CHAPTER 12
SPACE HEATING EQUIPMENT

Kevin D. Rafferty, P.E.
Geo-Heat Center
Klamath Falls, OR 97601

12.1 INTRODUCTION

The performance evaluation of space heating equipment for a geothermal application is generally considered from either of two perspectives: (a) selecting equipment for installation in new construction, or (b) evaluating the performance and retrofit requirements of an existing system.

With regard to new construction, the procedure is relatively straightforward. Once the heating requirements are determined, the process need only involve the selection of appropriately sized hot water heating equipment based on the available water temperature.

It is important to remember that space heating equipment for geothermal applications is the same equipment used in non-geothermal applications. What makes geothermal applications unique is that the equipment is generally applied at temperatures and flow rates that depart significantly from traditional heating system design.

This chapter presents general considerations for the performance of heating equipment at non-standard temperature and flow conditions, retrofit of existing systems, and aspects of domestic hot water heating.

12.2 HEATING EQUIPMENT PERFORMANCE AT NON-STANDARD CONDITIONS

For about the past 40 years, heating systems have been designed for a hot water supply temperature of 180 to 200°F with a 20°F temperature drop (ΔT). These temperatures were chosen largely to result in equipment requirements similar to those of the older steam systems. Equipment manufacturer's selection data are indexed to these temperatures as are the practices of many design professionals.

Geothermal resources, of the variety frequently applied to space heating applications, are generally characterized by temperatures less than the standard 180 to 200°F range. Because well pumping costs constitute a sizable portion of the operating costs of a geothermal system, it is in the best interest of the designer to minimize flow requirements. This requires higher system ΔT than conventional designs. Accordingly, it is beneficial to examine the performance of heating equipment at low flow or temperature conditions.

Figure 12.1 illustrates the effect of low water velocity on heat transfer in hot water heating equipment. As indicated by the curve, heat output is relatively unaffected by water side velocity above a certain critical value. It is important when designing for larger than normal ? T (low flow rate) that the critical velocity for the heating equipment in question be avoided, as capacity falls off asymptotically in this region.

Figure 12.1 is a generalized relationship. Because the issue illustrated is really one of Reynold's Number and transition to laminar flow, critical velocity will vary with temperature and line size. However, for the piping diameters and temperatures generally encountered in heating equipment, velocities of 0.25 ft/s or less should be avoided for 1 to 2 in. lines (typical of finned tube radiators) and 0.50 ft/s or less for 1 in.and smaller lines (typical of finned coil equipment). For the 5/8 in. tubes commonly found in finned coil equipment, this velocity corresponds to a flow rate of approximately 0.6 gal/min gpm. In most cases, this very low velocity would only become a factor in applications of very low capacity (<15,000 Btu/h) using a ΔT of 40°F or more.

Figure 12.2 illustrates the average effect of reduced water temperature on hot water heating equipment performance. Individual terminal equipment types respond differently. Consult ASHRAE (1983) for exact performance.

Figure 12.2, as for most heating equipment, is indexed to a temperature of 215°F. The percent capacity shown on the vertical axis is the percent of the 215°F rated capacity at the temperature in question. For example, the output of a particular piece of heating equipment at 150°F would be approximately 45% of its capacity at 215°F. This relationship holds for equipment such as finned tube radiators, unit heaters, cast iron radiators, and convectors.

For finned coils, the considerations are somewhat more complex with respect to low temperature service. For other types of equipment, compensation for low temperature operation is primarily in terms of additional length, larger individual units, or a greater number of units. For finned coils, the physical size (in terms of face area) can remain unchanged and the configuration of the coil (number of rows and fins/in. or both) adjusted to accommodate low temperature operation.

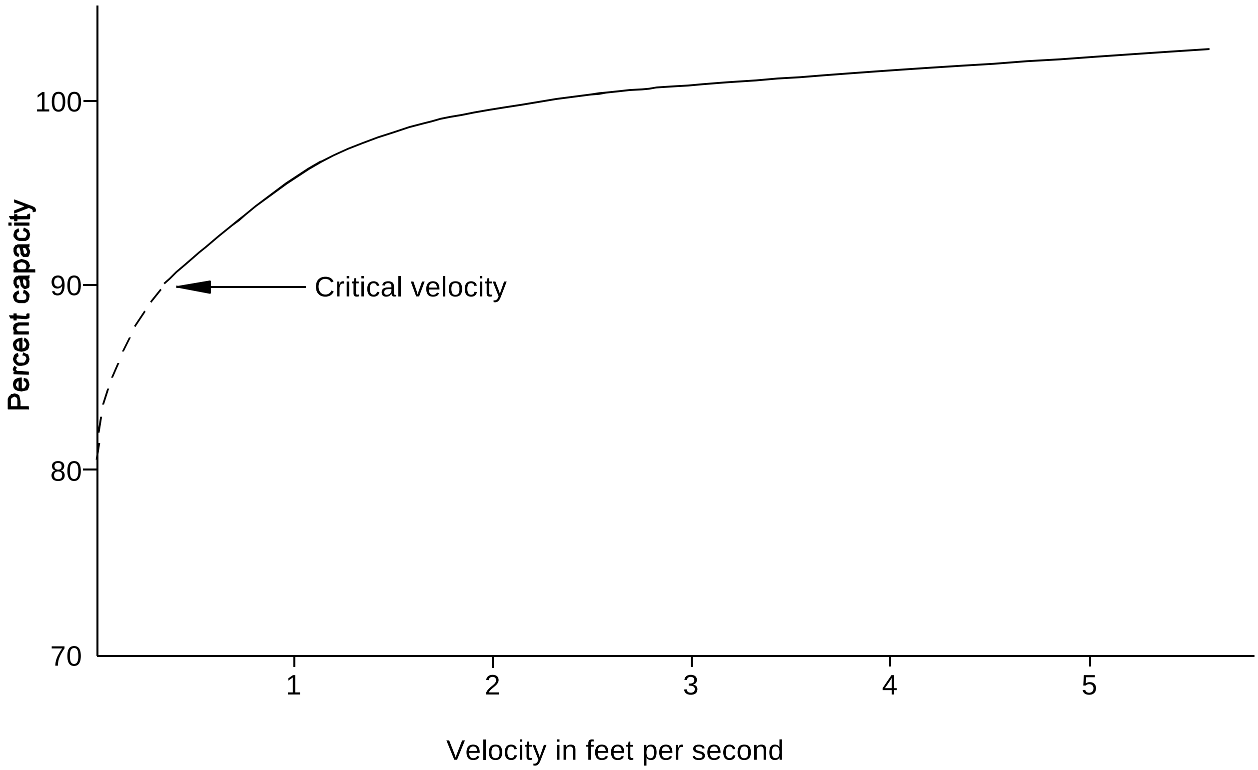

Figure 12.1 The effect of low water velocity on heat transfer in hot water heating equipment (ASHRAE, 1983).

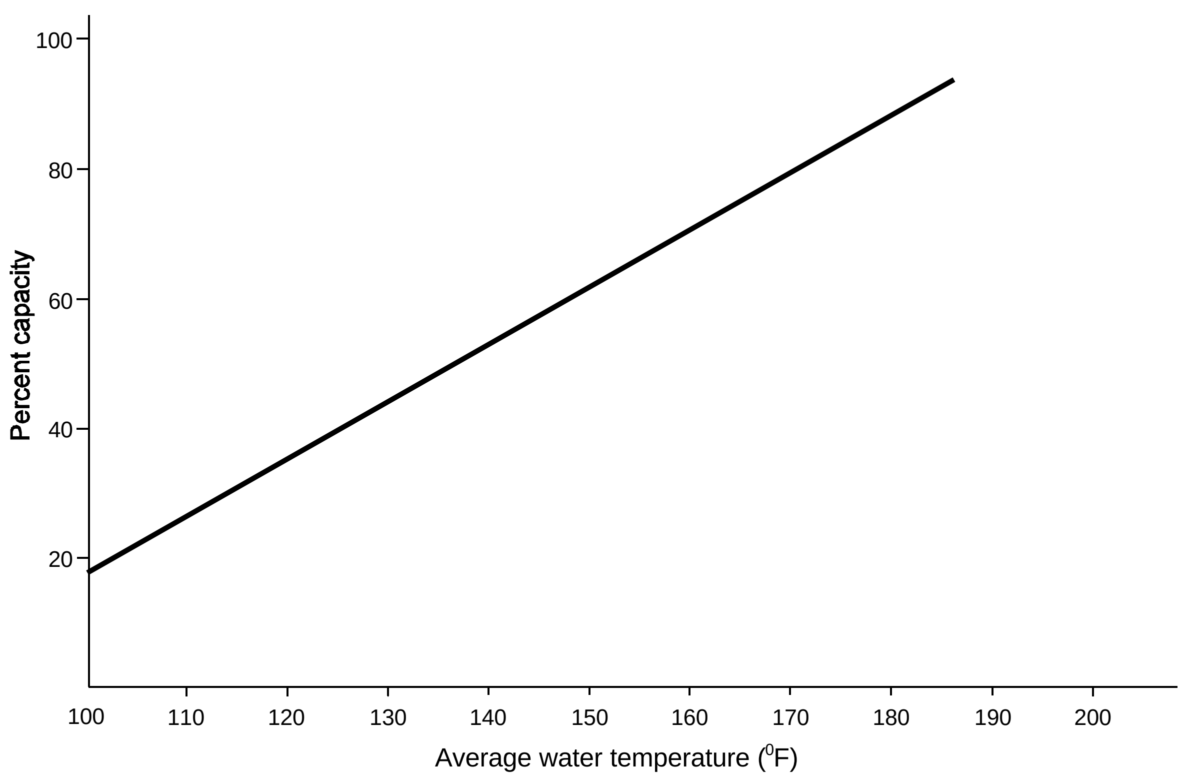

Figure 12.2 Average capacity at reduced water temperature (ASHRAE, 1983).

