GEOTHERMAL DIRECT-USE EQUIPMENT OVERVIEW

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This article provides an overview of the various equipment components that are used in most geothermal direct-use project. Following, are articles describing in more detail five major types of equipment: well pumps, piping, heat exchangers, space heating equipment and absorption refrigeration equipment. These five articles are condensations of chapters written by Kevin Rafferty and Gene Culver, mechanical engineers with the Geo-Heat Center, that appear in the 3rd edition of our "Geothermal Direct-Use Engineering and Design Guidebook" (1998). Additional specifications and design information on these five major equipment items appear in this book as Chapters 9 through 13. Since these articles and chapters address only items used in direct heat projects (generally above about 100°F or 40°C), geothermal or ground-source heat pumps are not discussed. For information on the specifications, design and use of geothermal heat pumps used in commercial and institutional buildings, see Kavanaugh and Rafferty (1998)

INTRODUCTION

Standard equipment is used in most direct-use projects, provided allowances are made for the nature of geothermal water and steam. Temperature is an important considerations; so is water quality. Corrosion and scaling caused by the sometimes unique chemistry of geothermal fluids, may lead to operating problems with equipment components exposed to flowing water and steam. In many instances, fluid problems can be designed out of the system. One such example concerns dissolved oxygen, which is absent in most geothermal waters, except perhaps the lowest temperature waters. Care should be taken to prevent atmospheric oxygen from entering district heating waters; for example, by proper design of storage tanks. The isolation of geothermal water by installing a heat exchanger may also solve this and similar water quality derived problems. In this case, a clean secondary fluid is then circulated through the user side of the system as shown in Figure 1.

The primary components of most low-temperature direct-use systems are downhole and circulation pumps, transmission and distribution pipelines, peaking or back-up plants, and various forms of heat extraction equipment (Figure 1). Fluid disposal is either surface or subsurface (injection). A peaking system may be necessary to meet maximum load. Thus can be done by increasing the water temperature or by providing tank storage (such as done in most of the Icelandic district heating systems). Both options mean that fewer wells need to be drilled. When the geothermal water temperature is warm (below 120°F or 50°C), heat pumps are often used. The equipment used in direct-use projects represent several units of operations. The major units will now be described in the same order as seen by geothermal waters produced for district heating.

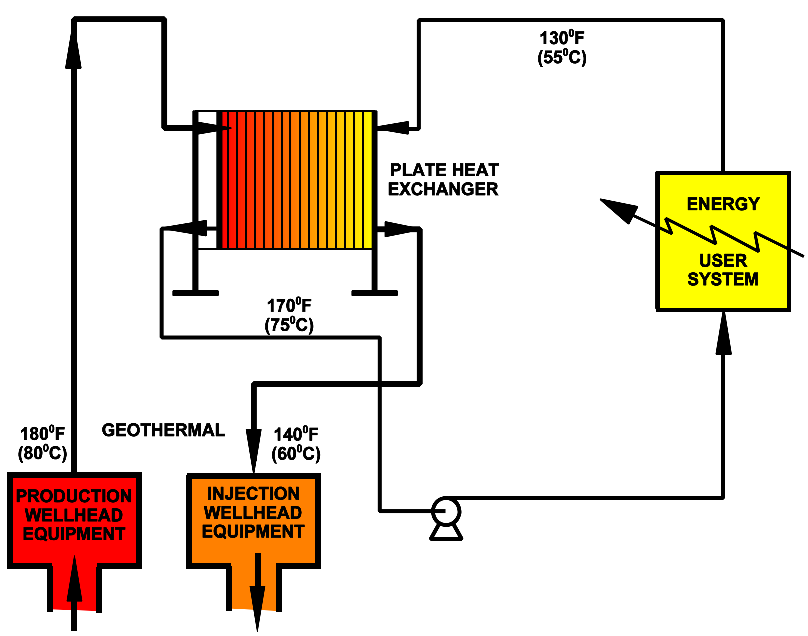

Figure 1. Geothermal direct utilization system using a heat exchanger.

