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Fundamentals of Heat Metering in Hydronic Systems

CALEFFI

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from
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Dear Plumbing and Hydronic Professional,

Although relatively new to North America, heat metering has many practical applications. One is verifying if a heating (or cooling) source is producing its expected thermal output. One example is a solar thermal heating system. The heat output of the solar collector array, as well as the balance of system can be accurately measured over any period of time. In some cases, financial incentive from government agencies for solar thermal or other types of renewable thermal energy systems are based upon verified performance, which can only be measured using heat meters.

Another application is apportioning energy costs to multiple customers served by a central heating or cooling system based on their consumption. A typical example would be the owner of an apartment building invoicing tenants based on measured thermal energy use rather than a fixed monthly charge or other means of assessing thermal energy costs that don't encourage energy conservation. In Europe, the high cost of energy, and requisite need for energy conservation, has lead to extensive use of heat metering for this purpose.

With the recently enacted ASTM E3137/E3137M-17 standard for Heat Metering (which you will read about in this issue), the stage has been set for heat metering to become increasingly used for these and other purposes in North America.

This issue of idronics elaborates on the benefits of heat metering in hydronic systems. It also explains the technical concepts used and illustrates how heat meters can be integrated into several different applications.

We hope you enjoy this issue of idronics and encourage you to send us any feedback by e-mailing us at idronics@caleffi.com.

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Mark Olson

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Fundamentals of Heat Metering in Hydronic Systems

1. INTRODUCTION

Many buildings are divided into individual spaces that are occupied by multiple families or different businesses. Apartments and condominiums are examples of the former. Leased office spaces or "strip malls" are examples of the latter.

In some cases, the energy required to heat or cool each of these adjoining building spaces is supplied by the building owner at a fixed monthly cost, irrespective of usage. In other cases, each building space is equipped with its own heating and cooling system, along with the associated meters for electrical and natural gas usage. In the latter case, the cost of heating and cooling each space is typically paid directly to a utility based on metered usage of electricity or natural gas. Occupants that use energy conservatively enjoy lower monthly utility bills, and vice versa.

When the cost of a beneficial service is not borne by those receiving that service, the perceived value of the service is diminished. In these situations, most people are inclined to use that service liberally, with less thought or concern about conservation or potential "waste" of that service.

History has shown this is especially true for the energy needed to heat and cool buildings. If the cost of that energy is perceived as low, or even "free," there is very little incentive to conserve it through thermostat setbacks, improved insulation and air sealing of the building envelope, or even keeping windows closed while the heating or cooling system is operating.

The common "solution" to this example of human nature is to install a separate heating and cooling system in each building space, and thus, have the occupants or tenants using that space pay for the heating or cooling energy they require.

While this approach is somewhat intuitive from the standpoint of paying for the energy used, it is not necessarily the best technical or economic option.

For example, consider a commercial building divided into eight leased spaces, each with their own natural gas furnace for heating, and their own split direct expansion (DX) system for cooling. The building owner leases each space based on having each tenant pay an individual utility bill for the electrical energy and natural gas. The rental agreement stipulates that any maintenance cost associated with the installed heating and cooling systems will be covered by the building owner. Each space is equipped with its own electric meter and natural gas meter. The meters are grouped together at one end of the building, as shown in figure 1-1.

Figure 1-1

Although this approach of individual mechanical systems in each space, each with their own heat source and cooling source, is common in North America, it has several undesirable traits. They include:

1. If the design heating load is low, perhaps 25,000 Btu/hr or less, there are very few choices for natural gas or propane-fired boilers or furnaces with comparable outputs.

Gas-fired furnaces with rated heating outputs of less than 30,000 Btu/hr are uncommon.

Most current-day modulating/condensing boilers are not offered with rated heat outputs of less than 50,000 Btu/hr. A small boiler with a typical 5:1 turndown ratio has a minimum sustained heat output of 10,000 Btu/hr. When the heating demand of the small space is lower than this, the boiler must cycle on and off frequently to prevent overheating. Frequent boiler cycling reduces seasonal efficiency, increases emissions and ultimately shortens the boiler's service life.

Some installers have evaded this issue by using gas-fired water heaters, instead of boilers, for heat sources in small hydronic systems. In some locations, this is a violation of codes. Even where allowed, it's not considered a good practice by the majority of the hydronics industry. Gas-fired water heaters are *not* designed as hydronic heat sources. When applied as such, they will have significantly lower thermal efficiency relative to modern boilers. Their service life will be shortened by operating conditions significantly different from those the product was designed for.

Electric resistance boilers are available with low rated heat output in the range of 5 KW. Some of these are well-matched from a capacity standpoint to the small heating loads of individual spaces. However, the cost of electric resistance heating, on a $/MMBtu basis, is relatively expensive in comparison to natural gas in many areas of North America. The high cost of electricity discourages the use of electric resistance boilers.

There are also electrically powered heat pumps with variable-capacity compressors that could be used for heating and cooling small spaces. The matching of the heating load of these spaces and the heat pump's heating or cooling capacity is relatively good. However, most of the currently available variable-speed heat pumps are designed for forced-air delivery of heating and cooling. As such, they cannot be interfaced with hydronic distribution systems. The owners or occupants cannot enjoy the unsurpassed comfort, virtually silent operation and high distribution efficiency that only hydronic heating and cooling can provide.

2. Each space with its own combustion-type heat source requires a fuel supply and venting system.

This requires natural gas or propane distribution piping to be installed throughout the building, which adds cost. It also presents more potential for danger in the case of fires, lightning strikes, earthquakes or careless use of cutting or drilling tools during remodeling.

Each combustion heat source would require venting for exhaust gases. In some cases, this can be done with side wall venting. In other cases, it will require a separate chimney and roof penetration for each heat source, as seen in figure 1-2.

Separate venting systems can add thousands of dollars to total installed cost relative to a centralized boiler system. It also increases maintenance costs to ensure that all roof penetrations remain leak-free over the life of the building.

Figure 1-2

3. Each space requires access for maintenance.

The only way to ensure proper operation of individual heat sources or cooling sources is to allow technicians access to them. That access can be disruptive of normal activities, as well as creating dirt, odors and noise. It's not desirable, but it is necessary.

In some cases, the heating and cooling hardware installed in one space may be very different from that installed in adjoining spaces. It may have to be maintained by different service companies. Although possible, this is not as efficient or cost-effective as having a single company service all heating and cooling hardware in the building.

4. Each space must allocate floor or wall space for the heating and cooling hardware.

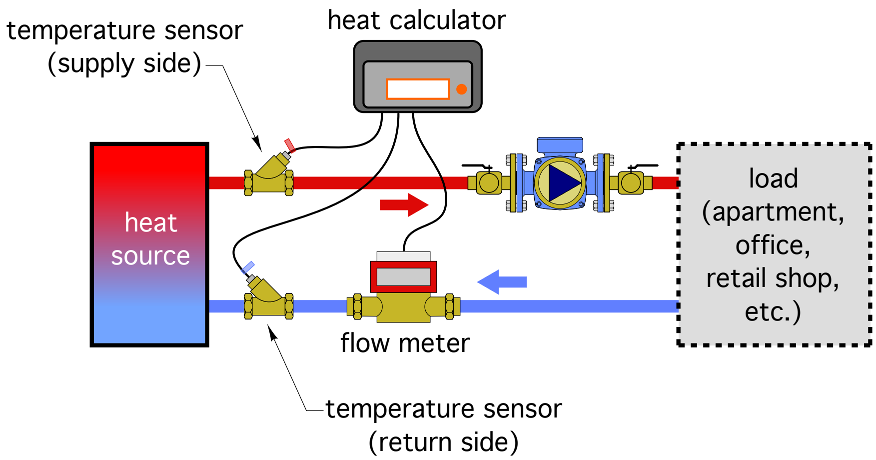
This reduces the floor or wall space available for the prime purpose of the building unit (housing, retail, leased office space, etc.) In prime markets, each square foot of "unavailable" floor space represents a lower selling price or reduced lease/rent potential.

A better approach:

The alternative to having separate heating and cooling sources in each occupied unit of a multi-family or mixed-use office building is to *centralize* heat production as well as cooling capacity. Centralized heating/cooling production is then coupled to a distribution system that carries heated or chilled water to each unit.

This approach has been used in many buildings in North America, but until recently, such systems lacked the benefit of accurately *measuring* the thermal energy usage of each space served by the central system.

Figure 1-3



The ability to accurately measure total heat transfer to each of several spaces provides the technical basis for charging owners or renters for the thermal energy they use.

Without such measurements, it is not possible to charge the occupants of each building space based on their thermal energy usage.

That situation is beginning to change in North America.

Modern methods of accurately measuring the thermal energy transferred from a central heating and cooling plant to each building space are now available. This technology is called “heat metering.” Within North America, it is also referred to as “Btu metering.”

Heat metering requires a continuous and accurate measurement of the flow rate of water, or water/antifreeze solution, passing into and out of each building space. It also requires a continuous and accurate measurement of the temperature change of that fluid, from the location where it enters the space to where it exits. The flow rate and temperature change measurements can then be mathematically combined to determine the instantaneous *rate* of heat transfer to that space. They can also be used to determine total heating and cooling energy use over time.

Figure 1-3 shows the concept of a heat source supplying heat to a load. The latter could be an apartment, condominium, retail shop, leased office space or an entire building.

The two temperature sensors and the flow meter provide information to a heat calculator, which determines the instantaneous rate of heat transfer, and the total amount of heat that has passed from the heat source to the load over time. The technical basis for these calculations is covered in section two.

It’s not new:

The principals involved in heat metering have long been understood. They have also been implemented over several decades using various hardware.

Figure 1-4 shows an early generation heat meter installed in a European hotel.

This is a mechanical (non-electric) heat meter. The upper scale indicates the temperature difference (in °C) between the supply and return piping at one point in the system. This instrument also measures flow rate using a turbine located in the flow stream.

Figure 1-4

The mechanisms within the meter perform "mechanical integration" of flow rate multiplied by temperature differential. The total amount of heat measured by this meter is shown in units of Mega Watt•hours ((MWh) on the odometer-like scale seen in the lower part of the meter. The internal precision mechanisms in this meter are protected under the glass shell.

Modern heat meters use highly accurate RTD or thermistor sensors combined with one of several types of flow meters. The information conveyed from these sensors is processed by a heat calculator using digital electronics.

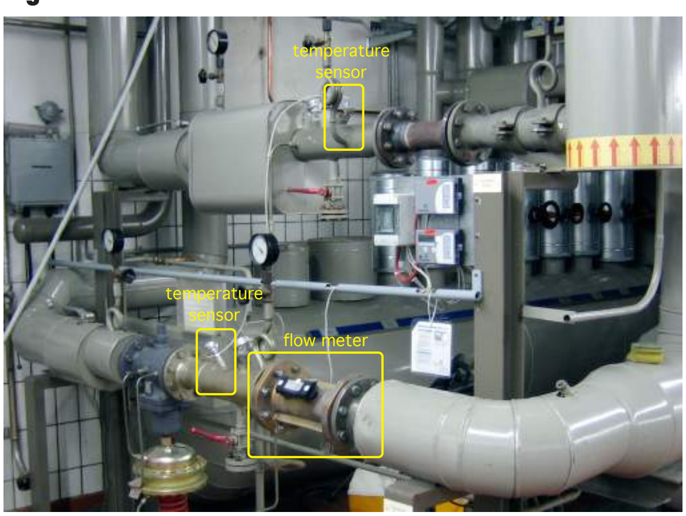
Figure 1-5 shows an example of heat metering being used to record heating energy transfer from a large district heating station to a commercial building.

Heat is supplied to this building through insulated underground piping. A supply and return pipe enters the building from the underground mains. These pipes connect to a large plate and frame heat exchanger that separates the district heating plant and underground piping from the building's hydronic distribution system.

The temperature of the water entering the building is measured by a precision temperature sensor that's directly immersed in the water stream, and fitted with a utility lead seal to prevent tampering. That sensor is visible in the upper portion of figure 1-5.

The temperature of the water leaving the building is measured by a similar sensor seen in the lower portion of figure 1-5. The flow rate of the municipal water stream is measured by an ultrasonic flow meter, also seen in figure 1-5. The two temperature sensors and flow meter connect to an electronic meter that performs all necessary calculations to determine the total heat energy entering the building from the municipal system. The building owner is periodically invoiced for this energy.

Figure 1-5



Heat metering has also been used on a smaller scale to verify the performance of thermally based renewable energy systems. Some pumping stations used for solar thermal systems or geothermal heat pump systems contain hardware that provides heat metering.

This issue of *idronics* explains the technical aspects of heat metering. It will also provide more detailed discussions of the benefits associated with this technology and the modern hardware used to implement it. This information will help prepare HVAC design professionals for what will be an expanding market opportunity in North America.

2. TECHNICAL CONCEPTS USED IN HEAT METERING

This section presents the technical underpinnings of heat metering. It also discusses the importance of high-quality sensors, and the recently enacted ASTM E3137/E3137M-17 standard of accuracy for heat-metering hardware used in the United States.

Instantaneous rate of heat transfer:

The *instantaneous rate* of heat transfer created by a fluid stream can be determined using formula 2-1.

Formula 2-1:

$$q = (8.01Dc)f(\Delta T)$$

Where:

q = rate of heat flow (Btu/hr)
D = density of fluid (lb/ft^3)
c = specific heat of fluid (Btu/lb/ºF)
f = flow rate (gpm)
ΔT = temperature change of fluid (ºF)
8.01 = units conversion factor

This formula is valid for systems using water, as well as other fluids, such as antifreeze solutions. The density and specific heat of these different fluids is accounted for by formula 2-1.

Here's an example: Water at 140.0ºF enters the heating distribution system for an apartment unit at 5.00 gallons per minute (gpm). The water returns from the distribution system at 127.0ºF. The heat meter for the apartment is located on the supply pipe of the distribution system. What is the instantaneous rate of heat release from the water into the apartment under these conditions?

To use formula 2-1, it's necessary to determine the density of the fluid, which in turn depends on the temperature of the fluid. Assuming that the flow meter and one temperature sensor are located on the supply side of the system, the density of water will be calculated at that location, which is currently at 140.0ºF.

The density of water can be accurately calculated using formula 2-2.

Formula 2-2:

$$D = 62.56 + 0.0003413(T) - 0.00006255(T)^2$$

Where:

D = density of water (lb/ft^3)
T = temperature of water (ºF)

At 140.0 ºF, the density of water calculates to:

$$D = 62.56 + 0.0003413(140) - 0.00006255(140)^2 = 61.38\frac{lb}{ft^3}$$

The specific heat of water is often taken as 1.00 Btu/lb/ºF. However, when highly accurate measurements are needed, it's possible account for slight variations in the specific heat of water using formula 2-3:

Formula 2-3:

$$c = 1.012481 - 3.079704\times10^{-4}(T) + 1.752657\times10^{-6}(T)^2 - 2.078224\times10^{-9}(T)^3$$

At 140.0ºF, the specific heat of water calculates to:

$$c = 1.012481 - 3.079704\times10^{-4}(140) + 1.752657\times10^{-6}(140)^2 - 2.078224\times10^{-9}(140)^3 = 0.998\frac{Btu}{lb{\bullet}^\circ F}$$

Keep in mind that formulas 2-2 and 2-3 apply to water only. Antifreeze fluids, such as solutions of propylene or ethylene glycol, will have different densities and specific heats that are also dependent on the specific antifreeze used, its concentration, and the temperature of the antifreeze solution. Manufacturers of antifreeze solutions can provide accurate information for the densities and specific heats of various concentrations of their fluids. Modern heat-metering systems, such as the Caleffi CONTECA Easy, can be configured to account for these different glycol-based antifreeze solutions.

