SPACE HEATING EQUIPMENT

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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.

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 tempera-tures were chosen largely to result in equipment require-ments similar to those of the older steam systems. Equip-ment 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.

Heat output is relatively unaffected by water side velocity above a certain critical value. It is important when designing for larger than normal ΔT (low flow rate) that the critical velocity for the heating equipment in question be avoided, as capacity falls off asymtotically in this region. 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 1 illustrates the average effect of reduced water temperature on hot water heating equipment performance. Individual terminal equipment types respond differently. Consult ASHRAE (1996) for exact performance.

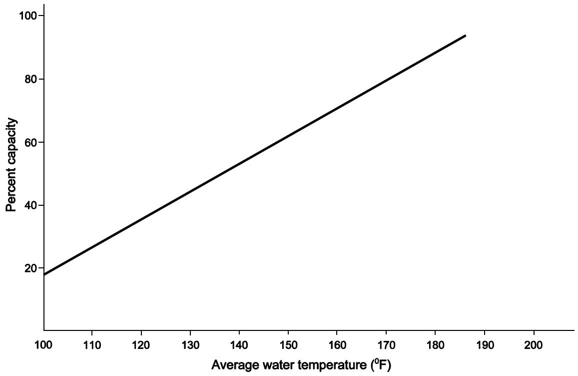

Figure 1. Average capacity at reduced water temperature (ASHRAE, 1996).

Figure 1, 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.

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°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°F approach to the geothermal temperature.

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.

Main Heat Exchanger Control

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 2. 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.

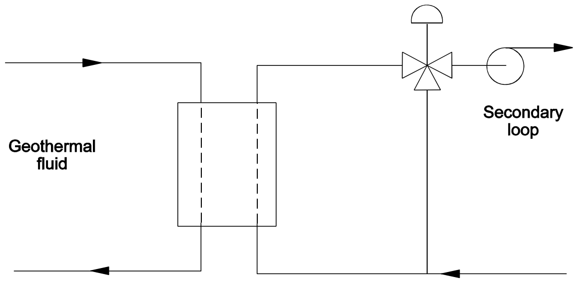

Figure 2. Heat exchanger used to isolate building heating loop from geothermal fluid.

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.

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.

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.

Design for Higher System ΔT

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 ΔT of 30 to 40°F or more is desirable.

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, 1996).

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 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.

Table 1. Retrofit Suitability Values[a,b] of Selected Heating Systems (Rafferty, 1986)

	Retrofit Suitability	
	Single Air Handler	Multiple Air Handler
Air System		
Low temperature hot water (<150°F)		
Single zone, multi-zone, dual duct	10	8
Terminal reheat, variable volume, induction	8	6
Standard hot water (180-200°F)		
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

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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, $1.10 \times 1.10 \times 1.05 \times 1.25 \times 1.05 = 1.68$, 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.

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.

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.

Many of the small building systems 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.

Water Systems

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: (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 Figure 3, uses a very low temperature water loop serving a large number of individual heat pump units throughout the building.

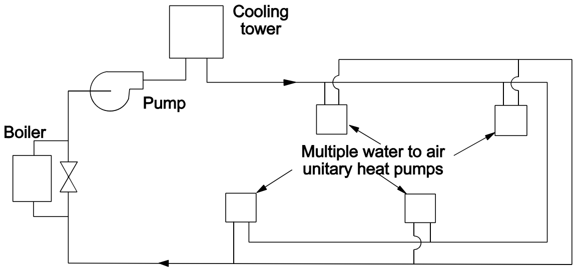

Figure 3. Water loop heat pump system flow schematic (Bloomquist, 1987).

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.

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 involve the circulation of warm water (90 to 130°F) through piping that is embedded in the floor of the 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.

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 4 and 5, 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.

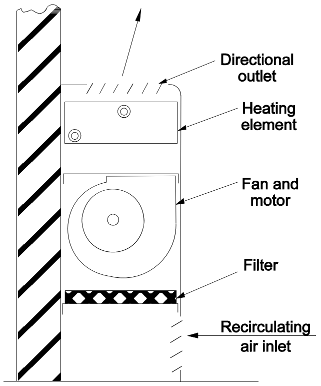

Figure 4. Vertical fan coil unit (Bloomquist, 1987).