DOWNHOLE PUMPS

Unless the well is artesian, downhole pumps are needed, especially in large-scale direct utilization systems. Downhole pumps may be installed not only to lift fluid to the surface, but also to prevent the release of gas and the resultant scale formation. The two most common types are: lineshaft pump systems and submersible pump systems.

The lineshaft pump system (Figure 2a) consists of a multi-stage downhole centrifugal pump, a surface mounted motor and a long drive shaft assembly extending from the motor to the pump. Most are enclosed, with the shaft rotating within a lubrication column which is centered in the production tubing. This assembly allows the bearings to be lubricated by oil, as hot water may not provide adequate lubrication. A variable-speed drive set just below the motor on the surface, can be used to regulate flow instead of just turning the pump on and off.

The electrical submersible pump system (Figure 2b) consists of a multi-stage downhole centrifugal pump, a downhole motor, a seal section (also called a protector) between the pump and motor, and electric cable extending from the motor to the surface electricity supply.

Both types of downhole pumps have been used for many years for cold water pumping and more recently in geothermal wells (lineshafts have been used on the Oregon Institute of Technology campus in 192ºF [89ºC] water for 36 years). If a lineshaft pump is used, special allowances must be made for the thermal expansion of various components and for oil lubrication of the bearings. The lineshaft pumps are preferred over the submersible pump in conventional geothermal applications for two main reasons: the lineshaft pump cost less, and it has a proven track record. However, for setting depths exceeding about 800 ft (250 m), a submersible pump is required.

PIPING

The fluid state in transmission lines of direct-use projects can be liquid water, steam vapor or a two-phase mixture. These pipelines carry fluids from the wellhead to either a site of application, or a steam-water separator. Thermal expansion of pipelines heated rapidly from ambient to geothermal fluid temperatures (which could vary from 120 to 400ºF [50 to 200&#176C]) causes stress that must be accommodated by careful engineering design.

