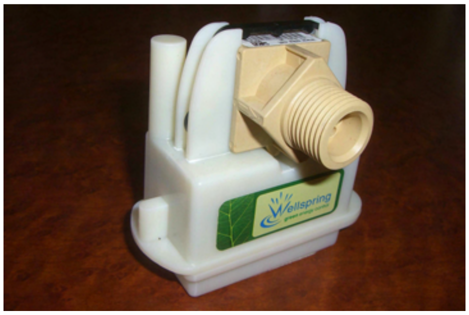
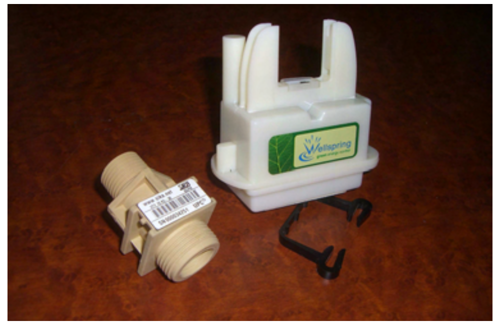
Aqura Water and Domestic Hot Water Energy Measurement

This white paper documents the method Wellspring uses to measure water and domestic hot water energy consumption with the Aqura water and wet energy meter.



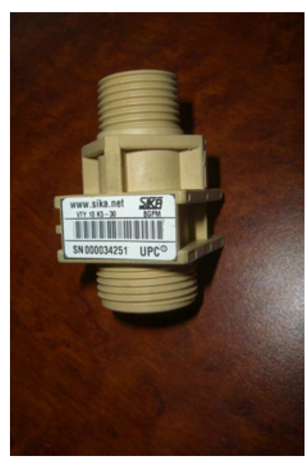


Each Aqura water meter contains two sensors – a Hall Effect sensor and a thermistor. The Hall Effect sensor is used to determine the amount of water consumed. The amount of water consumed is used in conjunction with the thermistor sensor to determine the energy content of domestic hot water.

Water Use Measurement

The Hall Effect sensor generates an electronic pulse every time a magnetic field in its vicinity changes polarity. This Hall Effect sensor tracks the rotations of a magnet embedded in the Aqura flow sensor turbine as it spins, generating two pulses per rotation. Turbine speeds in the Aqura flow sensor are very fast, generating nominally 750 rotations, and therefore 1500 pulses per liter of water. The capacity of the Aqura flow sensor is 30 liters per minute (nominally 8 gallons per minute (gpm). At the maximum flow rate the flow sensor turbine rotates at 22,500 rpm with the Hall Effect sensor producing 45,000 pulses per minute.

The pulses from the Hall Effect sensor are interpreted by a micro-processor, which recognizes that the relationship between the rotational speed of the turbine and the flow rate of the water is not perfectly linear, especially at low flows. The micro uses the pulse width (time between pulses) and the turbine flow curve, which relates pulse width to flow rate, in order to compute water use. The computed water usage is added to a perpetual register that logs the amount of water consumed in gallons. The frequency of this computation depends on whether the flow rate is changing – in a steady flow condition samples are less frequent to preserve battery life.

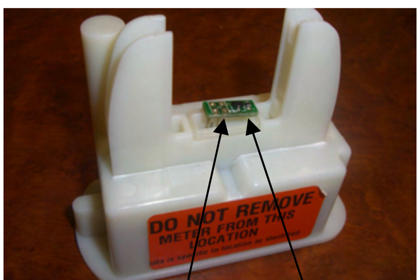


This method provides measurement accuracy that meets national standards of plus or minus 1.5% over the normal flow range of 1 gpm to 8 gpm. At lower flow rates down to 0.5 gpm, accuracy is plus or minus 3% around the midpoint of the measurement range. The software skews the low flow results to +1% to -5% in order to comply with the national standard ASME A112-4.7-2002 (Point of Use and Branch Water Submetering Systems), and the NIST Handbook 44.