Now that the density and specific heat for the fluid (water) have been accurately determined, formula 2-1 can be used to calculate the *instantaneous rate* of heat transfer.

$$q = (8.01\times61.38\times0.998)\times5.00\times(140.0 - 127.0) = 31{,}894\frac{Btu}{hr}$$

It's important to understand that this number, 31,894 Btu/hr, is an *instantaneous rate*. It is only valid while the temperature difference between the sensors and the flow rate remain exactly the same.

If one assumes that the temperature difference and flow rate held constant for one hour, the total amount of heat transferred during that hour would be:

$$H = \left(31{,}894\frac{Btu}{hr}\right)(1hr) = 31{,}894\,Btu$$

Although it's possible for the temperature difference and flow rate to remain constant for an hour, it is not probable. The operating characteristics of many heating and cooling systems make it much more likely that the temperature difference or flow rate *will* change a *detectable amount* within a minute or two. This must be accounted for when determining the total amount of heat transferred over any significant time.

Quantity of heat transferred:

When a rate of heat transfer is *known to hold constant* over some time increment, the total amount of heat transferred over that time increment can be calculated using formula 2-4:

Formula 2-4:

$$Total = rate \times time$$

$$\text{Total heat transferred} = (\text{heat transfer rate}) \times (\text{time})$$

The common North American units used in formula 2-4 would be as follows.

$$Btu = \left(\frac{Btu}{hr}\right) \times hr$$

Although the mathematics associated with formula 2-4 are very simple, the stipulation of the rate of heat transfer holding constant over any significant time interval (e.g., more than one minute) is highly unlikely in most heating and cooling systems. Those systems seldom operate in "steady state" conditions. Instead, they operate with transient (frequently changing) conditions. This leads to more complexity when determining the total amount of heat transferred over a period of perhaps an hour or more.

In theory, the exact amount of heat passing from a source to a load over any period of time could be calculated using formula 2-5.

Formula 2-5:

$$H = \int_{t=0}^{t} \left[(8.01Dc)f(\Delta T)\right] dt$$

Where:

H = total quantity of heat measured (Btu)

D = density of fluid (lb/ft^3)

c = specific heat of fluid (Btu/lb/ºF)

f = flow rate (gpm)

ΔT = temperature change of fluid (ºF)

8.01 = units conversion factor

t = elapsed time over which heat is being measured (hour)

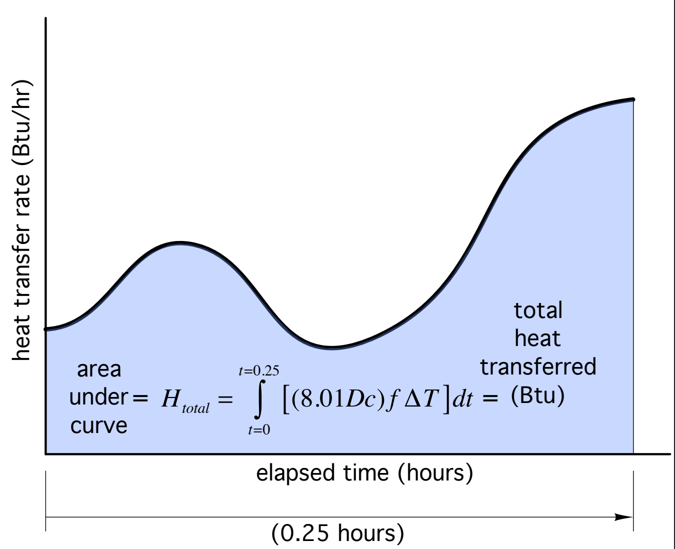
dt = differential time

This formula would be used if the flow rate (f) and temperature difference (ΔT) were both known as continuous mathematical functions of time (t). Although it's possible make up simple examples of such functions for demonstrating the integration described by formula 2-5, these functions seldom exist in real applications.

Formula 2-5 can be interpreted as the summation of an infinite number of infinitesimally small time steps during which the instantaneous rate of heat transfer is calculated and multiplied by that infinitesimally small time step.

Figure 2-1 shows the concept represented by formula 2-4.

Figure 2-1



This graph shows the rate of heat transfer on the vertical axis, and as a continuous function of time, which is represented on the horizontal axis. The value of the shaded blue area under the black curve is determined by evaluating formula 2-5. This area represents the exact amount of heat transferred in this situation over an elapsed time of 0.25 hours.

Since continuous mathematical functions for the differential temperature (ΔT) and flow rate (f) are not likely to exist in real applications, formula 2-5 is seldom used. However, it is possible to make close approximations of the shaded blue area in figure 2-1 by assuming that ΔT and flow rate hold constant over very small (but finite) time steps. Using this approach, formula 2-5 can be replaced by another formula that represents this approximation (formula 2-6).

Formula 2-6:

$$H = \sum_{\Delta t=1}^{\text{elapsed time}} \left[(8.01Dc)f(\Delta T)\right] \times \Delta t$$

Where:

H = approximation of quantity of heat transferred (Btu)

D = density of fluid (lb/ft^3)

c = specific heat of fluid (Btu/lb/ºF)

f = flow rate (gpm)

∆T = temperature change of fluid (ºF)

8.01 = units conversion factor

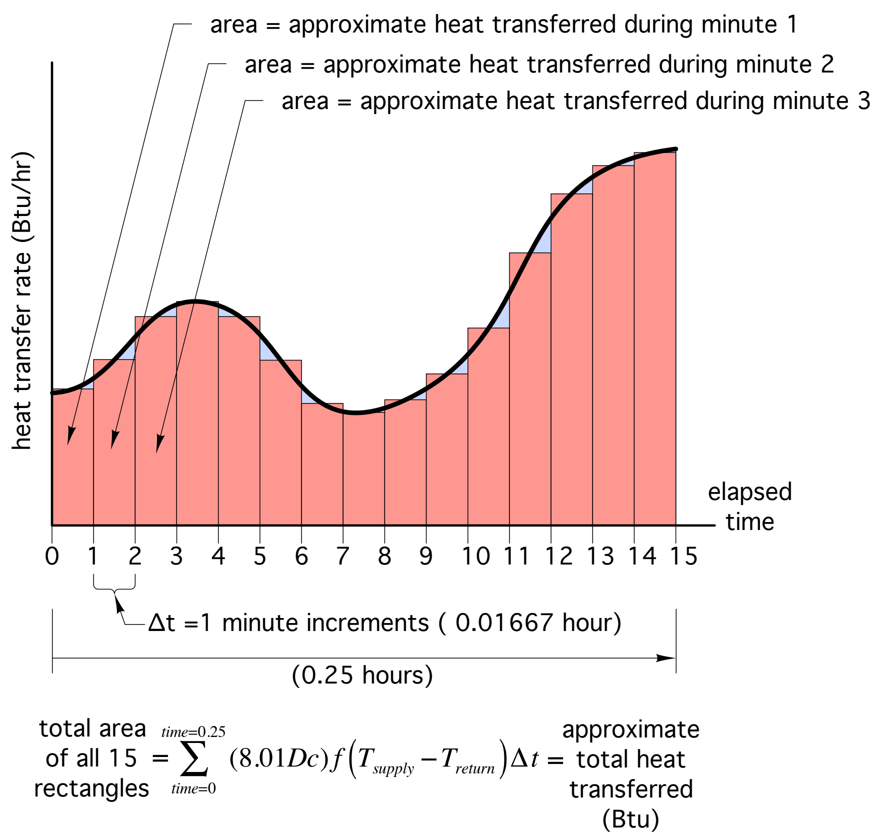
∆t= elapsed time over which heat is being measured (hour)

As an example, assume the short time increment is one minute, which is 0.01667 hour. Figure 2-2 shows a collection of rectangular areas that are all one minute “wide,” and have a height equal to the average heat transfer rate over each one-minute time interval.

In this example, there are 15 rectangular areas that represent the total elapsed time of 15 minutes (0.25 hour). The sum of the areas of all 15 rectangular areas closely approximates the blue shaded area under the curve in figure 2-1, and thus, is a reasonably close approximation of the total heat transferred from source to load over the total time interval of 15 minutes.

Consider how the accuracy of this approximation would change if the time steps were reduced from one minute to 30 seconds. This would create 30 rectangular areas, each half as wide as those in figure 2-2. However, the height of each of these rectangular areas would be a more accurate estimate of the rate of heat transfer averaged over the 30-second time step, rather than the previous one-minute time step. The total area of all 30 rectangles would be a more accurate approximation of the blue shaded area under the curve in figure 2-1.

Figure 2-2



One could extend this logic to shorter and shorter time steps. As the time step is reduced, accuracy improves. Modern heat meters use relatively short time steps of only a few seconds, and thus, create sufficiently accurate approximations of the “exact” amount of heat transferred. That accuracy is quantified by the new ASTM E3137 standard. Caleffi CONTECA Easy meters meet or exceed the accuracy requirements of this standard.

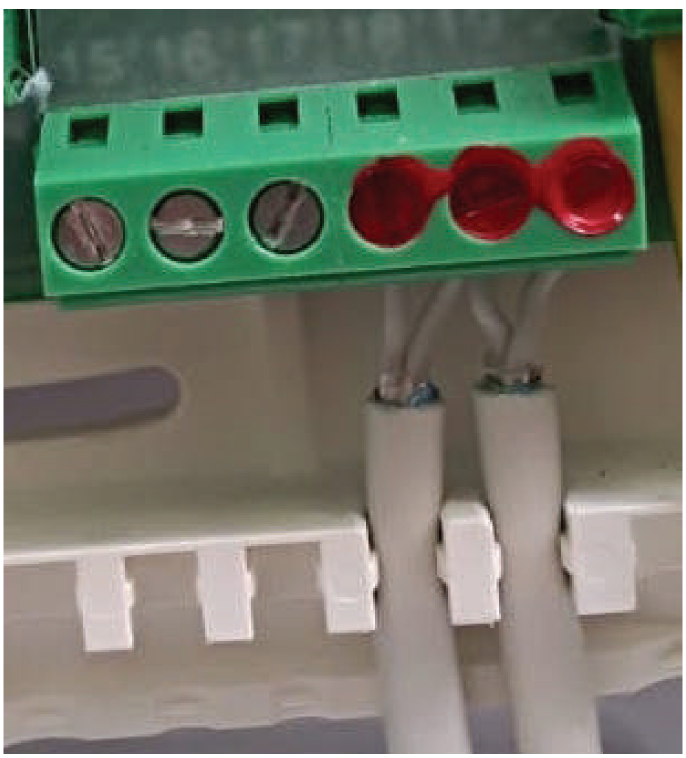
Temperature sensor accuracy:

Other basic concepts related to heat meter accuracy are important to understand. One of the most important is the accuracy of the temperature sensors used in the heat-metering system.

Most modern heat meters use resistance temperature detector (RTD) or thermistor sensors. The electrical resistance of these sensors changes as these sensors change temperature. The relationship between sensor temperature and sensor resistance is very stable. The heat calculator that the sensors connect to “feels” the resistance of the each sensor and its lead wiring (e.g., the wiring between the sensor probe and the heat calculator). The lead wires between the sensor probe and the heat calculator also have electrical resistance. This resistance is relatively small relative to that of the sensor itself, but not insignificant given the accuracy expectations of the heat meter. Modern heat meters account for the resistance of the lead wires. *Accuracy standards, such as ASTM E3137, require each heat-metering system (e.g., temperature sensors, flow meter and heat calculator) to be individually calibrated to the sensors and their attached lead wires.* Because of this individual calibration, ***it is critically important not to modify the sensor wiring.*** Doing so would affect the calibration of the heat meter system and comprise its measuring accuracy.

Some metering systems have sensor leads permanently attached to an internal printed circuit board, or attached to terminals that have been “sealed” to prevent tampering, as shown in figure 2-3.

Figure 2-3



The sealed terminals eliminate the possibility of loose or improperly done field connections that could affect the resistance of the sensor circuits, and thus, compromise the accuracy of the heat meter. It also helps protect the metering system from unauthorized modifications.

ASTM E3137 requires that the two sensors used on heat meters are a matched pair. This implies that the two sensors supplied with the meter must be used as a pair. Care should be taken during handling and installation to ensure that the sensors are not physically damaged. ***If one sensor or its lead wire(s) are damaged, it may be necessary to replace both sensors, as well as the heat calculator to which they would attach.***

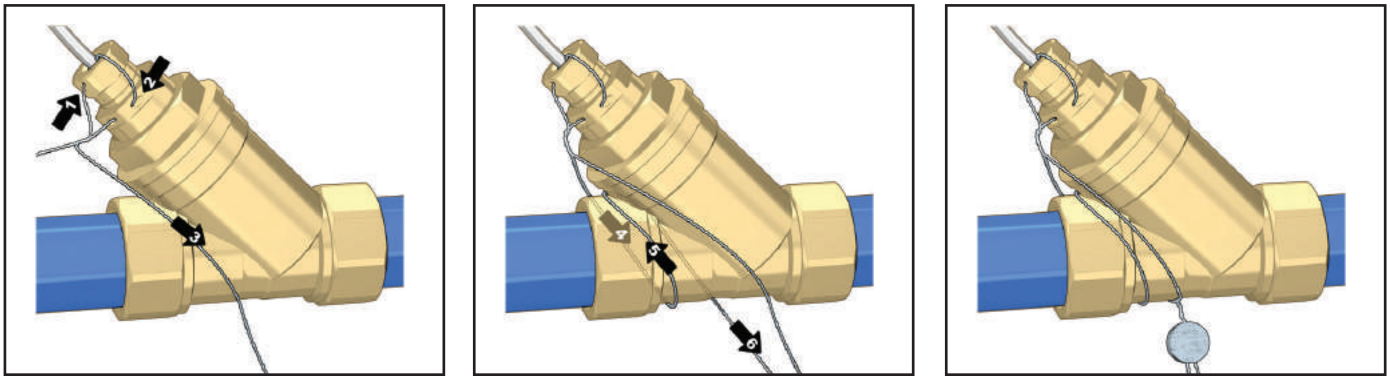
The heat meter system should be ordered with sufficient sensor lead length to enable the sensors to be placed within their respective mounting fittings. Any extra sensor lead cable should be neatly coiled, fixed with zip ties and mounted where it will not be disturbed.

It is also very important that both temperature sensors be properly mounted. The preferred mounting system places the tip of each sensor directly in the fluid stream. This eliminates the thermal resistance created by mounting the sensors in a well, or surface mounting them to piping.

Figure 2-4 shows one of the temperature sensors and its mounting fitting that are supplied with the Caleffi

Figure 2-4

Figure 2-5



CONTECA Easy meter system. The length of the sensor probe places the tip of the sensor directly in the flow stream. The probe seals to the fitting using a small gasket.

It is also important not to route any sensor cable in conduit with, or adjacent to, AC electrical wiring.

Flow metering:

The Caleffi CONTECA Easy heat meter uses a turbine flow meter. This meter is accurately calibrated to generate a specific number of electrical pulses based on the amount of fluid passing through it. The pulse signal allows the length of the lead cable between the flow meter and heat calculator to be extended without affecting the accuracy of the metering system. (See product specifications for the recommended wiring between the flow sensor and heat calculator.)

Whenever possible, mount the flow meter with at least ten pipe diameters of straight pipe upstream of the meter, and at least five pipe diameters of straight pipe downstream of the meter.

The flow meters used with the CONTECA Easy system have an inlet screen. That screen is removable if necessary to remove debris. To maintain the accuracy of flow-rate measurement, it is good practice to install one or more low-velocity zone dirt separators in the system. Dirt separation should occur upstream of the flow meters whenever possible.

