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Building Energy Instrumentation for Determining Retrofit Savings: Thermal and Flow Meter Equipment Selection.

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ABSTRACT

A variety of equipment is available for the measurement of energy used in chilled and hot water systems in commercial buildings. Throughout the first three years of the LoanSTAR program, several different combinations of thermal energy meters and liquid flow meters have been used. This paper summarizes some of the basic principles of operation of these meters, and discusses some of the major advantages and disadvantages of each encountered in operation in the LoanSTAR program.

INTRODUCTION

Heating and cooling energy use for buildings with hot and chilled water systems can be measured using thermal energy meters. These meters require the input of temperature sensors and flow meters. Some thermal energy meters can report both energy rates and flow rates. This paper discusses some of the thermal energy and flow meters used in the LoanSTAR program. Special features and limitations of equipment from several different manufacturers are mentioned.

Thermal Energy Meters

A thermal energy meter is typically an electronic device that is used to calculate chilled water or hot water energy used in a building or facility. Each thermal energy meter requires three input signals: a flow meter signal and a temperature signal for the supply and return lines. Each thermal energy meter has its own requirements on the type of flow meter and temperature sensors needed for proper operation. A schematic of a typical thermal energy meter setup is shown in Figure 1.

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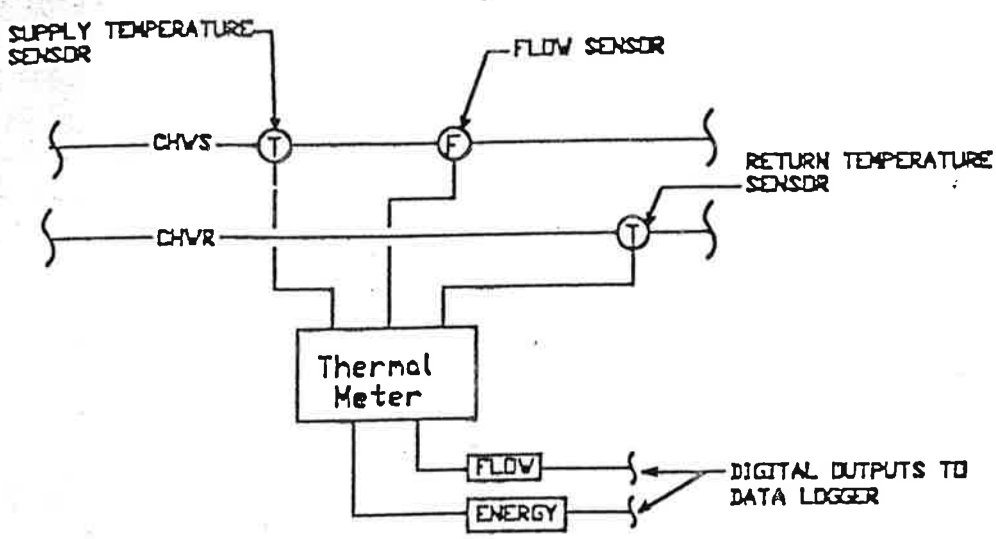

FIGURE 1: *Typical Thermal Energy Meter Set-up*

The calculation procedure performed by the thermal energy meter is based on the following equation:

$$E_T = \dot{m}\, C_p\, \Delta T \qquad (1)$$

where

$$\dot{m} = \rho\, \bar{V}\, \pi\, D^2/4 \qquad (2)$$

E_T = thermal energy usage

$\dot{m}$ = mass flow rate of water

C_p = specific heat of water at a given temperature

ΔT = difference between entering and leaving water temperatures

ρ = density of water

D = inside pipe diameter

Most flow meters don't measure mass directly, but measure the velocity of the water or the volumetric flow rate. The flow rate or velocity is then multiplied by a constant, which converts the flow rate or velocity into mass flow rate. A modified form of equation (1) that includes the volumetric flow rate is given as:

$$E_T = KQ\Delta T \qquad (3)$$

where K is a constant containing ρ and c_p for water, and some other constants needed for units conversions. The symbol Q represents the volumetric flow rate. The value of K is approximately 500, for E_T in units of Btu/hr, Q in gpm, and ΔT in units of degrees F.

The ΔT value is very straight forward, and is taken as the difference between temperature of the supply and return lines. The flow rate is a function of pipe size, and fluid velocity through the pipe.

Thermal Energy Meters Used on the LoanSTAR Program

Three brands of thermal energy meters have been used throughout the LoanSTAR program. They are designated as brands A, B, and C for the remainder of this paper. The main differences between these meters are the flow meter and temperature sensor requirements, and the ability to specify scaling factors based on pipe size, and flow meter calibration. Brand A is field scaleable, while brands B and C are not.

