to use commercial stock sizes of lift fittings, but if these are not available in the sizes required a satisfactory lift connection can be made from standard pipe fittings as shown by Fig. 19. When a lift assembly requires a union, it should be installed in a horizontal run. The use of a lift in any part of the system results in slower heat-up as well as interrupted return of the condensate from the section ahead of the lift. Lift fittings should not be used in place of an auxiliary tank in the return main at the inlet to the vacuum pump receiver.

A condensate pump may be used as a mechanical lift where severe outlying lift conditions cannot be avoided. This may be piped into the system as shown by Fig. 20 in such a manner as not to interfere with the normal functioning of the vacuum pump and without loss of vacuum on the returns preceding the condensate pump.

TWO-PIPE SUBATMOSPHERIC SYSTEMS

Subatmospheric systems are similar to vacuum systems but, in contrast, provide control of building temperature by variation of the heat output from the radiators. The radiator heat emission is controlled by varying the pressure, temperature, and specific volume of steam in circulation. These systems differ from the ordinary vacuum system in that they maintain a controllable partial vacuum on both the supply and return sides of the system, instead of only on

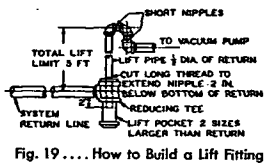

Fig. 19.... How to Build a Lift Fitting

the return side. In the vacuum system, steam pressure above that of the atmosphere exists in the supply mains and radiators practically at all times. In the subatmospheric system, atmospheric pressure or higher exists in the steam supply piping and radiators only during severe weather. Under average winter temperature the steam is under partial vacuum which in mild weather may reach as high as 25-in. Hg, after which further reduction in heat output is obtained by restricting the quantity of steam.

The rate of steam supply is controlled by a valve in the steam main or by thermostatically controlling the rate of steam production in the boiler. The control valve may be of the automatic *modulating* or *floating* type governed thermostatically from selected control points in the building, or it may be a special pressure reducing valve which will maintain the desired subatmospheric pressures by continuous flow into the heating main. In some systems radiator supply valves include adjustable orifices, or are equipped with regulating orifice plates. The sizes of orifices used are larger than for other types of orifice systems because, for equal radiator sizes, the volume flowing is larger. Orifices are omitted on some systems. Radiator traps and drips are designed to operate at any pressure from 15 psig to 26-in. Hg.

Steam for heating domestic hot water should be taken from the boiler header back of the control valve so that pressures sufficiently high for heating the water may be maintained on the heater. The subatmospheric method of

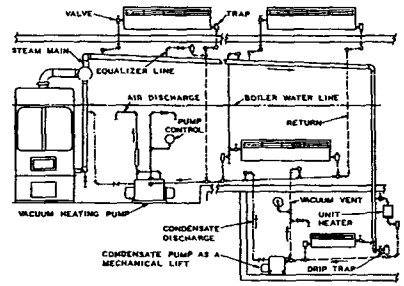

Fig. 20.... Use of Condensate Pump as a Mechanical Lift

heating can be used for the heating coils of ventilating and air-conditioning systems. The flexible control of heat output secured by this method materially reduces the required size of bypass around the heaters. Some applications of subatmospheric systems are proprietary.

TWO-PIPE ORIFICE SYSTEMS

Orifice steam heating systems may have piping arrangements identical with vacuum systems. Some of these omit the radiator thermostatic traps, but use thermostatic or combination float and thermostatic traps on all drip points. A return condensate pump with receiver vented to atmosphere, a return-line vacuum pump, or a return trap, is generally used to return the condensate to the boiler or place of similar disposition, such as a feed-water heater or hot well. The heat emission from the radiators is controlled by varying the pressure differential maintained.

The principle on which these systems operate is that the steam flow through an orifice will vary with square root of pressure drop when the ratio of the absolute pressures on the two sides of the orifice exceeds 58 percent. If the absolute pressure on the outlet side is less than 58 percent of the absolute pressure on the inlet side, no further increase in flow will be obtained as a result of the increased pressure difference. If an orifice is so designed in size as to exactly fill a radiator with 2 psig steam on one side and ¼ psig on the other, the absolute pressure relation is

$$\frac{14.7 + 0.25}{14.7 + 2.0} = 0.90 \text{ or } 90 \text{ percent.}$$

If the steam pressure were dropped to ¼ psig on the supply pipe, the pressure on each side of the orifice would be balanced and no steam flow would take place. From this it will be apparent that if an orifice of a given diameter will fill a given radiator with steam when there is a given pressure on the main, reducing this steam main pressure will permit filling various desired portions of the radiator down to the point where the main pressure equals the back pressure in the radiator, provided the supply pipe pressures are closely controlled. If orifices are designed on a similar basis for a given system and proportioned to the heating capacity of the radiators they serve, all radiators will heat proportionately to the steam pressure. The range of pressure variation is limited by the permissible noise level of the steam flowing under the pressure difference required for

maximum heat output. The control of the steam supply is obtained by a valve placed in the steam main to maintain a determined pressure, and by varying the vacuum in the return lines. The valves are frequently set manually from a remote location, guided by temperature indicating stations in the building; or thermostatically controlled from a thermostat on the roof, which automatically measures the differential of outdoor and indoor temperatures. Since the range through which the pressures may be varied is usually from 0 to 4 psig, the control should be capable of maintaining close regulation of the desired space temperatures, particularly in mild weather.