Fluid factors:

Most heat meters are configured, by default, to make internal calculations using the assumption that the system fluid is 100% water. The firmware used in the CONTECA Easy heat meter's heat calculator can accurately calculate the density and specific heat of water based on its temperature.

However, heat metering can also be used in systems that operate with various solutions of ethylene glycol or propylene glycol antifreeze. One example would be monitoring the thermal energy supplied by a solar collector array operating with a 40% solution of propylene glycol. The density and specific heat of glycol-based antifreeze solutions also depends on fluid temperature, as well as the glycol concentration. Modern heat-metering systems such as the Caleffi CONTECA Easy can be configured to base their internal calculations on the type and concentration of glycol-based antifreeze being used.

Anti-tampering provisions:

Because heat meters can be used as the basis of billing customers for energy use, they must be protected against tampering. An example of such tampering would be removing a temperature sensor from its mounted position to simulate a lower temperature differential between the sensors. The lower temperature differential would imply a lower rate of heat transfer.

The sensors, sensor mounting fittings and heat calculator supplied with the Caleffi CONTECA Easy meter system are equipped with small holes through which a fine-stranded stainless steel cable can pass. That cable is then wrapped around the fitting holding the temperature sensor, as shown in figure 2-5. The ends of the stranded stainless steel cable are then joined using a lead seal. In some cases, the tool used to crimp the lead seal imprints a specific marking indicating the entity that made the seal.

When properly installed, the anti-tampering cable and lead seal would have to be cut or otherwise damaged in order to change the mounting of either temperature sensor, or open the cover of the heat calculator (which provides access to firmware settings). A broken or damaged cable or lead seal provides physical evidence of tampering.

ASTM E3137/E3137M-17 standard:

The latest version of *Standard Specification for Heat Meter Instrumentation* (ASTM E3137/E3137M-17) was issued in February 2018. It provides a standard covering several categories of heat-metering equipment and the accuracy of that equipment.

This standard was developed over several years by ASTM committee E44.25. It makes reference to several previous heat-metering standards, such as EN1434, which is extensively recognized in Europe, and OIML (*Organisation Internationale De Metrologie Legale*) R75-1 Edition 2002, which is an International Recommendation that establishes the metrological characteristic required of certain measuring instruments, as well as methods for testing their conformity. The ASTM E3137/E3137M-17 standard will likely be referenced by the majority of North American engineering firms that include heat-metering specifications for the systems they design.

ASTM E3137/E3137M-17 establishes maximum permissible measurement variations for the flow sensor, temperature sensor pair and heat calculator. It classifies these elements of a heat-metering system based on their accuracy at maximum and minimum flow rates and temperature differentials.

The details of this standard are beyond the scope of this issue of *idronics*. Interested readers can obtain the standard at: https://www.astm.org/Standards/E3137.htm

3. BENEFITS OF HEAT METERING

There are many compelling reasons to use modern heat-metering technology in a variety of applications. This section discusses the benefits associated with heat metering.

1. Reduce energy waste:

The concept of paying for metered energy is certainly not new. Consumers and commercial properties owners are very familiar with paying for metered electricity and natural gas service. They are also used to paying for fuels such as #2 heating oil or wood pellets based on the measured volume or weight delivered. Those who practice energy conservation pay lower electricity or fuel bills, and vice versa.

It's the same concept with heat metering. Each metered "client" of a central thermal energy delivery system pays for the heating or cooling energy that enters their building unit or the unit they lease/rent.

Heat metering encourages energy conservation relative to situations where a central system supplies heating or cooling to a space at a fixed monthly charge, or where the cost of providing heating or cooling is included with rent or lease payments. The latter situations present no monetary "penalty" for energy waste, and thus, place little value on the energy provided. In such situations, occupants have minimal incentive to conserve energy.

High-rise public housing buildings in major urban areas built during the mid-1900s are common examples of poorly monitored energy use.

Figure 3-1

Source: National Public Radio

Figure 3-2

The original heating systems in many of these buildings are large but rudimentary. They often lack controls that are necessary for properly balancing on a floor-by-floor level, or a room-by-room level. The interior stack effect developed by rising warm air, combined with hot water thermosiphoning and lack of balancing, often delivers more heat than necessary to upper floors. Occupants adapt by opening windows to control interior temperature; hence the origin of the term "double-hung thermostat." In situations where occupants don't pay for the heat they use, or must resort to opening windows to maintain reasonable comfort, energy waste is rampant.

Another situation would be a building space that is either rented or owned by its occupants, and where utilities, including heating or cooling energy, are covered by a flat monthly fee. Again, there is little monetary incentive for the occupant to conserve energy. There is also a possibility that occupants who are away from their unit for an extended period must pay the fixed monthly utility cost, even when very little energy has been used during their absence.

These situations can be made more "equitable" by charging occupants based on the thermal energy they use for space heating, cooling and domestic hot water production. Modern heat metering provides huge opportunities in such situations. This technology is widely used in Europe. Figure 3-2 shows an example of a mechanical system using heat meters to record thermal energy use in each of several apartments.

2. Centralized heat production:

When heat metering is used in multi-unit buildings, all heat sources can be located within one mechanical room. This holds many advantages over the scenario of separate heat sources within each building unit, with their commensurate fuel supplies, venting systems and safety devices.

Figure 3-3

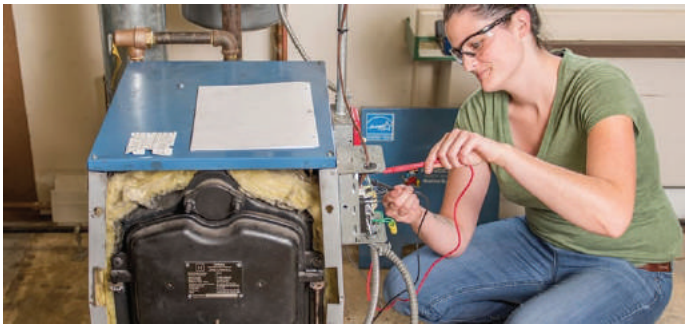
The combined thermal load of all building units provides an ideal application for a modern multi-boiler system, as illustrated in figure 3-3.

Multiple boiler systems allow a wide range of heat output modulation for improved load tracking while retaining high efficiency. They also have the ability to provide partial heat output if one boiler is down for service. Boiler operation can also be coordinated to serve high-priority loads, such as a high morning demand for domestic hot water in an apartment or condominium building.

3. Centralized servicing:

All heating and cooling systems require servicing, especially the heating and cooling source equipment. By keeping the source equipment in a central location, the access requirements, noise, dust, fluid spills and odors associated with service work can be isolated from individual building units. Any need to enter individual living spaces or disrupt business activities for service work is greatly reduced. This adds perceived value to leased commercial or retail space.

Figure 3-4



Northeast Technical Institute, www.ntinow.edu.

4. Single fuel supply and venting location

Keeping all combustion-type heat sources within a single location allows the fuel supply and venting system to be isolated from the individual building units. This frees up valuable floor and wall space within those units. It also reduces the possibility of carbon monoxide or other combustion byproducts from entering individual building units due to backdrafting. This is especially important in tightly-sealed buildings with low air leakage rates and high exhaust air flow due to range hoods or other ventilation systems. Reducing potential exposure to carbon monoxide by eliminating combustion within individual building units may also lower insurance premiums.

Figure 3-5

Courtesy of HomePro Home Inspections LLC

The cost of installing a "centralized" fuel supply and venting system is usually significantly lower than that associated with installing gas supply piping throughout the building and separate venting provisions within each building unit. Centralized venting also improves building aesthetics, reduces potential leaks at roof penetrations and reduces future service requirements.

5. Reduced metering charges

Most utility meters have basic service charges or delivery charges. These costs are associated with each meter (electricity or natural gas) installed in the building.

Figure 3-6

When a separate natural gas service is provided to each unit in a multi-unit building, each meter has an associated monthly basic service charge. If heat for the building was instead supplied by a central system, there would only be one meter and one basic service or delivery charge. That charge can be apportioned to each building unit in combination with thermal energy usage. This results in savings for all units within the building.

Figure 3-7

6. Enabling district energy systems

Previously discussed benefits have been in the context of heat metering in a multi-unit building. This concept can be scaled up to include several buildings within a reasonable distance of each other. A central plant provides heating and/or cooling to all buildings within its "district."

Large-scale district energy systems have been used for decades. Common applications include college campuses, military bases and multiple buildings in urban areas.

Figure 3-8

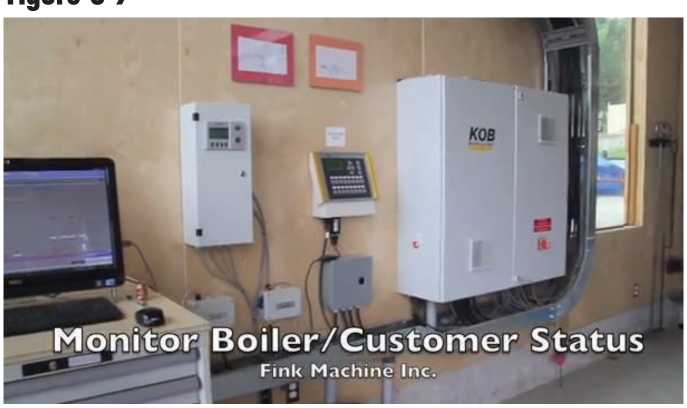
Courtesy of Fink Machine, Inc.

Large-scale district heating systems in North America have traditionally used steam as the heat transport media. Large-scale district cooling has been supplied by multiple large-scale chillers, and by water drawn from deep lakes.

One example of a modest but appropriate district heating system is the Fink Enderby District Energy System in Enderby, BC Canada. Constructed in 2011, this heating system's primary heat source is a 1.8 MMBtu/hr (540 KW) wood chip boiler. A 1 MMBtu/hr (300 KW) propane-fired boiler provides backup if necessary. Both boilers are housed in the same building.

The hot water produced by the boiler(s) is distributed through 4,600 feet (1.4 KM) of insulated underground pipe, and currently provides heat for 12 loads, including several local businesses, a hotel and a municipal swimming pool. Heat metering is used to apportion cost to each load. All metering is managed by the central control system seen in figure 3-9. More information is available at **https://www.youtube.com/watch?v=HE0ezWs1kIE**

Figure 3-9



Courtesy of Fink Machine, Inc.

District energy systems can also be configured for cooling. Thirty large buildings in downtown Toronto, Ontario, Canada are cooled by a system that dissipates heat into Lake Ontario. Even during the hottest weather, the water drawn from 270 feet below the lake's surface and approximately 3 miles offshore remains at approximately 39.2ºF (4ºC). That water passes through the primary side of 36 large plate and frame heat exchangers, as seen in figure 3-10.

Figure 3-10

Source: Enwave

The secondary sides of these heat exchangers connect to an insulated underground piping network that distributes cool water to each building served by the system. Each building is connected to the district system using large plate and frame heat exchangers. This allows each building's distribution system to be a closed system that's isolated from the underground piping. This system delivers approximately 75,000 tons of cooling capacity. Heat meters are used to assess the cooling effect used by each of the buildings.

Heat metering is an essential part of district energy systems. It allows the system operator to apportion each "client" based on the thermal energy used at their facility, as well as a portion of the energy loss from underground piping between the energy plant and the buildings being served.

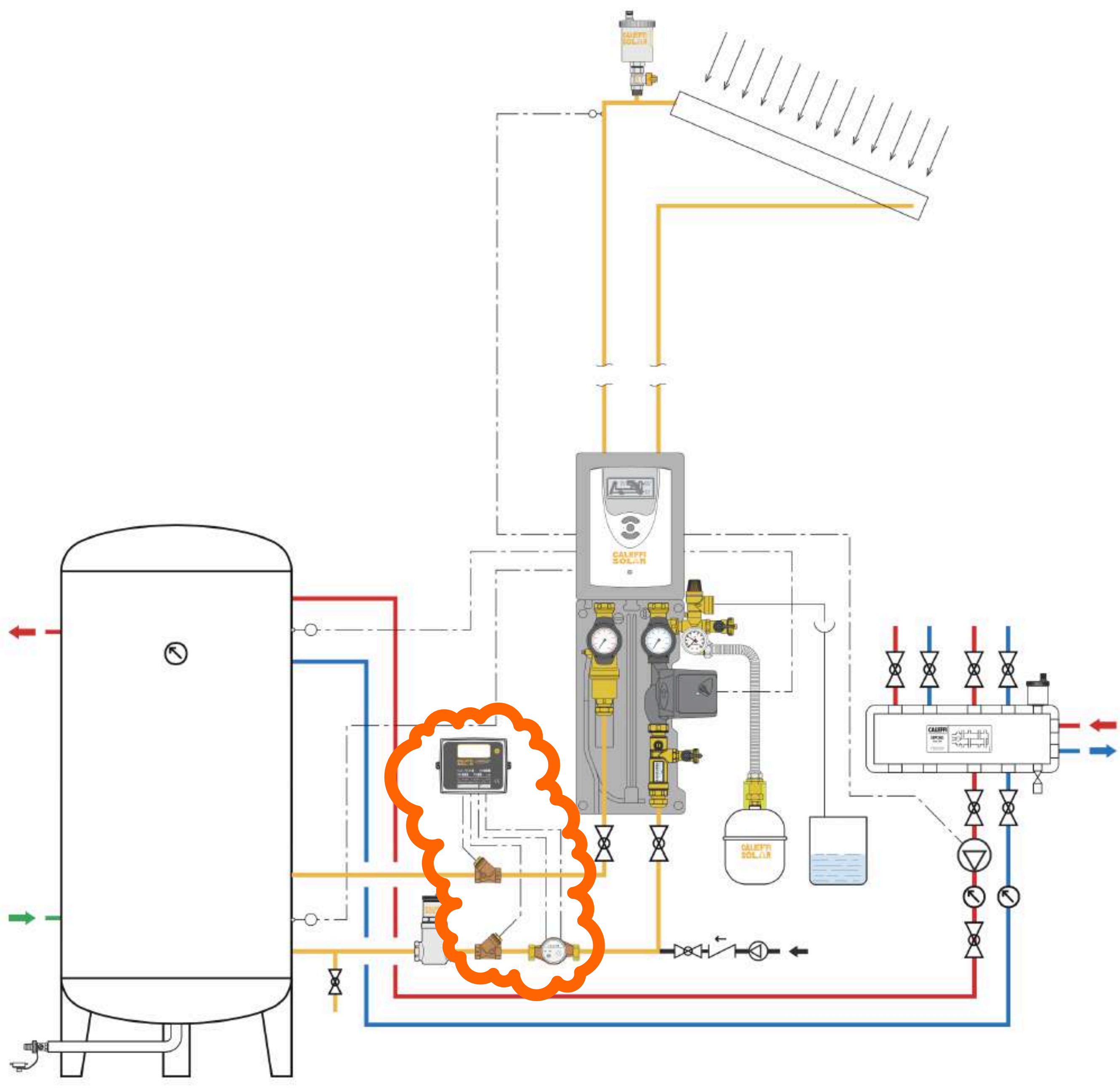
7. Performance verification:

Heat metering also provides a way of monitoring the performance of heating and cooling systems. This is especially important in systems using renewable energy heat sources, such as solar thermal collectors, geothermal heat pumps or biomass boilers. Several state-sponsored programs developed to incentivize these renewable heat sources require installation of heat-metering subsystems to verify energy yield. In some cases, financial incentives are based on verified thermal energy yield from the renewable energy heat sources. Figure 3-11 shows a heat-metering subsystem installed within a solar thermal system.

