UNITED STATES POSTAL SERVICE™

Maintenance Series Handbook MS-24

Heating, Cooling, and Ventilating (HVAC)

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UNITED STATES POSTAL SERVICE

Maintenance Series Handbook MS-24
Heating, Cooling, and Ventilating (HVAC)

Transmittal Letter 10
March 17, 2020

A. Explanation

This handbook is a complete revision of the MS-24 Handbook, Heating, Cooling, and Ventilating (HVAC). It prescribes policies, procedures, and practices governing the operation of systems installed in USPS buildings and in leased space where the USPS has maintenance responsibility. It will be available on the MTSC web site at https://www1.mtsc.usps.gov in PDF.

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C. Rescissions

Please discard all previous TLs of this handbook.

D. Comments and Questions

Suggestions for improving this handbook are solicited from all sources. To provide comments and suggestions, or to report handbook errors, use the Handbook Comment selection on the MTSC Feedback link at https://www1.mtsc.usps.gov/. This handbook will be updated as future needs demand.

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SECTION 1

SAFETY SUMMARY AND INTRODUCTION TO HVAC

1.1 SAFETY

Safety is the responsibility of every individual in the USPS. Personnel should be instructed in safety practices applicable to the operation and maintenance of the equipment. Each individual operating and maintaining the equipment must understand and observe established safety standards and procedures. USPS handbook EL-803, Maintenance Employee’s Guide to Safety, can be ordered by sending Form 7380, MDC Supply Requisition, to your Material Distribution Center.

1.1.1 Safety Symbols and Statements

The following standard safety symbols appear where special caution or attention is required. Text associated with each symbol describes the purpose of the symbol itself. A statement describing a specific hazard or supplying additional required information, as appropriate, accompanies each symbol throughout the handbook.

WARNING

A warning alerts to conditions, practices, or procedures that must be observed to avoid danger to personnel. It emphasizes what to do or not do to avoid the danger. It also describes the potential outcome of the danger, such as health problems, personal injury, or loss of life.

CAUTION

A caution alerts to conditions, practices, or procedures that must be observed to avoid equipment damage. It emphasizes what to do or not do to avoid equipment damage. It also describes the potential damage or destruction that can occur to the equipment.

1.1.2 Safety Precautions

Every USPS employee should know how to quickly summon medical aid if required.

The following standard safety precautions are typical and may not appear elsewhere, except where special emphasis or precautions are required. Understand and apply these precautions in all phases of maintenance when working on this equipment.

Potential elements of danger may exist when performing maintenance on mail processing or other equipment, or buildings. Safety precautions may include the use of personal protective equipment, erection of barricades, application of local lockout procedures, or adherence to other safety procedures. Ensure guards are installed and interlocks are not defeated prior to returning equipment to normal operation. Carelessness can result in injury from moving equipment, chemicals, falls, or electrical shock. Questions about safety, or the discovery of safety deficiencies, should be brought to the attention of a supervisor.

1.1.2.1 General Safety Precautions

These precautions must be observed by all personnel operating or working on or around the machine.

- Warn others of possible hazards.
- Always use the proper tool for a job.
- Do not operate unsafe or defective equipment. Tag defective equipment using *Form 4707, Out of Order* tag, and remove equipment from service. Immediately report tagged equipment to a supervisor.
- Do not engage in horseplay around equipment.
- Never operate equipment or machinery unless guards are in place and all other safety devices, such as E-Stops, are functioning properly.
- Avoid unsafe acts and conditions.
- Follow all safety precautions.
- Keep mentally and physically alert.
- Practice good housekeeping by keeping work areas clean and neat.
- Report all hazardous conditions to the immediate supervisor.
- Use all designated safety devices.
- Operate or maintain equipment only when authorized to do so.
- Do not defeat an interlock switch unless authorized to do so.
- Stop machine before opening any access door.
- Do not wear loose-fitting clothing, a tie, jewelry, or other articles that can catch in moving parts.
- Keep hair away from equipment to avoid entangling it in moving parts.

- Keep fingers, hands, and arms clear of belts, augers, chains, gears, and pulleys.
- Never pull on equipment parts such as belts, pulleys, or shafts to assist slow-starting equipment.
- Never take anything for granted. When working with inexperienced personnel, review every machine operation before it is performed.

1.1.2.2 Cleaning Safety Precautions

The following precautions must be followed when cleaning equipment or buildings.

- Avoid the use of toxic or flammable solvents for cleaning purposes, unless specifically required.
- Do not use compressed air for cleaning. Use of compressed air is prohibited.
- Do not use vacuum cleaner exhaust as a substitute for compressed air.
- Do not use canned or blown air as an alternative to compressed air.
- Use a High Efficiency Particulate Arresting (HEPA) filtered vacuum cleaner to clean mail processing equipment.
- Use only vacuum cleaner attachments and devices that are non-metallic.
- Use a small brush, lint free cloth, or similar item to reach debris not accessible with a vacuum attachment. Keep the amount of airborne (disturbed) dust to a minimum.

1.1.2.3 Maintenance Safety Precautions

The following precautions must be followed when performing maintenance on postal equipment.

- Ensure that every Postal Service employee is authorized and trained on lockout procedures for the specific equipment being worked on.
- Follow prescribed local safety procedures when maintenance work requires bypassing guards or safety devices.
- Use the current local lockout procedure to lock out mail processing equipment, building equipment, and other systems before performing preventive and corrective maintenance.
- Follow required local lockout procedures to protect personnel from injury or death from unexpected machine energization, startup, or discharge of stored energy.
- Lock out equipment by installing a padlock on a lockout device according to current local lockout procedure, and affix a “Do Not Operate” tag to all energy isolation devices identified in the current local lockout procedure.
- Be aware that a padlock is identified only with the person to whom it is assigned, regardless whether it came from a toolkit or central point of issue.

- Do not remove a padlock identified with another employee under any circumstances. A padlock must be removed only by the employee to whom it is assigned.
- Do not install a padlock assigned to another employee to an equipment lockout device.
- Never lend a padlock to another employee, or borrow a padlock assigned to another employee. Retain and use only personally assigned keys and padlocks.
- Verify all energized electrical sources are isolated after the equipment is locked out, and before work is performed.
- Assume all electrical circuits are energized and dangerous until verified safe to work on.
- Place all controls in the off or neutral position before isolating energy sources.
- Do not substitute fuse-pulling for locking out equipment.
- Do not use push buttons, selector switches, or other circuit control devices as energy-isolating devices.
- Do not rely solely on safety interlock devices for power isolation. Remove power from the source to isolate power from equipment.
- Be aware of all equipment energy sources and ensure that all are locked out or in a zero energy state before working on equipment. Some machines are powered by more than one type of energy source (electrical, pneumatic, or hydraulic).
- Bring energy accumulation devices, such as capacitors, and pneumatic or hydraulic lines, to a zero energy state, and lockout before starting work on equipment.
- Do not perform maintenance work on energized equipment except as required for testing or troubleshooting of the equipment.

1.1.2.4 Troubleshooting and Testing Safety Precautions

The following precautions must be followed when troubleshooting and testing postal equipment.

- Ensure employees are authorized and trained to troubleshoot and test energized equipment or circuits.
- Take extra care when troubleshooting or performing tests on energized circuits. Troubleshooting and testing energized circuits may expose personnel to energized power sources that may cause electrical shock and/or possible death.
- Be knowledgeable of voltage levels, circuit functions, and energized part locations when troubleshooting or testing energized circuits.
- Be familiar with and use appropriate Personal Protective Equipment (PPE), tools, and work practices for safe performance of the work.
- Ground test equipment to the equipment under test, unless otherwise specified.

- Lock out equipment after troubleshooting or testing energized circuits, and before performing service or repair activities.
- Be aware of potential pinch-point hazards from rotating or moving equipment when performing adjustments, such as belt tracking, on energized or operating equipment.
- Take extra care to avoid contact with moving parts when performing adjustment procedures.

1.1.2.5 Electrical Safety Precautions

The following precautions must be followed when performing maintenance, or troubleshooting and testing around electric current.

WARNING

Procedures within this handbook may expose employees to hazardous voltages. Before performing these types of procedures employees must don Electrical Work Plan (EWP) Personal Protective Equipment (PPE) in accordance with the current EWP MMO. Failure to comply may cause injury or death.

- Do not perform maintenance work on an energized circuit, except for troubleshooting or testing of the circuit.
- Lock out current-carrying components before working on them.
- Use extreme caution when troubleshooting or testing electrical circuits.
- Know the location of main power shutdown devices.
- Do not wear a metal bracelet, wristwatch, ring, long neck chain, or similar jewelry, while working on electrical equipment.
- Keep clothing, hands, and feet as dry as possible.
- Do not replace fuses while circuits are energized.

1.1.2.6 Operating Safety Precautions

- Do not wear loose-fitting clothing, a tie, jewelry, or other articles that can catch in moving parts.
- Keep hair away from moving equipment to avoid entangling it in the machine.
- Keep fingers, hands, and arms clear of feed belts, chains, gears, and pulleys.
- Never place hands on any moving part while the equipment is in operation.
- Always stop the equipment before attempting to clear any debris from the track areas.
- Ensure that personnel are clear of moving parts before starting the equipment.

- Stop equipment before opening any door or panel on the machine.
- Do not place food or drink on any part of the equipment, even if not in operation.
- Do not defeat an interlock switch unless authorized by your immediate supervisor.
- Keep the equipment power off when performing preventive maintenance procedures.
- Operate equipment only when authorized to do so.
- Do not operate unsafe or defective equipment.
- Immediately report all hazards and unsafe conditions to a supervisor.
- Never operate equipment or machinery unless guards are in place and all other safety devices, such as E-stops, are properly functioning.
- Know the locations and operation of all EMERGENCY STOP push buttons.
- Keep clearly labeled EMERGENCY STOP buttons in plain view and accessible.
- Always listen and watch for the start-up alarm to sound and flash when a machine is being started.

1.1.3 Electrical Fires

Do not use water, soda-acid, or any liquid stream (type A, B) extinguishers. Use only type C, BC, or ABC extinguishers. A liquid stream extinguisher presents a shock hazard and can cause considerable damage to electrical equipment.

1.1.4 ESD Sensitive Devices

Some equipment printed circuit cards are extremely sensitive to electrostatic discharge (ESD). Metal-oxide semiconductor (MOS) card components can be damaged or destroyed by careless handling. To prevent ESD damage, special precautions are required during the removal, replacement, storage, and shipment of circuit cards.

Refer to current MMO entitled Protecting Equipment From Electrostatic Discharge (ESD).

1.1.5 Handling Hazardous and Environmentally Sensitive Materials

It may be necessary to handle hazardous and environmentally sensitive materials and products. The handling of such materials or products is subject to Safety Data Sheet (SDS) requirements, and may be subject to federal, state, and local regulations.

Handling instructions for hazardous and environmentally sensitive materials are included in all maintenance documents because of the potential danger associated with improper handling. In addition to these instructions, the following warning is included in any written maintenance procedure in which hazardous and environmentally sensitive materials are used:

WARNING

The following procedure requires handling of hazardous or environmentally sensitive material. Refer to SDS handling requirements for hazardous or environmentally sensitive material. Failure to comply may cause injury or death.

1.1.6 Storage/Disposal of Hazardous or Environmentally Sensitive Waste

Maintenance documentation does not include instructions for storage and disposal of hazardous, environmentally sensitive, and recyclable waste materials because of difficulties in keeping information current.

Safety Data Sheets (SDS) that address storage and disposal of hazardous and environmentally sensitive products are furnished by suppliers. When a facility stocks a hazardous or environmentally sensitive material or product, its current SDS must be kept on file in the local office. When the product is re-ordered, or when the same or a similar product is acquired from a different supplier, the current SDS must be obtained. Every SDS must be readily available to all employees.

Federal, state, and local regulations concerning storage and disposal of hazardous, environmentally sensitive, and recyclable materials change. State and local regulations may vary from one area to another. Penalties for noncompliance with any federal, state, or local regulation can be severe.

1.1.7 Hazardous Components and Operations

The following types of hazards require special attention during equipment operation.

- Mechanical hazards catch, pinch, cut, or crush.
- Electrical hazards cause electric shock.
- Other hazards such as equipment height or weight, routing of cables and wires, or other potential dangers.

1.1.7.1 Mechanical Hazard Avoidance

The following precautions must be followed when performing maintenance or troubleshooting and testing near mechanical hazards.

- Prevent falling object injuries by supporting or securing items that can fall before detaching them from equipment.
- Prevent pinched fingers by keeping them away from energized or moving drive motor belts, chains, and pulleys.

1.1.7.2 Electrical Hazard Avoidance

The following precautions must be followed when performing maintenance or troubleshooting and testing near electrical hazards.

- Don Electrical Work Plan (EWP) Personal Protective Equipment (PPE) in accordance with the current EWP MMO before performing procedures exposing employees to hazardous voltages.
- Remove power from entire system when working on the machine if possible.
- Remove power from individual units or subsystems that do not require power during troubleshooting and testing, by opening appropriate circuit breaker.
- Remove power by switching distribution or junction box to OFF position, then tagging and locking out power per current local lockout procedures before performing maintenance.
- When necessary to leave power ON, use extreme caution when working near live circuits.

1.1.8 Other Hazard Avoidance

The following precautions must be followed when performing maintenance or troubleshooting and testing near hazards not previously listed.

- Ensure all wires are clear of belts or moving parts.
- Ensure cables are routed to proper locations and not within walkways. Improperly routed cables can cause tripping and possible injury.
- Always have additional personnel assist when lifting components over 25 pounds.

1.1.9 Specific Safety-Related Components and Information

The following components require special attention during equipment operation.

1.1.9.1 Interlocks

A machine interlock isolates power and stops moving parts when a gate, door, or panel is opened. Interlocks typically shut down all moving parts throughout the system.

Although an interlock shuts down moving parts and allows access to an area with a temporary power shutdown, it should never be used as a substitute for lockout during maintenance.

1.1.9.2 Energy (Power) Isolation

Steps for isolating machine power must be used for personal safety. This may include removing of main facility power to the machine, removing power from main control panel circuit breakers, and/or removing power from power disconnect switches on system main control panels.

Don Electrical Work Plan (EWP) Personal Protective Equipment (PPE) in accordance with the current EWP MMO before performing procedures exposing employees to hazardous voltages.

1.1.9.3 Capacitive Circuits

Control cabinets and power factor correction units may have large capacitors that hold a high-power capacitive charge. Capacitors may still be energized even with main power removed from the machine.

1.1.9.4 Heavy Components

Components on the machine may be heavy. Any component weighing over 25 pounds must be handled with additional personnel or appropriate equipment for handling heavy component weights.

1.1.9.5 Areas With and Without Guarding

Some areas of the machine may not have safety guarding. Take extra precaution when working on or around moving belts, chains, rollers, gears and rotating parts. Guarding should be used as follows:

- Always replace guards before returning equipment to normal operation.
- Do not operate equipment with guards removed unless the maintenance procedure specifically instructs to do so.
- Follow all local and handbook safety procedures for machine operation, maintenance, and proper use of guarding to avoid possible injury or death.

1.1.9.6 Illumination Areas (Intense Visible Lights)

Some areas of the machine may have high-intensity lamps. Precautions must be taken not to look directly into lamp lighting without proper eye protection.

Lamp surfaces are hot. Do not stand near high-intensity lamps. Heat radiating from high-intensity lamps can cause short-term skin irritation and/or severe burns from prolonged exposure.

Use caution when working around lamps, and allow them to cool before handling. When replacing bulbs, follow procedures to avoid contact with hot surfaces or ballast voltages.

Do not handle or place hands near energized high-intensity lamps without wearing protective gloves.

1.1.9.7 Pneumatics

High-pressure air lines can cause severe personal injury from flying objects. Follow these instructions for handling items that operate by compressed air:

- Remove all high-pressure air sources to the system, if possible.
- Take precautions to remove pneumatic fittings properly from the system.
- Never use pneumatic lines for cleaning the equipment.

1.1.9.8 Sound Hazard

Permanent hearing loss may occur from exposure to continuous alarm horn noise. Always use ear plugs when prolonged exposure to the noise is required.

1.2 EQUIPMENT-SPECIFIC SAFETY SUMMARY

Learn and always follow all safety procedures pertaining to your assigned Heating, Cooling, and Ventilation equipment.

1.3 GENERAL MAINTENANCE REQUIREMENTS

1.3.1 Basic Requirements

The proper operation and maintenance of building heating, cooling, and ventilation systems requires a careful consideration to a variety of factors, such as:

- Environmentally acceptable atmosphere for employees.
- Operation of equipment within guidelines established by the United States Postal Service (USPS), manufacturers, and other relevant parties.
- Maintenance of the equipment and building enclosures to provide maximum safety to the operation, postal employees, and the general public.
- Efficient operation and maintenance to provide functional reliability and extend service life.

1.3.2 Other Factors

Effective maintenance management requires proper tools, adequate supervision, timely inspection, meaningful information, and technical competence. It also requires open lines of communications and competence at all levels.

1.4 SCOPE

This handbook applies to USPS personnel engaged in the operation and maintenance of facility heating, cooling, and ventilation systems. It prescribes policies, procedures, and practices governing the operation of systems installed in USPS buildings and in leased space where the USPS has maintenance responsibility.

1.5 SAFETY

The procedures prescribed in this handbook place special emphasis on safe work practices and maintaining a safe environment for building occupants and the public. The provisions set forth by EL-801, Supervisor's Safety Handbook, *EL-803,* Maintenance Employee's Guide to Safety, and the specific manufacturer's operating and maintenance manuals or bulletins apply to all work and maintenance. All employees must be properly trained in these procedures.

1.6 ADDITIONAL REFERENCE MATERIAL

Maintenance bulletins prepared and distributed by the Maintenance Planning and Logistic Policies (MP&LP), Maintenance Technical Support Center (MTSC) may contain additional instructions for supplementing or modifying procedures and practices prescribed in this handbook. Additional discussion of material presented in the handbook is also found in the following handbooks:

- MS-1, Operation and Maintenance of Real Property

- MS-49, Energy Conservation and Maintenance Contingency Planning in Large Postal Facilities

1.7 BASIC SKILLS TRAINING

The United States Postal Service must protect the health and safety of its personnel and customers as well as the capital investment in facility heating, cooling, and ventilating systems. Therefore, personnel should not be allowed to operate, repair, maintain, or modify these systems unless they have been properly trained and/or facility management supervision deems the task appropriate. Furthermore, equipment or process modifications should adhere to management of change (MOC) principles. Management of change requires the employer to establish and implement written procedures to manage change, except for in kind replacement.

Although this handbook provides an understanding of postal policy and equipment operation, it is not suitable for development of employee skills from a level of first introduction to heating, cooling, and ventilating principles. To obtain a basic understanding of the concepts presented in this handbook, use the following self-study courses available from the National Center for Employee Development (NCED):

- "Maintenance Safety Awareness Training"
- "Introduction to Refrigeration and Air-Conditioning"

NOTE

Maintenance supervisors at each site should be familiar with the content of these courses and should use them as foundations for developing operations and maintenance training plans.

1.8 SYSTEMS TRAINING

Maintenance personnel must be appropriately trained before performing full operational maintenance on heating, ventilation, and air conditioning (HVAC) equipment. The following courses provided by NCED, Norman, Oklahoma, may be necessary to ensure fully developed operating and maintenance skills:

- "National Electrical Code"
- "Mechanic Skills Training"
- "Rooftop HVAC"
- "Heat Pump Operation & Maintenance"
- "Refrigerant Training Certificate Test"
- "Industrial Electrical Service"
- "Environmental Control I (HVAC)"
- "Environmental Control III (HVAC Heating)"
- "Environmental Control IV (Advanced Air-Conditioning)"

- "Infrared Thermography"
- "Airborne Ultrasound"

NOTE

Maintenance supervisors at each site should be familiar with the content of these courses and use them as foundations for operations and maintenance training plans.

1.9 SUPERVISORY TRAINING

The opportunity to attend NCED training listed in Paragraph 1.8, SYSTEMS TRAINING," as well as course "Building Systems for Supervisors" and other training necessary to ensure the safety and well-being of the building and its occupants, should be available to USPS supervisory personnel responsible for building heating, cooling, and ventilating.

1.10 NON POSTAL TRAINING

The wide diversity of manufacturers and types of equipment installed in postal facilities constrains in depth technical training for every specific make and model of building equipment. Therefore, suitable equipment training may require contractual commitment with commercial vendors for training designed to develop operations and maintenance proficiency for Postal Service personnel. The procedures necessary to obtain approval for this type of training are contained in Chapter 7 of the Employee and Labor Relations Manual (ELM), Part 740.

SECTION 2

SELF-CONTAINED HVAC UNITS

2.1 DESCRIPTION

A self-contained heating, ventilating, or air-conditioning (HVAC) unit incorporates some or all of the components of air-conditioning or heating systems, except possibly the duct work and water piping. In most installations, the air is either discharged directly into the room through grilles, or to attached duct work for distribution to remote areas of the conditioned space.

2.2 GENERAL INFORMATION

2.2.1 Capacity

To establish a uniform method of measuring capacity, manufacturers comply with standards to test and rate their systems in terms of British Thermal Units per hour (Btu/Hr). Air-Conditioners are rated according to the number of Btu's of heat they will remove from a room, in a given period of time, at Air Conditioning and Refrigeration Institute Design conditions. For example, a one-ton air-conditioner will remove 12,000 Btu/hr. Window unit capacities usually range from 4,200-36,000 Btu/hr. Btu is a unit of energy used primarily in the United States of America; in most of the world, it has been replaced with International Systems of Units (SI), the joule (J). One Btu (International table) is 1055.056 joules.

2.2.2 Operating Efficiency

2.2.2.1 Air-Conditioners (A/C)

The efficiency of self-contained units is expressed as an Energy Efficiency Ratio (EER). The EER is obtained by dividing the unit rating in Btu/Hr at a specific temperature level by the electrical power input.

$$\text{EER} = \frac{\text{Cooling Capicity (Btu/Hr)}}{\text{Electrical Input (Watts)}}$$

For most units, an EER of 9 or 10 would be considered good; an EER of 5 or 6 would be considered very poor. Some window units have been built with EERs as high as 12 to 14.

2.2.2.2 Heat Pumps

A Heat Pump is an air conditioning (AC) unit that automatically reverses the condenser and evaporator functions with a reversing valve controlled by the room thermostat.

2.2.2.2.1 Heat Pump Efficiency

The Coefficient of Performance (COP) measures the efficiency of a heat pump. The COP is the ratio of the heat out in Btu's to the electrical energy input in Btu's.

$$\text{COP} = \frac{\text{Heat Out (Btu/Hr)}}{\text{Electrical Energy In (Btu/Hr)}}$$

The COP goes down as the outside air temperature goes decreases. A typical COP rating would be as follows:

Outdoor Temp.	COP
65	2-3/4
40	2-1/2
30	2-1/4
10	1-3/4
-10	1-1/3
-20	1-1/10

Therefore, the heat pump operates more efficiently than an electrical resistance heating because the electrical resistance heating has a constant COP of 1.0.

2.2.2.3 Installation

Windows are not required to install self-contained HVAC units. They may be installed in transoms or directly in outside walls (commonly called through-the-wall installations). The units, however, must have access to outside air for ventilation and exhaust purposes, and for the air-cooled condenser.

2.2.2.4 Thermostats

Most room air conditioners are equipped with thermostats that maintain, within reasonable limits, a fixed dry-bulb temperature and, indirectly, area moisture content.

Seasonal Energy Efficient Ratio (SEER) measures how efficient a residential central cooling system operates over an entire cooling system. SEER is calculated by dividing the total amount of cooling in Btu’s the system will provide over the entire season by the total number of watt-hours it consumes:

$$\text{SEER} = \frac{\text{Seasonal Btu of Cooling}}{\text{Seasonal Watt-Hours Used}}$$

As with ERR, a higher SEER rating implies greater efficiency. By federal law, every central split cooling system manufactured or sold in the United States (U.S.) must have a seasonal energy efficiency ratio of at least 14.0.

2.3 WINDOW AIR-CONDITIONING UNITS

2.3.1 General

The window unit is a small and simplified version of a system designed to service a complete floor or building. The basic components of a window unit are shown Figure 2-1 and Figure 2-2 and described in the following sections.

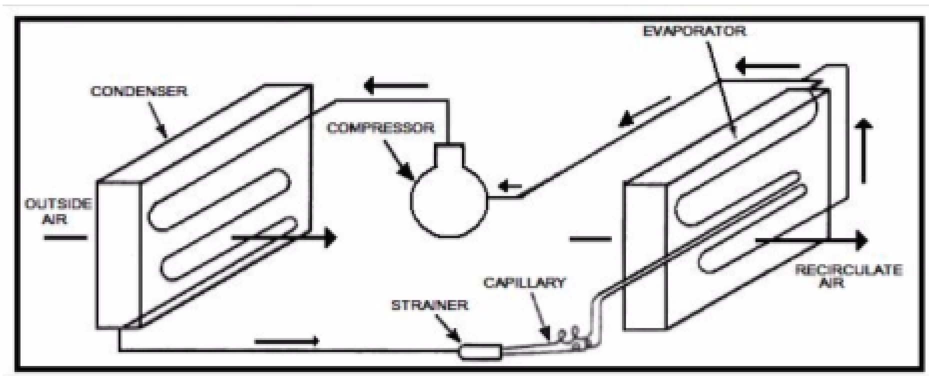


Figure 2-1. Refrigerant Cycle of a Room Air Conditioner

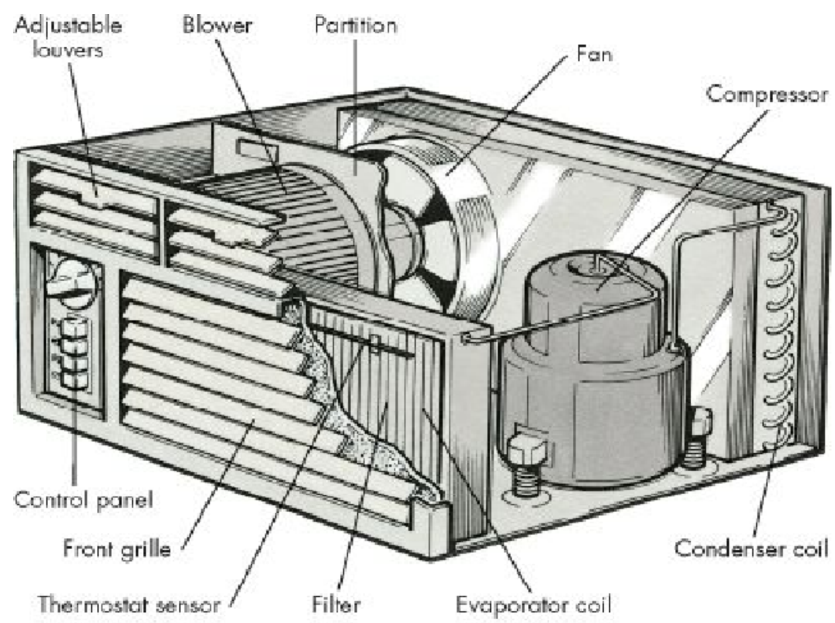


Figure 2-2. Air Handling Components for a Room Air Conditioner

2.3.1.1 Compressor

In a window unit, the compressor is usually a hermetic single cylinder reciprocating, or rotary type.

2.3.1.2 Condenser

Air from the condenser fan cools the condenser coil. Air from the humid room condenses to become water as it comes in contact with the evaporator coil. A pan at the bottom of the evaporator channeled to flow over the liquid line to add sub-cooling collects the condensate and directs it to the condenser fan. The fan has a "slinger ring" which picks up the water and blows it though the condenser in the form of droplets and mist which evaporates on contact with the condenser coil, thereby removing additional heat from the condenser.

2.3.1.3 Evaporator

Due to space limitation inside window units, they use a fin-on-tube or spiny tube evaporator because it transfers more heat per foot of tubing. The space between the fins may vary from one unit to another, but the evaporator will generally have more fins per inch than the condenser. Some units use the "spiny tube" coils that look like aluminum fur. On all units, the cleaning and changing of the evaporator filter is of utmost importance in keeping the evaporator coil clean.

2.3.1.4 Capillary Tube

Generally, window units use single or multiple capillary tubes, or a restrictor with a distributor as metering devices. The capillary tube small inside diameter creates the necessary pressure drop to cause vaporization of the refrigerant. To create the desired pressure drop, the capillary tube or tubes, are cut to definite lengths for particular sized units. Restrictors depend only on the size of the orifice for the restriction.

NOTE

> Thermostatic Expansion Valves are used on higher efficiency units because of better refrigerant control.

2.3.1.5 Fan Units

The evaporator fan that blows air across the evaporator coil also circulates the room air; it is a forward-curved blower wheel. Blower wheels move small to moderate amounts of air in a high-resistance system, while fan blades move moderate to high air volumes in low-resistance applications, such as over the condenser.

2.3.2 Controls and Operation

2.3.2.1 Controls

Window units usually have two primary controls. The first is a thermostat having a remote bulb element that responds to return air temperature changes; and either starts or stops the unit at a predetermined temperature setting. The second primary control sets the speed of the evaporator/condenser fan motor. The unit usually operates at more than one speed within the range, which is manually operated. Other controls adjust the discharge louvers to direct the flow of air in the desired direction, and in some units, to control the intake of outside air, or to vent inside air to the outside.

2.3.2.2 Operation

Improper adjustment of louvers on window-mounted units will result in cold blasts of air. Position the louvers for upward air discharge to improve circulation; the cold air is then directed to the ceiling, and flows downward to the opposite side of the room, avoiding direct contact with people. Additionally, pre-cooling the room will increase operating effectiveness if expected occupancy is to be higher than normal.

2.3.3 Maintenance Guidelines

2.3.3.1 Blades

Figure 2-3 shows a typical window unit. Keep fan blades and finned tubes clean; do not allow foreign material to build up on them. When cleaning the blades make sure the fan is electrically disconnected and do not use abrasives that will wear surfaces. If solids form on blades, scrape them off with a putty knife; clean the blades with detergent and a sponge. Do not bend, twist, or warp the blades, and do not allow blades to catch or bind in the housing or shroud. Excessive vibration damages the fan shaft and bearings. Vibration is caused by a bent shaft, imbalance in the fan, loose anchor bolts, or loose setscrews on the fan hub.

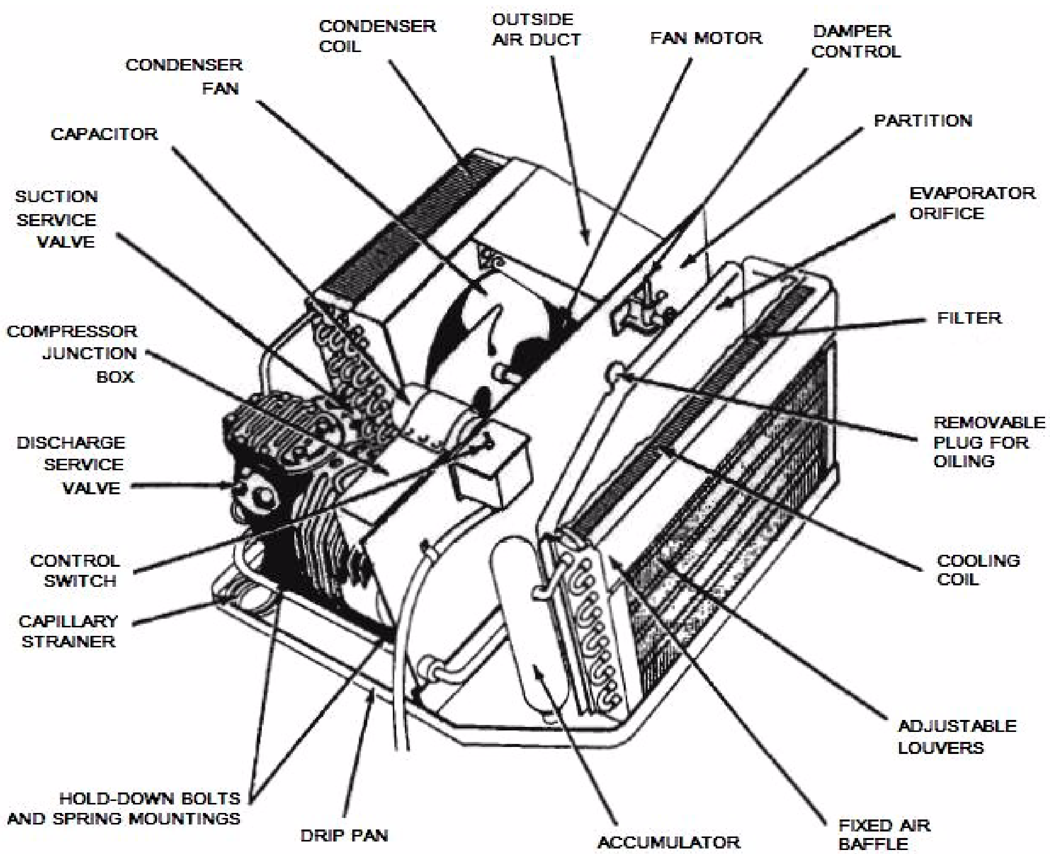


Figure 2-3. Window Mounted Air Conditioner Showing Maintenance Points

2.3.3.2 Motors

Keep motors clean and lubricate according to the manufacturer's recommendations. Check for loose electrical connections, switches, and terminals.

2.3.3.3 Filters

Check filters as frequently as necessary to prevent excessive dust and lint collecting, which reduces the unit's efficiency. Under no circumstances may air-conditioners be operated without filters.

2.3.3.4 Inspections

Make periodic checks to determine the need for tightening or replacing broken parts or repainting surfaces. Keep controls in operable condition.

2.3.3.5 Other Procedures

In the maintenance of these units, observe the following:

- Do not tamper with the hermetically-sealed refrigeration equipment, factory-calibrated automatic temperature controls, or other devices covered by warranties.
- Never mix different refrigerants in the same system. Operating characteristics of refrigerants are different and use of the wrong refrigerant may cause equipment damage.
- The refrigerant should not be allowed to become contaminated with moisture, or to escape into the environment. According to the Clean Air Act, it is unlawful to knowingly vent or otherwise knowingly release or dispose of any Class I or Class II substance used as a refrigerant in appliances (or industrial process refrigeration) in a manner that permits such substance to enter the environment.
- Air-Conditioning units should not be operated when the refrigerant supply in the system is very low. One indication of a low refrigerant charge is an evaporator covered with frost or iced over.

2.4 FLOOR-MOUNTED UNITS

2.4.1 Package Air Conditioning Systems

Package heating, ventilation, and air conditioning units are single package systems where all components are in one factory made unit. Units made primarily for through-the-wall installations will range in size from 1 to 5 tons, as shown in Figure 2-4.

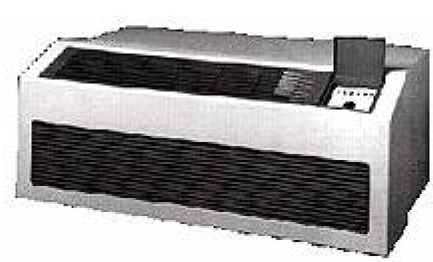


Figure 2-4. “Free Throw” Package Air Conditioning System

Rooftop and ducted units range in size from 1 to 100 tons and are sometimes referred to as "package" units. They may be used with "free throw:" (i.e., without ducts), or with duct work as shown in Figure 2-5. Like window units, these larger units contain the complete system of refrigeration components.

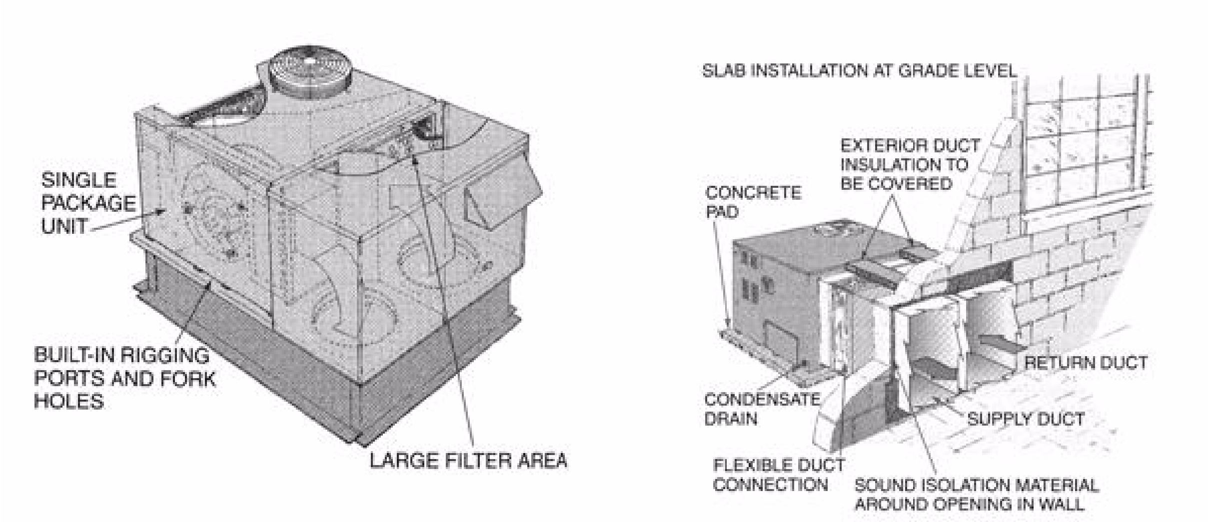


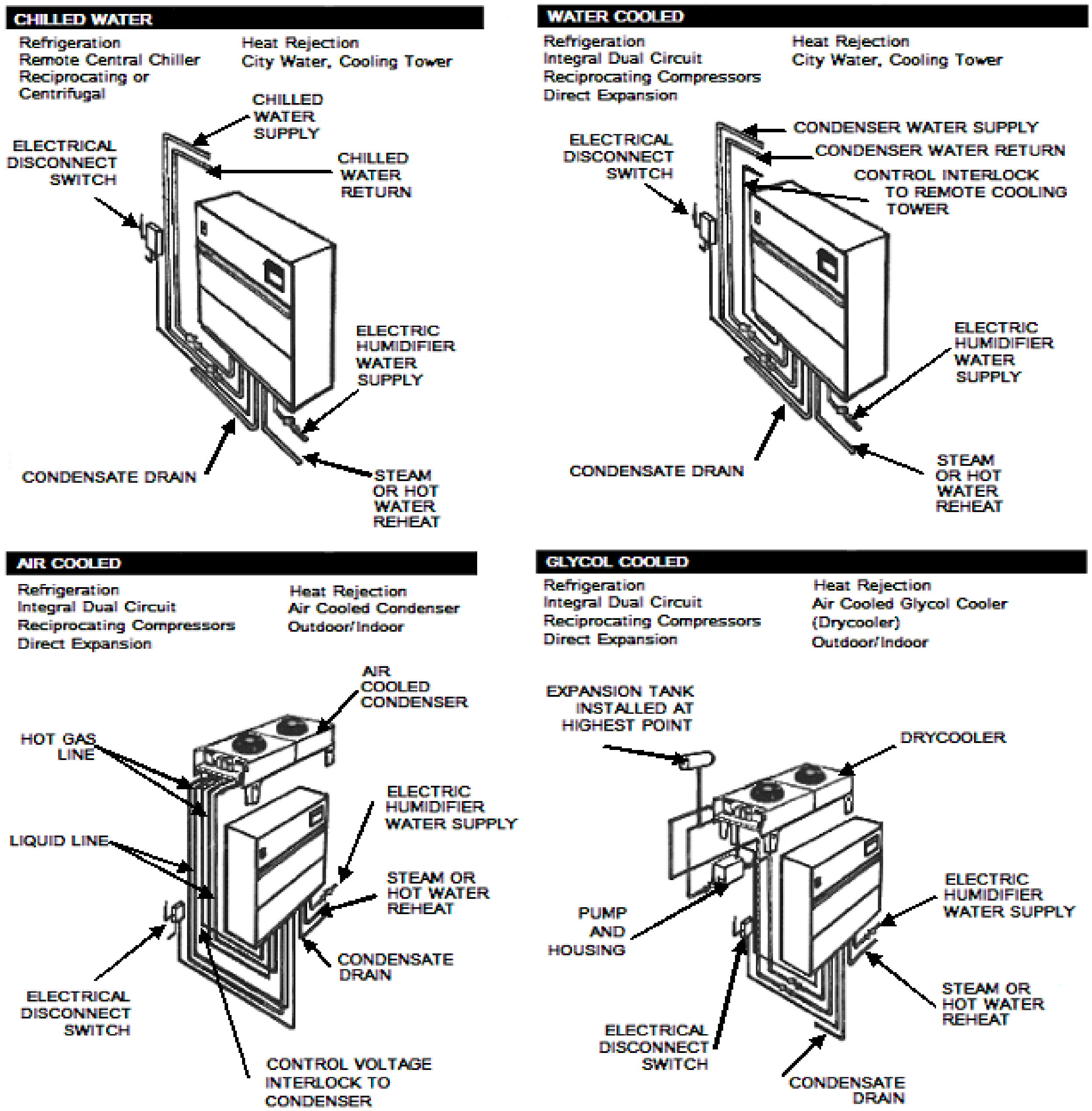
Figure 2-5. Package Air Conditioning System with Duct Work

2.4.1.1 Compressor

Many floor-mounted units use hermetically-sealed, reciprocating compressors. Compressors in the larger capacity units may be the serviceable hermetic, or single or multiple scrolls.

2.4.1.2 Condenser

In floor-mounted units, chilled-water, water-cooled, air-cooled, or glycol-cooled condensers are used. Some may be equipped with remote air-cooled condensers. See Figure 2-6 for representative installations.