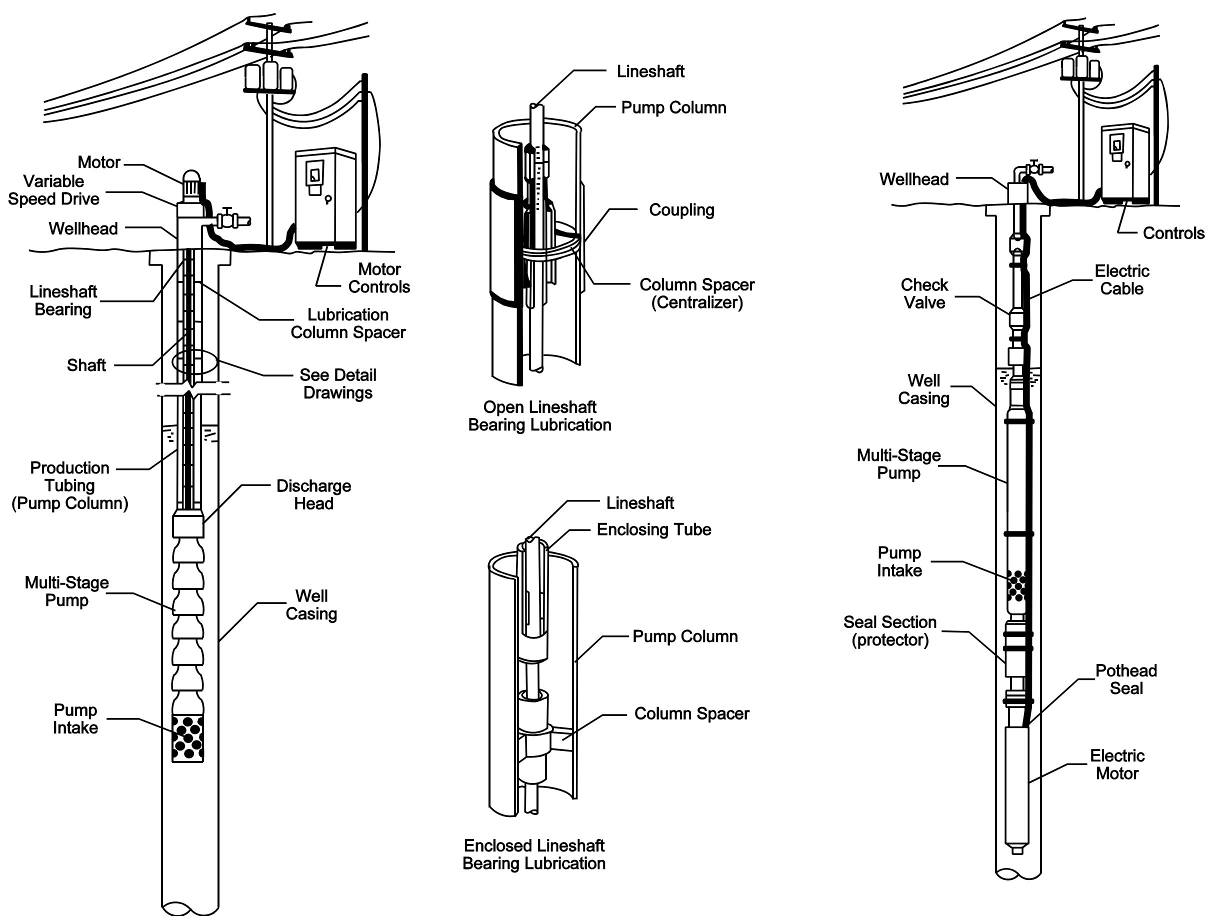

Figure 2. Downhole pumps: (a) lineshaft pump details, and (b) submersible pump details.

The cost of transmission lines and the distribution networks in direct-use projects is significant. This is especially true when the geothermal resources is located at great distance from the main load center; however, transmission distances of up to 37 miles (60 km) have proven economical for hot water (i.e., the Akranes Project in Iceland - Georgsson, et al., 1981), where asbestos cement covered with earth has been successful (see Figure 4 later).

Carbon steel is now the most widely used material for geothermal transmission lines and distribution networks, especially if the fluid temperature is over 212°F (100°C). Other common types of piping material are fiberglass reinforced plastic (FRP) and asbestos cement (AC). The latter material, used widely in the past, cannot be used in many systems today due to environmental concerns; thus, it is no longer available in many locations. Polyvinyl chloride (PVC) piping is often used for the distribution network, and for uninsulated waste disposal lines where temperatures are well below 212°F (100°C). Conventional steel piping requires expansion provisions, either bellows arrangements or by loops. A typical piping installation would have fixed points and expansion points about every 300 ft (100 m). In addition, the piping would have to be placed on rollers or slip plates between points. When hot water pipelines are buried, they can be subjected to external corrosion from groundwater and electrolysis. They must be protected by coatings and wrappings. Concrete tunnels or trenches have been used to protect steel pipes in many geothermal district heating systems. Although expensive (generally over $100 per ft ($300/m), tunnels and trenches have the advantage of easing future expansion, providing access for maintenance, and a corridor for other utilities such as domestic water, waste water, electrical cables, phone lines, etc.

Supply and distribution systems can consist of either a single-pipe or a two-pipe system. The single-pipe is a once-through system where the fluid is disposed of after use. This distribution system is generally preferred when the geothermal energy is abundant and the water is pure enough to be circulated through the distribution system. In a two-pipe system, the fluid is recirculated so the fluid and residual heat are conserved. A two-pipe system must be used when mixing of spent fluids is called for, and when the spent cold fluids need to be injected into the reservoir. Two-pipe distribution systems cost typically 20 to 30 percent more than single-piped systems.

The quantity of thermal insulation of transmission lines and distribution networks will depend on many factors. In addition to minimize the heat loss of the fluid, the insulation must be waterproof and water tight. Moisture can destroy the value of any thermal insulation, and cause rapid external corrosion. Aboveground and overhead pipeline installations can be considered in special cases. Considerable insulation is achieved by burying hot water pipelines. For example, burying bare steel pipe results in a reduction in heat loss of about one-third as compared to aboveground in still air. If the soil around the buried pipe can be kept dry, then the insulation value can be retained. Carbon steel piping can be insulated with polyurethane foam, rock wool or fiberglass. Below ground, such pipes should be protected with polyvinyl (PVC) jacket; aboveground aluminum can be used. Generally 1 to 4 inches (2.5 to 10 cm) of insulation is adequate. In two-pipe systems, the supply and return lines are usually insulated; whereas, in single-pass systems, only the supply line is insulated.

