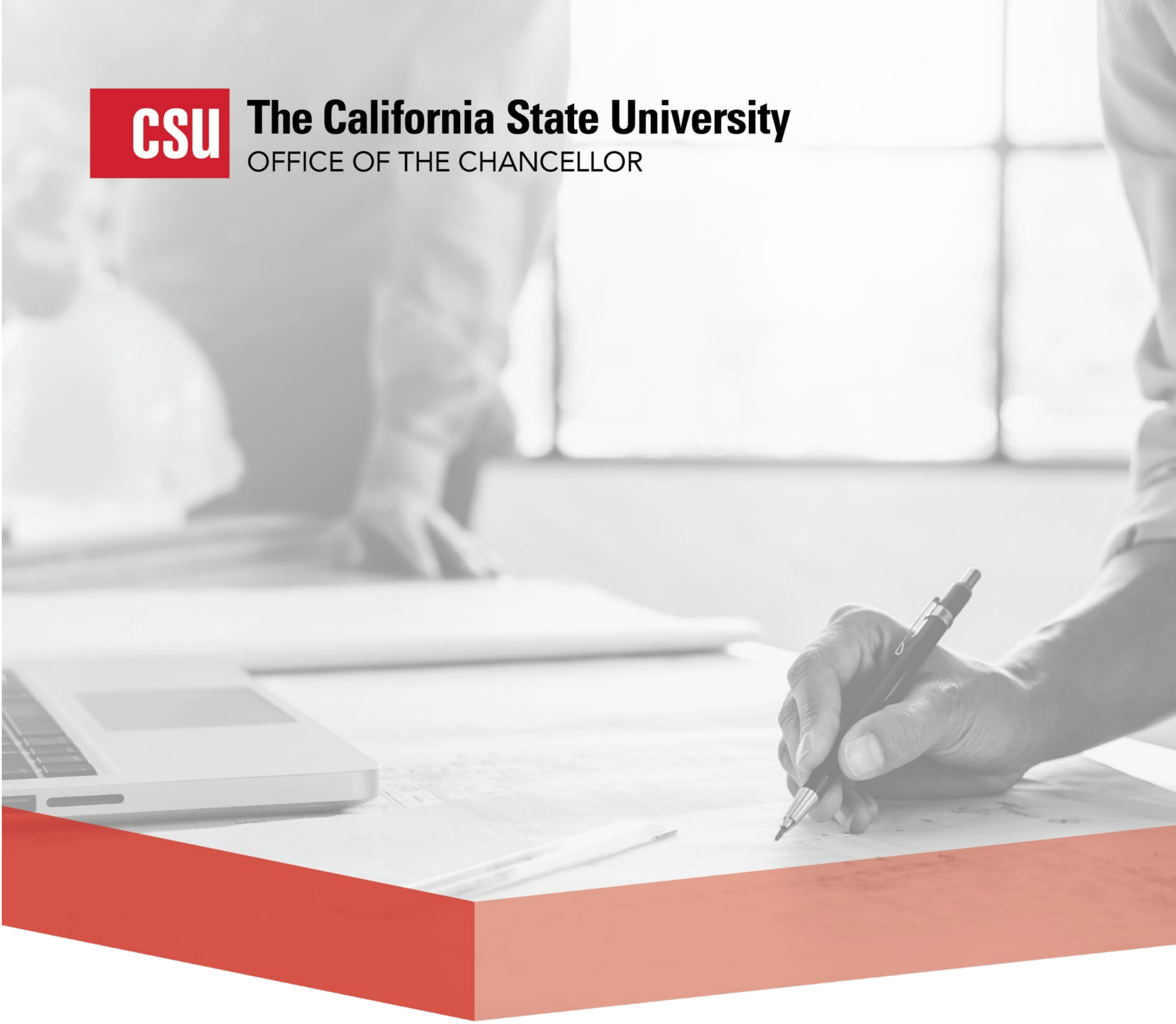

Building Metering Guide

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SECTION 1: Introduction

The purpose of this Guide is to assist CSU campuses in properly metering of utilities and other services at each building in the campus. This Guide is the first of a two-part series. This part covers:

- What utilities and services must or should be metered
- What devices can be used for metering
- How are these devices commissioned and calibrated to ensure accurate data

Part 2 (Energy Metering Guide for Utilities & Management) covers how to collect and store metering data and how to analyze and visualize the data to improve energy efficiency and operations.

SECTION 2:
What to Meter

Meters can be installed to measure data for several objectives:

- **For performance evaluation and benchmarking of a building.** Measured data are used to establish baseline energy use, monitor changes in consumption, and to share data with program managers and designers.
- **For billing purposes.** These meters should be utility revenue grade accuracy and installed with metering accuracy instrument transformers.
- **For measurement & verification of a building or building systems.** Measured data are used to identify inefficient operations and validate proper operation of systems during commissioning and on an ongoing basis.
- **To initiate demand side management programs.** Measured data are used to trigger demand limiting logic such as setting thermostat setpoints up a few degrees, limiting fan static pressure in VAV systems, etc.

Minimum metering requirements for CSU campuses are covered by two documents:

The Summary of CSU Energy and Sustainability Requirements document states:

a. Sub-metering shall be installed as part of the work when improvements affecting an energy or utility consuming system are made.

b. Meters shall be connected to campus Energy Information Systems.

c. New meter installations shall be communications capable meters for all commodities used by the building/project, including but not limited to:

    i. Grid supplied electricity

    ii. On-site renewable electricity

    iii. Natural Gas

    iv. Potable Water

    v. Irrigation water

    vi. Heating Hot Water

    vii. Chilled Water

    viii. Sanitary Sewer

d. Meter shall be capable of communication by TCP/IP, BACnet/BACnet IP or Modbus protocols.

This manual in part serves to interpret these metering requirements for CSU campuses to provide clarity and more uniform recommendations.

Table 1 summarizes both minimum and recommended metering requirements for CSU campuses. It applies to each building on campus unless the campus energy and utilities manager states otherwise.

Table 1 – CSU Metering Requirements (each Building)

Service	Minimum Metering	Recommended Metering	Remarks
Electricity	▪ Whole building	▪ Whole building ▪ Submeter lighting ▪ Submeter plug loads ▪ Submeter HVAC ▪ Submeter primary HVAC equipment (e.g. chillers, AHU fans)	Whole building meters shall be revenue-grade unless the campus energy and utilities manager gives written approval. Submeters are not required to be revenue-grade.
Natural Gas	▪ Whole building	▪ Whole building ▪ Submeter each boiler ▪ Submeter each domestic water heater	Whole building meters shall be revenue-grade unless the campus energy and utilities manager gives written approval. Sub-meters are not required to be revenue-grade.
Central Plant Chilled and Hot Water	▪ Whole building	▪ Whole building	A self-contained "BTU" meter is recommended as opposed to using separate flow and temperature sensors because the accuracy is generally better (matched sensors) and data collection is simpler, particularly if energy is being metered for revenue purposes.
Central Plant Steam	▪ Whole building	▪ Whole building	Revenue-grade meters are not required.
Domestic Water	▪ Whole building ▪ Meter or submeter irrigation	▪ Whole building ▪ Meter or submeter irrigation ▪ Submeter domestic hot water	Revenue-grade meters are not required.
Sewage	▪ Not Required	▪ Not Required	Only should be considered when water use for irrigation or evaporative processes (e.g. cooling towers) are large and utility provides financial credit for reduced sewer burden

SECTION 3:
Metering Devices

Metering Selection Criteria

The devices used to meter utility usage must be sufficiently accurate for the application and should be reliable with minimal periodic maintenance required. The first cost of metering must also be reasonable. This section discusses meters that are currently available. When there is more than one option, the plusses and minuses of each option are explained to assist CSU in making a choice that reasonably balances costs and performance.