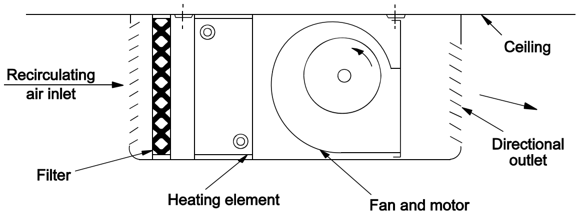

Figure 5. Horizontal fan coil unit (Bloomquist, 1987).

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 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 contain only one coil that serves as heating or cooling coil, depending upon the season.

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. Heating coils in these units generally require much higher water temperature than two pipe system units

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 6) and vertical (Figure 7), 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.

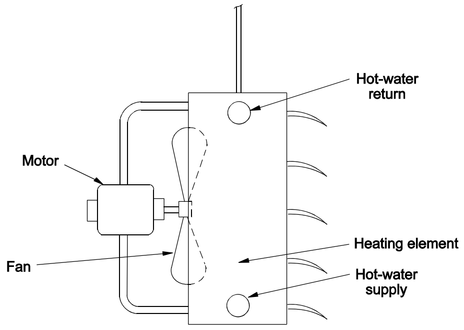

Figure 6. Horizontal hot water unit heater (Bloomquist, 1987).

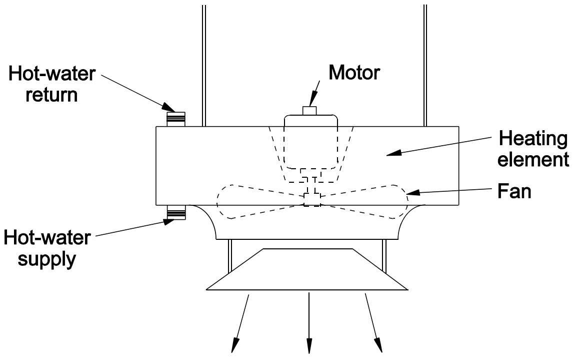

Figure 7. Vertical hot water unit heater (Bloomquist, 1987).

Finned tube/convector systems 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.

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.

Steam Systems

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 240°F. 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 200°F, the steam equipment will operate at a much reduced capacity because it was designed for 200 to 240°F. 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 8, 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.

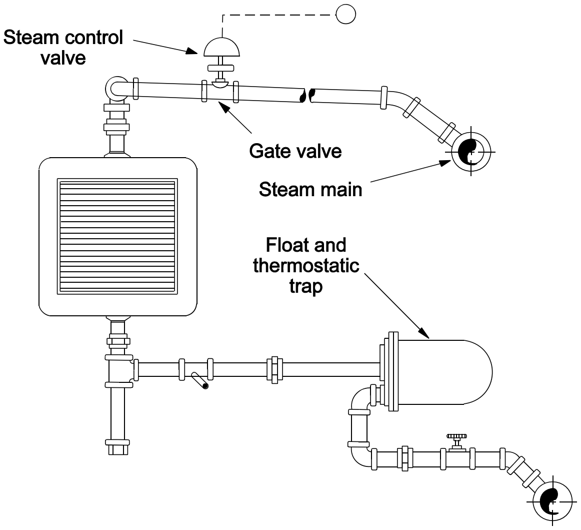

Figure 12.31 Steam unit heater (Bloomquist, 1987).

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.

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

Domestic Hot Water Heating

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.

The preferred arrangement for domestic hot water heating is shown in Figure 9. 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.

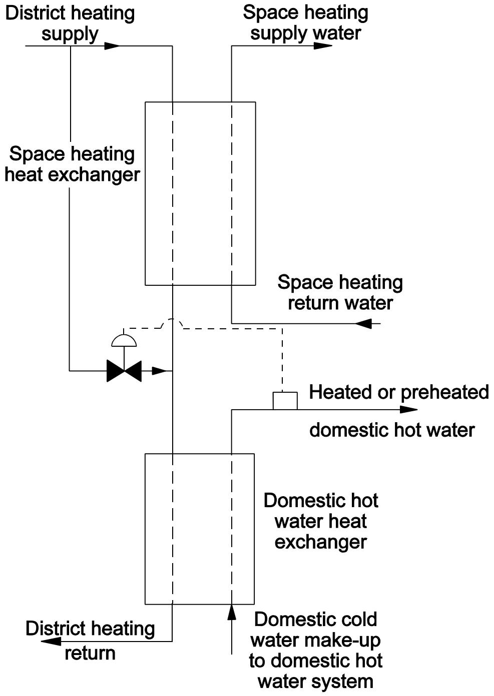

Figure 9. Typical domestic hot water heating flow scheme (Bloomquist, 1987).

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.

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