8. Compact modules provide heating and domestic hot water:

Another application for heat metering is within heating "substations" or "Heating Interface Units" (HIUs) for apartments, condominiums or leased office spaces. An HIU is a preassembled group of components that can be configured to provide space heating and domestic

Figure 3-11



hot water. The HIU contains all the necessary hardware for independent space heating and domestic hot water for each building unit, and is often small enough to fit into a wall cavity within a closet. HIUs are commonly used in Europe, and can be purchased in common application configurations. They are not widely available as a pre-assembled product in North America at this time. However, they can be custom-built to the specific needs of a project.

Figure 3-12 shows one concept for an HIU that supplies space heating and domestic hot water. The latter is provided using a stainless steel brazed plate heat exchanger that receives heat from non-potable water that's also used for space heating.

The HIU is connected to a set of "riser" pipes that provide supply and return for non-potable heated water from the system's heating plant (e.g., mechanical room or a large

Figure 3-12

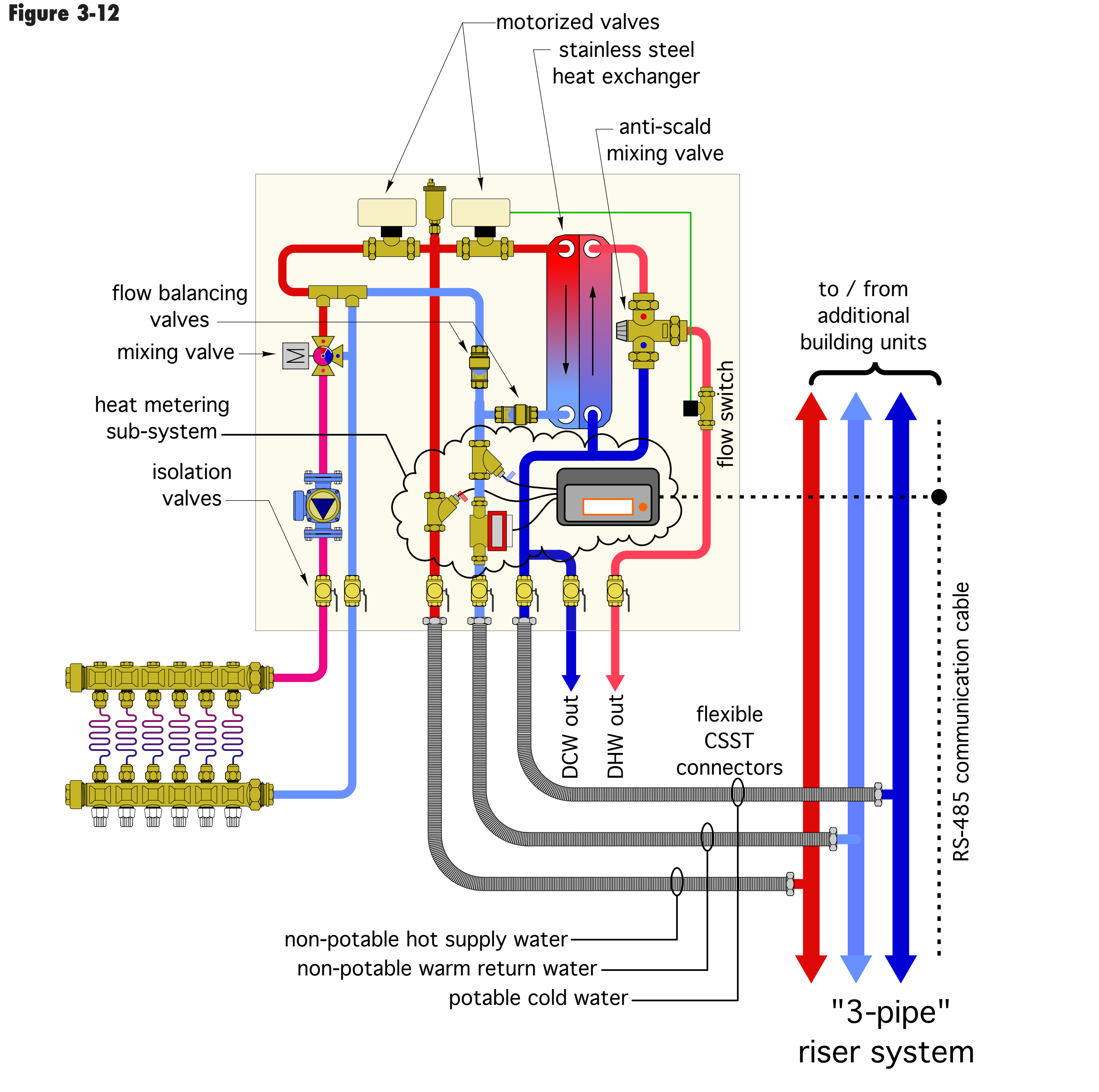


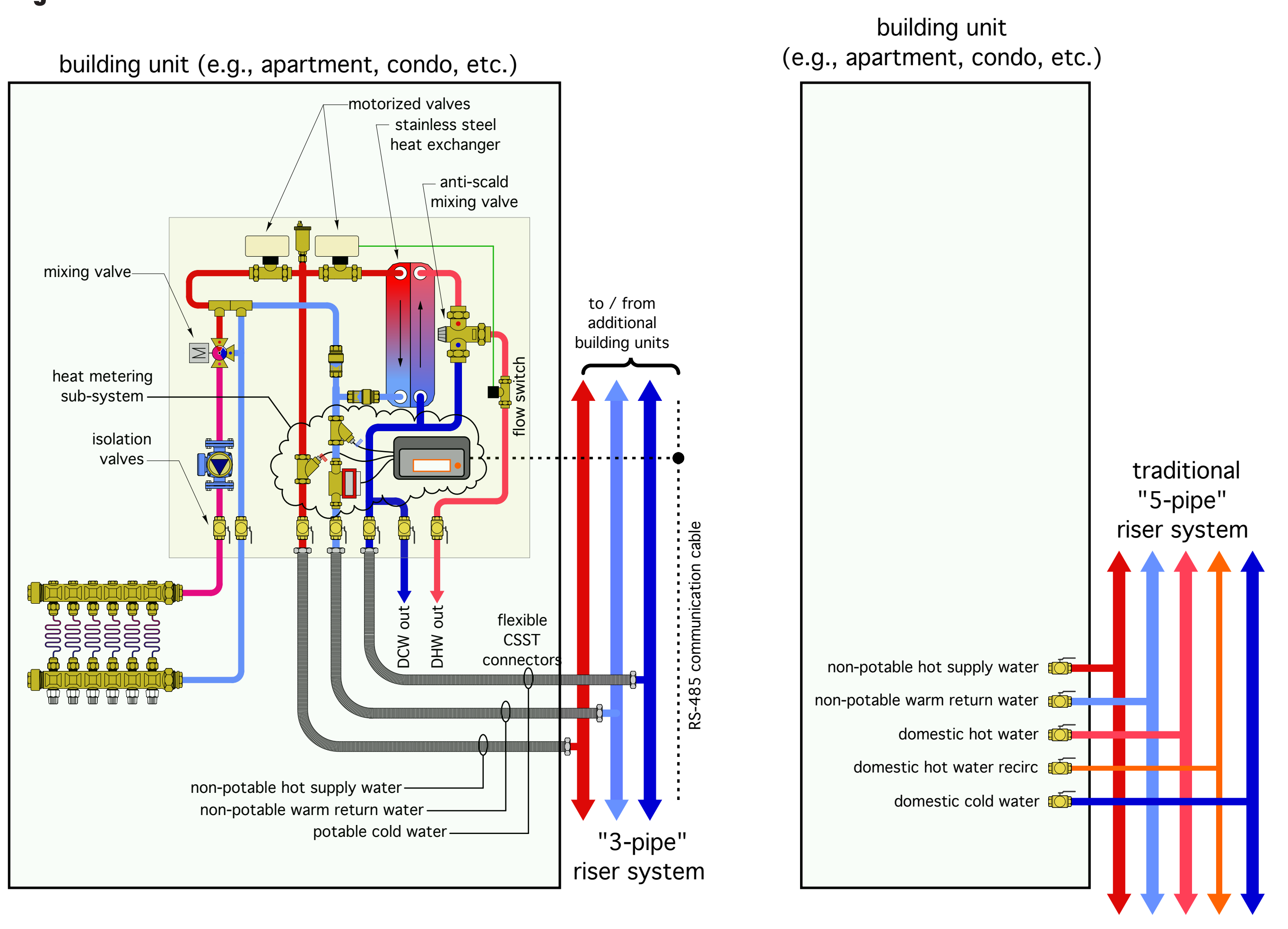
plate heat exchanger served by a district heating system). The hot non-potable water is used for space heating when needed. The flow rate of the non-potable heated water passing through the HIU is monitored by a flow meter. The temperature drop of this water stream is measured by a set of matched precision temperature sensors. The flow meter and temperature sensors connect to a heat calculator within the HIU that tallies the amount of heat transferred. In modern applications, the heat calculator in each HIU is connected by a 2-wire communication cable to either a data logger or a building automation system (BAS). The total thermal energy used at each HIU can be recorded without having to physically be at the HIU.

The HIU shown in figure 3-12 creates domestic hot water "on demand." When a hot water faucet is opened, and the domestic hot water stream reaches some minimum flow rate, a flow switch activates a motorized valve that allows hot non-potable water to pass through the primary side of a stainless steel brazed plate heat exchanger. Heat is immediately transferred to the cold domestic water passing through the secondary side of the heat exchanger. The domestic water is fully heated on a single pass through this heat exchanger. A thermostatic mixing valve provides anti-scald protection. The heated domestic water flows to the open fixture(s). When the domestic water flow rate drops below a minimum set value, the flow switch turns off the motorized valve to stop domestic water heating.

This approach greatly reduces the volume of domestic water that remains at an elevated temperature, thus *decreasing the potential for Legionella growth*. It also reduces standby heat loss in comparison to tank-type water heaters.

Because domestic hot water is created "as needed" within each building unit, *there is no need of a domestic hot water recirculation system in the building.*

Figure 3-13



All the energy used for domestic water heating comes from the non-potable heated water flowing through the HIU, and is recorded by the heat meter subsystem. Some HIUs can "tag" the energy passing through the heat meter as being used for space heating or domestic water heating, when these loads are mutually exclusive. Some also have a separate flow meter to total the amount of domestic water used within the building unit.

9. Fewer riser pipes in building:

Another significant benefit of using HIUs for space heating and domestic water heating is that it allows for a "3-pipe" riser system instead of a "5-pipe" riser system in multi-unit buildings. Risers are the pipes that provide space heating and domestic hot water to each unit in the building. A common "5-pipe" riser system would have the following pipes:

1. Space-heating hot water pipe
2. Space-heating return water pipe
3. Domestic hot water supply pipe
4. Domestic hot water recirculation return pipe
5. Cold domestic water pipe

When a heat-metered HIU is used in each unit, the riser piping is reduced to the following:

1. Non-potable hot water supply pipe
2. Non-potable hot water return pipe
3. Cold domestic water pipe

Figure 3-13 shows both riser piping configurations.

4. INTEGRATING HEAT METERING

Adding heat metering to a heating or cooling system is relatively simple. This section presents the components of a typical thermal energy metering system, with some specific information on the Caleffi CONTECA Easy system.

Basic components:

Heat-metering systems that are intended to accurately measure the amount of heating or cooling energy passing from the source side of a system to the client side require hardware to measure flow rate and temperature difference.

The temperature difference is measured by a *matched pair* of temperature sensors. The Caleffi CONTECA Easy system uses 100,000 ohm negative temperature coefficient (NTC) thermistor sensors. These sensors vary their electrical resistance as their temperature changes. The relationship between electrical resistance and temperature is accurately calibrated and highly repeatable. The electrical resistance of the lead wires between the sensors and the heat calculator unit is also accounted for. *This is why the lead wires supplied with a heat meter should never be cut or otherwise modified.*

Figure 4-1

The "brain" of a heat-metering system is the heat calculator. It receives signals from both temperature sensors and the flow meter. It uses the measured flow rate and temperature difference to calculate the rate of heat transfer, as well as the total amount of heat that has passed through the metering system over time. The heat calculators used in modern metering systems can display operating conditions such as flow rate and temperatures. They can also display the current rate of heat transfer and the total amount of heat that has passed through the metering system over time. Modern heat calculators can also communicate with data acquisition systems or building automation systems using protocols such as Modbus or BACnet.

Figure 4-1 shows the heat calculator, flow meter, temperature sensors and sensor-mounting fittings supplied with the Caleffi CONTECA Easy heat-metering system.

Flow meter types:

Several types of flow meters are currently used for heat-metering systems. They include:

- Turbine
- Ultrasonic
- Doppler
- Vortex
- Electromagnetic

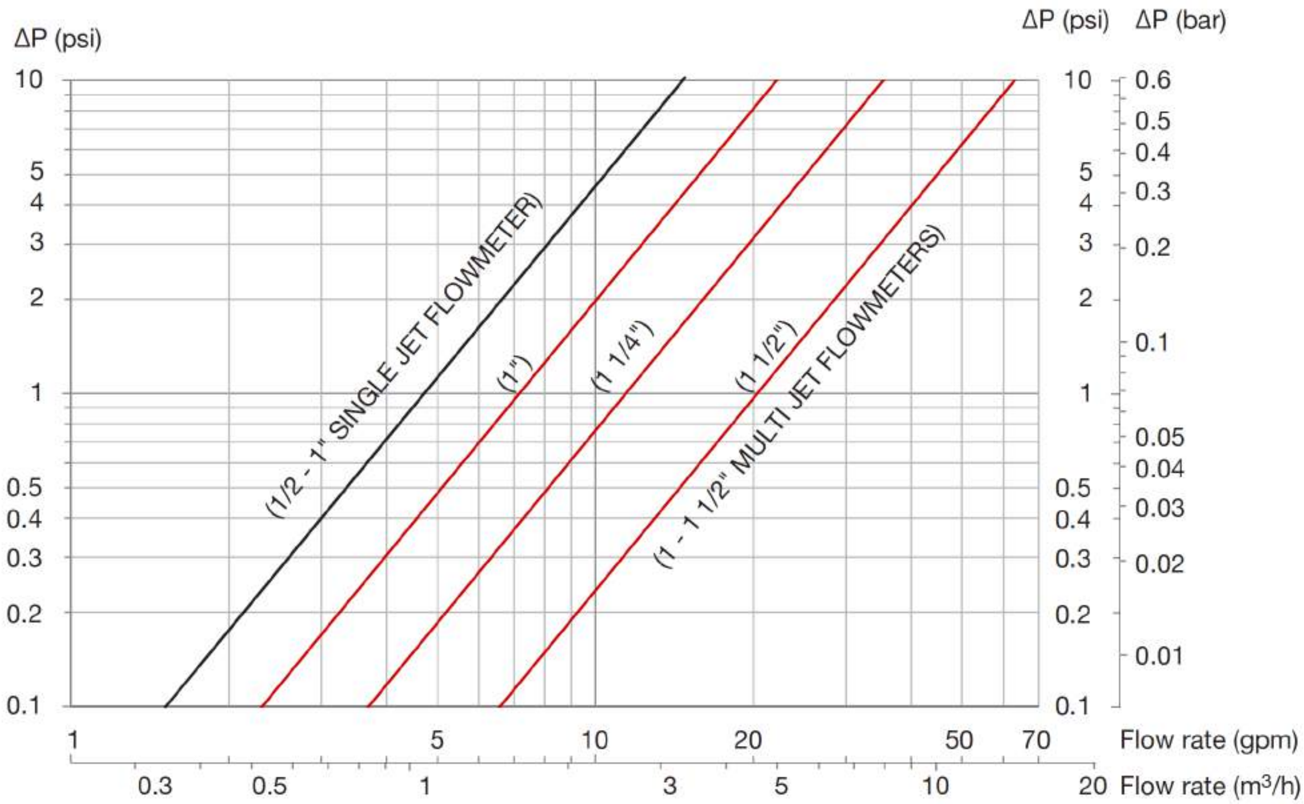
All of these meters have strengths and limitations.