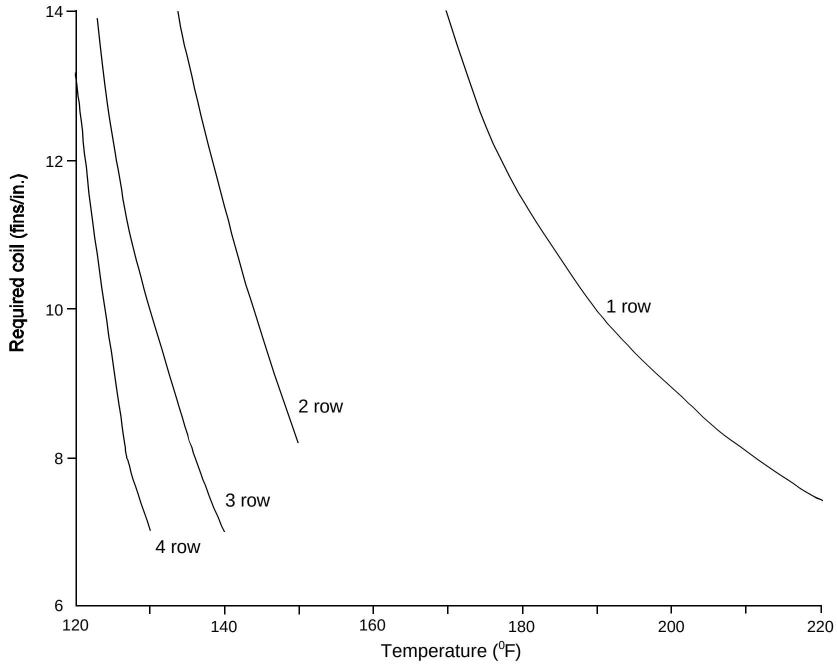

Figure 12.3 Coil configuration for reduced water temperatures.

To illustrate this point, Figure 12.3 presents an indication of the coil configuration required for a specific duty (500 ft/min face velocity, 40° ΔT water, 65°F air in - 100°F air out). Coil surface area (in terms of fins/in. or rows) requirement increases as supply water temperature is reduced. However, as indicated in the figure, a two row coil will suffice down to supply water temperatures of approximately 135°F.

Because the terminal equipment in most large buildings primarily consists of finned coil units, it is useful to explore the impact of deeper coils upon capital and operating costs for a typical application.

Assume a geothermal resource is available that will be capable of producing a building supply water temperature of 140°F. The competing conventional system is a gas boiler that would be operated at a 200°F supply water temperature. Using Figure 12.3, the required coil (for the boiler system) would be a one row, 9 fin/in. model. For the geothermal case, a two row, 11 fin/in. coil would be required.

The left side of Figure 12.4 indicates the air side pressure drop associated with these coils. For the 200°F case, this amounts to approximately 0.08 in. water gauge (in. wg) and for the 140°F case, about 0.21 in. wg.

The two curves on the right side of Figure 12.4 convert these air side pressure drops into operating costs in terms of dollars/ 1,000 cfm (at $.06/kWh and 50% overall fan and drive efficiency). Assuming the application is an office building (approximately 2500 operating h/y), the operating cost for the 200°F case would amount to $3.00/ 1,000 cfm and the 140°F case $7.50/1000 cfm. For a 50,000 ft^2 office building, this would amount to less than $250/y in incremental operating costs for the geothermal terminal equipment over the conventional terminal equip-ment. For buildings operated 24 h a day, or in areas of higher electrical rates, the cost would increase; however, it is unlikely to increase to the extent that it constitutes more than a small fraction of the annual operating costs for the system as a whole.

The second cost factor associated with low temperature operation of the system is the incremental capital cost of the low temperature equipment over the standard temperature equipment. For finned coils, this cost increase can be estimated by the ratio of the number of rows to the 0.45 power as follows:

- One row coil cost = $110/$ft^2$ (typical of coils of approximately 4.0 ft^2 each)
- Two row coil cost = $(2/1)^{0.45}$ x ($110) = $150 /$ft^2$.

This relationship is developed from coil costs appearing in the Means Mechanical Cost Data (1990) and from previous project cost data on file in the Geo-Heat Center.

For the 50,000 ft^2 office building mentioned above (at 1 cfm/ft^2 and 500 fpm face velocity), this would result in a coil incremental capital cost of approximately $4,000.

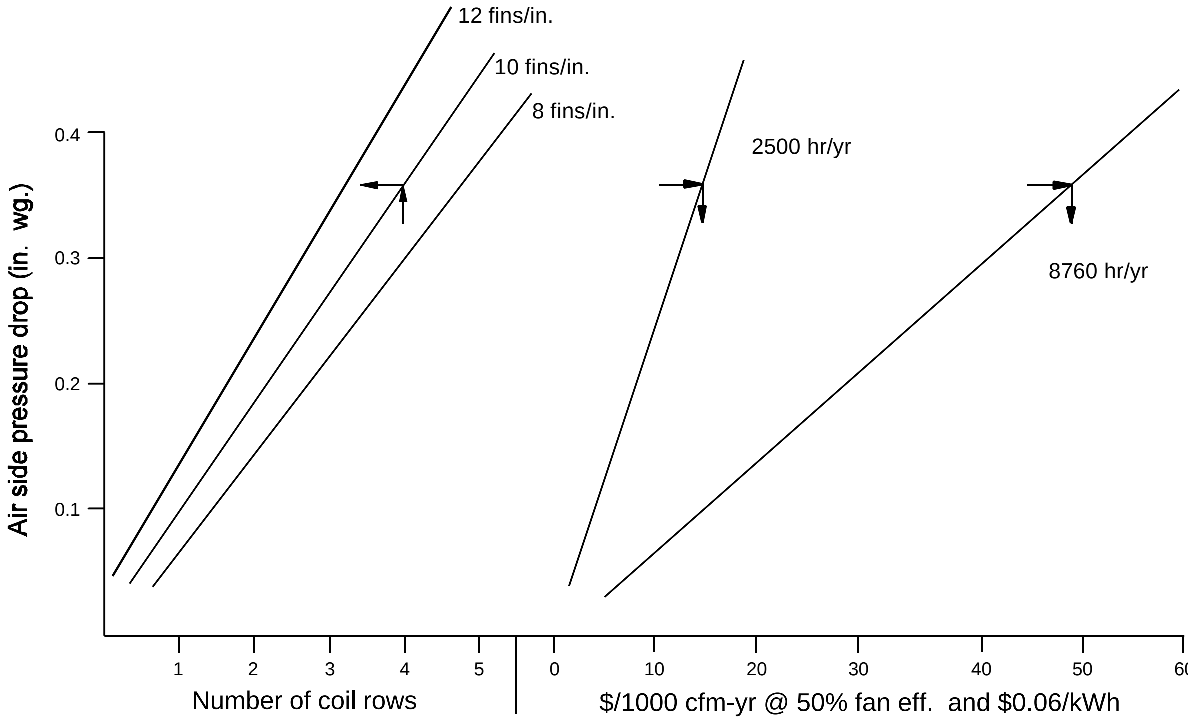

Figure 12.4 Pressure drop and operating costs for hot water coils.

Assuming a variable air volume (VAV) system in the example building with a total heating energy consumption of 20,000 Btu/ft^2·yr, the savings in energy consumption (at $0.50/therm) would repay the incremental coil cost in less than one year even when incremental fan energy costs are deducted from the savings.

12.3 USE OF HEAT EXCHANGERS

Most geothermal systems will employ a heat exchanger to isolate the building heating loop from the geothermal fluid. As a result, the supply water temperature available to the heating system will be less than the geothermal resource temperature. In most cases, an allowance of a 10^{o}F loss through the heat exchanger will be sufficient for the selection of heating equipment. Economical heat exchanger selections generally fall between the 5 and 10^{o}F approach to the geothermal temperature. Heat exchangers are discussed more fully in Chapter 11.

12.4 CONTROLS CONSIDERATIONS

Certain control strategies enhance the effectiveness of using a geothermal resource in a building HVAC system. Some of the more important of these are discussed in the paragraphs below.

12.4.1 <u>Main Heat Exchanger Control</u>

Most geothermal systems use a plate type heat exchanger to isolate the building's circulating loop from exposure to the geothermal fluid. A variety of options can be used for control of this heat exchanger.

A method that can be utilized when the user has little or no control over the resource temperature and flow rate is shown in Figure 12.5. Under this design condition, the primary side of the heat exchanger is permitted to run wild (operate without temperature control) and temperature control is accomplished on the secondary side. This approach may be used for applications that involve cascaded resources, or when a constant resource flow must be maintained. A three-way valve on the secondary side of the heat exchanger is used for supply water temperature control.

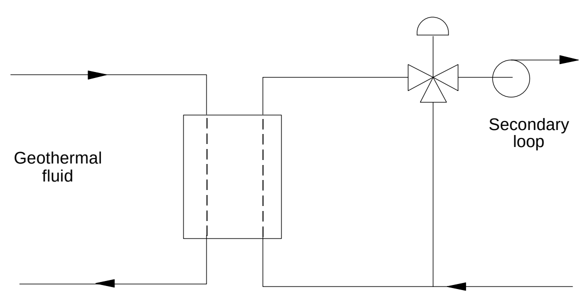

Figure 12.5 Heat exchanger used to isolate building heating loop from geothermal fluid.

Because most larger geothermal systems produce fluid from a well, there is adequate control of the source. As a result, control is applied to the primary side of the heat exchanger. In most cases, it is desirable to use a two-way control valve at the heat exchanger. The two-way valve allows for either throttling control of the production well pump or, when used in conjunction with a variable speed drive, allows control of the drive through production line pressure. In this way, only the quantity of geothermal fluid necessary to meet the load is pumped.

For temperature control, it is acceptable to place the control valve on either the inlet or outlet of the heat exchanger. Because of the very small fluid volume in the plate heat exchanger, there is little thermal mass to interfere with response to load changes as can sometimes be the case with downstream control valve locations in other applications.

In some cases, it may be desirable to place the control valve at the heat exchanger outlet. This location is preferred when the geothermal fluid contains a high percentage of dissolved gases, particularly CO_2. It is common for such gases to come out of solution when the fluid pressure is reduced (such as at a control valve) below the gas saturation pressure. Release of CO_2 can change the fluid pH to allow other species to precipitate out on nearby surfaces. However, downstream location for the control valve maintains the pressure on the heat exchanger to prevent such an occurrence.

Under most circumstances, the valve is controlled to maintain a particular supply fluid temperature. This set point can be reset by a discriminator control or by outdoor air temperature, depending upon the design of the system.

12.4.2 Supply Water Reset Control

Using a supply water reset control on the building loop, if possible, is desirable because this type of control results in a reduced supply water temperature with reduced load. Assuming a constant geothermal fluid temperature, such control allows for an increasing ΔT on the geothermal side of the heat exchanger as load decreases. This, in turn, allows for reduced fluid flow requirements from the production well. Reduced flow rates are always desirable in a geothermal system from both an economic standpoint and for aquifer conservation purposes.

