chiller, the primary pumps could also be installed into a shared header arrangement. The dedicated pump arrangement is preferable for simplifying controls and allowing the individual pumps to be sized for the particular chiller it serves. The headered arrangement has the advantage of any pump serving any chiller and the ability to have a standby/backup pump. Operating controls are more complex with the headered arrangement.

In a primary-secondary system it is critical that the control system ensures that the primary chilled water flow (primary) equals or exceeds the secondary (load) flow.

One obvious advantage of a primary-secondary system, compared to the primary-only system, is that the primary-secondary system does not require complex chiller staging controls. Another advantage is that the primary-secondary system does not require a bypass valve which could malfunction. Consider a primary-secondary system for applications when a fail-safe system is required or when there are no on-site operations personnel or when operations personnel have limited technical expertise

6.3.4 Chiller Oil Purging

One simple method of increasing efficiency of refrigeration chillers is to reduce the amount of lubricating oil that makes its way into the chiller refrigerant. ASHRAE Research Project RP-751 found that all of the chillers studied had an excessive amount of oil entrained in the refrigerant. The amount of oil in the refrigerant varied from 3 to 23 percent, *see* Figure 6-8. The oil was from the chiller's oil sump and it significantly decreased the chiller's efficiency. Chiller refrigerant can be purged of oil using one of the various commercial refrigerant purging systems. The payback period is typically less than six months.

6.3.5 Cooling Tower

Whether a cooling tower is a forced- or induced-draft type both benefit from the same improvements to reduce energy usage and improve performance. An improperly maintained cooling tower will produce warmer condenser water temperatures. This results in the chiller consuming 2.5 to 3.5 percent more energy for every 1°F (-17°C) increase in condenser water temperature.

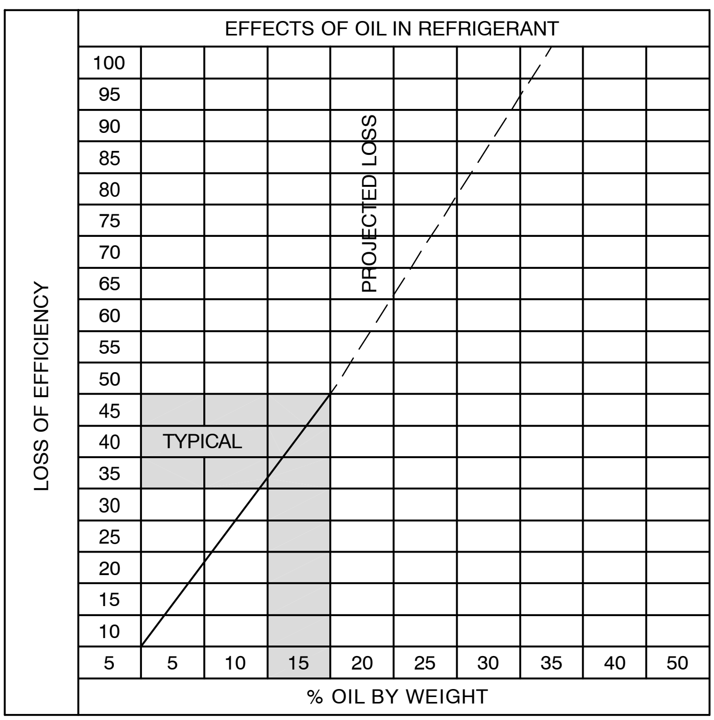

FIGURE 6–8 CHILLER EFFICIENCY LOSS VS. %OIL IN REFRIGERANT

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6.3.5.1 Cooling Tower – Speed Control

Since a majority of the cooling tower's operation is at part-load, reducing the speed of the cooling tower fans and pumps may be an opportunity to reduce energy costs. Operating cooling tower fans at the lowest possible speed while maintaining the required cool water temperature will minimize fan energy. A 2-speed fan motor is an improvement over a single speed motor but a VFD has the potential to yield the greatest savings.

However, maximizing cooling tower fan energy savings may not result in maximizing overall system energy savings. It is possible that running the cooling tower fan at maximum speed to drive down the condenser water temperature will result in greater energy savings due to the decreased load on the condenser. A BAS with real-time energy consumption and analysis is invaluable in knowing the critical operational points to determine whether reduced fan energy provided more savings than lower condenser water temperatures.

6.3.5.2 Cooling Tower – Energy Recovery

During the heating months when a cooling tower is operating at part-load the condenser water may be diverted to heat exchangers to heat or at least pre-heat domestic water or incoming ventilation air.

