Lower Operating Costs and Conserve Energy in Hydronic Heating and Cooling Systems
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INTRODUCTION

Awareness of limited energy resources, coupled with the drive to minimize operating costs, has focused attention on energy management in hydronic heating and cooling systems over the last decade. Like any business, commercial and industrial facilities are always looking for ways to conserve energy and save money. Measuring energy in hydronic systems is one way to accomplish these goals. Energy meters provide granular data on energy usage, which can be used to preserve valuable resources and equitably allocate costs to tenants or departments.

Figure 1: Hydronic energy meters enable commercial and industrial facilities to preserve valuable resources.

TODAY’S ENERGY CHALLENGES

Hydronic systems, a heat-transfer medium in heating and cooling systems, are some of the most common building operating systems currently in use. A hydronic system can include both a chilled and a heated water loop to provide heating and air conditioning in large-scale commercial and industrial facilities.

By definition, energy efficiency in a hydronic system is the energy out (heating/cooling) divided by the energy in (fuel). Multiplying the result by 100 provides a percentage. The less energy put in, or the more energy put out, the higher the efficiency – and the lower the fuel cost to get the same amount of heating or cooling.

Balancing supply and demand is a critical challenge for any commercial or industrial site. Planning must consider the effect of energy efficiency programs on demand and on improved services and customer satisfaction. Upgrades of boilers or chillers and their components, and switching to using waste heat, where possible, further improve energy efficiency.
In the U.S., key drivers for improved heating and cooling efficiency include:

- **Climate change**: Sustainability and resilience are connected concepts within the building and facilities industry, and the role that sustainability has in reducing climate change is gaining greater attention.

- **Certifications**: There is a growing requirement to certify facilities based on their sustainability, wellness and resilience. Energy consumption plays a role here.

- **Human factors**: Consumers and investors are getting smarter about their expectations around social responsibility, and building owners and operators can expect more direct and specific questions around this area.

Today, there are increasing demands to address the crucial links between heating/cooling-associated carbon emissions and their implications for the environment. In particular, efforts are underway to develop optimal heating/cooling strategies compatible with the development and expanded use of renewable energy sources.

**NEED FOR ACCURATE MONITORING**

Facility owners and operators need to monitor energy consumption to allow for fair and accurate energy cost allocation. They also seek to raise awareness among occupants to lower their consumption, and by doing so, increase the buildings’ energy efficiency and save on related costs.

Without accurate measurement systems, however, facilities will not be able to allocate costs effectively. The results can include lower returns on investments for suppliers, increased end-user consumption (waste) and unfair bills to end consumers.

The specific requirements for energy monitoring in hydronic systems include:

**System Balancing**

Monitoring energy consumption provides data that can be used to balance the hydronic system, help reduce energy consumption, save money and enhance system performance. Hydronic systems have a continuous life cycle that requires adjustments. They are balanced during initial installation but need ongoing adjustments for performance changes due to system age, building occupancy fluctuations, temperature preferences in specific heating/cooling zones and the addition/removal of machinery. Higher energy bills, occupant complaints and opening windows to remove excess heat are all symptoms of an out-of-balance system.

**Energy and Temperature Optimization**

Energy management helps to monitor and optimize energy requirements and temperatures within a building heating/cooling loop or zone, resulting in increased occupant and environmental satisfaction. For networked systems, continuous energy usage monitoring informs the energy management system when to raise or lower temperatures, thereby eliminating long hours of wasted energy and costly stand-by heat loss. Further, building system automation can adjust temperature set points based on actual occupancy.
For standalone systems, energy monitoring provides the data to effectively balance the system during service calls with reduced callbacks caused by overcompensation in balancing.

Manufacturers also benefit from measuring energy consumption in their industrial processes. With the right solution, they can optimize the efficiency of their heating/cooling systems and other energy-consuming processes. The results include greater energy savings and reduced variability in product quality from maintaining target temperature, and, in some cases, extended equipment life.