In addition to measuring consumption, the Aqura meter logs the number of flow events and the time of flow. These data items are used in diagnostic algorithms to determine the nature of leaks and the performance of water fixtures (gallons per flush and gallons per minute), and to explain high use results (average number of flushes, number of uses, and average time per shower, etc.)

Domestic Hot Water Energy Measurement

A thermistor is the second sensor included with every Aqura water meter. This sensor tracks the temperature sensed on the sensing plate of the flow sensor – which is the thinnest section of the flow sensor housing. Every 15 seconds, the microprocessor measures the temperature at this location. Wellspring lab data reveals that the temperature measured at this location is within one degree of the actual water temperature. Each time the microprocessor computes the amount of water consumed, it also computes a second value which provides the foundation for determining the BTU content of the domestic hot water being consumed.



Aqura sensor board removed from its plug.
Hall Effect Sensor and Thermistor shown.

This value is called a “Trenkler” unit after one of its inventors, and is similar to a BTU, or British thermal unit. A “BTU” is defined as the energy required to raise one pound of water one degree F. In order to compute BTU’s, one must know the weight of water consumed, and the rise in temperature as the water was heated. The Aquara meter knows the weight of water consumed by simply multiplying the gallons times the weight per gallon (8.33 pounds of water per gallon). The Aqura meter also knows the temperature in degrees F – but it does NOT know the temperature of cold water, which is the beginning temperature before the water it is sensing was heated. So, the Aqura meter makes an extreme assumption, that the temperature of the cold water entering the hot water heater is 32 degrees. Trenkler units are the result of taking the weight of water consumed times the rise in temperature from 32 degrees F to the sensed temperature value and then dividing by 200. This last step (dividing by 200) is simply scaling the value in order to accommodate the resources of the microprocessor. In short, one Trenkler is equal to 200 BTU’s, assuming a cold water temperature of 32 degrees F.

The Trenkler units are added to a perpetual energy register in the Aqura meter, and they are reported along with the other registers (water gallons, flow time, and number of events) through a ZigBee Pro open protocol radio mesh network that is compliant with the IEEE standard 802.15.4.

Once each day, the Wellspring host computer uses the Trenkler unit and water usage registers to compute the weighted average water temperature sensed by each Aqura meter. This value is reported and becomes part of the diagnostic data Wellspring reports. Next, the host system computes the BTU energy content of the water consumed, using a new cold water temperature, which is determined by using a lookup table which contains a single cold water temperature for each month of the year. Alternatively the temperature of the cold water can be measured at the central domestic hot water heater serving the meter's location. This computation is simple – the gallons x 8.33 (pounds per gallons) times the change in temperature (actual weighted average temperature sensed minus either the lookup table cold water temperature based upon the month of the year or the actual cold water temperature).

Domestic Hot Water Measurement Accuracy & System Losses

It takes nominally 15 seconds for the thermistor in an Aqura meter to register the actual temperature of the hot water – this measurement is not instantaneously accurate. This is a sobering recognition, when one considers that many water flow events last less than 15 seconds. A study by the California Energy Commission showed that 60% of the time, hot water flow events at bathroom sinks end before hot water is actually delivered to the faucet. In other words, people wash their hands using the hot water faucet, but accept room temperature water and then end the use event before the heated water ever arrives.

The question we are trying to answer and report is simply this – how much energy was consumed by the resident when they used the hot water? Unfortunately, the answer is found at the domestic hot water heater in the boiler room – for every pound of hot water consumed, the hot water heater must heat a pound of cold water (for example, starting at a cold water temperature of 60 degrees F) to some hot water set-point (for example a hot water temperature of 120 degrees F), thus consuming 60 BTU of energy per pound of water. This energy is consumed regardless of the actual hot water temperature at the point-of-use.