12.4.3 Lower Supply Water Temperatures

Designing for the lowest secondary supply water temperature that is economically feasible reduces geothermal flow requirements. At a constant resource temperature, progressively lower supply water temperatures (on the building side of the heat exchanger) result in correspondingly lower geothermal flow requirements assuming a constant approach to the return water temperature.

12.4.4 Design for Higher System ? T

For purposes of reduced geothermal flow, it is desirable to design for larger than the standard 20°F temperature difference. Depending upon the specific design, a Δ T of 30 to 40°F or more is desirable.

12.4.5 Use of Two-Way Control Valves

Two-way control valves are the preferred method of control for a geothermal space heating system. In addition to their superior control characteristics in general, they provide additional benefits for geothermal systems. With two-way valve control, the system responds to load reductions at a relatively constant ΔT. This contrasts with the three-way valve or "constant" flow control under which the system ΔT decreases with the load. The ability to maintain higher system ΔT is desirable with geothermal systems. Two-way control provides this feature (Haines,1983)(ASHRAE, 1984).

12.5 CASCADED USES

Relatively low temperature applications such as domestic hot water heating and ventilation air preheat should be cascaded from the primary space heating heat exchanger if possible. These loads can be served by a physically separate heat exchanger operating on effluent from the primary space heating heat exchanger. Alternately, the load can be served by a duplex type plate heat exchanger. Duplex heat exchangers are discussed in the heat exchanger chapter (Chapter 11, Section 11.2).

12.6 RETROFIT OF EXISTING SYSTEMS

Certain types of heating systems are more amenable to geothermal retrofit than others. For existing hot water systems, adequate operation at lower supply water temperatures may have to be verified. For non-hot water systems, it is likely that new hot water equipment will need to be installed adjacent to or in place of the existing equipment. Over the years, the Oregon Institute of Technology's Geo-Heat Center has gained considerable experience in evaluating heating systems for retrofit. Table 12.1 summarizes the results of this experience with regard to some of the systems that may be encountered. It is important to note that the retrofit suitability of these systems as indicated in the table is not absolute. Site specific considerations can easily alter the ability (either positively or negatively) of a system to accommodate hot water use. Some of these issues will be discussed for specific systems in the paragraphs below.

Table 12.1 Retrofit Suitability Values[a,b] of Selected Heating Systems (Rafferty, 1986)

	Retrofit Suitability	
Air Systems	Single Air Handler	Multiple Air Handler
Low temperature hot water (<150ºF)		
Single zone, multi-zone, dual duct	10	8
Terminal reheat, variable volume, induction	8	6
Standard hot water (180-200ºF)		
Single zone, multi-zone, dual duct	8	7
Terminal reheat, variable volume, induction	7	6
Steam		
Single zone, multi-zone, dual duct	6	6
Terminal reheat, variable volume, induction	5	4
Electric resistance forced air	6	5
Air-to-air split system heat pump	4	3
Fossil fuel fired furnace	5	4
Roof top packaged equipment	4	3
Fossil fuel fired unit heaters	4	3
Water Systems		
Loop heat pump	--	10
Radiant panel	--	10
Fan coil/unit ventilator		
2 Pipe	--	9
4 Pipe single coil	--	9
4 Pipe	--	7
Unit heaters	--	7
Finned tube/convector	--	6
Steam Systems		
Finned tube radiation	--	3
Unit ventilator	--	3
Two pipe cast iron radiator	--	2
One pipe cast iron radiator	--	1
Perimeter Electric Systems		
Electric resistance baseboard	--	2
Through-the-wall units	--	1

a. Suitability values shown above are average. Site specific conditions frequently influence suitability in positive or negative ways. The table addresses only the mechanical considerations of the retrofit. The relative energy efficiency of the existing system also heavily influences retrofit suitability.
b. A value of 10 is best, 1 is worst.

The most important considerations is the degree of excess capacity present in the existing system. This excess capacity, present in most systems, is the result of a number of factors, the most important of which is conservative design practice. In addition, manual methods of equipment selection used in the past resulted in conservative results compared to present automated methods. It is not unusual to find a heating system with an over-design factor of 50% or more. This is a result of the nature of the system design. First, the peak heat loss is calculated, sometimes using unrealistically low outside design temperature that artificially increases the load by approximately 10%. Then a 10 to 30% safety factor is added, a 5% duct loss factor, and a 25% pickup factor (for regain after night set back). When equipment is selected, the capacity may be anywhere from 5 to 20% over the requirements because of equipment availability. When the results of all this are considered together, 1.10 x 1.10 x 1.05 x 1.25 x 1.05 = 1.68, the system can be grossly oversized. As a result, it can be operated at significantly reduced capacity and still meet heating requirements with no difficulty. In many cases, over-designed hot water systems have been operated at much reduced supply water temperatures (lower capacity) and actually provided improved performance through better part-load valve control.

The existing equipment capacity does not always reflect the actual heating requirements of the building. The presence of excess capacity in the existing system generally offers some advantage in the retrofit process.

12.6.1 Air Systems

Air systems involve the delivery of heated air from a central source, generally through a ducted distribution system, to the space to be heated. This group can generally be split into two classifications: (a) large building systems, and (b) small building systems.

Large Buildings

Large building systems include those described in Figures 12.6 through 12.11. Of these, the most favorable for retrofit are the single-zone, multi-zone and dual duct systems (Figures 12.6, 12.7 and 12.8). These systems include only a single heating coil in the central air handler. As a result, retrofit, if necessary, is confined to the mechanical room. The terminal reheat, variable air volume, and induction systems all include coils in the terminal equipment located in each heating zone. Because an individual air handler may serve from a few to several hundred terminal units, retrofit, if any, could be costly for these heating coils. Because the heating coils are located in the occupied spaces, retrofit of the units would be disruptive to the building tenants. The heating coils in these systems are generally designed for a fairly low temperature rise on the air side (that is, the air is generally heated to only 80 to 105°F), which generally allows for acceptable low supply water temperature operation. In the event that the individual zone heating coils will not operate acceptably at the temperature available from the geothermal system, a peaking arrangement with the existing boiler is generally more acceptable than retrofit of the coils. Under this approach, the system operates on geothermally supplied heat for most of the year. During unusually cold periods, the supply water temperature is boosted by the building's existing boiler.

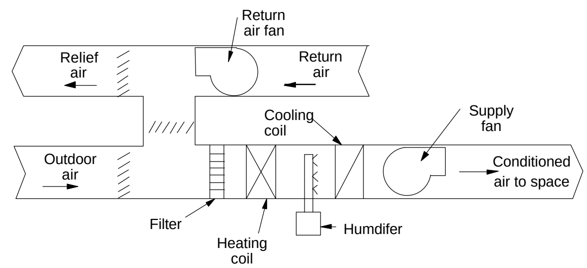

Figure 12.6 Single zone system (Bloomquist, 1987).

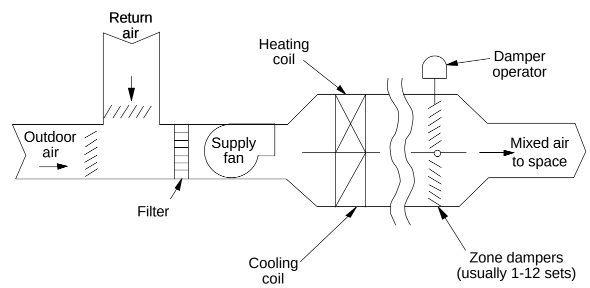

Figure 12.7 Multizone system (Bloomquist, 1987).

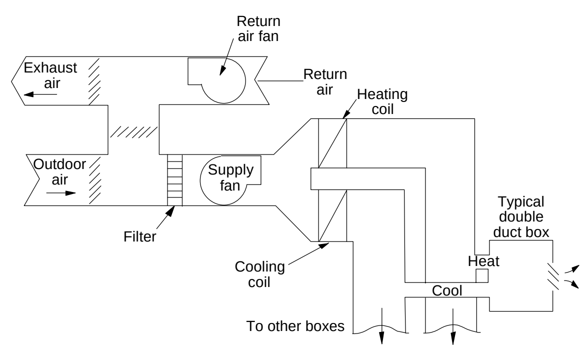

Figure 12.8 Double duct system (Bloomquist, 1987).

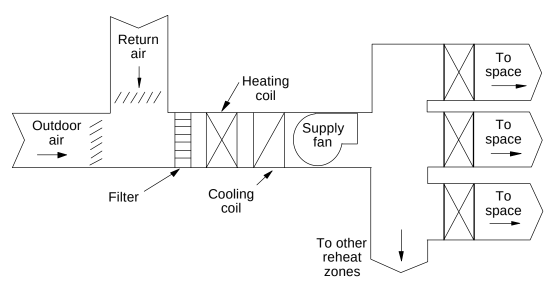

Figure 12.9 Terminal reheat system (Bloomquist, 1987).

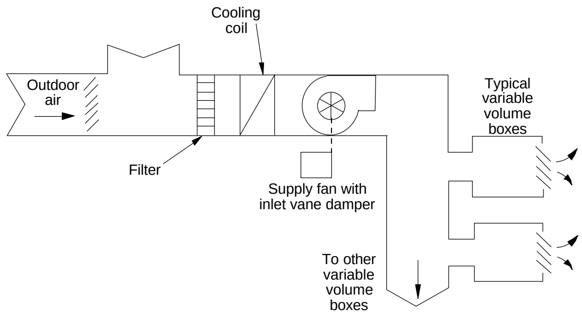

Figure 12.10 Variable air volume system (Bloomquist, 1987).

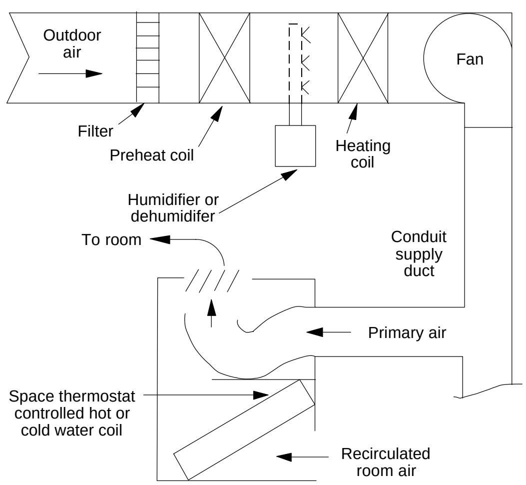

Figure 12.11 Induction system (Bloomquist, 1987).