Meter Selection is based on many factors including: cost, functionality, data storage and retrieval, communication, integration into existing facilities data networks, and security. In each case, a meter is selected for each application after consideration of the following criteria:

- Identify the data requirements for the meter. Is the meter measuring the utility for a recharge account? Is the facility a laboratory or building with sensitive power or other special requirements? Is the meter going to be used as a sub-meter to monitor a utility within a building?
- Identify compatibility issues and technical criteria. Many campuses have existing metering systems. Meters should be compatible with the Building Automation System (BAS) and the data network and centralized utility management software.
- Develop a campus standard for the metering system based on first cost, operation costs, and operation and maintenance. Meters can be specified with a local display and communications ports to allow local and remote data retrieval and troubleshooting. Meters should be installed so they can be easily isolated and removed from service without impacting building services or network operation. Meters or data acquisition software should alarm for a meter fault.
- Prepare a campus specification or design guideline for use by campus personnel, Architects and Engineers for the specification, application and procurement of all utility meters. New meters must comply with the campus standard and design guideline and integrate seamlessly with BAS and utility monitoring software. The completed installations must include all communications cabling and be commissioned for service.
- Prepare acceptance testing and commissioning requirements for new meters. Meter installations must be verified as working properly before acceptance. Acceptance testing and commissioning must include confirmation of instrument transformer ratio, polarity and connections to the meter, sensor ratings and other issues that can affect the data produced. The meter readings must be validated by a second standard. Controls, communication and data acquisition must be function tested.

Electric Power Meters

Metering System

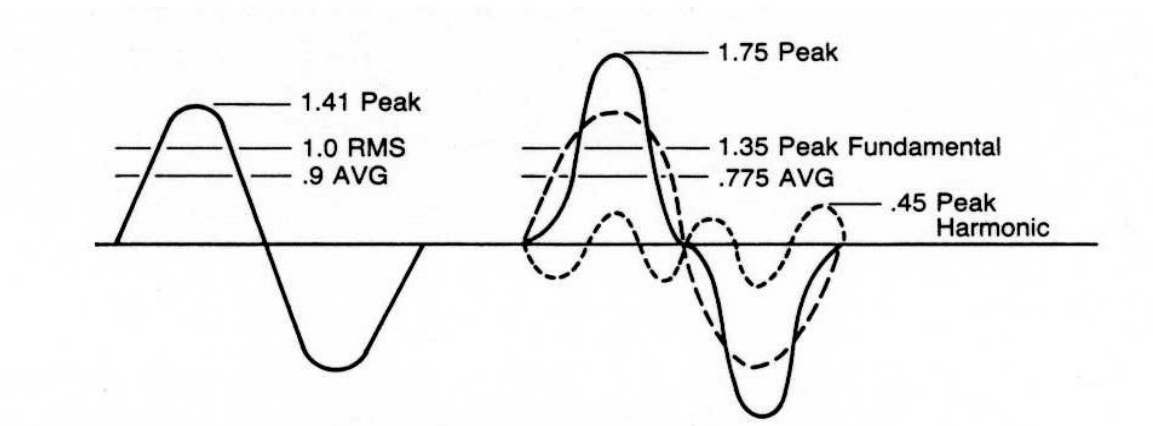
Electric power meter measurement, power quality analysis and data storage have kept pace with the advances in solid state components, especially microprocessors, memory and communication. Data measurement, data storage, data processing and analysis, event capture, remote data monitoring and retrieval, and remote control are all features that are readily available from the modern power meter. The modern campus metering system will consist of the power meter, a secure data communication network, data collection hardware, data storage, and software for data collection, data analysis, presentation, and cost allocation. It is recommended that revenue grade power meters and metering accuracy instrument transformers be installed in buildings whenever possible. Revenue grade power meters used in combination with metering class instrument transformers will provide accurate data.

Metering Fundamentals

Electric power measurements and calculations for alternating current (AC) circuits are made in terms of root mean square (RMS) values.

Each of the sine waves shown in Figure 1 below has the exact same RMS value of 1.0 when measured with a true RMS responding meter. If an average responding meter is used, it will read 0.9 in one case and 0.775 in the other. Only true RMS responding meters should be used in electric power measurements.

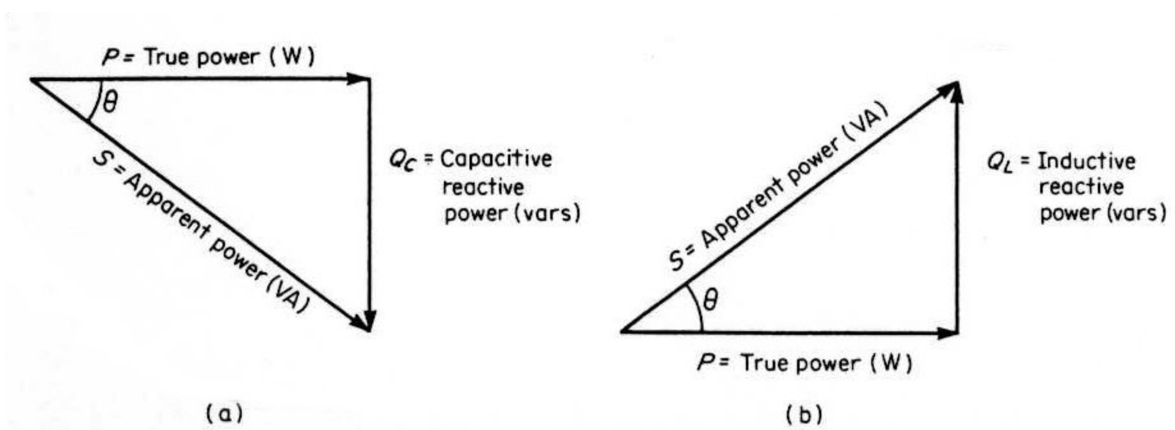
Figure 1. Effects of Harmonics on a Sine Wave



(a) Pure Sine Wave **(b) Sine Wave with Third Harmonic Distortion**

Power in an AC circuit consists of apparent power (total power), true power (work), and reactive power (capacitive and inductive power) – see Figure 2. Apparent power is the sum in quadrature of the true power and reactive power. Power factor is the ratio of true power divided by apparent power. Power factor is also the cosine of the phase angle, between the voltage across the circuit (or load) and the current through the circuit (or load).

Figure 2. Power Triangles for Capacitive and Inductive Circuits



Metering electric energy usage requires the measurement of several variables including:

- Voltage (V)
- Current (A)
- Frequency (Hz)
- Phase angle between the voltage and current (θ)

Electric energy is measured for both magnitude (kW) and time (hour) and is metered as kilowatt-hours (kWh) where the constant "k" stands for "kilo" and is a multiplier of 1,000. Electric energy billings typically consist of an energy consumption component (kWh), a demand component (kW) and power factor (pf) or reactive power component (kVar).

Electro-mechanical watt-hour-meter technology and nomenclature were developed and evolved during the twentieth century. The advent and application of solid-state technology to the watt-hour-meter has greatly enhanced the data processing capabilities of power meters. Electro-mechanical meters measured energy use and demand through rotation of an induction disk as a result of torque created by the applied voltage, current and system frequency. A solid-state meter converts current and voltage inputs to digital signals through an analog to digital converter and measures power using microprocessor-based algorithms, calculations and an internal clock. The microprocessor-based meter is also capable of measuring harmonics, event capture and estimating peak demand.