Lets take an example. Assume the measured hot water temperature at a use point is 80 degrees F during a one minute hot water flow event, on a faucet consuming 2 gallons per minute. The energy consumed at the faucet is computed as a 20 degree rise (80 – 60) multiplied by 16.66 pounds (8.33 pounds per gallon times 2 gallons used) of water which equals 333 BTU's. Yet, at the hot water heater, 2 new cold gallons entered the hot water heater and each was increased to 120 degrees, or a 60 degree rise multiplied by 16.66 pounds which equals 1,000 BTU. Assuming that the combustion efficiency of the heater is 80%, then to deliver 1,000 BTU of energy into the water, 1,250 BTU of natural gas was consumed.

What happened to the 1,250 BTU of gas?

- 250 BTU went up the chimney
- 667 BTU were lost during storage and transport
- 333 BTU were delivered to the resident

In other words, the domestic hot water system efficiency (in this example) is 26.7% - with 73.3% lost. To put this in perspective, NYSERDA (the New York State Energy Research and Development Authority) did a study of domestic hot water systems in New York City, and found that most domestic hot water systems operate close to 30% efficiency.

The efficiency of the domestic hot water system in any building is easy to determine when an Aqura water meter system is installed. The efficiency is simply the total of all energy measured at each meter in the building divided by the measured natural gas consumed at the domestic hot water heater. Admittedly, a portion of the difference between BTU's of gas consumed and Aqura measured energy is attributable to the lag in sensing the actual hot water temperature at the meter. This measurement error represents only a small portion of the total system losses, especially since most of the domestic hot water energy is consumed in the shower, tub and dishwasher where flow events are much longer than in the previous example and measurement accuracy is higher.

Wellspring's Domestic Hot Water Energy Register

Once the domestic hot water system efficiency is known, then the energy consumed at each Aqura meter can be computed. At the host computer, the Trenkler units are converted to BTU's, and then the BTUs are divided by the system efficiency. The result of this computation is added to a perpetual register for BTU's measured and computed previously. This water energy register is then reported to the billing company for each Aqura water meter.

Essentially, Wellspring reports the energy required at the domestic hot water heater, to provide the energy consumed and measured at each meter.

Hot Water BTU Meter

Wellspring also offers a true BTU meter, consisting of a larger pulse-generating cold water meter, and two temperature sensors – one sensor for cold water, and a second for hot water. This meter can be installed at the hot water heater, measuring cold water volume in gallons coming into the heater, and the actual temperature rise between the cold water feed and the hot water discharge. The

Wellspring radio module accepts three inputs – a dry contact from the water meter that relates to gallons consumed, and two temperature inputs.

With these inputs, the Wellspring processor computes the BTU content of water consumed, multiplying gallons times 8.33 (pounds per gallon) times temperature rise in degrees F. This BTU calculation is performed with each pulse and the resulting BTU measurement is added to the BTU register, which increases perpetually. Normally, larger water meters generate one dry contact closure (a pulse) for each gallon consumed which defines the resolution of the BTU meter register.


Pulse water meter wired to Wellspring BTU meter

Wellspring BTU meters may be used on hot water heaters, to compute the actual hot water heater efficiency, by comparing the measured wet-btu's computed, to the gas consumed as measured by a gas meter on the heater inlet. If Aqura BTU meters are deployed downstream at each use point, one can account for the gas energy consumed, assigning it to three categories:

- Combustion and storage losses
- Transport losses
- Energy delivered to each use point.

Wellspring BTU meters are also technically capable of measuring BTU's delivered in a hot water heating system, but this application is not recommended. Water meters are generally designed for measurement of potable water consumption. When placed into a re-circulating heating or cooling system, the meter will "see" semi-continuous flow of water that includes chemicals and particulate. The combination of high use hours, high flow rates (relative to domestic water use) and particulate laden water shorten the bearing life of the meter dramatically. A meter that may last 15 to 20 years measuring domestic water use might last only 12 to 18 months in a recirculating system.