Brands B and C must be scaled by the manufacturer. The purchaser specifies pipe diameter, flow meter model, and estimated maximum flow. The manufacturer then programs the appropriate scale factors into "ROM" chips within the meter electronics. Many times the meters were programmed incorrectly because the diameter was incorrectly estimated, or the manufacturer mistakenly programmed the wrong size into the meter. Mistakes of this type were usually not discovered until after the thermal energy meters were installed. Excessive time delays resulted from removing and shipping these meters back to the manufacturer for reprogramming.

Brand A meters require no information about the site when ordering except temperature range being measured (either cold or hot). They have DIP switches that allow the scaling factors to be specified in the field. This model also has another DIP switch that lets the user scale the output signals.

The temperature sensors used with these meters are included when the meter is purchased. Brands A and C sensors are interchangeable. This means any one sensor is identical to the next and can be used in either the supply or return line. The brand B thermal energy meters are individually calibrated to the sensors, and are labeled "hot" and "cold." Recalibration efforts and repairs are more difficult when the sensors are not interchangeable.

A summary of meter features for the three thermal energy meters used in this program are listed below.

Features	Brand A	Brand B	Brand C
Cost	$450	$275	$1,700
Field Scaleable	yes	no	no
Output Signals	Flow, Btus	Flow, Btus	Btus
Temp Sensors	Thermistor	Solid State	RTD
Interchangeable Tmp Sensors	yes	no	yes
Flow meter Signal	Pulse	Pulse	Pulse or Analog
No. of water lines meter is capable of monitoring	1	1	2

The output signal from all three meters, is a simple electrical contact closure, digital pulse, that is detected by the data logger. The scaling of each pulse is dependent on the pipe size, flow meter characteristics, and thermal energy meter electronics configuration.

Another factor to consider when assessing the validity of the data produced by these thermal energy meters is calibration. The brand A manufacturer produces a test device that simulates a flow meter input and two temperature signals. Brands B and C do not offer such a device, however, the temperature sensors can be checked by measuring resistance or milliamps produced by the sensor at a given temperature. The brand C temperatures are easily checked, by measuring resistance of the RTD sensors, and using a table to calculate temperature. Brand B temperature sensors produce a 1 milliamp current per degree Kelvin signal, when a voltage is placed across the leads. However, the manufacturer states that direct measurements are accurate to only +/- 5 degrees F.

As always, a reasonableness check should be made with the energy measured by these meters. One easy check is to calculate the energy used per square foot. In the LoanSTAR program, measured building chilled water use ranges between 3 and 10 Btu/ft^2-hr [1].

<u>Flow Meters</u>

Many different types of flow meters exist for measuring fluid flow through piping systems. Each meter type has advantages and disadvantages regarding method of installation, accuracy, cost, calibration, and ease of maintenance. Several meters commonly found on chilled water distribution systems are discussed below.

Obstruction Meters

One category of flow meters relies on a pressure drop across a flow obstruction permanently fixed within a pipe. Measurement of the pressure-drop across the obstruction is taken as an indication of flow rate. Common obstruction flow meters found in building metering applications include venturi, and orifice flow meters. A schematic of these three meters is shown in Figure 2.

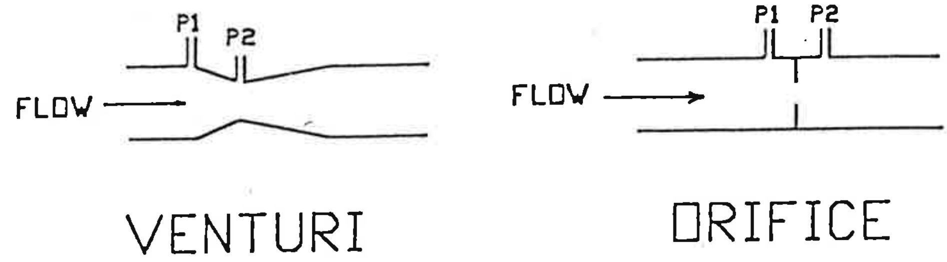

FIGURE 2: *Obstruction Flow Meters*

The flow rate through these meters is proportional to the square root of the pressure drop across the obstruction. This pressure drop is typically measured using a differential pressure transducer. The transducer provides a 4 - 20 mA signal that is proportional to either ΔP or the square root of ΔP. The signal required depends on the thermal energy meter or other data logging device.