Electric energy parameters such as KW, KVAR, kVA, and power-factor, can be calculated as follows:

- kW = $V * A *$ *cosine* θ (True Power for single phase loads)
- kW = $\sqrt{3} * V * A *$ *cosine* θ (True Power for three phase loads)
- kVAR = $\sqrt{3} * V * A *$ *sine* θ (Reactive Power for three phase loads)
- Power factor = *cosine* θ (True Power)÷(Apparent Power)
- kVA = (kw^2+kVAR^2) ½ (Apparent Power for three phase loads)

Meter Types

The most basic energy meters provide energy and demand information. More sophisticated meters provide information on power quality, capture events, log and store data, display data through a local screen and communicate with or control other devices or systems. Meters can be grouped into several categories based on their capabilities: revenue grade meters advanced energy meters, and sub-meters.

Meters can be installed as socket-mount, semi-flush switch board case style, or on panels in cabinets. Meters should be installed indoors in a dry conditioned space, such as an indoor service entrance switchboard room, whenever possible. Other factors to consider include the proximity to a data network gateway, Modbus, BACnet or other network communication to a building BAS, as well as sub-meter locations and other communication requirements.

Power meters are available in several ampere rating classes. The class designation denotes the maximum load capacities (in amperes) of the meter. The classes typically used include 2, 10, 20,100, 200 and 320. Class 2, 10 and 20 meters are intended to be used with current transformer (CT) and potential transformer (PT) inputs while Class 100, 200 and 320 meters are direct reading requiring no current transformers. Class 100 and 200 meters are limited to 480V circuits rated no more than 100 A, 200 A and 320A respectively. In general, voltage transformers are required for circuit applications where the voltage exceeds 600V. Consult with the meter manufacturer or the meter specification data sheet for input requirements and limitations.

Power meters are also rated in terms of accuracy. Metering accuracy should be a minimum of 1% where used for billing purposes. Meters with accuracy classifications better than 1% are readily available at reasonable cost. ANSI Standard C12.10, Code for Electricity Metering lists metering accuracy requirements and applications. In general, except for campus service entrance, certified revenue grade meters are not required to be installed on CSU installations. However, revenue grade meters are readily available that are cost competitive with the non-revenue grade type. Revenue grade and metering accuracy class instrument transformers should be specified for campus power distribution and building service entrance meters whenever possible. The total accuracy of any meter installation depends on the accuracy of the meter and also the accuracy of the instrument transformers.

Table 2 – Typical Meter Capabilities By Type

Capability	Revenue Grade Meter	Advanced Energy Meter	Sub-meter
Configuration	Utility Socket, Panel, Switchboard	Utility Socket, Panel, Switchboard	Panel Stand-alone
Revenue Accuracy	Yes	Yes	Not Typical
Energy and Demand	Yes	Yes	Yes
Power Quality Analysis	No	Yes	No
Data Logging	Optional	Yes	Optional
Data Output And Communications	Pulse RS-232/485 Fiber Optic Wireless Modem Ethernet TCP/IP Modbus, BACnet DNP3.0	Pulse RS-232/485 Fiber Optic Wireless Modem Ethernet TCP/IP Modbus, BACnet DNP3.0	Pulse RS-232 Modem Modbus, BACnet
Alarm and Control	No	Yes	No
Programmable Input Connections	No	Yes	No
Graphic Display	No	Yes	Not Typical
Cost	$800-$2,000	$2,000 - $5,000	$600-$1,200

Figure 3. Typical Socket Based Meter

Figure 4. Typical Panel Mounted Advanced Meter

Figure 5. Typical Sub-meter

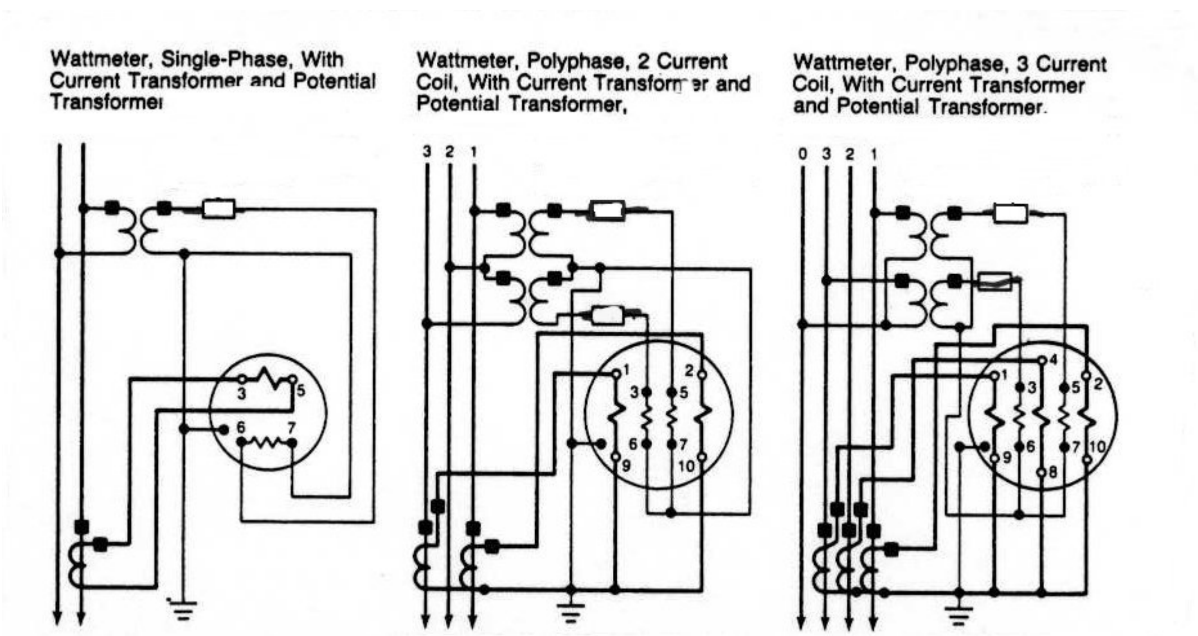
Instrument Transformers

All electric power meters, except Class 100 and 200, require inputs from CTs, PTs, or both. Metering accuracy transformers with the proper burden ratings should be used for all installations. Instrument transformers complying with requirements and ratings stipulated in ANSI Standard C57.13 should always be specified. Relaying class instrument transformers are not suitable for use in metering circuits where billing and revenue accuracy is required. Split core CTs should never be installed where revenue grade accuracy readings are desired.

A common problem with power meters after installation is data measurement errors or gaps in data due to insufficient current flow to the meter. This may be the result of the installation of CT's with a primary ratio that is too large for the actual load. This problem is avoided by specifying CTs that have primary ratios based on expected demand and having a rating factor of RF2.0 (200% of the primary rating). Specifying metering class multi-ratio CTs is another option to address the ratio issue. For instance, a typical 2000 A switchboard will be manufactured with 2000:5 CTs. Consider specifying 1000:5 CTs with a rating factor RF2.0 for the metering circuit when the expected power demand is roughly half of the connected load.

All metering devices require the installation of voltage and current circuit disconnecting devices. These circuits should always include a properly rated (circuit voltage and interrupting rating) fused disconnect with rejection type fuses and a CT shorting terminal block with safety ground.

Figure 6. Typical Wattmeter Three-line Diagram with Instrument Transformers



Natural Gas

Meter Types

There are numerous common types of meters that may be used to measure natural gas –*diaphragm*, *rotary, turbine, and thermal gas mass flow*.