Turbine flow meters:

Turbine flow meters have an impeller that spins at very stable and repeatable rates based on the flow passing through them. Each rotation of the turbine creates a low-voltage electrical pulse signal. These pulses pass through a cable that connects to the heat calculator.

Different sizes and types of turbine flow meters are each calibrated for a specific relationship between pulse counts and the volume of fluid that has passed through the meter. For example, a small turbine meter might generate an output of one pulse per liter of fluid passing through it, whereas a larger turbine meter might generate an output of one pulse per 10 liters of fluid passing through. The heat calculator unit can be configured to be compatible with the pulse output calibration of different sizes and types of turbine flow meters.

Figure 4-2



Turbine-type flow meters have an established history of accurate performance and reliability. Turbine flow meters are simple and low cost relative to other flow-measuring technology. They are relatively immune to bubbles or particles passing through with the fluid stream.

Still, systems that use turbine-type flow meters should include a microbubble air separator to minimize any potential for bubbles in the flow stream. Particulates in the system should also be minimized through the use of dirt separators. Keeping the fluid stream passing through the turbine meter as clean and bubble-free as possible extends the life of the meter and maintains its accuracy.

As is true with any component having flow passing through it, turbine flow meters create some flow resistance, which results in head loss. Figure 4-2 shows the head loss and pressure drop of the turbine flow meters used in the Caleffi CONTECA Easy meter system.

Two variations of turbine flow meters are supplied with the Caleffi CONTECA Easy system. A single jet meter is used for pipe sizes ranging from 1/2" to 1". A multi-jet meter is supplied in pipe sizes of 1.25" and larger. Multi-jet meters have multiple fluid channels that route incoming flow to the meter's impeller. This improves the accuracy of flow-rate measurement in larger pipe sizes.

Turbine flow meters must be mounted in a horizontal pipe with the axis of the turbine vertical, and the fluid-filled portion of the meter at the bottom, as shown in figure 4-3. Be sure the meter is installed so that flow passes through it in the correct direction, as indicated by an arrow on the base of the meter.

Figure 4-3

It is also a best practice to install any flow-metering device with at least 10 diameters of straight pipe upstream of the meter, and at least 5 pipe diameters of straight pipe downstream of the meter.

Time transit ultrasonic flow meters:

Time transit ultrasonic flow meters can determine the average flow velocity of a fluid moving through a closed cavity by measuring the difference in travel time of ultrasonic sound pulses that are alternately directed in the direction of the fluid stream and opposite the fluid stream.

Because they do not have internal moving parts, time transit ultrasonic flow meters typically have a lower pressure drop characteristic than turbine flow meters. However, accurate flow measurements require relatively clean and bubble-free fluids.

Figure 4-4 shows an example of a time transit ultrasonic flow meter installed as part of a heat-metering system for a large commercial building.

Figure 4-4

Time transit ultrasonic flow meters are also available as "strap-on" devices, an example of which is shown in figure 4-5.

Figure 4-5

Courtesy of Khaled Yousef

Strap-on ultrasonic meters are used in situations where it is not possible (or practical) to penetrate or cut an existing pipe that's in service. They are often installed on a temporary basis as instrumentation for building energy audits. Strap-on ultrasonic meters have the advantage of not creating any obstruction or pressure drop in the fluid path. However, the accuracy of strap meters is highly dependent on their mounting, including proper application of an acoustic coupling compound between the meter body and the outer surface of the pipe. Errors in installation can significantly reduce the accuracy of these meters.

Doppler shift flow meters:

Doppler shift flow meters also calculate average flow velocity based on the time difference between ultrasonic pulses directed with and against the flow stream. However, doppler shift flow meters measure the reflection of sound pulses from particles or bubbles entrained in the fluid stream. This type of meter requires a specific minimum density of particles or air bubbles within the fluid. It is not suitable for use with clean fluids, and as such has more limited applications. It is commonly used to measure the flow rates of slurries.

Vortex flow meters:

It is also possible to measure flow rates using a meter with a cylindrical flow chamber that contains a flat-surfaced peg. This peg only covers a portion of the flow area. Its flat surface faces the oncoming flow. As flow passes over the peg, vortices are created. Each vortex sheds away from the peg in the opposite direction of the previous vortex. Each vortex creates a slight pressure pulse that is detected by a piezoelectric sensor mounted downstream of the peg. The frequency of the shed vortices is directly proportional to the flow rate through the flow chamber. The piezoelectric sensor counts the pulses, and solid state electronics within the flow sensor calculate the flow rate based on the frequency of the pulses. The internal electronics of the flow sensor create a linear voltage output signal that's proportional to flow rate over a specific range of flow rates. Current generation vortex flow sensors are small and relatively inexpensive. They are commonly used for approximate flow-rate measurements in devices such as pumping stations for solar thermal systems or geothermal heat pumps. They are not used in heat-metering systems meeting the EN1434 or ASTM E3137 standards.

Electromagnetic flow meters:

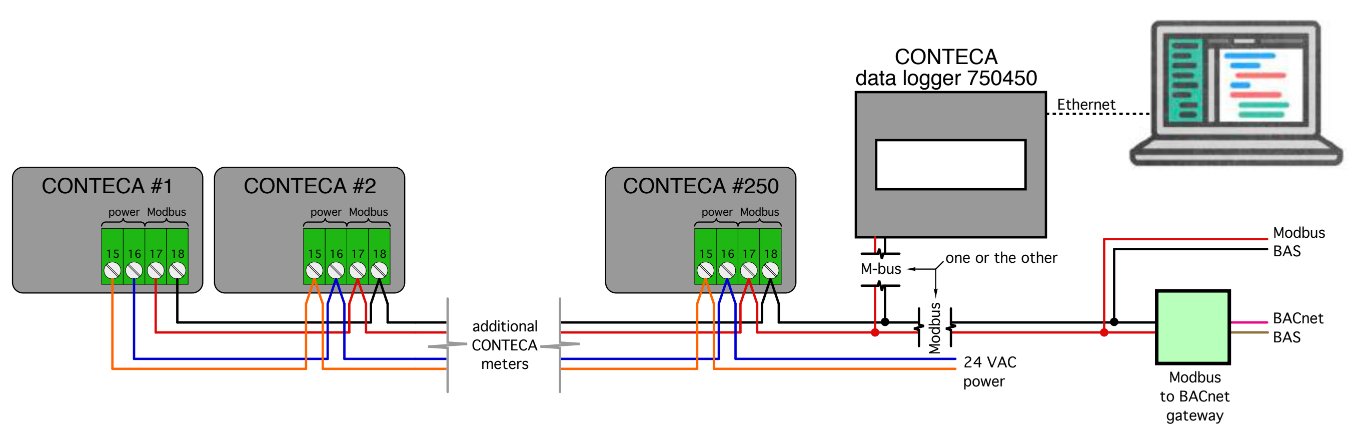
Electromagnetic flow sensors work on the principal that an oscillating magnetic field that's perpendicular to a fluid stream creates a small voltage that's proportional to the flow rate of that fluid stream. The voltage is detected by electrodes mounted perpendicular to the flow direction. Electromagnetic flow meters require the fluid being measured to have a specific minimal electrical conductivity. Highly demineralized water would not be compatible with such meters.

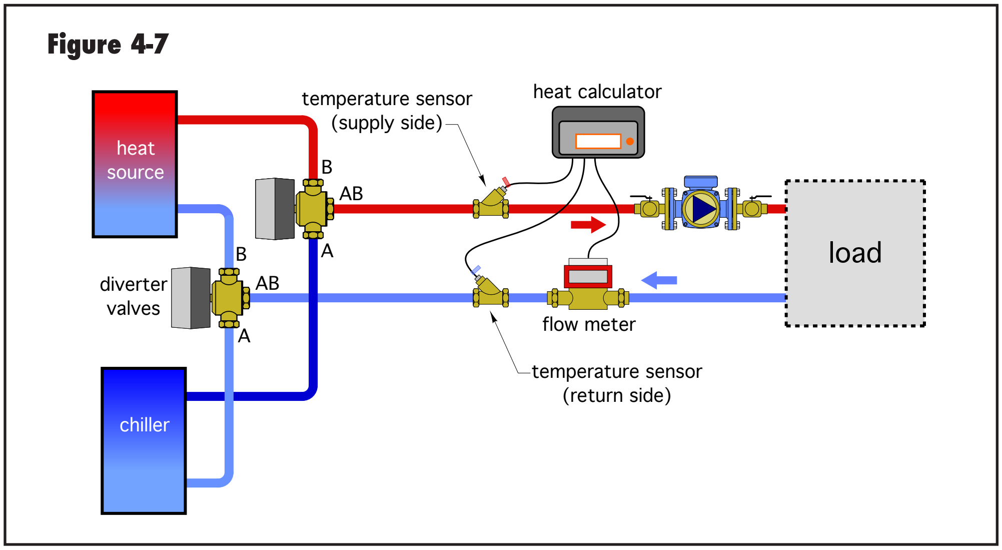
Connecting multiple CONTECA Easy heat meters:

One common use of heat meters is recording the thermal energy use in each of several building units (apartments, condominiums, leased office spaces, etc.) in multi-unit buildings.

While it's possible to periodically go to the location of each meter within the building and read the heat calculator unit,

Figure 4-6





The CONTECA Easy meter system can automatically switch between recording the thermal energy used for heating and that used for cooling. The changeover logic is integrated in the overall operating algorithm for the meter, as shown in figure 4-8.

this requires significant time. Any requirement to enter individual building units to read the meter also imposes undesirable privacy and security issues for the occupants.

Modern heat-metering systems such as Caleffi's CONTECA Easy provide the ability for each heat calculator unit to be connected to a 2-wire communication network. Up to 250 CONTECA Easy heat calculator units can be connected to such a network, as represented in figure 4-6.

Terminals 17 and 18 in the CONTECA Easy heat calculator constitute an RS-485 communication port that can be configured for either a Modbus output or an M-bus output, *but not both at the same time*.

The Modbus output would be used to interface with a Modbus-based building automation system (BAS), or when the heat calculator needs to communicate with other building automation system protocols such as BACnet. In these latter cases, it is necessary to include a gateway device to convert the Modbus output to these other communication protocols.

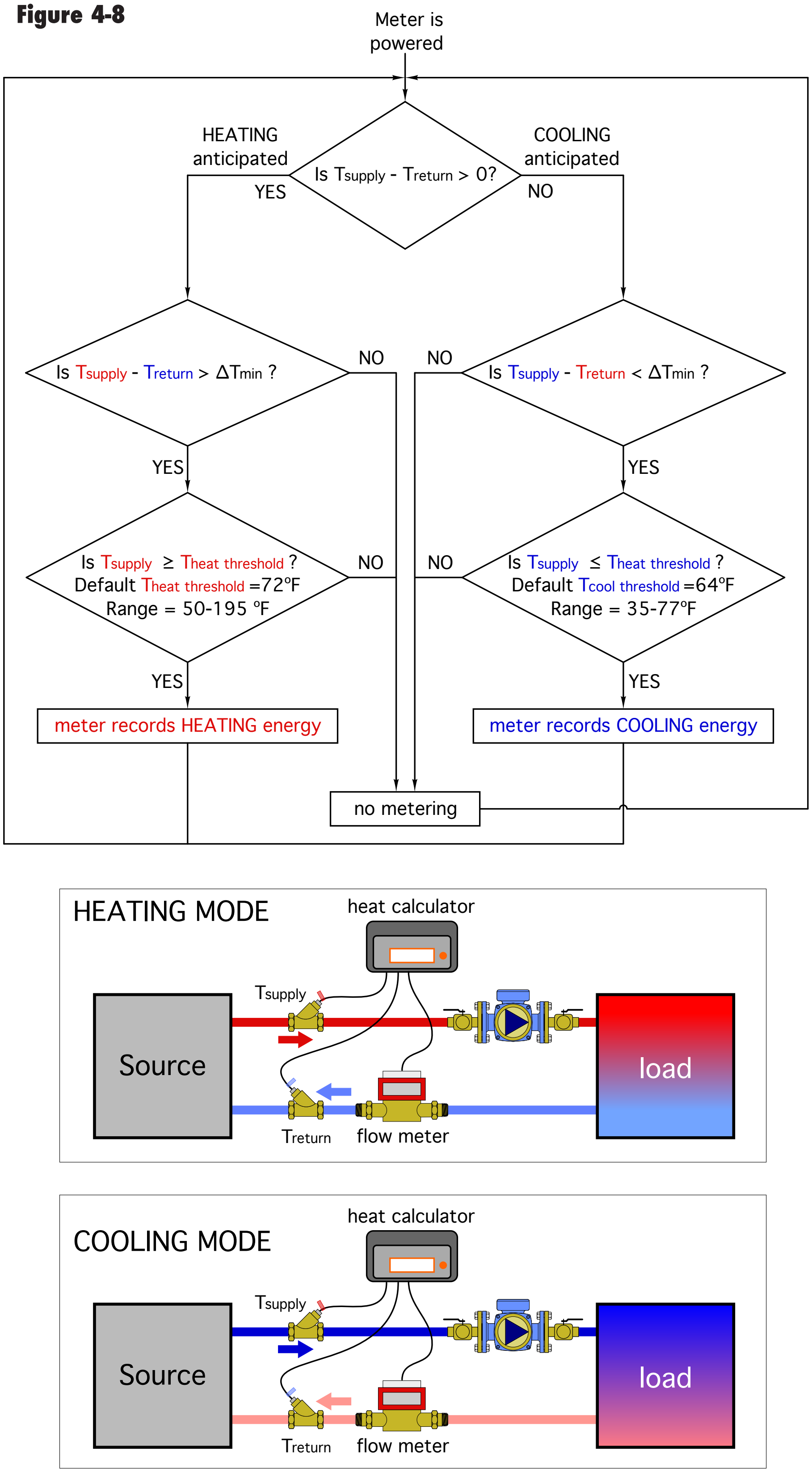
The M-bus configuration for the RS-485 output would be selected if one or more CONTECA Easy heat calculators will be connected to the CONTECA data logger.

Measuring heating and cooling energy:
The Caleffi CONTECA Easy metering system is capable of measuring the thermal energy used in space heating as well as cooling systems. One way to configure the piping for systems that provide both heating and cooling is shown in figure 4-7.

Heating mode metering:
When the meter is powered on, it boots its internal firmware and checks to see if the temperature of the sensor on the supply side of the system (T_{supply}) is greater than the temperature on the return side of the system (T_{return}). If it is, the meter *anticipates* that the system is in heating mode. It then tests to see if the temperature of the supply sensor (T_{supply}) is at least some minimum amount (ΔT_{min}) *higher* than the temperature of the return sensor (T_{return}). If this is *not* true, the meter will *not* record any heating energy use. If it is true, the meter then tests to see if the temperature of the supply sensor (T_{supply}) is at or above the ($T_{heat\ threshold}$) value. This parameter is the lowest supply temperature at which the meter will begin recording heating energy. Its default value is 72ºF, but this value can be changed to any temperature between 50ºF and 195ºF (10 to 90ºC). If the temperature of the supply sensor is at or above the ($T_{heat\ threshold}$), the meter begins recording heating energy use.