6.3.5.3 Cooling Tower – Cold Water Basin

Strainers in the cold water basin should be cleaned regularly to keep debris out of the water pump and off of the system components, which decreases the heat transfer efficiency. A good upgrade option is to offer to install a sump sweeper and piping along with a filtration unit to keep the basin free of dirt and debris. The sump sweeper will greatly increase the time it takes for nozzles to clog and buildup debris on the cold water basin, thus maintaining a higher level of increased efficiency and reducing future and ongoing maintenance costs.

6.3.5.4 Cooling Tower – Water Distribution

Look for corrosion, excess debris, and clogged nozzles. For the cooling tower to perform at maximum efficiency the water distribution system must be properly maintained, clean, and in good working order. Clean or replace malfunctioning nozzles so that the spray is evenly distributed for maximum cooling effect. Corrosion and debris both negatively affect the tower's cooling capacity and operating efficiency.

6.3.6 Fan Coil and Package Terminal Air–Conditioner (PTAC) Units

There are three retrofit options with fan coil and PTAC units: service existing unit, upgrade existing unit, or replacement. Each option corresponds with an increasing capital cost to the customer.

Servicing an existing unit will involve the following:

- Steam clean the evaporator and condenser coils and drip pans. Some utilities offer rebates to building owners for this service. Offer a maintenance agreement to perform the steam cleaning every two to three years.
- Check and tighten fan belts.
- Grease bearings.
- Clean the inside of the cabinet and the blower wheel.
- Inspect and clean condensate drain and pan.
- Verify proper operation of controls, thermostats, and sensors.
- Inspect cabinet and mountings for damage and adjustment.
- Inspect and repair/replace access door seals.
- Check and adjust refrigerant charge.
- Inspect, replace, or repair electrical connections and fuses.
- Check amperage draw of compressor and fan to verify performance.

An excellent way to upgrade a fan coil or PTAC unit is to install a variable speed drive (VSD). A VSD will give the fan coil unit the ability to match the delivered airflow to the needs of the occupied space. The VSD can be tied into existing building controls or operate independently. Not only will there be the obvious energy savings, there will be less of the blower throttling on and off, resulting in a quieter and more thermally-uniform environment. Expect an energy savings of 30 to 45 percent after replacing an existing 60 percent efficient motor with a more efficient VSD controlled motor.

If the existing units are over 20 years old or have become a maintenance nuisance, the owner may consider replacement of the existing fan coil units. In this instance, a replacement option is warranted. New fan coil units will be more efficient, use non-ozone depleting refrigerant, have a VSD motor, and have built-in DDC controls that can be tied into a BAS. Since this is likely the most expensive option for the customer, the economic benefit must be obvious and convincing. Benefits will include increased energy efficiency, the confidence of knowing that the refrigerant is not being phased out, and that the equipment will have negligible maintenance costs in the near future.

6.3.7 Variable Refrigerant Flow (VRF)

Variable Refrigerant Flow (VRF) systems have been in use for over 25 years, having been introduced in Asia as a quieter, more efficient alternative to window units. A VRF system varies the refrigerant flow to several individual, independently operated fan coil units. Small refrigerant pipes route "energy" flows throughout the building rather using air in large ducts. A VRF system controls the amount of refrigerant flowing to each of the evaporators, allowing the use of several evaporators of differing capacities and operating schedules.

There is a wide range of reported costs associated with installing a VRF system and the cost savings is very application specific. The two primary benefits are little or no duct is required and independent zone temperature control is provided. Examples of applications that might prove favorable for a VRF system are:

- historical buildings where disturbing the structure is undesirable or prohibited,
- where no mechanical room is available,
- were existing windows meet the code requirement for ventilation,
- where new data centers are added to the interior of an existing building,
- situations where increased air-conditioning capacity is needed but space for duct or larger equipment is limited,
- hospitals and nursing homes to avoid zone-to-zone air mixing, and
- other situations where cooling capacity is needed without additional ventilation or where a DOAS is used to supply ventilation requirements.

VRF systems are inherently heat recovery devices that can cool and heat different areas of a building simultaneously. They are air cooled so there are no issues with water treatment or cooling towers. In multi-tenant buildings sub-metering and reconfiguration is simpler to accomplish. They do not require the extension of chiller piping or central ducts. The small refrigerant piping is easier to route for multi story buildings but VRFs are unlikely to be competitive in single story building applications where roof top equipment can be easily installed. Most VRFs are cooling only so they are at a disadvantage where heating is also required. There are some concerns with the length of refrigerant piping and leaks but if brazed joints are used this should not be an issue.