2.4.1.3 Evaporator

The floor unit is built with a direct expansion evaporator. Units may have a large single stage evaporator with single or multiple compressors. Some units will have a single fin-on-tube evaporator, but it will be divided into multiple sections with multiple circuits. Each stage uses a separate complete condensing system.

2.4.1.4 Metering Device

The refrigerant control in a floor unit is generally a thermostatic expansion valve with a multi-circuit distributor. Tubes are connected from the distributor to each circuit in the evaporator, reducing the pressure drop across the large evaporating coil.

2.4.1.5 Fan Unit

With the added static pressure and required low noise level, these units are normally equipped with two centrifugal blowers.

2.4.1.6 Ducting

Ducting shall be installed in accordance with local codes. Industry manuals, such as the National Environmental Systems Contractors Association (NESCA), may be used as a guide when sizing and designing the duct system.

The unit should be placed as close as possible to the space to be air-conditioned and ducts should run as directly as possible to supply and return outlets.

2.4.1.7 Humidity Controls

Depending on the site criteria, some floor units also provide humidity control by either removing moisture from the air (dehumidification) or adding moisture (humidification). Humidity control is common in computer room air-conditioning units, where, to prevent static discharge problems, the relative humidity is generally maintained between 40 and 60 percent.

To dehumidify, the compressor must work beyond the point of removing sensible heat. The result is a room temperature that is uncomfortably low. After the moisture has been removed by the evaporator, the temperature of the excessively cold air is then raised to the desired level by a reheat coil. The reheat coil is supplied with hot water or steam from an independent source or from the water-cooled condenser.

To humidify, water is fed into a holding trough in the air-conditioning unit. This water is then heated via lamps or heating elements until the water temperature approaches 160ºF or higher. At this point, water vapor is released into the air-stream passing over the trough. Some units inject steam directly into the air-stream.

2.4.1.8 Economizer

The economizer, an additional cabinet with dampers, sensors, actuators, controls, and linkages, uses outside air for free cooling. The decision to use outside air can be based on outside air dry bulb temperature, dew point, and enthalpy. With a dual enthalpy sensor system, the economizer will bring in outside air when the outside air enthalpy is lower than the air inside the building. In some areas, economizers can significantly reduce energy usage. However, a failed economizer (i.e. damper stuck in the open position or damaged sensors) could significantly add to the building summer heat load, and increase winter heating costs.

2.4.1.9 Adjustable Speed Drives (ASD)/Variable Frequency Drives (VFD)

ASD/VFD match the speed of the fan to the amount of air needed.

2.5 MAINTENANCE GUIDELINES

2.5.1 Filters

WARNING

There is a possibility of contacting live voltages within the unit. Before opening the unit, be sure power is turned off and, where applicable, locked out and tagged out (LO/TO). Failure to comply may cause injury or death.

Filters are usually the most neglected item in an environmental control system. To maintain efficient operation. In buildings with Building Automation Systems (BAS), the filter alarms should be used to schedule the replacement. The detection systems should be maintained to ensure optimization of our filtering needs and cost. In facilities without BAS, they should be checked and changed as required. If replacement of air filters is needed on a unit with multiple "throw away" filters, it is best to replace every other filter each time a filter replacement is called for due to air restriction indicated by the manometer. Although some manufacturers may recommend replacing all "throw away" filters at one time, this procedure will tend to increase the dirt collected in the evaporator coil, which can make coil cleaning more difficult. After replacing filters, check the manometer reading and test the operation of the filter clog switch.

2.5.2 Humidifier

WARNING

There is a possibility of contacting live voltages and hot water within the unit. Before removing the humidifier pan, be sure all power to the unit is disconnected, and the water temperature in the humidifier pan is not too hot to handle. Failure to comply may cause injury or death.

CAUTION

Humidifier lamps are subject to damage by the slightest oil deposit. Do not touch the humidifier lamps with your bare hands; any oily deposits (fingerprints) will severely shorten bulb life. Failure to comply may cause equipment damage.

A humidifier introduces water vapor into the environment. During the course of normal humidifier operation, deposits of mineral solids collect on the sides and bottom of the humidifier pan. The pan should be inspected and cleaned periodically to ensure efficient humidifier operation. Each city and locality has different water characteristics making it difficult to establish definite time intervals between cleanings. Nonetheless, ensuring that the unit is free from debris and biological growth is extremely important since these can promote sick building syndrome. The term "sick building syndrome" (SBS) is used to describe situations in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building, but no specific illness or cause can be identified. The complaints may be localized in a particular room or zone, or may be widespread throughout the building. In contrast, the term "building related illness" (BRI) is used when symptoms of diagnosable illness are identified and can be attributed directly to airborne building contaminants (EPA Indoor Facts No. 4).

2.5.3 Blower Package

2.5.3.1 Inspection

Periodic checks of the blower package include inspection of the fan housing, belts, motor mounts, fan bearings, and impellers. Additionally, motor and shaft bearing should be lubricated per manufacturers' specifications and local experiences. According to major motor manufacturers, most fan and motor bearings fail due to over-lubrication and excessive belt tension.

2.5.3.1.1 Fan Impellers and Bearings

Periodically inspect and remove debris from fan impeller. Ensure tight fit between impeller hub and shaft. Check housing and impeller for wear marks. Check for excessive bearing play, which causes vibration.

2.5.3.1.2 Belts

WARNING

Rotating equipment presents multiple pinch, slash, and contact hazards. Always perform lock out and tag out (LO/TO) before working on rotating equipment. Failure to comply may cause injury or death.

CAUTION

Loose motor mounts present a hazard to the equipment. After adjusting or changing belts, ensure that motor mounts are tight; loose mounts produce vibration. Failure to comply may cause equipment damage.

Check drive belts for proper tension and wear. The current draw of the motor should be checked to see if it is within tolerance. Belts that are too tight can cause excessive bearing wear. With units using more than one V-belt in a single drive, power "band" belts (dual belts joined by a single carcass across the widest part) should be considered for installation because they provide a perfectly matched drive. Otherwise, purchase only matched-set belts for replacement. Always replace all of the belts regardless of the condition of one or more of the belts.

2.5.4 Electric Panel

WARNING

There is a possibility of contacting live voltages within electric panels. Be sure all safety precautions are followed and that power to the unit is turned off, locked out, and tagged out (LO/TO) before attempting to tighten any fittings or connections. Failure to comply may cause injury or death.

Electrical panels, and disconnecting means, shall be clearly labeled to indicate their purpose and any associated danger as required by OSHA and NEC. Additionally, electrical panels should be inspected periodically by qualified personnel.

2.5.5 Refrigeration System

2.5.5.1 Inspections

The components of the refrigeration system should be inspected for proper function and signs of wear. Often, evidence of malfunction is present prior to component failure. Therefore, periodic inspections are a major factor in the prevention of system failures. The installation of effective monitoring devices is a viable alternate to frequent inspections. Monitoring devices with alerts and alarms provide warnings of abnormal or faulty conditions. Alerts generally signify that the malfunctioning circuit can be restarted without human interaction; an alarm, however, generally means that the damaged circuit will not restart without an alarm reset.

2.5.5.1.1 Compressor Oil Level

To view the oil level, use the glass "bull's-eye" (if provided) on the compressor. Normally, the oil level should be ½ to ¾ from the bottom of the sight glass. Newer sight glass models may indicate minimum and maximum oil levels. However, this level may vary during operation due to the action of the moving parts. When idle, the oil level may be higher due to absorption of refrigerant. After a compressor has been idle for an extended length of time, restarting the compressor will generally lead to foaming. An accurate check of the oil level requires the compressor to operate 5 to 10 minutes before viewing the oil level.

Refrigeration oil does not deteriorate with normal usage and need not be changed unless discolored or acidic. Periodically inspect the compressor compartment for signs of oil leakage. If a leak is present, it must be corrected and the oil returned to its proper level. It is recommended that oil be taken from sealed containers opened at the time of use. Refrigeration oil exposed to the air absorbs moisture; moisture in the oil contributes to acid formation. Therefore, a means to detect moisture should be in place or an acid and moisture test should be performed annually.

2.5.5.1.2 Refrigerant Lines

Refrigerant lines must be properly supported and must not vibrate against ceilings, floors, or unit frames. Inspect capillary and equalizer lines from the expansion valve and support as necessary.

Some liquid lines have a sight glass that indicates liquid-refrigerant flow and the presence of moisture. Bubbles in the sight glass indicate a shortage of refrigerant, a restriction in the liquid line, or the presence of non-condensable. Commonly, moisture indicators change from green to yellow or purple to pink when moisture is present in the system (Figure 2-7). The sight glass should be located as close to the metering device as possible.

Figure 2-7. Liquid-Line Sight Glass

2.5.5.1.3 Suction Pressure

Suction pressure varies with load conditions. On units with a low-pressure switch, if suction pressure falls below the cutout setting, the low-pressure switch shuts the compressor down. On units with suction gas motor cooling, high suction line temperature can reduce the ability of the refrigerant to cool compressor components and can result in compressor damage. Low-pressure cutouts are most often automatically resetting; therefore, you must make sure the cut-out and cut-in pressure settings are at factory requirements. Do not depend on the cut-out's pressure markings, use the suction gauge readings to get the actual set points.

2.5.5.1.4 Superheat

Superheat is the difference between the saturation temperature (the temperature at which the refrigerant boils at a given pressure) and the temperature of the refrigerant leaving the evaporator coil. It can be adjusted on most Thermostatic Expansion Valves (TEV or TXV). However, adjustment of the superheat is rarely needed unless it has been changed since it left the unit's manufacturing plant. To determine superheat:

1. Measure the temperature of the suction line at the point where the TEV bulb is clamped.
2. Obtain the gauge pressure at the suction line access valve.
3. Add the estimated pressure drop between bulb location and suction valve, generally about 2 psig if taken at the compressor. This number may need to be increased if an extra-long line set is used.
4. Convert the suction line pressure to the saturation temperature, using a Pressure/Temperature (P/T) chart, or the proper scale on the suction gauge.
5. Subtract the saturation temperature from the actual suction line temperature; the difference is the superheat.

2.5.5.1.5 Discharge Pressure

Discharge pressure is increased or decreased by either load conditions or condenser efficiency. The high-pressure switch shuts the compressor down at its cutout setting. These are generally manually reset; and must be set at the manufacturer's recommended setting.

2.5.5.1.6 Hot Gas Bypass Valve Operation

The hot gas bypass (HGBP) is inserted between the compressor discharge line and the downstream side of the expansion valve through the side outlet distributor (Figure 2-8). Under careful evaluation and painstaking design, the HGBP is used as a form of capacity control. However, it should be used only as a last resort when all other design options fail to meet the demands of the application, such as when diminishing loads force the refrigeration system to operate at unstable conditions, resulting in coil frosting and compressor flooding.

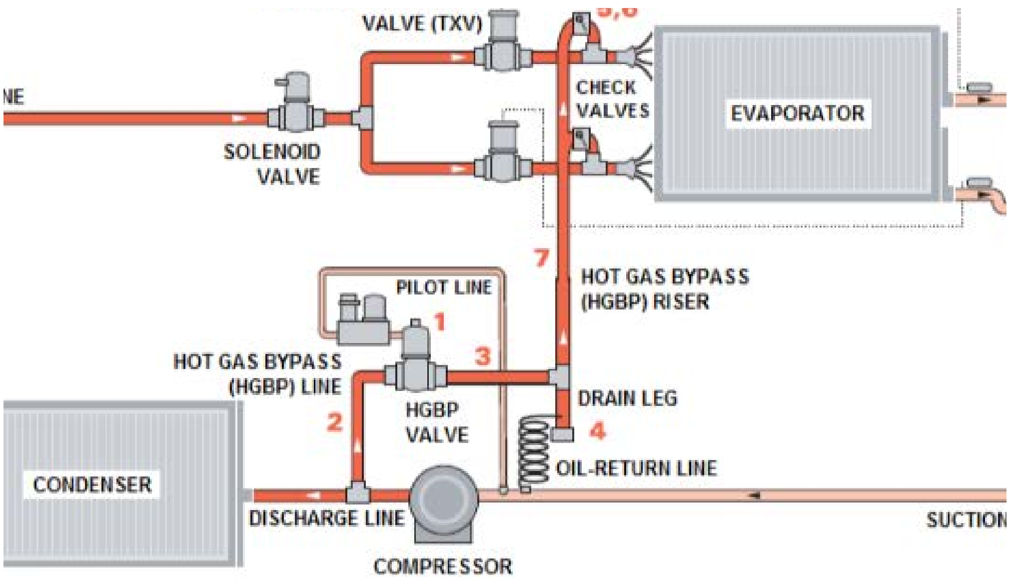


Figure 2-8. Hot Gas Bypass to Evaporator Inlet

Understanding the year-round loads and properly sizing the system to provide thermal comfort eliminates the need for HGBP, which results from an oversized system. The HGBP often increases power consumption and hence life cycle cost.

A system operating with a fully loaded evaporator will maintain enough pressure on the outlet of the HGBP valve to keep the valve port closed. If the load on the evaporator decreases to the point where the coil is below the set point, the discharge of the hot gas allows some hot gas to mix with the liquid discharge of the expansion valve. This raises the evaporator pressure and temperature, preventing icing of the coil. However, it also increases the load on the compressor, causing higher operating costs.

2.5.5.1.7 Thermostatic Expansion Valve Operation

The thermostatic-expansion valve (TXV) is a precision device used to maintain a constant superheat, by controlling the flow, to match the evaporator load. If the rate of refrigerant flow to the evaporator is inadequate, the suction line temperature will be higher than the saturation temperature in the evaporator. The higher temperature will cause the thermostatic bulb pressure to increase, pressing down on the diaphragm, opening the valve, keeping the evaporator supplied with refrigerant to satisfy load conditions. The TXV, like any other metering device, provides a pressure drop in the system's liquid line, restricting refrigerant flow to the evaporator. The TXV separates the high-pressure and low-pressure sides of the system. If the increased bulb pressure is higher than the combined evaporator and spring pressure, it will open the TXV valve. Proper valve operation can be determined by measuring superheat (Figure 2-9).

NOTE

Consult manufacturer's instructions for proper superheat value. As long as 30 minutes may be required for the new balance to take effect. Most manufacturers' valves will increase the superheat approximately 3°F for each revolution of the adjusting stem in the clockwise direction. Since the superheat of a unit is in constant fluctuation, superheat readings must be taken over a period of time so that the highest and lowest superheat reading is obtained. Then, the mid-point of the superheat swing must be calculated. This superheat number should match the manufacturer's recommended setting ±2°F.

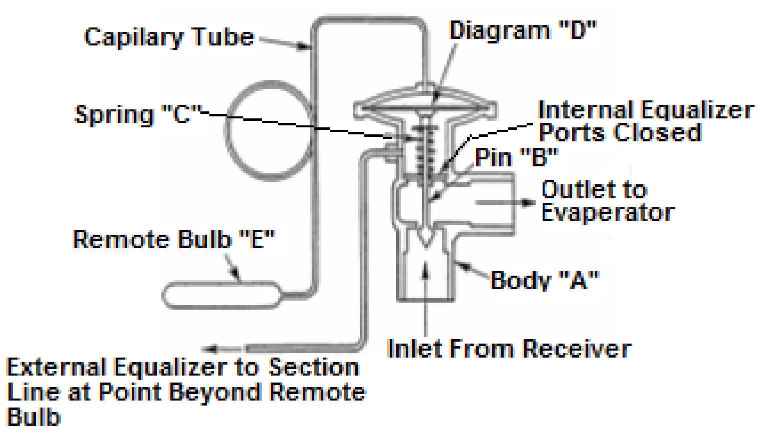


Figure 2-9. Thermostatic Expansion Valve

2.5.5.1.8 Crankcase Heater

When compressors operate in cold areas, or are left idle for long periods of time, refrigerant will migrate to the compressor and be absorbed into the crankcase oil. The lowering of the oil's viscosity can cause excessive motor bearing wear, and oil foaming, which can cause compressor damage at startup. Therefore, the crankcase heater should be turned on at least 24-hours prior to operation of the unit, or consideration given to leaving it on year round.

NOTE

Consult manufacturer's instructions for proper superheat value and make no more than one turn of the stem at a time. As long as 30 minutes may be required for the new balance to take place.

2.5.5.2 Air-Cooled Condenser

Coils become fouled as a result of normal operations. Restricted airflow through the condenser coil reduces the operating efficiency of the unit, resulting in high compressor head pressure and loss of cooling. Clean the condenser coil of all debris that inhibits airflow. Some units may have more than one condenser coil. LO/TO the unit, disconnect, and use an appropriate power washer with a compatible cleaning solution to clean the coils. Let the water dissipate before restoring power to the unit. Improper cleaning techniques can bend or damaged the coil's fins or spines. Snow should not accumulate around the sides or underneath the outdoor coil of heat pumps. Check all refrigerant lines and capillaries for vibration isolation and support as necessary. Visually inspect all refrigerant lines for signs of oil leaks.

2.5.5.3 Water/Glycol-Cooled Condensers

Each water or glycol-cooled module has a shell and tube condenser, most with removable heads, tubesheets, gaskets, and copper tubes. The tube bundle (tubes and tubesheets) should be inspected and cleaned periodically to remove any scale or slime that could collect. Periods between cleanings will vary with local water treatment and glycol conditions. As deposits build up, a cleaning tool, available at any refrigeration supply house, should be used to clean the heat exchanger tubes. Some units are sealed, and must be chemically cleaned.

2.5.5.4 Water/Glycol Solution Maintenance

Frequent cooling tower water treatment and analysis, will prevent scale formation, biological growth, and metal corrosion. The cooling tower water treatment and preventive maintenance processes should be thoroughly documented and rigorously implemented. The complexity of water-caused problems and their correction makes it important to obtain the advice of a water-treatment specialist and to follow a regularly scheduled maintenance program. It is important to note that the improper use of water-treatment chemicals can result in problems more serious than using no chemicals at all.

The EPA has indicated that glycols are toxic; therefore, glycols must be separated from the potable water system, and used glycols recycled. A glycol solution is generally a mixture of corrosion inhibited ethylene-glycol (EG) and water, and is used in "computer room" type cooling systems and water cooled condensers. It removes heat from the room to an outdoor radiator with a fan, expelling the heat. Glycol solutions in contact with air can form corrosive acids. Therefore, pH buffers (inhibitors) added to the glycols provides corrosion protection. Periodically test the inhibited glycol solution to determine depletion and add inhibitors as required. OSHA has set permissible exposure limits for EG.

WARNING

Glycol solution may be classified as a hazardous material. Check with USPS Environmental Compliance to determine if the glycol solution is classified as a hazardous material. If so, at disposal it becomes a hazardous waste subject to Environmental Protection Agency guidelines for proper storage, handling, disposal, and documentation. Follow all legal requirements for proper disposal. Failure to comply can cause environmental damage and/or result in criminal prosecution.

2.5.5.5 Compressor Failure

If a compressor motor burns out, the stator wiring insulation decomposes forming carbon, water, and acid. Not only must the compressor be replaced, but also the entire refrigeration system must be cleaned of the harmful contaminants left by the burnout. Successive burnouts of the same system can usually be attributed to improper system cleaning. See the manufacturer's instructions for clean out procedures. Before proceeding with a suspected burnout, a preliminary check should be performed of all electrical components, including all fuses and the operation of Hi-Lo pressure switches.

2.5.5.6 Electrical Failure

An electrical failure of the compressor is indicated by the distinct pungent odor of refrigerant being released through the service port. If a severe burnout has occurred, the oil will be darkened and acidic.

2.5.5.7 Mechanical Failure

If the motor attempts to run, and no odor of burned gas is released at the service port, a mechanical failure is indicated (Table 2-1).

Table 2-1. Troubleshooting Guidelines for Self Contained Air Conditioners

SYMPTOM	CAUSE	REMEDY
A. Open Type Compressor		
1. Electric motor will not start.	a. Power failure.	a. Check circuit for power source.
	b. Compressor stuck.	b. Locate cause and repair.
	c. Belt too tight.	c. Adjust belt tension.
	d. Manual reset in starter open.	d. Determine cause of overload and repair. Reset overload output.
	e. Thermostat setting too high.	e. Lower thermostat setting.

SYMPTOM	CAUSE	REMEDY
(continued)	f. Low voltage.	f. Check with voltmeter; then call power company.
	g. Burned-out motor.	g. Repair or replace.
	h. Frozen compressor (caused by locked or damaged mechanism).	h. Remove and repair compressor.
2. Unit cycles on and off.	a. Intermittent power interruption.	a. Tighten connections or replace defective power supply parts.
	b. High-pressure output defective.	b. Replace high-pressure output.
	c. High-pressure output set too low. Overload opens after having been reset.	c. Raise output pressure. Check voltage and current drawn.
	d. Leaky liquid-line solenoid valve.	d. Repair or replace.
	e. Dirty or load evaporator.	e. Clean or defrost evaporator. Check filters and fan drive.
	f. Overcharge of refrigerant or non-condensable gas.	f. Remove excess refrigerant or purge non-condensable gas.
	g. Lack of refrigerant.	g. Repair refrigerant leak and recharge.
	h. Restricted liquid-line strainer.	h. Clean strainer.
	i. Faulty motor.	i. Repair or replace faulty motor.
3. Coil frosts.	a. Filters dirty	a. Clean filters.
	b. Not enough air over coil.	b. Clean or remove restriction from supply or return ducts or grilles.
	c. Defective expansion valve	c. Replace valve.
4. Unit runs but will not cool.	a. Unit not fully charged.	a. Recharge slightly and check for leaks in the refrigerant circuit; then fully charge.
	b. Leaky suction valve or discharge valve.	b. Remove compressor cylinder head and clean or replace valve plate.
	c. Expansion valve not set correctly.	c. Adjust expansion valve.

SYMPTOM	CAUSE	REMEDY
(continued)	d. Strainer clogged.	d. Remove, clean, and replace strainer.
	e. Air in refrigerant circuit.	e. Purge unit of air. Clean orifice and install silica gel drier.
	f. Flash gas in liquid line.	f. Add refrigerant.
5. No air blows from supply grille.	a. Ice or dirt on evaporator.	a. Clean coil or defrost.
	b. Blower belt broken or loose.	b. Adjust belt tension or replace belt.
	c. Blower bearing frozen.	c. Repair or replace bearing and lubricate as directed.
6. Discharge pressure is too high.	a. Improper operation of condenser.	a. Correct air flow. Clean coil surface.
	b. Air in system.	b. Purge.
	c. Overcharge of refrigerant.	c. Remove excess or purge.
7. Discharge pressure is too low.	a. Lack of refrigerant.	a. Repair leak and charge.
	b. Broken or leaky compressor discharge valves.	b. Remove head, examine valves, and replace those found to be operating improperly.
8. Suction pressure is too high.	a. Overfeeding of expansion valve.	a. Regulate superheat setting expansion valve and check to see that remote bulb is properly attached to suction line.
	b. Expansion valve stuck in open position.	b. Repair or replace valve.
	c. Broken section valve in compressor.	c. Remove head, examine valves, and replace those found to be inoperative.
9. Suction pressure is too low.	a. Lack of refrigerant.	a. Repair leak and charge.
	b. Clogged liquid-line strainer.	b. Clean strainer.
	c. Expansion-valve power assembly has lost charge	c. Replace expansion-valve power assembly.
	d. Obstructed expansion valve	d. Clean valve and replace if necessary.

SYMPTOM	CAUSE	REMEDY
(continued)	e. Contacts on control thermostat stuck on closed position.	e. Repair thermostat or replace if necessary.
B. Hermetic Motor-Compressor Combination		
1. Compressor runs continuously (good refrigeration effect).	Air over condenser restricted.	Remove restriction or provide for more air circulation over the condenser.
2. Compressor runs continuously (unit is too cold).	a. Thermostatic switch contacts badly burned.	a. Replace thermostatic switch.
	b. Thermostatic switch bulb loose.	b. Secure bulb in place.
	c. Thermostatic switch improperly adjusted.	c. Readjust thermostatic switch.
3. Compressor runs continuously (little refrigeration effect).	a. Extremely dirty condenser.	a. Clean condenser.
	b. No air circulating over condenser.	b. Provide air circulation.
	c. Ambient temperature too high.	c. Provide ventilation or move to a cooler location.
	d. Load too great.	d. Analyze load.
4. Compressor runs continuously (no refrigeration).	a. Restriction that prevents the refrigerant from entering the evaporator. (Usually indicated by a slight refrigeration effect at the point of point of restriction.)	a. Locate the possible points of restriction, and try jarring with a plastic hammer, or heating to a temperature of about 100ºF. If the restriction does not open, replace the unit.
	b. Compressor not pumping. (Indicated by a cool discharge line and hot compressor housing; wattage generally low.)	b. Replace the unit.
	c. Short of refrigerant.	c. See manufacturer's instructions.
5. Compressor short-cycles (poor refrigeration effect).	a. Loose electrical connections.	a. Locate loose connections and make them secure.
	b. Defective thermostatic switch.	b. Replace thermostatic switch.

SYMPTOM	CAUSE	REMEDY
(continued)	c. Defective motor starter.	c. Replace defective motor starter or relay.
	d. Air restriction at evaporator.	d. Remove air restriction.
6. Compressor short-cycles (no refrigeration).	a. Dirty condenser.	a. Clean the condenser.
	b. Ambient temperature too high.	b. Provide ventilation or move to a cooler location.
	c. Defective wiring.	c. Repair or replace defective wiring.
	d. Thermostatic switch operating erratically.	d. Replace thermostatic switch.
	e. Relay erratic.	e. Replace relay.
7. Compressor runs too frequently.	a. Poor air circulation around the condenser or too high ambient temperature.	a. Increase the air circulation around the condenser. In some localities, the temperature is extremely high and nothing can be done to correct this.
	b. Load too great; worn compressor; generally accompanied by rattles or knocks.	b. Analyze end use. Replace unit or bring it to the shop for repairs.
8. Compressor does not run.	Motor not operating	If the trouble is outside the sealed unit, it should be corrected; for example, wires should be repaired or replaced and thermostatic switches or relays should be replaced. If the trouble is inside the sealed unit, the sealed unit should be replaced.
9. Compressor will not run. (Assume that the thermostatic switch and relay, and the electric wiring and current supply are in good condition and operating normally.)	a. If the cabinet has been move, some oil may be on top of the piston.	a. Wait an hour or so, and then attempt to start the motor by turning the current on and off many times. On some compressors, it may be necessary to wait 6 or 8 hours.
	b. Compressor may be struck, or some parts may be broken.	b. Replace the unit.
	c. Connections may be broken on the inside of the unit, or the motor winding may be open.	c. Replace the unit. Sometimes after sealed units have been standing idle for a long time, the piston may stick in the cylinder wall. It is sometimes possible to start the compressor by turning on the current and bumping the outer housing with a rubber mallet.

SYMPTOM	CAUSE	REMEDY
10. Compressor is unusually hot.	a. Condenser dirty or lack of air circulation.	a. Clean the condenser; increase the air circulation.
	b. unusually heavy service or load.	b. If possible, decrease load. Perhaps another unit is required.
	c. Low voltage.	c. This could be cause by too small feed wires. If the wires feeding the refrigerating unit become warm, it is an indication that they are too small and should be replaced by larger wires.
	d. A shortage of oil.	d. Add oil of possible; if this is not possible, the unit must be replaced A shortage of refrigerant will cause a shortage of oil in the crankcase of the compressor.
11. There is no refrigeration after starting.	Generally, during a long shutdown, an amount of liquid refrigerant will get into crankcase of the compressor. When this happens, the compressor operation will cause no noticeable refrigeration effect until all the liquid refrigerant has evaporated from the crankcase.	Allow the compressor to operate until its internal heat drives the liquid refrigerant from the crankcase. Under some conditions, this may take as long as 24-hours. This time can be shortened by turning an electric heater on the compressor and raising the compressor temperature, not exceeding 110ºF.
12. Compressor is noisy.	a. Mountings have become worn or deteriorated. The walls against which the unit is placed may be of an extremely hard surface and may resound and amplify the slight noise from the compressor into the room.	a. Replace the rubber mountings. Place a piece of sound-absorbing material on the wall against which the unit is placed, or move the unit to a new location.
	b. Shortage of oil and/or refrigerant.	b. Add oil and refrigerant if possible. If it is impossible, the unit must be replaced.
	c. The sealed unit mechanism has become worn.	c. Replace the unit.

SYMPTOM	CAUSE	REMEDY
13. After each defrosting, there is a long cycle before refrigeration is again normal.	a. Slight shortage of refrigerant.	a. Add refrigerant if possible; if not, replace the unit.
	b. Condenser is dirty.	b. Clean the condenser.
	c. Thermostatic switch bulb is loose.	c. Secure the bulb in place.
	d. There is a restriction between the receiver or condenser and/or the evaporator.	d. Attempt to remove the restriction by jarring with a plastic hammer or by heating the possible points of restriction to about 110ºF. If this does not correct the trouble, the unit must be replaced or brought to the shop for repairs.

2.5.6 Diagnostic Software

Diagnostic software detects and diagnoses common problems associated with heating, ventilation, and air conditioning systems as well as other building assets. Most diagnostic software are able to track energy usage, monitor the performance of air handlers and detect problems with outside air control, as well as vibration problems. Diagnostic software, when properly implemented and managed, can improve operational and maintenance reliability.

2.6 HEAT PUMPS

A heat pump is similar to a conventional air conditioner, except that it can cool and heat building spaces. For cooling, the heat pump collects heat from inside the building and expels it to the outside. For heating, it extracts heat from the outside air and circulates it inside the building, thus reversing the refrigerant flow (Figure 2-10).

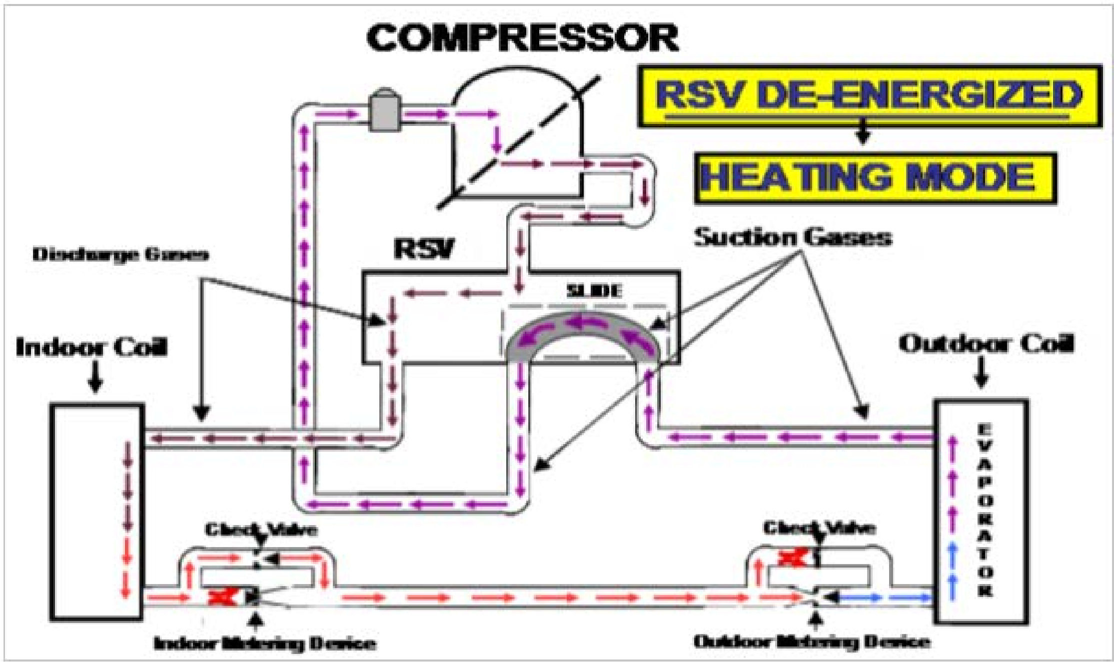


Figure 2-10. Heat Pump Heating Cycle

The heating process starts with refrigerant circulation through the outdoor coil in a low-temperature, low-pressure state. Since the refrigerant is much colder than the outside coil temperature, the refrigerant gains heat and changes into a hot gas. The refrigerant gas is then fed into the compressor where it raises the gas temperature and pressure, and forces it to the indoor coil. When the hot refrigerant gas passes through the indoor coil, it is cooled by (gives up heat to) the lower temperature airflow surrounding the coil. When the gas cools, it condenses and returns to a liquid state completing the heat transfer at the indoor coil. After exiting the indoor coil, the liquid refrigerant passes through the thermostatic-expansion valve (TEV or TXV) or capillary tube that transfers the refrigerant back to a low-pressure state.

In addition to the heating cycle, a heat pump has two other cycles, cooling and defrosts. During the cooling cycle, a four-way valve redirects refrigerant flow and, in conjunction with check valves installed in the line between the indoor and outdoor coils, allows the outdoor coil to operate as the condenser as in a regular air-conditioner. Refrigerant flow is directed from the compressor to the outdoor coils where it becomes a low-temperature high-pressure liquid, the pressure is lowered when the refrigerant passes through the thermal expansion valve. The low-temperature low-pressure refrigerant is vaporized in the indoor coils.

The defrost cycle is a reversal of the heating cycle to compensate for temperatures near or below zero, during the heating cycle, which causes moisture condensation and accumulation on the coils, creating frost. Sensing controls activate the reversal to cooling mode and turn on the auxiliary heat to compensate for the cooling of the indoor air by the indoor coil.

2.6.1 Specialized Components

2.6.1.1 Four-Way Reversing Valve

A four-way interchange reversing valve causes a rapid change in direction of refrigerant flow, resulting in a quick changeover from cooling to heating, and vice versa. It also facilitates frost removal during the heating season.

2.6.1.2 Backup Heating

As outdoor temperatures decrease, the efficiency of a heat pump decreases. Some heat pumps are equipped with electric heating coils to supplement the operation of the unit during cold weather and during defrost.

2.6.2 Installation

Heat pumps may be installed either as a unitized system or as a split system with the indoor coil mounted in a distribution duct, as in a forced-air system (Figure 2-11 and Figure 2-12).

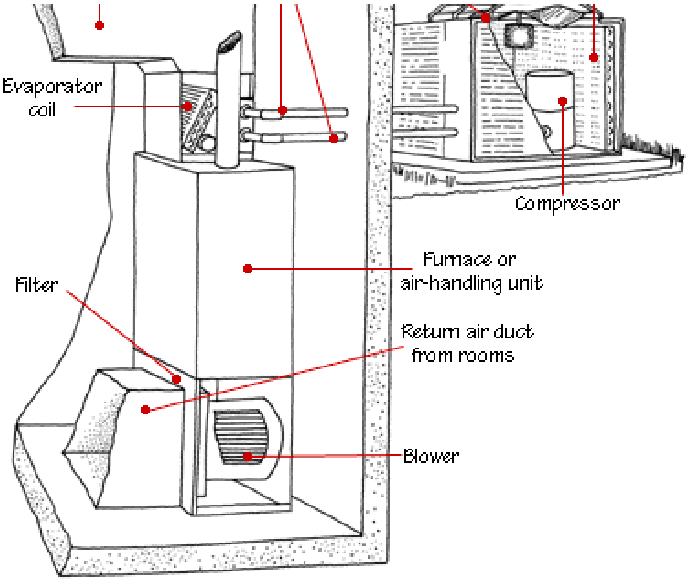


Fig)

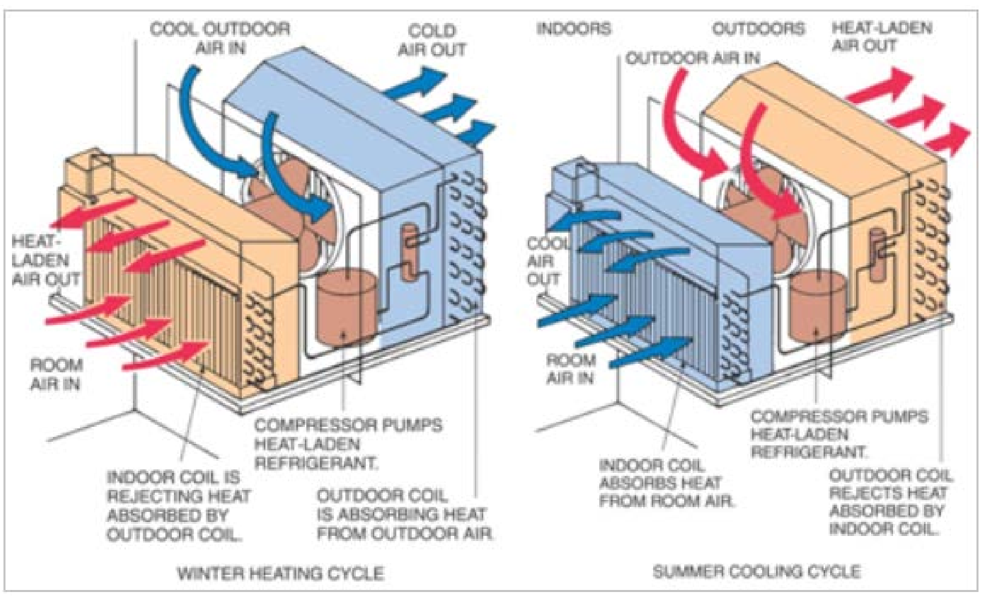


Figure 2-12. Heat Pump Installation (Unitized System)

2.6.3 Maintenance Guidelines

Maintenance of heat pump systems requires operating under the same guidelines as any package air-conditioning unit (Paragraph 2.3.3). The proper refrigerant charge is very important in all heat pump systems because they operate under a wide variety of ambient conditions. Improper refrigerant charge can result in a number of undesirable conditions (sludge, acid, oil breakdown, etc.) any of which may cause compressor failure. Always refer to the manufacturer's instructions for refrigerant checking and charging procedures. Also refer to Table 2-2.

Table 2-2. Troubleshooting Guide for Heat Pumps

SYMPTOM	CAUSE	REMEDY
1. Heat pump will not operate.	a. Disconnect switch off.	a. Turn disconnect on. Both disconnects must be on in split systems.
	b. Incorrect thermostat setting.	b. Change to proper setting.
	c. Tripped circuit breaker or unit fuse.	c. Turn unit disconnect switch(es) off. Check unit fuses and replace with same size and type fuse. Check current draw and find over-current cause. Repair or replace part.
2. Unit runs but there is little heat.	a. Obstructed outdoor coil.	a. Remove obstruction.
	b. Dirty or plugged air filter.	b. Clean or change if necessary.
3. Reversing valve will not shift from heat to cool.	a. No voltage to coil.	a. Repair electrical current.
	b. Defective coil.	b. Replace coil.
	c. Low refrigerant charge.	c. Repair leak and recharge system.
	d. Pressure differential too low due to valve being stuck in-between heat and cool.	d. Lightly tap valve on the ends only with a small plastic faced hammer.

SYMPTOM	CAUSE	REMEDY
(continued)	e. Pilot valve operating correctly (dirt in one bleeder hole).	e. De-energize solenoid, raise head pressure, and reenergize solenoid to break dirt loose. If unsuccessful, remove valve and wash out. Check on air before installing; if no movement, replace reversing valve, add strainer to discharge tube, and mount valve horizontally.
	f. Piston cup leak.	f. Stop unit. After pressure equalizes, restart with valve solenoid energized. If valve shifts, reattempt with compressor running. If still no shift, replace reversing valve.
	g. Clogged pilot tubes.	g. Raise head pressure and operate solenoid to free tube of obstruction. If still no shift, replace reversing valve.
	h. Both ports of pilot open. Back seat port did not close.	h. Raise head pressure and operate solenoid to free partially clogged port. If still no shift, replace reversing valve.
4. Reversing valve starts but does not complete reversal.	a. Not enough pressure differential at start of stroke, or not enough flow to maintain pressure differential.	a. Check unit for correct operating pressures and charge. Raise head pressure. If no shift, use valve with smaller ports.
	b. Body damage	b. Replace reversing valve.
	c. Both ports of pilot open	c. Raise head pressure and operating solenoid. If no shift, replace reversing valve.
5. Reversing valve starts but does not complete reversal (continued).	d. Valve hung-up at mid-stroke; pumping volume of compressor not sufficient to maintain reversal.	d. Raise head pressure and operate solenoid. If no shift, use a four pilot tube reversing valve with smaller ports.

SYMPTOM	CAUSE	REMEDY
6. Reversing valve has apparent leak in heating position.	a. Piston needle on end of slide leaking	a. Operate reversing valve several times, then recheck. If excessive leak, replace valve.
	b. Pilot needle and piston needle leaking	b. Operate reversing valve several times.
7. Reversing valve will not shift.	a. Pressure differential too high	a. Stop unit. Valve will reverse during equalization period. Recheck system.
	b. Clogged pilot tube	b. Raise head pressure. Operate solenoid to free dirt. If still no shift, replace reversing valve.
	c. Dirt in bleeder	c. Raise head pressure and operate solenoid. Remove reversing valve and wash it out. Check on air before installing; if no movement, replace valve. Add strainer to discharge tube. Mount valve horizontally.
	d. Piston cup leak	d. Stop unit. After pressure equalizes, restart with solenoid de-energized. If valve shifts, reattempt with compressor running. If it still will not reverse while running, replace reversing valve.
	e. Defective pilot	e. Replace valve.
	f. Pilot valve not energizing.	f. Check for voltage coming to the coil and for magnetism at the end of the coil. Replace holding coil if bad. Repair or replace electrical component keeping the coil from being energized.