The large building air systems described above can use low temperature hot water, standard hot water or steam for the heating coils. By far the most common is standard hot water coils designed for 200ºF supply and 180ºF return. Because of over-design, these systems often will operate acceptably at reduced water temperatures. Systems designed in the last 10 years, may use a lower temperature hot water system with supply temperatures from 140 to 160ºF, rather than the standard 200ºF used in the past. These systems are more attractive for retrofit because it is unlikely that any terminal equipment retrofit or peaking will be required. It is rare to find steam used for terminal heating coils in large building air systems, though a few have been designed.

Some air systems, which use larger percentages of outside air (typical of hospitals) or are located in very cold climates, may include a preheat coil in the main air handler. This preheat coil serves to heat the mixture of return air and outside air (or 100% outside air in some buildings) to a temperature of 55 to 60ºF before entering the main duct system. Even when the balance of the system is a hot water design, the preheat coil is frequently designed for steam use. These steam preheat coils would require retrofit for hot water operation.

It is important to use specific design techniques when implementing hot water preheat coils in order to maintain an adequate water velocity that prevents freezing in the coil. This value is generally taken to be approximately 3 ft/s. A number of control strategies are available to accomplish this with most using a recirculation pump at the coil. Hot water preheat coil design is discussed in detail in Haines (1983) and ASHRAE (1984).

Large building air systems are frequently installed with a separate system that provides heating to the perimeter of the building. This second system is usually a hot water radiation- finned pipe system. As a result, it is important to consider the performance of both the central air system and the perimeter system when analyzing the building retrofit requirements. The hot water radiation system will be discussed further under water systems.

A final consideration for large building air systems relates to the number of air handlers used in the building. If retrofit of the main heating coils is required, fewer units are better. During the 1950s and 1960s, it was a common practice to use a small number of very large air handlers. In recent years, the trend has been the opposite (i.e., large number of small air handlers).

In summary, for large buildings, the most attractive system from the geothermal use standpoint is a single-zone, multi-zone, or dual duct system that uses hot water (or low temperature hot water) heating coils and includes a small number of air handling units.

Small Building Air Systems

Small building air systems are distinct from large building systems in terms of complexity and heat source. In smaller buildings, a separate boiler to supply hot water or steam to the air handlers is generally not included. As a result, individual equipment serves as both the heat source and the air handler as in the case of air-to-air heat pumps, roof top gas/electric units, and fossil fuel fired and electric resistance furnaces. The duct distribution system, if any, is generally much less sophisticated than in the large air systems. Retrofit costs for small building air systems are as much a function of the number of individual units as of the type of unit.

Furnaces of the fossil fuel fired or electric resistance variety are found primarily in small office and municipal buildings, residences, and to some extent, in retail buildings. As indicated in Table 12.1, the electric furnace is considered fair in terms of retrofit ease.

Retrofit cost is influenced by the number of units involved; the fewer the better. Retrofit of this type of system involves the installation of a hot water coil in the supply air duct. Electric furnaces (Figure 12.12), because they are designed for fairly low supply air temperature are considered to be more easily retrofit than fossil fuel fired equipment. The low supply air temperature permits low supply water temperature operation and less costly coil installation (because of larger ductwork); however, it may be necessary to increase fan horsepower to accommodate the higher air side pressure drop imposed by the coil (Knipe, 1987). Finally, electric resistance supplied heat can be very expensive and, as a result, savings can be high when a geothermal system is added.

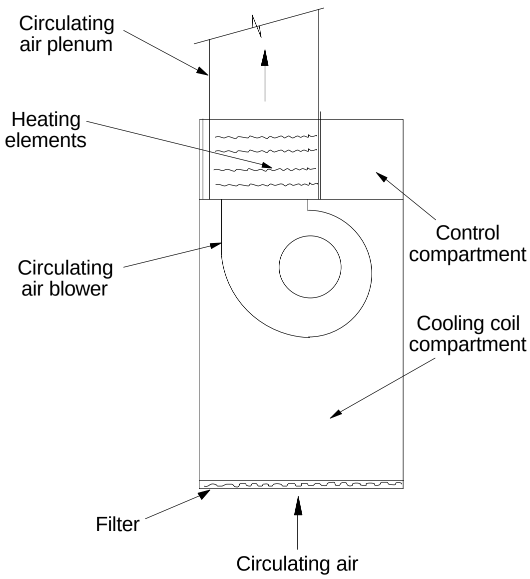

Figure 12.12 Electric resistance furnace (Bloomquist, 1987).

Fossil fuel fired furnaces (Figure 12.13) are somewhat less easily retrofit than electric resistance units. This is because of higher supply air temperature used with this type of furnace, smaller ductwork, and difficulty in coil installation.

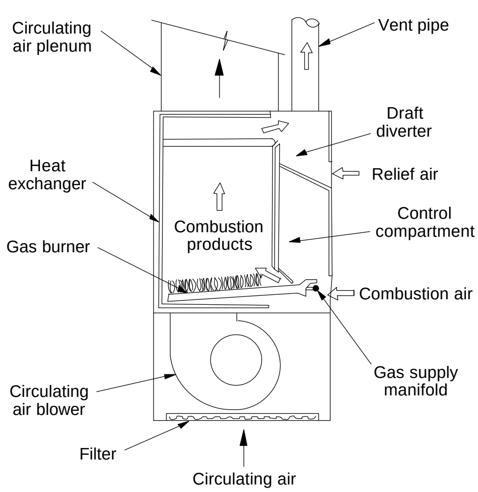

Figure 12.13 Fossil fuel fired furnace (Bloomquist, 1987).

When analyzing any furnace based heating systems, be aware that oversizing of the existing equipment is very likely. Furnaces are available in only a limited number of sizes and installation invariably involves selection of the next larger unit for safety. As a result, the equipment is generally much larger than required. Electric furnaces, because of the higher cost of operation, are less likely than fossil fuel fired equipment to be grossly oversized.

Air-to-air heat pumps are available in two configurations: split system and package. Of the two, the split system is the more easily retrofit. Split systems, as shown in Figure 12.14, involve an outside unit that contains the compressor and a heat exchanger and an inside unit, which contains a heat exchanger unit and a fan. The inside unit is usually installed in a mechanical closet and, as a result, access for retrofit is good. As with the furnaces described above, retrofit consists of the installation of a hot water coil in the supply air unit. Split system heat pumps are most commonly found in small office buildings and residences. Because of their relatively low cost of operation and the likelihood that a large number of units will be installed in a building of any reasonable size, this system is unlikely to be a good candidate for retrofit.

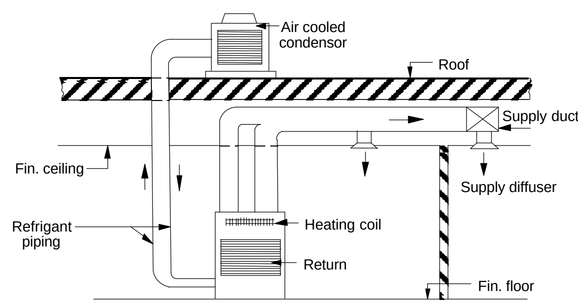

Figure 12.14 Split system air to air heat pump (Bloomquist, 1987).

Rooftop package equipment, as shown in Figure 12.15, can involve an air-to-air heat pump, an electric cooling/ electric resistance heating combination, or more commonly, an electric cooling/gas heating unit. The rooftop package unit is most often found in retail applications, particularly shopping centers, fast food outlets, and in low rise office buildings. The compact nature of this equipment usually precludes installation of a heating coil in the unit itself except in very large capacity units. Coil installation should be in the supply air duct, usually located in a restricted space between the suspended ceiling and the roof (or floor) above. The limited space available, and the requirement to install the coil in the occupied area of the building, results in only a fair rating for this type of system in terms of retrofit suitability. One favorable characteristic of the rooftop system is it virtually always includes air conditioning capability, resulting in somewhat larger ductwork than would be the case for a heating only installation. This larger ductwork reduces hot water coil retrofit difficulties.

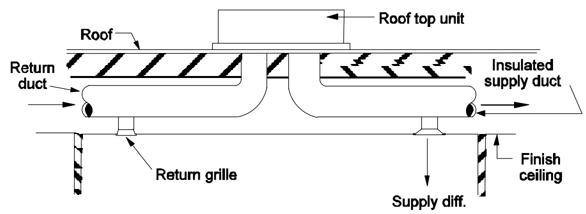

Figure 12.15 Packaged roof top system (Bloomquist, 1987).

The number of units to be retrofit significantly affects the total cost. A building with a single large rooftop unit would be a much more favorable candidate than a similar building with five smaller units.

A final comment on rooftop equipment relates to name plate rating (heating capacity). These units are generally selected on the basis of cooling capacity with little consideration given to the heating capacity. Heating capacity of rooftop package equipment frequently bears little resemblance to actual building requirements and, in many cases, may exceed requirements by a factor of two or three.

Fossil fuel fired unit heaters are a self contained device including a fan, burners, and heat exchanger as shown in Figure 12.16. These units are usually suspended from the ceiling in applications such as smaller food markets, shops, small retail stores, coffee shops, and auto dealerships. The retrofit of fossil fuel fired unit heaters involves replacement with new hot water unit heaters. The suitability of a particular system for retrofit is mostly dependent upon the number of units required. As the number of individual units increases, costs for hot water distribution piping within the building increases, along with equipment costs for the new unit heaters. Because unit heaters are typically used in buildings that require little or no heating during unoccupied hours, savings generated by the retrofit may be very small. As a result, the retrofit suitability of this system is shown in Table 12.1 as a 4.

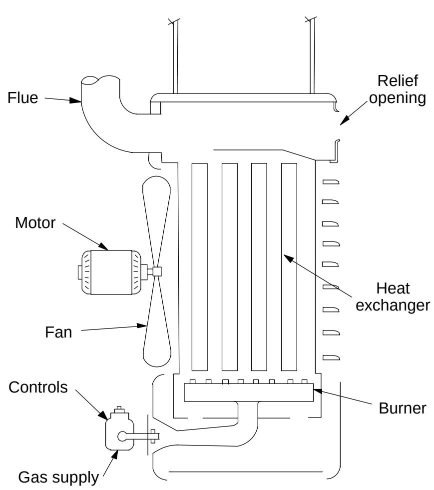

Figure 12.16 Fossil fuel finned unit heater (Bloomquist, 1987).