VRF systems do not typically include ventilation air intakes or economizers so they cannot always—by themselves—comply with code ventilation requirements. VRF equipment ratings and certifications may not be applicable to or compliant with local code requirements. A number of VRF manufacturers are actively addressing these issues so many problems and limitations should be solved in the coming years.

6.4 HEATING SYSTEM

6.4.1 Boilers

More than 60 percent of the 400,000 commercial and industrial boilers in the U.S. are over 20 years old and operate at efficiencies of 60 to 75 percent. Many owners will benefit from boiler replacement or upgrade. To know what savings will result from replacement or retrofit, estimate the efficiency of existing units by measuring excess air, flue and boiler room temps, and percent of flue-gas oxygen and carbon monoxide (CO).

6.4.1.1 Boiler Replacement

It must be emphasized to the owner that the cost of the boiler is actually the smallest portion of owning this piece of equipment. Operating and maintenance costs are by far the most substantial. Think of boiler replacement as a 20 year investment in the purchase price of hot water. Purchasing a more efficient boiler will result in a lower price for hot water for decades to come.

New packaged boilers have efficiencies in excess of 90 percent, and are outfitted with advanced controls, consistent air/fuel ratio, high turndown, excess air, and guaranteed efficiency levels. The boiler manufacturer can often assist with calculating net savings from replacing an old, inefficient boiler with a new one. Paybacks can be compelling.

6.4.1.1.1 Steam Boilers

If possible, replace steam boilers with a new high-efficiency hydronic boiler rather than a new steam boiler.

Studies have shown that water use in steam heated buildings is about twice the national average on a per-person basis. A study of seven buildings in New York concluded that replacing the existing steam boiler with a new steam boiler resulted in a 0.6 percent savings of total heating use, while replacing a steam boiler with a new hydronic boiler resulted in an average savings of 40 percent of heating costs.

Of course, consideration of the differences between steam and water distribution piping design must be taken into consideration. Typically, steam piping is smaller and may be of a single pipe design, especially in older systems. *See HVAC Systems Applications* for detailed explanations of the differences between steam and hot water distribution piping systems. Conversion from steam to hydronic is likely to be more practical where steam air coils are used instead of in baseboard or radiator systems. It may be possible to accommodate the lower total heating capacity of a water versus steam boiler where distribution piping is a factor by making envelope improvements or putting additional heat into the building via a DOAS.

6.4.1.2 Decentralize, Stage, and Downsize

Staging smaller boilers so that each operates at or near full capacity saves energy compared to operating a large boiler at part-load. Distribution losses can also be reduced by locating smaller boilers strategically around a large facility. Installation costs can be reduced with smaller units that fit through standard sized doorways. Knowing the peak heating demand and load profile is critical in determining the number, capacity, and sizing of staged or distributed boilers. Multiple boilers also provide redundancy so that if one boiler needs maintenance others can be brought online to provide heating.

6.4.1.3 Boiler Retrofit

If boiler replacement is not an option, retrofitting the existing boiler may be a viable alternative. There are several boiler retrofit options that will increase the efficiency of the existing boiler and provide short payback periods.

6.4.1.4 DDC Controls

Outfitting a boiler with DDC controls allows the boiler to operate at higher efficiency by utilizing real-time data and monitoring flue exhaust temperatures to make adjustments to air/fuel ratio, feedwater temperature, steam pressure, and temperature reset.

6.4.1.5 Reduce Excess Air

Having more than enough air ensures complete combustion but when there is an excessive amount of air, combustion efficiency is reduced. According to the Department of Energy, combustion efficiency can be increased by adjusting the air-fuel ratio, and provide fuel cost savings from 3 to 10 percent.

The excess air required depends on firing-rate and boiler type. Using a flue gas analyzer, the amount of excess oxygen and carbon monoxide levels can be quantified. The relationship between excess oxygen and excess air is 1 to 5. For natural-gas boilers with high-firing rates, 10 percent (2 percent excess oxygen) or less excess air is desired. Natural-gas boilers with low-firing rates may require more than 30 percent excess air (6 percent excess oxygen) for complete combustion. Oil-fired boilers require more excess air than gas-fired units. Note that less air is needed as supply air temperature is decreased since air density increases.