2.7 GAS FORCED-AIR FURNACES

2.7.1 Operation

Some smaller postal facilities are heated by one or more forced-air furnaces, supplying heat via sheet metal ducts, or ceiling mounted free heated air discharge. To provide heat, air is drawn into the furnace by convection created by ignition of the burner flame. A small percentage of this combustion air is mixed with natural gas and ignited as it exits from the burners. The remainder of the combustion air continues past the burners where it is heated and rises through the heat-exchanger. During passage, heat is transferred from the combustion gases to the heat exchanger. After passing through the heat exchanger, the cooled combustion gases exit the furnace through the vent that exhausts outside of the facility. Building interior air is drawn through a filter and is then directed to the heat exchanger where it is heated and forced into the area surrounding the furnace or into distribution ducts (Figure 2-13).

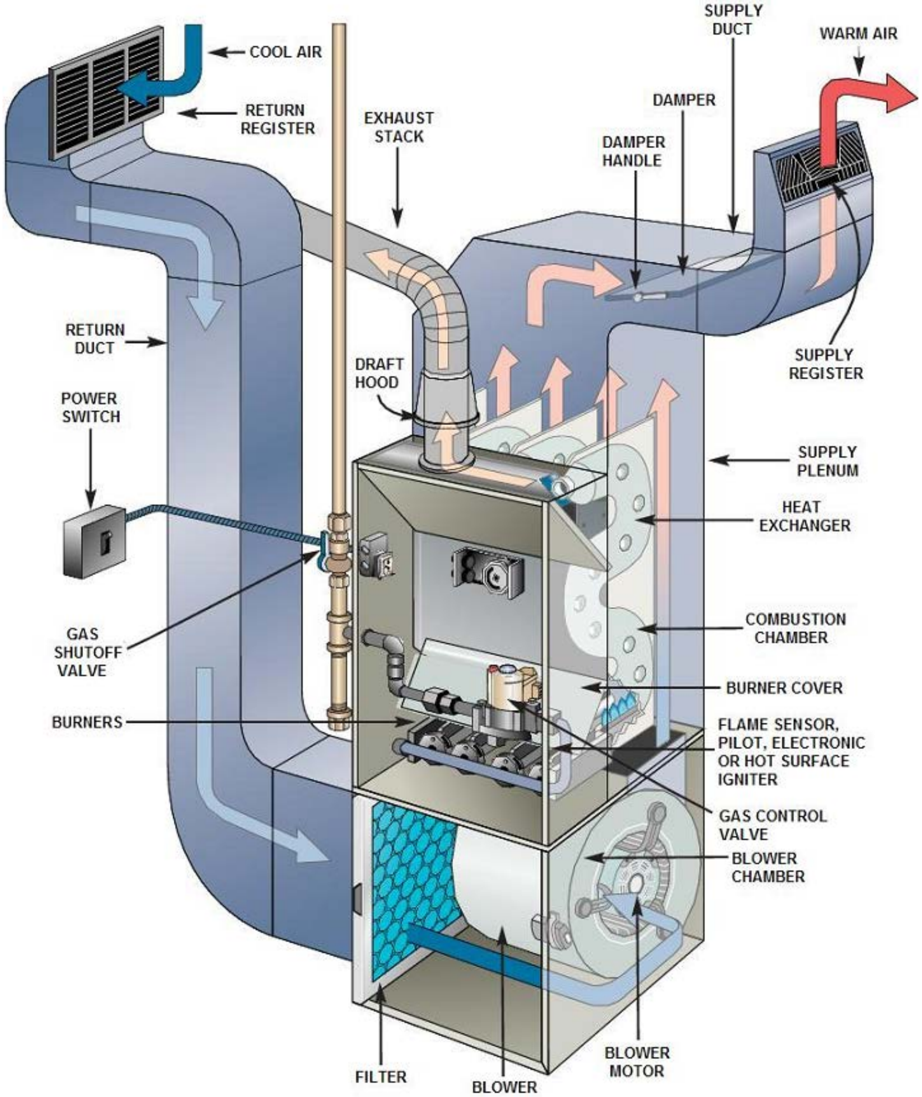


Figure 2-13. Forced Air Furnace

Modern furnaces are often equipped with controls that integrate boilers, burners, pumps and other components to create an efficient, safe, and reliable source of heat. Some controls provide complete self-diagnosis and troubleshooting, and can be linked via a communication bus, allowing electronic exchange of information (troubleshooting) from remote locations. Additionally, modern high efficiency combustion furnaces (condensing or recuperative units) can achieve 98 percent efficiency without a conventional flue, (a vent is still required) and often are equipped with electronic ignition. Condensing gas furnace burners are similar to conventional furnaces; they possess an additional corrosion resistant heat exchanger surface, because flue gases will condense and may be acidic or corrosive. Condensing furnaces may use pulse combustion technology to ignite small amounts of gas at frequent intervals.

2.7.2 Components

2.7.2.1 Gas Burner Control

Gas forced-air furnace controls must regulate gas pressure, provide ignition of pilot and/or main flame, and prove the flame or shut down the system. Gas pressure regulation is often integrated in the gas valve assembly, or may be independent. Gas forced-air furnaces typically provide a safety shutoff and gas control via the use of a low-voltage solenoid valve.

On a standing pilot system, the solenoid also functions as an automatic safety for the pilot flame via a thermocouple sensor. Some systems use a direct spark ignition or hot surface igniter with a flame rod to prove flame.

High temperature limits include heat exchanger temperature, flame roll-out sensing, flue temperature sensing, ambient air sensing, and are often wired in series with the operating control, and will shut down the system.

2.7.2.2 Filter(s)

The filter(s) keeps the heat-exchanger surfaces clean in order to maintain effective heat transfer. Filters should be cleaned or replaced regularly.

2.7.2.3 Blower

The blower draws air into the furnace from either return air ducts or the area surrounding the furnace. It forces air around the heat exchanger and into supply ducts or the surrounding air.

2.7.2.4 Heat Exchanger

The heat exchanger transfers heat between the hot combustion air and the building interior air, while eliminating the possibility of combustion air and gas residues mixing with the building interior air.

2.7.2.5 Burner

The burner ensures that the flame created by the combustion of natural gas is of uniform size and mixture and achieves good combustion efficiency.

2.7.2.6 Vent

WARNING

Carbon monoxide gas is not compatible with human life. The vent must be practically airtight to prevent carbon monoxide gas from building up inside the building. Failure to comply may cause injury or death.

The vent or flue removes combusted air and gases from the furnace and exhausts them outside of the building. Two or more vent connector shall not enter a common venting system, unless the inlets are offset and are not opposite to one another. Moreover, in the event that two or more appliances are commonly vented, the common vent should be properly sized and the smaller connector shall enter at the highest level.

2.7.3 Maintenance Guidelines

2.7.3.1 Flue Maintenance

The integrity of the flue should be maintained at all times to prevent leakage of carbon monoxide. If two or more appliances vent to a common flue, the area of the common flue should be at least equal to the area of the largest flue or vent connector plus 50 percent of the combined area of additional flue or vent connector(s).

2.7.3.2 Piping Maintenance

WARNING

Carpeting can build up and discharge static electricity that presents an ignition hazard around gas equipment. Ensure that gas equipment has not been installed on carpeting unless the equipment has been specifically designed and built for that purpose. Failure to comply may Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

After installing or repairing gas piping, and before start up, carefully check all the connections with a soap solution to detect the presence of leaks. When using compound on threaded pipe joints, ensure compatibility with liquefied petroleum gases.

2.8 OIL-FIRED HOT-WATER BOILERS

2.8.1 Operation

Many older and smaller post offices are heated by oil-fired hot-water boilers. These units operate on the same principles as larger boilers, but differ in construction design. These units operate on No. 2 fuel oil and, when their design capacity is less than 400,000 Btu per hour, are like the typical design shown in Figure 2-14. To release the heat energy from the fuel oil, the oil-fired burner initially ignites the fuel by forcing small atomized droplets past an electrical spark generated between two high voltage electrodes. This ignition then heats the surrounding oil droplets producing additional vaporization. The process continues until the droplets are vaporized and burning. If conditions for combustion are ideal, all oil droplets will burn completely and cleanly within the combustion zone.

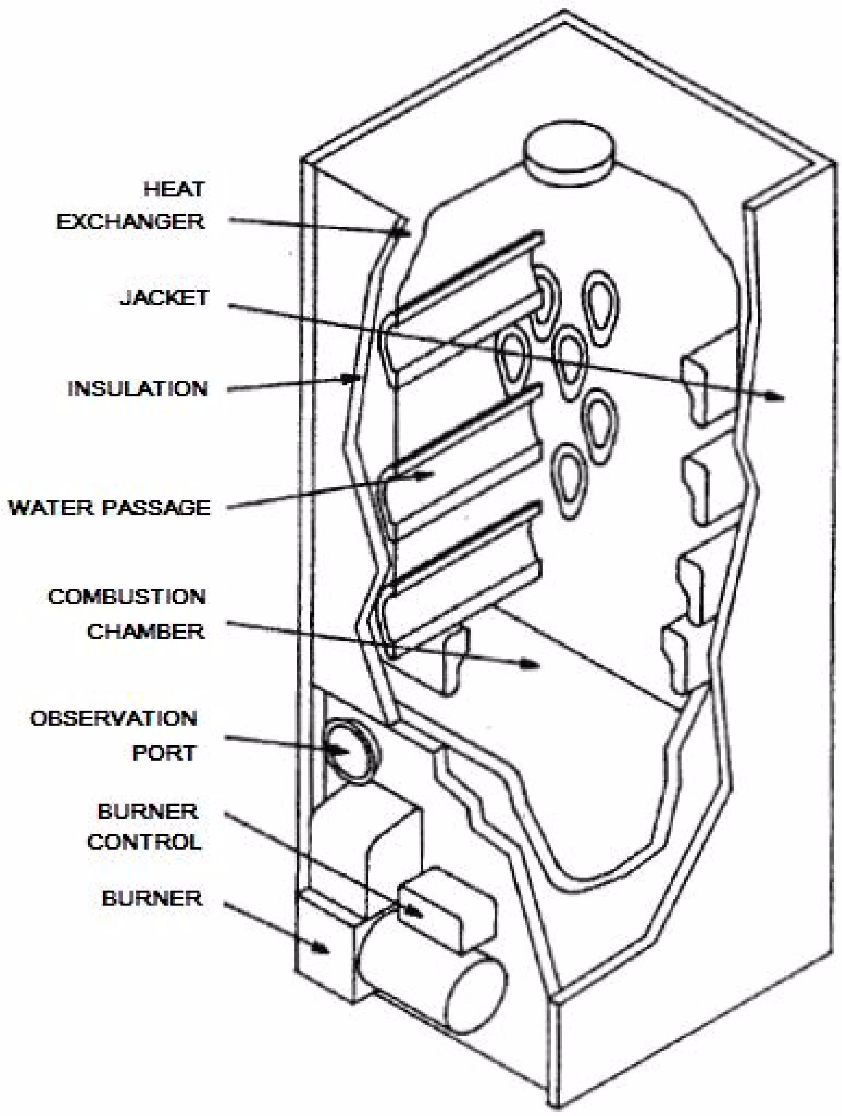


Figure 2-14. Typical Oil Fired Water Boiler

Annual Fuel Utilization Efficiency (AFUE) is the most widely used measure of furnace heating efficiency. It measures the amount of heat actually delivered to the furnace compared to the amount of fuel that must be supplied to the furnace. The U.S Department of Energy (DOE) determined that after January 1, 1992 all furnaces sold in the US must have a minimum AFUE of 78 percent. Therefore, it is important to know how to determine the efficiency of old furnaces and boilers. The existing AFUE can be compared to the AFUE of modern high-efficiency boilers and furnaces to determine potential savings that could result from replacing the existing unit. Many old furnaces with pilot lights have estimated AFUE ratings of only 55-65 percent. Energy star qualified furnaces must have an AFUE of 90 percent or higher. Consideration should be given to upgrading low efficiency units to the newer high efficiency furnaces.

2.8.2 Components

2.8.2.1 Jacket

A jacket provides a medium for ensuring uniform heat transfer; it is the boiler encasement.

2.8.2.2 Heat Exchanger

A heat exchanger is a device that transfers heat through a conducting wall from one fluid to another. The conducting wall for hot water boilers is generally cast iron; it allows the transfer of heat between the heated combustion gases created by the boiler flame, and the cooler water circulated through the heat exchanger. This transfer takes place in two ways, by hot combustion gases directly contacting the heat-exchanger surfaces, and by radiant energy in the combustion chamber heating the exchanger surfaces.

2.8.2.3 Combustion Chamber

The combustion chamber is designed to surround the flame and radiate heat back into the flame to aid in combustion. The chamber must be made of the correct material, properly sized for the burner nozzle firing rate, and shaped correctly to ensure unburned droplets of oil do not to touch the chamber. It should also be able to attenuate noise generated by the burner. Furnaces equipped with sealed combustion chambers require a source of outside air.

2.8.2.4 Burner

The burner is where the gas or fuel oil is delivered and burned to produce heat. Modern furnaces use electronic ignition switch as opposed to a constant burning pilot light. The burner package incorporates several functions. It provides for appropriate mixture and ignition, as well as ensuring that the combustion achieves the desired flame size and shape. The components of a burner package and their functions are listed below:

- Drive Motor - The drive motor powers both the blower and the fuel unit.
- Blower. The blower provides airflow sufficient to force the air and fuel oil mixture into the combustion chamber.
- Bulk Air Band - This device provides gross adjustment of the quantity of air mixed with vaporized oil.

- End-Air Shutter - This device provides the fine adjustment of the quantity of air mixed with vaporized oil.
- Fuel Unit - This "pump" draws oil from the storage tank to the burner unit. Additionally, it pressurizes the oil (normally around 100 psi) being fed into the burner nozzle, forcing the oil through the small nozzle orifice in order to break it down into atomized particles.
- Nozzle - The nozzle breaks the oil down into atomized particles. It determines the rate at which oil is burned and affects both the shape and efficiency of the flame. Nozzle selection is based on the shape of the chamber, the shape of the air pattern, and the rating of the boiler. Always follow the manufacturer's guidance.
- Electrodes - The electrodes ignite the vaporized oil when the furnace is first started, and until the flame becomes self-sustaining.
- Ignition Transformer - The transformer provides a high-voltage spark across the electrodes (normally around 10,000 volts) in order to ignite the fuel/air mixture when the furnace initially starts.
- Air Tube - The air tube controls flame shape by creating a desired airflow pattern as the air/fuel mixture ignites and enter the combustion chamber.
- Burner Control - The burner control provides control of the burner motor, ignition system, and oil valve.
- Flame Control - The flame-control circuit provides a means for shutting down the burner during startup or when running if the flame in the burner fails to ignite or is extinguished.

2.8.2.5 Auxiliary Controls and Equipment

Auxiliary controls and equipment are as follows:

- High-Limit Aquastat - The aquastat shuts down the burner when the operating temperature is exceeded (not shown).
- Circulator - The circulator pump takes heated water from the boiler and circulates it throughout the water loop.
- Operating Aquastat - The aquastat shuts down the burner when the operating temperature is met (not shown).
- Pressure-Relief Valve - The pressure-relief valve opens to release water when the hot water in the boiler exceeds either the desired safe temperature or pressure .
- Low-Water Cutoff - The low-water cutoff shuts down the boiler if water in the boiler drops below a safe level (not shown).
- Flue - The flue vents products of combustion from the furnace to outside the building.
- Damper - The damper controls the airflow or "draft" through the furnace in order to ensure efficient combustion.

2.8.3 Maintenance Guidelines

2.8.3.1 General Maintenance

Hot water boilers set at 160 psi and below require an external inspection every 24 months, or as required by Management Instruction (MI), currently *Safety Inspection of Heating Boilers, Unfired Pressure Vessels, Elevators, Escalators, Dumbwaiters, Platform Lifts, and Chairlifts*. Additionally, operating logs are recommended, but not required for **boilers rated at less than 400,000 Btu/Hr**. Consideration should be given to the following items:

- Protect the water supply to the boiler with an approved backflow preventer; identify piping and flow direction and ensure that they are well supported.
- Check fuel system and test boiler safety devices per manufacturer, state, Federal or Postal requirement, whichever is more stringent.
- Provide adequate and unobstructed ventilation for "combustion air" for all fired appliances as required by code.
- Assure there is adequate boiler water analysis and chemical treatment.
- If oil is used, the oil-line filter should be replaced every year to avoid contamination of the fuel unit of atomizing nozzle.
- The atomizing nozzle should be replaced every year.
- If a chemical cleaner is used on the fireside of the heat exchanger, be sure that it is compatible with the material used to construct the combustion chamber. Moreover, that the chemical is neutralized upon completing the cleaning process.
- The area around the heating unit must be kept clean and free of any combustible materials - especially paper and oily rages.

CAUTION

Boilers are designed to burn only the type of fuel per manufacturer’s specifications. Never burn garbage or refuse in the unit. Never try to ignite oil by tossing burning papers or other material into the unit. Failure to comply may cause equipment damage.

2.8.3.2 Combustion Efficiency Guidelines

2.8.3.2.1 General Procedures

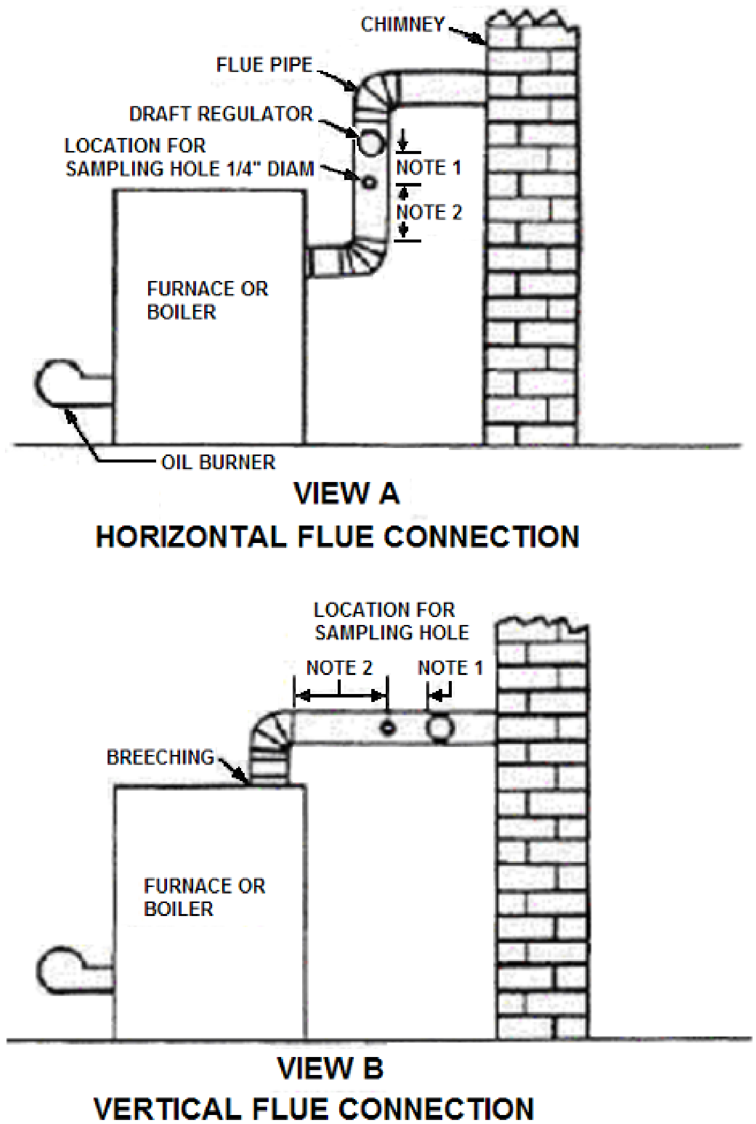
Combustion efficiency is the heating efficiency of the boiler or furnace. Annual checking, adjusting, and documenting burner settings per manufacturer's instructions will maximize combustion efficiency. The following procedure determines boiler combustion efficiency:

1. If not already equipped, drill flue pipe sampling holes as shown in Figure 2-15.
2. Calibrate and check the operation of the test equipment.

WARNING

Atomizing nozzles are designed and manufactured to match the boiler or furnace in which they are installed. When replacing, it is critical to match the design and size of the previously installed atomizing nozzle. Do not oversize the atomizing nozzle. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

3. Replace the atomizing nozzle and oil-line filter. The nozzle must match the design load. DO NOT OVERSIZE.
4. To ensure prompt ignition, adjust the ignition electrodes according to burner manufacturer's instructions.
5. Operate the burner, adjust the air setting until a good flame appears, and run the burner for at least 10 minutes or until operation has stabilized.
6. Check oil pump discharge. Bleed air from the pump and nozzle piping, and check the nozzle piping. Check the pump pressure and adjust it to 100 psi, if necessary (or to manufacturer's specification).



DESIRABLE LOCATION FOR 1/4" FLUE PIPE SAMPLING HOLE FOR TYPICAL CHIMNEY CONNECTIONS:

1. LOCATE HOLE AT LEAST 1 FLUE PIPE DIAMETER ON THE FURNACE OR BOILER SIDE OF THE DRAFT CONTROL.

2. IDEALLY, HOLE SHOULD BE AT LEAST 2 FLUE DIAMETERS FROM BREECHING OR ELBOW.

Figure 2-15. Placement of Flue Pipe Sampling Hole

2.8.3.2.2 Draft Readings

Check the draft reading over the fire using a draft gauge by way of a ¼-inch hole drilled in the fire or inspection door. (This hole should be in the inspection door for oil-fired matched units, or in the fire door for conversion installations. If possible, the hole should be above the flame level.) Adjust the barometric-draft regulator on the flue to give the over-fire draft recommended by the manufacturer. If no such recommendations are available, set the over-fire draft to ensure a negative pressure within the combustion chamber (usually 0.02 inches water column). With some equipment, it will not be possible to take draft readings over the fire. In this case, adjust the draft regulator to give a breech draft reading between 0.04 and 0.06 inches water column (taken at the sampling hole).

After these tests have been made, seal the draft or sampling hole in the inspection or fire door using a plug, bolt, or high-temperature sealant. The flue sampling hole should also be sealed.

2.8.3.2.3 Smoke Readings

After the burner has operated for 5 or 10 minutes, make a smoke measurement in the flue, following the smoke tester instructions. Oily or yellow smoke spots on the filter paper are usually a sign of unburned fuel, indicating very poor combustion (and likely high emissions of carbon monoxide and unburned hydrocarbons). This condition can sometimes be caused by not enough air. If this condition cannot be corrected, major renovation or even burner replacement may be necessary.

2.8.3.2.4 Smoke-CO_2 Curve Development

Measurements of smoke and carbon dioxide (CO_2) shall be recorded to establish the Smoke-CO_2 curve.

2.8.3.2.5 Air Setting Adjustment

Examine the Smoke-CO_2 plot and note the location of the "knee" where the smoke number begins to rise sharply. Note the air gate position marks, and adjust the air setting to a CO_2 level ½ to 1 percent lower than the CO_2 level at the "knee." (This provides a tolerance against possible shifts in the setting over time.) Do not increase the air setting any more than necessary on the lower portion of the curve below the "knee." Lock the air adjustment and repeat draft, CO_2, and smoke measurements to make sure the setting has not shifted.

NOTE

The characteristic curve for some burners may not yield a distinct "knee" in the curve. In such cases, the setting should be made near the minimum smoke setting (using judgment).

2.8.3.2.6 Performance Check

A well-matched and well-tuned burner should be capable of operation with smoke not greater than No.1 and at a CO_2 level as high as possible. If this cannot be reached, check the following:

1. Air Leaks. Air leaks into the combustion chamber or heat exchanger dilute the combustion gases and prevent normal CO_2 readings. Boilers are ASME coded; therefore, repair methods shall follow ASME standards and certification process. To check for dilution by leakage, measure the CO_2 at as high a point as possible over the fire, using a stainless steel tube inserted through the fire door sample hole (as described for over-fire draft measurements in Paragraph 2.8.3.2.2); compare this with the CO_2 measured in the flue. A difference of more than 1 percent CO_2 between the flue and over-fire readings usually indicates air entry through leaks that have not been properly sealed. Seal between the probe and fire door sample hole during test. The fire door hole should be sealed when not being used to avoid leakage of air through it.
2. Air-Fuel Mixture. If CO_2 level still cannot be reached without exceeding No. 2 smoke, poor mixing of air and fuel is likely. This could be caused by a combustion heat (blast-tube nosepiece) with too large a throat for good mixing, or an improper match between air and nozzle spray patterns. Frequently, replacement of the nozzle with another having a different spray angle and pattern improves performance. It may be necessary to replace the combustion head or try different settings if the burner is equipped with an adjustable head or mixing devices.
3. Unmatched Chambers. The combustion chamber must be matched in size and shape to the nozzle spray and the burner air pattern. Oversized chambers do not ensure adequate mixing. Undersized chambers may allow flame impingement on the chamber walls or heat exchanger.

2.8.3.2.7 Stack Temperature Measurement

Operating the unit at an excessive firing rate generates more heat than the heat exchanger can utilize and results in unnecessary heat loss up the chimney. The causes of excessive heat loss are badly soothed heat-exchanger surfaces and excessive draft. The temperature of the flue gas provides an indication of these heat losses. Measure the net stack temperature by subtracting the room air temperature from the flue thermometer reading. Excessive stack loss is indicated if the net stack temperature during steady operation exceeds 400°F to 600°F for matched-package units, or 600°F to 700°F for conversion burners.

CAUTION

Significantly lower temperatures may be observed in properly adjusted burners when operating at high altitudes. Care should be taken that the stack temperature is not low enough to allow condensing of the flue gases in the breeching. Failure to comply may cause breeching and chimney damage.

2.8.3.2.8 Ignition Check

Check operation over repeated cycles to ensure prompt ignition on starting.

2.8.3.2.9 Pump Cutoff Check

Slow pump cutoff at the end of a firing cycle can cause smoke and other pollutant emissions. Check for prompt pump cutoff by observing the flame or by testing smoke at shutdown. If poor cutoff is observed, ensure air is purged from the pump and nozzle line. Air trapped in the pump or nozzle line will expand when heated, causing oil to drip into the combustion chamber after shutdown. If poor cutoff persists check the nozzle for tightness, and repair or replace the pump if necessary.

NOTE

Check the settings of all operating and limit controls before leaving the installation.

2.9 WATER HEATERS

2.9.1 General

Adequate supplies of hot water must be provided to postal facilities in order to achieve health and sanitation standards. Water heaters range from units with several hundred gallon capacities to small point-of-use instantaneous types. Though some solar-powered systems have been installed, the bulk of domestic hot-water heaters in postal facilities are either electric or gas. Factors to be considered in evaluating hot-water heater use and selection are the capacity of the tank, the recovery rate in gallons per hour at a 90°F water temperature rise, and the heater input requirements in watts or Btu per hour.

2.9.2 Tank-Type Water Heaters

Tank-type water heaters are the most common type of water heater in the U.S. These units contain a large tank heated by either a natural gas, propane, or an oil burner located beneath the tank, or by electric heater elements located in the side of the tank. While not as efficient as other style heaters, such as hydronic or point-of-use units, their low initial cost and wide availability make tank-type water heaters attractive. The energy factor (EF) represents the energy efficiency of water heaters.

2.9.3 Components

2.9.3.1 Tank

The tank holds heated water. The design of the tank allows the heated combustion gases to cover the bottom of the tank before entering the vertical flue. Other openings in the tank are provided for water lines, temperature controls, and a drain valve. The tank is insulated to reduce heat transfer to the surrounding air.

2.9.3.2 Expansion (Compression) Tanks

Expansion tanks are required on the supply line in facilities where the public water supply utility department has installed back flow preventers. Refer to local codes for requirements such as size, etc.

2.9.3.3 Cathodic Protection

Water is called the universal solvent because it becomes more corrosive as it is heated. The more dissolved mineral solids in the water, the greater its ability to carry electric current and cause corrosion.

Corrosion results from a flow of electric current caused by a potential difference between two metals. When two dissimilar metals are in contact in a corrosive environment, one of the metals experiences accelerated galvanic corrosion while the other remains galvanically protected. Dissimilar metals present in a tank may be steel tank surfaces, drain-valve nipples, thermostat rods, magnesium anodes, and inlet and outlet nipples. New England, east coast, and northwest areas have very soft surface water, but, due to the large amounts of carbon dioxide (CO_2) gas dissolved in it, the water is very corrosive. Since much of it is supplied by wells, Midwestern and Southwestern water tends to be very hard. In the presence of these types of heated water, an electric current flows between dissimilar metals causing corrosion and gradual dissolution of one of the metals. To protect vital heater parts, an anode is installed in the water heater. This anode is generally made of an anodic or active material such as magnesium. See Figure 2-16 for an illustration of this process. On some electric water heaters, the heater elements also present a sufficiently large enough surface to quickly dissipate anodes. This is prevented by insulating the element from the tank and controlling the cathodic circuit current flow with a resistor (Figure 2-17).

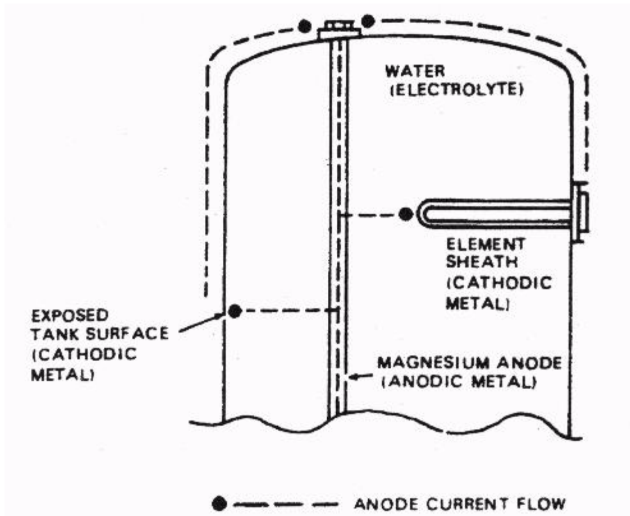


Figure 2-16. Water Heater Anode

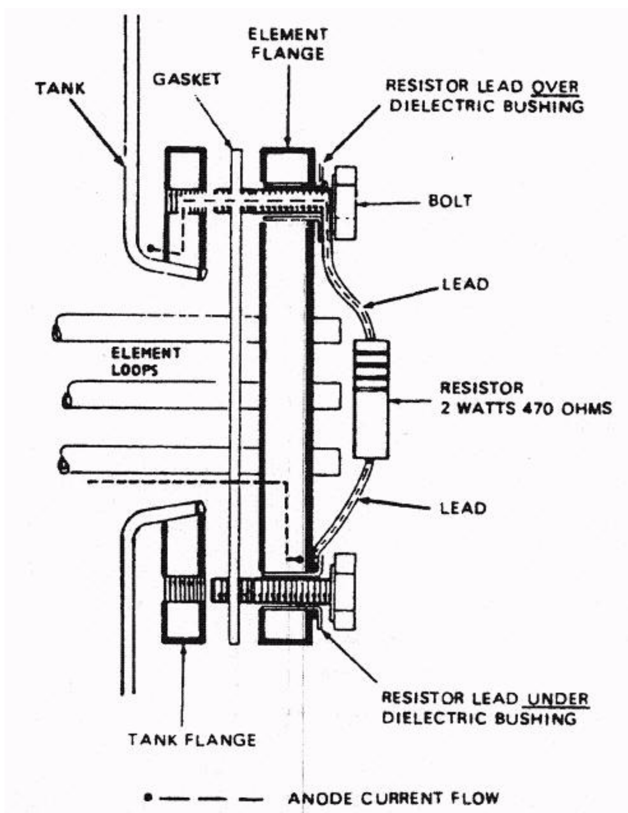


Figure 2-17. Water Heater Heating Element

2.9.3.4 Valves

2.9.3.4.1 Relief Valve

WARNING

It is critical to always have a relief valve that is properly matched to the hot water heater pressure and temperature requirements. When replacing a hot-water heater, never reuse an old relief valve. Use of a worn valve may compromise the safe operation of the new heater. Failure to comply may cause injury or death and/or equipment damage.

Potable water heaters must be protected with a Pressure/Temperature (P/T) relief valve. The relief valve has several functions. It is designed to protect life and property. Principles of this valve's function should be thoroughly understood, and the operation of this valve must never be defeated. The functions of the valve are:

- Temperature relief. The valve is usually designed to be fully opened at a water temperature of 210°F. This is sensed by the extension thermostat and protects the hot-water user from the possibility of being exposed to steam or the hazard of explosion (Figure 2-18).
- Pressure relief. The valve is designed to protect the water heating system from the damaging effects of high supply pressure, water hammer, and thermal expansion.
- Test lever. The test lever should be lifted periodically to prevent lime buildup from sealing the discharge opening. The lever manually lifts the disc from the seat and indicates the condition of the waterway by the amount of flow observed.
- Relief valves should be included in the preventive maintenance (PM) program and tested periodically. The test, findings, and corrective actions should be documented. It is inappropriate to install potential obstructions between the relief valve and the vessel or to plug the relief valve discharge.

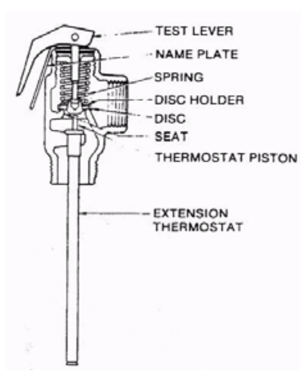


Figure 2-18. Temperature and Pressure Relief Valve

2.9.3.4.2 Dip Tube

Water heaters with a cold-water inlet at the top of the tank have a dip tube leading toward the bottom. This tube delivers the incoming cold water through the stored water to the bottom of the tank. In doing this, cold water does not mix with hot water and is delivered to the area where it can be heated rapidly. The dip tube has a small hole located near the top end of the tube that prevents the hot water in the tank from being siphoned out by an interruption in the cold water supply.

2.9.3.4.3 Drain Valve

The drain valve removes stored water from the tank when necessary. This draining removes solids from the bottom of the tank that may have settled out of the incoming water. Regular use of the drain valve to remove sediment from a water heater is necessary.

2.9.3.5 Controls

2.9.3.5.1 Heating Element

Electric water heaters use one or more electric heating elements immersed in the tank. These elements are comprised of a terminal for electrical connection, mounting flange, sheath to protect the heating wire from the water, magnesium oxide to insulate between the sheath and heating wire, and a resistance wire generally made of nichrome (Figure 2-19).

2.9.3.5.2 High-Limit Control

WARNING

The high-limit control protects against water heater over temperature. Whenever a high-limit control operates, the reason for operation must be determined. Failure to comply may cause equipment damage or injury.

Electric water heater high-limit controls are resettable or non-resettable. The high-limit control stops the flow of electricity to the heating circuit when the tank surface adjacent to the device reaches a predetermined temperature. This item is a safety device designed to protect against excessive water temperature caused by a defective thermostat or grounded heating element.

2.9.3.5.3 Thermostat

In electric water heaters, the thermostat is a discrete device. It is designed to be the primary device starting and stopping the flow of electricity to the heating elements (Figure 2-19).

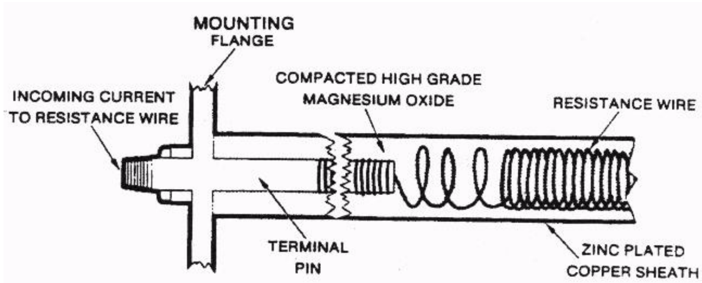


Figure 2-19. Electric Heating Element

2.9.3.5.4 Thermocouple

Thermocouples consist of two dissimilar metals or wires joined together at a point called the "hot" junction. This junction, when subjected to heat, produces a potential difference between the two metals, generating current. This current is taken from the free ends of the metals at a point called the "cold" junction.

2.9.3.5.5 Burner Control

Gas-fired hot-water heater burners are operated via a burner control that provides the following controls (Figure 2-20):

- Thermostat -The thermostat controls water temperature (control knob not shown in Figure 2-20. In accordance with postal energy conservation guidelines for water heaters serving washrooms, the thermostat should be adjusted to provide delivered water temperature no warmer than 105ºF. Where the water heater supplies a kitchen or cafeteria, delivered water temperature should be 140ºF. Only kitchens that have a dishwasher without an internal heater require a delivered water temperature of 180ºF.

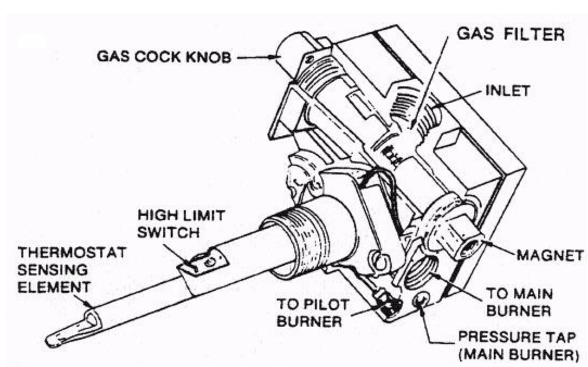


Figure 2-20. Typical Gas Control

- Gas cock - The gas cock is designed to cut off burner gas supply while the pilot is being manually lit.

- High-temperature limit - When water temperature exceeds desired limits, gas flow is cut off by the high-limit switch.
- Pilot safety - The electric current generated by the thermocouple powers an electromagnet in the burner control that functions as a pilot safety that cuts off all gas to the burner and pilot.
- Gas pressure regulation - The control maintains gas pressure at levels consistent with efficient burner and pilot operations.
- Gas filter - Contaminants present in the natural gas supplied to the water heater are captured by the filter to prevent clogging of the control or burner.

2.9.3.6 Main Burner and Pilot

Gas-fired hot-water heaters are equipped with burners designed to provide a uniform flame. They may be either the upshot or annular venturi, depending on where the natural gas and air are mixed. The pilot provides an ignition source for the burner (Figure 2-21).

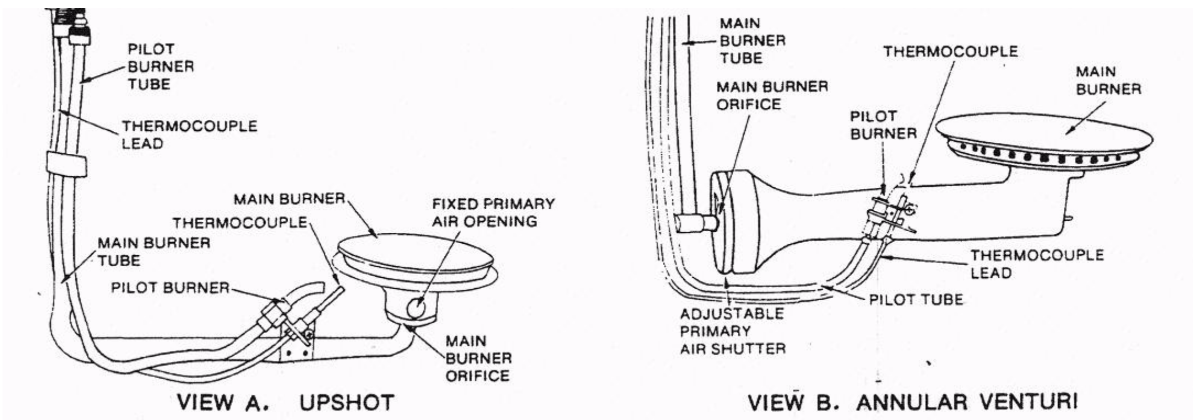


Figure 2-21. Main Burner and Pilot

2.9.3.7 Flue

The flue is designed to move the products of combustion through the heater to the chimney with a maximum of efficiency. The inside of the flue may be equipped with baffles to improve heat transfer by swirling the heated air as it rises through the flue.

2.9.3.8 Draft Hood

The draft hood/diverter regulates the over-the-fire draft by introducing dilution air, thus limiting the stack effect. This device offers a ready means of escape for combustion products when there is no draft, a back draft, or actual stoppage within the vent itself (Figure 2-22). The draft vent should be periodically checked to verify proper vent conditions. If the flame of a lighted match is drawn into the opening and continues to burn well, proper vent operation is present. If the match is blown away or snuffed out, the vent beyond the water heater must be checked to determine the cause of improper draft.

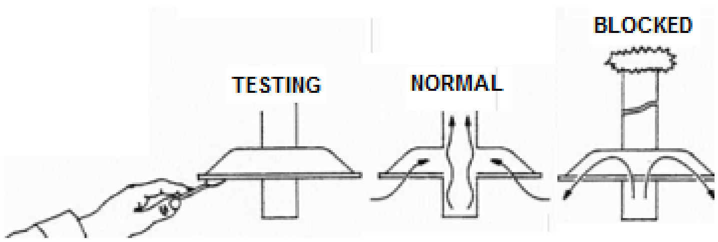


Figure 2-22. Checking Vent Operation of Draft Hood

2.9.4 Tank Water Heater Maintenance Guidelines

2.9.4.1 General Maintenance

Any unit which exceeds any of the following limitations must be inspected by a boiler inspector:

- Heat input of 200,000 Btu/hr
- Water temperature of 210ºF
- Nominal water capacity of 120 gallons or greater

1. Water heaters should have a small amount of water drained periodically. Open drain valve and allow water to run until the flow is clear of sediment. This prevents sediment buildup in the tank bottom.
2. Relief valves should be periodically operated to prevent lime buildup. Operate tri-lever on P/T relief valve. Water should flow freely and stop when tri-lever is released. Replace valve if it is defective.