At flowing conditions, the temperature loss in insulated pipelines is in the range of 0.3 to 3°F/mile (0.1 to 1°C/km), and in uninsulated lines, the loss is 6 to 15°F/mile (2 to 5°C/km) in the approximate range of 80 to 240 gpm flow for a 6-in. diameter pipe (5 to 15 L/s for a 15-cm pipe)(Ryan, 1981). It is less for larger diameter pipes and for higher flows. As an example, less than 3°F (2°C) loss is experienced in the new aboveground 18-mile (29-km) long and 31- and 35-in. (80 - and 90-cm) wide line with 4 inches (10 cm) of rock wool insulation that runs from Nesjavellir to Reykjavik in Iceland. The flow rate is around 8,900 gpm (560 L/s) and takes seven hours to cover the distance. Uninsulated pipe costs about half of insulated pipe and thus, is used where temperature loss is not critical. Pipe material does not have a significant effect on heat loss; however, the flow rate does. At low flow rates (off peak), the heat loss is higher than at greater flows. Figure 3 (Gudmudsson and Lund, 1985) shows fluid temperature as function of distance, in a 18-in. (45-cm) diameter pipeline, insulated with 2 inches (5 cm) of urethane.

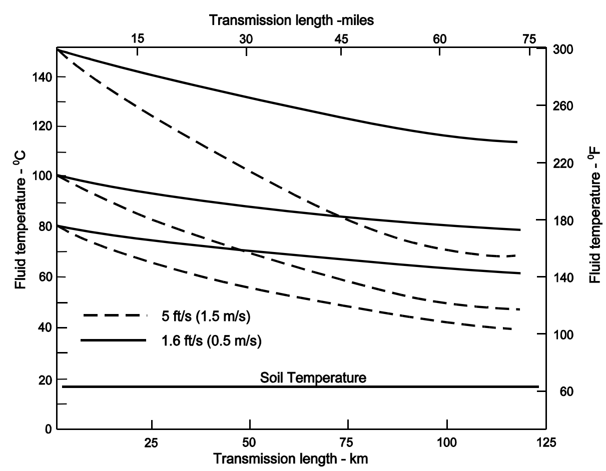

Figure 3. Temperature drop in hot water transmission line.

Several examples of aboveground and buried pipeline installations are shown in Figure 4.

Steel piping is shown in most case; but, FRP or PVC can be used in low-temperature applications. Aboveground pipelines have been used extensively in Iceland, where excavation in lava rock is expensive and difficult; however, in the USA, below ground installations are most common to protect the line from vandalism and to eliminate traffic barriers. A detailed discussion of these various installations can be found in Gudmundsson and Lund (1985).