Diaphragm meters are positive-displacement devices that have fixed-volume measurement compartments formed by a two-sided convoluted diaphragm. A small pressure drop across the meter causes it to cycle so these compartments alternately fill with gas at the inlet, and then empty at the outlet. By counting the number of cycles, the meter provides a measure of gas volume.

Figure 7. Diaphragm Meter

Figure 8. Rotary Meter

Rotary meters are also positive-displacement measurement devices. In this case, a pair of impellers form the fixed-volume compartments. When downstream demand initiates the flow of gas, the impellers rotate to receive a fixed volume of gas at the inlet and then discharge it at the outlet.

In place of fixed-volume compartments, a *turbine meter* has a rotor in the gas stream. As gas flows through the meter, the rotor turns at a speed that is proportional to the rate of gas. This type of meter is termed an inferential meter.

Figure 9. Turbine Meter

Figure 10. Thermal Mass Meter

Natural gas *thermal mass flow meters* utilize a thermal sensing principle for direct mass measurement of the gas. These meters can be specified as insertion type or in-line type. The thermal mass flow sensor consists of two RTDs. The sensor elements are constructed of a reference grade platinum wire wound around mandrels usually inserted into stainless steel or Hastelloy tubes. The reference RTD measures the gas temperature. The instrument electronics heats the mass flow sensor to a constant temperature differential above the gas temperature and measures the cooling effect of the gas flow. The electrical power required to maintain a constant temperature differential is directly proportional to the gas flow rate.

Deciding which type of meter is the best choice for a particular application depends upon the following:

- the pressure of the gas being measured
- the maximum flow rate to be measured
- the minimum flow rate to be measured
- the cost of the meter

These issues are summarized in Table 3.

Table 3. Domestic Water Flow Meter Comparison

Meter Type	Maximum Gas Pressure psig	Maximum (Minimum) Capacity scfh	Typical Accuracy/ Rangeabilit y	Advantages	Disadvantages
Diaphragm	100	5,000 (no minimum)	±1% 100:1	▪ Inexpensive ▪ Good at measuring low flow rates	▪ Mechanical components can get fouled and fail ▪ Temperarature correction recommended
Rotary	285	16,000 (1,000 scfh minimum)	±1% 30:1 to 120:1	▪ Good for commercial and industrial gas flow measurment	▪ Mechanical components can get fouled and fail

Meter Type	Maximum Gas Pressure psig	Maximum (Minimum) Capacity scfh	Typical Accuracy/ Rangeabilit y	Advantages	Disadvantages
Turbine	300	150,000 (50,000 scfh minimum)	±1%of reading	▪ Great for large gas flow rates such as central heating plants ▪ Low pressure drop	▪ Expensive ▪ Not good for measuring low flow rates
Thermal Gas Mass flow	300	384,000 (no minimum)	±1%+ 0.2% of full scale	▪ Easy to install	▪ Straight pipe critical for accuracy and stability

Adjustment for Pressure and Temperature

Gas meters perform measurements at line conditions of pressure and temperature. This measurement is known as the uncorrected volume. With many meters, it is necessary to convert uncorrected volume to the equivalent volume at standard conditions (corrected volume). At line pressures above the reference pressure (typically 14.73 psia), the corrected volume will be greater than the uncorrected volume. The effect of pressure can be calculated as:

$$V_{SCF} = V_{ACF} \frac{P_a}{P_{ref}}$$

$$= V_{ACF} \frac{(P_{atm} + P_g)}{P_{ref}}$$

where V_{SCF} is gas volume in "standard" cubic feet, V_{ACF} is the actual volume, P_a is absolute gas pressure, P_{ref} is the reference gas pressure, P_{atm} is atmospheric pressure, P_g is the gas gauge pressure (pressure relative to atmospheric pressure).

When actual flowing temperatures are above the reference temperature (60ºF), corrected volume will be less than the uncorrected volume. Conversely, at temperatures below 60ºF, corrected volume will be greater than uncorrected volume. The effect of temperature can be calculated as:

$$V_{SCF} = V_{ACF} \frac{(460 + T_{ref})}{(460 + T_g)}$$

where T_{ref} is the reference temperature and T_g is the actual gas temperature.

In actual practice, some type of correcting device is normally used with a meter to automatically convert to standard cubic feet. For diaphragm, rotary and turbine meters in an application where line pressure is stable, the meter can be supplied with an index that corrects for a constant pressure. Diaphragm and rotary meters can also be supplied with an integral continuous mechanical temperature-compensating device for temperature correction. For turbine meters and larger diaphragm meters, a correcting instrument is typically used.

Hot Water and Chilled Water

BTU Calculation

Metering building hot and chilled water energy usage requires the measurement of three variables:

- Entering water temperature (T_E, ºF)
- Leaving water temperature (T_L, ºF)
- Flow rate (GPM)

From these, energy usage, *Q*, in Btu/hr can be calculated as

$$Q = \dot{m}\Delta h$$
$$\approx 500 * GPM * (T_L - T_E)$$

This equation has several sources of error:

- The equation assumes water is an incompressible fluid. This is a good assumption for the pressures and temperatures commonly found in building hydronic systems.
- The conversion "constant" 500 assumes a density and specific heat based on 68ºF water. The value is reasonably accurate for chilled water but a few percent off for hot water. This may or may not be significant in energy calculations depending on how the energy data are used. If metering is for utility cost charge back, a more accurate calculation of this constant is probably warranted and can be interpolated from the following table as a function of average fluid temperature:

Table 4. Water Properties as a Function of Temperature

Property of Water	Units	Symbol	Temperature				
			40	60	80	100	200
Specific Heat	Btu/lb_m-°F	c	1.006	1.001	0.999	0.999	1.006
Density	lb_m /ft^3	ρ	62.42	62.36	62.21	61.99	60.12
Conversion Constant	Btu-min/gal-°F-hr	C	503.4	500.7	498.6	496.7	485.1

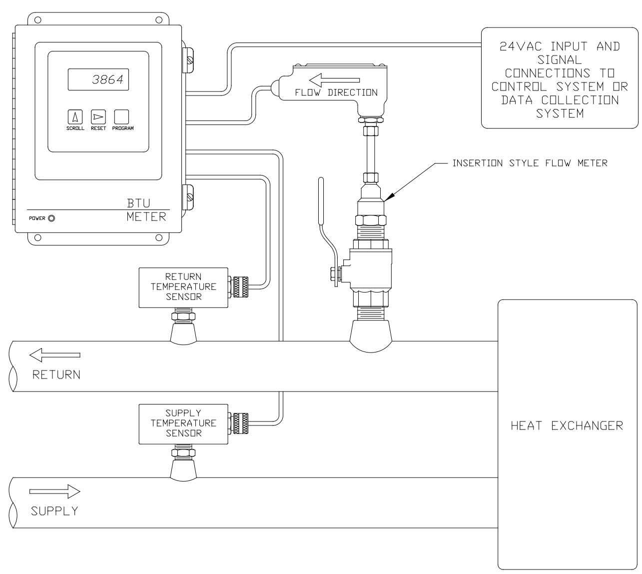
- Flow measurement can be quite inaccurate depending on the type of meter, calibration, and how it is installed. Meter types are discussed in detail below.
- Temperature measurement accuracy also varies by sensor type and calibration. For non-revenue metering of hot water, relatively inexpensive sensors can be used since the temperature difference between entering and leaving water is generally large (>20ºF). For chilled water applications, sensor accuracy relative to each other becomes significant since the temperature differences can be small (<10ºF). For instance, if one sensor reads 1ºF high while the other is 1ºF low, the energy calculation can be on the order of 20% off. Temperature sensor types are also discussed in more detail below.