NOTE

Should the water supply become contaminated, the tank should be chlorinated using a chlorine disinfectant such as household bleach (sodium hypochlorite). Check the manufacturer's or health department instructions for guidance.

WARNING

There is a possibility of contacting live voltages while performing tank water heater maintenance. Be sure all safety precautions are followed and that power and gas to the unit are turned off, locked out, and tagged out (LO/TO) when performing maintenance. Never touch electrical components with wet hands or if standing in water. Use insulated tools. Failure to comply may cause injury or death.

CAUTION

Water heater elements are designed to be constantly immersed in water when operating. Never operate the heating element without being certain the heater is filled with water. Failure to comply may cause equipment damage.

3. Water leaks should be corrected promptly. Leaks cause waste as follows:
   - 60 drops/minute - 7 gallons/day
   - 90 drops/minute - 10 gallons/day
   - 120 drops/minute -14 gallons/day

See Figure 2-23 and Figure 2-24 for component identification.

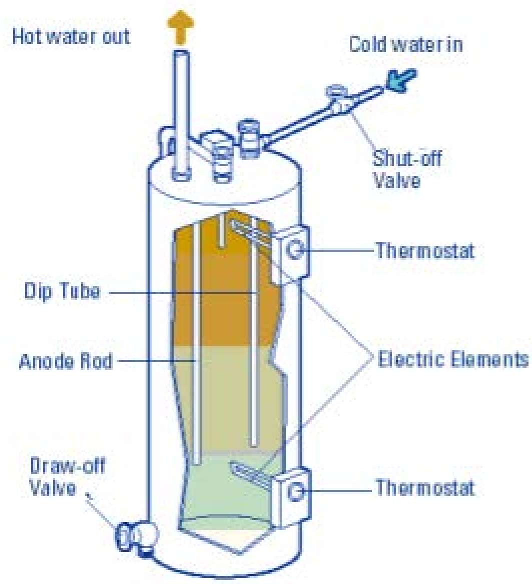
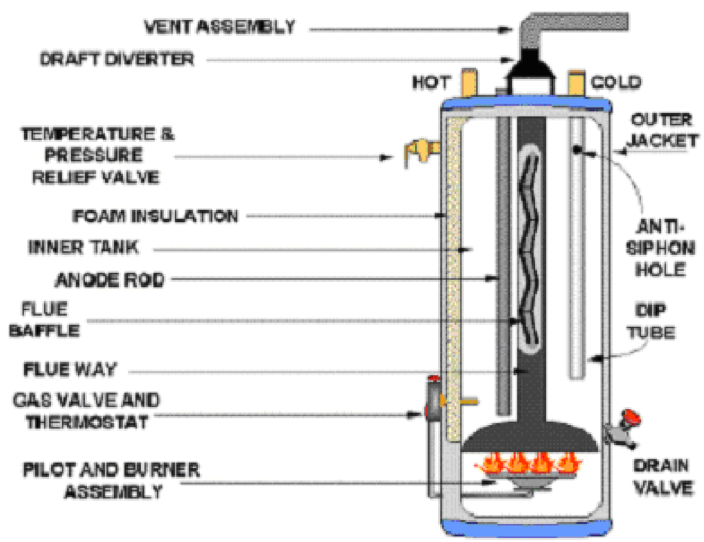


Figure 2-23. Electric Water Heater Checkpoints



* Source: RHEEM website

Figure 2-24. Gas Water Heater Checkpoints

2.9.5 Burner and Flame Guidelines

2.9.5.1 Flames

The normal color zones (Figure 2-25) of a Bunsen-type flame are as follows:

- A thin, blue inner cone within which is a darker area of unburned gas-air (This represents the first step in the burning process).
- A darker, outer flame cone that surrounds the inner cones.
- A nearly invisible outer mantle that surrounds the flame cone.

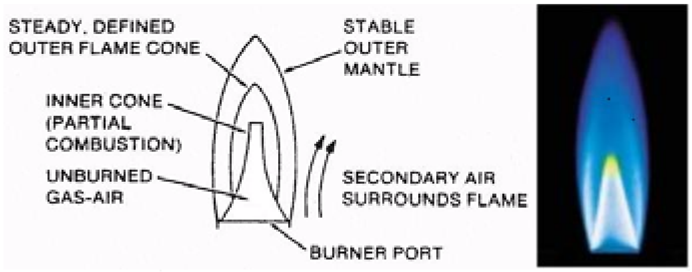


Figure 2-25. Normal Color Zones of Bunsen Type Flame

NOTE

LP-gas burners have a blue-orange color flame. The outer mantle tips have a slight yellow tinge. This is a normal characteristic.

2.9.5.2 Burners

The main burner should display the following operating characteristics:

- Complete combustion of gas.
- Rapid ignition and carryover of flames across entire burner.
- Quiet operation during ignition, burning, and extinction.
- No excessive lifting of flames from burner ports.
- Uniform heat spread over the bottom head of the tank.

Check gas input and then reduce primary air, if necessary, and if it is adjustable. When reducing primary air, make sure yellow flame tips do not occur. Check the burner orifice size.

2.9.6 Typical Tank Water Heater Burner Problems

The following list may help identify and solve typical problems in tank water heaters:

- Explosive Combustion- Explosive combustion usually results from delayed ignition (a collection of air and gas) and indicates adjustments are necessary. Do not allow unburned gas to collect in combustion chambers or confined spaces because a gas-air mixture within flammability limits explodes if ignited.

- Yellow flame. Incomplete combustion can produce carbon monoxide, causing soot buildup and product damage. Check for:
  - Restricted airflow into heater, caused by secondary air openings and/or poor venting.
  - Inadequate air supply into heater area.
- Lifting Burner Flames- Flames lift or burn some distance above the port. Flame cones may rupture, and complete burning does not take place. Lifting (blowing) flames are noisy, form carbon monoxide and reduce efficiency (unburned gas escapes (Figure 2-26)).

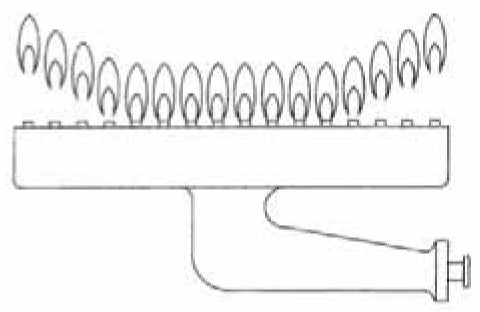


Figure 2-26. Lifting Burner Flames

- Flashback- Flashback is the cone inversion of the inner flame. The flame strikes back through the port to ignite the mixture in the burner head near the orifice. Burning in the mixer tube usually creates a roaring noise like a blowtorch. Flashback can occur on flame ignition or extinction although it is more likely to occur on a hot burner. Flashbacks cause carbon monoxide, soot, and burner damage. Check the following:
  - Decrease the primary air, if adjustable. This lowers the tendency for flashback.
  - Determine that air adjustment does not produce yellow tipping of flames.
  - Check the orifice size and gas pressure.

CAUTION

There is a possibility that a gas valve may develop a leak. Ensure there are no leaking gas valves. A leaking valve can cause burning at the orifice when the gas control has shut off. Failure to comply may cause equipment damage.

- Extinction Pop -Extinction pop is a form of flashback that occurs upon, or a few seconds after, shutdown. The concussion may blow out the pilot flame. Reducing the primary air, if adjustable, may eliminate the problem.

Yellow Tipping Flame -Yellow tips are caused by glowing carbon particles in the flame (Figure 2-27). Impinging yellow tips on cool surfaces lead to soot and carbon monoxide build up) and dust particles may glow as they pass through the flame. If the primary air, adjustable, increasing it eliminates yellow tipping. Dust streaks disappear when viewed through some tinted glasses such as brazing goggles. Yellow tipping, however, will not disappear. Look for dirty orifice, blocked air openings, and lint or dust in burner tubes or underneath ports.

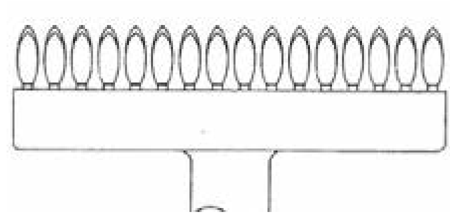


Figure 2-27. Yellow Tipping

- Fluctuating Flame - Varying flame length over a short period of time without burner adjustment is an indication of non-uniform orifice gas pressure. Irregularities associated with the gas regulator, meter, or supply may cause the length of the flame to fluctuate. Check the orifices for cleanliness.
- Unstable or Wavering Flame - Drafts across the burner may cause the flame to waver. Incomplete burning results when the flame impinges on cool surfaces. Pilot flame may go out or divert from the thermocouple, causing shutdown. Check for proper over-the-fire drafts.

NOTE

Reducing the supply of primary air will not stop floating flames. If a draft is established, floating flames may disappear after a burner operation comes up to steady state.

- Floating Flame - A lack of secondary air may cause the burner flames to float and appear hazy. Floating flames may indicate incomplete combustion and must be corrected (Figure 2-28). Check the following:
  - Secondary air supply may be restricted.
  - Input gas pressure may be too high.
  - Flue ways may be sooted or blocked.
  - Yellow tipping may exist and require adjustment.

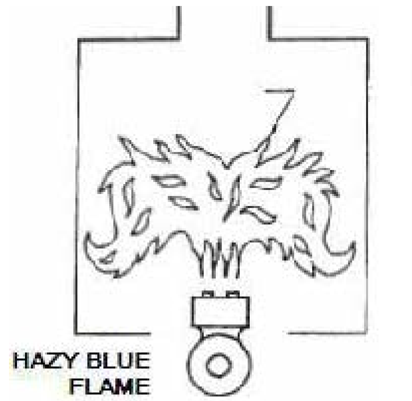


Figure 2-28. Floating Burner Flames

- Flame Rollout. Flame roll out is the term used to describe fuel gas combustion occurring outside the combustion chamber, which can affect wirings, gas valves, and nearby combustible materials. Flame rollout is akin to floating flames outside the combustion chamber (Figure 2-29).

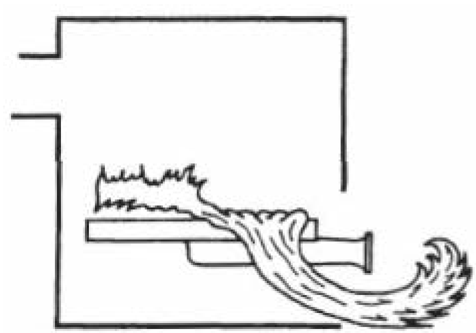


Figure 2-29. Flame Rollout

The basic cause is lack of combustion air due to the following:

- Excessive gas input
- Poor draft
- Blocked Flue ways

Use the same corrective measures as floating flames and, if the gas valve is a step-opening type, check to see if it is operating properly.

- Gas Odor at Primary Air Openings. To draw in air, a vacuum exists at primary air openings. If all of the gas fed to a burner by the orifice does not flow to the head, some may spill from the primary air openings. Check the burner restrictions and proper orifice alignment.
- Very Small Pilot Flame. Usually indicates a clogged orifice or restricted pilot line. If the pilot becomes small when the main burner turns on, the pilot filter may be clogged.
- Lazy Blue Pilot Flame. This wavy, undefined shape indicates burning at the orifice. This condition may be accompanied by high-pitched whistling sounds that also indicate a burred or partially blocked orifice.
- Lifting, Blowing Pilot Flame. This is generally caused by high gas pressure and/or too large an orifice.
- Hard Sharp Pilot Flame. This is usually noisy, and may blow out or backfire and burn at the orifice. It usually indicates an incorrect orifice (too small).
- Yellow Pilot Flame Tips. This is commonly caused by a clogged pilot primary air opening (if used). Small yellow tips are normal on LP-gas.
- Lazy Yellow (Candle Lighting) Pilot Flame. Check for low pilot gas pressure and a dirty pilot burner. Check the main burner orifice to determine that it is not too large (this would create high combustion chamber temperature).
- Pilot Flame Pulled Away from Thermocouple. This happens when secondary air rushes across the pilot burner (usually during main burner shut-off) and extinguishes the flame.

2.9.7 Point-of-Use Water Heaters

2.9.7.1 General

Multiple point-of-use water heaters, sized to meet locational requirements, are alternatives to centralized water heating systems and are located where the water is used. Point-of-use water heaters heat the water as it flows through the unit and do not retain any water internally, except for what is in the heating coil (Figure 2-30) for typical single basin installation.

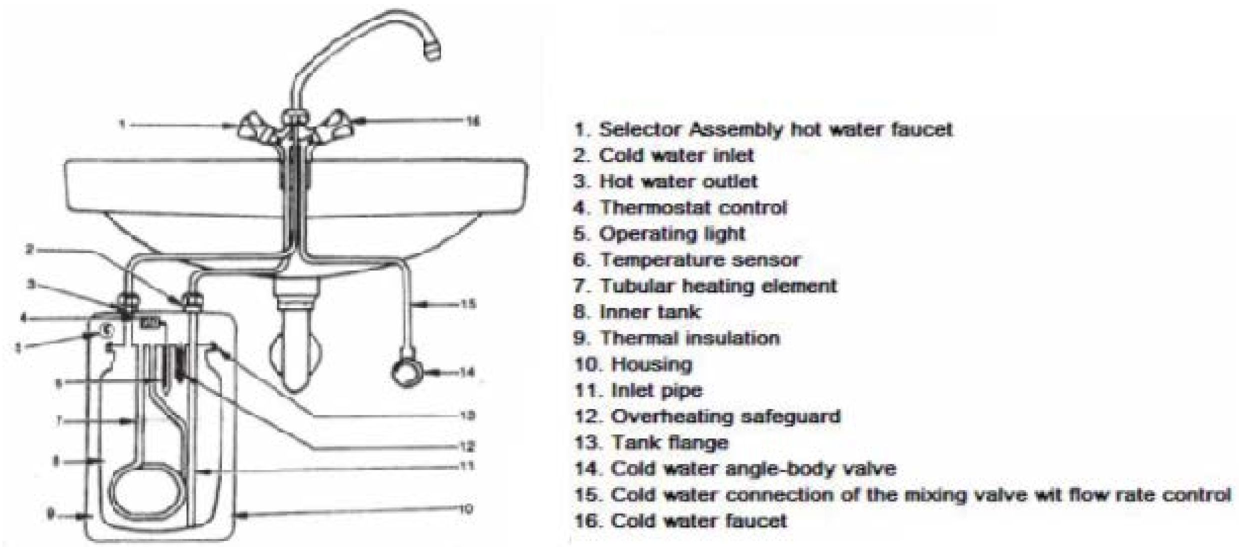


Figure 2-30. Typical Single Basin Installation

2.9.7.2 Operating and Maintenance Guidelines

Point-of-use water heaters use either gas or electricity. They gain their efficiency and instantaneous heating capabilities by heating only a small volume of water. The same general maintenance practices use with tank-type heaters are used with these units. Figure 2-31 shows the construction details of a gas-powered unit. Because of the diversity of types and construction, individual manufacturer's maintenance instructions should be followed in formulation preventive maintenance checklists.

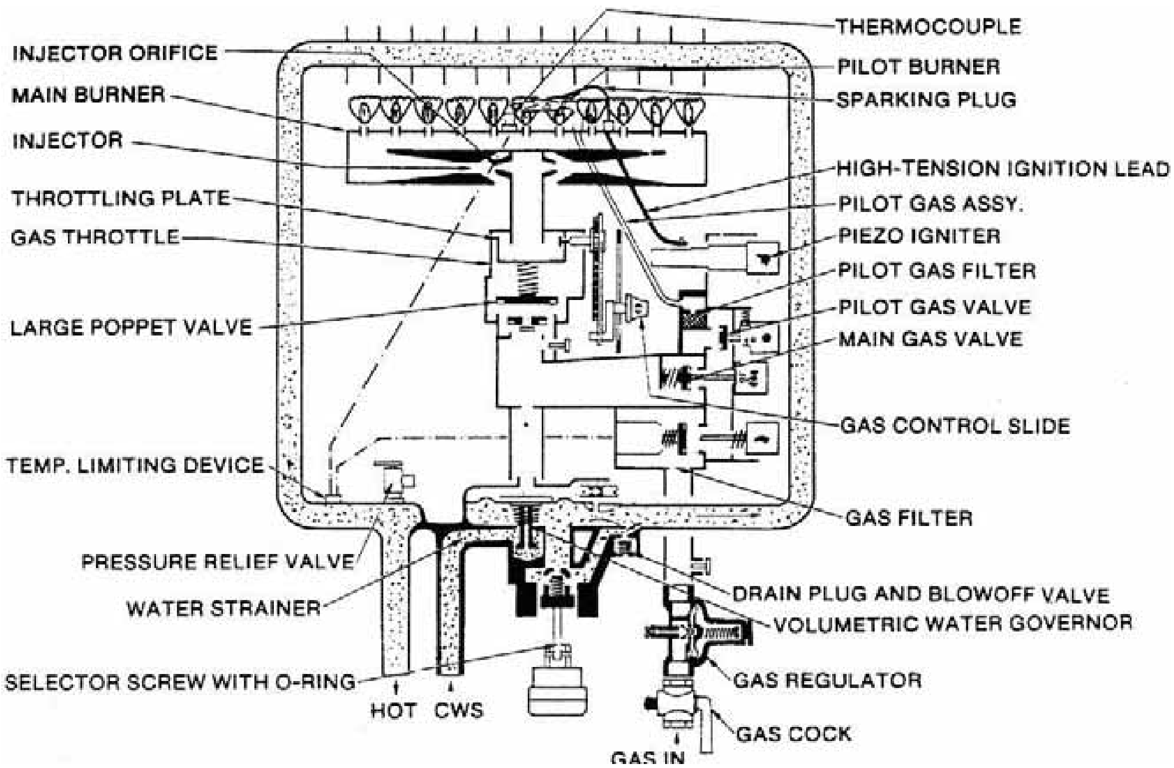


Figure 2-31. Gas Fired Point of Use Water Heater

2.10 AIR CLEANERS AND FILTERS

2.10.1 General

Special air filtration systems may be required for specific areas, such as welding areas that can generate toxic vapors. Additionally, some mail processing equipment may have built-in, or are associated, with air cleaning or dust collection equipment. Many factors influence the selection of dust collection systems, such as particle size to the presence of fumes.

2.10.2 Dry-Media Systems

Dry-media-type air cleaners use cleanable filter elements to remove dust from air passed through multiple filters. Often these filters are a cloth material which when vibrated allows the dust to fall off into storage containers. Figure 2-32 shows a typical dry-media-type air cleaner.

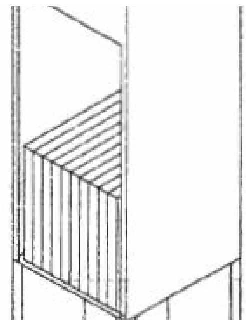


Figure 2-32. Media Type Air Cleaner

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SECTION 3

REFRIGERATION

3.1 THEORY

3.1.1 Principles of Refrigeration

Liquids absorb heat when changed from liquid to gas. Gases give off heat when changed from gas to liquid. For an air conditioning system to operate with economy, the refrigerant must be used repeatedly. For this reason, all air conditioners use the same cycle of compression, condensation, expansion, and evaporation in a closed circuit. The same refrigerant is used to move the heat from one area, to cool this area, and to expel this heat in another area.

- The refrigerant comes into the compressor as a low-pressure gas, it is compressed and then moves out of the compressor as a high-pressure gas.
- The gas then flows to the condenser. Here the gas condenses to a liquid, and gives off its heat to the outside air.
- The liquid then moves to the expansion valve under high pressure. This valve restricts the flow of the fluid, and lowers its pressure as it leaves the expansion valve.
- The low-pressure liquid then moves to the evaporator, where heat from the inside air is absorbed and changes it from a liquid to a gas.
- As a hot low-pressure gas, the refrigerant moves to the compressor where the entire cycle is repeated.

3.1.2 Reciprocating Compressor

The reciprocating compressor pumps refrigerant vapor from the evaporator to the condenser using a piston-type of arrangement that compresses the low-temperature gas, thus raising the pressure and temperature. The high-temperature vapor containing the absorbed heat from the evaporator is discharged to the condenser where the heat flows from the hot vapor into the water or air passing through the condenser.

3.1.3 Centrifugal Compressor

This system is identical to one employing the reciprocating compressor, but the means of compressing the refrigerant vapor is different. The centrifugal compressor has a rotating impeller that imparts a high velocity to the refrigerant vapor, discharging it into a smaller space, and increasing the pressure.

3.1.4 High- And Low-Pressure Separation

Pressure in the refrigeration cycle (or system) is divided into two parts. From the expansion valve through the evaporator to the compressor is the low-pressure section. From the compressor through the condenser and back to the expansion valve is the high-pressure section. Figure 3-1, which shows a simple schematic of a refrigeration system, illustrates this division.

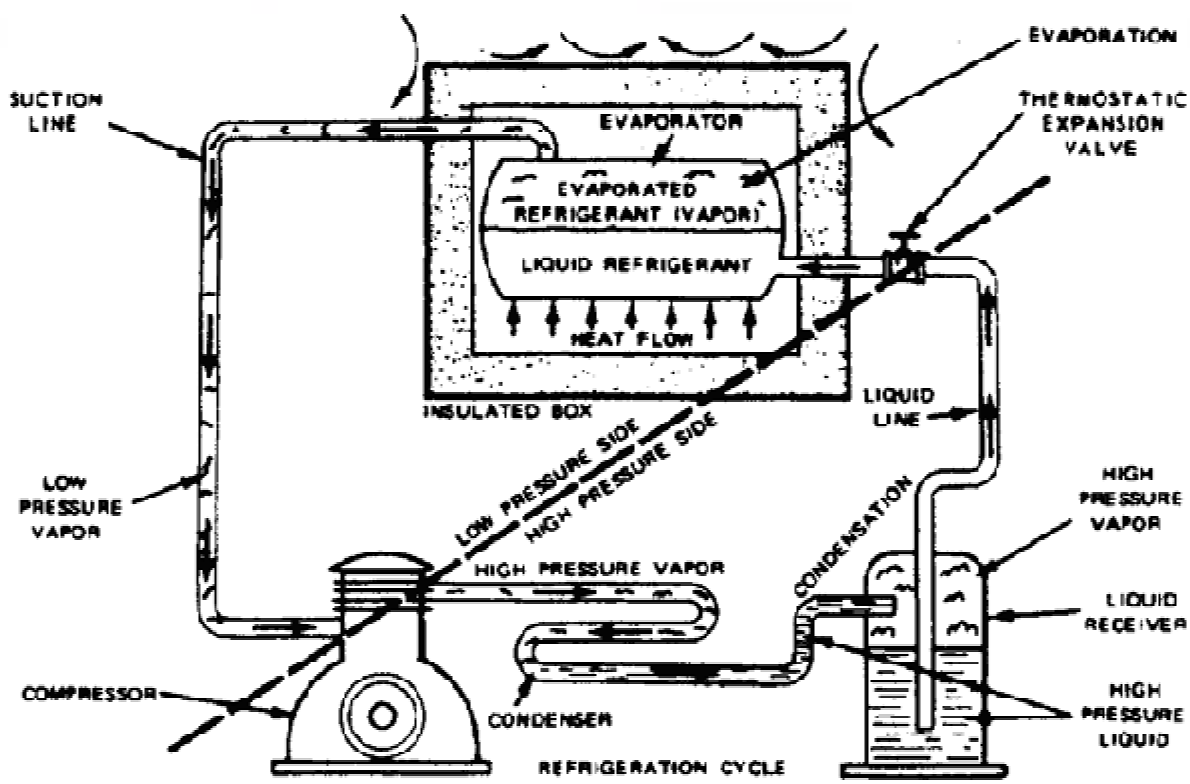

Figure 3-1. Low-Pressure and High-Pressure Sections of Simple Refrigeration Cycle

3.2 REFRIGERANTS

3.2.1 Definition and Theory

Refrigerants are chemical compounds that, during their cycle, absorb heat, vaporize at a low temperature and pressure. They also give up heat, and condense into a liquid at a higher temperature and pressure.

3.2.2 Refrigerant Properties

3.2.2.1 Thermodynamic Properties

Thermodynamic properties are those concerned with the relationship of heat and work. The thermodynamic properties of refrigeration process refrigerant are pressure, temperature, density, enthalpy, and entropy. Published tables that give in detail the thermodynamic properties of the refrigerant are available from manufacturers, local dealers, and American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).

On February 11, 1992, the United States (US) announced the phase out of the production and consumption of ozone depleting chemicals (chlorofluorocarbons (CFCs), halons, and carbon tetrachloride) by December 31, 1995. And, following the 1998 revisions of the *Clean Air Act,* the US confirmed the phase out of methyl chloroform and indicated that beyond 2005 production and import would be limited to critical, emergency, quarantine, and pre-shipment uses.

Table 3-1 lists the phase out schedule of class II ozone-depleting substances, which comprises all hydro chlorofluorocarbons (HCFCs).

According to the *Clean Air Act Amendment of 1990*, effective July 1 1992, it shall be unlawful for any person, in the course of maintaining, servicing, repairing, or disposing of an appliance or industrial process, to knowingly vent or otherwise release or dispose of any class I or class II substance used as refrigerant in such appliance (or industrial process refrigeration) in a manner which permits such substances to enter the environment (Section 608 of the *Clean Air Amendment of 1990*).

> This information can also be found at the United States Environmental Protection Agency's web site: http://www.epa.gov/spdpublc/title6/phaseout/.

Table 3-1. HCFC Phase Out Schedule

Comparison of the Montreal Protocol and United States Phase out Schedules			
Montreal Protocol		**United States**	
Year to be Implemented	**% Reduction in Consumption, Using the Cap as a Baseline**	**Year to be Implemented**	**Implementation of HCFC Phase out through Clean Air Act Regulations**
2004	35.00%	2003	No production and no importing of HCFC-141b
2010	65.00%	2010	No production and no importing of HCFC-142b and HCFC-22, except for use in equipment manufactured before 1/1/2010 (so no production or importing for NEW equipment that uses these refrigerants)
2015	90.00%	2015	No production and no importing of any HCFCs, except for use as refrigerants in equipment manufactured before 1/1/2020
2020	99.50%	2020	No production and no importing of HCFC-142b and HCFC-22
2030	100.00%	2030	No production and no importing of any HCFCs

3.2.2.2 Physical Properties

3.2.2.2.1 Definition

Physical properties, such as density, heat capacity, vapor pressure, viscosity, and thermal conductivity influence the selection of refrigerants for a particular system.

3.2.2.2.2 Moisture

Refrigerants absorb moisture in varying quantities. With the exception of an absorption system, moisture should be kept out of the refrigeration system as moisture can freeze as "free" water at low-temperature points in the system. This stops up metering devices, floats, etc., and shuts down the system. Moisture also contributes to the formation of corrosive acids, causing sludge, copper plating, and general deterioration within the system.

3.2.2.2.3 Leak Detection

The refrigerant system must be free of leaks to prevent the introduction of moisture into the system or loss of refrigerant. Any leak that occurs must be detected and repaired. Every refrigerant-containing part of every system that is erected on the premises, except compressors, condensers, evaporators, safety devices, pressure gages, control mechanisms, and systems that are factory-tested, shall be tested and proved tight after installation completion and before operation.

WARNING

Nitrogen is a colorless and odorless gas; when inhaled in a confined environment it can be fatal. Take all necessary measures to insure adequate ventilation exists in the maintenance area and structure containing the system being tested. Failure to comply may cause injury or death.

Tests shall be performed with dry nitrogen or another nonflammable and nonreactive dried gas. Oxygen, air, or mixtures containing them shall not be used. The means used to build up the test pressure shall have either a pressure-limiting device or a pressure reducing device and a gage on the outlet side. The system should be tested above normal operating pressures, but shall not exceed 1.5 times maximum allowable working pressure (MAWP). The pressure relief device on the test equipment shall be set above the test pressure, but low enough to prevent permanent deformation of the system's components. Isolate pressure relief devices associated with the system from the test.

American National Standards Institute (ANSI)/ASHRAE 15 Safety Code for Mechanical Refrigeration in the USA have specific requirements for refrigerant leak detection systems. In general, systems over 100 HP, or any system required to be housed in a standard or Class T machinery will by code require a detector.

3.2.2.2.4 Lubrication

The ability of a refrigerant to mix with oil is called miscibility. It is a physical property that makes it easy to lubricate the refrigeration system. Most of the refrigerants in common use are miscible with oil. Ammonia, sulfur dioxide, and water are not miscible with oil.

3.2.3 Typical Refrigerants

As a result of the Montreal Protocol, and subsequent revisions, ozone depleting refrigerants are being phased out and substituted with non-ozone depleting refrigerants. The treaty dictated the cessation of the production of halons in 1994 and CFCs in 1996.

The phase out of HCFCs, which includes R-22, was also included in the treated. The Montreal Protocol does not regulate the production and use of HFCs, such as R-134a, but the Clean Air Act regulates the use of all refrigerants that have GWP (Global Warming Potential). For additional information on refrigerants, refer to the Air Conditioning, Heating, and Refrigeration Institute (AHRI) Guidelines to Refrigerants at: www.ahrinet.org.

3.2.4 Harmful Matter

Many of the difficulties that occur in refrigerating systems are caused by dirt and other foreign particles in the refrigerant. This foreign matter is carried through the pipelines by the refrigerant and, if it reaches the solenoid or expansion valves, it prevents them from closing, or clogs orifices and valve seats. To prevent this, a strainer may be installed in the liquid line ahead of both the solenoid and thermal-expansion valves. Large installations are often equipped with purging systems for removal of moisture by means of a dehydrator or filter arrangement that contains a drying agent. Dirt and foreign particles also foul internal surfaces adversely affecting heat transfer.

3.2.5 Mixing of Charging Refrigerants

When charging any system, it is important that the equipment manufacturer's requirements concerning the proper refrigerant be followed. Use of the incorrect, refrigerant can create severe motor overloading and explosive conditions. For example, when ammonia is used in a system containing copper, chemical reactions take place that can create explosions and fire. Mixing of refrigerants creates pressure and temperature conditions that do not accomplish the refrigeration required and confuse the operating or servicing personnel.

3.2.6 Selection of Refrigerants

A numbers of factors should be consider when selecting refrigerants such as the Montreal Protocol (accelerated phase outs), thermodynamics properties, technology and economics, safety (explosiveness, toxicity) and environmental effects (global warning, ozone depletion, etc.), availability, potential for corrosion, and so on. Currently, R134a is the main refrigerant used in the United States and Japan for large chillers and R410A for unitary units. The type of compressor largely determines the choice of refrigerant. Reciprocating compressors work most efficiently on refrigerants with high vapor pressures and boiling points below 30ºF. Rotary and centrifugal compressors may use refrigerants with low vapor pressures. In centrifugal compressors, pressure is built up by high rotary speed, and large volumes of gas must be handled. Centrifugal compressors work best on refrigerants with boiling points between 30 and 90ºF; however, refrigerants with boiling points between 0 and 80ºF are suitable for rotary compressors. The ideal refrigerant should be a gas at normal temperatures, should liquefy at reasonable pressures, and should not require excessive cooling. It must have a high latent heat of evaporation per unit weight; it must expand and evaporate readily when the pressure is reduced; it must produce the required amount of refrigeration; and it must have a freezing point below the lowest temperature in the evaporator. It should also be nontoxic, non-explosive, and harmless to the human body and the environment. It must not have an offensive odor, yet it should permit easy detection of leaks.

3.2.7 Danger of Refrigerant Additives

3.2.7.1 Desiccants

When refrigerants absorb moisture or water, adverse consequences can occur. Moisture and water contribute to acid formation that destroy motor windings, causing motor burn out; acid formation can also corrode piping and equipment. Desiccant, a chemical compound, can be used to dry the system. However, the use of an improper desiccant can create a chemical reaction that produces acid and causes corrosion. Additionally, some desiccants dust severely and others slake or otherwise deteriorate enough to contaminate the system.

WARNING

Ensure the current SDS for the desiccants utilized at the facility are on file and available for reference by all employees. Refer to SDS for appropriate personal protective equipment and important reactivity information.

3.2.8 Handling

ANSI/ASHRAE 15 Safety Code for Mechanical Refrigeration requires appropriate safety precautions and procedures for the use of refrigerants, such as adequate ventilation; refrigerant leak detectors; at least one-hour rating separation of the machine room walls, floor and ceiling separation from other occupied spaces, etc. The accidental discharge of large quantities of gas, even though non-toxic can cut off the supply of air. Anyone working in areas where there is a high concentration of certain refrigerants must immediately leave the area and notify appropriate USPS supervision. When handling refrigerants with extremely low boiling points, protective equipment such as gloves, face or eye protection should be used to prevent possible frostbite.

3.2.8.1 Installation Restrictions

ANSI/ASHRAE Standard 15 specifies safe design, construction, installation, and operation of refrigeration systems. Section 8 describes the installation requirements and requirements for nonflammable (type A1 and B1) refrigerants. It also covers flammable refrigerants. According to Section 8 refrigeration components in the air stream must be able to withstand 700°F without leaking; the mechanical room must be large enough to allow service and have clear headroom of 7.25 feet. Moreover, the room should have enough doors to allow adequate escape in the event of an emergency and it cannot have openings that will allow refrigerant to enter the occupied space in the event of leak (*ANSI/ASHRA 15*, Paragraph 8.11.2). Furthermore, each mechanical room shall have a refrigerant leak detector with an alarm and ventilation system at a value not greater than the TLV-TWA of the refrigerant. The alarm shall be audio and visual and located at each entrance to, and in the mechanical room. There shall be a manual reset of the alarm located in the mechanical room. Absorption chillers using water as the refrigerant do not require detectors (*ANSI/ASHRA 15*, Paragraph 8.11.2.1).

Chiller mechanical rooms shall be vented to the outdoors as follows (*ANSI/ASHRA 15*, Paragraph 8.11.3 through 8.11.5):

- Mechanical fans are required.
- Openings for inlet air must be provided and situated to avoid recirculation.
- Supply and exhaust air ducts shall serve no other area.
- Discharge of exhaust air shall be in such a manner as not to cause a nuisance or danger.
- The emergency ventilation capacity shall be calculated as follows:
- Q = 100*G0.5
    - Q = the airflow rate in cubic feet per minute
    - G = the mass of refrigerant in pounds in the largest system (i.e., the chiller), any of which is located in the chiller mechanical room.
- General ventilation shall be provided when occupied at a rate of 0.5 CFM /Ft² or 20 CFM/person.
- The general ventilation rate must be capable of maintaining a minimum 18°F temperature rise above the inlet air or a maximum space temperature of 122°F.

Natural ventilation is acceptable under certain circumstances such as open structures (Standard 15 for additional information). However, open flame that uses combustion air from the chiller mechanical room is not allowed, such as a natural draft boiler. Combustion equipment can be in the chiller mechanical room if combustion air is drawn directly from outdoors or a refrigerant detector is used to shut down the combustion device in the event of a leak (*ANSI/ASHRA 15*, Paragraph 8.11.6). Additionally, there shall be no air flow from occupied spaces through the chiller mechanical room unless the air is ducted and sealed in such a manner as to prevent refrigerant leakage from entering the air stream. Access doors must be gasketed and tight fitting (*ANSI/ASHRA 15*, Paragraph 8.11.7). Furthermore, access to chiller mechanical rooms shall be restricted to authorized personnel and clearly marked as restricted (*ANSI/ASHRA 15*, Paragraph 8.11.8). The discharge from purge systems (i.e., negative pressure centrifugal chillers) shall be governed by the same rules as pressure relief and fusible plug devices. Absorption chillers using water as the refrigerant are exempt (*ANSI/ASHRA 15*, Paragraph 8.14).

3.2.9 Refrigeration Oils

3.2.9.1 Definition

Refrigeration oils are special lubricating oils for refrigerant compressors and require consideration apart from normal lubricants.

3.2.9.2 Properties

Refrigeration oils should be able to withstand extreme temperatures, maintain their viscosity, and compatibility with the refrigerant, as well as protect against deposits. The oil must be mutually soluble with the refrigerant and be able to separate quickly from the refrigerant when the oil returns from the low-pressure side to the compressor. It should contain a minimum of moisture. Ability to resist deterioration by oxidation is important in prolonging the life of the oil. It should also contain little or no corrosive acid.

3.2.9.3 Selection

Lubricants in the refrigeration system lubricate rotating compressor components and aid heat dissipation. Thus, refrigeration oils confront extreme conditions. Refrigerant lubricating oils must be capable of circulating throughout the system with the refrigerant. Therefore, the selected oil must be highly soluble with the refrigerant.

Mineral oils, used with CFC refrigerants are not highly soluble with HFCs; they cannot be sufficiently transported throughout the refrigeration system by R-134a. Studies recommend the use of Polyolester (POE) oil for HFC-134a. Usually, the manufacturer recommends the oils most suitable for its compressor under rated conditions. It is advisable to follow the manufacturer's recommendations. Periodic laboratory analysis of oil samples from all large chillers is highly recommended.

3.3 ABSORPTION REFRIGERATION

3.3.1 Absorption Cycle Definitions

Before discussing the absorption-refrigeration cycle, certain terms should be defined:

- Absorbent: A substance readily capable of taking in and retaining moisture from the atmosphere.
- Absorber: A vessel containing liquid for absorbing refrigerant vapor.
- Concentrator: A vessel containing a solution of absorbent and refrigerant to which heat is supplied to boil away some of the refrigerant.
- Concentrated Solution: A solution with a large concentration of absorbent and only a small amount of dissolved refrigerant.
- Dilute Solution: An absorbent solution, diluted by a large amount of dissolved refrigerant.
- Condenser: A vessel in which vaporized refrigerant is liquefied by removal of heat.
- Evaporator: A vessel in which refrigerant is vaporized to produce a refrigerating effect.
- Heat Exchanger: A device used to transfer heat between two physically separate fluids.
- Heat of Condensation: The heat released when a vapor condenses to a liquid.

- Heat of Dilution: The heat released when two liquids are mixed. This is sometimes referred to as the Heat of Absorption since in the mixing process one liquid may absorb the other.
- Sensible Heat: Heat used to raise or lower the temperature of a substance.

3.3.2 Operation

3.3.2.1 Theory

3.3.2.1.1 Absorption Cycle

The absorption cycle is a process of using two fluids and heat as the primary source of energy for driving refrigeration. The absorption cycle is similar to the mechanical compression cycle; both machines accept heat to evaporate a refrigerant at low-pressure in the evaporator to create a cooling effect. Additionally, both condense vaporous refrigerant at higher pressure and temperature in the condenser, so the refrigerant can be reused in the cycle. In both cases, the capacity of the machine depends upon the pressure that exists in the evaporator since this determines the evaporator temperature.

3.3.2.1.2 Vapor Compression Cycle

The vapor compression cycle employs a mechanical compressor to create the pressure difference necessary to circulate the refrigerant. The absorption system uses the secondary fluid or absorbent to circulate the refrigerant. Absorption systems create a low-pressure area by controlling the temperature and concentration of the lithium bromide/water (LiBr/H_2O) solution (Paragraph 3.3.2.2.2).

3.3.2.1.3 Moving Refrigerant Vapor

In compression systems the refrigerant vapor is mechanically compressed and moved from the low-pressure to the high-pressure side of the system. In absorption systems the vapor is first condensed and mixed into a solution of lithium bromide, then is pumped to a higher-pressure area where heat is applied. The heat causes the solution to boil, driving off the refrigerant vapor at the higher pressure. It is therefore evident that exactly the same function--that of taking low-pressure refrigerant vapor from the evaporator and delivering high-pressure refrigerant vapor to the condenser--has been performed in both the compression and absorption cycles. The only difference is in the method of transporting the vapor from the low-to-the-high-pressure side.

3.3.2.2 Operating Components

3.3.2.2.1 General

The absorption cycle, shown in Figure 3-2, illustrates a simplified relationship between the cycle main components. Figure 3-3, however, depicts a more realistic absorption cycle.