**Accurate Cost Sharing**

Monitoring energy usage helps allocate heating and cooling costs fairly to each tenant or department within a building serviced by a central boiler or chiller. Consumers will use energy more wisely when they understand the associated cost. Examples of this situation range from apartment buildings and office complexes to large laboratory facilities.

Portioning out energy costs across departments in an organization leads to a clearer understanding of profit and loss. Data illustrates energy consumption trends and analyzes whether off-peak energy rates can be leveraged for further savings. United States Department of Energy (DOE) research focuses on reducing idle losses in hydronic heating systems to achieve energy savings by regulating boiler temperature with advanced controls. A DOE meeting report states, “lowering idle losses from 2% to 1% increases the overall efficiency by 7.6%, and lowering idle losses to 0.5% increased the overall efficiency by 11.8%.”

An idle condition occurs when generated heat exceeds demand. Outputs from energy meters provide valuable information to the building automation system (BAS), enabling it to adjust parameters based on demand.

**Measurement and Verification**

A Measurement and Verification (M&V) program validates energy saving measures. M&V is the term for the process used to quantify savings from an Energy Conservation Measure (ECM). The program shows the amount of energy saved, rather than the total cost saved, since total cost fluctuates based on energy prices and other factors.

The proliferation of advanced technologies for generating and analyzing large amounts of energy consumption data is one of the most visible trends affecting M&V. Widespread implementation of advanced metering infrastructure, together with other devices and various energy management systems, is particularly significant.

Energy meters are the best method to determine energy savings, since each facility’s hydronic system is unique. Alternative statistics-based approaches are either too general to provide accurate results or are very complicated to use if they are more accurate. However, an energy meter is simple to install, provides an accurate measurement of building energy use and is easy to read, either on a local display or via a network connection.

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Energy Program Incentives

Monitoring energy usage provides legitimate data to qualify for energy program tax deductions and other incentives. In recent years, federal and state agencies have developed programs to encourage investment in energy-saving technology upgrades.

For instance, the Better Buildings Initiative launched by the U.S. DOE drives leadership in energy innovation. The initiative aims to make homes, commercial buildings and industrial plants more energy efficient by accelerating investment and sharing of successful best practices. The initiative enlists public and private sector organizations to work together to replicate positive gains in energy efficiency. Through the related “Better Plants” program, for instance, industrial organizations voluntarily set a specific goal, typically to reduce energy intensity by 25% over a 10-year period across all their U.S. operations.

Other incentive examples include the Housing and Urban Development (HUD) program, which focuses on energy conservation investment in public housing (24 CFR 990.185), and the Go Solar California program, which encourages adoption of solar water heaters. Some utilities offer incentive programs for investing in solar water heaters while others, like Con Edison, provide rebates for installing high-efficiency boilers and other improvements.

In addition to federal and state energy-saving programs, Leadership in Energy and Environmental Design (LEED) standards have fueled research and development efforts by placing greater emphasis on reducing energy consumption and carbon footprints. The resulting product solutions, such as solar water heating and geothermal heating/cooling loops, not only suit LEED facilities, but also benefit a wider range of new and existing facilities. For example, a New York City co-operative housing complex opted for hydronic heating because it allowed the architect to isolate the air exchange in each apartment, improving overall air quality for each tenant.

Contract Validation

Energy usage data helps to validate supplier service contracts that guarantee specific energy savings in conjunction with system investment. Typical energy bills from the utility company are facility-wide and energy improvements may target specific areas or departments. Because energy usage fluctuates with demand (for example, downtime for holidays or cutting back by a shift on the manufacturing floor due to decreased demand), strategically located energy meters provide readings specific to the focus of the supplier service contract. Dedicated energy meters make it easy to isolate improvement projects in the event of overlapping time periods in contracts, since the user may want to initiate additional energy savings contracts in other areas of the facility. Without this solution, contractor A may get credit for contractor B’s improvements.