BTU Meters

The BTU calculation above can be performed by the BAS from flow and temperature sensors or it can be done by a device called a "BTU meter." The BTU meter generally is configured to send calculated BTU data, optionally along with individual temperature and flow measurement data, to the BAS or other data collection system for monitoring. It may also have a display for manual reading of internally stored energy usage data. The main advantage of the BTU meter is that temperature sensors are factory matched to minimize temperature difference calculation error. However, they generally cost more than using individual sensors connected to the BAS. Nevertheless, BTU meters are recommended due to their improved temperature measurement accuracy and stability and ease of data collection, particularly if energy is being metered for revenue purposes (allocating costs of chilled or hot water usage per building).

Figure 11 shows a typical BTU meter. With this style, which is used for larger piping, the flow meter and temperature sensors are all field mounted; with some smaller BTU meters, the flow meter and one temperature sensor are built into the main meter housing. The temperature sensors are provided with BTU meter so that they can be factory matched and calibrated for improved accuracy. The flow meter can be any type depending on the desired accuracy – see flow meter discussion below. The output of the Btu meter can be a pulse or analog output connected to an BAS or other data collection system. Modern BTU meters also include the ability to directly connect to common control networks such as BACnet/MSTP, Modbus/EIA-485, LonWorks, and various proprietary networks. This allows, at low cost, not only the BTU data but also the flow and temperature data to be monitored by the BAS.

Figure 11: BTU Meter



Flow Meters

The most common flow meters used for chilled and hot water metering applications are:

- Turbine (Figure 12)
- Full-bore magnetic (Figure 13)
- Single point magnetic (Figure 14)
- Vortex shedding (Figure 15)
- Transit time ultrasonic (Figure 16)

This Guide does not include a description of how each meter works; the reader is referred to manufacturer's websites for this information. Another resource is ASHRAE's *Fundamentals of HVAC Controls* self-directed learning textbook.

Figure 12. Dual Turbine Meter

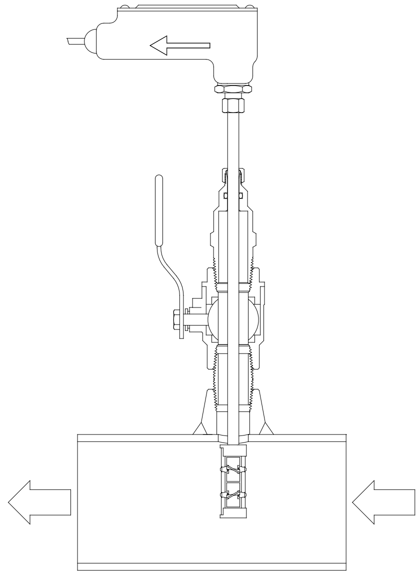


Figure 13. Full-bore Magnetic Meter

Figure 14. Insertion Magnetic Meter

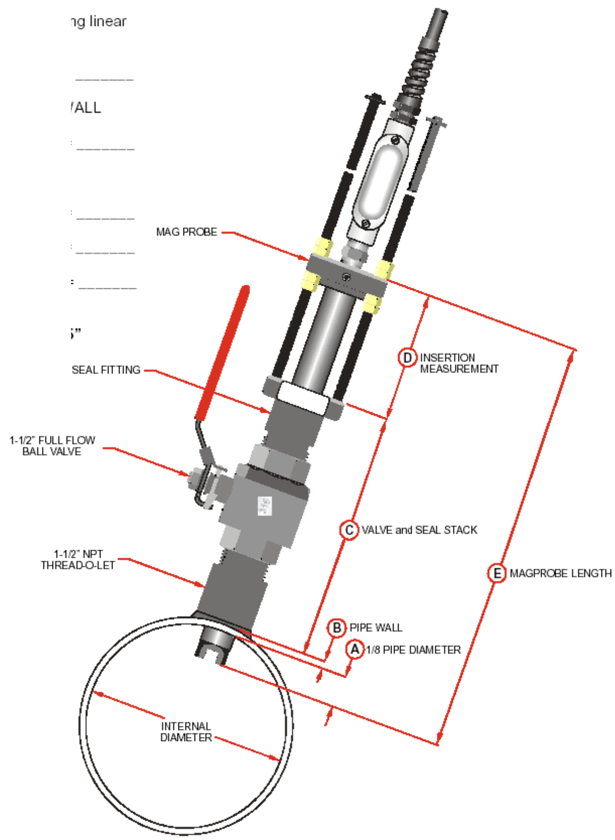


Figure 15. Vortex Shedding Meter

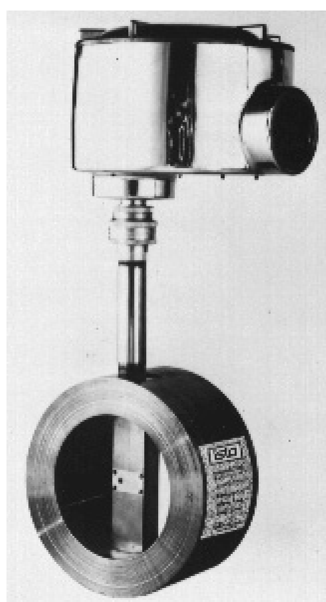


Figure 16. Transit Time Ultrasonic Meter

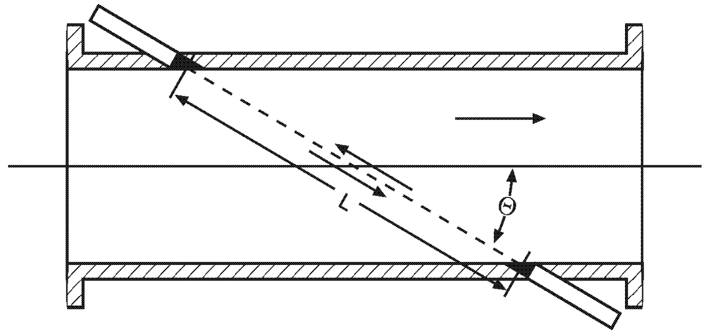


Table 5 compares the features, advantages and disadvantages of these meters, with application issues summarized below:

- The turbine meter is perhaps the most common for this application because of its low cost, but it is prone to clogging on open systems such as condenser water systems. Because of the moving parts, routine maintenance is required.
- Full-bore magnetic flow meters are the best from an accuracy standpoint (very accurate even at very low flow rates), operational standpoint (lowest maintenance costs, longest lasting), and they require the shortest runs of straight piping, but they are expensive. Until recently they were extremely expensive because most manufacturers designed the meters for the more demanding industrial market, but commercial quality meters are now available at much lower cost. Because the full-bore meter senses the entire water flow (not just a single point), they are much less sensitive to installation problems; as long as turbulence does not cause reversing eddy currents within the flow tube the meter will be accurate.
- Single point magnetic meters are often used for large piping when the cost of full-bore meters becomes prohibitive, but because they measure flow only at a single point in the pipe, they are less accurate than full-bore meters. They also require very long runs of straight piping that seldom are available at most building connection points.
- Vortex shedding meters were more common before magnetic meters came down in price. They are now more commonly used on gas and steam flow. A significant limitation is that they are not very accurate at low flow.
- Ultrasonic meters are non-invasive, i.e. they do not require any openings into the pipe and were initially used for ad hoc flow measurements such as for test and balance. Installation details are critical. Manufacturers provide jigs and assemblies to ensure the sensors are accurately installed, but they are still prone to inaccuracies from installation error. Because they are non-invasive, ultrasonic meters are particularly applicable to retrofit applications.