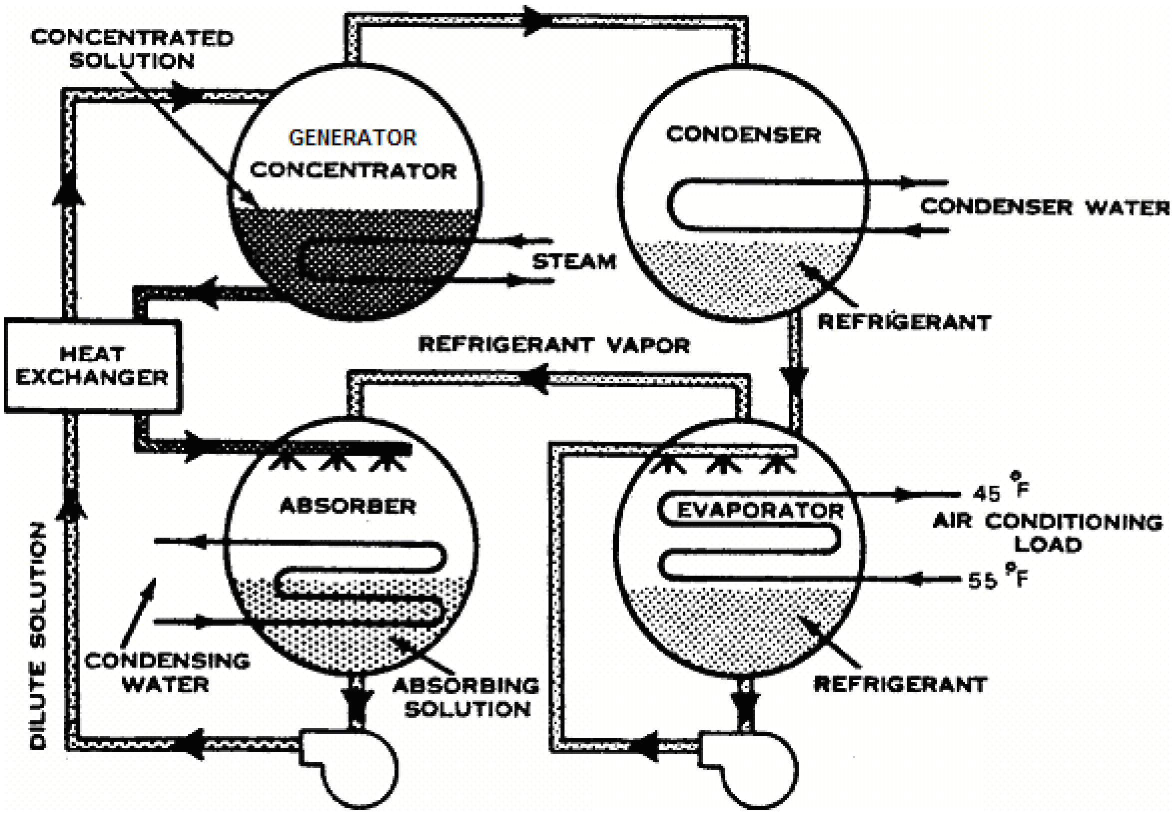

Figure 3-2. Absorption Systems

3.3.2.2.1 Evaporator

Water returns from a chilled water system at about 55ºF, is cooled to about 45ºF in the evaporator: it is then pumped to the air-handlers where it picks up heat from the conditioned space. The chilled-water pump is external to the refrigeration machine and is not shown in Figure 3-3. Liquid refrigerant in the bottom of the condenser moves from the condenser to the evaporator spray nozzles. The refrigerant evaporator pump takes refrigerant from the bottom of the evaporator and delivers it to the spray trees in the evaporator, which sprays the evaporator tubes. Due to extreme vacuum in the lower shell (~6mmHG (0.8kPa) absolute pressure), the refrigerant liquid boils at 39ºF, creating the refrigerant effect (Courtesy Trane Company York Millennium YIA Absorption Chiller).

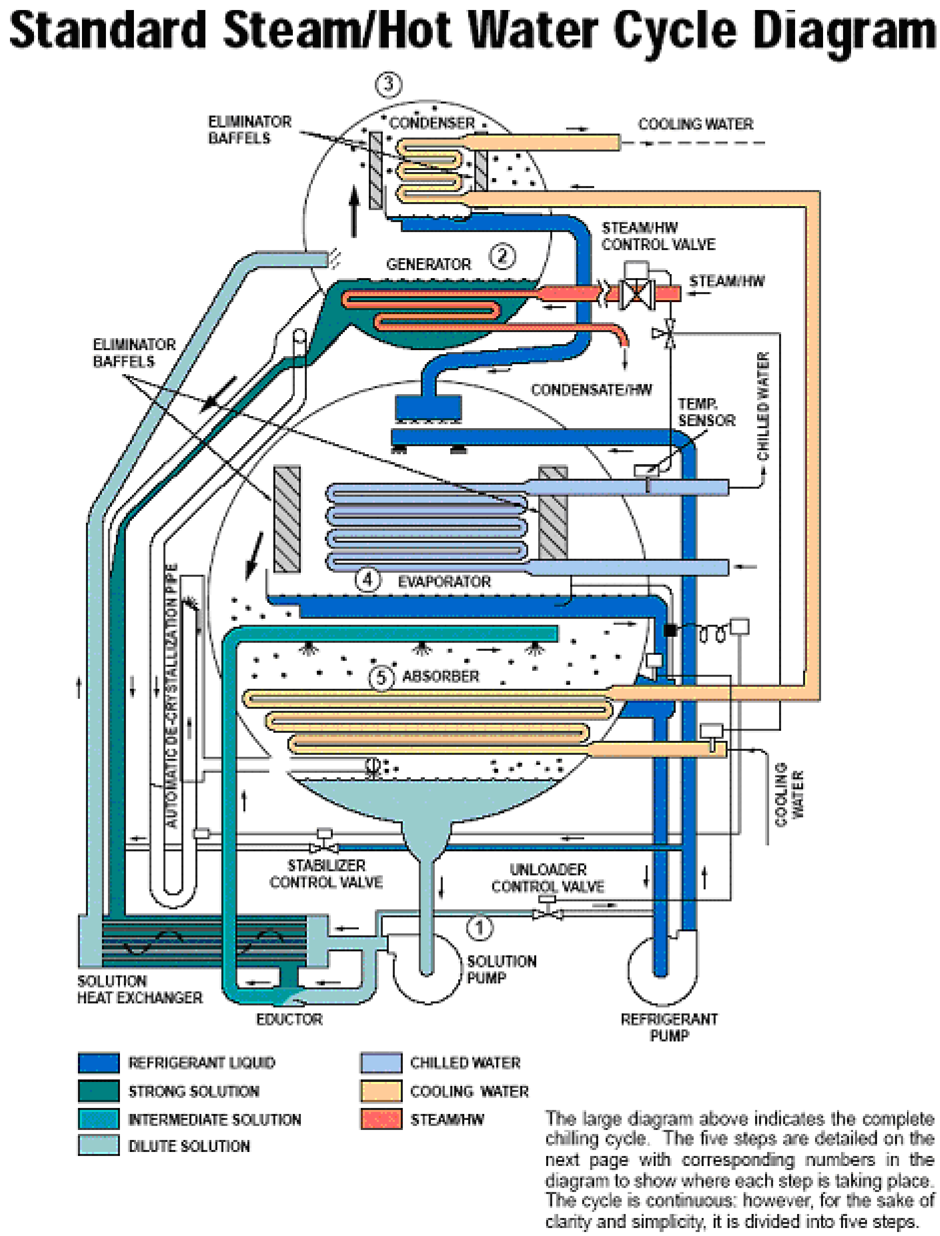

Figure 3-3. Absorption Systems

3.3.2.2.2 Absorber

As the refrigerant vapors migrate from the evaporator to the absorber, the strong lithium bromide solution, sprayed on the absorber tube bundle, pulls the refrigerant vapor into solution, creating the extreme vacuum in the evaporator. Because of the lower pressure in the absorber, the refrigerant vapor produced in the evaporator flows to it. This low-pressure exists because the concentrated absorbent solution (lithium bromide) exerts a strong attractive force on the molecules of refrigerant (water) vapor. The molecules of refrigerant vapor condense into a liquid and generate heat as they contact the molecules of the absorbent solution.

In the absorber three quantities of heat are released: The heat of condensation, the heat of dilution, and sensible heat. In order to remove this heat and maintain a constant temperature in the absorber, the absorbent solution falls over a cooling coil after being sprayed into the absorber. Cooling water is supplied to this coil to remove the three quantities of heat from the absorber. If this heat was not removed, the temperature and pressure in the absorber would rise, and the flow from the evaporator would stop.

The weak lithium bromide (mixed with water), after falling over the cooling coil drops into the bottom of the absorber shell, where it flows to the solution pump. Non-condensable gases may be present in the refrigeration system. These gases must be removed to permit continuous operation of the machine. The surface of the solution in the bottom of the absorber is relatively quiet and non-condensable gases tend to collect in this location. These gases are then removed by a large-capacity vacuum pump, or by an auxiliary absorber and a smaller vacuum pump. Purging of these gases is tremendously important to the successful operation of the absorption refrigeration machine, regardless of the design. Without proper purging, the pressure in the absorber increases to a point that the flow of refrigerant vapor from the evaporator stops.

3.3.2.2.3 Solution Pump

The solution pump continually takes the weak solution from the absorber and delivers it through a heat exchanger for preheating.

3.3.2.2.4 Heat Exchanger

The efficiency of the absorption cycle is substantially improved by the use of an external heat exchanger that preheats the weak solution. After exiting the heat exchanger the weak solution enters the generator. The strong hot solution leaving the generator exchanges heat, in the heat exchanger, with the weak solution leaving the absorber. After passing through the heat exchanger, the concentrated solution from the generator is sprayed over the top of the absorber tube bundle. The use of a heat exchanger results in a twofold gain: A lower steam consumption for the same amount of refrigerant evaporated from the concentrator; and less heat to be removed from the absorber by the cooling water.

3.3.2.2.5 The Generator

In the generator, also known as the concentrator, the solution surrounds a bundle of tubes that carry either steam or hot water. The steam or hot water coils supply heat to boil off the refrigerant from the weak solution leaving behind concentrated absorbent (lithium bromide) in the bottom of the generator and sending the refrigerant vapor upward into the condenser. The concentrated lithium bromide moves down through the heat exchanger and it is cooled by the weak solution leaving the absorber. The boiling away of the refrigerant from the solution while the absorbent remains in the concentrator is possible because the refrigerant has a lower boiling point than the absorbent. The concentrator is never hot enough for the absorbent to boil. As the refrigerant vapor boils away from the solution, the absorbent left in the bottom of the unit has a higher percentage of absorbent than it does refrigerant. The solution is said to be "concentrated;" hence, the name "concentrator" for this component of the machine.

3.3.2.2.6 Condenser

The refrigerant vapor, boiling from the solution in the generator/concentrator, flows upward through the mist eliminators to the condenser tube bundle. The refrigerant vapor condenses on the tubes; cooling water within the tubes removes the heat of condensation. The refrigerant vapor condenses and drops to the bottom of the condenser from which it flows to the evaporator through a regulating orifice. This completes the operating cycle.

3.3.2.3 Techniques

Heat is released within the absorption machine in two places, the absorber and the condenser. Water inside the condenser tubes removes the heat. Figure 3-3 shows an economical method for using water in an absorption system.

SECTION 4 addresses sources of condenser water and cooling methods. Water is an operating expense and should be included in the economics of unit selection.

3.3.2.4 Capacity Control

In an absorption machine, good capacity control is attained from 100 percent to 10 percent of full load. The machine automatically meets any changing load condition from full load down to 10 percent load. If the demand for chilled water decreases further, the machine shuts itself down. One particular control system is simple and yet completely reliable. It consists of a control element that senses the temperature of chilled water leaving the evaporator and, if it is below the set temperature, throttles the quantity of steam supplied to the concentrator. The reduced amount of steam boils a smaller quantity of refrigerant out of the solution in the concentrator. Therefore, the solution flowing from the concentrator to the absorber contains less absorbent. The solution sprayed over the tubes in the absorber is less concentrated and the ability to absorb refrigerant vapor is reduced, producing less cooling effect in the evaporator.

3.3.2.5 Application

There are no reciprocating parts on the absorption machine; the only moving parts are the solution pumps and a vacuum pump. Thus, the machine does not vibrate and operates relatively quietly. The absorption machine is lightweight and has a low floor loading factor. This makes it ideal for hospitals, hotels, apartment buildings, and office buildings. It can be placed in basements, intermediate floors, or on roofs of such buildings. In a plant that generates steam for electric power, or has steam available, air-conditioning requirements of 1000 tons or more are provided economically by combining the absorption equipment with centrifugal refrigeration equipment. Water for air-conditioning is pumped through the absorption and centrifugal equipment in series. Common designs cool the water from 60 to 47ºF in the absorption machine and from 47 to 40ºF in the centrifugal equipment. The centrifugal compressor is normally driven by a steam turbine using extracted steam at about 125 psig from a turbo generator unit. Steam from the turbine driving the centrifugal compressor is exhausted at about 12 psig and used in the absorption machine. Such a combination of absorption and centrifugal refrigeration equipment has a lower operating cost than either type of equipment used singly to meet the total load.

CAUTION

An absorption machine requires properly treated water to function properly. The use of improperly treated water may cause scaling, erosion, corrosion, algae or slime formation. Ensure properly treated water is always used in the absorption machine. Failure to comply may cause equipment damage.

3.4 CENTRAL REFRIGERATION PLANT

3.4.1 General

A given air-conditioning system may use any one of several refrigeration plants. It is the purpose of this sub chapter to briefly describe some of the common refrigeration plants used in postal facilities. Figure 3-4 shows a typical compression-type refrigeration plant and indicates the various components that make up a central system and their location with respect to each other.

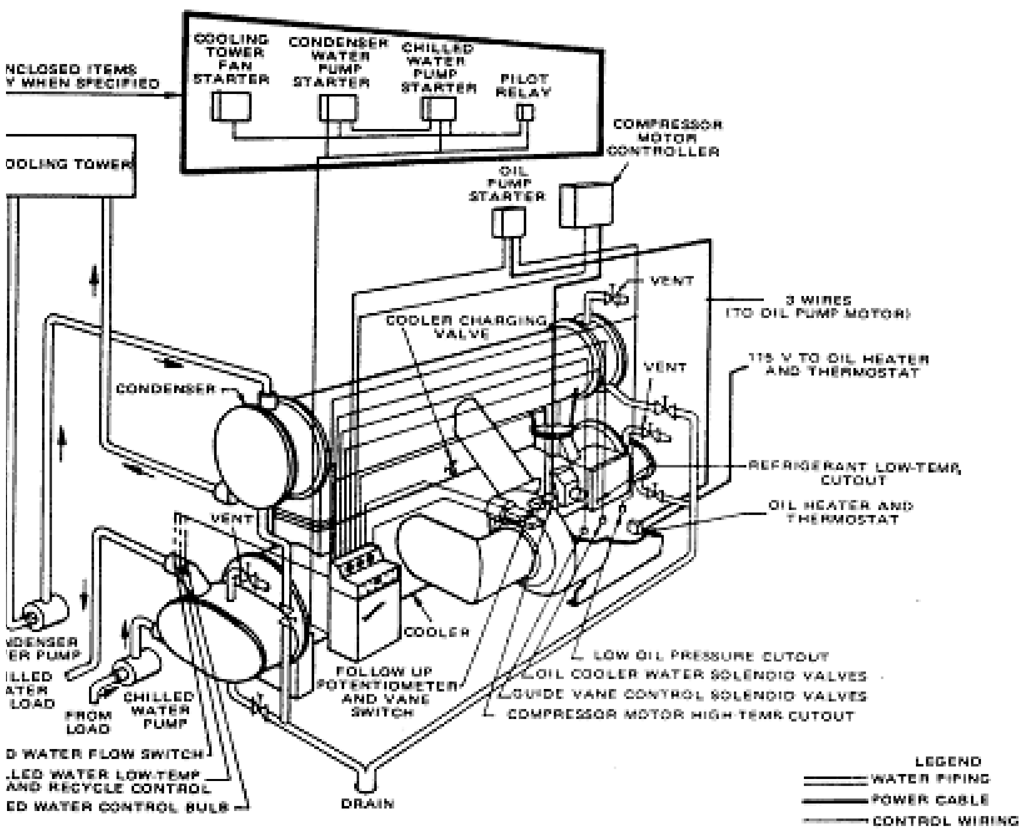

Figure 3-4. Typical Compression Type Refrigeration Plant

3.4.2 Components

3.4.2.1 Compressors

The compressor raises the pressure of the refrigerant vapor received from the chiller (or evaporator) and delivers it to the condenser, where it is condensed to a liquid.

3.4.2.1.1 Reciprocating

Reciprocating compressors are positive displacement machines; they increase the refrigerant vapor pressure by reducing its volume. Reciprocating compressors use cylinders, pistons, and connecting rods (Figure 3-5). There are two main types of reciprocating compressors: open and hermetic. The open compressor is driven by a separate motor through an open crankshaft that extends out the end of the housing. In the hermetic-type, the motor and compressor are in the same housing and the motor is cooled by the refrigerant vapor.

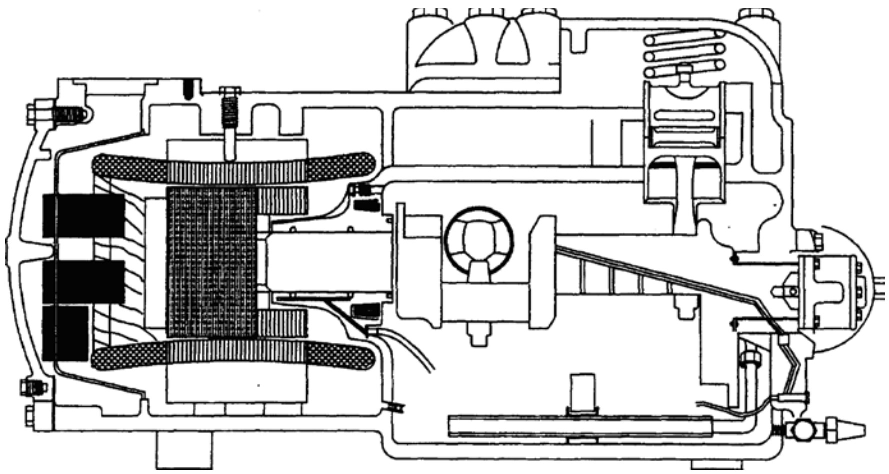

Figure 3-5. Hermetic Type Reciprocating Compressor

3.4.2.1.2 Centrifugal Compressor

The centrifugal compressor is driven by the turbine principle.

3.4.2.2 Condenser

The condenser is a heat exchanger that converts the high-temperature refrigerant vapor received from the compressor to a liquid and delivers it to the thermal expansion valve ahead of the chiller as a high-pressure liquid.

3.4.2.2.1 Thermal Expansion Valve

The thermal expansion valve (TEV) controls the refrigerant flow and reduces its pressure from the condenser to the evaporator.

3.4.2.3 Evaporator

The evaporator (chiller) is a heat exchanger that receives the high-pressure liquid from the thermal expansion valve. By expanding in this low-pressure area, the liquid refrigerant boils, evaporates, and becomes a vapor again. Figure 3-6 shows the path of the chilled water as it leaves the chiller, how it is controlled, and how its temperature changes as it leaves the air handlers and is returned to the chiller.

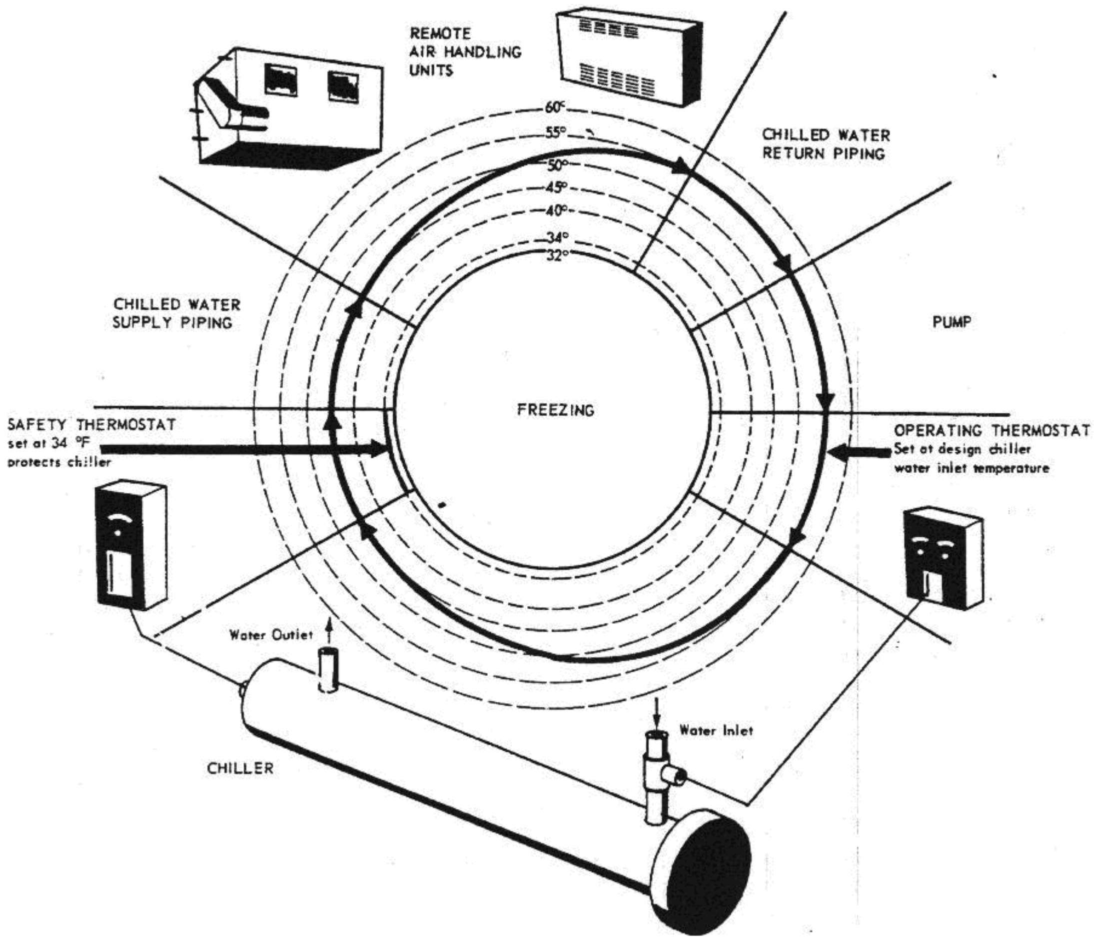

Figure 3-6. Temperature Graph of Cold Water Circulating in Typical Chiller Installation

3.4.2.4 Cooling Tower

A cooling tower is a heat exchanger in which two fluids, air and water, transfer heat. There are two basic types of cooling tower: direct or opened, and indirect or closed. The cooling tower receives hot water from a water cooled condenser; spray nozzles in the distribution basins distribute the hot water onto the heat transfer media (fills) inside the cooling tower. A pump in the cold-water collection basin at the base of the cooling tower re-circulates the cold water back to the condenser water system.

3.4.3 Maintenance Controls

Seasonal, as well as daily and weekly, operations subject air conditioning loads to considerable variation. Additionally, maintaining proper building conditions and minimizing operating costs require good control of refrigeration equipment. It is also important to have a posted written emergency shutdown procedure next to the unit.

3.4.3.1 Reciprocating Compressor

Reciprocating compressors displace a constant volume of gas regardless of operating conditions. When refrigeration demand varies, capacity can be varied by:

- Multi-speed compressor motors
- Multiple compressors
- Clearance pockets
- Cylinder cutouts
- Cylinder ports
- Suction-valve-lift unloaders
- Artificial compressor loading by balance loaders and hot gas bypasses

3.4.3.2 Centrifugal System

Compressor controls manage output volume based on pressure feedback and provide a means for safe operation of the compressor. However, managing output to maintain desired pressure limits compressor performance. The most common controls methods are:

- Off-and-on control
- Hot gas bypass control
- Condenser water regulation
- Butterfly dampers
- Speed control (VFD)
- Variable-inlet guide vanes

3.4.3.3 Controls

The most commonly used methods of control in postal facilities are the hot gas bypass control and the variable-inlet guide vanes. The hot gas bypass control consists of the installation of a bypass between the discharge and suction side of the compressor (Paragraph 2.5.5.1.6). When the compressor load is reduced to almost the surge point, a valve in the bypass line opens and permits high-pressure vapor from the discharge side of the compressor to enter the evaporator. As the load decreases further, the bypass opens wider so as to maintain a fixed minimum-volume flow rate to the compressor. Because there is no reduction in power input to the compressor once the bypass starts to open, bypass control is uneconomical.

Variable-inlet guide vanes vary capacity by changing the angle at which the suction vapor is directed into the inlet of the impeller. The variable inlet guide vane operation is discussed in Paragraph 3.6.3.3.

The basic cycle control is a device that starts, regulates, and/or protects the refrigeration system and its components. Cycle controls are divided into two distinct categories, primary and secondary. The primary control actually starts and stops the cycle as dictated by the temperature requirements. In an air-conditioning system, the primary control is the thermostat. Secondary controls can be further divided into operating and safety controls. The operating controls include the thermal expansion valve, motor controls, valves for controlling refrigerant and water flow, back-pressure valve, and the check valve. The safety controls include protection against electrical overload, the low-temperature safety thermostat, high-pressure cutout, low-pressure control, and the oil-safety switch.

3.4.4 Troubleshooting and Preventive Maintenance Guide

A troubleshooting guide has been provided (Paragraph 3.6.3) listing the most common troubles that may occur to the refrigeration plant using centrifugal-type compressors. The guide includes the probable causes of the listed troubles and recommended remedies for the correction of the troubles. Data contained in this guide is of a general nature and intended to provide a standard approach for identifying and analyzing the most common troubles. It is recommended that this guide be reviewed at the local level and expanded, if necessary, to include the results of local experiences. While performing troubleshooting procedures, observe all normal precautions for safeguarding personnel and equipment. Preventive Maintenance guides can be found in the Current MMO Guidelines to Creating Detailed Local Building Preventive Maintenance Checklists.

3.4.5 Logs and Records

3.4.5.1 General

An operating record of all refrigeration machines must be kept. Usually the manufacturer includes in his maintenance manual suggested methods for preparing a log in his maintenance manual. Proper interpretation of the record ensures efficient operation of the refrigeration plant and protects it from costly breakdowns.

Building automation systems (BAS) provide centralized communication with HVAC equipment and are capable of record keeping and troubleshooting.

3.4.5.2 Reciprocating Type Refrigeration Machines

For this type of machine, use Form 4990, Operating Log for Reciprocating Refrigeration Machines (Appendix A.1). Form 4990 is available online from the USPS PolicyNet Forms Webpage (https://blue.usps.gov/formmgmt/forms/4990.pdf).

3.4.5.3 Centrifugal Refrigeration Plants

For this type of machine, use Form 4994, Operating Log for Centrifugal Refrigeration Plants (Appendix A.2). Form 4994 is available online from the USPS PolicyNet Forms Webpage (https://blue.usps.gov/formmgmt/forms/4994.pdf).

3.4.6 Central Refrigeration Maintenance

3.4.6.1 General

Proper design/selection and maintenance of equipment in the central refrigeration plant is necessary to protect the health and safety of the general public and USPS employees. Furthermore, the large capital investment in this equipment makes proper design/selection and maintenance of this equipment vital.

3.4.6.2 Absorption Machines

Only personnel with appropriate training and experience may work on absorption-type refrigeration machines. Preventive Maintenance guides can be found in the current MMO Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Preventive Maintenance Checklists.

3.4.6.3 Centrifugal and Reciprocating Refrigeration Machines

Only personnel with appropriate training and experience may work on centrifugal and reciprocating refrigeration machines as well as cooling towers. Preventive Maintenance guides can be found in the current MMO Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Preventive Maintenance Checklists.

3.4.6.4 Cooling Towers

Proper design, operation, and maintenance of the cooling tower can have an impact on the operational efficiency of the entire refrigeration system. Under no circumstances may a cooling tower be modified without seeking professional advice.

3.4.7 Non Destructive Testing (NDT)

3.4.7.1 Eddy Current

Eddy-current testing is a procedure for evaluating the condition of tubing. A probe with an electrical coil that induces eddy currents in the tube wall is pushed through each tube. The eddy current varies with the tube wall thickness, and this variation is indicated on an oscilloscope and strip chart or hard drive. Experienced, properly trained technicians can interpret the oscilloscope pattern and determine the tube wall thickness with a high degree of accuracy. The state of the internal probe non ferromagnetic eddy-current testing has advanced rapidly because of the need for increased reliability of heat exchangers used in nuclear plants, and has spread to other plants as a cost-saving maintenance procedure.

3.4.7.1.1 Ultrasonic

Ultrasonic testing (UT) is a procedure for examining tubes of all types of material. It uses probes with pulse-echo techniques. The result of the examination is presented visually demonstrating the unfolding tube wall.

3.4.7.2 Maintenance Cycles

Maintenance cycles are as follows:

- For locations where there is only one central chiller and failure with extended downtime would disrupt operation, eddy-current testing of both condenser and evaporator tubes must be conducted on the same 5-year cycle used to clean and inspect the evaporator. Both evaporator and condenser sections must be tested.
- All central chillers 10 years of age and older should have eddy-current tests conducted at the next scheduled cleaning (5-year) of evaporator sections. Both evaporator and condenser sections must be tested. Thereafter, tests should be conducted on a 10-year cycle unless the tests indicate defects requiring more frequent inspection.
- Absorption-type air-conditioning must have eddy-current tests conducted on all sections (evaporator, condenser, absorber, and concentrator) every 5 years. Air (oxygen) leakage in the absorption chiller can cause metallurgical deterioration and loss of vacuum.
- When tube failure occurs, rather than replacing all tubes (which is often done), it is prudent to conduct eddy-current tests on a random number of tubes to determine if tube failure is specific or generalized. Tubes with 30 percent or more wall thinning are normally considered candidates for replacement or isolation. This 30 percent criterion will vary with type, model, and manufacturer of equipment. Additionally, only 12 percent of tubes shall be isolated per section. Generally, when heat exchangers have lost 12 percent of the tubes they become ineffective.
- Special (more frequent) eddy-current tests should be conducted under the following conditions:
  - When there is suspected damage to the tubes caused by poor water-treatment or other maintenance deficiencies.
  - On any make or model of central chiller that is known to be prone to tube failure.
  - When a previous eddy-current test indicated the tube-wall thinning but did not require replacement or isolation.

Eddy-current tests may be conducted at more frequent intervals to determine if the tubes are continuing to deteriorate.

- The Maintenance Technical Support Center (MTSC), Norman, Oklahoma, should be contacted for more information on eddy-current testing. Questions concerning contract specifications should also be directed to MTSC.

3.5 ABSORPTION PLANT

3.5.1 Controls

3.5.1.1 Capacity Controls

Modern absorption chillers are equipped with microprocessor control capability and extensive unit diagnostics. Thus, allowing the chiller to operate under a broad range of non-standard conditions. The diagnostic unit simplifies troubleshooting and allows more efficient scheduling of preventive maintenance. The control system automatically throttles the quantity of steam or hot water supplied to the generator (concentrator) when it senses changes in chilled-water temperature. The capacity is modulated as required to satisfy changing system requirements. When cooling is no longer required, the unit automatically dilutes the absorbent solution before shutting down the system. This procedure prevents absorbent-solution crystallization when the solution cools to ambient temperature. The system motor starters, capacity-modulation controls, and safety devices are consolidated into a single electrically interlocked system. This arrangement ensures proper sequence of operation and provides protection against mechanical failure and improper operating procedure.

3.5.1.2 Automatic Controls

The automatic control system for the absorption machine and its auxiliary chilled-water and condenser-water pumps energizes the circuits of the solution pump, evaporator pump, purge pumps, chilled-water pump, and condenser-water pump as parallel circuits. Other controls are the purge tank liquid-level control, purged/not-purged switch, time-delay pressure switch, chilled-water low-temperature cutout, purge tank high-level cutout, and the capacity control valve.

NOTE

Since different installations may vary electrically, the system described here may not be exactly the same as that found in a particular postal installation; however, basic principles will be the same.

3.5.2 Operating Sequence

3.5.2.1 Startup

Single chiller plants can be manually or automatically enabled. Figure 3-7 illustrates a typical absorption chilled-water generator control arrangement. The chilled-water pump is started by pushing the START button on the push button station (PB). Interlocked with the chilled-water pump starter (MS2), through a set of auxiliary motor starter contacts and a flow switches (FS) in the chilled-water circuit are the pneumatic-electric switch (PE) and the condenser-water pump starter (MS3). Operating a chiller without flow can result in serious damage.

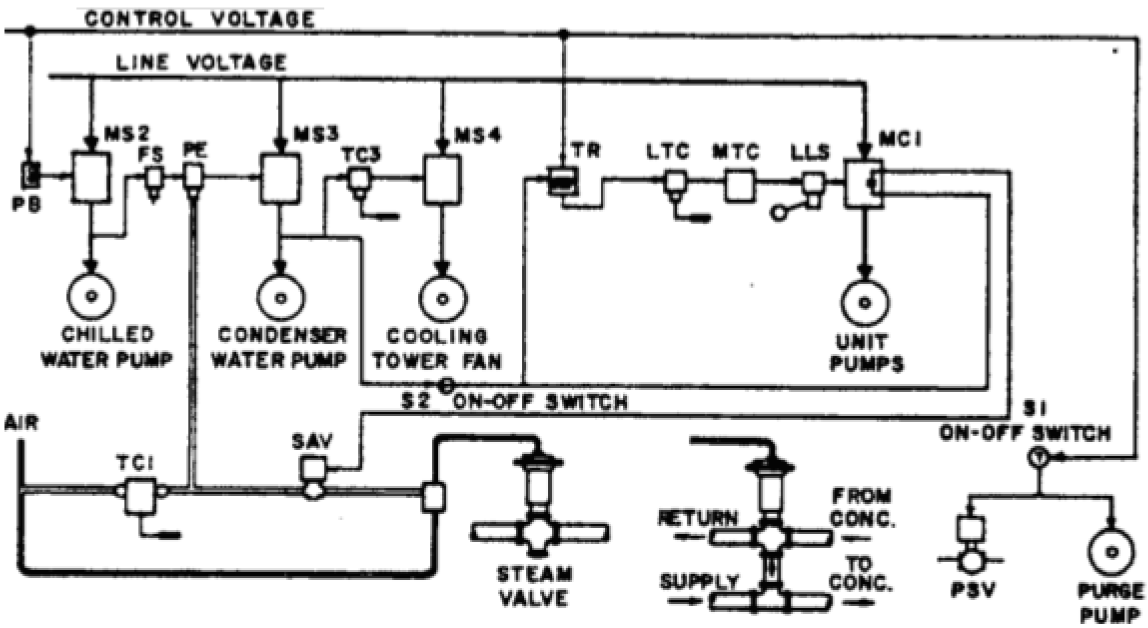

Figure 3-7. Typical Absorption Cold Generator Control Arrangement

3.5.2.2 Cooling

A demand for cooling, as indicated by the temperature of the chilled water leaving the unit, causes the branch-line pressure of the pneumatic chilled-water temperature control (TC1) to rise. The rising branch-line pressure closes the contacts of the pneumatic-electric switch (PE), starting the condenser-water pump through its starter (MS3).

3.5.2.3 Cooling Tower

The cooling-tower fan starter (MS4) is interlocked with the condenser-water pump starter (MS3) permitting the cooling-tower fan to start. Once started, the operation of the cooling-tower fan is cycled on and off automatically by the cooling-tower thermostat (TC3). Once the chilled-water pump is started, the absorption machine can be operated. Turning the system shutoff switch (S1) to the ON position energizes the time-delay relay (TR). This supplies control voltage through the contacts of the low-temperature control (LTC), motor-temperature control (MTC), and the liquid-level switch (LLS) to the unit pump starter (MC1), which starts the unit pumps.

3.5.2.4 Solenoid

The solenoid air valve (SAV) is energized through a set of interlocking contacts in the unit pump starter (MC1). The energized air valve supplies thermostat branch-line pressure to the pneumatic-steam or hot-water valve, allowing the valve to function.

3.5.2.5 Load Control

Control valves maintain space temperature by altering chilled water flow. Valves can be either on or off (two position) or vary flow in response to a given load (modulating). Variations in branch-line pressure operate the pneumatic valve, controlling the flow of steam or hot water to the concentrator. This governs the rate of vaporization and concentration within the unit, enabling the absorption cold generator to hold a stable chilled-water temperature over a wide range of load conditions. When lowering chilled-water temperature, as sensed by TC1, indicates that cooling is no longer needed, the reduced branch-line pressure causes the contacts of the pneumatic-electric switch (PE) to open. This stops the condenser-water pump, which in turn de-energizes the time-delay relay, (TR), the solenoid air valve (SAV), and the cooling-tower fan starter (MS4), stopping the fan. De-energizing the SAV causes the pneumatic valve to close, stopping the flow of steam or hot water to the concentrator.

3.5.2.6 Shutdown

Prior to complete shutdown, the unit pumps under control of the time-delay relay (TR) continue to function for approximately 4 minutes, bringing about a mixing of the diluted and concentrated solutions. The temperature of the cooling water is controlled by means of a pneumatic valve installed in a cooling-tower bypass arrangement. A thermostat, sensing the temperature of the water supplied to the absorber, positions the valve to mix proper proportions of recirculated and tower water to hold the temperature of the water within design limits. The purge pump and purge solenoid valve (PSV) are energized by closing the purge ON/OFF switch (S2).

3.5.3 Troubleshooting Guide

Table 3-2 lists the most common troubles that may occur in a refrigeration plant during the absorption process. The guide includes the probable causes of the listed troubles and recommended remedies for the correction of the troubles. Data contained in this guide is of a general nature and is intended to provide a standard approach to identifying and analyzing the most common troubles. It is recommended that this guide be reviewed at the local level and expanded, if necessary, to include the results of local experiences. While performing troubleshooting procedures, observe all normal precautions for safeguarding personnel and equipment.

Table 3-2. Troubleshooting Guide for Absorption Machines

COMPLAINT	CAUSE	POSSIBLE REMEDY
1. Decreased capacity	a. Condenser and absorber tube fouling.	a. Clean tubes. Purge unit.
	b. Non condensable.	b. Trace and seal possible air leak.

COMPLAINT	CAUSE	POSSIBLE REMEDY
(continued)	c. Concentrator water or stem temperature not within prescribed limits.	c. Correct water stem temperature to comply with manufacturer's limits.
2. Crystallization	a. Non condensable.	a. Activate the purge unit. If purge unit operates properly, leak test the absorption unit.
	b. Operation with condenser water temperature lower than design temperature.	b. Make repairs as necessary. Increase condenser water temperature.
	c. Power failure of long duration.	c. Refer to manufacturer's instructions for startup of unit.
	d. Shutting machine down with insufficient dilution.	d. Check operation of dilution cycle Time Delay Relay for proper operation and adjustment.
	e. Improper solution and water charges.	e. Adjust or replace relay as necessary. Bring solution to proper equilibrium according to Equilibrium Chart and manufacturer's requirements.
This table is not intended to cover every possible symptom, but is rather a list of the more frequent problems and some of their causes.		

3.5.4 Logs and Records

Viewing current as well as historical system operations and trends can provide invaluable information. Therefore, it is essential to keep an operating log of the absorption machines. Usually the manufacturer includes a log format in the maintenance manual. The form records data important to the machine's operation and maintenance. Accurate interpretation of the data ensures proper operation of the absorption plant and protects against costly breakdown. Building Automation System (BAS), when properly used, can provide status information that can help with troubleshooting. Due to the different types of absorption machines and the requirement for different factors to be checked and logged, each installation must either use a log sheet printed by the manufacturer of their equipment or develop its own log sheet using the company furnished log sheet as a guide. All log sheets developed locally should be no larger than 8-1/2" x 11" and must have regional approval before being used.

3.6 COMPRESSORS

3.6.1 General

A compressor is a mechanical device that increases the pressure of a gas by reducing its volume and hence raising its temperature. There are many different types of compressors used for refrigeration purposes and some are discussed below.

3.6.2 Reciprocating Compressors

3.6.2.1 Description

The basic operating parts of a reciprocating compressor are a rotating crankshaft that drives a piston back and forth in a sealed cylinder and valves that admit vapor at a low-pressure and discharge vapor at high-pressure. In some applications, compound or multistage systems are designed to compress refrigerant vapors in two or more stages. These compressor systems are applied if refrigeration requirements are too severe for a single compressor system to handle.

Refrigerant passes through the intake manifold and the compression cylinder where it is compressed by the reciprocating pistons and sent to the discharge manifold into the condenser.

3.6.2.2 Types

3.6.2.2.1 Open

The open compressor (Figure 3-8) is so-called because one end of the crankshaft extends outside the crankcase. This compressor is adaptable to a variety of drives. Semi-hermetic compressors prevent air and dust from entering the casing.

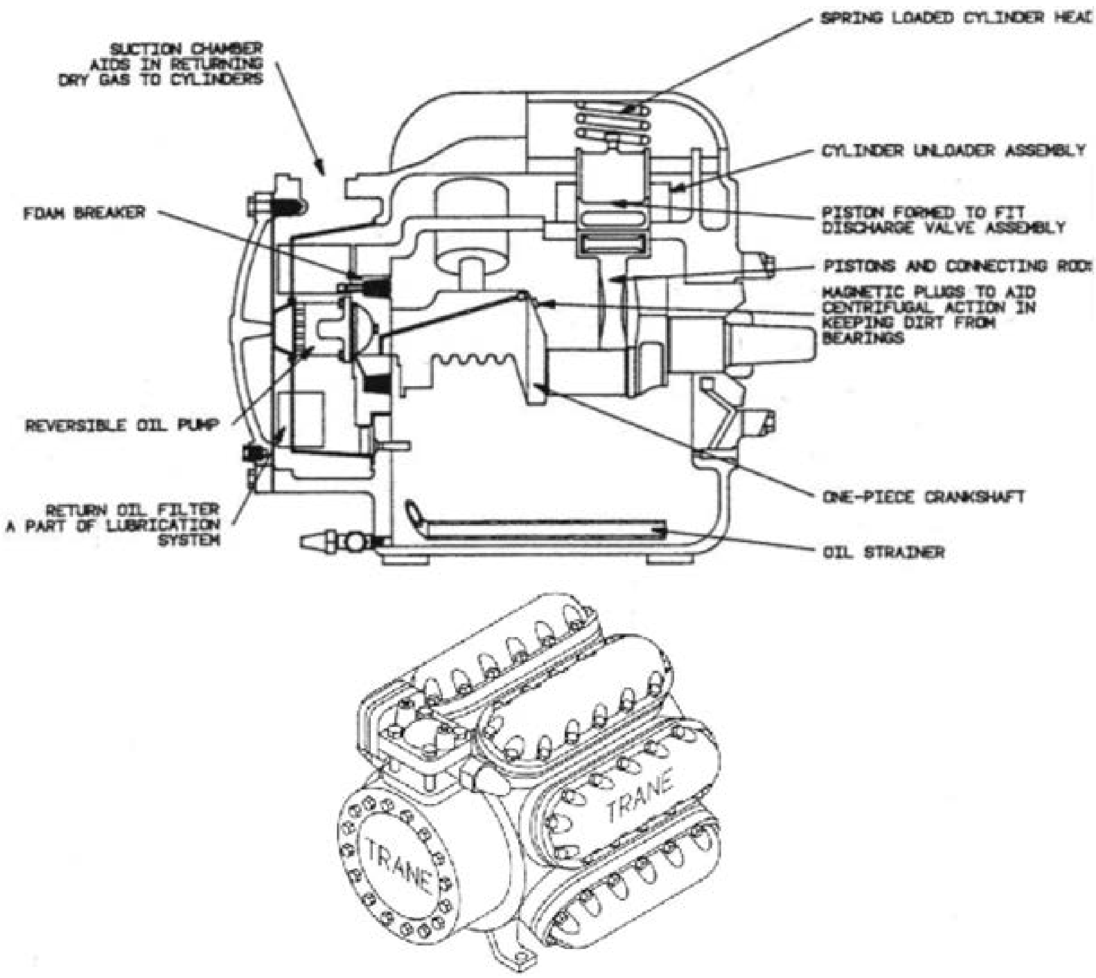

Figure 3-8. Open Type Reciprocating Compressor

3.6.2.2.2 Hermetic

Reciprocating compressors are hermetic when the casing is welded closed and sealed, and the heads of the cylinder cannot be accessed for inspection or maintenance (Figure 3-9). The compressor portion is basically the same as the open-type compressor, but the compressor and motor are connected by a common shaft inside the housing.