A similar set of logic conditions is used to determine if the meter should record cooling energy use. When the meter is powered on, it checks to see if the temperature of the supply side sensor (T_{supply}) is greater than the temperature of the return side sensor (T_{return}). If the supply side is cooler than the return side, the meter *anticipates* that the system is in cooling mode. It then tests to see if the temperature of the supply sensor is at least some minimum amount (ΔT_{min}) *lower* than the temperature of the return sensor. If this is *not* true, the meter will *not* record any cooling energy use. If it is true, the meter tests to see if the temperature of the supply sensor (T_{supply}) is at or below the $T_{cool\ threshold}$ value. This parameter is the highest supply temperature at which the meter will record cooling energy use. Its default value is 64ºF, but this value can be changed by the user to any temperature between 35ºF and 77ºF (2 to 25ºC). If the temperature of the supply sensor (T_{supply}) is at or below the ($T_{cool\ threshold}$), the meter begins recording cooling energy use.

Figure 4-8



Invoicing for thermal energy:

Because heat metering is relatively new in North America, there are no widely accepted standards or legal requirements for how thermal energy can be invoiced to clients of heat-metered systems. This situation could change at state or municipal government levels as heat metering becomes more widely accepted and implemented.

In the absence of any specific legal requirements governing billing for thermal energy, the owners of buildings in which heat metering is used can establish their own agreements for how occupants will pay for the thermal energy they use, as well as cost associated with maintaining the system.

The potential occupants of each building unit using heat metering would then decide if the owner's agreement for thermal energy invoicing is acceptable as part of the overall decision to purchase or rent the building space.

Any agreement covering invoicing for thermal energy should address the following:

- The current cost of fuel to the central plant that supplies hot water for heating and/or chilled water for cooling. This should include all fixed and variable fees, surcharges, tariffs, etc., associated with the fuel used by the system.

- How the cost of fuel and any associated fees may increase or decrease over time.

- Heat loss (or heat gain in cooling mode) from components on the building owner's side of the heat meters. This would include heat loss (or gain) from the central plant equipment, as well as heat loss from distribution piping up to the points where heat passes through individual heat meters. The overall energy input to the system will always be more than the sum total of all heat meter readings due to equipment inefficiencies and heat loss/gain from the building's distribution system upstream of the heat meters.

• The current and projected maintenance costs for the system.

• How any required maintenance or service cost on the heat-metering hardware for each building unit will be initiated and paid for.

• How any required maintenance or service costs on the client's side of the heat meter will be initiated and paid for.

• How the administrative costs for reading energy meters and issuing invoices will be allocated.

• Any applicable regulations dealing with sales tax or fees on metered energy.

• How a contingency fund to cover maintenance or service work on the central portion of the system will be funded and managed.

The following suggestions are offered for consideration in drafting an agreement between the owner of the central heating/cooling system and each client of that system. Specific wording for each consideration should be vetted by an attorney. The agreement should include:

1. A statement detailing how the cost of energy used by the central plant for heating and cooling, and any associated fees, surcharges, tariffs, etc., will be allocated to each client of the system.

2. A statement specifying when invoices for thermal energy will be issued to each client, along with terms on how those invoices must be paid.

3. A statement covering the possibility of prorated partial payments if the client sells or otherwise transfers responsibility for the building unit at a time between energy invoices.

4. A statement ensuring that each client of the system has opportunity to know the owner's cost of energy supplied to the central plant, as well as how any sales tax or other associated fees for that energy are accounted for in client billing.

5. A statement in which each client of the system agrees not to tamper with any heat-metering equipment.

6. A statement assuring clients that all heat-metering equipment meets the ASTM 3137 accuracy requirement, *and that the client accepts this standard of accuracy for the heat-metering equipment.*

7. A statement describing how each client will receive an annual report on the status of the heating/cooling system, including an accounting of maintenance/service/administrative costs, and the fund balance of an established maintenance/service account.

8. A statement covering how any future additions, extensions, component replacements or other modifications to the central system will be initiated and paid for.

9. A statement detailing how any necessary maintenance/service work *on the client's side of the heat-metering equipment* will be initiated and paid for.

10. A statement that energy usage of individual clients will be maintained as confidential, and thus, not reported to other clients.

11. Language that stipulates the maximum and minimum thermostat settings in both heating and cooling modes within any building unit. If the thermostats are configured and locked for these maximum and minimum settings, the clients should acknowledge their acceptance of the settings.

One of the most intuitive approaches to cost allocation is to generate a monthly total cost for the fuel used by the central plant and any associated fees, tariffs, etc., combined with an allowance for maintaining the system and covering administrative costs, and then dividing this total among the clients of the system *in proportion to their metered thermal energy use.*

This approach assumes that an account is established to pay for any required maintenance or service on the central system, up to and including the heat meters. This account is maintained by adding a monthly allocation that is in turn divided among the system's clients in proportion to their percentage of the total energy used by the central plant. The rationale being that higher energy users create more "wear and tear" on the system relative to low energy users.

The maintenance/service account would require an initial deposit and then be maintained by periodic contributions paid by each client in their invoices. A maximum account balance could be established so that client contributions could be temporarily reduced or eliminated provided that the account remains above a level deemed adequate to handle reasonably anticipated maintenance or service costs. The status of the maintenance/service account would be periodically reported to each client.

Here's an example of proportional cost allocation based on the following assumptions:

1. Total monthly cost of fuel and associated fees for the central plant = $3,000

2. Allocated monthly installment for maintenance/service/administration = $300

3. Monthly invoicing of clients.

4. The agreement between the owner and each client is such that the cost associated with maintenance or service on the client's side of the heat meter will be paid by the building owner and then added to the client's cost of energy.

Thus, the total cost of operating the central system up to and including the heat meters would be $3,300, which is divided among the clients in proportion to their energy use.

The agreement between the building owner and clients should also address and coordinate with other legal stipulations and insurance issues on the use and costs associated with each building unit. For example, if the client causes damages to the system on their side of the meter, how will those damages be resolved?

The above is intended to serve as suggested concepts that could be incorporated into an agreement associated with heat metering. It is not represented as specific legal advice. An attorney should be consulted to draft a specific agreement that includes relevant details for each project.

Client	Monthly meter reading (kBtu)	% of total metered usage (decimal %)	Total monthly energy cost (proportional to meter reading)	Maintenance/ service on client side of meter	Invoiced amount to each client
client A	800	0.2759	$910.47	0	**$910.47**
client B	400	0.1379	$455.07	0	**$455.07**
client C	200	0.06897	$227.60	$200	**$427.60**
client D	1000	0.3448	$1137.84	$300	**$1337.84**
client E	500	0.1724	$568.92	0	**$568.92**
	total=2900 kBtu	total=0.99997			

5. EXAMPLE APPLICATIONS

This section provides examples of how heat metering can be used in modern hydronic systems that supply space heating, cooling and domestic hot water. The systems presented are conceptual and require proper equipment sizing, as well as suitable operating and safety controls.

1. Verification of energy flows in systems with renewable energy heat sources:

Heat metering can be used to assess the energy flows in systems that have one or more renewable energy heating/cooling sources. Examples include systems with solar thermal collectors, geothermal heat pumps, air-to-water heat pumps and biomass boilers.

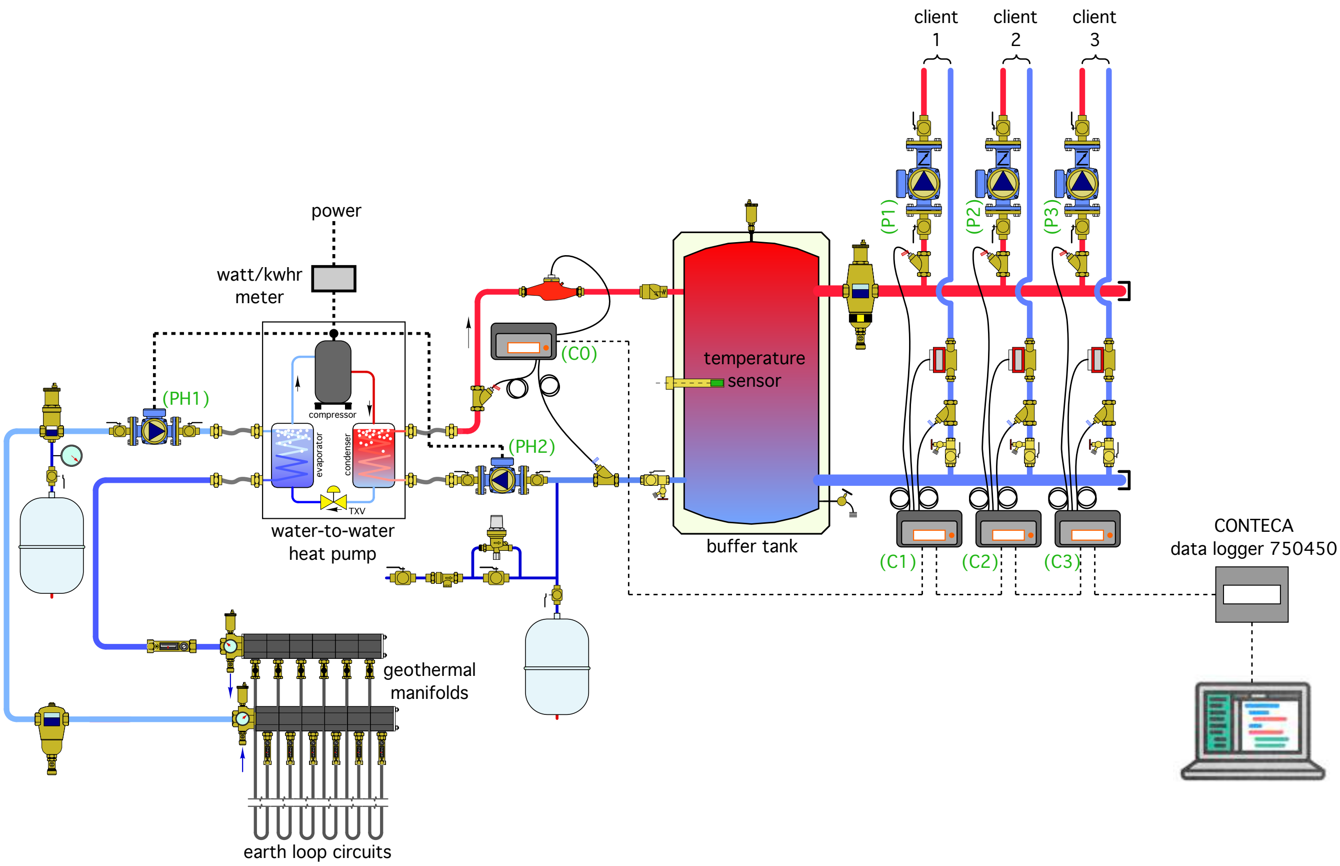
Some government incentive programs mandate that heat metering be used in certain types of renewable energy systems to verify energy yield.

Figure 5-1 represents a geothermal water-to-water heat pump system that supplies heating and cooling to three "client" loads. The system is shown in heating mode operation.

In this system, one of the CONTECA Easy heat-metering systems monitors the output from the heat pump in both heating and cooling modes. The heat pump is also equipped with an electrical power meter that measures instantaneous electrical power input to the heat pump and its associated circulators (P1) and (P2). That meter also records the total electrical energy use of the heat pump and circulators over time.

This combination of metering allows the coefficient of performance (COP) of the heat pump to be determined on both an instantaneous basis and as an average over any elapsed time.

Figure 5-1



The instantaneous COP of the heat pump + circulators could be determined by combining the thermal power reading from the CONTECA Easy (in kBtu/hr), and the electrical power input to the heat pump and circulators in kilowatts using formula 5-1.

Formula 5-1:

$$COP_i = \frac{Q_o}{P_e \times 3.413}$$

Where:

COP_i = instantaneous COP of heat pump + circulators

Qo = heat output of heat pump (kBtu/hr)

Pe = electrical power input to heat pump + circulators (kW)

3.413 = conversion factor

For example, assume the CONTECA Easy thermal power reading was 30 kBtu/hr, and the electrical power input to the heat pump + circulators was 2,500 watt = 2.5 kw. Putting these values into equation 5-1 yields the instantaneous COP of the heat pump + circulators:

$$COP_i = \frac{Q_o}{P_e \times 3.413} = \frac{30\frac{kBtu}{hr}}{2.5kw \times 3.413\frac{kBtu/hr}{kw}} = 3.52$$

Note: the COP calculated in this manner includes the power input to both circulators that must operate whenever the heat pump operates. This inclusion reflects the *effective* COP of the geothermal heat pump and its required ancillary equipment, rather than the COP of the heat pump by itself.

The *average* COP of the heat pump + circulators over a period of time is determined in a similar manner. It can be calculated by dividing the total heating or cooling energy recorded by the Contecta meter by the total kilowatt•hours of electrical energy supplied to the heat pump + circulators over the same period. This ratio can be expressed as formula 5-2.

Formula 5-2:

$$COP_a = \frac{H}{E \times 3.413}$$

Where:

COP_a = average COP of heat pump + circulators over time period

H = heat output of heat pump over time period (kBtu)

E = electrical energy input to heat pump + circulators (kWhr)

3.413 = conversion factor

For example, over a month the CONTECA Easy meter shows that the heat pump + circulators have delivered 5,000 kBtu of heat. The electrical meter shows that 475 kWhr of electrical energy has been delivered to operate the heat pump + circulators. The average COP of the heat pump + circulators over that month is:

$$COP_a = \frac{H}{E \times 3.413} = \frac{5,000kBtu}{475kwhr \times 3.413\frac{kBtu}{kwhr}} = 3.08$$

The three CONTECA Easy meters on right side of the buffer tank monitor energy usage of the three client loads. These meters automatically switch between heating and cooling mode metering based on the change in temperature at the supply water sensors. All three meters would have the same temperature threshold settings at which they begin monitoring heating energy, and the same temperature threshold at which they begin monitoring cooling energy.

The RS-485 terminals in all four CONTECA Easy heat meters are daisy-chained together, as detailed in figure 4-6, and connected to the Caleffi CONTECA data logger. The RS-485 outputs on all four CONTECA Easy meters must be set for M-bus to enable proper communication with the data logger. The laptop computer connected to the data logger has been loaded with the CONTECA Easy APP, allowing it to access all current and historical data on each heat meter, and format that data into various reports.

Figure 5-2

Figure 5-2 shows an example where several CONTECA Easy heat meters are used to monitor the performance of a geothermal water-to-water heat pump system.

2. Thermal energy allocation to multiple building spaces

One of the most common applications for heat metering is recording the thermal energy used for space heating and domestic hot water in apartment or condominium buildings.

The system shown in figure 5-3 uses a multiple boiler system to supply heat that's used for both space heating and domestic water heating.

Each mod/con boiler in this system has a turndown ratio of at least 5:1, and perhaps as high as 10:1. This makes the turndown ratio of the overall boiler system at least 15:1, to as high as 30:1. High turndown ratios allow the boiler system to adapt to widely varying load conditions without short cycling.

The multiple boiler system can go to full power output, if necessary, to meet a high morning heat demand created when many of the building units come out of thermostat setbacks, or when there's a high demand for domestic hot water for morning showers.

A SEP4 hydraulic separator is used between the boilers and the balance of system. It isolates the pressure dynamics of the boiler circulators from that of the variable-speed "building circulator." The SEP4 also provides central air, dirt and magnetic particle separation for the system.

The variable-speed building circulator is set to maintain specific differential pressure across the riser piping. This circulator automatically changes speed depending on the flow requirements of the building. When building demand decreases, so does the circulator's speed and associated electrical energy use.

This system illustrates the possibility of supplying space heating to some building units (e.g., units 2 and 4), and space heating *plus domestic hot water* to other building units (e.g., units 1, 3, and 5).