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2Information on Go Solar California’s program: http://gosolarcalifornia.org/
4ConEdison’s program for HVAC efficiency: http://www.conedci.com/HVAC.aspx
5Case Study: LEED-Platinum Co-op Hits All the Right Notes, Goodman, Jennifer. www.ecohomemagazine.com September 6, 2011.
HYDRONIC METERS: AN AFFORDABLE SOLUTION

In an ideal scenario, every organization would be able to upgrade to a newer, more energy-efficient hydronic system. However, this approach may not be realistic as budgets are often stretched in the current economic environment, resulting in the need to maintain and improve existing hydronic systems.

Hydronic energy meters are an affordable solution that can be easily installed during scheduled maintenance on any hydronic system. The meters’ flexibility enables both standalone and networked configurations, which make it easy to incrementally add system smarts to a standalone hydronic system that can be later connected to a full-service BAS. Energy meters provide an excellent means to monitor energy consumption in multiple facilities supplied by a central boiler or chiller. Not only do they enable immediate benefits from energy measurement, but the user also starts collecting baseline data for measuring the effectiveness of future upgrades. Oftentimes, such data justifies new upgrades.

The use of Industrial Internet of Things (IIoT)-based monitoring, remote communications and predictive data/analytics are among the recent trends in hydronic system design. These technology advancements enable facilities to use smart and cloud-connected devices that are capable of integrating with a larger ecosystem of IIoT-enabled solutions. Moreover, sophisticated analytical tools provide greater sensitivities due to higher prediction accuracies, leading to significant energy savings and highly efficient building system operations.

HOW THE TECHNOLOGY WORKS

A hydronic energy meter, also referred to as a British Thermal Unit (Btu) meter or heat meter, measures heat energy generated by a source or transferred to a load depending on heating or cooling demands. Energy transfers in a hydronic system via a liquid that circulates through a hydronic loop. The liquid is heated or cooled, and then supplied to the load. Heat energy is measured at:

- **Sources:** boilers, chillers, solar water heaters and geothermal ground loops
- **Loads:** building zones, radiators, air handlers for space heating/cooling, radiant floors, heat exchangers for domestic hot water, heating coils for snow melting on parking lots and driveways and cooling coils for ice rinks
A hydronic system with energy meters comprises:

- One flow sensor to measure the flow of the liquid
- One temperature sensor to measure liquid in the inlet pipe
- One temperature sensor to measure liquid in the outlet pipe
- One processing module to integrate the sensor data to compute energy rate and total
- Optionally, a display or a transmitter to send the data to a BAS

The hydronic energy meter calculates the total energy produced or consumed from measurements of liquid flow and differential temperature, combined with the specific gravity and the heat transfer characteristic for the liquid used in the system. One Btu is the energy required to raise or lower one pound of water 1° Fahrenheit (F). To calculate Btu:

1. First convert the flow rate from gallons per minute (GPM) to lb./hr.:

   \[ \text{Flow Rate (GPM)} \times 60 \text{ min./hr.} \times 8.3 \text{ lb./gal.} \times \text{Specific Gravity} = \text{Mass Flow Rate (lb./hr.)} \]

   \textbf{Note:} Flow is usually measured as a volumetric measurement (GPM or LPM) so density is required to convert volumetric flow to mass flow. Specific gravity of the fluid accounts for the density of the liquid. Specific gravity is the ratio of the fluid density to water and is computed based on the temperature of the medium at sensing element. This is especially true when large temperature variations (e.g., \( \Delta t \)) are expected, as can occur with chill water-based refrigeration.