<u>Location of Retrofit Hot Water Coils</u>

Many of the small building systems discussed thus far involve installation of a hot water coil for retrofit purposes. In many cases, the access to, and the sizing of, the return air duct would result in a much easier retrofit than the supply air duct location. Return air hot water coil retrofits should be avoided. Locating the heating coil in the return air stream results in two primary difficulties because of the elevated return air temperature: (a) reduced fan motor cooling, and b) reduced fan capacity.

Most small equipment is designed for return air cooling of the fan motor. Raising the temperature of the air stream (with the new coil) results in motor overheating. In addition, an increased return air temperature increases the specific volume of the air, thus reducing fan capacity. Placing the coil in the return air stream should be used only when full consideration has been given to these issues.

12.6.2 <u>Water Systems</u>

Water systems can be variously configured, but each will have a main hot water circulating loop that serves a number of individual heating units. Though individual terminal units may use small duct-type distribution systems within their respective zones, water systems do not have a central duct distribution system. Systems included in this chapter consist of: (a) loop heat pump, (b) radiant panel, (c) fan coil/unit ventilator, (d) hot water unit heater, and (e) finned tube/convection.

The loop heat pump system provides for one of the simplest retrofits to geothermal. This type of system, as depicted in Figures 12.17 and 12.18, uses a very low temperature water loop serving a large number of individual heat pump units throughout the building.

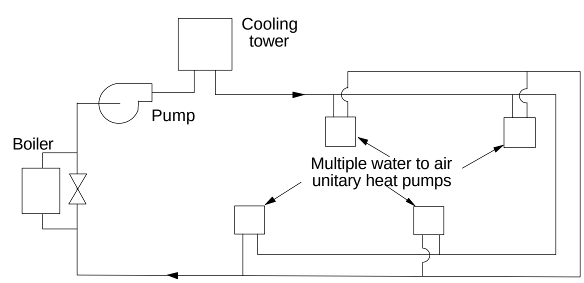

Figure 12.17 Water loop heat pump system flow schematic (Bloomquist, 1987).

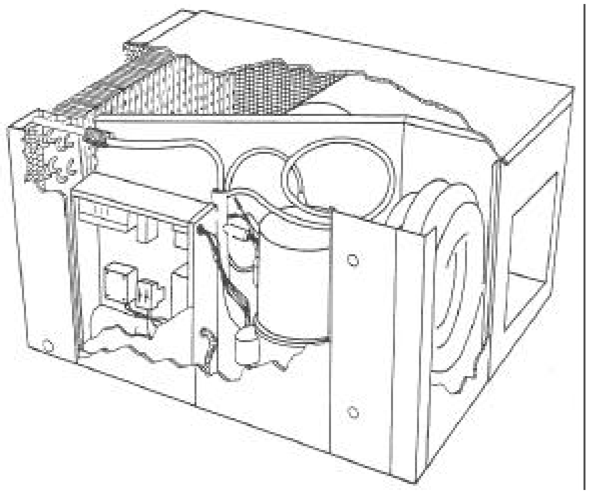

Figure 12.18 Typical water loop heat pump unit (Bloomquist, 1987).

During the cooling season, heat is rejected from the cooling tower to cool the circuit. During the colder periods of the year, heat is added to the loop by a boiler. The attractiveness of the loop heat pump system lies in the fact that the water circuit serving the heat pumps is generally maintained at 60 to 90°F, depending upon the season.

Retrofit of the system involves only the installation of a heat exchanger adjacent to the existing boiler. Because of the low temperature operation of this system in comparison to most geothermal resource temperatures, the heat exchanger requirement is very small. A large temperature drop can be used on the geothermal side of the system. Because of the ease of the retrofit of this system, it is rated as a 10 in terms of retrofit heating suitability. Although the practical retrofit considerations for this system are excellent, economics may be quite poor.

The loop heat pump system is an energy efficient system because it has the ability to recycle heat within the building. This frequently results in a very small auxiliary heating requirement.

The water loop heat pump system is used primarily in large, multi-story office buildings and similar structures that have year round cooling requirements. One variation of the system that would not be suitable for geothermal heating retrofit is the cooling only loop system. Under this design, the individual units are not capable of operating as a heat pump and electric resistance heaters are used for perimeter heating of the building.

Radiant panel systems are rarely used today, but were fairly common in construction of the 1950s. Applications that lend themselves well to this type of system are automotive repair shops,large high ceiling manufacturing structures, and schools. Radiant panel systems as indicated in Figure 12.19 involve the circulation of warm water (90 to 130°F) through piping that is embedded in the floor of the

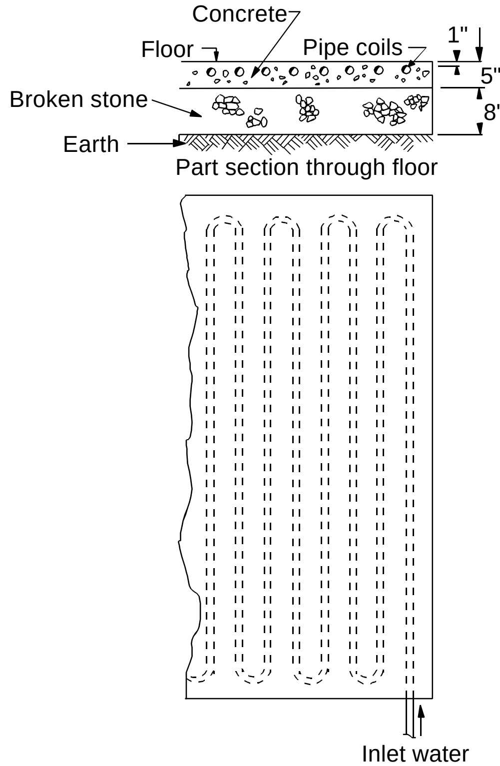

Figure 12.19 Radiant panel system (Bloomquist, 1987).

building. Older systems were constructed with copper or steel piping. Leaks that developed because of expansion and contraction, and corrosion resulted in expensive repair requirements. As a result, the panel system fell into disuse for many years. With the advent of new, nonmetallic piping products (primarily polybutylene), radiant panel systems have begun to reappear.

Retrofit of the system consists of the installation of a heat exchanger adjacent to the system boiler. As with the loop heat pump system, the low temperature operation of the panel system greatly enhances retrofit prospects in comparison to other hot water systems. As shown in Table 12.1, the system rates a 10 in retrofit suitability.

Fan coil (FC) and unit ventilator (UV) systems or both are found primarily in hotel/motel chains and schools. The system consists of a main hot water loop that serves a large number of terminal units located throughout the building. Coil units, as shown in Figures 12.20 and 12.21, consist of a sheet metal box containing a fan, air filter, and one or two coils. A unit ventilator is similar to a fan coil unit with the exception that it contains accommodations for the supply of outdoor air for ventilation.

Two types of FC/UV systems are available: two pipe and four pipe. The two or four pipe designation refers to the water distribution system serving the terminal equipment. A two-pipe system includes only one supply

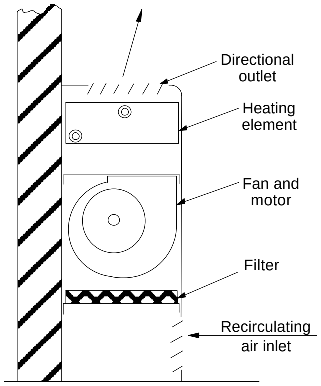

Figure 12.20 Vertical fan coil unit (Bloomquist, 1987).

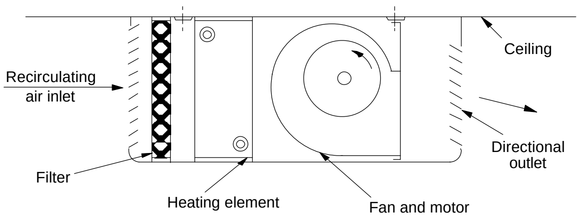

Figure 12.21 Horizontal fan coil unit (Bloomquist, 1987).

line and one return line. As a result, it can supply only heating or cooling to the building at any particular time. Fan coil units and unit ventilators served by a two pipe system (Figure 12.22) contain only one coil that serves as heating or cooling coil, depending upon the season.

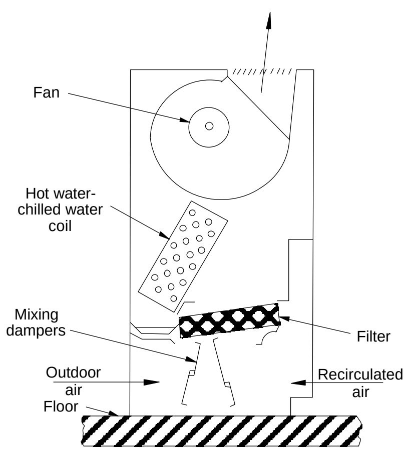

Figure 12.22 Unit ventilator served by two pipe system (Bloomquist, 1987).

For purposes of this discussion, the four pipe single coil system will be considered as a two pipe system because its design offers similar advantages with respect to low temperature retrofit.

Because the coil must perform both heating and cooling functions, it is designed for the most demanding duty, which is cooling. As a result, it is able to meet heating requirements at very low water temperatures (<120°F). This low temperature capability provides the same advantages discussed above for water systems.

The four pipe system includes a distribution system that contains both hot water supply and return lines and chilled water supply and return lines. As a result, either heating or cooling can be delivered to any zone at any time. Terminal equipment (fan coil units or unit ventilators) for the four pipe system usually contains both heating and cooling coils as shown in Figure 12.23. Heating coils in these units generally require much higher water temperature than two pipe system units.