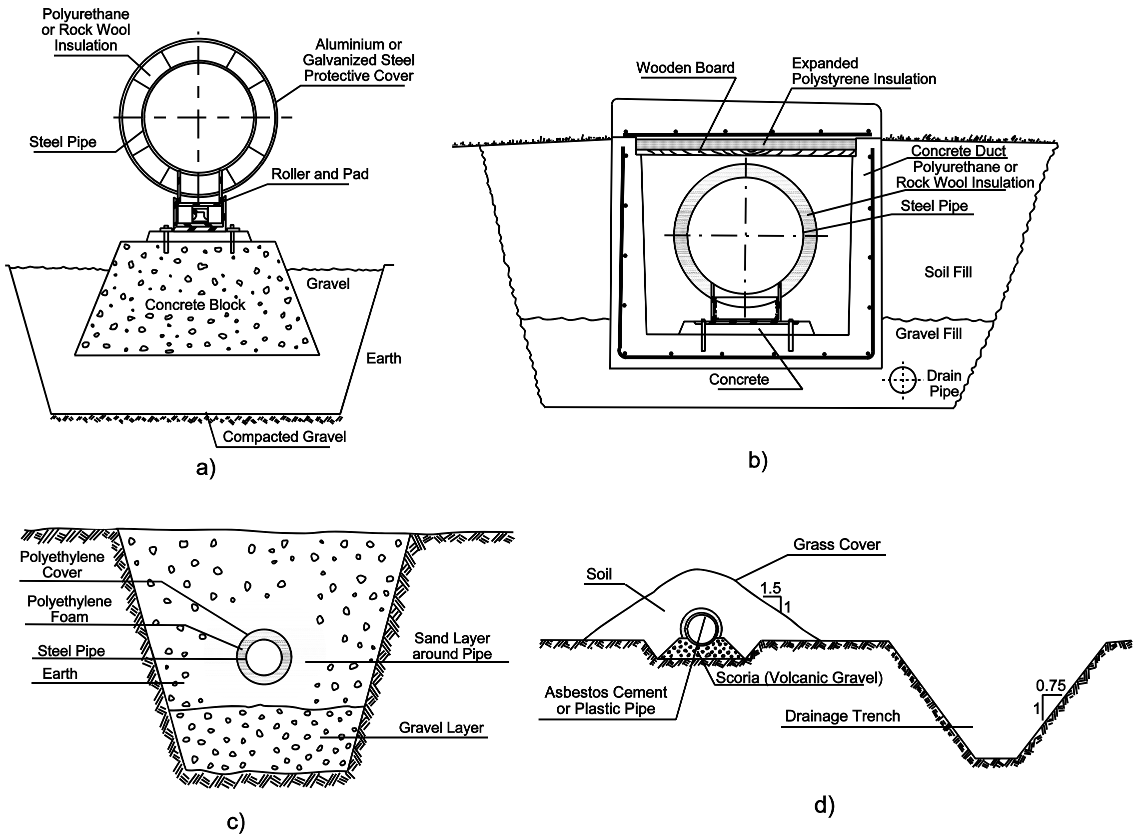

Figure 4. Examples of above and below ground pipelines: a) aboveground pipeline with sheet metal cover, b) steel pipe in concrete tunnel, c) steel pipe with polyurethane insulation and polyethylene cover, and d) asbestos cement pipe with earth and grass cover.

HEAT EXCHANGERS

The principal heat exchangers used in geothermal systems are the plate, shell-and-tube, and downhole types. The plate heat exchanger consists of a series of plates with gaskets held in a frame by clamping rods (Figure 5). The counter-current flow and high turbulence achieved in plate heat exchangers provide for efficient thermal exchange in a small volume. In addition, they have the advantage when compared to shell-and-tube exchangers, of occupying less space, can easily be expanded when additional load is added, and cost about 40% less. The plates are usually made of stainless steel; although, titanium is used when the fluids are especially corrosive. Plate heat exchangers are commonly used in geothermal heating situations worldwide.

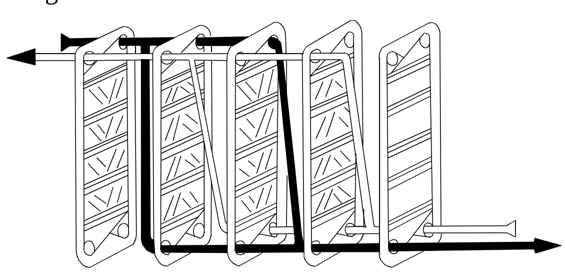

Figure 5. Plate heat exchanger.

Shell-and-tube heat exchangers may be used for geothermal applications, but are less popular due to problems with fouling, greater approach temperature (difference between incoming and outgoing fluid temperature), and the larger size.

Downhole be heat exchangers eliminate the problem of disposal of geothermal fluid, since only heat is taken from the well. However, their use is limited to small heating loads such as the heating of individual homes, a small apartment house or business. The exchanger consists of a system of pipes or tubes suspended in the well through which secondary water is pumped or allowed to circulate by natural convection (Figure 6). In order to obtain maximum output, the well must be designed to have an open annulus between the wellbore and casing, and perforations above and below the heat exchanger surface. Natural convection circulates the water down inside the casing, through the lower perforations, up in the annulus, and back inside the casing through the upper perforations (Culver and Reistad, 1978). The use of a separate pipe or promotor has proven successful in older wells in New Zealand to increase the vertical circulation (Dunstall and Freeston, 1990).