2. Second, apply the change in temperature (\( \Delta t \)) to the flow rate:

   \[ \text{Mass Flow Rate (lb./hr.)} \times (\text{Final Temp – Initial Temp}) \times \text{Specific Heat} = \text{Heat Flow/hr. (Btu/hr.)} \]

   \textbf{Note:} Specific heat is a temperature-dependent variable that defines the amount of heat energy a specific mass measure of liquid can hold or transport. Since the change in specific heat of water is small, it is often considered a constant. However, the specific heat variable can be quite large and should not be ignored when using common additives like acrylic acid as a corrosion inhibitor, and either ethylene glycol or propylene glycol for coolant properties.
3. An absolute Heat Flow measurement in Btu is then determined by applying a period of time to the Heat Flow/hr. (Btu/hr.) rate.

\[
\text{Heat Flow/Hour (Btu/hr.)} \times (\text{Time Period}) = \text{Heat (Btu)}
\]

**Energy Units in Addition to Btu**

Btu meters can measure energy output in units other than Btu. In addition to Btu, MBtu and kBtu, other available units for energy output include kWh, MWh, kJ, and MJ. Regardless of the units, the energy calculation still adheres to the structure of \( Q = c \cdot F \cdot \Delta t \), where \( Q \) is energy, \( c \) is specific heat, \( F \) is mass flow rate and \( \Delta t \) is the temperature difference.

**WHERE TO INSTALL A BTU METER**

**To Determine the Efficiency of a Boiler or Chiller:** Monitor the flow coming out of the boiler/chiller (e.g., supply) and measure the temperature at both the supply and return.

**To Allocate Costs to Tenants or Apartments:** Monitor the flow going into the tenant/department (e.g., supply) and measure the temperature at both the supply and return. Monitor each tenant/department separately to apportion costs.
CHOOSING THE RIGHT APPROACH

Consider both the installation environment and system requirements to select the appropriate technology for hydronic energy management:

- **Pipe**: Proper flow sensor installation fit depends on pipe size, material, layout and available straight pipe runs.

- **Flow rate**: Size the flow sensors to accommodate any balancing configuration or valve position, since flow rates can vary greatly as system demands change.

- **System temperature**: Use flow and temperature sensors designed specifically for chilled or hot water systems. For example, thermistors work for chilled water, but resistance temperature detectors (RTDs) are a better choice for hot water systems.

- **Accuracy**: Accuracy and repeatability help determine measurement precision. Some applications leverage tighter accuracy and repeatability tolerances to maintain tighter controls on hydronic system performance.

- **Service considerations**: For new installations, insert sensors directly into the pipe. When retrofitting a system where pipes cannot be drained and must be hot-tapped, use clamp-on meters that are non-invasive and do not affect system operation.

- **Optional display**: Local displays of flow, temperature, energy rate and/or energy totals may be required depending on application requirements.

- **Optional connectivity**: Outputs provided by the flow metering technology must be compatible with the system’s connectivity options. Analyze data logging, supervisory control and data acquisition (SCADA) and the BAS for optional connectivity.

![TFX-5000 transit time ultrasonic flow clamp-on meter](image)
CONCLUSION

It is never too late to take incremental steps toward measuring energy in hydronic systems. Facility owners and operators have many good reasons—including social, financial and regulatory demands—for investing in new metering technology.

Hydronic energy meters provide valuable data leading to energy-saving improvements and reductions in operating costs. Achieving a balanced system through metering provides optimal energy usage and temperatures, accurate cost allocations, verification of energy savings and contract promises and money saving through energy program incentives. Energy meters are an affordable technology for any existing hydronic system.

Partnering with the right instrumentation supplier can have a major impact on operational and business performance. For this reason, facility owners anticipating a hydronic energy meter purchase should consult with a knowledgeable supplier in the early stages of a project. The effort spent learning about basic energy monitoring techniques, and available meter options, will ensure a successful application.

ABOUT BADGER METER

Badger Meter is a leading innovator, manufacturer and marketer of flow measurement and control products, serving water and gas utilities, municipalities and industrial customers worldwide. Measuring a variety of liquids—from water to oil and lubricants in commercial processes—products from Badger Meter are known for accuracy, durability and the ability to provide valuable and timely measurement information. For more information, visit www.badgermeter.com.