A recommended orifice schedule is shown in Table 1. Some systems use orifices not only in radiator inlets, but also at different points in the steam supply piping for the purpose of balancing the system to a greater extent. In this manner the difference between the initial and terminal pressure in the steam main may be compensated to a great extent. For example, if the initial pressure is 3 psig and the pressure at the end of the main is 2 psig, an orifice could be used in each branch for the purpose of obtaining a more uniform pressure throughout the system. Such a provision may be particularly useful in this system for branches close to the boiler where the drop in the main has not yet been produced. Some orifice systems are proprietary.

Table 1.... Orifice Capacities for Low-Pressure Steam Systems—Pounds per Hour

This table is based on data from actual tests[a]

Orifice Diameter 64ths of an Inch	6 in. Hg Differential	5 in. Hg Differential	4 in. Hg Differential
7	4.5–5.8	4.0–5.3	3.8–4.8
8	5.8–7.3	5.3–6.8	4.8–6.3
9	7.3–9.0	6.8–8.3	6.3–7.5
10	9.0–11.0	8.3–10.0	7.5–9.3
11	11.0–13.0	10.0–12.0	9.3–11.0
12	13.0–15.5	12.0–14.3	11.0–12.8
13	15.5–18.0	14.3–16.5	12.8–14.8
14	18.0–20.8	16.5–19.0	14.8–16.8
15	20.8–23.5	19.0–21.5	16.8–19.0
16	23.5–26.5	21.5–24.3	19.0–21.5
17	26.5–29.8	24.3–27.3	21.5–24.3
18	29.8–33.3	27.3–30.5	24.3–27.0
19	33.3–37.0	30.5–33.8	27.0–30.0
20	37.0–40.8	33.8–37.3	30.0–33.3
21	40.8–44.8	37.3–41.0	33.3–36.3

Orifice Diameter 64ths of an Inch	2 in. Hg Differential	1 in. Hg Differential	Orifice Area sq in.
7	2.5–3.3		0.00940
8	3.3–4.3	2.0–2.8	0.01227
9	4.3–5.3	2.8–3.5	0.01553
10	5.3–6.5	3.5–4.3	0.01917
11	6.5–7.8	4.3–5.0	0.02320
12	7.8–9.3	5.0–6.0	0.02761
13	9.3–10.8	6.0–7.0	0.03241
14	10.8–12.3	7.0–8.0	0.03758
15	12.3–14.0	8.0–9.3	0.04314
16	14.0–16.0	9.3–10.5	0.04909
17	16.0–18.0	10.5–11.8	0.05542
18	18.0–20.0	11.8–13.0	0.06213
19	20.0–22.0	13.0–14.5	0.06922
20	22.0–24.5	14.5–16.0	0.07670
21	24.5–26.8	16.0–17.8	0.08456

Note.—The radiator orifice plates recommended in this table are made of brass stampings 0.023 in. thick cup-shaped to be inserted in radiator valve unions.

[a] S. S. Sanford and C. B. Sprenger: Flow of steam through orifices into radiators (ASHVE TRANSACTIONS, Vol. 37, 1931, p. 371).

SIZING PIPING FOR STEAM HEATING SYSTEMS

The functions of the piping system are the distribution of the steam, the return of the condensate, and, in systems where no local air vents are provided, the removal of the air. The distribution of the steam should be rapid, uniform, and without noise, and the release of air should be facilitated as much as possible, because an air bound system will not heat readily nor properly. In designing the piping arrangement, it is desirable to maintain equivalent resistances in the supply and return piping to and from a radiator. Arrangement of the piping so that the total distance from the boiler to the radiator is the same as the return piping distance from the heating unit back to the boiler, tends to obtain such a result. The condensate which collects in steam piping as well as in radiators must be drained to prevent interference with the ready flow of the steam and air. The effect of back pressure in the returns and excessive revaporization, such as occurs where condensate is released from pressures considerably higher than the vacuum or pressure in the return, must be avoided.

It is important that steam piping systems distribute steam not only at full *design* load, but during excess and partial loads. Usually the average winter steam demand is *less than half* of the demand at the *design* outdoor temperature. Moreover, in rapidly warming up a system even in moderate weather, the load on the steam main and returns may exceed the maximum operating load for severe weather, due to the necessity of raising the temperature of the metal in the system to the steam temperature, and the building to the *design* indoor temperature. Investigations of the return of condensate have revealed that as high as 143 percent of the design condensation rate may exist under conditions of actual operation. Expressed in gallons per minute per 1000 sq ft equivalent direct radiation the theoretical condensing rate of the system at the design indoor temperature is 0.5. During the warming-up period this value will approach 0.72 gpm.

The piping design of a heating system is greatly influenced by its operating characteristics. Heating systems do not operate under constant conditions, because conditions change continually, due to variation in load. As the system is being filled with steam, the pressures existing in various locations may be different from those which exist for appreciable periods at other locations, although at equilibrium conditions the pressures are approximately the same. In designing piping it is of particular importance to arrange the system to preclude trouble caused by such pressure differences. The systems which readily release the air, permit uniform pressures to be attained in much shorter time intervals than those which are sluggish. Results are given in Fig. 21 from investigations[1] to determine the rate of condensate and air return from a two-pipe gravity heating system. Variations in the steam pressure during the warming-up period, when the rate of air elimination and condensation is high, are clearly indicated in these curves.

It is evident that the condensate flow during the initial warming-up period reaches a peak, which is greater than the constant condensing rate eventually reached when the pressure becomes uniform. Moreover, the peak condensing