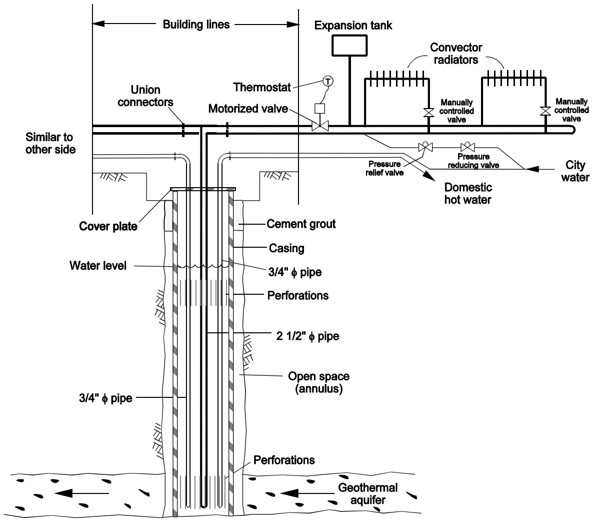

Figure 6. Downhole heat exchanger (typical of Klamath Falls, OR).

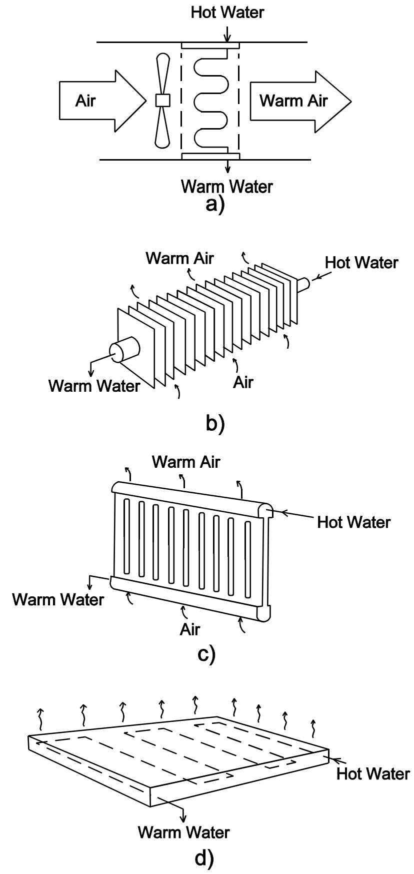

Figure 7. Convectors: a) forced air, b) material convection (finned tube), c) natural convection (radiator), and d) floor panel.

CONVECTORS

Heating of individual rooms and buildings is achieved by passing geothermal water (or a heated secondary fluid) through heat convectors (or emitters) located in each room. The method is similar to that used in conventional space heating systems. Three major types of heat convectors are used for space heating: 1) forced air, 2) natural air flow using hot water or finned tube radiators, and 3) radiant panels (Figure 7). All three can be adapted directly to geothermal energy or converted by retrofitting existing systems.

REFRIGERATION

Cooling can be accomplished from geothermal energy using lithium bromide and ammonia absorption refrigeration systems (Rafferty, 1983). The lithium bromide system is the most common because it uses water as the refrigerant. However, it is limited to cooling above the freezing point of water. The major application of lithium bromide units is for the supply of chilled water for space and process cooling. They may be either one-or two-stage units. The two-stage units require higher temperature (about 320°F - 160°C); but they also have high efficiency. The single-stage units can be driven with hot water at temperatures as low as 170°F (77°C)(such as at Oregon Institute of Technology). The lower the temperature of the geothermal water, the higher the flow rate required and the lower the efficiency. Generally, a condensing (cooling) tower is required, which will add to the cost and space requirements.

For geothermally-driven refrigeration below the freezing point of water, the ammonia absorption system must be considered. However, these systems are normally applied in very large capacities and have seen limited use. For the lower temperature refrigeration, the driving temperature must be at or above about 250°F (120°C) for a reasonable performance. Figure 8 illustrates how the geothermal absorption process works.