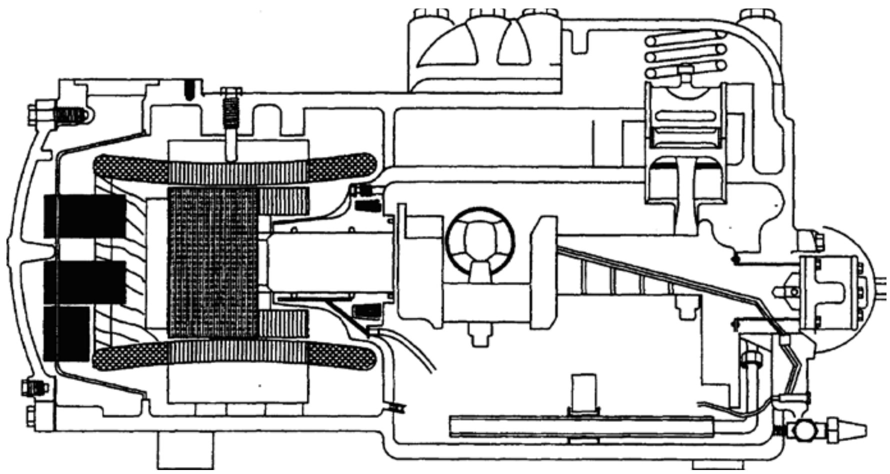

Figure 3-9. Hermetic Type Reciprocating Compressor

3.6.2.3 Capacity Controls

3.6.2.3.1 Compressor

Capacity control is necessary because refrigeration and air-conditioning loads constantly vary. A compressor is often required to do only a part of the work for which it was designed. Four common methods of controlling compressor capacity are cylinder unloading, variable-speed motors, hot gas bypass, and cylinder bypass.

3.6.2.3.2 Cylinder Unloading

Cylinder unloading means that the suction valves on the cylinders affected are mechanically held off their seats and are inoperative. The capacity control actuator (the unit that lifts and holds the suction valves off their seats) is actuated by oil pressure or an electro-mechanical device. The capacity control actuator operates because of a difference between the refrigerant-suction pressure and atmospheric pressure. If the demand for refrigeration in the evaporator decreases, the suction pressure drops and a solenoid opens. This action relieves oil pressure from the actuator valve mechanism, causing a mechanical linkage to lift the suction valve from its seat. Multiple-cylinder compressors have an unloading valve on each cylinder. As suction pressure continues to drop, the unloader mechanisms unload each cylinder in sequence until the operating cylinders have matched the load on the refrigeration system. This system is driven by a constant-speed motor.

3.6.2.3.3 Varying Speed

Capacity control of the compressor is accomplished by the use of variable-speed motors or electric motors with two or more speed adjustments. The speed change can be made manually or automatically, if desired.

3.6.2.3.4 Hot Gas Bypass

The hot gas bypass capacity can be controlled by temperature or pressure, depending upon the type of application. As the controller calls for capacity reduction, a solenoid valve opens in a bypass line allowing some hot gas to return to the inlet of the evaporator from the discharge side.

3.6.2.3.5 Cylinder Bypass

The fourth method of controlling compressor capacity is the cylinder bypass system. This system is also activated by either temperature or pressure sensing. When the controller calls for capacity reduction, a solenoid opens and the discharge vapor from one block of cylinders returns to the suction side of the compressor. A check valve prevents high-pressure vapor from entering the isolated bank of cylinders. High-pressure cannot be created in the bypassed cylinders, so they operate with suction pressure both above and below the valve plate and the cylinders do no work. When the system operates under partial loads, without the above listed controls, low back pressures may result in coils freezing at the evaporators.

3.6.2.4 Safety Controls

Safety controls are designed to protect the components of the refrigeration system from electrical overloads, excessive temperatures, high-pressure, low-pressure, and loss of lubricating-oil pressure. Several types of electric switches and pressure cutouts have been developed that stop the compressor in the event of failure in some part of the system.

3.6.2.4.1 Circuit Protection Devices

The current in an electrical circuit does not always follow its intended or designed path; it may be altered by a number of factors and cause serious damage to personnel and/or assets. Therefore, electrical circuits require protection from direct short, excessive current and excessive heat. Circuit protection devices connected in series are used to stop unintended current flow. The circuit protection device operates by opening and interrupting the current to the circuit. Two common types of circuit protection devices are fuses and circuit breakers. The former melts and the latter is re-satiable.

In motor circuits a reset-type of protector is used. When excessive current is drawn in the load circuit, this device will break the circuit, stopping the compressor. Also, in water-chilling systems, it is important that the water not be allowed to freeze and cause physical damage to the equipment. To prevent this from happening, a thermostat is used with the temperature-sensing element immersed in the water at the coldest point. The thermostat is set to break the control circuit at some temperature above the freezing point of water. This stops the compressor and prevents further lowering of water temperature and possible freezing.

3.6.2.4.2 Excess Pressure Protection

The American Petroleum Institute (API) is an important authority regarding standards and recommendations for the use of safety relieving devices. API *Recommended Practice 520 Part I* - describes the design, sizing, and selection of components for pressure relieving devices and API *Recommended Practice 527* - provides a basis for testing and acceptance for set pressure and seat tightness of pressure relief valves. All pressure vessels used in refrigeration systems require overpressure protection. The main means of overpressure protection is by ensuring methodical design, installation, and maintenance of a pressure relieving system.

The simplest pressure relief system consists of pressure relief device such as relief valve, fusible plug, rupture disc, interconnecting piping and catch tank.

3.6.2.5 Troubleshooting Guide

Table 3-3 lists the most common troubles that occur with reciprocal-type compressors and includes probable causes and recommended remedies. It is not intended to cover every possible symptom but is rather a list of the more frequent problems and some of their causes. The guide provides a standard approach for identifying and analyzing common troubles. It is recommended that this guide be reviewed at the local level and expanded, if necessary, to include local experiences.

NOTE

When performing troubleshooting procedures, observe all normal precautions for safeguarding both personnel and equipment.

Table 3-3. Troubleshooting Guide for Reciprocal Types Compressors

COMPLAINT	CAUSE	POSSIBLE REMEDY
1. Compressor will not start.	a. Thermal overload elements in motor starter too small.	a. Install correct elements.
	b. Bearings frozen.	b. Replace bearings.
	c. No power.	c. Investigate loss of power and make necessary repairs or corrections.
	d. Moving parts of compressor sticking.	d. Disassemble compressor; clean or replace faulty parts.
	e. Improper line voltage.	e. Check line voltage.
	f. Poor terminals or starter contacts.	f. Ensure good contacts.

COMPLAINT	CAUSE	POSSIBLE REMEDY
2. Compressor stops. (low-pressure a, b) (high-pressure c, d)	a. Expansion valve stuck closed.	a. Remove and free or replace valve.
	b. Leaky power element or expansion valve.	b. Repair or replace power element.
	c. Shortage of condenser water.	c. Increase supply of water.
	d. Air in condenser.	d. Purge the air from the condenser and restart the compressor.
3. Compressor starts and stops at frequent intervals (short-cycling hi or low-pressure switch).	a. Expansion valve obstructed.	a. Remove and clean valve.
	b. Leaky power element on expansion valve.	b. Repair or replace power element.
	c. Solenoid valve leaking.	c. Replace valve.
	d. Strainer in liquid line clogged with dirt.	d. Remove and clean strainer.
	e. Valve on liquid receiver partially closed.	e. Replace valve.
	f. Obstruction in liquid line.	f. Clear obstruction from line.
	g. Shortage of condenser water.	g. Increase supply of water.
	h. Expansion valve improperly adjusted.	h. Adjust to pass more liquid.
	i. Insufficient water or air over evaporative condenser.	i. Check for insufficiency of water or air. Make necessary corrections and restart compressor.
	j. Low-pressure control set too high.	j. Lower control setting.
	k. High-pressure control set too low.	k. Increase control setting.
	l. Insufficient charge.	l. Repair leak and add refrigerant.
4. Compressor is pounding.	Too much oil in crankcase.	Drain excess oil.

COMPLAINT	CAUSE	POSSIBLE REMEDY
5. Compressor is noisy.	1. Loose belt wheel or motor pulley. Excessive end play in motor shaft.	1. Checkbook wheel, motor pulley, and shaft. Repair or replace as required.
	2. Valves leaking, broken, carbonized, or loose.	2. Check valves. Clean and replace as required.
	3. Carbon build-up on top of piston(s).	3. Clean piston(s). Repair or replace parts as required.
	4. Cylinder scratched, worn or scored.	4. Replace or repair as required.
	5. Piston scratched, worn or scored.	5. Repair or replace as required.
	6. Defective ball bearings on crankshaft or motor shaft.	6. Check ball bearings. Replace as required.
6. Suction connector and part of suction line is warm.	Suction valves leaking.	Replace valves.

3.6.3 Centrifugal Compressors

3.6.3.1 General

3.6.3.1.1 Description

The centrifugal compressor has two to six rotors or impellers mounted on a single shaft rotating in a housing. The rotating element is supported by bearings. Each rotor or impeller consists of two or more rows of axially-mounted vanes. Vapor, which will be compressed, flows from the center of the impeller to the outer edge. In the process, the rotating impeller imparts a high velocity to the vapor, increasing its kinetic energy. This energy is then converted to static pressure in the expanding section of the impeller housing. The result is the development of pressure necessary for the refrigeration cycle.

3.6.3.1.2 Impellers

To achieve the pressure necessary in high-capacity refrigeration units, a single compressor may have two to six impellers. Vapor from the discharge of one impeller is directed to the suction side of the next. Each impeller is designed to operate at the best efficiency for handling the vapor at each stage of compression.

3.6.3.1.3 Capacity

The centrifugal compressor is capable of handling large volumes of vapor. Because of their large capacity, centrifugal compressors dominate the 200 ton and larger chiller market, where they are the least costly and most efficient cooling compressor design. Centrifugals are most commonly driven by electric motors, but can also be driven by steam turbines and gas engines.

3.6.3.2 Compressor Type

3.6.3.2.1 Open

Open-type compressors have external drives. One end of the impeller shaft extends beyond the compressor housing.

3.6.3.2.2 Hermetic

The hermetic centrifugal compressor and its drive motor are completely enclosed within a sealed casing. The impellers and motor are mounted on the same shaft.

3.6.3.3 Controls

3.6.3.3.1 Power Requirements

Maximum cooling requirements of a typical air-conditioning system last for only a few consecutive hours each day during the summer cooling season. During the remainder of the day, there may be long periods of constant partial load or a load varying from minimum to maximum in a relatively short time. Under these conditions, it is desirable to reduce or increase power requirements to meet cooling demand.

3.6.3.3.2 Capacity Controls

The movement of inlet valves, which permit the correct quantity of refrigerant, controls the compressor capacity. Various methods of capacity control are used to obtain compressor efficiency at partial load. The most economical means is the use of adjustable inlet guide vanes (Figure 3-10).

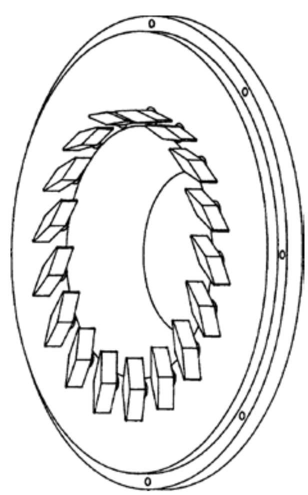

Figure 3-10. Adjustable Inlet Guide Van for Capacity Control of Centrifugal Compressor

3.6.3.3.3 Guide Vanes

The variable-inlet guide vane consists of a number of wedge-shaped center-pivoted dampers that divide the gas stream into several segments. A control device, through an actuator and linkages, positions all the guide vanes simultaneously. The reduction in area between the vanes, as they are moved automatically from the fully open position toward the closed position, causes a pressure drop that in turn increases the specific volume of the vapor entering the impeller and reduces the main flow. The guide vanes also impart a spin to the vapor flowing into the impeller in the direction of impeller rotation. The spinning vapor reduces the tendency for compressor stall at the inlet edge of the impeller blades, providing greater compressor stability and preventing surging.

3.6.3.3.4 Other Control Methods

Other methods of accomplishing capacity control have been used and are currently available. They vary considerably in their effectiveness and efficiency at partial load. The methods listed below are inefficient in operation and are not common in postal facilities:

1. Off-and-on control
2. Condenser water regulation
3. Speed control through variable frequency drives (VFD)
4. Suction dampers
5. Microprocessors

3.6.3.4 Safety Controls

3.6.3.4.1 General

Microprocessor-based compressor control systems minimize blow-off and surges, provide overload protection, load sharing (if more than one unit is used), capacity control, process decoupling, sequence shutdown on lack of load, and other station controls.

3.6.3.4.2 Load-Limit Control

The load-limit control limits the current drawn by the motor to prevent motor burnout. Thermal-overload relays serve the same purpose when the demand of the refrigeration unit exceeds the capability of the drive motor.

3.6.3.4.3 Oil-Pressure Control

The oil-pressure control measures the effective oil pressure at the bearings. This control prevents the compressor motor from starting until the oil pump is delivering oil at the proper rate and shuts the unit down if oil pressure drops below a preset limit.

3.6.3.4.4 Oil-Temperature Control

The oil-temperature control and its components maintain the oil temperature at the point that prevents an excessive amount of refrigerant from being absorbed by the oil. This eliminates oil pump and compressor cutouts caused by oil foaming and loss of oil-pump prime.

3.6.3.4.5 Other Controls

It is important that a proper sequence of events be scheduled for starting a centrifugal refrigeration system. To prevent damage to the equipment, the system is provided with controls that will not allow the compressor to start until the chilled-water pump is circulating water through the evaporator. There are also inter-lock devices that ensure the condenser water pump is circulating water through the condenser and cooling tower before the starting circuit to the compressor is closed. Through the safety controls, the compressor motor is stopped if any of the above auxiliaries fail. In this way, the system is protected against mechanical failure and improper operating procedure.

3.6.3.5 Troubleshooting Guide

Table 3-4 lists the most common troubles that may occur to centrifugal-type compressors and includes the probable causes of the listed troubles and recommended remedies for the correction of the troubles. Data in this guide is of a general nature and is intended to provide a standard approach to identifying and analyzing the most common troubles. It is recommended that this guide be reviewed at the local level and expanded, if necessary, to include the results of local experiences.

NOTE

While performing troubleshooting procedures, observe all normal precautions for safeguarding personnel and equipment.

Table 3-4. Troubleshooting Guide for Centrifugal Type Compressors

COMPLAINT	CAUSE	POSSIBLE REMEDY
1 Compressor will not start.	a. Power failure.	a. Check for building power failure. Check and reset circuit breaker.
	b. Disconnect or control switch open.	b. Determine why switch was opened. If everything normal, close switch.
	c. Overload relays in starter tripped.	c. Check overload relays and reset.
	d. Vanes are open and/or vane closed switch is open.	d. Check position of vane motor and vane closed switch. Vane closed switch must be closed for starting.
	e. Oil pump not running.	e. Check for faulty oil pump starter, circuit breaker, fuses, or starting switch. Check for faulty wiring from the pump starter to the pump. Check for faulty pump motor.
	f. Low oil pressure or defective cutout switch.	f. Check to be sure that the low oil pressure cutout contacts are closed. Check low oil pressure cutout switch for improper setting.

COMPLAINT	CAUSE	POSSIBLE REMEDY
		Check oil level; add oil if required.
(continued)	g. Water pumps not running.	g. Check cooler and condenser water pump for operation. If a pilot relay is installed for automatic pump starting, check relay for possible sticking contacts.
	h. Refrigerant temperature below normal.	h. Check low refrigerant cutout switch for proper setting. Check refrigerant level. Determine cause of refrigerant loss. Add refrigerant. Check leaving chilled-water temperature to be sure it is not below normal. Check cooler float valve. Be sure it is not binding. Binding float would cause refrigerant to accumulate is condenser.
	i. High condenser pressure.	i. Check items listed under Item 7.
	j. Chilled-water temperature below normal.	j. Check the chilled-water temperature. If below normal, allow the temperature to rise and machine will restart automatically. Chilled-water pump should be running.
	k. Improper setting of chilled-water low temperature cutout and recycle switch.	k. Check setting. Reset if necessary.
2. Chilled-water temperature is too high (compressor is running).	a. Chilled-water thermostat set too high.	a. Check and reset position of thermostat.
	b. High temperature in conditioned area.	b. Machine loaded to capacity. Excessive infiltration of outside air may be the cause.
	c. Vanes not fully open.	c. Excessive load in conditioned area. Vane opening limited by the motor overload module. Check vane motor and vane linkage to be sure that linkage and shaft are not slipping.
	d. High condenser pressure.	d. Check Item 7 for causes of high condenser pressure.
	e. Gradual increase in temperature difference in refrigerant and chilled water.	e. Shut down the machine and check refrigerant loss. Add refrigerant as required. Check cooler for dirty or obstructed tubes and clean if necessary. Check the division plates and division plate gaskets in cooler water box for possible water bypass.

COMPLAINT	CAUSE	POSSIBLE REMEDY
(continued)	f. Shortage of refrigerant.	f. Determine cause of loss. Repair, as required. Add refrigerant.
3. Chilled water temperature is too low (compressor is running).	a. Chilled water thermostat set too low.	a. Reset thermostat.
	b. Vanes open too far.	b. Check to be sure "thermostatic-manual" switch is in the "thermostatic" position. Check calibration of chilled-water module.
	c. Low chilled-water temperature cutout and recycle switch not operating properly.	c. Check setting of recycle control. Reset if necessary. Control must shut down the machine when the water temperature is 5°F below design temperature.
4. Compressor short-cycles.	a. Chilled-water temperature control not functioning properly.	a. Repair or replace control.
	b. Air compressor not supplying proper air pressure to pneumatic control circuit.	b. Repair compressor and air lines, as required.
	c. Pneumatic-electric switch not functioning properly.	c. Check switch and determine cause of trouble. Repair or replace.
	d. Dirty oil filter malfunctioning regulating valve.	d. Clean filter or repair regulating valve.
5. Suction pressure is too high.	Excessive load on evaporator.	Look for excessive infiltration of warm air into conditioned space and correct.
6. Suction pressure is too low.	a. Lack of refrigerant.	a. Correct cause of refrigerant loss. Add refrigerant.
	b. Vane control switch on "manual."	b. Place switch on automatic.
	c. Water in chilled-water circuit being bypassed around evaporator or insufficient flow of water through evaporator.	c. Adjust chilled-water circuit valves.

COMPLAINT	CAUSE	POSSIBLE REMEDY
(continued)	d. Chilled-water temperature control set too low or not functioning properly.	d. Check action of temperature control. Repair or replace.
	e. Chilled-water thermostat not set correctly.	e. Reset thermostat.
7. Condenser pressure is too high.	a. Low condenser water flow, or high condensing water temperature.	a. Check condensing water pump for proper operation. Check to be sure all valves in condensing water circuit are open. Check cooling tower fan and fan control for proper operation. Check tower makeup water valve to be sure valve is not stuck closed. Check strainer in condenser water line. Check condensing water temperature in and out of condenser to determine if water box diffusion plate or gaskets are damaged. This could cause water bypass.
	b. Air in condenser.	b. Check for presence of air and purge if necessary. Check purge for proper valve and switch settings.
	c. Fouled condenser tubes.	c. Check for fouled condenser tubes and clean if necessary.
8. Condenser pressure is too low.	Excessive water flow or water temperature too low.	Check for excessive flow. Adjust flow to maintain minimum leaving condenser water temperature.
9. Compressor cuts out.	a. Low voltage.	a. Contact power Company. Regulate voltage.
	b. Starter overloads incorrectly set.	b. Correct setting of overloads.
	c. Load limit relay not properly set.	c. Correct setting of load limit relay.
	d. Lack of refrigerant.	d. Correct cause of refrigerant loss. Add refrigerant.
	e. Light load on evaporator.	e. Adjust chilled-water circuit valves.
	f. Chilled-water temperature control set too low or not functioning properly.	f. Check action of temperature control. Repair or replace.

COMPLAINT	CAUSE	POSSIBLE REMEDY
(continued)	g. Pilot positioner and vane operator not set correctly.	g. Reset pilot positioner and vane operator.
	h. Low temperature control not functioning properly.	h. Readjust, repair, or replace low temperature control.
	i. High-pressure control not functioning properly.	i. Readjust, repair, or replace high-pressure control.
	j. Insufficient oil charge.	j. Locate and correct cause of oil loss. Add oil.
10. Oil temperature in sump is too low.	a. Check action of temperature control. Adjust, repair, or replace.	a. Check action of temperature control. Adjust, repair, or replace.
	b. Clean water valve.	b. Clean water valve.
	c. Replace heater.	c. Replace heater.
	d. Check and reset or repair heater.	d. Check and reset or repair heater.
11. Oil temperature in sump is too high.	a. Oil temperature control not functioning correctly.	a. Check action of temperature control. Adjust, repair, or replace.
	b. Water valve not opening.	b. Replace coil. Clean water valve.
	c. Manual valve in water line closed.	c. Open valve.
	d. Cooling coil fouled.	d. Clean cooling coil.
12. Compressor surges.	High condensing pressure.	See Item 7.
13. Purge unit will not build up pressure.	a. Purge condenser float valve stuck in open position.	a. Remove purge condenser head and clean or repair float valve mechanism.
	b. Purge compressor valve worn.	b. Repair or replace valve plate assembly.
	c. Valves between condenser and purge compressor closed.	c. Open valves.
	d. Regulating valve to purge unit not opening.	d. Repair or replace valve.

COMPLAINT	CAUSE	POSSIBLE REMEDY
14. Purge unit relieves at too low a pressure.	Relief valve stuck or set too low.	Repair, clean, adjust, or replace relief valve.
15. Purge unit relieves liquid from condenser relief valve	a. Float valve stuck shut or float assembly rotated out of proper position in purge drum head.	a. Remove purge condenser head and clean or repair float valve mechanism.
	b. Manual valve on purge return line at evaporator closed.	b. Open valve.
16. Purge compressor loses oil.	a. Oil separator heater not functioning.	a. Replace burned-out heater. Check setting and action of purge temperature control. Readjust, repair, or replace.
	b. Oil separator float valve stuck shut.	b. Remove purge unit oil separator. Clean or repair float assembly.
17. Mixture in purge condenser is dark in color and sight glass is etched.	Oil separator heater set too high.	Reset purge temperature control. Replace oil in purge unit. Clean compressor, oil separator, and purge condenser. Check for damaged compressor.
18. Purge does not operate in "auto" position.	a. Normal.	a. Purge pump cycling may not be required if machine tightness does not warrant. Compare purge and condenser pressure gauges to determine if purge should be cycling. If purge should be cycling, check the condenser for evidence of air present.
	b. Blown fuse.	b. Check fuse. Replace if necessary.
	c. Loose connections or broken wires.	c. Check electrical connections at purge switch, solenoid switch, and coil; purge motor and fuse. Make sure connections are tight and wires or their insulation is not broken.
	d. Defective purge electrical switch.	d. Disconnect the leads from the purge switch and check it with a volt ohmmeter using the ohm scale with the leads across the switch lugs. Check the switch for continuity with the switch in the closed position. Replace switch if faulty. The solenoid switch can be checked in a similar manner.

COMPLAINT	CAUSE	POSSIBLE REMEDY
(continued)	e. Incorrect purge safety or operating switch setting.	e. Recalibrate the purge operating switch or the purge switch settings.
19. Purge cycles are often in "auto" position.	a. Purge valves not tightly closed.	a. Check to be sure that the purge valves are set in accordance with the purge valve chart. Be sure that the valves that should be closed are closed tightly.
	b. Solenoid valve or check valve leaking.	b. The direct acting solenoid valve and check valve prevent leakage from atmosphere to the condensing chamber. If found leaking, replace the valves. The replacement valves must be designed for refrigerant duty.
	c. Incorrect operating switch setting.	c. Recalibrate the purge operating switch to the proper setting.
	d. Excessive air leakage into machine.	d. Check machine for leak tightness with halide leak detector.
	e. Float valve stuck in close position.	e. Check float chamber to be sure that a refrigerant level can be seen. If level is above the sight glass, valve is stuck in closed position. Remove the valve and determine cause of sticking.
20. There is excessive refrigerant loss.	a. Purge pump cycles often in "auto" position	a. See Item 19 for causes.
	b. Float valve stuck in closed position or refrigerant return line plugged.	b. Check float valve chambers for refrigerant level. If level is above the sight glass, valve is stuck in closed position. Check refrigerant return line for obstructions. Correct as required.

3.6.4 General

3.6.4.1 Heat Transfer

The transfer of heat is normally from a higher to a lower temperature object. Heat can be transferred through conduction, convection, or radiation. The condenser transfers high-temperature, high-pressure refrigerant gas discharged from the compressor to the cooling medium flowing through the condenser. The gas entering the condenser contains both sensible and latent heat, which is gradually transferred to the cooling medium, either air or water or, in some cases, both.

Condensers are heat exchangers capable of condensing substances from their gaseous state to their liquid state.

3.6.4.2 Refrigeration Condenser

Condensers for refrigeration are made in a variety of designs, although the trend is towards vertical or horizontal shell and tube types.

Condensers, whether water-cooled or air-cooled, removed heat from the refrigerant to change the superheated gas leaving the compressor into saturated or sub-cooled liquid.

3.6.4.3 Cooling

Hot refrigerant gas from the compressor enters the condenser. As the gas comes into contact with the cooler surfaces of the condenser, it begins to give up heat and is gradually cooled to the saturation temperature corresponding to its pressure. The heat removed is sensible heat. Heat removal continues until all the gas condenses to a liquid. However, heat removed at constant temperature is latent heat. Since all the refrigerant is now a liquid, further cooling will sub cool it below the condensing temperature. In normally operated condensers, there would be some degree of sub-cooling.

3.6.4.4 Sensible/Latent Heat

Sensible heat is the heat required to change the temperature of a substance, but not its state. Latent heat is the heat required for a material to undergo a change in phase or state. Two latent heats are typically described: fusion and vaporization. Most of the heat removed in a condenser is latent heat. A basic concept of condenser theory is that the heat given up by the refrigerant must equal the heat gained by the cooling medium.

3.6.5 Air-cooled Condensers

3.6.5.1 Types

Air cooled condensers removed heat by air flow over the condenser coil. There are two types of air-cooled condensers; natural-draft and forced-air.

3.6.5.1.1 Natural Draft Condensers

The natural-draft, air-cooled condenser is normally found in one of two types of construction: The tube and fin, or the plate-type, in which the plates are pressed into the outline of the condenser coil and welded together. This leaves interior space for tubes through which the hot refrigerant gas passes. Because the air moves very slowly across the surface of the natural-draft condenser, relatively large surfaces are required for heat transfer, resulting in very limited usage.

3.6.5.1.2 Forced-Air Condensers

Forced-air condensers are acceptable for use in clean, nonhazardous environments, with acceptable ambient temperatures. Usually, they are of finned tube construction and use a variable speed motor to operate the fan. The fan forces air across the condenser finned tubes for the purpose of heat removal. Depending on the size of the condenser, noise level and potential fan vibration could be significant. The increased airflow makes this type condenser more practical for larger installations. Figure 3-11 shows a typical forced-air condenser. In addition, vertical airflow is recommended to avoid airflow interference by walls and other obstructions and to avoid wind resistance problems.

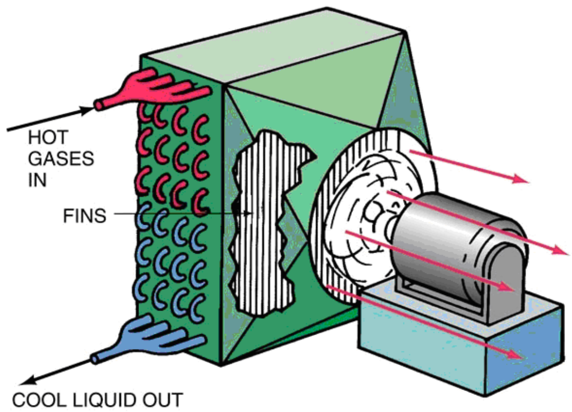

Figure 3-11. Forced-Air Condenser

3.6.5.2 Maintenance

Air-cooled condensers rely on the air circulating through the condenser to affect the proper heat transfer. For this reason, the principal maintenance function is to keep airflow through the condenser unobstructed and to maintain sufficient distance between the discharge side of the condenser, the walls, and other objects, so that the airflow is not restricted.

3.6.6 Water-cooled Condensers

3.6.6.1 Types

Water-cooled condensers use water as the condensing medium. The two basic types used in post office installations are the shell and tube, and the shell and coil.

3.6.6.2 Shell and Tube

3.6.6.2.1 Design

Shell and tube condensers consist of a tube bundle with tubesheets installed inside a steel shell. The water flows inside the tubes while the refrigerant vapor flows outside, around the tube bundle. The vapor condenses on the outside surface of the tubes and drips to the bottom of the condenser shell used as a receiver for the storage of liquid refrigerant. Shell and tube condensers are used for practically all water-cooled refrigeration systems.

3.6.6.2.2 Heat Transfer

In order to obtain a high rate of heat transfer through the surface of a condenser, water must pass through the tubes at a fairly high velocity. For this reason, the tubes in shell and tube condensers are separated by dividers in the bonnets that mate to the tubesheet. The bonnet dividers force the cooling (water) medium through only a fraction of the tube, causing the water to flow one, two, or four times the length of the heat exchanger before it leaves the outlet. When the cooling medium flows four times the length of the heat exchanger, the condenser is known as a four-pass condenser. The fewer number of passes in a condenser, the greater the number of tubes in each pass.

3.6.6.2.3 Operation

Figure 3-12 shows a typical water-cooled condenser. Hot gas from the compressor is admitted and flows over the tubes to the outlet. Cold water from the cooling tower is circulated through the tubes and, being cooler, absorbs heat from the hot gas. The heat surrendered by the gas raises the temperature of the water. The gas, upon surrendering a sufficient amount of heat, condenses on the cold surfaces of the tubes.

3.6.6.3 Shell and Coil

A shell and coil condenser is simply a continuous copper coil mounted inside a steel shell. Water flows through the coil, and refrigerant vapor from the compressor is discharged inside the shell to condense on the outside of the cold tubes. In many designs, the shell also serves as a liquid receiver. The shell and coil condenser has a low manufacturing cost, but this is offset by its maintenance cost. If a leak develops in the coil, the head must be removed from the shell and the entire coil removed in order to find and repair the leak. A continuous coil is a nuisance to clean, whereas straight tubes are easy to clean with mechanical tube cleaners. The shell and coil condenser is seldom found in postal installations.

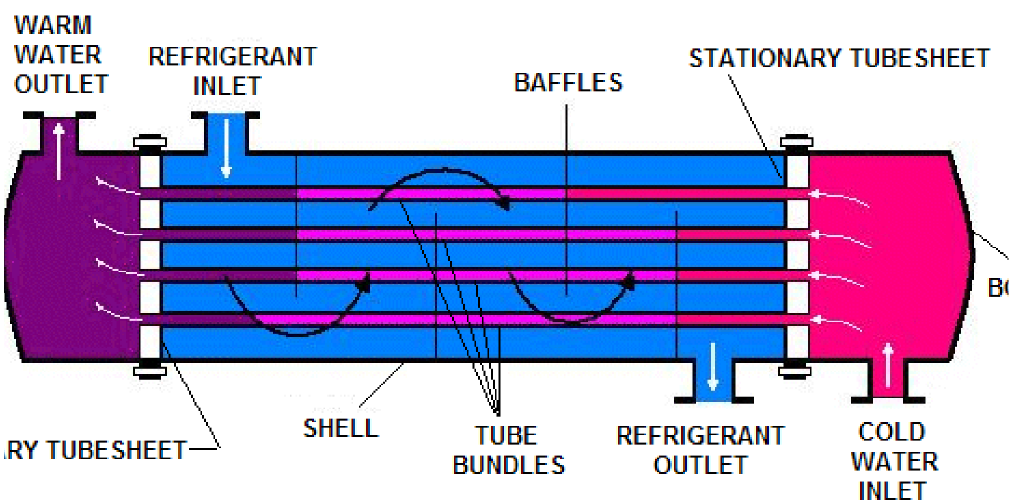

Figure 3-12. Operation of Water-Cooled Condenser

3.6.7 Evaporative Condensers

3.6.7.1 Operation

Evaporative condensers use water to spray the outside of the condenser tubes. Air pulled over the tubes causes a small amount of water to evaporate cooling the refrigerant and causing it to condense. The cooling water flows downward in an open flow over the outside of a vertical coil of pipe containing the refrigerant. Some of the water is evaporated and is carried off by the air stream flowing from bottom to top and is discharged outdoors through duct work. Evaporative condensers are sometimes confused with cooling towers since they use a fan and water operating within a housing similar to a cooling tower. There are two main types of evaporative condensers: forced-draft and induced-draft. Figure 3-13 shows two typical evaporative condensers.

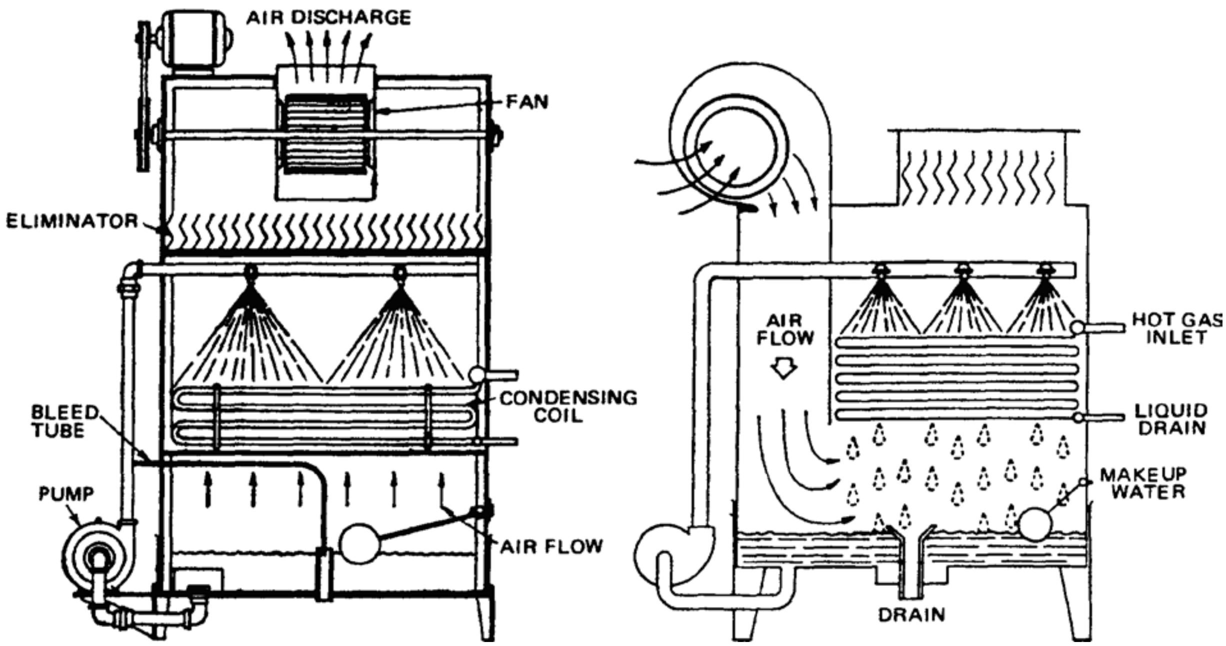

Figure 3-13. Evaporative Condenser

3.6.7.2 Location

An evaporative condenser may be located outdoors or in an indoor equipment room. The outdoor location is recommended only when operation is limited to temperatures above freezing, as it is impractical to run an evaporative condenser without spray water.

3.6.8 Condenser

A condenser involves the transformation of vapor to liquid. The capacity of a water-cooled condenser is affected by the temperature of the water, the quantity of water circulated, and the temperature of the refrigerant gas. The amount of condenser water required for any specific condensing unit must be determined from the manufacturer's data. While well-designed condensers of different makes will probably have approximately the same capacity for a given water rate, this is not true for all makes. Since comfortable air-conditioning requires 240 Btu/min per ton heat transfer to the condenser water with a temperature rise of 10ºF, a good rule of thumb is 3 gallons per minute of condenser water will be required for each ton of refrigeration.

3.6.9 Condenser Fouling

The main function of a water-cooled condenser is to transfer heat from the hot refrigerant gas to the cool condenser water. This heat transfer must take place through the walls of the condenser tubes. Due to the high temperatures present in condensers, impurities in the condenser water will gradually buildup on the water side of the condenser tubes, decreasing the overall heat transfer rate. Water with a high degree of hardness or impurities forms scale on the inside of the tubes if not properly treated, or if cycles of concentration are not properly controlled by bleed off.

3.6.10 Condenser Cleaning

Condensers that become fouled, by either sludge or scale, require cleaning to restore proper heat transfer. There are several standard cleaning methods:

- The acid cleaning method is used primarily to remove scale deposits rather than slime or sludge (Paragraph 4.6.3 for a detailed discussion of acid cleaning.)
- The mechanical method is recommended for removing slime and sludge that has settled in the tubing. Both ends (heads) of the condenser must be removed to gain access to the tubes. A nylon brush, sized to the ID of the tubes being cleaned and attached to a long rod, makes an effective tool to free foreign matter in the tubes. After the tubes have been brushed clean, flush by running cool water through them. Replace gaskets and cross-tighten nuts on bolts, when reassembling the condenser end plates.
- Hydro blasting, which uses high-pressure water, is another method of cleaning condenser tubes. Hydro blasting should be done by professionals, since it could be extremely dangerous.

3.7 EVAPORATORS AND CHILLERS

3.7.1 General Operation

Liquid refrigerant is released through an expansion device into a reduced pressure area called the evaporator. The evaporator is the part of the refrigeration system in which the refrigerant absorbs the unwanted heat. In theory, the heat picked up by the refrigerant must equal the heat given up by the medium being cooled. If the area to be cooled is located some distance from the evaporator, the evaporator cools water that is piped to the area and circulated through cooling coils. In this use, the evaporator is also known as a chiller.

3.7.2 Types

3.7.2.1 General

There are two basic types of evaporators: The dry or direct-expansion type, and the flooded-coil type.

3.7.2.2 Direct Expansion

The direct-expansion evaporator usually uses refrigeration applications to cool and sometimes dehumidify air. The air to be cooled flows over a bank of tubes and gives up its heat to the liquid refrigerant inside the tubes. The liquid refrigerant evaporates and exits the evaporator as a gas. The refrigerant is metered to the evaporator tubes through an expansion valve.

3.7.2.3 Flooded Coil

In the flooded evaporator, the cooling tubes carry the water to be chilled and are almost entirely covered with liquid refrigerant. The liquid is cooler than the water. Therefore, heat flows from the water in the tubes to the refrigerant in the evaporator shell, evaporating the liquid refrigerant. Liquid carry-over to the compressor is prevented by an equalizer plate. The refrigerant level in the evaporator is controlled by metering devices discussed in Paragraph 3.7.4.

3.7.3 Temperature

The temperature of the water leaving the chiller can be controlled by adjusting the flow rate of water within a given range depending on the size of the chiller.

3.7.4 Metering Devices

3.7.4.1 General

Metering devices regulate the amount of liquid refrigerant passing into the evaporator. They deliver the proper amount of liquid refrigerant which, after vaporization, is removed by the compressor, regardless of the load. These devices are of five different types:

- Automatic expansion valve (also known as a constant-pressure expansion valve) (Paragraph 3.7.4.2).
- Thermostatic expansion valve (Paragraph 3.7.4.3).
- Low-side float valves (Paragraph 3.7.4.4.1).
- High-side float valves (Paragraph 3.7.4.4.2).
- Capillary tube/fixed restrictor (Paragraph 3.7.4.5).