The disadvantage of the obstruction meters is their difficulty of installation and calibration. A complete system shutdown is required at installation. The pipes must be drained, pipe sections cut, and the appropriate flanges welded in place. It is also impossible to remove such a meter and calibrate it at a later date in a testing facility such as a calibration flow loop.

These meters are commonly installed during the initial piping installation. They require little maintenance and are conceptually very simple. These flow meters have been used several times at LoanSTAR project sites where they were already installed. Due to the difficulties retrofitting these meters in existing lines, they are usually not installed as part of the LoanSTAR project metering system.

Averaging Pitot Tubes

Another type of meter commonly found in commercial buildings is the averaging pitot tube. This meter can be installed using "hot taps" or more commonly, during the initial piping installation. It consists of a fixed probe with several sensing ports along its length. These ports average the "impact" pressure for the upstream flow, and provide a single static pressure downstream. A differential pressure transducer is used to measure the difference between these two pressures. The square root of this pressure difference is proportional to the fluid flow velocity. A schematic of an averaging pitot tube is shown in Figure 3.

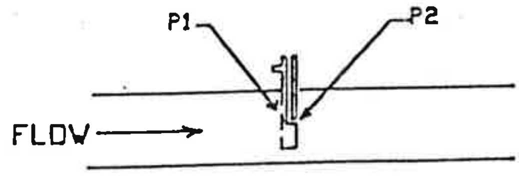

Figure 3: *Averaging Pitot Tube*

These meters are noted for their low maintenance, and low permanent pressure drop. They are relatively expensive, and are difficult to check for calibration.

Insertion Flow Meters

The insertion flow meter consists of a sensor with a paddle wheel or turbine that is immersed into the pipe flow. The paddle wheel or turbine spins at a rate proportional to the fluid velocity. This rotation produces an electronic signal that is transmitted to the thermal energy meter or other logging device. These meters can be installed on pipes under pressure through the use of "hot taps," thus not requiring a system shut down. A schematic of a typical insertion meter installed in a pipe is shown in Figure 3.

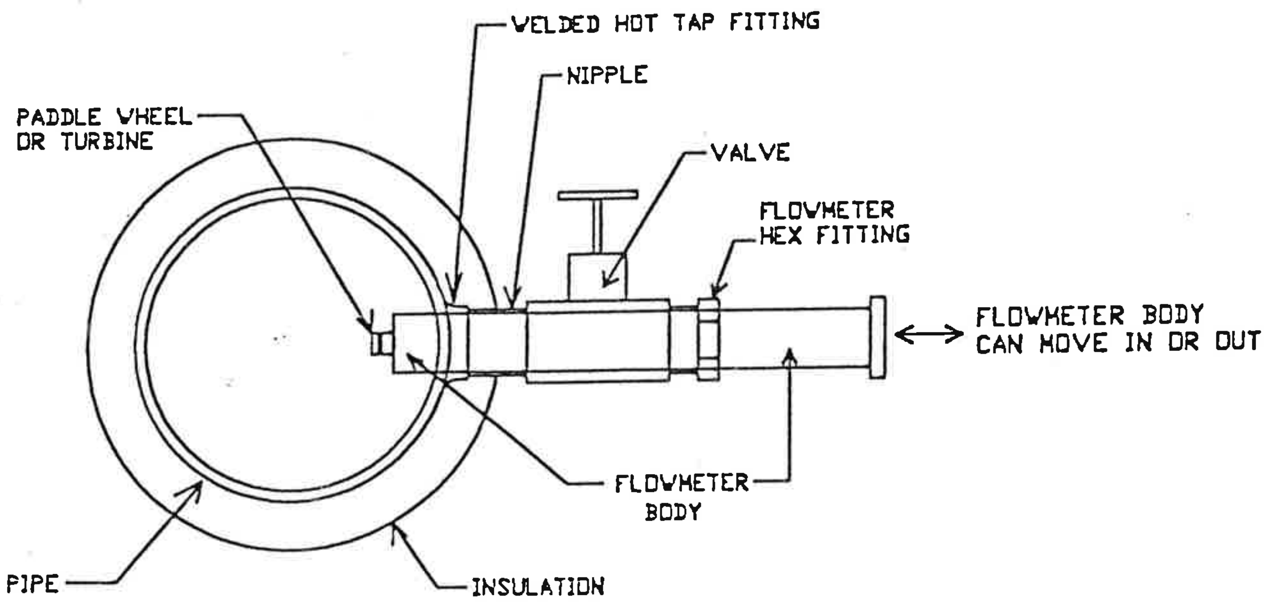

FIGURE 3: *Typical Hot-tap Flow Meter Installation*

There are several advantages to using the insertion flow meter. They are relatively inexpensive and are easily removed for calibration or repair. A special insertion tool is all that is required to install or remove these meters.