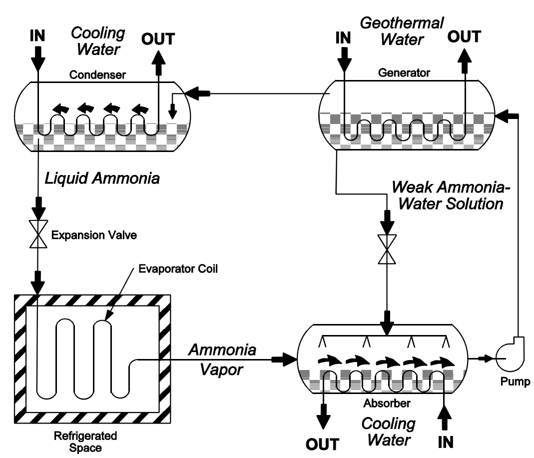

Figure 8. Geothermal absorption refrigeration cycle.

METERING (K. Rafferty)

For district heating systems (where heat is distributed to a large number of buildings from a central source), some means of energy use measurement is necessary to accommodate customer billing. Several approaches are available to accomplish this; but, the three most common approaches are: energy metering, volume metering and flat rate.

Energy (sometimes called Btu) metering involves the measurement of the water flow rate and the temperatures of the water entering the building (supply) and the water leaving the building (return). From the three values, the rate of energy use (Btu/min) can be calculated. Integrating these values over a longer period (a month) results in a value that can be used for customer billing. Energy metering requires a water flow meter, two temperature sensors and an electronic "integrator" to make the calculations (Figure 9). It provides the most accurate method of energy measurement, but at a cost much higher than the other methods. The cost of installing an energy meter in a small commercial customer would be in the range of $1000 to $1500 for moderate quality components.

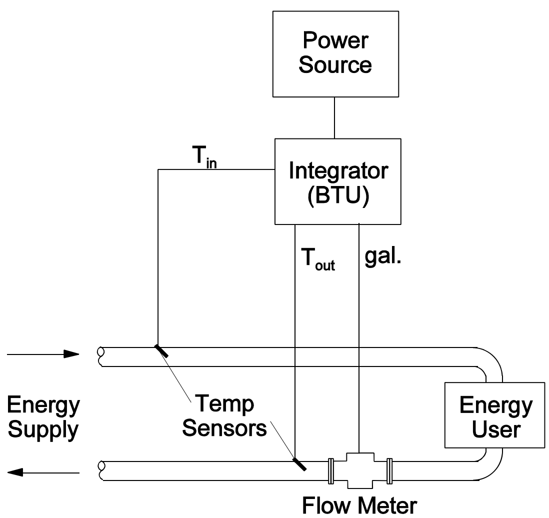

Figure 9. Energy metering.

Volume metering involves the measurement of only the water flow very much the same as in municipal water system operations. The volume of water over the period (gallons per month for example) is read from the meter and the customer's energy use is determined by multiplying the water volume used by an assumed heat content per volume (Btu per gallon for example). The equipment to accomplish this consists only of a water meter suitable for use in hot water. The cost of this for a small commercial customer would be in the range of $300. Because the customer's cost is determined only by the volume of water used, and the energy content of a given volume is directly related to the temperature difference, it is in his best interest to design and operate his system in such a way as to achieve a high temperature difference between the supply and return. This is also important to the district system operator since the capacity of any system is related to temperature difference.

Flat rate is the least sophisticated of the methods for customer billing. It simply consists of an agreement between the customer and the system operator that a flat sum ($/month or $/year) will be paid for the hot water service provided. In most systems that use a flat rate, there is some mechanical device installed to limit flow to the customer or regulate temperature. One of the primary advantages of flat rate is simpler marketing. There is no question in the customer's mind as to the savings, meter accuracy of impact of his current system efficiency. This approach works well with existing, small, simple customers for which there is a history of previous heating energy use.

In states where district heating is considered a regulated utility, the Public Utility Commission may have specific requirements for customer metering.

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