Check that the carbon monoxide levels in the flue exhaust are less than 100 ppm. Levels higher than 100 ppm may indicate improper combustion due to insufficient air or insufficient air-fuel ratio.

6.4.1.6 Add an Economizer/Heat Exchanger to Boiler

Consider adding boiler feedwater preheat by installing an economizer or heat exchanger in the boiler flue. The boiler efficiency will increase 1 percent for every 10°F (-12°C) increase in feedwater temperature. Make sure that the resulting stack temperature is maintained above the flue gas dew point to prevent flue stack corrosion caused by condensation of corrosive combustion gases.

6.4.1.7 Add Boiler Tube Turbulators

Turbulators are baffles placed in boiler tubes that increase the heat transfer by creating turbulent flow. Consult the boiler manufacturer for availability, cost, and installation instructions regarding retrofitting the existing boiler with retrofit tabulators.

6.4.1.8 Automatic Boiler Blowdown Controls

Boiler blowdown—draining water from the bottom of the boiler—removes solids entrained in the water or sedimented near the bottom of the boiler. It is an important part of the water treatment regime for the boiler to limit water impurities that reduce the boiler efficiency. Install automatic blowdown controls that perform blowdown based on boiler water conductivity and pH instead of at arbitrary, preset intervals.

6.4.1.9 Boiler Electronic Ignition System

Replacing a gas pilot ignition with electronic ignition is a commonly cited retrofit item but may not be worth the cost. They may be difficult to install and these retrofits often have long paybacks, up to 10 years. In some designs, a standing pilot is required to keep corrosive condensate from forming on boiler heat exchanger surfaces.

6.4.1.10 Boiler Insulation

If the boiler wall or existing pipe is missing insulation, the addition of insulation will reduce energy loss both by reducing heat loss and the introduction of heat that may have to be removed by the cooling system. Typically, this is a low-cost, must-do boiler upgrade when it is needed.

6.4.2 Heat Pumps

A heat pump is essentially an air conditioner that can reverse the direction of flow in its refrigerant circuit so that heat can be delivered to or removed from the occupied space. For heating, heat pumps deliver two to three times more heat to the space per kWh than resistant-type electric heat since the electricity is used to transfer (move) heat rather than generate heat.

6.4.2.1 Ground Source Heat Pumps

Ground source heat pumps (GSHP) are heat pumps that use the earth as the heat source and sink to capitalize on the year-around stability of the earth's temperature.

GSHPs are classified as either open or closed systems. Open system GSHPs typically use water wells for the heat source but they can also use surface water from lakes or rivers. Closed loop GSHPs use piping filled with water or anti-freeze solutions that are installed in trenches or vertical well bores and circulating pumps move the fluid through the heat pump and closed loop/heat exchanger to utilize the energy directly from the earth.

Open loop systems require attention to water quality and may need chemical water treatment to reduce scaling and bacteria or filtration or centrifugal devices to remove sand or other solid contaminants, depending on water quality. Heat exchangers require periodic de-scaling to maintain peak system operational efficiency.

Closed loop systems are becoming more prevalent. They require careful attention to loop design and experienced loop installers are an important partner to ensure overall system design and trouble-free operation. Trenched systems are often used where land area is available and near-surface soil conditions are conducive to trenching (not rocky or sandy) and the soil has good heat transfer (soils with good thermal conductivity). Vertical bore holes are more commonly used in large commercial installations and loop performance is generally more predictable.

GSHP systems require careful upfront planning and design. They are beneficial where electric energy costs are high; where vandalism with outdoor equipment is an issue, such as schools, remote sites, or inner city; or were there is a desire to have no visible outdoor equipment, such as historical buildings. GSHPs are most effective where outdoor design temperatures are high for long periods and airsource equipment performance is negatively affected or where outdoor design temperatures are cold for long periods and airsource heat pump efficiencies are low.

There are few existing buildings that use GSHPs but those that use GSHP technology may have special service and retrofit needs.

For open systems, water treatment and heat exchanger de-scaling is often needed, especially for older systems. Testing for water flow volumes and delta-T across water-to-refrigerant heat exchangers should be done to evaluate the performance and condition of heat exchangers. If water flow is set by fixed-flow valves, the addition of refrigerant pressure-activated water regulator valves is a very cost effective retrofit option that will conserve water and the energy required to pump the water and keep the heat pump operating in a more ideal range.