For metering chilled and hot water flows at buildings, particularly for revenue purposes, the full-bore magnetic flow meter is strongly recommended. The pipe sizes are generally small enough at building connections that these meters are affordable. If budget constraints are such that they are cost prohibitive, dual turbine meters are recommended. They are reasonably accurate if well maintained but they are relatively inexpensive. Full-bore magnetic flow meters are also strongly recommended for metering total central plant output of variable flow chilled water and heating hot water systems.

Table 5. HW & CHW Flow Meter Comparison

Type	Configuration	Typical Accuracy/ Minimum Flow	Advantages	Disadvantages
Turbine (single for small pipes, dual for pipes 2.5" and larger)	Insertion	±2% 0.5 fps	▪ Usually least expensive ▪ Insertion style allows easy retrofit (via hot tap) and removal for cleaning, replacement	▪ Can be fouled by contaminants in water; not recommended for open circuit systems ▪ Moving parts result in lower operating life, possibly degrading accuracy ▪ Requires correct installation depth to be accurate ▪ Sensitive to installation details – long straight inlet and outlet runs required
Full-bore magnetic	Flow tube	±0.5% 0.05 fps	▪ Most accurate meter ▪ Lowest minimum flow rate ▪ Least sensitive to installation problems and requires least amount of straight piping runs at inlet and discharge ▪ Very little maintenance required; no moving parts ▪ Long life with little calibration required	▪ Most expensive meter, and especially expensive for large pipes (>12") ▪ Cannot be removed without shutting off system or providing an expensive bypass
Single point magnetic	Insertion	±1% 0.2 fps	▪ Insertion style allows easy retrofit (via hot tap) and removal for cleaning, replacement ▪ Very little maintenance required; no moving parts ▪ Long life with little calibration required	▪ Relatively expensive for small pipe sizes ▪ Requires correct installation depth to be accurate ▪ Sensitive to installation details – long straight inlet and outlet runs required

Type	Configuration	Typical Accuracy/ Minimum Flow	Advantages	Disadvantages
Vortex shedding	Insertion	±2% 1 fps	▪ Insertion style allows easy retrofit (via hot tap) and removal for cleaning, replacement	▪ Not accurate at low flows ▪ Can be fouled by contaminants in water; ▪ Requires correct installation depth to be accurate ▪ Sensitive to installation details – long straight inlet and outlet runs required
Transit time ultrasonic	External	±0.5% 1 fps	▪ External mount allows easy retrofit and replacement ▪ No moving parts and no parts exposed to fluid so maintenance costs are low	▪ Relatively expensive for small pipe sizes ▪ Not accurate at low flows or quick rate of change ▪ Requires correct configuration to be accurate – sensitive to configuration details such as pipe dimensions and wall thickness ▪ Sensitive to installation details – long straight inlet and outlet runs and precise mounting required

Temperature Sensors

The most common temperature sensing devices used in hydronic applications are:

- Thermistors
- Resistance Temperature Detectors (RTDs)
- Integrated circuit (solid-state) temperature sensors

These all use materials whose resistance or impedance changes with temperature.

Thermistors are generally the least expensive and are fairly accurate (±0.4ºF for standard thermistors, ±0.2ºF for extra precision thermistors). Historically they had problems staying in calibration, but this is not a problem with modern thermistors which drift less than about 0.04°F over a five-year period. Thermistors have sufficient resistance that they may be connected to the BAS with only a two-wire connection; a transmitter is not required. Their temperature range is very broad, so a single thermistor sensor can be used for virtually all HVAC applications; specific ranges do not have to be specified. Their signal is non-linear with respect to temperature changes so signal conditioning is required, but this capability is standard for most modern BAS.

RTDs were once the most common temperature sensor in HVAC applications, but they recently have been mostly displaced by less expensive thermistors. RTDs have low resistance so transmitters are required and, unlike thermistors, they must be ordered for the specific temperature range required by the application. Accuracies of RTDs vary widely from ±0.02°F to ±1.0°F depending on the material (platinum is most common) and construction.

Integrated circuit temperature sensors are not commonly used in HVAC applications except with BTU meters. They are not very accurate (~±1.0°F) but they are extremely repeatable and linear. They also do not require calibration. Hence, they are excellent for differential temperature measurement once the two sensors are matched and calibrated at the factory. Differential temperature measurement accuracy is typically about ±0.15°F.

Differential temperature accuracy and sensor recommendations for metering purposes are:

- Hot Water Systems. Differential temperature accuracy: ±0.5ºF. Two extra precision thermistors (±0.2ºF each) can meet this requirement, as can high accuracy RTDs with at least ±0.25ºF accuracy, and matched integrated circuit sensors supplied with a BTU meter.
- Chilled Water Systems. Differential temperature accuracy: ±0.15ºF. Thermistors will not be able to meet this accuracy requirement. Ultra-high accuracy RTDs or matched integrated circuit sensors supplied with a BTU meter must be used.

The accuracy and long-term stability of the BTU meter integrated circuit sensors is one of their main advantages and why BTU meters are recommended for chilled and hot water flow metering.

Steam

Steam usage can be metered in two ways:

- Measuring steam vapor flow and converting to mass flow (lbs/hr) by adjusting for density variations based on steam temperature or pressure (if steam is assumed to be saturated) or based on temperature and pressure (if steam is superheated)
- Measuring steam condensate flow and converting to mass flow (lbs/hr) by adjusting for density variations based on fluid temperature

Historically, the latter approach was most popular because measuring liquid flow was much less expensive and it is accurate over a very wide flow range. Utility grade diaphragm meters were most commonly used (see Figure 7) particularly for building sub-metering applications, but turbine meters (see Figure 9) are another option. However, condensate flow does not include processes for which no condensate is returned, such as steam used for humidification and some sterilizers. With the advent of more accurate gas flow measurement devices, direct measurement of steam is becoming the preferred metering approach and the approach recommended for CSU campuses.

The most common steam volumetric flow measuring device is the vortex shedding meter (see Figure 15). It is accurate across a fairly wide flow range (at least 25::1 but as high as 150::1), but as with all meters its accuracy drops off at very low flow rates. If the range is expected to vary widely and accuracy is required at low flow rates, consider splitting the steam service into two or more (e.g. one service for year-round low flow steam usage and another for high flow winter heating and humidification loads) each with its own meter sized for the expected flow rate and range.

Steam vapor volumetric flow rate can be converted to mass flow rate using the following equation:

$$G = \dot{V}/_{v}$$

where G is the mass flow rate (lbs/hr), $\dot{V}$ is the volumetric flow rate (ft^3/hr) as measured by the flow meter, and υ is the specific volume (ft^3/lb). To determine the specific volume for saturated steam, steam temperature or pressure must be measured from which specific volume can be determined from a look-up table (Table 6) or equations approximating the table. For superheated steam, both temperature and pressure must be measured from which specific volume can be approximated by perfect gas laws or determined more accurately with empirical correlations with temperature and pressure. Typically, steam is not superheated by the time it reaches the meter from the steam boilers so these more complex calculations are not required.