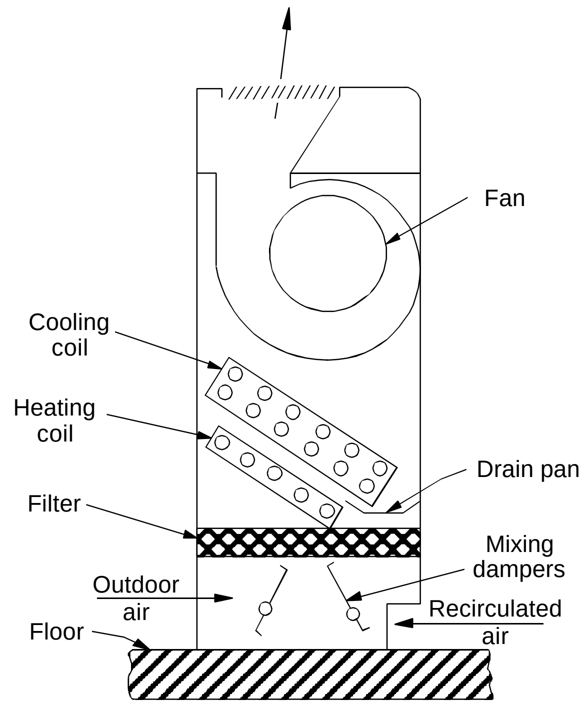

Figure 12.23 Unit ventilator served by 4-pipe system (Bloomquist, 1987).

As a result, if expected supply water temperatures under the geothermal system are to be less than existing system supply water temperature, coil retrofit or peaking would have to be evaluated for this system.

In recognition of the low temperature capability of the two pipe system its retrofit suitability index is shown as 8 and the higher temperature four pipe system as a 6.

Hot water unit heaters are a simpler version of the system described above. This equipment is found in applications in which noise generation and aesthetics are less of a consideration, such as automotive repair shops, warehouses, supermarkets, and small retail stores.

Unit heaters are available in two basic configurations: horizontal (Figure 12.24) and vertical (Figure 12.25), with horizontal units the most common. Assuming that the supply fluid temperature after connection to the geothermal system will be equal to or greater than the present supply temperature, this system would be a good candidate. If the expected supply fluid temperature will be less than the existing system, retrofit of the terminal equipment or peaking may be required. When operated on lower than originally designed water temperature, unit heaters produce correspondingly lower supply air temperatures. This can result in a drafty sensation for occupants. However, because of the application in which these units are normally found, a greater latitude can be taken with respect to performance. As a result, this option rates a 7 in terms of retrofit suitability.

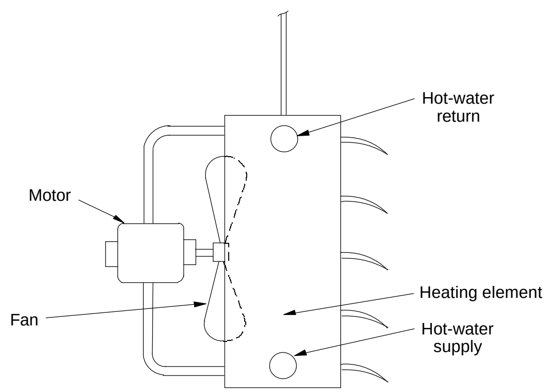

Figure 12.24 Horizontal hot water unit heater (Bloomquist, 1987).

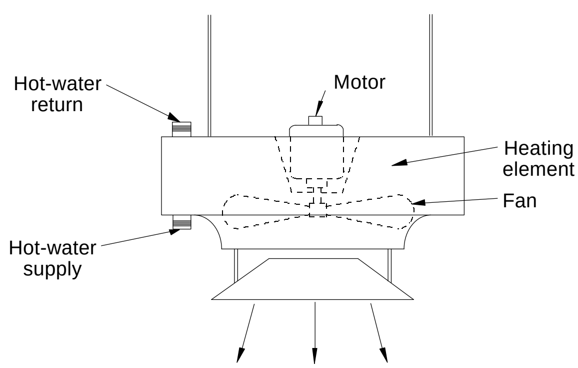

Figure 12.25 Vertical hot water unit heater (Bloomquist, 1987).

Finned tube/convector systems, as illustrated in Figures 12.26 and 12.27, require the highest temperature of all hot water systems. This equipment is found in many types of buildings and frequently in conjunction with an air system in larger buildings. Because this system uses no fans for circulating, it relies entirely on elevated temperature to promote the air convection by which it operates. As a result, it does not perform well at temperatures less than that for which it was designed.

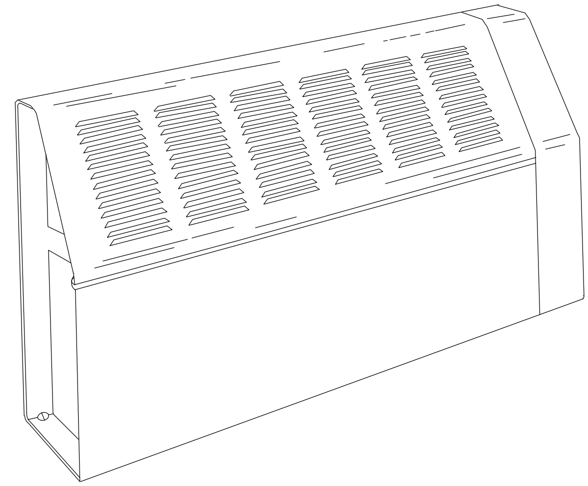

Figure 12.26 Fin tube radiator (Bloomquist, 1987).

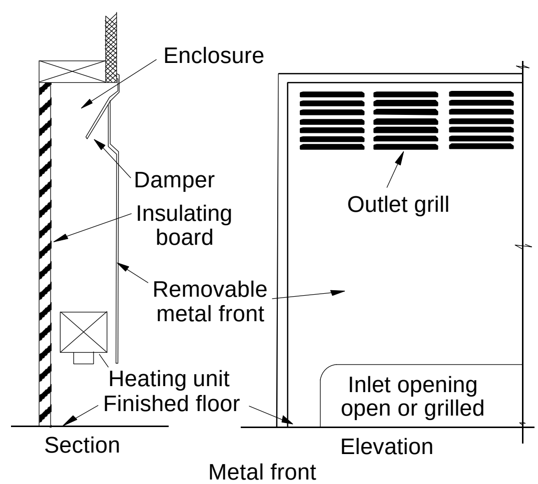

Figure 12.27 Typical recessed convection (Bloomquist, 1987).

Most finned tube/convector systems incorporate a supply water temperature reset control. This control (as described in Section 12.4.2) reduces system supply water temperature as outdoor temperature rises. It is useful to examine the reset schedule on this control and determine the compatibility with the expected supply water temperatures under the geothermal system. In this way, the quantity of peaking, if any, required from the conventional boiler can be determined.

It is also useful when considering the retrofit of a building to lower the setting of the reset controller steadily during cold weather to determine the minimum acceptable operating temperature for the system. In some cases, lowering the water temperature actually results in improved system performance.

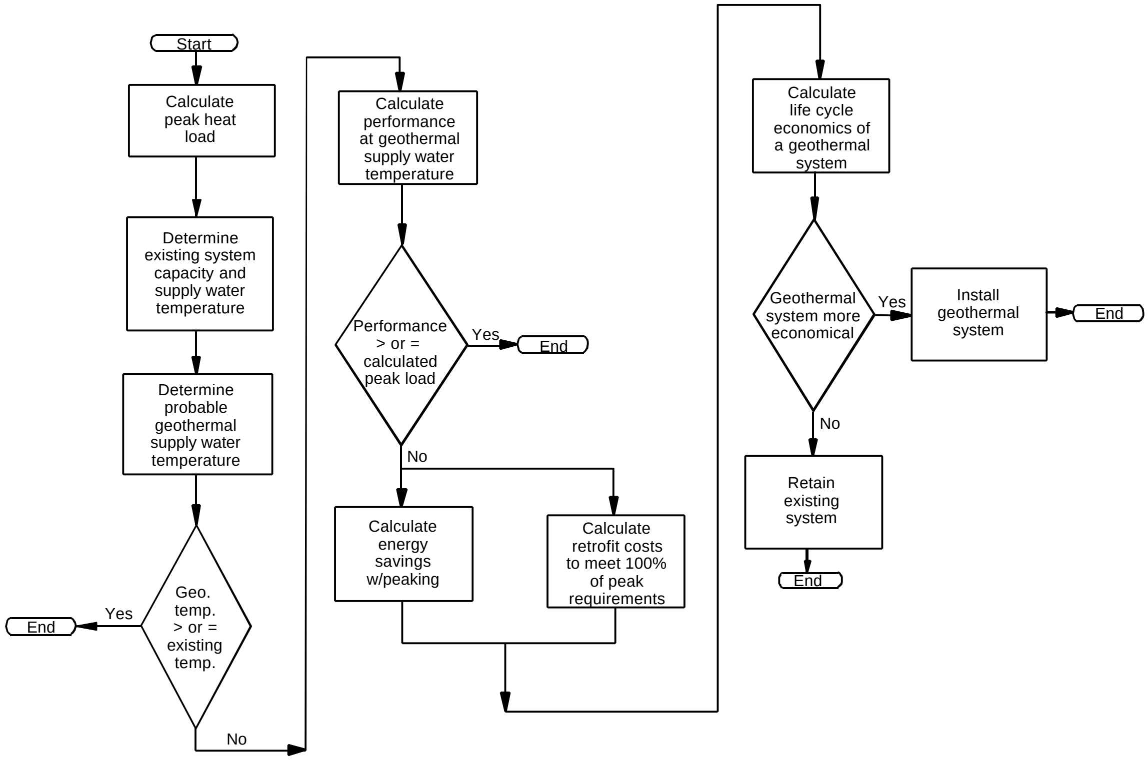

Figure 12.28 Retrofit analysis flow diagram.

As with most other water systems, retrofit of the equipment is generally less economical than occasional peaking with the conventional boiler. The design philosophy for finned tube systems involves using a relatively low output/ft (Btu/h· lf) of element so as to result in a large length requirement, thus covering most of the inside perimeter of the building. As a result, it is difficult to compensate for lower temperature operation by installing additional heating elements.

The hot water finned tube/convection system is rated as a 6 in terms of its retrofit characteristics.

Because many of the air systems described above and all of the hot water systems involve distribution of hot water to some form of heating equipment, a procedure for evaluating these systems for geothermal retrofit systems is necessary. The following outlines such a procedure. Figure 12.28 is a flow diagram for a retrofit analysis of an existing hot water system.

The first step is to calculate the peak heating requirements in Btu/h. This is the quantity of heat the heating system must supply to keep the building warm in the coldest weather. It is important to be as accurate as possible and to use realistic design temperatures such as those published by ASHRAE (ASHRAE, 1985). The design load is critical because it will determine the required capacity of the heating equipment. An overly conservative approach, such as that described earlier, will suggest a more extensive retrofit or peaking requirement than is actually necessary.

Next, the installed capacity of present equipment is determined. This can most easily be accomplished with the building design drawings. A comparison of the calculated load from the first step and the installed capacity will give an immediate indication of the degree of oversizing in the present system.