3.7.4.2 Automatic Expansion Valve

The automatic expansion valve, also known as the constant-pressure expansion valve, maintains a constant pressure in the evaporator regardless of the cooling load. However, under a large variable load, the valve will not feed enough refrigerant to the evaporator and will over feed the evaporator at low loads

3.7.4.3 Thermostatic-Expansion Valve

3.7.4.3.1 Operation

The thermostatic-expansion valve (TXV) keeps a constant superheat in the refrigerant vapor leaving the coils/tubes; it controls the liquid refrigerant level. The TXV has a power element that is activated by a remote bulb located at the end of the coils/tubes. The bulb senses the superheat at the suction line and adjusts the flow of refrigerant into the evaporator. As the superheat increases (suction line), the temperature, and therefore the pressure, in the remote bulb also increases. This increased pressure, applied to the top of the diaphragm, forces open the valve, admitting replacement refrigerant from the receiver to flow into the evaporator. This replacement has three effects. First, it provides additional liquid refrigerant to absorb heat from the evaporator. Second, it applies higher pressure to the bottom of the diaphragm, tending to close the valve. And third, it reduces the degree of superheat by forcing more refrigerant through the suction line.

3.7.4.4 Float Valve

The float valve is generally used with flooded-coil or flooded-shell/and/tube evaporators. The float ball may be located directly in the evaporator, in a chamber next to the evaporator, on the low-or-high-pressure side of the evaporator.

3.7.4.4.1 Low-Side Float Expansion Valve

The low-side float expansion valve controls the liquid refrigerant flow where a flooded evaporator is used. It consists of a ball float in either a chamber or the evaporator on the low-pressure side of the system. The float actuates a needle valve through a lever mechanism. As the float lowers, refrigerant enters through the open valve; when it rises, the valve closes.

3.7.4.4.2 High-Side Float Expansion Valve

In a high-side float expansion valve, the valve float is in a liquid receiver or in an auxiliary container on the high-pressure side of the system. Refrigerant from the condenser flows into the valve and immediately opens it, allowing refrigerant to expand and pass into the evaporator. Refrigerant charge is critical; an overcharge of the system floods back and damages the compressor. An undercharge results in a capacity drop.

3.7.4.5 Capillary Tube/Fixed Restrictor

The capillary tube/orifice acts as a constant throttle on the refrigerant. Capillary tube consists of a long tube of small diameter. The length and diameter of the tube are important; any restrictions cause trouble in the system. Capillary tubes/restrictors feed refrigerant to the evaporator based on the pressure differential across the restrictor. When the quantity of refrigerant in the system is correct or the charge is balanced, the flow of refrigerant from the condenser to the evaporator stops when the compressor unit stops. The capillary tube/fixed restrictor is best suited for household boxes, such as freezers and window air-conditioners, where the refrigeration load is reasonably constant and small horsepower motors are used.

3.8 COOLING TOWERS

3.8.1 General

A cooling tower is a specialized heat exchanger in which two elements, air and water, are brought in direct contact to transfer heat. Pumps transfer cool water from the cooling tower sump basin to condensing equipment. Warm water from these systems returns to the cooling distribution basins, flowing through the spray distribution nozzles onto the transfer media (fill) inside the cooling tower (Figure 3-14).

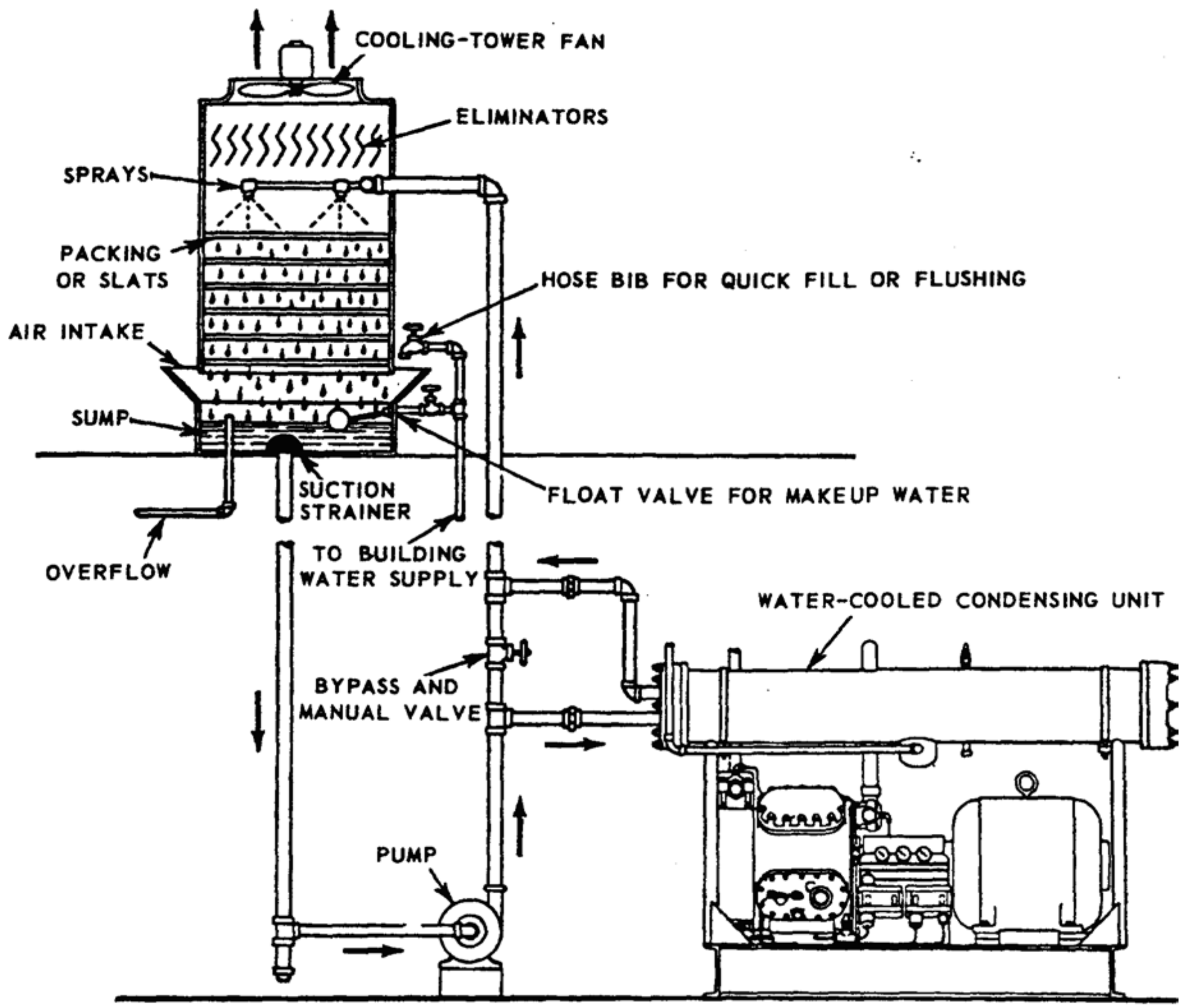

Figure 3-14. Typical Cooling-Tower System

The cooling tower conserves water and lowers the temperature of the water being circulated. Where the cost of water is not prohibitive, condensing-water systems are sometimes designed as a "once-through" system in which the cooling tower is eliminated and the condensing water is wasted directly to a sewer connection. Normally, cooling towers are provided to avoid waste. There are two basic types of cooling towers, direct or open and indirect or closed. An "open system" exposes cooling water to the atmosphere. A "closed system" circulates water through tubes in the tower.

3.8.2 Description

Cooling towers use evaporation to release waste heat from returning warm water. The distribution basin at the top of the cooling tower spread the returning warm water across the fill. However, a portion of the returning warm water, which cools the bulk water, evaporates. Fans, powered by electric motors, at the top of the cooling tower generate large volume of air flowing through the fill, which increases the rate of evaporation and the cooling tower capacity. Atmospheric cooling towers, however, do not use fans to create air flow through the tower; they use natural induction. Mechanical-draft cooling towers use fan power to move air rather than natural draft or wind velocity. Mechanical-draft towers are classified as forced-or induced-draft. Hybrid draft towers are also equipped with draft fans to augment air flow.

Cooling towers are also characterized by air flow. In counter-flow towers air moves vertically through the fill, counter to the downward water flow. In cross-flow towers, the air flows horizontally, across the downward water fall. Spray-filled towers have no heat transfer fill surface; they depend on the water break up to produce maximum water-to-air contact.

3.8.3 Operation

3.8.3.1 General

3.8.3.1.1 Design

The cooling-tower shell is vertical and made of treated wood, metal, polyvinyl chloride (PVC), fiberglass reinforced plastic (FRP), or other suitable materials. Flumes or spray nozzles distribute water near the top of the shell. As the water splashes down over the fill, it breaks into small drops, flooding a maximum amount of surface area. This falling water passes through a flow of air circulated through the tower by forced-or induced-draft fans, and drops into a collecting basin at the bottom.

3.8.3.1.2 Controls

Special baffles called drift eliminators may be placed above the inlet-water distribution on updraft systems to prevent excessive loss of entrained moisture and the operating nuisance that it creates. The cooling tower loses water through evaporation, bleed off, and drift. Additionally, evaporative cooling causes build-up of salt concentrations in the cooling water. Some cooling towers require the ability to start and stop the fan and to operate it a varying speeds. Thus, cooling towers require a good water treatment program, sensors to ensure that the fan is rotating in the proper direction and not causing unnecessary vibration, sump water temperature control, and sump level control.

3.8.3.1.3 Capacity

Cooling tower capacity is a function of a given flow rate of water from one temperature to another under a specific wet bulb condition. Cooling capacity is improved by increasing the amount of fill, or the height of the tower. These improvements increase the contact time of water and air without additional fan power.

3.8.3.2 Forced-Draft Tower

Forced-draft cooling towers are designed for high velocity air entry and low velocity air exit, making them susceptible to recirculation, and icing in cold environments. Recirculation is the process of inducing saturated air back in the tower. The fan on a forced-draft cooling tower is located in the air intake and air is forced through the tower (Figure 3-15).

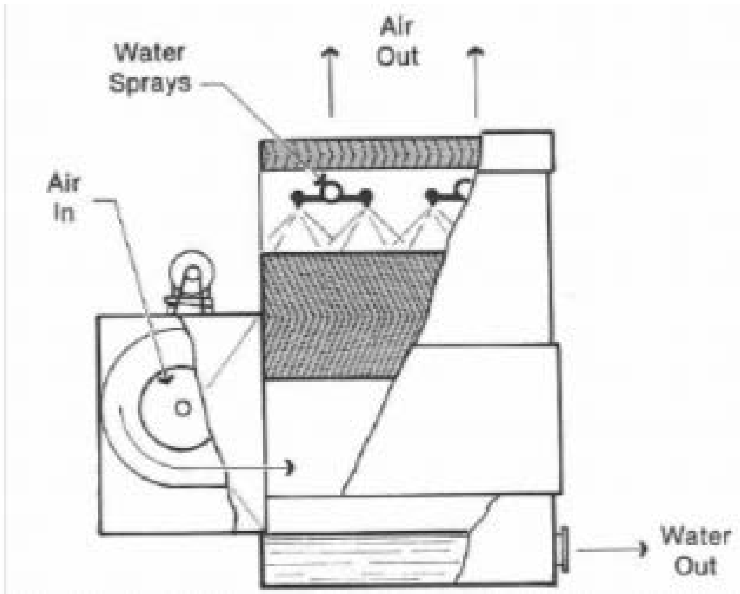

Figure 3-15. Forced-Draft Tower

3.8.3.3 Induced Draft Tower

3.8.3.3.1 Design

There are two types of design for induced draft towers; counter-flow and cross-flow. Counter-flow units have a fan on top that draws air up against the water falling through the filling (Figure 3-16 and Figure 3-17). The main advantages are that the coldest water contacts the driest air and the warmest water contacts the most humid air. Recirculation is seldom a problem since the outlet fan discharges hot air upward, directly away from the air-intake louver below. Larger fans, up to 60 feet in diameter, can be used with this design.

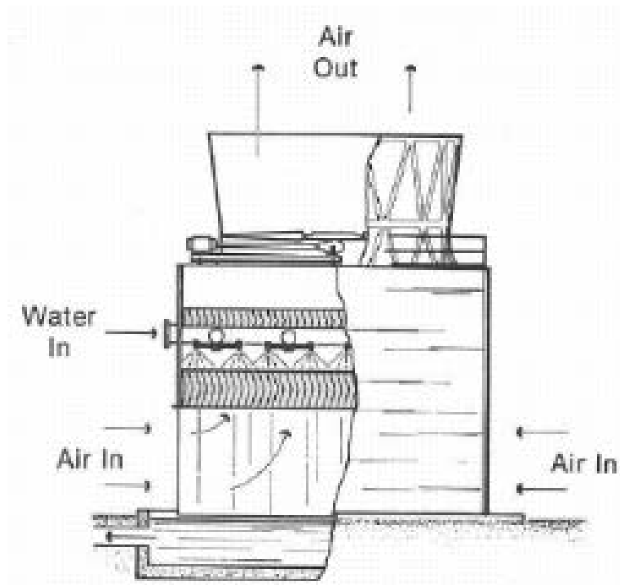

Figure 3-16. Induced-Draft Cross-Flow Tower

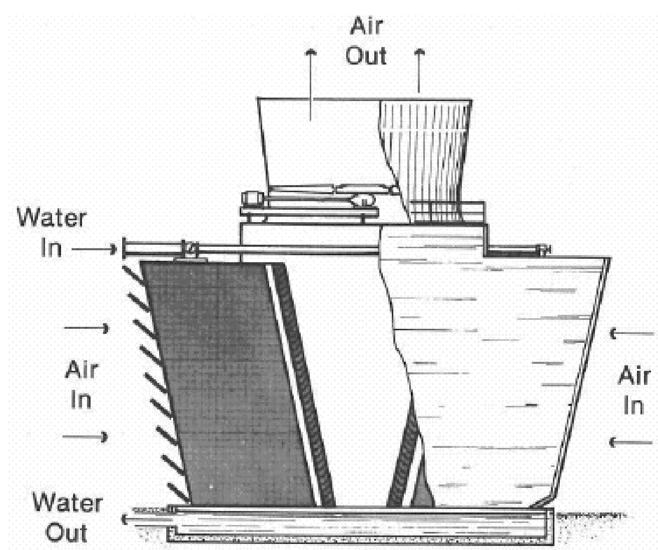

Figure 3-17. Induced-Draft Double-Flow and Cross-Flow Tower

3.8.3.3.2 Airflow

Cooling tower performance is also related to air flow. In counter-flow towers, the resistance of falling water and upward air creates higher static pressure loss and higher fan horsepower requirements than in cross-flow towers. Cross-flow towers have a fill configuration through which air flows horizontally across the downward flow of water. Counter-flow design handles the same cooling load as cross-flow design, with less air column.

3.8.3.3.3 Air Velocities

Air velocities through the fill are usually unevenly distributed, with very little movement near the walls and center of the tower. This problem is readily eliminated by the fill design and proper orientation of counter-flow tower internal structure.

3.8.3.4 Cross-flow Induced Draft Tower

Cross-flow induced-draft towers provide horizontal airflow as water falls across the filling. The fan is centered at the top of the unit and draws air through two cells paired to a suction chamber partitioned midway beneath the fan. Drift eliminators are fitted to turn the air upward toward the outlet fan. Water falls from the distribution pan in a cascade of small drops over the fill and across the horizontal flow of air. Since there is less resistance to airflow, draft loss is lower. Offsetting this gain is the fact that more air is required compared to counter-flow draft designs.

3.8.3.5 Factors Influencing Operation of Cooling Towers

3.8.3.5.1 Evaporation

When the condensing water passes over the cooling tower, a portion is lost to evaporation. The loss amounts to about one percent of the water quantity circulated per 10ºF drop in water temperature through the tower. The evaporation produces the cooling effect needed to lower the temperature of the water being circulated back to the condenser. As evaporation takes place, the dissolved solids in the evaporated water are left behind, resulting in an increase in the amount of solids in the circulated water. Depending on conditions, the solids in the condensing water may become concentrated to a point where they are precipitated out of the water solution as sludge or scale. Due to the physical or chemical characteristics of the solids, the precipitation is usually greatest in the hottest part of the system, the condenser area. (For instance, the ability of calcium carbonate to remain in solution decreases as the temperature increases.)

3.8.3.5.2 Air Exposure

Most cooling towers used at postal facilities are mechanical-draft type, where a fan forces air through the tower and over its wetted portions. Along with the desired effect of lowering water temperature, the tower has an unfavorable side effect of washing out smoke, dust, dirt, bacteria, gases, and other materials introduced into the tower. The dust and dirt show up as mud or silt in the cooling-tower sump. The bacteria and other organisms promote the growth of slime and algae. Acid gases (such as sulfur dioxide from a nearby chimney) may change neutral water to a very corrosive one. Mud, silt, etc., may be washed into the circulating-water system and accumulate on the condenser as sludge.

3.8.3.5.3 Bleed Off

The concentration of solids may be held in check by bleeding off some of the concentrated circulating water and replacing it with more diluted makeup water. Therefore, it is standard practice to provide a bleed line at the tower that wastes a portion of the water from the system to avoid excessive buildup of dissolved solids. Considering the purpose and importance of bleed off, every tower must be equipped with a bleed line and an adequate rate of bleed must be established. The required amount of bleed is determined by evaluating the chemical characteristics of the water, the type of water treatment, if any, to be employed and other factors. (This is fully covered in SECTION 4.) The bleed line at the tower should be tapped into the circulating system just ahead of the inlet discharge, so that when the circulating pump is in operation water is bled to waste only. The bleed-line discharge should adhere to the Federal Water Pollution Control Act, known as the Clean Water Act (CWA), which requires a National Pollutant Discharge Elimination System permit for cooling tower discharges. Therefore, cooling tower blow down waste is a permitted discharge. For permit information, contact the environmental specialist.

3.8.3.5.4 Water Losses and Makeup

When a cooling tower is operating, the float valve in the basin or sump of the tower admits water to the system to make up for the water lost as a result of evaporation, windage, splash, and deliberate bleed. Neglecting splash and leakage, the amount of makeup represents the sum of evaporation, windage, and bleed. Evaporation represents a loss of approximately one percent of the circulating water. In a mechanical-draft tower, windage represents a 0.1 to 0.3 percent loss. Evaporation and windage are characteristics of system design. Bleed is adjusted as required.

3.8.3.5.5 Cycles of Concentration

Cycle of concentration is a measure of the degree to which dissolved solids are being concentrated in the circulating water. It is a comparison of dissolved solids in the circulating water with those in the makeup or raw water. If, as a result of evaporation, the solids in the tower water become twice as great as those in the makeup, there are two cycles of concentration. Three times as many solids would result in three cycles of concentration, four times would be four cycles, and so on. The maximum allowable cycles of concentration are predetermined by laboratory analysis of the makeup water and other factors. They are based on water analysis, heat transfer rate of the equipment, and feed equipment present. Normally, chlorine is used to determine a tower's cycles of concentration. The equation below is used to calculate cycles of concentration.

$$\mathbf{C = (E + D + B) / (D + B)}$$ where

C = Cycles of concentration

E = Evaporation, ~ GPM x 0F range x 0.0008

D = Drift loss, ~ GPM x 0.0002

B = Blow-down, GPM

During temporary water shortages, treatment can be increased beyond the normal cycles to allow operation with increased cycles of concentration and reduced bleed off. Only under extreme conditions should the bleed off be reduced below the safe level to prevent scale formation with maximum chemical treatment. When this is necessary, the following actions must be taken:

1. Reduce air-conditioning load as much as possible.
2. If possible, operate only one chiller (where two or more are available) to prevent scaling the tubes in both units during severe temporary conditions.
3. Carefully maintain and monitor the chiller operating log to determine the severity of scale formation.
4. After the temporary shortage is over, clean the condenser to remove scale. This usually requires mechanical removal of deposits; however, depending on the severity and type of scale, it may be done by chemical treatment.

NOTE

See Paragraph 4.1.6, Paragraph 4.5.6, and Table 4-2 for further information on controlling cycles of concentration.

3.8.4 Capacities

Knowing how much water is used in the system, and the actual heat the water picks up for each ton of refrigeration actually produced, is necessary to calculate the capacity of a cooling tower. The heat load of a cooling tower is equal to 500 times gpm times the difference between inlet and outlet temperatures divided by 1 cooling tower ton {h = (500 x gpm x ΔT)/15,000 Btu/h}. Equipment should be "right sized" rather than oversized; this means avoiding equipment that have more capacity than currently needed.

3.8.5 Problems of Cooling Towers

3.8.5.1 Spillover

When the tower is operating, the makeup water float should be positioned so that there is no spillover into the overflow of the basin. This requires periodic checks to prevent wasting both water and the chemicals used in treating it.

3.8.5.2 Water Change

The water in the circulating system is affected by the natural impurities in the makeup water, the concentration of solids resulting from evaporation, and the presence of airborne particles washed out of the air as the water passes over the tower. To combat the change in water, chemicals are required. This is covered in detail in SECTION 4.

3.8.5.3 Wood Decay

The wood in the cooling tower becomes decayed or destroyed as a result of chemical or biological attack or by rupture of the wood cells from salt crystallization. Chemical attack results in delignification of the wood leaving long, stringy fibers of greatly reduced strength. Excessive use of chlorine seems to speed up the process. Biological attack includes fungi, destroying the wood on the surface and from within. The fungi are reproduced from spores washed out of the air by the tower water. Rupture of the wood fibers of the tower by the crystallization of salts is caused by the intermittent splashing and drying of the wooden parts, producing concentrated salt deposits through evaporation.

3.8.5.4 Slime, Algae, and Fouling

3.8.5.4.1 General

One of the worst problems with algae and slime is the fouling of the tower and associated equipment. Cooling efficiency of the tower is determined by the water-to-air contact surface, and the length of time water and air are in contact. When a tower is clean, the water will film out on the tower fill to make use of the total contact area. The air passages are clear and the maximum amount of air passes over or through the fill area. This results in maximum contact area and contact time between the water and air.

3.8.5.4.2 Algae and Slime

If a tower has a heavy growth of algae or slime, the tower fill is soon covered by this growth. Other material is filtered out of the air by this sticky covering and a buildup of material is formed. This restricts the airflow through the fill area and reduces the filming action of the water. Tower efficiency goes down and the water temperature goes up. Algae grow on the exposed outside area of the fill and can completely block air from passing through the fill area. In order for a cooling tower to carry its share of the load, it must be clean and have an even flow of water and air throughout the fill area. If distribution basins are clogged with algae or other material, part of the tower fill does not receive its flow of water. This dry area offers less resistance to the airflow passing through the tower, so more air is pulled through the dry area, resulting in reduced airflow in the other areas.

3.8.5.4.3 Other Material

Tower fouling is also caused by other material in the system and deposits of calcium carbonate, mud, or other airborne material usually found in the tower pan (distribution basing) or sump. The cooling tower acts as a settling basin for undissolved solids traveling with the water. This is due to the relative quiet area of the tower with less velocity or movement of the water. This buildup of loose material settles in the distribution pans or on the wood slats of the packing and diverts or restricts water and air much like algae. The worst problem experienced in evaporative condensers is fouling by slime, scale, or other material. Because green alga is not a problem with indoor systems, and since the water is pumped from the basin back to the tip, there is no water problem, other than in the condenser itself.

3.8.5.5 Corrosion

3.8.5.5.1 Cause

Corrosion is mainly caused by dissolved gases, aggressive water (low pH), bacterial attack, and dissimilar metals, as well as acidic conditions due to chemical treatment. A cooling tower or evaporative condenser increases the possibility of corrosion by increasing exposure to air.

3.8.5.5.2 Gases

Dissolved gases that cause corrosion are usually oxygen, carbon dioxide, and sulfur dioxide. Sulfur dioxide usually results from burning coal or other fuels that contain sulfur or industrial plant fumes. Oxygen and carbon dioxide are common gases and are part of the atmosphere. The water in the tower system washes these gases from the air as the air passes through the tower packing, and circulating water carries large amounts of dissolved gases into the piping system. The amount of carbon dioxide and sulfur dioxide present in the water depends on the amount present in the air that goes through the tower. If the tower is picking up air close to a boiler stack or other source, the concentration of these gases may be quite high. Carbon dioxide gas forms carbonic acid; sulfur dioxide gas forms sulfuric acid, which reduces the alkalinity of the water. If enough of the gases are absorbed into the system, the water becomes acidic, which attacks and dissolves the metal in the system.

3.8.6 Water Quality

Proper ongoing cooling tower water treatment is important to the cooling process and associated equipment. To prevent scale build up, the most important choice is the operating water chemistry of the cooling loop as determined by the inlet and outlet water volumes from the system.

Practical tools for automating water removal are instruments for measuring circulating water conductivity and solids in the water. These signal a solenoid valve to bleed the water system when necessary. Bleeding waste from cooling tower basins, however, requires a National Pollutant Discharge Elimination System permit.

Once the type of solids and concentrations are known, an inhibitor can be selected to mitigate deposition of scales on critical equipment. Limit the air-wash effect (nutrient and bacteria) by filtering (centrifugal separator or sand filter) suspended solids and the bacteria that reside in them. Finally, consistent use and effective biocide addition will help to mitigate biological fouling.

3.8.7 Troubleshooting Guide

Table 3-5 lists the most common troubles that may occur in many cooling towers. It includes the probable causes of the listed troubles and recommended remedies for their correction. Data in this guide is of a general nature and is intended to provide a standard approach to identifying and analyzing the most common troubles. It is recommended that this guide be reviewed at the local level and expanded, if necessary, to include the results of local experiences.

NOTE

While performing trouble-shooting procedures, observe all normal precautions for safeguarding personnel and equipment.

Table 3-5. Troubleshooting Guide for Cooling Towers

Problem	Possible Causes	Corrective Actions
Increase in the leaving water temperature.	1. Excess water flow; over pumping.	1. Adjust to the design flow.
	2. Recirculation of hot discharge air, back into the cooling tower air intakes. Obstructed air intakes.	2. Eliminate obstructions that impede air discharge. Baffle air discharge, if necessary.
	3. Proximity of other heat source or discharge of moist air.	3. Remove source or relocate tower.
	4. Improper operation of spray system.	4. See water distribution system instructions.
	a. Orifices clogged.	A. Flush spray nozzles, clean orifices, clean system, install outlet strainer.
	b. Actual water flow is lower than design sprinkler rating.	B. Install properly rated spray nozzles or increase to design flow.
	5. Clogged fill.	5. Clean the fill.
	6. Damaged fill.	6. Replace the fill.
	7. Additional heat load on system.	7. Contact manufacturer for possible upgrade or addition of another cooling tower selected for additional load.
	8. Wet-bulb temperature higher than design.	8. None required if condition is temporary.
Drop in the water flow rate.	1. Blockage of spray nozzle orifices.	1. Flush spray nozzle. Clean whole system. Install outlet strainer.

Problem	Possible Causes	Corrective Actions
Low water flow rate.	2. Low water level in sump causing air to be drawn into pump and piping.	2. Adjust float valves. Be sure the system is flooded and balanced.
	3. Improper selection of water circulating pump.	3. Replace with proper size pump designed for flow and head requirements. Check pump “Net positive suction head.”
	4. Blockage of strainers.	4. Backwash or clean.
	5. Pump malfunction.	5. Consult pump specialist.
Noise and vibration.	1. Loose bolts.	1. Recheck and tighten all bolts to specified torque.
	2. Mechanical interference of rotating parts.	2. Inspect propeller for free rotation. Check propeller for mechanical interference. Adjust, repair, or replace, as necessary.
	3. Fan propeller damaged or out of balance.	3. Replace components, as necessary and check balance. Install vibration cut-out switch.
	4. Air intake at pump.	4. Check basin water level and irregular piping design.
	5. Pump cavitation.	5. Match pump net positive suction head (NPSH) with system hydraulics.
	6. Damaged motor bearings.	6. Check and replace motor.
Unusual motor noise.	1. Motor running single phase.	1. Stop motor and attempt to start it. Motor will not start if single phased. Check wiring, controls, and motor.
	2. Electrical unbalance.	2. Check voltages and currents of all three lines. Correct if required.
	3. Ball bearings.	3. Check lubrication. Replace bad bearings.
Sudden or short term irregularities of cold water level in basin.	1. Peculiarities of specific system and its operation.	1. Inspect system and review operation procedures. Correct, as applicable valve settings, loss of water in system, fill system to flooded capacity.

Problem	Possible Causes	Corrective Actions
Excessively high water level in sump on gravity drain installation.	1. Gravity flow restrictions due to insufficient head differential.	1. A. Outlet piping should terminate below sump tank water level.
		B. Increase discharge pipe size.
		C. Increase head by mean other than A.
	2. Air lock.	2. Install an air bleed valve at highest point of piping, usually at a vertical angle.
	3. Unnecessary obstruction of water flow (i.e., partially closed valve).	3. Remove obstruction.
	4. Undersized piping.	4. Increase pipe size.
	5. Horizontal pipe run too long.	5. Shorten, if possible.
	6. Improper hydraulic pipe design.	6. Correct design.
	7. Outlet vortex breaker provided.	7. Remove vortex breaker.
Excessively high water level in tower basin on closed loop system installations.	1. Make-up valve float set too high.	1. Readjust float arm.
	2. Valve or float damaged or malfunctioning.	2. Repair or replace.
	3. Make-up water pressure too high.	3. Reduce pressure.
Uneven water level in tower basins of multicell installations.	1. Unbalanced system hydraulics.	A. Install equalizer line with isolation valves between modules.
		B. Adjust inlet water flow to insure equal distribution to each cooling tower module.
		C. Review outlet header hydraulics and correct piping design, if applicable.
		D. Contact manufacturer for assistance.
	2. More than one make-up valve operating, and set for different water levels.	A. Adjust float level settings relative to one another.
		B. Shut-off and or/throttle flow to one or more valves.

Problem	Possible Causes	Corrective Actions
(continued)		C. Installation of equalizers is highly recommended.
Excessive water carry over (drift).	1. Surfaces of top layer of fill damaged causing “pooling” of water.	1. Replace top layer. Protect fill when working inside tower.
	2. Eliminator(s) not in place.	2. Reinstall.
	3. Damaged eliminator.	3. Replace.
	4. Excess water flow.	4. Reduce water flow or install spray nozzles designed for the actual operating flow.
	5. Orifices in spray nozzles clogged causing improper water dispersal.	5. Install outlet strainer. Clean whole system and spray nozzles.
	6. Blockage of fill.	6. Clean fill.
Premature or excessive corrosion of fan drive components.	1. Excessive drift.	1. See “Excessive Water Carry Over (Drift)” above.
	2. Presence of corrosive chemicals in air or water that was not known at time of supply.	2. Remove source of corrosion.

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SECTION 4

WATER TREATMENT

4.1 GENERAL

4.1.1 Background

4.1.1.1 Definition

Water treatment can be defined as any procedure or method used to alter the chemical composition or natural "behavior" of water. Water treatment is the control of dissolved gases and minerals normally present in water to prevent scale, corrosion, and microbiological growth from affecting mechanical systems that use water as a means of heat transfer. Water treatment is necessary when operating steam and hot-water boilers, air-conditioning systems using cooling towers, air-handling systems having wet wash, or any type of closed- or open-loop water system requiring makeup water.

4.1.1.2 Use

The goal of a water-treatment program is to alter the chemical content of the supply water to minimize corrosion and prevent scale deposits on the heat exchanger, cooling tower, and other equipment that use or process cooling tower water. The water-treatment program is also an effective means of preventing the formation of algae and slime. A basic knowledge of the types of chemicals used and an understanding of the various methods for introducing the chemicals into the water systems is essential for a successful water-treatment program.

WARNING

Chemicals, acids, testing reagents, etc. are hazardous and must be properly controlled. Make sure all chemicals, acids, testing reagents, etc., are properly marked and kept in a safe location so that no one will mistake their contents. When using chemicals, proper personal protective equipment (PPE) must be worn at all times. Failure to comply may cause injury or death.

4.1.2 Biological Fouling

4.1.2.1 General

All water contains living organisms in some form. Recirculated water provides an excellent environment for bacteria and algae growth that can foul heat exchanger and other surfaces. Microbiological growths are very small organisms like molds, bacterial slimes, algae, and bacteria. Some are dangerous to health, others cause bad taste and odors, and many produce clogging deposits. Biological fouling is a common problem in cooling towers and usually appears as algae and slime in the tower. Various other kinds of bacteria interact with iron and sulfur to cause corrosion and produce insoluble salts. These are usually carried to another part of the system and deposited as sludge. Algae consist of tiny cells that multiply and produce large masses of plant material in a short time. The growth is usually quickest in hot weather and bright sunlight. Slime consists of a gelatinous mass that clings to practically all surfaces in the system. It traps organic matter, debris, and scale-forming material. When microbiological growth breaks loose from the tower, pipelines, pumps, and heat exchangers could be adversely affected. Biological growth attacks, and may destroy, wooden parts of the cooling tower and reduces the heat transfer between the air and water in the tower.

4.1.2.2 Safety

Chemical treatments, such as chlorine, iodine, and bromine, are used to address biological issues. Water treatment controls are set up to maintain chemical levels that prevent scaling and corrosion and control biological fouling. Extreme care should be exercised when handling chemicals; personnel using chemicals should be trained and equipped with appropriate personal protective equipment (PPE). Additionally, OSHA approved safety shower and eye wash must be installed in the immediate area where water is chemically treated.

4.1.3 Corrosion

4.1.3.1 General

Corrosion is the destruction of metal by a chemical or electrochemical reaction. Corrosion of metal piping systems and equipment is a very costly and serious problem. Corrosion not only eats away metal from the system, it deposits the resulting material at other locations. Corrosion products increase friction and pumping costs, reduce the capacity of lines, and may result in the complete blockage of a system.

4.1.3.2 Type of Corrosion

4.1.3.2.1 Basic Types

There are many types of corrosion and some are described below.

4.1.3.2.2 Acidity

Water with a pH reading below 7.0 is corrosive to metal. In a cooling tower, pH readings below 7.0 may be caused by sulfuric, hydrochloric, or nitric acids that enter the system through makeup or are chemically formed in the system from certain gases picked up from the air or from applying inappropriate chemical treatments.

4.1.3.2.3 Oxygen Corrosion

Dissolved oxygen can destroy protective hydrogen film form on many metals and oxidize dissolved ions into insoluble forms. Oxygen corrosion is the main reason for boiler-tube corrosion, condensate return-line corrosion, closed-loop piping corrosion, and tower-system corrosion. Oxygen reacts with iron to cause iron oxide (rust). This usually pits the metal and bores small holes completely through the metal wall.

4.1.3.2.4 Galvanic Corrosion

Galvanic corrosion is an electrical reaction between two dissimilar metals in electrical contact. Galvanic corrosion requires three factors to produce the action: two metals, an electrolyte, and a connection between the two metals. Galvanic corrosion usually results in pitting of the exposed metal.

4.1.3.2.5 Biological Action

Biological action is pitting corrosion caused by metal-consuming bacteria, or by oxygen cell corrosion caused by algae, fungi, or slime sticking to metal. The slime releases oxygen into the water and the result is the same as oxygen corrosion. Other slimes combine with sulfates in the water to give off weak acids that attack the metal.

4.1.3.2.6 Erosion

Erosion is the wearing away of metal surface due to water moving along it at high speeds. Erosion, or metal loss, is higher when gas bubbles or solids of any type are present in the water flow.

4.1.3.2.7 Stress Cracking

Stress corrosion cracking (SCC) is cracking induced from tensile stress and a corrosive environment. SCC is an insidious type of corrosion; the damage is often not obvious to casual inspection. However, SCC can trigger sudden fracture and catastrophic failures. Carbon and low alloy steels can suffer SCC in a wide range of environments, such as strong caustic solutions, phosphates, carbonates, etc. Stainless steel can suffer SCC in a chlorinated environment.

4.1.4 Scale

4.1.4.1 General

It is important to understand the properties of water. Water analysis will provide a good understanding of what is in the water. Although scale is not normally considered a problem in low-pressure boilers, it sometimes does occur, reducing boiler efficiency or burning out tubes (bulging effect). Scale deposits are a very common problem in any open recirculating system that uses a cooling tower where a portion of the water is evaporated and must be replaced by makeup. However, closed-loop systems that are properly maintained should never incur scale problems.

4.1.4.2 Definition

Scale is a coating that forms on the inside surface of boilers, kettles, cooling tower fill, and other containers that repeatedly heat water. Scale is a material that precipitates from solution. It usually consists of calcium carbonate (limestone), calcium sulfate (gypsum), magnesium carbonate (magnesium), and silica (silicate). Calcium carbonate accounts for over 85 percent of all scale buildup in air-conditioning systems, but the scale may contain all of the above materials to some degree. The iron in ferric oxide comes from ferric oxide in the makeup water or from iron picked up from the system itself as a result of corrosion in another part of the system.

4.1.4.3 Formation

Scale is formed when dissolved mineral salts in the solution become insoluble due to certain chemical and physical forces. The dissolved salts come out of solution as a solid and are deposited as scale or settle out as sludge. The inability of the dissolved material to remain in solution is the real reason for scale. The three main features that affect the rate of scale formation are temperature, pH, and mineral content of the solution. Increasing any of these factors increases the probability of scale forming.

4.1.4.4 Effects

The main effect of scale is the loss of heat transfer and reduction of water flow. The result is higher system operating temperatures, inefficiency, and eventual shutdown of the system. Additionally, localized scale can cause under-deposit corrosion (pitting).

4.1.5 Sludge

Boiler water sludge is the soft, mud-like material that settles to the bottom of the boiler. It is removed by blow down or by flushing out the boiler with water. It is a combination of mineral and organic matter that enters as part of the makeup water or is added to the boiler as part of the regular internal treatment. Sludge that settles on top of boiler tubes may have the water cooked out of it. This produces the same result as scale formation. Cooling tower sludge is similar to boiler sludge and is formed in the same manner; however, sludge found in a tower system is usually composed of a mixture of material from the makeup water and material that is washed out of the air stream as it passes through the tower.

4.1.6 Cycles of Concentration

The term "number of concentrations" or "cycles of concentrations" refer to the ratio of dissolved solids in the recirculating system water to the dissolved solids in makeup water (Paragraph 4.5.6).

4.1.7 Acidity vs. Alkalinity (pH)

4.1.7.1 Measurement

Water is acidic, alkaline, or neutral. The control of acidity or alkalinity is an important aspect of the water-treatment program. The pH value is the measurement of acidity or alkalinity of the water.

4.1.7.2 pH Value

In practical application, the pH value of water is represented by a number between 0.0 and 14.0, indicating the degree of acidity or alkalinity. The midpoint of the scale is 7.0. A solution with this pH is considered neutral. Solutions with pH values below 7.0 are considered acidic and above 7.0 basic (alkaline). A pH below 7.0 encourages corrosion of equipment; a pH above 7.5 encourages the deposit of calcium carbonate scale.

pH Scale

Acidic						**Neutral**						**Alkalinity**		
0	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Normal pH values are considered as follows:

- Closed-Loop Systems (Hot-Water Heating and Chilled-Water Systems). The quality of water used in a closed-loop system has an effect on the performance of the system. For instance, raw water from municipal or private wells may possess hardness. Thus, it is recommendable to soften the water for hot systems operating at 250ºF if it exceeds 400 parts per million (ppm) of total hardness. Similarly, closed chilled water loop should be treated before startup; and subsequent water treatment is not required unless the system has been opened. If makeup (Mu) chilled water is added, it should be tested to insure proper water treatment is maintained (corrosion control), and pH held in the range of 7.5 to 9.0. Additionally, opening or leak in the closed system will allow air to enter; this air should be removed by bleeding or purging the system at the highest point. Normally, it is not necessary to treat closed-loop systems to control pH. A tight system should stabilize itself and have a pH value between 7.5 and 9.0.
- Boiler Water (Steam Boilers). Water treatment is required to maintain a pH value of between 10.0 and 11.5 in boiler water.
- Condensate Return (Steam Boilers). Condensate return can provide significant energy savings. However, because of the carbonic acid prevalent in condensates, corrosion controls are required to protect equipment and maintain the condensate as a quality feed water source. The condensate return pH should be at least 7.0 or slightly higher.
- Cooling Tower System. Maintain a pH of 7.0 to 8.0 in the cooling tower or atmospheric-condenser system. If it is necessary to control factors other than pH and hardness, such as control of sodium hydroxide formation, pH may be carried lower or higher.

4.1.8 Hardness

Water hardness is a measure of calcium and magnesium salts in the water. Precipitation of these minerals can cause scaling. The addition of chemicals and treatment with zeolite softeners can control water hardness. Hardness of water is a problem in vessels in which water is heated or evaporated. Hardness data is readily available from the water supply company.

4.2 BOILER SYSTEMS

4.2.1 High-Pressure Steam Boilers

High-pressure steam boilers operate above 15 psig. Few postal facilities have high-pressure boilers and, due to the small number involved, treatment for high-pressure steam boilers is not covered in this handbook.

4.2.2 Low-Pressure Steam Boilers

4.2.2.1 General

Low-pressure boilers are steam boilers operating at 15 pounds per square inch (psig) or less and hot water boilers operating at pressures and temperatures not exceeding 160 psig and 250°F respectively. High-pressure steam boilers exceed 15 psig. The postal service has been replacing low-pressure steam boiler with hot water boilers. Steam-heating systems are more likely to have water treatment problems than the hot-water heating systems.

This section covers water treatment for steel boilers, fire-tube boilers, and cast-iron sectional boilers that operate below 15 psig and require very little makeup. Common chemicals and their use in boiler water treatment are shown in Table 4-1.