The insertion flow meter is the meter of choice for the LoanSTAR project. Three different brands of meters have been installed in the field and tested in the calibration lab facility. Again, they will be referenced as brands A, B, and C.

Brand A contains a stainless steel turbine that is immersed in the fluid flow. This model is capable of withstanding the high temperatures found in hot water distribution systems and boiler feed water and condensate lines. One drawback to this model is its high expense. Another difficulty with this flowmeter is that it requires an oscilloscope to diagnose any problems it may have in the pipe. For instance, if one of the blades has broken, the turbine will continue to rotate and produce a signal. Thus, it would appear that nothing is wrong with the turbine. However, the signal would no longer represent the true flow through the meter.

Brand B is the most inexpensive model used. It consists of a plastic paddle wheel with embedded magnets. When the paddle wheel rotates, a voltage with a frequency proportional to fluid velocity is generated. Testing at our calibration facility has shown this meter to be accurate at flow rates above 3 feet per second. Extra drag due to the magnetic fields may attribute to the loss of accuracy at a low flow rate. These magnets also tend to collect any iron filings that may be circulating through the water system. Removal of several flow meters that had been in use for 6 months showed significant amounts of iron filings attached to the paddle wheel. These filings can eventually prevent the paddle wheel from rotating. Another problem with this brand is that at low flow rates the generated voltage is very low, thus making detection with some equipment difficult.

Brand C is the flow meter most commonly used on the LoanSTAR project. It is similar to brand B, except that there are no magnets on the paddle wheel. A voltage must be supplied to this meter. The sensor converts this voltage to a square wave frequency that is detected at the thermal energy meter or logger. Calibration tests show this meter to be accurate at flow rates as low as 0.5 foot per second. The cost of this meter is only slightly higher than brand B.

A summary of insertion meter features is provided in Table 2.

Features	Brand A	Brand B	Brand C
Cost	$1,600	$300	$500
Sensor	Turbine	Paddle Wheel	Paddle Wheel
Temperature Range	N/A	32 - 220°F	-4 - 220°F
Fluid Velocity Range	N/A	1 to 30 ft/sec	1 to 30 ft/sec
Output	4 - 20 mA	Frequency	Frequency

Table 2. Insertion Flow Meter Feature Comparison.

Non-Intrusive Flow Meters

Another type of flow meter uses ultrasonic waves to measure the fluid velocity in the pipe. A sensor is placed on each side of the pipe as shown in Figure 4 below. A ultrasonic wave is generated at one sensor, and then measured at the other. Any debris or small air bubbles within the fluid will create a Doppler shift in the sound wave that is detected and converted into a flow velocity.