For closed systems, anti-freeze solutions require periodic testing and flow rates through water-to-refrigerant heat exchangers should be checked and adjusted for ideal delta-Ts. Some of the larger closed loop GSHPs integrate cooling towers and boilers into the loop systems. The same checks and testing can be applied to this equipment as presented elsewhere in this manual. If pumps are single speed it may be beneficial to apply VFDs, especially if several GSHP units are served off of main, common headers

Where a DOAS is installed or to be installed, GSHPs may be the most cost effective system to dehumidify and condition the DOAS ventilation air. Since the DOAS operates year-round, the higher inherent efficiencies of GSHPs will shorten payback periods. In addition, DOAS typically requires approximately ⅓ the capacity of the peak cooling load so smaller GSHPs and loops are required but they will operate more annual hours than the primary cooling system which will offset the higher capital cost more quickly via more operational hours.

6.4.2.2 Water Source Cooling

Water source cooling is the same basic technology as ground source heat pumps except there is no reversing valve—these are cooling-only devices that use either open or closed water supply. These are often used above dropped ceilings in a similar manner as a VAV box except that the thermal energy is supplied by a circulated fluid. These have similar application opportunities as VRF devices since only small water lines are required and ducting often serves only the immediate area. Historically, once-through water supply from the domestic water system has occasionally been used but codes are beginning to prohibit this practice. When several of these units are tied into the same water circuit, the group of units on the exterior work as an energy recovery system by moving heat from the buildings' core when cooling is needed to the perimeter areas for winter-time perimeter heating.

6.4.2.3 Air Source Heat Pump

Air source heat pumps are commonly used for residential and light commercial applications. A proper installation will result in delivering two to three times more energy during heating than using conventional electrical resistance heating. Air source heat pumps in zones where temperatures drop below freezing require that auxiliary heat be provided. Check that outdoor thermostats are used to keep the auxiliary heat off in all but the coldest weather, typically around freezing.

6.4.2.3.1 Air Source Heat Pump Water Heater

Electric domestic water heaters are available that use one-way air source heat pumps (no reversing valve) instead of resistance heating elements. These heat pump water heaters (HPWH) can be installed as a new unit that is integrated with the water storage tank or as an add-on retrofit to an existing water storage tank or water heater.

Since the heat pump will cool the space in which it is located, locate the heat pump in areas that are large enough to accommodate the additional cooling and that will benefit from additional cooling or dehumidification. Units are available that can be ducted with outside air but caution must be exercised that these do not negatively affect combustion appliances. An equipment room with a furnace and a combustion supply air source or similar location that is on the warm side is a good location for HPWHs.

Typically, 140°F (60°C) is the highest temperature to which HPWHs will heat water efficiency and output capacity drops at higher water temperatures. Heat pump water heaters are most efficient at lower water temperatures. Using two water storage tanks in series or installing an add-on unit in series with a water heater heated by another source are both efficient operational strategies. As with all heat pumps reheat is an issue so no reheat should be introduced to incoming water to the heat pump itself.

HPWHs use ½ to ⅓ the electric energy to heat water and have lower power supply requirements than resistance heater with some models available in 120 volt power supply—a plug in appliance. Rebates, incentives, or tax credits are often provided to encourage HPWHs instead of using or as a replacement to resistance-heated water heaters.

HPWHs are most viable where natural gas is unavailable and electric rates are high. Payback periods are shortened where there is high demand for warm water and substantial hot water storage capacity.

6.5 ENERGY RECOVERY SYSTEMS

Energy recovery systems are also called heat recovery systems since heat is what is most often being recovered. To implement a heat recovery system a heat source is needed (waste hot water or air) and a need (heating load). Heat can be extracted or recovered from hot water or air that otherwise would be exhausted to the atmosphere. For more detailed information regarding energy recovery systems, refer to the *SMACNA Energy Systems Analysis and Management* (ESAM) manual. The ESAM manual also has an entire chapter devoted to economic analysis for energy recovery systems.

6.5.1 Condensate Heat Recovery

The condensate return portions of many steam systems exhaust large quantities of heat in the form of flash steam when the hot condensate is reduced to atmospheric pressure in the condensate receiver. Recover waste heat by installing a heat exchanger in the condensate return main before the receiver to reduce condensate temperature to approximately 180°F (82°C).