Table 6. Specific Volume for Saturated Steam

Temperature, °F	Pressure		Specific Volume, ft3/lb
	Absolute, psia	Gauge, psig	
212	14.7	0.0	26.802
220	17.2	2.5	23.133
230	20.8	6.1	19.371
240	25.0	10.3	16.314
250	29.8	15.1	13.815
260	35.4	20.8	11.759
270	41.9	27.2	10.058
280	49.2	34.5	8.6431
290	57.6	42.9	7.4600
300	67.0	52.3	6.4658
310	77.7	63.0	5.6263
320	89.7	75.0	4.9142
330	103.1	88.4	4.3075
340	118.0	103.3	3.7884
350	134.6	119.9	3.3425

Many meters are available that make the volumetric to mass flow rate conversion using a built-in temperature or pressure sensor and conversion logic within the meter transmitter so that external conversion to mass flow rate is not required. Figure 17 is an example or a vortex shedding meter with this capability.

Figure 17. Vortex Shedding Meter with Integral Mass Flow Conversion

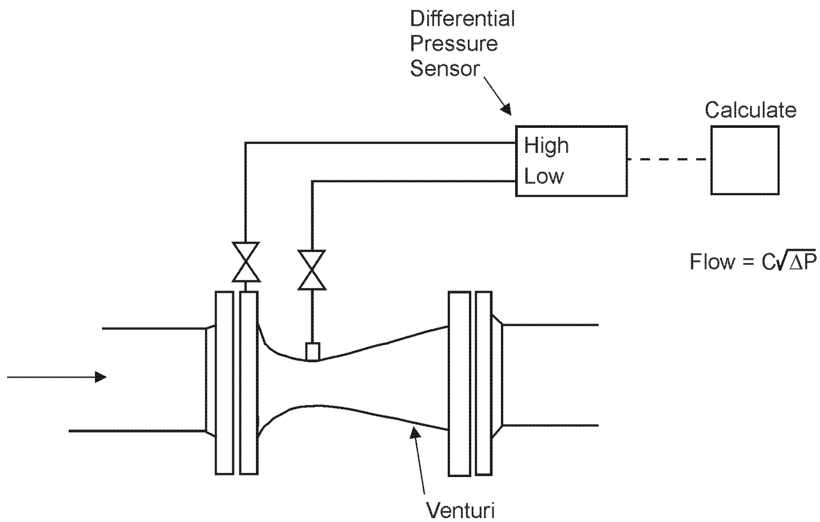
Domestic Water

Meter Types

Water meters can be classified into two basic types: positive displacement and velocity. Each of these meter types has variations, leading to the perception that there are several different kinds. Meters that feature both positive displacement and velocity are known as compound meters. The unit of measurement is typically in gallons or cubic feet. Water meters specified should meet performance and accuracy requirements listed in the American Water Works Association (AWWA) applicable standards.

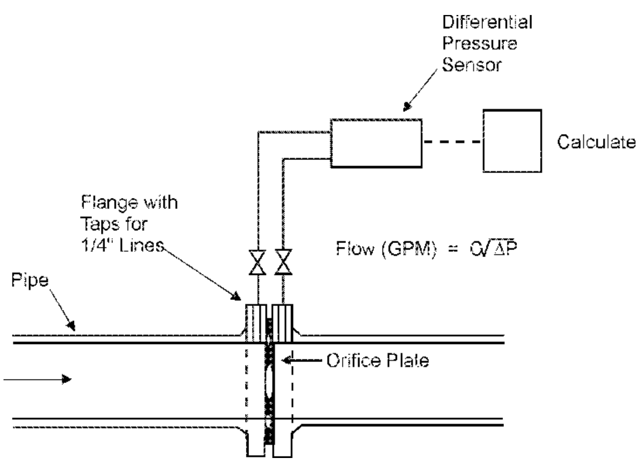
- Positive Displacement Meters
- In this type of meter, a known volume of liquid in a tiny compartment moves with the flow of water. Positive displacement flow meters operate by repeatedly filling and emptying these compartments. The flow rate is calculated based on the number of times these compartments are filled and emptied. The movement of a disc or piston drives an arrangement of gears that registers and records the volume of liquid exiting the meter. There are two types of positive displacement meters: nutating disc and piston.
- Nutating disc meters have a round disc that is located inside a cylindrical chamber. The disc is mounted on a spindle. The disk nutates, or wobbles, as it passes a known volume of liquid through the cylindrical chamber. The rotating motion of the disk is then transmitted to the register that records the volume of water that went through the meter. (See Figure 1 below.)
- Piston meters have a piston that oscillates back and forth as water flows through the meter. A known volume of water is measured for each rotation, and the motion is transmitted to a register through an arrangement of magnetic drive and gear assembly.
- Positive displacement meters are sensitive to low flow rates and have high accuracy over a wide range of flow rates. Positive displacement meters are used for smaller flow applications. They are available in sizes from 5/8” to two inches.
- Velocity Meters
- Velocity meters operate on the principle that water passing through a known cross-sectional area with a measured velocity can be equated into a volume of flow. Velocity meters are good for high flow applications.
- Velocity meters come in different types, including venturi, orifice, turbine, ultrasonic, and magnetic meters.
- Venturi meters (Figure 18) have a section that has a smaller diameter than the pipe on the upstream side. Based on a principle of hydraulics, as water flows through the pipe, its velocity is increased as it flows through a reduced cross-sectional area. Difference in pressure before water enters the smaller diameter section and at the smaller diameter “throat” is measured. The change in pressure is proportional to the square of velocity. Flow rate can be determined by measuring the difference in pressure. Venturi meters are suitable for large pipelines and do not require much maintenance.

Figure 18. Venturi Flow Meter



Orifice meters (Figure 19) work on the same principle as venturi meters, except that, instead of the decreasing cross-sectional area, there is a circular disk with a concentric hole. Flow rate is calculated similarly to the venturi meter by measuring the difference in pressures. Pressure drop is very high through these meters and consequently they are seldom used in modern applications.

Figure 19. Orifice Plate Flow Meter



Turbine meters have a rotating element that turns with the flow of water. The number of rotor revolutions measures volume of water. See Figure 9.

Magnetic meters have an insulated section through which water flows. The flow of water induces an electrical current that is proportional to the velocity and hence the flow rate. See Figure 13.

- Compound Meters

  In some cases, it is necessary to have a combination meter—both a positive displacement meter and velocity meter installed together—to be able to measure extremely high flow rate applications. Low flows are measured through positive displacement while high flows are measured by velocity. A valve arrangement directs flows into each part of the meter.

Selecting a Meter

Meters are selected using several factors: flow range, size of pipe, pressure loss and safety considerations, such as fire service regulations. The most common meters used in domestic water applications are positive displacement and turbine flow meters.

For sizes of one inch and smaller and low flow rates, positive displacement types of meters are common.

For flows up to 160 gpm, positive displacement meters in sizes of 1”, 1-1/2”, or two inches are commonly used. In sizes of 2-3 inches, either, displacement or turbine types of meters can be used. In the 3-4 inch size range, the meter type depends on the average flow rate. If the flow rate is between five and 35 percent of maximum flow rate, the positive displacement type is better. If the flow rates are going to be 10 to 15 percent of the maximum capacity, a turbine type should be used. If close accuracy at low flows is important, but large flows also have to be measured, a compound meter is best.

Venturi meters can be considered as an option for a large range of flows such as metering a main if you need a meter that will not interfere with the flow if the meter fails. Magnetic meters offer high accuracy with no head loss but are the most expensive option for metering water.