Determine the present supply water temperature. Because many larger systems involve a temperature reset schedule, it is not acceptable to simply check the supply temperature at any time. It must be monitored during the coldest weather period or verified at the reset controller.

Next, calculate the probable supply water temperature under geothermal operation. If the installed capacity is much larger than the calculated heating load, then it is likely that the system can be the probable supply temperature is equal to or greater than the existing system supply water temperature, the analysis need proceed no further. The system will operate acceptably with no equipment retrofit. If the geothermal system water temperature is less than the existing supply temperature, it is necessary to calculate the existing equipment performance at the reduced temperature. As a first cut, Figure 12.29 can be used to estimate this value. The correction factor for the probable geothermal supply fluid temperature divided by the factor for the existing temperature, multiplied by the existing capacity will give the new capacity of the system. If this value is at or above the calculated heating load, the analysis is completed. If the capacity is less than the calculated requirement, two options should be evaluated: (a) retrofit

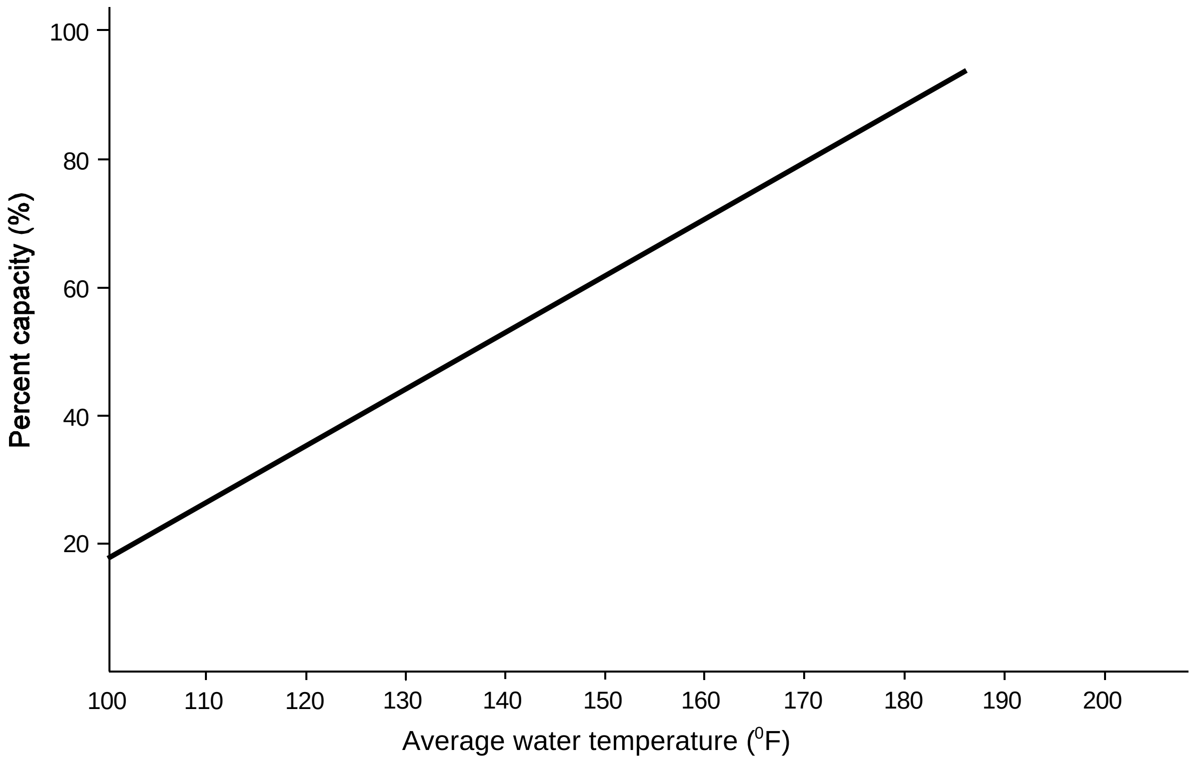

Figure 12.29 Performance of hot water equipment at non-standard temperatures (ASHRAE, 1983).

requirements (and cost) to meet 100% of the design load, or (b) quantity of annual energy that could be met by the reduced capacity geothermal system and conventional peaking.

Retrofit requirements to meet the entire peak load would consist of equipment replacements and the installation of additional equipment or both. The possibility of using existing cooling coils for heating purposes can substantially reduce retrofit costs. This approach is generally more favorable in situations where the geothermal supply temperature is significantly less than the present supply temperature, and there is only a small number of units to retrofit or both. The second option is usually more economical if the geothermal supply temperature is close to the existing system and there are a large number of units to be retrofit or both. Figure 12.30 illustrates the reason for this. The figure is a generalized plot of percentage of peak load versus annual hours of operation. It is apparent from the figure that once 60% of the peak load has been met, the bulk of the annual space heating energy requirements have been met. Supplying the remainder of the requirements with a conventional peaking system would not result in significant fuel costs.

After determining the more economical of the above two options, the final step is to calculate the overall economics of the geothermal system, including capital and operating costs for the balance of the system.

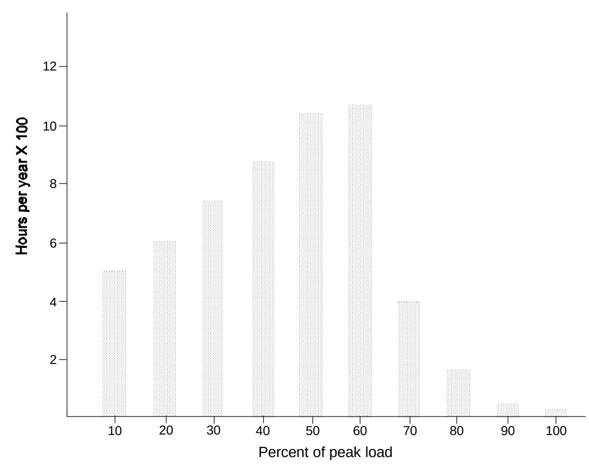

Figure 12.30 Annual hours of operations versus percent of peak load (Bloomquist, 1987).

12.6.3 <u>Steam Systems</u>

As with the water systems, steam systems may take a variety of configurations. Those included under this classification are: (a) finned tube radiation/convector, (b) unit heater/unit ventilator, (c) two pipe cast iron radiation, and (d) one pipe cast iron radiation.

The principle characteristic which distinguishes these from other systems is the use of a steam heating medium directly in the terminal equipment. Many buildings contain a steam boiler but use a convector to produce hot water for heating purposes. The system described in this section delivers the steam directly to the heating equipment. This is generally low pressure steam at 15 lb/in.^{2} (psi) or less. As a result, it has a temperature of approximately 200 to 240ºF. This illustrates the primary disadvantage of steam equipment for geothermal heating operations. It is unlikely that most geothermal systems will be capable of delivering water that is hot enough to generate steam for the existing building's steam system. Because the supply water temperature for a hot water system will likely be less than 200ºF, the steam equipment will operate at a much reduced capacity because it was designed for 200 to 240ºF. If the system does not contain sufficient excess capacity to accommodate this, much of the terminal equipment will have to be replaced or significant peaking will be needed.

A second difficulty with steam systems that must be converted to hot water lies in the piping arrangement. Steam systems produce heat by allowing the steam to condense in the heating equipment. For each pound of steam condensed, 1000 Btu is supplied to the space. When the steam condenses, a large volume reduction occurs (1 lb of condensate or water is much smaller than 1 lb of steam). To accommodate this volume reduction, steam systems employ very large lines to deliver the steam to the heating equipment and very small ones to carry away the condensate. When the system is converted to hot water, the steam piping is usually much larger than required, which does not present a problem. The condensate lines, however, are frequently much smaller than required for the hot water flow. These lines, in some cases, must be replaced with adequately sized piping.

Steam controls are rarely acceptable for hot water operation. As shown in Figure 12.31, steam systems include not only a valve to control the flow of steam to the heating equipment, but a trap for regulating condensate flow out of the equipment. In a conversion to a hot water system the steam control valve should be replaced with a hot water control valve and the trap removed from the line.

The difficulty of the replacement of this equipment is compounded by the fact that most steam systems are at least 25 years old, and many are closer to 50 years old.

In summary, the magnitude of the retrofit requirements for steam systems frequently causes them to be uneconomical to connect to geothermal systems.

Finned tube radiation/convector systems operated on steam are very much the same as those described under the hot water systems above. The difficulty associated with installing additional elements discussed above is compounded by a large capacity reduction that is experienced in converting from steam to hot water. When piping and controls replacement are considered, this system is rated as only a 3 in terms of retrofit suitability.

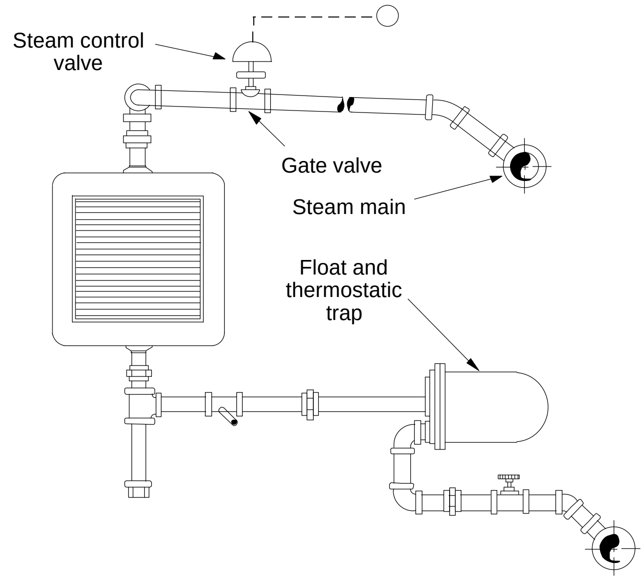

Figure 12.31 Steam unit heater (Bloomquist, 1987).

Unit ventilator systems for steam operation are the same as those discussed under the hot water section. It is possible to replace the steam coil in the unit ventilator with a hot water coil. However, because of the age of most steam unit ventilator systems, experience has shown this to be uneconomical in comparison to replacing the existing unit ventilator with a new hot water unit ventilator. Many of the unit ventilator systems, particularly those in schools constructed during the 1940s and 1950s, have steam piping installed in trenches around the inside perimeter of the building. These trenches do not provide adequate access to the piping for replacement of the condensate system and this greatly increases retrofit cost.