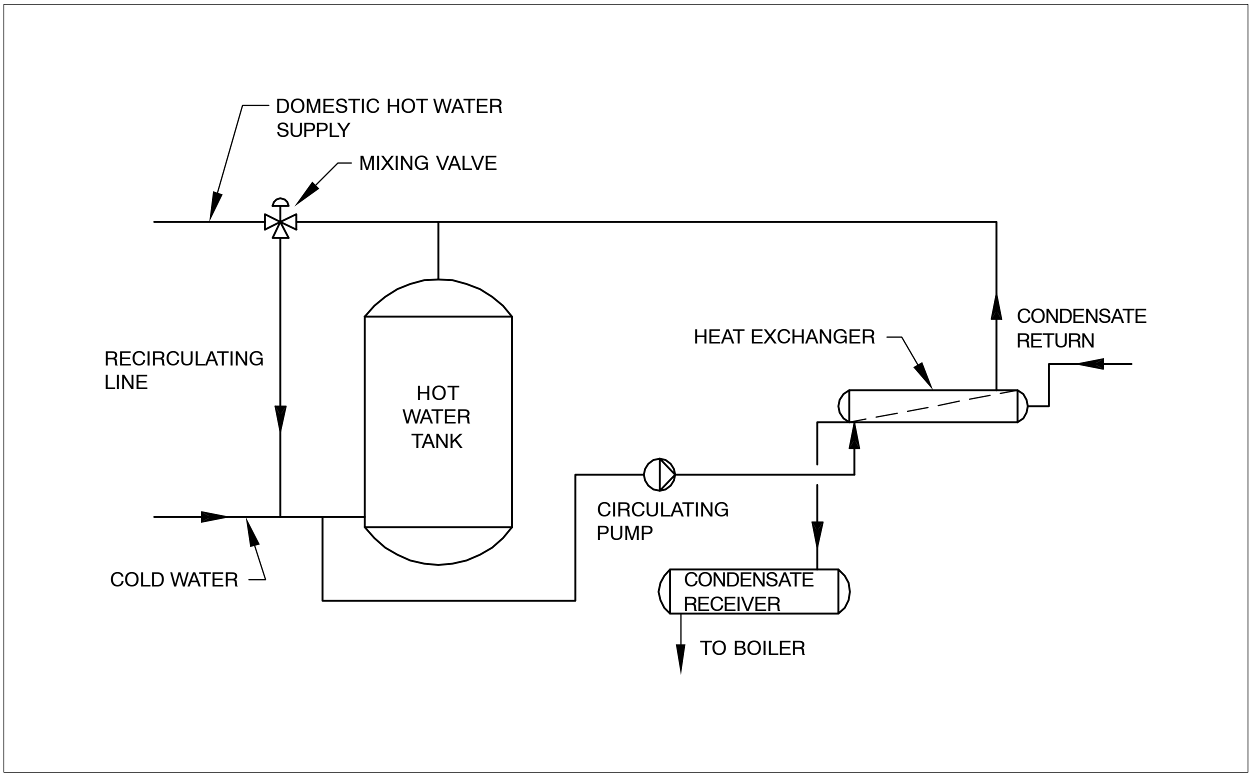

FIGURE 6–9 CONDENSATE HEAT RECOVERY

Use the heat recovered to heat or pre-heat domestic hot water as shown in Figure 6-9. This concept should be analyzed to determine if reheating of the condensate at the boiler will negate the expected heat recovery savings.

6.5.2 Waste Water Heat Recovery

Buildings with kitchens, laundries, and other service facilities which use large quantities of hot water and, in many cases, discharge hot waste water to drains are candidates for waste heat recovery. By installing a heat exchanger with proper pre-filtering, heat can be recaptured to heat or preheat water for heating or domestic use, *see* Figure 6-10.

In general, it is economical to preheat water from 50°F to 105°F (10°C to 41°C) without excessive equipment cost. The hot water at 105°F (41°C) can then be fed into the domestic hot water tank for further heating to the required utilization temperature.

6.5.3 Hot Gas Heat Recovery

A typical refrigeration machine with a water-cooled condenser rejects approximately 15,000 Btu per hour (4.4 kW) for each 12,000 Btu per hour (3.5 kW) of refrigeration. An air-cooled condenser rejects up to 17,000 Btu per hour (5.0 kW) for each 12,000 Btu per hour (3.5 kW) of refrigeration. Up to 5000 Btu per hour (1.5 kW) of the heat rejected from either system can be recovered. To recover the heat of compression, install a heat exchanger in the hot gas discharge line between the compressor and the condenser. A typical arrangement in conjunction with a domestic hot water system is shown in Figure 6-11. Hot gas temperature depends on the head pressure but is usually on the order of 120°F to 130°F (49°C to 54°C).