Meter Installation

Meters are installed either in outdoor meter pits (also known as meter wells) or inside the building served. General guidelines for installing meters are:

- In outdoor meter pits, the face of the meter should be between 18 and 24 inches from the ground surface or top of the meter pit lid.
- Meter pits or wells should have six to 12 inches of gravel at the bottom to help with drainage.
- If at all possible, the meter pit or well should not be located in an area prone to flooding.
- The meter setting should have a shut-off valve on both sides of the meter
- If possible, the meter should be installed in a horizontal position.
- The meter should be easily accessible for service, inspection, and reading
- Protect the meter from freezing, where applicable

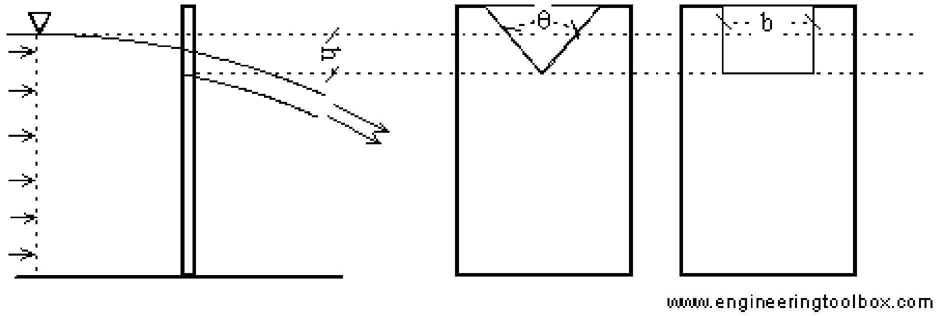
Sewage

The most accurate sewage flow meter is a full-bore magnetic flow meter (Figure 13) in part because it can measure flow in a partially filled waste line. Most other sensors (e.g. single point magnetic, turbine, and ultrasonic meters) cannot be used to measure flow in partially filled pipes. Unfortunately, full-bore magnetic flow meters are extremely expensive for the size required for most waste lines.

A less expensive option is a velocity meter (e.g. ultrasonic, single point electromagnetic) combined with a level meter (e.g. radar) or depth meter (e.g. pressure transducer) to estimate flow area. Accuracy is typically no better than ±5%.

Another option commonly used prior to the affordability of velocity meters but less popular today is the weir meter. It consists of an obstruction (see Figure 20) across the open channel with a specially shaped opening or notch. The obstruction results in an increase in the water level upstream of the structure. The flow rate can be calculated from this depth (measured with an ultrasonic level sensor or pressure transducer), basic flow equations, and a field calibrated flow coefficient. One obvious problem with weir meters is that flow is restricted possibly causing a sewage backup.

Figure 20. Weir Meters



Because of the expense and potential problems, measuring sewage flow should only be considered when water use for irrigation or evaporative processes (e.g. cooling towers, evaporative condensers, direct/indirect evaporative cooling) are large and the local utility provides a financial credit for the reduced sewer burden. Even in these cases, it is usually more cost effective to sub-meter the water flow to these applications and deducting these flows from overall water usage.

SECTION 4: Commissioning and Calibration

Definitions

Commissioning and calibration of metering devices are the processes that contribute to the proper installation and provision of adjustments necessary to generate accurate meter data. The accuracy and reliability of the data obtained from meters largely depends on whether they are properly installed and calibrated. Installation details must strictly follow the meter manufacturer's instructions. Once a meter is properly installed, a process must be conducted to confirm accuracy and calibration.

Accuracy is the ability of a measurement to match the actual value being measured. Calibration is the act of checking or adjusting the accuracy of meter by comparison it with a known standard. The known standard in the case of most meters can be a portable meter of greater accuracy with calibration traceable to the National Institute of Standards and Technology (NIST). All revenue grade meters should have a calibration certificate indicating measurements traceable to the NIST or equivalent institution. Meter manufacturers and suppliers must produce the criteria for installed accuracy validation. Documentation affirming that the meter was properly installed and providing accurate data should be specified to be a part of the commissioning process.

Installation

Proper installation must be verified in detail by a commissioning process containing checklists of all items and processes necessary to ascertain compliance to the installation criteria provided by the meter manufacturer. Different types of meters have very specific installation requirements that are necessary for proper function. The meter manufacturer installation procedures and recommendations should be followed in detail. Meters should be installed by factory qualified contractors under the supervision of the project commissioning agent, the project inspector, the project manager and the engineer of record.

Practical Accuracy Validation Process

Since NIST traceable accuracy validation may be impractical, expensive, or unnecessary for certain applications, a more practical approach should be implemented as discussed below followed by a formal approach for cases that require a formal traceable calibration process.

It is at times more practical to require that meters be factory calibrated rather than field calibrated since the necessary instrumentation and test rigs are readily available in the factory. This is particularly true of flow meters, since field calibration is often impractical if not impossible, due to lack of a good location to mount a temporary meter (it is hard enough finding a good location for the permanent meter) and because finding a sufficiently accurate temporary meter may not be practical. Still, a check must be made to ensure that the meter and transmitter were properly configured. For instance, a flow meter can be checked by causing the entire flow to go through a device with a flow measurement capability (however accurate) or with a known flow and pressure drop relationship (e.g. a chiller). This test will allow the meter to be checked for the right order of magnitude reading to ensure proper configuration, but it cannot be used for actual calibration; the factory calibration must be relied upon.

It is ultimately the responsibility of the project team to assure that the data produced by a meter is sufficiently reliable for the given application. For applications requiring a very high degree assured accuracy a more formal process should be followed as discussed below.

Formal Calibration and Validation Process

Formally, the definition of calibration traceability that has achieved global acceptance in the metrology community is contained in the International Vocabulary of Basic and General Terms in Metrology (VIM; 1993):

"…The property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons, all having stated uncertainties."

It is important to note that traceability is the property of the result of a measurement, not of an instrument or calibration report or laboratory. It is not achieved by following any one particular procedure or using special equipment. Merely having an instrument calibrated, even by NIST, is not enough to make the measurement result obtained from that instrument traceable to realizations of the appropriate SI unit or other stated references. The measurement system by which values are transferred must be clearly understood and under control. In other words, traceable measurements or meter data must follow a traceable calibration protocol involving proper instruments and certified calibration professionals.

Therefore, a thorough review of the installation process and requirements for each meter needs to be conducted. This process must address proper installation, calibration verification and traceability to a known established standard. Usually, manufacturer installation manuals furnish specific information on the proper installation of meters and related devices.

Test equipment used for testing and calibration of field devices shall be at least twice as accurate as respective field device. For example, if field device is ±0.5% accurate, test equipment shall be ±0.25% accurate over same range.

SECTION 5:
Specifying Metering

To fully specify metering, include all of the following:

- Show the locations of meters on plans (physical location) and on schematics (e.g. piping diagrams, control schematics, one-line electrical diagrams).
- Show how meters are to be monitored (e.g. connected to the BAS or directly to the campus Ethernet network). The second part of this Metering Guide will go into more detail about monitoring options.
- Include meters in specifications. Guide specifications from manufacturers are a good source of metering specification language, but be careful the language does not lock the campus into a specific manufacturer, unless a sole-source arrangement has been approved by the campus and Chancellor's office. Important elements of the specification are:
  - Meter type
  - Minimum accuracy and repeatability
  - Range or turn-down capability
  - Materials of construction, where applicable. For instance, flow meters for high temperature hot water may have to be constructed of special materials. Consult manufacturers for options.
  - Installation requirements. Typically, the specification simply needs to require that the meter be installed in accordance with manufacturer's recommendations.
  - Calibration requirements. Typically, this would include factory calibration as well as field calibration or check, as discussed in Section 4.
  - Testing and commissioning requirements.