This system only requires three riser pipes: the supply and return piping for non-potable water, and a pipe for cold domestic water. This reduces installation cost compared to standard approaches that would require five riser pipes: two for space heating, a cold domestic water supply pipe, hot domestic water supply pipe, and a domestic hot water recirculation pipe.

Each building unit that only requires space heating connects to two of the riser pipes. The units that require space heating and domestic hot water connect to all three riser pipes.

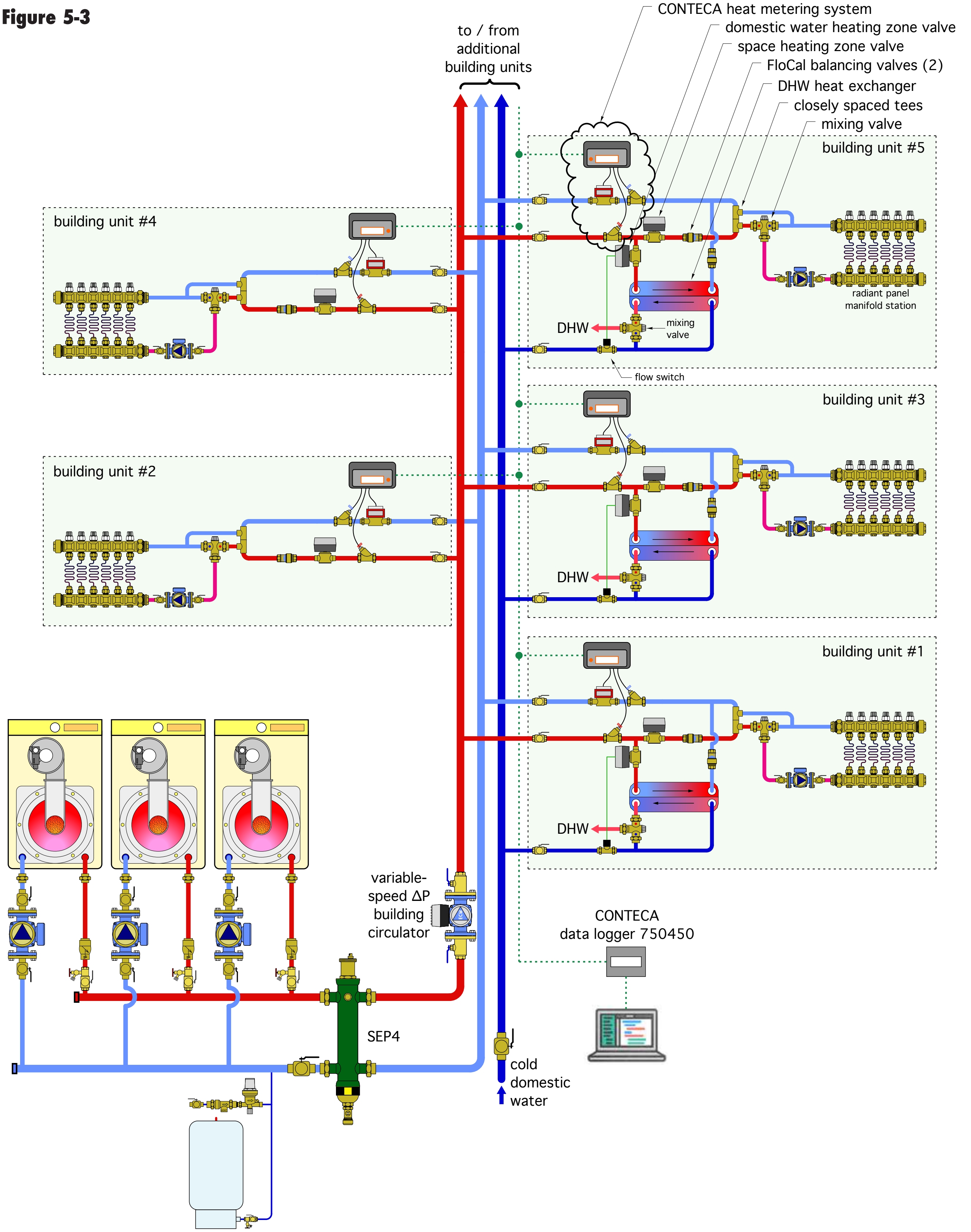
All thermal energy passing into each building unit, regardless of its use for space heating or domestic water heating, is recorded by the CONTECA Easy heat meter.

When a building unit requires space heating, a zone valve opens. Flow from the hot non-potable water riser flows into the piping within the building unit and passes by the supply temperature sensor for the CONTECA Easy heat meter. It passes through the heating zone valve and onward to a set of closely spaced tees (or equivalent means of hydraulic separation). The hot water is drawn into the hot port of a 3-way thermostatic mixing valve, which reduces its temperature to the value required by the radiant panel circuits. A Caleffi FloCal automatic balancing valve downstream of the closely spaced tees maintains a preset flow rate through this portion of the system whenever the heating zone valve is open. Cooler water returning from the radiant panel circuit passes through the return temperature sensor fitting and flow meter of the CONTECA Easy metering system. After leaving the building unit, the cooler water flows back to the non-potable return riser, and then back to the boiler plant.

Each building unit that requires space heating and domestic hot water has additional piping. A flow switch closes its contacts whenever a domestic hot water flow of 0.6 gpm or higher is detected within the building unit. This temporarily stops any flow of heated non-potable water to the space heating portion of the system. The switch closure also opens another zone valve that allows non-potable hot water to flow past the supply temperature sensor of the CONTECA Easy meter, and then through the primary side of a brazed plate stainless steel heat exchanger. Cold domestic water passes through the other side of this heat exchanger and is fully heated to, or slightly above, the required domestic hot water delivery temperature. A thermostatic mixing valve near the domestic hot water outlet of the heat exchanger ensures a safe delivery temperature to plumbing fixtures in the building unit. Flow through the primary side of the heat exchanger is regulated by a Caleffi FloCal automatic balancing valve.

All CONTECA Easy heat meters in this system are connected by a 2-wire RS-485 communication cable to the Caleffi CONTECA data logger. The RS-485 output in each CONTECA Easy meter would be set for M-bus

Figure 5-3


CONTECA heat metering system
domestic water heating zone valve
space heating zone valve
FloCal balancing valves (2)
DHW heat exchanger
closely spaced tees
mixing valve
to / from
additional
building units
building unit #5
building unit #4
radiant panel
manifold station
DHW
mixing
valve
flow switch
building unit #3
building unit #2
DHW
building unit #1
DHW
variable-
speed ΔP
building
circulator
CONTECA
data logger 750450
SEP4
cold
domestic
water

mode. The data logger can generate reports on the thermal energy consumption of each building unit.

Another major advantage of this approach is that very little domestic hot water is present in the system other than when it is being used. This reduces the standby heat loss associated with storage water heaters. It also greatly reduces the volume of heated water that could potentially harbor Legionella bacteria.

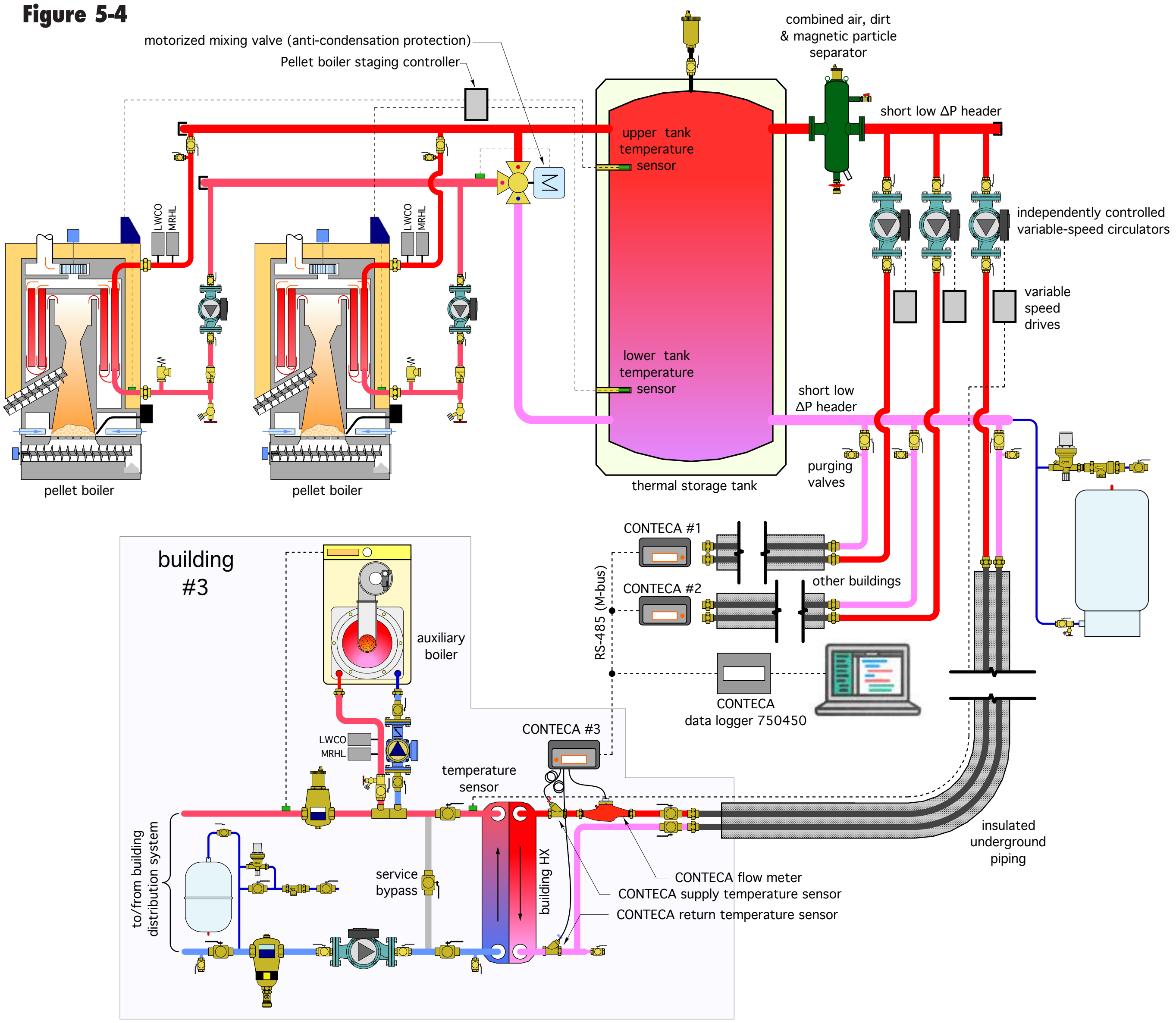
3. Mini-district heating system

District heating systems are another common application for heat metering.

Some district heating systems contain miles of underground piping that transports tens of millions of Btu/hr to many buildings, usually in urban areas, or on college campuses. However, district heating can be scaled down to serve several smaller buildings that are located in close proximity to each other. These are called "mini" district heating systems. Figure 5-4 shows the concept for such a system.

The primary heat source for this mini district heating system is a pair of pellet boilers. They are turned on an off by a staging controller that monitors the temperature in the upper and lower portions of the thermal storage

Figure 5-4



tank. The pellet boilers are not controlled by that status of any specific heating load, only the temperatures in the thermal storage tank. The size of the thermal storage tank, in combination with the heating capacity of the pellet boilers, allows the boilers to have relatively long on and off cycles. This helps keep them running at or near steady state conditions much of the time. It optimizes their thermal efficiency and decreases emissions.

The water temperature supplied to each pellet boiler is maintained above the dewpoint of the exhaust gases by a 3-way motorized mixing valve. The controller for this valve monitors the temperature of water entering the boilers, and creates partial or full bypass of higher temperature water from the boiler outlet, when necessary, to protect the boilers from sustained flue gas condensation.

The distribution system in each building is isolated from the district system by a stainless steel plate heat exchanger. This is done as a precaution to prevent a leak or other service problem in one building from compromising heat delivery to other buildings served by the district system.

Isolation and bypass valves are provided on the building side of the heat exchanger should service be required. This allows the auxiliary boiler and building distribution system to continue operating if and when the heat exchanger is taken offline for servicing.

Heat from the thermal storage tank is conveyed to each building through insulated underground piping. The flow rate of heated water supplied to each building heat exchanger is controlled by a variable-speed circulator. The controller that regulates each circulator's speed monitors the water temperature supplied to the distribution system in its associated building. The controller attempts to maintain the supply water temperature at either a fixed setpoint or a target temperature based on outdoor reset control.

A CONTECA Easy heat-metering system is installed on the district side of each building heat exchanger to record all heat supplied to the building by the district system. All the heat meters are linked to a data logger via a 2-wire RS-485 communication cable.

If supplemental heat is needed within a building, it's provided by a separate boiler connected downstream of the building heat exchanger.

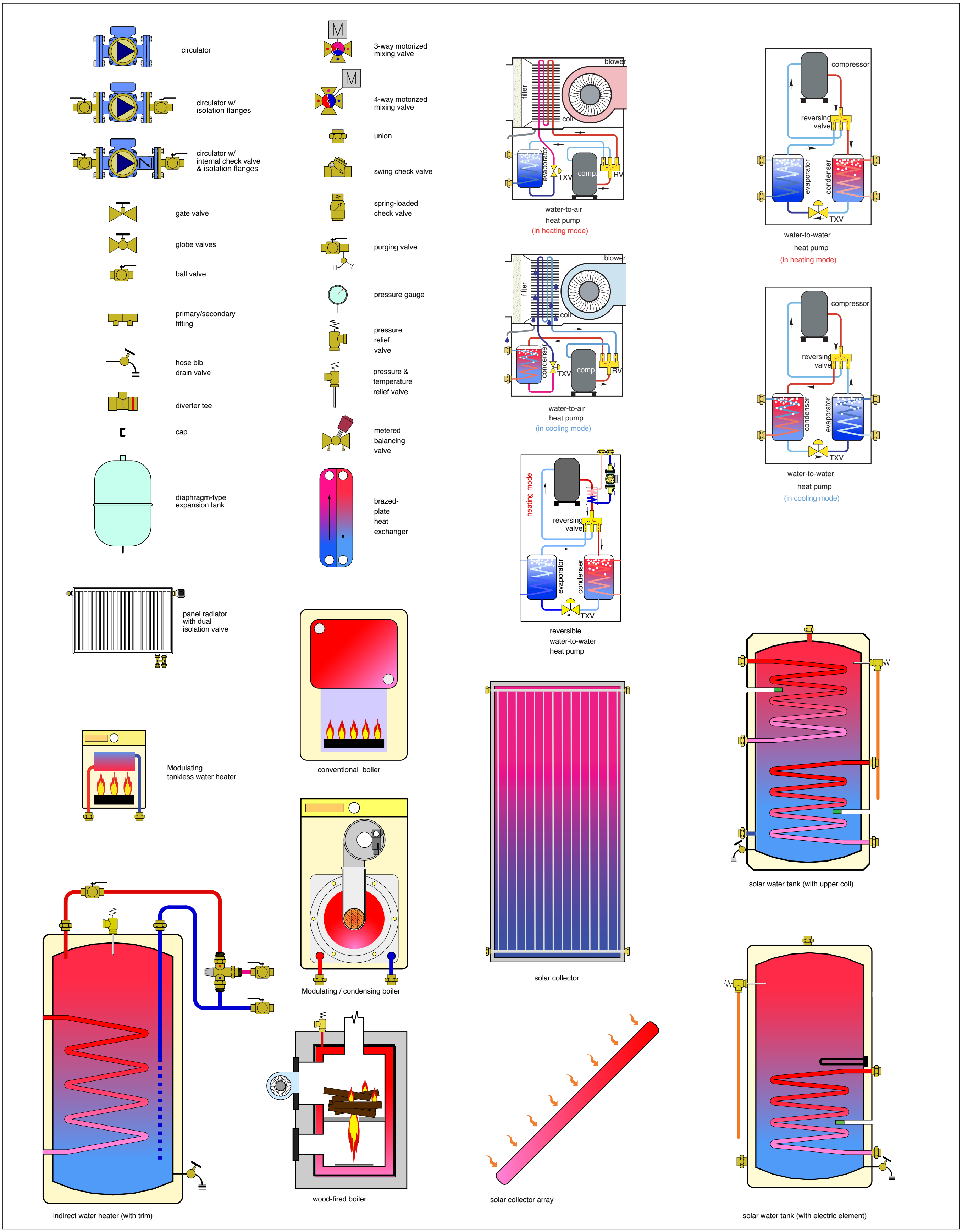
Although not shown, it would be possible to install additional CONTECA Easy heat meters on each pellet boiler to record their thermal performance.