6.5.4 Waste Heat Recovery

Adding waste heat recovery capabilities to the electric generation equipment can increase the total thermal efficiency to as high as 75 percent. Waste heat can be recovered in many ways and is usually converted to hot water or low pressure steam.

Steam extracted from the turbine or from the turbine exhaust outlet can be used by heat exchange equipment, absorption refrigeration equipment, and steam turbine driven centrifugal chillers.

The quality of heat recoverable from turbine exhaust is greater than that of reciprocating engines because of the larger flow. Because of the large percentage of excess air in the turbine exhaust, afterburners can supple-

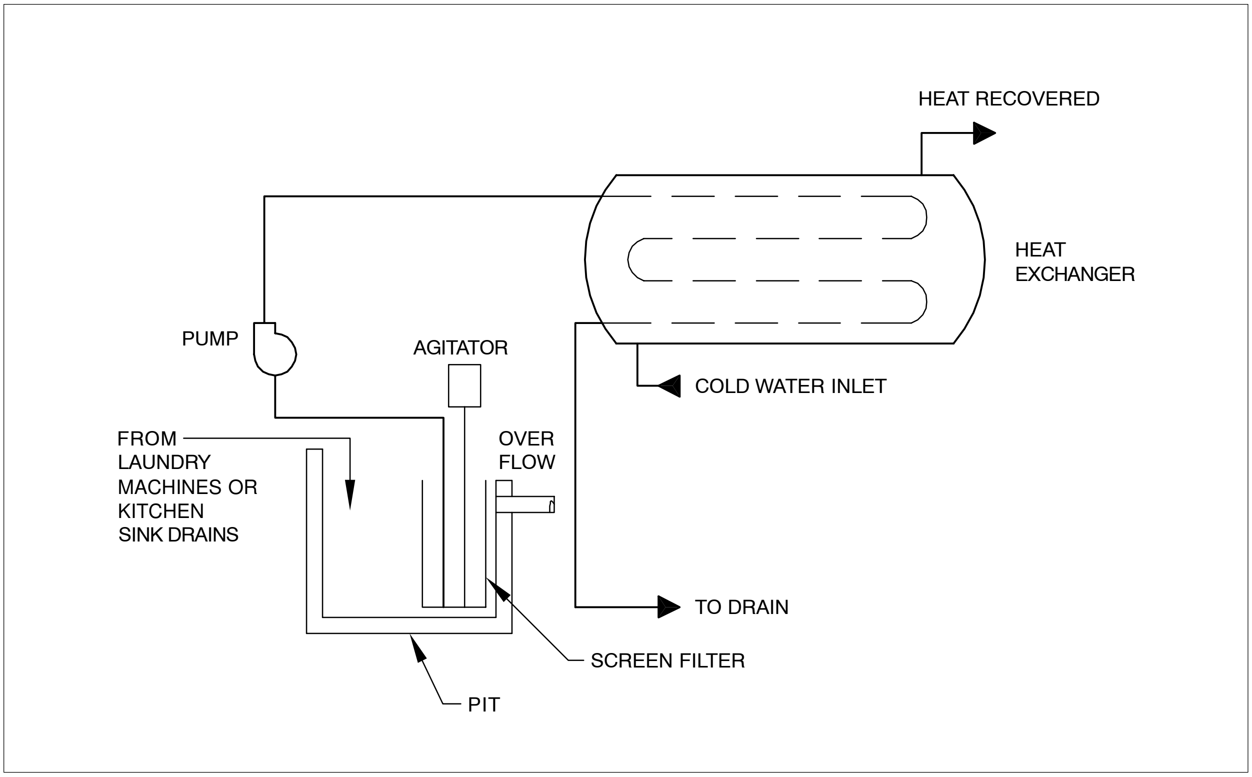

FIGURE 6–10 LAUNDRY AND KITCHEN HOT WATER RECOVERY SYSTEM

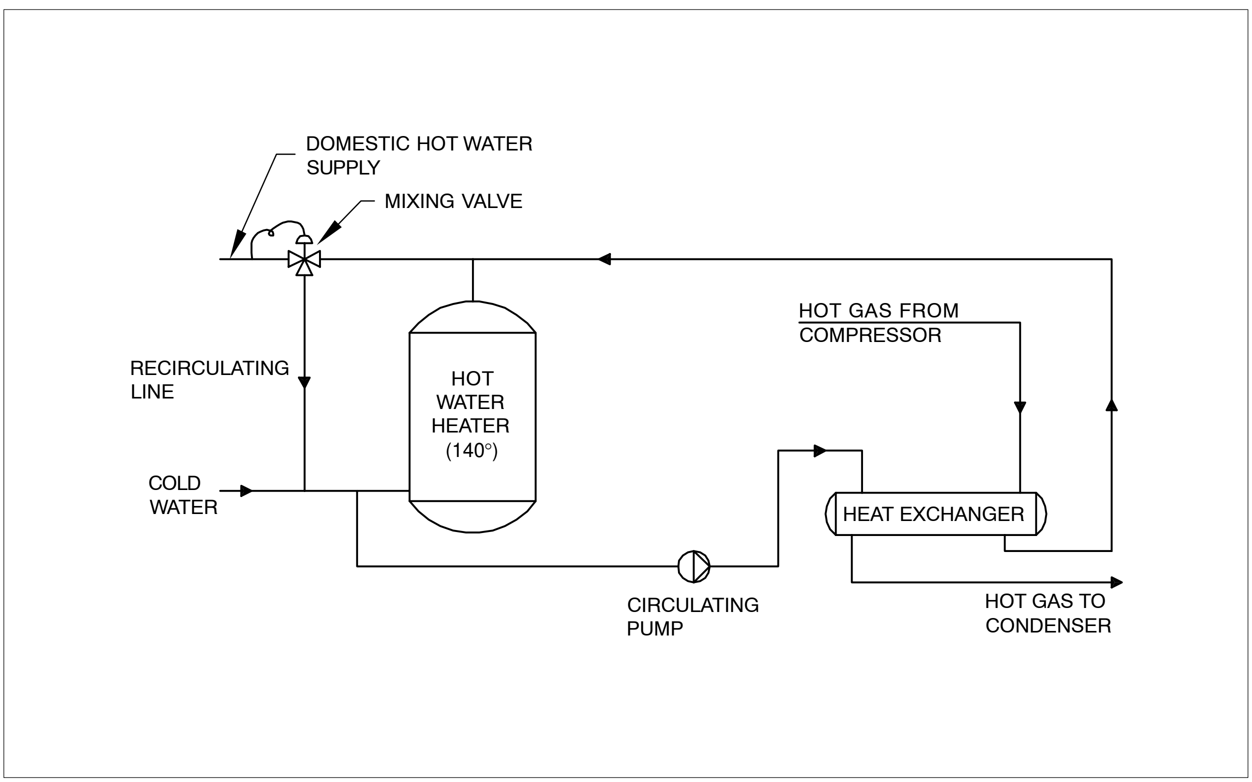

FIGURE 6–11 COMPRESSOR HEAT RECOVERY

ment the recovered heat during reduced turbine loads with a possible system efficiency increase to 90 percent. The engine exhaust heat recovery equipment also acts as a muffler or silencer.

6.6 PARTICULATE AIR FILTRATION

Mechanical air filters remove particles from the air stream by capturing them on filter materials. Mechanical air filters can capture dust, pollen, dust mites, and some molds. The efficiency of a mechanical air filter is determined by the filter's minimum efficiency reporting value (MERV). Flat or panel air filters with a MERV of 1 to 4 were the type of filter historically used in residential furnaces and air conditioners. Medium efficiency filters with a MERV of 5 to 13 are reasonably efficient at removing both small and large particulate pollutants.

Pleated or extended surface filters are typically used in commercial and institutional air distribution systems. Medium efficiency filters that have a MERV of between 7 and 13 are less expensive than high efficiency particulate air (HEPA) filters but can be nearly as efficient at removing particulate pollutants without the high pressure losses across a HEPA filter. Using a filter with a MERV rating between 7 and 13 in lieu of a HEPA filter should result in increased airflow and a resulting reduction in fan power and noise. Higher efficiency filters with a MERV of 14 to 16 are similar in physical appearance to HEPA filters. HEPA filters have a MERV rating from 17 to 20.

The pressure drop across air handler and critical filters should be electronically monitored so that they can be replaced when the maximum recommended pressure drop is reached. A pressure monitor should be installed to communicate with the building controls to trigger a service alarm for maintenance staff.

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CHAPTER 7

BUILDING AUTOMATION SYSTEMS AND CONTROLS