This system is rated as a 3 in terms of its ability to accommodate hot water operation.

Cast iron radiation systems (Figure 12.32) are divided into two groups: one pipe and two pipe. Neither of these are particularly suitable for hot water operation.

The one pipe radiation system employs only a single pipe to the individual radiators. This riser accommodates steam flow up the line while condensate flows down. These are the oldest of the steam systems and are generally found in buildings of only a few stories in height. The one pipe nature of this system eliminates any possibility of hot water operation without substantial piping installation.

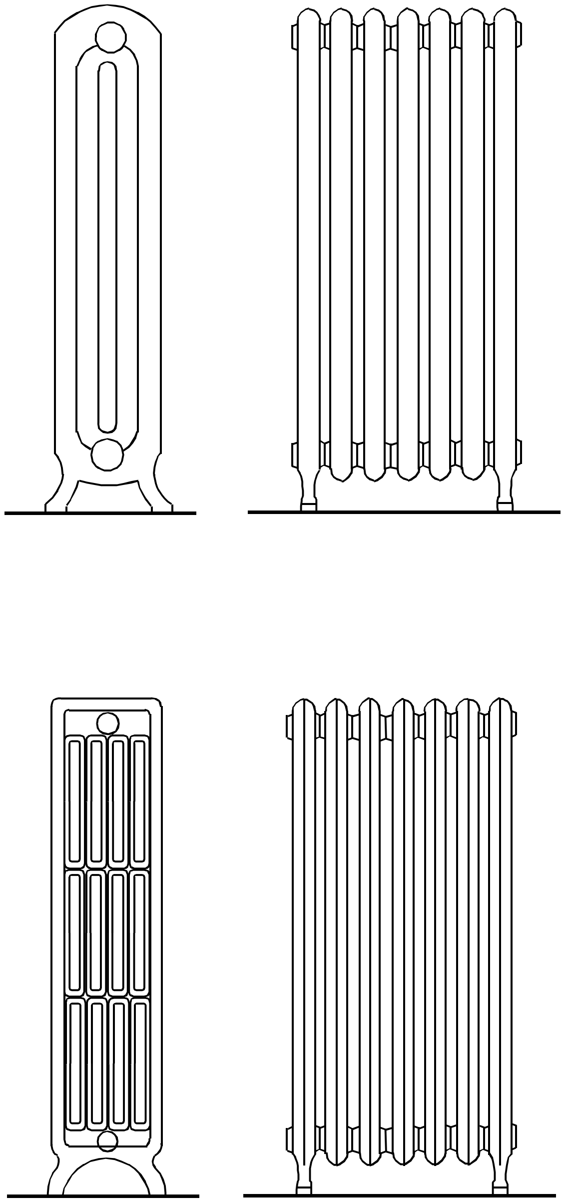

Figure 12.32 Typical cast iron radiators (Bloomquist, 1987).

In addition, it is likely that de-rating for hot water service would result in insufficient capacity. These systems can be considered for retrofit only if a total building remodeling effort is planned.

The two pipe cast iron radiation system is only marginally better for retrofit purposes than the one pipe system. As suggested by the above, the two pipe system employs a separate steam supply line and condensate return line to the heating equipment. Few of these systems have been successfully retrofit for hot water operation. The retrofit generally includes the removal of the steam trap and installation of a new hot water thermostatic control valve (most steam systems have only manual valve control of steam to the radiator). As with all other steam systems, de-rating for hot water service is a problem unless significant oversizing is present. Piping retrofit requirements, with respect to condensate lines, varies greatly. Many smaller buildings (low rise) employ steam and condensate mains in the basement. To these mains, individual risers to each radiator are attached. When this is the case, usually only condensate piping replacement in the basement is required and the risers can remain. In taller buildings, submains are frequently used and a number of radiators on different floors are connected to the same riser. Under these conditions, piping retrofit becomes more complicated and retrofit less attractive.

12.6.4 Perimeter Electrical Systems

These systems are distinct from all of those discussed thus far in that they contain no allowances for piping or duct work associated with the heating system. Heating is provided by some type of electric device such as electric baseboard, unit heaters, or through-the-wall units. The large number of these units typically installed in the building, in conjunction with the requirement to install a completely new heating system, generally renders buildings containing these systems to be low priority candidates for connection to a geothermal system.

The electric resistance baseboard system can be found in many types of buildings from residences to retail buildings to offices. It is typically used in low first cost construction in which the rental tenant will be responsible for the heating bill. As a result, there is little motivation for the owner to convert to a geothermal system, because it is the tenant who will benefit.

For relatively small buildings with central air condition-ing, a hot water coil can be installed in the air conditioning distribution system. In the absence of this approach, a new hot water baseboard or hot water unit heater system must be installed. The relatively poor economics of this magnitude of retrofit result in this system being designated as a 2 in terms of retrofit suitability.

The through-the-wall system involves a unit similar to that shown in Figure 12.33. These units can be either air-to-air heat pumps or electric air conditioners with electric resistance heating. The through-the-wall system is most common in hotels/motels and apartment buildings.

Because one unit is required for each occupied room, the number of units in a single building can easily reach several hundred. This system is nearly impossible to retrofit and is designated as a one.

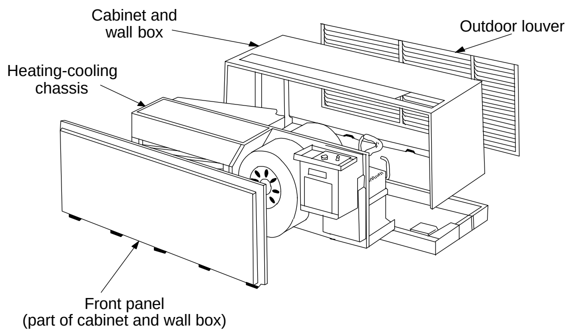

Figure 12.33 Typical through-the-wall type unit (Bloomquist, 1987).

12.6.5 <u>Domestic Hot Water Heating</u>

Domestic hot water heating is frequently served by retrofit heating systems. One of the early determinations to be made in a geothermal feasibility study is whether or not to connect a particular building's domestic hot water system to the retrofit heating system. The decision should be based primarily upon the volume of hot water used in the building. In general, hotels, motels, apartment buildings, high schools, restaurants, hospitals, and health clubs will be characterized by sufficient domestic hot water consumption to warrant retrofit of the existing system. Buildings such as offices, retail stores, theaters, and elementary schools are unlikely to be attractive domestic hot water candidates.

Table 12.12 outlines average hot water consumption for various types of buildings.

The preferred arrangement for domestic hot water heating is shown in Figure 12.34. Under this design, water exiting from the space heating heat exchanger is directed to the domestic hot water heat exchanger. This scheme provides for larger temperature drop in both the end user building and in the retrofit heating system. Larger temperature drops reduce system flow rates and required piping sizes.

Sizing procedures for this type of instantaneous heating arrangement are found in the ASHRAE, 1984 Systems Volume, Chapter 34. Basically, hot water demand in fixture units is determined and the required hot water flow rate for the building in question is found using the Modified Hunter Curves.

Under some conditions, the flow rate from the space heat exchanger will not be sufficient to raise the domestic hot water to the required temperature. In this case, a second circuit connected to the primary hot water supply can be added to the domestic hot water heating heat exchanger. This second circuit would provide the additional boosting of the domestic hot water to the required temperature.

Table 12.2 Domestic Hot Water Consumption for Selected Applications (ASHRAE, 1983)

Application	Consumption Average Day
Men's dormitory	3.1 gal/student
Women's dormitory	2.3 gal/student
Motels: 20 units	20.0 gal/unit
60 units	14.0 gal/unit
100 units	10.0 gal/unit
Nursing homes	18.4 gal/bed
Office buildings	1.0 gal/person
Restaurants (Full service)	2.4 gal/meal
Luncheonettes	0.7 gal/meal
Apartment houses:	
20 or less	42.0 gal/apt.
50	40.0 gal/apt.
75	38.0 gal/apt.
100	37.0 gal/apt.
200	35.0 gal/apt.
Elementary schools	0.6 gal/student
Jr & Sr high schools	1.8 gal/student

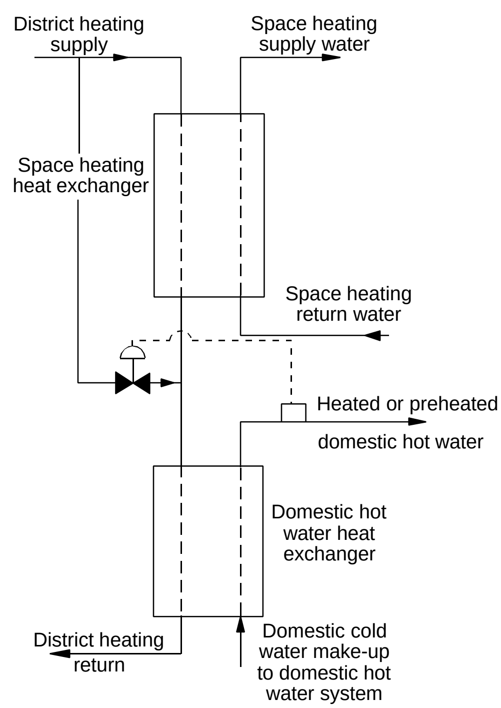

Figure 12.34 Typical domestic hot water heating flow scheme (Bloomquist, 1987).

REFERENCES

ASHRAE 1983 Handbook of Equipment, American Society of Heating, Refrigeration and Air Conditioning Engineers, Chapter 29, Atlanta, GA.

ASHRAE 1984 Handbook of Systems, American Society of Heating, Refrigeration and Air Conditioning Engineers, Chapter 31, Atlanta, GA.

ASHRAE 1985 Handbook of Fundamentals, American Society of Heating, Refrigeration and Air Conditioning Engineers, Atlanta, GA.

Bloomquist, G., et al., 1987. "District Heating Development Guide," Washington State Energy Office, Olympia, WA.

Haines, R. W., 1983. "Control Systems for Heating, Ventilating and Air Conditioning," Van Nostrand Reinhold Company, New York, NY.

Knipe, E., 1987. Personal communication.

Rafferty, K., 1986. "Geothermal Retrofit of Existing Space Heating Systems," Geo-Heat Center Quarterly Bulletin, Vol. 9, No. 3, Oregon Institute of Technology, Geo-Heat Center, Klamath Falls, OR.