The district system, as well as the distribution system within each building, is provided with high-efficiency air, dirt and magnetic particle separation. This helps ensure longer component life and preserves heat-metering accuracy.

SUMMARY

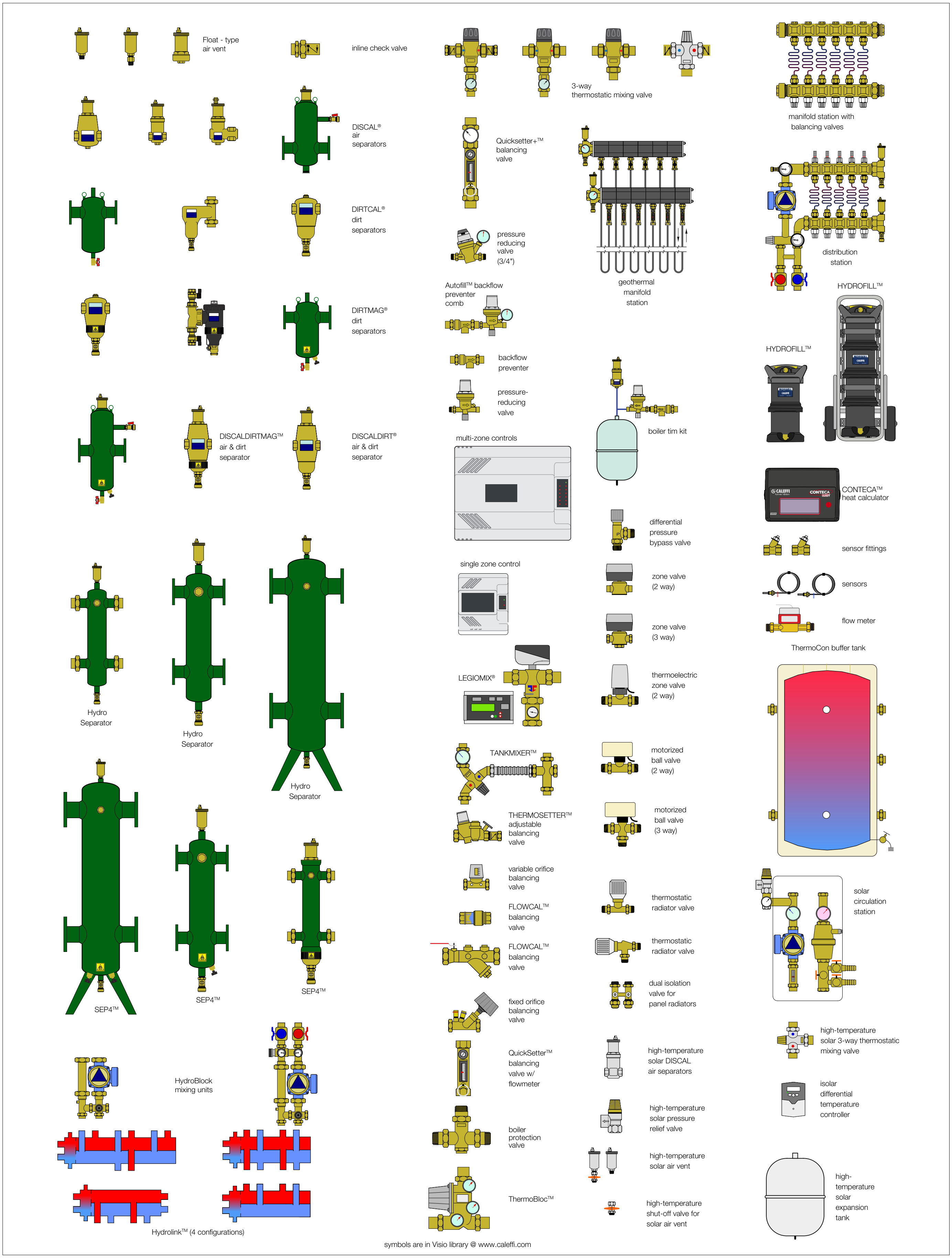
Heat metering represents an exciting technical innovation applicable to a wide variety of hydronic heating and cooling systems. Modern heat metering systems such as the Caleffi CONTECA Easy meet or exceed the accuracy requirement of the recently enacted ASTM E3137/E3137M-17 standard. This ensures that both owners and clients of a heat metered system have accurate reporting of thermal energy use. Properly applied heat metering systems can reduce the complexity and cost associated with traditional methods of heating buildings with multiple living units or commercial spaces. The future of heat metering in North America is indeed rife with opportunity.

GENERIC COMPONENTS



APPENDIX A: PIPING SYMBOL LEGEND

CALEFFI COMPONENTS



symbols are in Visio library @ www.caleffi.com

CONTECA™ heat energy meter

7504 series

Function

CONTECA™ measures and records thermal energy usage in residential and commercial buildings, for heating only, cooling only, or both heating and cooling. It features an 8-digit liquid crystal display that enables easy reading of BTU consumed as well as a range of technical data indicating equipment operating status and logged data. Each CONTECA includes an electronic control with user interface, two temperature sensors, sensor holder bodies with fittings included, a rotary pulse flow meter, two temperature inputs, a flow meter input and 4 additional pulse inputs for optional equipment monitoring. Data logging is available using the CONTECA datalogger via RS-485 connection. The CONTECA is easy to install and commission, and is certified to ASTM E3137/E3137M-17 Standard Specification for Heat Meter Instruments by ICC-ES.

The CONTECA heat meter has integral RS485 protocol 2-wire communication for remote access and configuration. M-bus protocol is used with the CONTECA Datalogger (default). The protocol can be changed to Modbus when using the CONTECA heat meter directly with a Modbus BAS or when using the Modbus-to-BACnet gateway for communication to a BACnet BAS. Up to 250 CONTECA meters can connect to one CONTECA data logger.

Product range

CONTECA Heat energy meter kit, complete with heat meter code 750405A, two integral temperature sensors, two sensor holder bodies, a rotary pulse flow meter, and:

7504_0A series	male NPT pipe connections	sizes ½", ¾" & 1"with unions
7504_3A series	female NPT pipe connections	sizes 1", 1¼" & 1 ½" with unions
7504_6A series	press pipe connections	sizes ½", ¾" & 1" with unions
7504_9A series	sweat pipe connections	sizes ½", ¾" & 1" with unions
Code 750450	Datalogger	
Code NA10520	Modbus-to-BACnet gateway	

Technical specifications

Heat meter:

Materials:	
-Housing & cover:	ABS, RAL 9004
Power supply:	24 VAC, 50/60 Hz, 1W
Data transmission:	2-wire RS485; selectable Modbus or M-bus (for use with datalogger)
Ambient temperature:	40 — 113°F (4— 45°C)
Environmental rating (protection class):	NEMA 3S (IP 54)
Pulse inputs:	Class 1B per EN 1434-2
Certification:	ASTM E3137/E3137M-17 by ICC-ES Directive 2014/32/EU EN 1434 (MI 004)

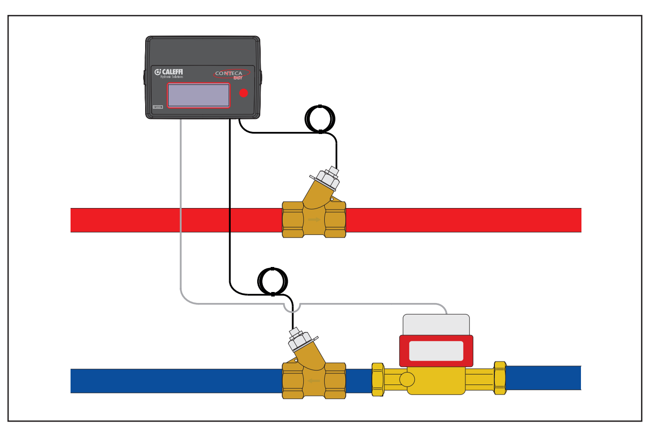
Temperature sensors:

Cable length*:	26¼ ft. (8 m)
Sensor type:	100 kOhm NTC matched
Temperature sensitivity:	< 0.1°F (0.05°C)
Temperature sensor thermowell:	Stainless steel
Sensor holder body:	Brass
Max. working pressure:	150 psi (10 bar)

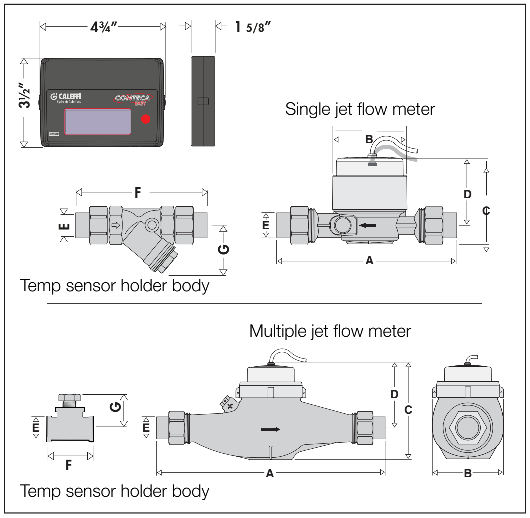
*Extra length of the 26¼ ft. cable must be carefully coiled and mounted in a safe place. Do not cut or splice.

Flow meters:

Flow meter type:	
	Single jet (½" - 1" to 10 gpm); Multiple jet (1" to 1½" to 45 gpm)
Body material:	Brass
Pulse output:	class OA-OC in accordance with EN 1434-2
Body threads:	ISO 228 male straight
Piping connections:	Dual unions, tailpieces NPT, sweat, press
Max. working pressure:	235 psi (16 bar)



Dimensions



Code	A	B	C	D	ends*	E	F	G	Wt (lb)
750449A	6 7/8"				sweat		7 ¼"		
750440A	8 3/8"				mnpt	½"	8 ¾"		6.2
750446A	7 1/8"				press		5 ¾"		
750459A	7 3/8"				sweat		7 ¾"		
750450A	7 5/8"	3 1/8"	4 ¼"	3 ½"	mnpt	¾"	8"	2"	7.1
750456A	7 ¾"				press		6 1/8"		
750469A	8 5/8"				sweat		9"		
750460A	8 3/8"				mnpt	1"	8 ¾"		7.9
750466A	8"				press		6 3/8"		
750463A	12 ¼"	4"	5 3/8"	3 ¾"	fnpt	1"	5 1/8"	2 1/16"	11.5
750473A	12 ¼"	4"	5 3/8"	3 ¾"	fnpt	1 ¼"	5 7/8"	2 3/8"	12.1
750483A	17 ¼"	5 ¼"	6 7/16"	4 5/8"	fnpt	1 ½"	5 5/8"	2 5/16"	18.7

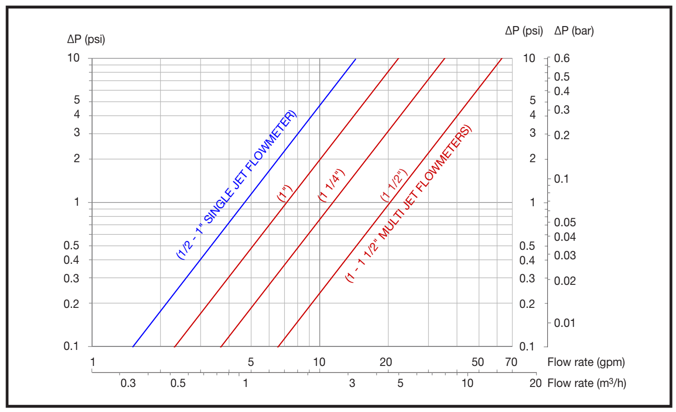
*end connections are the same for the flowmeter and sensor holder bodies for each code.
ex: code 750449A has union sweat ends on both the flow meter and the sensor holder bodies.

Flow rates

Code	Size	Flow meter type	Liters per pulse	Minimum Flow rate (gpm)	Maximum flow rate (gpm)
7504**4**xA	½"				
7504**5**xA	¾"	Single jet	1 (.26 gal)	0.25	10
7504**6**xA	1"				
750463A	1"		2.5 (.66 gal)	0.3	15
750473A	1¼"	Multiple jet	10 (2.6 gal)	0.5	25
750483A	1½"			1	45

Flow rate range for combined flow meter and 2 sensor holder bodies.

Hydraulic characteristics



	Single jet flow meter			Multiple jet flow meter		
	½"	¾"	1"	1"	1 ¼"	1 ½"
Cv	5.0			6.8	11.7	19.6

Flow rate range for combined flow meter and 2 sensor holder bodies.

750450 CONTECA™ Datalogger

The CONTECA™ datalogger allows acquisition and logging of the consumption data from CONTECA heat meters via M-Bus communication. The integrated browser provides logged and instantaneous data, and report generaton. The CONTECA datalogger can be set up locally via web interface by connecting a PC to one ethernet port with switch functionality.

The SMART function allows the automatic detection of the heat meters connected to the network. Data can be obtained with the automatic report generation, making the system user-friendly and reduces the number of operations to run.

Maximum number of heat meters: 250.

Main specifications of the datalogger:
- Power supply: 24 V (dc) ±10%,
  24 V (ac) - 3 W.
- 2 Ethernet ports: ETH1 (PoE), ETH2.
- Ambient temperature range: 32 - 122°F.
- Mounting: on a 35 mm DIN rail
  (EN 60715).
- Daily data logging: 10 years.
- Reports: In XLS or CSV format.

NA10520 Modbus-to-BACnet gateway

Converts CONTECA™ controller Modbus (RS-485 serial) output communication to BACnet IP or MSTP communication.

INNOVATIVE HYDRONIC AND PLUMBING COMPONENTS

Caleffi Hydronic Solutions, a leader in state-of-the-art engineered solutions, manufactures and supplies high-quality components for hydronic heating and cooling, plumbing, heat metering and renewable energy systems, for domestic, commercial and industrial buildings. Caleffi, an Italian based company, is a name recognized around the world for innovative solutions and superior performing products that help customers live comfortably and economically, while softening their impact on the environment.

Heating & cooling · Control · Plumbing · Heat systems · Renewables

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CONTECA™

Heat Energy Meter

- Displays and logs instantaneous and totalized energy and flow for both heating and cooling.
- Two pulse inputs for domestic cold and hot water meters, two universal pulse inputs for gas or electric measurement.
- Complies with new ASTM E3137/E3137M – 17 Standard Specification for Heat Meter Instrumentation.
- Daily and monthly log data accessible via local user interface or remotely.
- Integral RS485 2-wire communication for remote access and configuration.
- Network up to 250 units on one Datalogger; Modbus and BACnet communication.

Correct measurement for correct management

Heat systems

www.caleffi.com - Milwaukee, WI USA

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