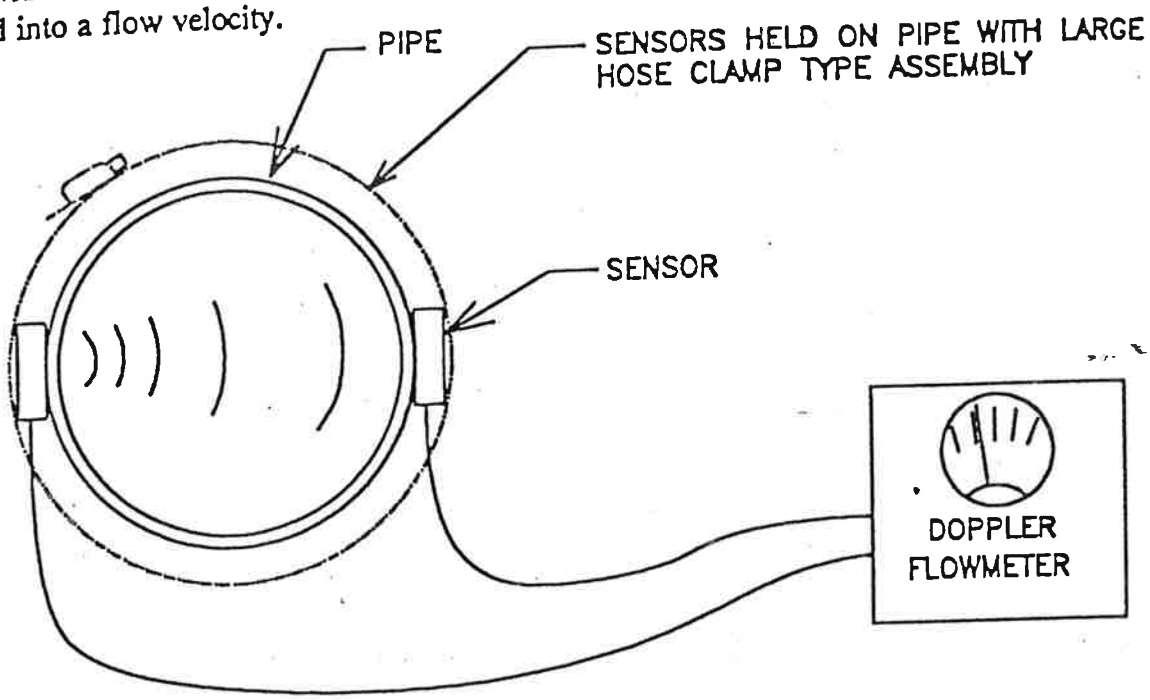

FIGURE 4: *Doppler Flowmeter*

A portable version of this type of meter is frequently used in the LoanSTAR program to check readings provided by other flow meters. The flow sensor must be attached directly to a bare pipe, necessitating the removal of any piping insulation (about a 15 inch section required). This meter is very expensive and is not commonly used. It also has some problems measuring "clean" fluid flows, because no debris is present to deflect the ultrasonic waves.

Deflection Meters

Another type of meter consists of a small stainless steel plate that is immersed into the pipe flow. This plate is attached to a rod that deflects some amount proportional to the fluid velocity. A strain gage is used to measure the amount of deflection. The deflection meter is relatively expensive and is not commonly used. A schematic of a meter that was acquired for evaluation is shown in Figure 5 below.

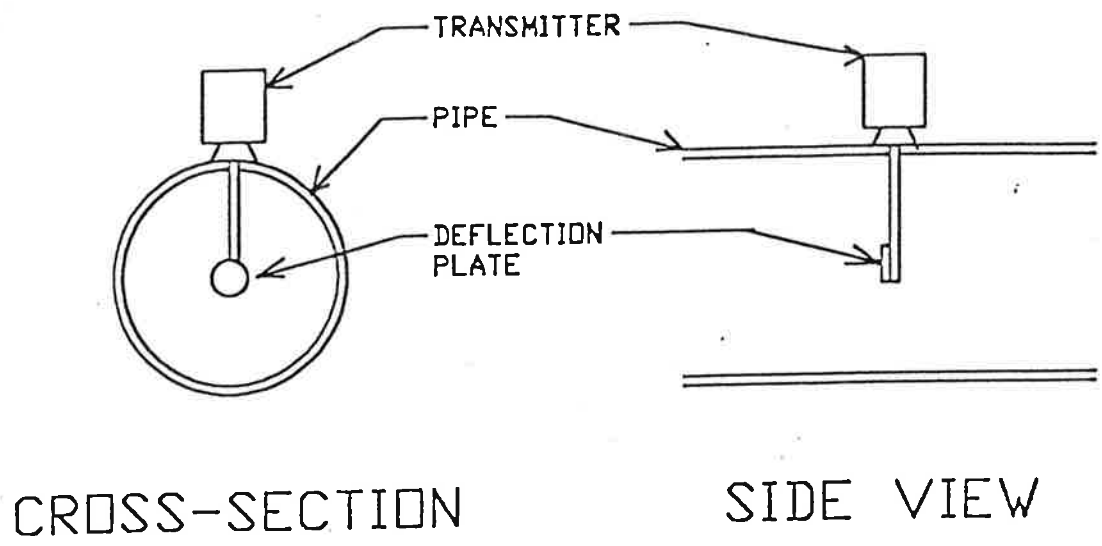

FIGURE 5: *Deflection Meter*

These meters are designed for a given pipe size. They are not interchangeable with other pipe sizes, as are the insertion type flow meters. This type of meter is currently under consideration because of its accuracy and potential reliability (no rotating parts) over turbine or paddle wheel type meters. Once it is evaluated in the LoanSTAR calibration flow loop, it use will be discussed.

SUMMARY

A variety of thermal energy meters and flowmeters are available for use on building energy monitoring projects. This paper has discussed the advantages and disadvantages of equipment that has been used in the LoanSTAR monitoring project. New equipment is continually being evaluated to see if it will provide a significant improvement in cost, operation, or reliability over current equipment.

REFERENCES

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