Table 4-1. Common Chemicals Used in Boiler Water Treatment

CHEMICAL	PURPOSE	COMMENT
Sodium hydroxide NaOH (caustic soda)	Increase alkalinity, raise pH, and precipitate magnesium.	Contains no carbonate, so does not promote CO_2 formation in steam.
Sodium carbonate Na_2CO_3 (soda ash)	Increase alkalinity, raise pH, precipitate calcium sulfate as the carbonate.	Lower cost, more easily handled than caustic soda. But some carbonate breaks down to release CO_2 with steam.
Sodium phosphates NaH_2PO_4, Na_2HPO_4, Na_3PO_4, $NaPO_3$	Precipitate calcium as hydroxyapatite ($Ca_{10}(OH)_2(PO_4)_6$).	Alkalinity and resulting pH must be kept high enough for this reaction to take place (pH usually above 10.5).
Sodium aluminate $NaAL_2O_4$	Precipitate calcium, magnesium.	Forms a flocculent sludge.
Sodium sulfite Na_2SO_3	Prevent oxygen corrosion.	Used to neutralize residual oxygen by forming sodium sulfate. At high temperatures and pressures, excess may form H_2S in steam.
Hydrazine hydrate N_2H_4. H_2O	Prevent oxygen corrosion.	Removes residual oxygen to form nitrogen and water. One part of oxygen reacts with three parts of hydrazine (35% solution).
Filming amines, octadecylamine, etc.	Control return-line corrosion by forming a protective film on the metal surfaces.	Protects against both oxygen and carbon dioxide attack. Small amounts of continuous feed will maintain the film.

CHEMICAL	PURPOSE	COMMENT
Neutral amines, Morpholine, Cyclohexylamine, Benzylamine	Control return-line corrosion by neutralizing CO_2 and adjusting pH of condensate.	About 2 ppm of amine is needed for each ppm of carbon dioxide in steam.
Sodium nitrate $NaNO_3$	Inhibit caustic embrittlement.	Used where the water may have embrittling characteristics.
Tannins, starches, glucose, and lignin derivatives	Prevent feed line deposits, coat scale crystals to produce fluid sludge that will not adhere as readily to boiler heating surfaces.	These organics, often called protective colloids, are used with soda ash, phosphate. They distort scale crystal growth and help inhibit caustic embrittlement.
Seaweed derivatives (sodium alginate, sodium mannuronate)	Provide a more fluid sludge and minimize carry-over.	Organics often classed as reactive colloids, since they react with calcium, magnesium, and absorb scale crystals.
Antifoams (Polyamides, etc.)	Reduce foaming tendency of highly concentrated boiler water.	Usually added with other chemicals for scale control and sludge dispersion.

4.2.2.2 Scale

Scale is formed when minerals precipitate out of heated water. However, when boiler water is properly treated, the minerals in suspension will not form scale. Scale acts as an insulator reducing heat transfer and can cause tubes to bulge and rupture. The main source contributing to scale formation is makeup water. Makeup water replaces water lost to leaks or as a result of blow downs.

4.2.2.3 Corrosion

Proper treatment is required to prevent or control corrosion in low-pressure boilers. All raw water contains impurities, including dissolved gases such as oxygen and carbon dioxide. Depending on the source of the water (lake, river, well, etc.), the water may be corrosive as received, or it may turn corrosive after it enters the system. Corrosion attack may be general throughout the boiler or may be localized pitting.

4.2.2.4 Corrosion

4.2.2.4.1 General

Proper treatment is required to prevent or control corrosion in low-pressure boilers. All raw water contains impurities, including dissolved gases such as oxygen and carbon dioxide. Depending on the source of the water (lake, river, well, etc.), the water may be corrosive as received, or it may turn corrosive after it enters the system. Corrosion attack may be general throughout the boiler or may be localized pitting.

4.2.2.4.2 Oxygen Corrosion

Pitting is usually the form of corrosion resulting from oxygen in the water. This is the worst type of corrosion, since it may create small hidden holes in a pipe or tube on the water side in a very short time. Oxygen enters the boiler with makeup water or with the condensate return. Oxygen corrosion in a steel boiler is usually discovered when the boiler tubes start leaking. Visual inspection is the only way to tell how much damage has been done. The corrosion area might be small or it may cover the entire area of the boiler. Oxygen is sometimes picked up at the condensate-return tank and, when this happens, the piping between the condensate pump and the boiler is the first to leak. Rusty water in the boiler is a certain indication that corrosion is taking place somewhere in the boiler or system. The corrosion cells are usually seen as small blisters, or deposits, on the boiler tubes or walls and, when the metal deposit is brushed off, it reveals pitting in the metal. Oxygen can also cause pitting corrosion without the depositing of material.

4.2.2.4.3 Return-Line Corrosion

Pure condensate (pH 7) implies that the limits of impurities of various types have not been completely identified or qualitatively defined for various operating conditions*. However, the condensate may have absorbed carbon dioxide from the air and become acidic. Thus, pure condensate is not necessarily desirable and, in some instances, can cause rapid pipe deterioration (http://www.wbdg.org/ccb/DOD/UFC/ufc_3_130_07.pdf). For this reason it is important to establish a good boiler water treatment process.

*Lane, R.W., Larson, T.E and Pankey, J.W Hydrogen exchange resin for steam purity testing, January 1995, Industrial and Engineering Chemistry, p. 47

4.2.2.5 Sludge

4.2.2.5.1 Frequency

Water contains impurities and in some instance man-made pollutants. Over time, the concentration of salts and suspended matter in the boiler water builds up to form sludge. Sludge if not treated properly can settle on heat transfer surfaces, forming a hard scale. Certain types of water treatment chemicals, if added incorrectly, can precipitate scale formation. Sludge is removed by a bottom blow down and a chemical treatment that conditions it to form in soft masses and settle to the bottom of the boiler.

WARNING

Many valves are designed to contain liquids, and gasses under varying pressures. Steam valves, or any valve under pressure, must never be opened quickly. Use a bypass, if provided, or open the valve slightly and wait for the pressure to equalize. Failure to comply may cause injury or death.

4.2.2.5.2 Treatment

Water hardness is generally controlled through carbonate and phosphate programs. The resulting sludge, however, has to be conditioned into a fluid substance for ease in bottom blow down. Sludge conditioners generally are very long synthetic or natural chains of polymeric molecules. The sludge conditioner physically bonds with the calcium carbonate or phosphate formed in the boiler to prevent the formation of precipitated scale on the heat transfer surfaces. Several of the most popular internal boiler sludge conditioners are sodium polycrylate, lignin, sodium polymethacrylate, tannins, and sulfonated copolymers. The materials used for conditioning sludge include various organic materials of the tannin, lignin, or alginate classes.

4.2.2.6 pH

Low-pressure steam boilers are maintained in the pH range of 10.0 to 11.5. This level must be maintained to eliminate precipitation of calcium carbonate and magnesium hydroxide and to prevent scale from forming. High pH, obtained through alkalinity control, reduces the possibility of corrosion occurring in the boiler. The chemical used to raise the pH to the desired level is caustic soda (lye).

WARNING

Caustic soda or soda lye reacts strongly when added to water. Consult SDS for necessary precautions. The solution can cause serious burns. Caustic soda must be added very slowly to water and the solution must be allowed to cool before handling the container. Always wear appropriate PPE when handling chemicals. Failure to comply may cause injury or death.

4.2.2.7 Return Line

Scale deposits rarely occur in the return system. When the system contains a constant amount of carryover from the boiler water, it may cause coagulation clogging of small lines or fittings, but not scale. Corrosion is the main problem encountered in return systems and usually results from an acid condition of the steam condensate (pH below 7.0), or a combination of oxygen and boiler water impurities that are carried over with the steam. The low pH of steam condensate usually results from carbon dioxide (CO_2) gas leaving the boiler with the steam and uniting with the condensate, forming carbonic acid that lowers the condensate pH level. Some CO_2 gas is produced in the boiler by treatment reaction (for example, soda ash, which is used by many companies for water treatment, releases large amounts of CO_2 gas). Oxygen pitting is more of a problem than acidic attack because it cannot be kept out of the return system in most plants. A steam boiler with impure steam, resulting in foaming and carryover, is much more likely to experience corrosion in the return system than a system with good steam purity.

The main causes of carryover are too high a water level, dirty boiler water, boiler overload, changing load, or over-firing. All of these cause the steam to carry material picked up from the boiler water. Treatment for return-line corrosion is not recommended for low-pressure heating boilers unless it is determined that a definite need exists. Proper operation and a good water-treatment program are the main requirements for a trouble-free system.

4.2.3 Testing

4.2.3.1 General

Perform, and log, water testing as prescribed by the manufacturer of the chemicals used. In most instances, the chemical companies have a chemist to help set up a testing program that will ensure proper use of the chemicals. The manufacturer can also recommend appropriate testing equipment. Except in limited circumstances water testing and water chemistry monitoring should be contracted to licensed, certified vendors equipped to perform these tasks.

NOTE

Blow down and water discharges associated with boilers are permitted activities regulated by the Federal Water Pollution Act. Consult with your environmental specialist before discharging water or blow down into the environment.

4.2.3.2 pH

If a test kit for pH is available, use it to check the boiler water. If a test kit is not available, determine the pH with pH test strips such as "pHydrion test strips." These are purchased locally and come in different pH ranges. A strip that checks from 10.0 to 12.0 pH is ideal. The pH should be maintained between 10.0 and 11.5. When testing indicates additional treatment is required, use caustic soda (lye) to raise the pH close to the 11.5 level. The pH reading can be made as soon as the sample is cool enough to handle. Drain off sludge or dirty water from the water column and take a sample in a clean glass container.

WARNING

Hot water and flashing steam present immediate burn hazards. Take care not to burn the skin by hot water or flashing steam. Learn the location and function of every valve on the system and use try cocks when in doubt about true water level. Failure to comply may cause injury or death.

4.2.4 Treatment Methods

4.2.4.1 Small Heating Boilers

Properly maintained small steam-heating boilers (almost 100-percent return with little makeup) require only annual treatment. Bottom blow down is not required. After the boiler has been cleaned, inspected, and refilled for summer lay-up, add treatment through the manhole. Prepare the caustic soda and tannin in separate containers and then add them to the boiler before it is fired to reduce the oxygen content. Once the boiler is properly treated and laid up, it can be serviced when needed by simply draining the water down to the operating level.

4.2.4.2 Boilers Requiring Makeup

Any boiler that requires a lot of make-up will also require a lot of treatment and attention. Makeup greatly enhances the probability of corrosion, and unless the loss of water can be stopped, the system may require additional types of treatment. Steam boilers usually require small amounts of makeup to replace what is lost from the boiler by such actions as blow down, but when a boiler requires constant makeup, the reason must be immediately determined. If it is necessary to treat the boiler during the heating season, a simple pot feeder is installed on most boilers for adding treatment. These feeders are inexpensive and can be installed by local personnel. Other methods of installing treatment are using the condensate return tank or by installing a simple pipe funnel at the steam gauge connection. All treatment should be followed by clean water to flush all the treatment into the boiler. Never add treatment by using the safety valve hole.

WARNING

Safety and safety relief valves are one of the most critical safety components of boilers. These valves shall be operated and tested per ASME codes. Manually check the boiler safety valves and safety relief valves under pressure every 30 days of operation and after any period of inactivity. Failure to comply may cause injury or death and/or equipment damage.

4.2.4.3 Boilers with Automatic Makeup Valves

When two boilers, connected in parallel, are both operated at the same time, one boiler may supply the makeup for both boilers. This causes a difference in the treatment level of the two boilers, as do different firing levels. When two boilers are used on one system, check and treat each boiler separately.

4.3 HOT-WATER HEATING SYSTEMS

4.3.1 Low-Temperature Systems

Low-temperature hot-water systems are closed circulating systems designed to operate with no leakage from the system and no makeup water. For postal installations, low-temperature hot water is defined as water temperature below 212ºF at the boiler outlet, regardless of the pressure. This type of heating system is standard in all new or remodeled postal facilities.

4.3.2 Scale

Scale is the precipitation of water-soluble inorganic salts. Hot water pipes, in areas with hard water, are prone to develop internal scale. However, in areas that do not have hard water, scaling should not be a problem.

4.3.3 Corrosion

All makeup water contains oxygen that unites with metal to form rust or corrosion. Whenever water is added to the system, a certain amount of corrosion will occur unless something is done to prevent it. For every 20ºF rise in the temperature of the water, the corrosion rate of the water doubles. Therefore, water at 180ºF is twice as corrosive as the same water at 160ºF. This is especially important if corrosion is known to be a problem in a hot water system. When the heating system is filled the first time with raw or untreated water, oxidation or rusting takes place until all of the oxygen in the water is gone or has combined with the metal to produce rust. If the system is tight, no water is lost, and no air or water is allowed to enter the system, treatment is not needed. Many hot-water heating systems operating without any type of treatment have no corrosion problems, because the amount of corrosion due to the initial water charge is very small. The real problem is the oxygen and dissolved gases brought into the system by makeup due to water leaks or improper design or operation. Very few hot-water heating systems are truly closed systems that require no makeup.

4.3.4 Makeup

Makeup must be added to all systems in a way that prevents any possibility of backflow, of boiler water and chemicals into the water-supply line. To do this, a device, commonly referred to as a "vacuum breaker," or "backflow preventer" is used. USPS policies, OSHA 29 CFR 1910.141 (b) (2) (ii), state, and local building codes require these devices to be installed to prevent the contamination of potable water systems. When water is cold, the pressure in the expansion tank may drop low enough to permit the admission of makeup water into the system. When the water temperature increases, the system pressure further increases due to expansion of the additional water in the system.

NOTE

Learn the location and function of every valve on the system.

4.3.5 Cleaning Hot-Water Systems

4.3.5.1 General

Cleaning a hot-water system consists of draining the system completely and giving the boiler a thorough internal cleaning. Make sure that all valves in the system are open so that all areas are thoroughly flushed. Consult your chemical supplier for a suitable treatment for cleaning hot-water systems.

NOTE

Maintain a written log or record of all events. Advise a supervisor of any change in operation or readings

4.3.5.2 Operation

Start the boiler and pump. Bring the solution to normal operating temperature (180ºF minimum) and pressure. Maintain for 4 hours while the solution circulates through the system. The boiler is then cut off and the temperature is allowed to drop to about 120°F. The pump is cut off and the entire system drained. Low points in the system should be flushed, if possible, to remove any material that has settled out. The system is again filled and vented for normal operation. If needed, the system may then be returned to normal service; if the system is not needed, it should be started and the boiler water circulated for at least 1 hour.

4.3.5.3 Treatment Program

A good chemical treatment program usually precludes the need for cleaning and flushing. The chemical supplier's representative knows requirements for cleaning. However, if the boiler is dirty (priming and/or surging), check the pH of the water and, if low, trisodium phosphate can be used to clean the boiler. Note that trisodium phosphate will raise the boiler pH. Thus, pH should be rechecked and properly adjusted.

4.3.5.4 Water Capacities

The quantity of water in a system must be known to determine the proper amount of treatment to be used. A small water meter used when filling the system is the best method for determining water capacity of a heating system. The meter can be used on other systems in the same manner.

4.3.6 Hot-Water Systems Treatment

4.3.6.1 General

Maintain the pH of the water between 8.0 and 9.0. Use caustic soda, trisodium phosphate, etc., to raise the pH if required.

WARNING

Caustics and acids can cause serious burns to skin and eyes and are fatal if swallowed. Always avoid direct contact with caustics, acids, and other chemicals. Consult SDS prior to handling chemicals, and wear all appropriate PPE when exposed to caustics, acids, or chemicals. Failure to comply may cause injury or death.

Protective garments are frequently worn to prevent dermatitis when using chemicals such as cleaning solvents. Leaking or permeable garments can increase the possibility of dermatitis by allowing the chemical to reach the skin and holding it there. Prior to use, inspect the garments for holes, breaks, or physical deterioration. If any are found, replace the garment. Do not use any garments that have a chemical odor inside. The odor is a sign that the garment material is incorrect for the chemical. To verify that the garment material and chemical are compatible, consult the information that comes with the garment or the garment manufacturer. Postal safety and health personnel can provide technical assistance on hazardous properties of material and protective equipment.

4.3.6.2 Sodium Sulfite

Oxygen attack is a principle cause of hot water heating system water side corrosion. This can usually be eliminated by heating the water to 180ºF for four to six hours or with mechanical de-aeration. If problem persists, sodium sulfite, (an "oxygen scavenger") eliminates oxygen by combining with it to form sodium sulfate, a compound chemical that does not affect the system. The best method of determining corrosion protection is to check the water for sodium sulfite content. Since sulfite and oxygen combine to form sulfate, any sulfite found in the system shows that there is more than enough treatment in the system. The presence of sulfite in a system indicates the oxygen has been removed.

4.3.6.3 Sulfite Testing

The frequency of these checks depends on the amount of water added to the system as makeup. A system with leaks may require testing and treating once a month. A system with no loss of water and no requirement for makeup can probably be checked and treated once a year. The representative of the chemical supplier knows how often to test the treatment level and what equipment is required. The pH can be checked with pH test strips, titration, or a colormetric kit. Some large offices use portable or built-in electric pH meters with a strip recorder. The pH should be maintained between 7.5 and 9.0; however, check with the manufacturer and water treatment service providers to ascertain the exact pH. An excess of sodium sulfite should be maintained between 20 and 40 ppm. A drop in sulfite content in the system is a sure sign of leaks. With a sulfite test kit, check the sulfite by a simple titration method. Exposing the water sample to the air destroys the test accuracy as sulfite will combine with the oxygen in the air and convert to sulfate. Follow instructions closely when collecting a water sample for sulfite testing.

NOTE

If the system is treated with an inhibitor, testing is the same as described in Paragraph 4.4.7.

4.3.6.4 Inhibitors

4.3.6.4.1 Use

Another treatment method used in closed-loop hot water heating systems is the use of an effective corrosion inhibitor. The inhibitor reduces corrosion by forming a coating on all metal surfaces but does not produce any chemical changes in the water.

There is no one type of inhibitor used in hot-water systems. Inhibitors formulated for closed-loop systems are also used in other systems. The same treatment may require different levels of concentration in different types of systems. Almost all chemical-treatment companies treat standard chilled-water and hot-water heating systems with the same inhibitor. However, a nitrite-base inhibitor is considered one of the best treatments for hot-water heating systems (Paragraph 4.5.6.2).

4.3.6.4.2 Chromates

Chromates are carcinogens. Therefore, use non-carcinogen inhibitors, such as nitrile or carbohydrazide. Do not use chromates.

WARNING

Caustics and acids can cause serious burns to skin and eyes and are fatal if swallowed. Always avoid direct contact with caustics, acids, and other chemicals. Consult SDS prior to handling chemicals, and wear all appropriate PPE when exposed to caustics, acids, or chemicals. Failure to comply may cause injury or death.

4.3.6.4.3 Molybdates

Molybdates may be used alone or in combination with other inhibitors in closed water systems. Often, they are referred to as "chromate substitutes," since they function in a manner similar to this classic inhibitor. However, they are weaker corrosion inhibitors than chromate.

Generally, a minimum of 100 to 200 ppm of molybdate as MoO_4 is required for corrosion protection. Higher dosages are required in more aggressive waters. The pH of the system should be maintained above 7.5. Enhanced protection for copper and brass can be obtained by blending molybdate with tolytriazole. Often molybdate is used in combination with nitrite to provide better protection at lower molybdate and nitrite concentrations.

Molybdates do not tend to support the growth of bacteria. Because they are a weak oxidant, they can be used in systems containing glycol. Although molybdates are accepted as being less toxic than chromate, the EPA is more closely looking at the environmental impact of molybdates. This eventually may lead to more stringent limitations on the use and discharge of molybdate inhibitors.

4.3.7 Treatment Methods

Large systems are now installed with a built-in bypass feeder for treating the water. However, many small systems do not have any type of treating equipment. If the system is treated only once a year, it is not necessary to install a feeder because the chemicals can be added by hand before the system is placed into operation at the beginning of the fall season. Nonetheless, the type of treating equipment required depends on many things, such as the type of material to be added to the system, the amount of material, how often treatment is required, how critical the water-treatment range is, and what reduction in work-hours will result from installing new equipment.

4.4 CHILLED-WATER SYSTEM

4.4.1 General

A chilled water system (CHWS) removes heat generated in a space or by a process and releases it to the outside. It is designed to deliver water to an air handler unit (AHU) or fan coil unit (FCU). The air circulating through the building flows across the AHU or FCU chilled water coils. The water absorbs the heat (40°F to 55°F) and returns it to the chiller, which uses refrigerant to transfer the heat to a higher temperature water loop (85°F to 100°F). The heat is then rejected to the outside through cooling towers or outdoor condensers. There are many different types of chillers, such as air-cooled roof top, indoor water-cooled with outdoor cooling towers. Water-cooled chillers are distinguished by the type of energy used: electric, gas-fired, absorption, and so on. There are two types of chilled-water systems: a closed system where the entire system is under pressure, with a sealed expansion tank compensating for the expansion due to water temperature changes; and an open system where the chilled water is used as an air-wash system. The standard system installed in postal facilities is a closed re-circulating system. Except for the difference in temperature, the chilled-water system is identical to the hot-water heating system.

4.4.2 Scale

Closed chilled water systems rely on untreated domestic water that contains hardness salts. Hardness salts precipitate out of solution with increasing temperatures causing scaling. Scale build-up adversely affects heat transfer. When a perfect new closed system is filled with domestic water, hardness salt evenly precipitates on the surface and local corrosion consumes dissolved oxygen.

4.4.3 Corrosion

Often, a basic chilled water system (CHWS) uses mild steel and copper as materials of construction. However, mild steel and copper can be susceptible to poor water quality corrosion. Dissolved gases are the main cause of corrosion, and oxygen is the worst offender.

4.4.4 Water Loss

Water lost from the system must be replaced with fresh water. This brings in additional oxygen and other dissolved gases which, without treatment, will combine with the iron piping and produce rust or flaking of the metal walls. Stopping all leaks to prevent loss of water is the best method to stop corrosion in the system.

4.4.5 Cleaning the Chilled-Water System

Fouling and scaling may affect, and reduce the effectiveness, of CHWS. Therefore, CHWS equipment requires periodic inspection and cleaning to maintain optimal performance. Soft salt deposits may be removed mechanically or by circulating hot fresh water (not to exceed an equivalent refrigerant pressure temperature of 1,000°F) through the tubes at high velocity. Otherwise, chemical, or alternate, treatment may be necessary. All lock out/tag out safety procedures should be adhered to when cleaning CHWS.

NOTE

Always follow all existing safety regulations.

4.4.6 Treatment

4.4.6.1 pH

The pH level should be maintained between 7.5 and 9.0, (follow manufacturer's specification) but chemical treatment is usually not necessary to maintain this level.

4.4.6.2 Inhibitor

Due to the low temperature of the chilled water, do not use sodium sulfite. A nitrite-based inhibitor is the best. It works very well on iron and steel and can be combined with other inhibitors when copper or aluminum is present in the system. The nitrite material does not stain and is compatible with all types of antifreeze solutions. Maintain the treatment levels prescribed as per manufacturer's specifications.

4.4.7 Testing

Conduct control tests often enough to ensure that pH and inhibitor levels are being maintained. (This ranges from monthly to annually.) The required test for inhibitor control is determined by the treatment used, but will probably be a test for ppm of nitrite. The chemical supplier knows the proper testing procedure and the frequency to ensure satisfactory chemical level in the system. However, it is important for USPS personnel to become familiar with the testing procedures.

4.4.8 Treatment Methods

All closed-loop systems use the same treatment methods. Follow the treatment directions in Paragraph 4.3.7. Automatic feeding or bypass feeders and one shot or pot feeders are the preferred methods for adding chemicals as automatic chemical feeders and monitoring equipment are not usually needed on closed loop systems.

4.5 COOLING-TOWER SYSTEMS

4.5.1 General

All cooling towers operate on the principle of evaporation as described in Paragraph 3.8.3.5.1.The initial cost of a cooling tower is high, but, when operated and maintained properly, cooling towers provide years of service and pay for themselves many times over. Most problems affecting towers are a result of mechanical neglect and improper water-treatment programs. Towers that should have operated for many additional years are replaced each year due to neglect.

WARNING

Cooling tower systems present unique hazards depending on the systems design. Never allow anyone to go inside a cooling tower system without following lock out and tag out procedures (LO/TO) on all associated equipment. Use Form 4811, Equipment Lockout Tag, to tag equipment that has been locked out. There may also be confined space entry and PPE rules depending on the system design. Follow all safety rules applicable to your cooling tower system. Failure to comply may cause injury or death.

4.5.1.1 Cooling Tower Start-up, Initial and Following a Shut-down Period

The Clean Water Act established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry. The Act made it unlawful for any person to discharge any pollutant from a point source into navigable waters, unless a permit was obtained under its provisions. Therefore, it is important to minimize, whenever possible, unnecessary drainage of cooling towers.

To minimize the risk of biological contamination during an extended shut-down period the cooling tower content should be treated and circulated throughout the system, including the unit distribution. The fans, however, should remain off.

If recirculation is not possible, it is recommended that the entire system (evaporative cooling equipment, system piping, heat exchangers, etc.) be drained. To resume operation of a drained system and at initial start-up, clean all debris from the cold water basin and fill the system with fresh water. Then execute one of the following biocide treatment programs while operating the circulating pump(s) and prior to operating the unit fans.

4.5.1.1.1 Treatment #1

Resume treatment with the biocide that was used prior to shut-down. Run the pump only while maintaining the maximum recommended biocide residual for a sufficient period of time (residual and time will vary with the biocide) as recommended by the water treatment supplier. Start the fan(s).

4.5.1.1.2 Treatment #2

Check the pH of the circulating water and, if necessary adjust to between 7.0 and 7.6. While running the pump only, treat the system with sodium hypochlorite to maintain a level of 4 to 5 mg/l (ppm) free chlorine (as Cl_2) over a six (6) hour period. Test kits that can be used to measure the free residual of chlorine are commercially available. Only after this treatment period is completed should the fan(s) be started.

4.5.2 Biological Fouling

Since a cooling tower depends on the evaporation of water to cool the remaining water, it is essential that nothing interfere with the evaporation process. Hot water entering the tower is directed through a distribution system to flow down through the tower in a uniform pattern that covers the entire fill area. As the water flows over the fill or packing, it is broken up and films out on the fill material. This provides the maximum contact surface exposed to the air stream through the tower. The air movement is also controlled so that an even flow of air travels through the fill area. The amount of surface where the water film and air come in contact determines the capacity of the tower. Anything (such as biological fouling) that reduces the filming action of the water, or alters the path or amount of air movement, reduces the capacity of the tower.

4.5.3 Foreign Material

Tower fouling also is caused by foreign material in the system. Deposits of calcium carbonate ($CaCO_3$), mud, and airborne material are usually found in the tower sump. The cooling-tower sump acts as a settling basin for undissolved solids traveling with the water and build-up of loose material that settles out in the distribution pans or on the fill. This has the same effect as algae by restricting or diverting water or air. The evaporative condenser has the same problems as the cooling tower, except that green algae are not a problem with indoor systems. Since the water is pumped from the basin back to the top, there is no water problem other than in the condenser itself. Fouling from slime, scale, and other materials is the worst problem experienced by evaporative condensers.

Maintain a written log or record of all events. Advise a supervisor of any change in operation or readings.

4.5.4 Corrosion

4.5.4.1 Cause

Corrosion is caused by dissolved gases, aggressive water (low pH), bacterial attack, and dissimilar metals.

4.5.4.2 Dissolved Gases

Dissolved gases that cause corrosion are usually oxygen, carbon dioxide, and sulfur dioxide. Sulfur dioxide is usually a result of burning coal or other fuels that contain sulfur, or from the operation of nearby industrial plants. Oxygen and carbon dioxide are common gases and are part of the atmosphere. These gases are absorbed from the air as the water passes through the tower fill. The circulating water then carries the oxygen, carbon dioxide, and/or sulfur dioxide into the piping system. The amount of carbon and sulfur dioxide present in the water depends on the amount present in the air that goes through the tower. If the tower is located close to a boiler stack or in an industrialized area, the amount of these gases may be quite high. When carbon dioxide is absorbed into water, carbonic acid is generated; when sulfur dioxide gas is absorbed into water, sulfuric acid is generated. Either of these acids reduces the alkalinity and pH of the water. If enough of the gases are absorbed into the system, the water will drop in pH until it is acidic and becomes aggressive. It will then attack and dissolve metal in the system.

4.5.4.3 Oxygen

Oxygen in the water attacks the metal and causes oxygen corrosion that either destroys the entire piping system in a short time or causes general or pitting corrosion throughout the system.

4.5.4.4 Bacteria

The constant supply of air and makeup water in the tower causes bacterial attack. Slime and algae growing in the tower end up in the piping system and increase the corrosion problem by forming oxygen corrosion cells.

4.5.5 Scale

4.5.5.1 Cause

Scale is the largest problem associated with cooling towers. It is mainly caused by the gradual buildup of minerals and other material in the water due to evaporation. Some makeup water is so high in scale-forming material that scaling would result if the water was used once and discarded. When this type of water is used in a cooling tower (where the concentrations are further increased), the scaling problem becomes severe. Due to its inability to stay in solution in hot water, calcium carbonate (limestone) is the chief producer of scale in a system. As the water temperature goes up, the ability of calcium carbonate to stay in solution diminishes, and it is deposited on the hottest surface as a white powder or soft scale. Thus, scale is more pronounced in the hot end of the condenser and the upper cooling tower fill.

4.5.5.2 Scaling Materials

Most scale in tower systems is actually a combination of several materials, but generally consists mostly of calcium carbonate. Other scaling materials are calcium and magnesium silicates, and calcium sulfate. If phosphate treatment is used and the system is over treated, phosphate scale may be precipitated in the condenser or elsewhere in the system.

4.5.6 Cycles of Concentration

4.5.6.1 General

Cooling-tower cooling is accomplished through the evaporation of water. As water is evaporated, the minerals are left behind in the cooling-tower water. Thus, the hardness of the remaining tower water is increased. The resulting increase in hardness is often described as the number of "cycles of concentration" of the tower water.

4.5.6.2 Number of Cycles

The cycles of concentration help in comparing the dissolved solids in the circulating water with those in the makeup or raw water. If, as a result of evaporation, the solids in the tower water become twice as great as those in the makeup, there are said to be two cycles of concentration. Three times as many solids would result in three cycles of concentration; four times would be four cycles, and so on. The maximum allowable cycles of concentration are predetermined by analysis of the makeup water and other factors. After a plant is placed in operation, increasing the bleed rate will lower the cycles of concentration; reducing the bleed rate will increase the cycles. Since all minerals found in the makeup water increase in content as water is recirculated and evaporated in an open-spray system, it must be determined which mineral will be used to determine and control the number of cycles.

$$\text{Cycles of Concentration} = \frac{\text{TDS Cooling Water}}{\text{TDS Make up Water}}$$

(TDS: Total Dissolved Solids)

4.5.6.3 General Water Treatment Chemical and Principles

Testing at the Center for Disease Control in Atlanta, GA, proves shock treatments, with generic chlorine compounds, are highly effective when the pH is kept low (approximately 7.2 or lower) and the residual chlorine (chlorine not attached to organisms) is maintained at 2 – 3 parts per million. Chlorine treatment is relatively inexpensive, and the chlorine evaporates as a gas without causing water pollution.

WARNING

Communicate with USPS Environmental Compliance prior to using Quaternary Ammonium Compounds (QuAC).

Generic Quaternary Ammonium Compounds (QuAC) also effectively control biological organisms at acceptable levels. But ammonium compounds are expensive, hazardous to handle, and must be discharged into sanitary sewer systems to prevent pollution of streams and lakes; they must be used with extreme caution and are not preferred.

4.5.6.4 Use of Chlorides

Chlorides are salts that have the ability to become concentrated in large amounts in water without precipitation taking place. This is the reason chlorides are normally used as the element to control blow down or to maintain concentration levels. If, for example, a system is maintained at four cycles of concentration, and a check on makeup water shows 100 ppm total hardness and a check of tower water shows 375 ppm total hardness, this is only 3.75 cycles of hardness; so the concentration level could still be increased without laying out scale. Do not depend on this test alone; use at least one other test, such as the one for chlorides. If 45 ppm of chlorides are found in the tower water and 10 ppm of chlorides in the makeup water, 4.5 cycles of chloride concentration would be present. This test shows that the water is oversaturated and means that, unless chlorides are being picked up from some other source, the water actually contains 4.5 cycles of concentration and something has happened to the hardness. Further tests would be more conclusive. However, based on the two tests alone, it is obvious that part of the minerals contained in the water has precipitated out as scale. The installation of an automatic blow down control in lieu of continuous bleed off should be considered. This device continuously monitors the dissolved solids and opens a blow down valve when the dissolved solids reach a preset level. The big advantage of the automatic blow down over the continuous bleed off is that it automatically adjusts to various load conditions. Water-treatment chemicals are added to the tower water to keep the minerals in suspension at the higher concentrations and not precipitate out on the surfaces of the condenser tubes. The suspended solids, however, cannot be drained to the sewer whenever the number of concentrations exceeds the predetermined number without an appropriate National Pollutant Discharge Elimination System Permit. New makeup water is then brought in to maintain the cooling-tower water level.

Since 4.5 cycles of hardness would total 450 ppm, and the test only revealed 375 ppm, the other 75 ppm must be laid out as scale and is calcium carbonate scale. The main point here is that chlorides are the most stable materials for determining hardness of the water, so they are used when controlling cycles in tower or evaporative-condenser systems by bleed off. Always ensure pH and residual chlorine are maintained at the proper level.

NOTE

Make sure an appropriate National Pollutant Discharge Elimination System Permit is in place prior to any cooling tower sewer discharge.

4.5.6.5 Scale

4.5.6.5.1 Allowable Cycles of Concentration

As already determined, the main effect of high concentrations in cooling tower water is the formation of scale. When starting up a new system that has not been checked for allowable cycles of concentrations, Table 4-2 and Table 4-3 should be used as the method to initiate a blow down or bleed off from the system. Table 4-2 shows allowable cycles of concentration based on the hardness of local makeup water. The cycles shown here are to be maintained in treating the system. Without any type of treatment (such as phosphate crystals), the allowable cycles would have to be reduced to maintain a scale-free system. After the allowable cycles are determined, the bleed can then be set to maintain this level.

Table 4-2. Hardness Relationships

HARDNESS OF LOCAL WATER	ALLOWABLE CYCLES OF CONCENTRATION
Soft water - less than 60 ppm	5
Medium hard - 61 to 120 ppm	4

HARDNESS OF LOCAL WATER	ALLOWABLE CYCLES OF CONCENTRATION
Hard - 121 to 180 ppm	3
Very hard - 181 and over ppm	2

Table 4-3. Bleed Rate* for Systems Having Capacities Up to 100 Tons

HARDNESS OF LOCAL WATER					
ppm	UNDER 60	60-120	121-180	OVER 180	NOTE
Bleed rate (gallons per hour)	3	5	7	16	Bleed should operate only when cooling tower pump operates

*Based on 10-ton system. For larger systems, adjust the bleed rate proportionally.

4.5.6.5.2 Softening Equipment

In arid locations or locations with very hard water, consider the installation of softening equipment for the makeup water. The cold process lime, lime-soda process, lime-gypsum process, or the zeolite process is recommended. It should be noted that this equipment is expensive and a careful consideration of all factors must be included in preparing an economic analysis. Consultation with a local water-treatment specialist is recommended.

4.5.7 Alkalinity

Reducing the amount of alkalinity in a tower system can be accomplished by increasing the bleed rate, but a large amount of water would have to be bled off. Sulfuric acid treatment is another method used in large systems. The acid converts the scale-forming calcium carbonate to a more soluble calcium sulfate and, as the alkalinity is reduced, so is the scale-forming tendency of the water. If the amount of calcium sulfate in the makeup water is high, the use of sulfuric acid may not be feasible, as its use would further increase the levels of calcium sulfate that also has a saturation level that cannot be exceeded without laying out a sulfate scale. Sulfuric acid also reduces the pH level of the water by increasing the hydrogen ions. Hydrochloric acid is sometimes used to reduce the alkalinity when it is not feasible to increase the calcium sulfate level by the use of sulfuric acid. During temporary water shortages, treatment can be increased beyond normal to allow operation with increased cycles of concentration and reduced bleed off. Only under extreme conditions should bleed off be reduced below the safe level to prevent scale formation with maximum chemical treatment.

4.5.8 Tower Wood

4.5.8.1 Delignification

Natural glue called lignin holds wood fibers together. Chemicals can leach the lignin out of the wood and cause chemical delignification. Treated (sealed, painted, or oiled) wood products are less prone to suffer chemical delignification.

4.5.8.2 Wood Rot

4.5.8.2.1 Definition

Wood rot is the common name for biological attack of lumber. Wood rot occurs whenever water gets into crevices or penetrates the wood finish and cannot dry out, causing fungi to grow in the wood moist environment. Wood rot can be prevented by sealing the wood. However, many wood preservatives have been banned. For instance, acid copper chromate and chromate copper arsenate are listed as hazardous substances under federal environmental laws. Thus, disposal of wood treated with these wood preserving solutions may be a regulated activity. Usually fungi, reproduced from spores that are washed out of the air by the tower, are responsible for wood rot. The fungi use cellulose from the wood for the carbon essential to their growth and development. Surface rot is more apparent in the flooded portions of the tower; internal rot is more apparent in the wood members that are not covered by a film of water. Oxygen is also a requirement for growth and the flooded areas prevent oxygen from entering the wood, however, enough oxygen is present in the water to support surface growth of the fungi.

4.5.8.2.2 Salt Definition

Salt deposits resulting from evaporation also subject the wood fibers to rupture. Crystallization of salts is caused by intermittent splashing and drying of the wood.

4.5.8.2.3 Severity

Wood towers that have a life expectancy of 20 to 25 years are frequently partially or totally replaced in 10 years or less, due to wood destruction from chemical or biological attack.

4.5.8.3 Treatment

Control of wood deterioration starts before the cooling tower is put into operation. Wood used in cooling towers should not be treated with creosote preservative. Creosote treated wood exposure is regulated by the EPA and OSHA. The EPA requires that creosote spills that exceed one pound be reported. OSHA limits the amount of exposure to creosote to 0.2 milligrams per cubic meter in a workplace for an average 40-hour work week. OSHA also requires that when working with creosote treated wood, workers must be properly protected through the use of respirators, gloves, sun block, goggles/glasses, and adequate protective clothing. However, pressure-treated lumber ensures many years of protection against biological attack. Other methods used to protect the tower are the following:

- Maintain pH below 8.0 and, if possible, between 6.0 and 7.0.
- Use non-oxidizing slimicide.
- At least once a year spray areas showing biological attack with a good fungicide.
- When chlorine-based material is used, do not exceed 1.0 ppm of chlorine.
- Thoroughly inspect the tower each year.
- Replace all damaged wood with pressure-treated wood.

4.5.9 Evaporative Condensers

4.5.9.1 General

An evaporative condenser is made up of hot-gas tube banks. Water is sprayed over the coils to remove the latent heat of condensation. A portion of the water evaporates as the water passes over the condenser coils. The evaporation cools the remaining water; absorbing heat from the tube surfaces. The major difference between the cooling tower and evaporative condenser is that the tower is filled with material that exposes the water to the air stream, while the evaporative condenser uses the condenser coils as the filming area.

4.5.9.2 Problems

Evaporative condensers experience the same general problems as cooling towers and are treated and maintained in the same manner. Algae and slime present the same problem as encountered in the tower. Corrosion and scale are more apparent than in the tower; all corrosion and scaling being on the outside of the system rather than inside the piping and condenser as in the tower system. Scaling is more of a problem in an evaporative condenser than in a tower system. Due to the higher temperature of the hot-gas piping, calcium carbonate precipitates out of solution as scale sooner than it would in the tower. Proper operation and treatment may require chemical removal of scale at least once a year. Cycles of concentration must be lower than would be permissible in a tower using the same water. A good cleaning once a month, along with proper treatment and bleed, usually results in satisfactory operation with few, if any, shutdowns due to high discharge pressure.

4.6 TREATMENT OF TOWER SYSTEMS

4.6.1 Systems 30 Tons and Under

4.6.1.1 General

A system of this size is usually a package unit consisting of a fan unit, compressor, control system, etc. The system is direct expansion with a remote cooling tower or evaporative condenser. The only required water treatment is in the condenser water circuit. Regular cleaning of the tower, maintaining proper bleed off, and regular water treatment will prevent water problems from developing.

4.6.1.2 Scale and Corrosion

Untreated water can corrode and scale critical equipment. Corrosion is a process of metal dissolution, usually from oxidation. Scaling occurs as a result of dissolved solids exceeding solubility limits. Phosphate crystals are used to inhibit the deposit of calcium carbonate scale in the tower systems and also to provide protection against corrosion.

4.6.1.3 Biological Fouling

Untreated water can also support biological growth. The most common problem experienced in cooling-tower systems is the growth of green algae. If not treated, the algae spread until the system must be shut down. Good housekeeping and chemical treatment are required to control the algae and slime found in the system. When algae are noted in the tower, the tower should be cleaned and all algae growth removed.

Sodium hypochlorite commonly referred to as laundry bleach, can be used. The bleach can be purchased at any grocery store in a 5 percent liquid solution. One pint of bleach per ten tons of refrigeration should prove effective for all towers. After 1 hour of operation, the bleed off can be reestablished. If the algae growth is excessive, the tower may have to be drained to remove the dead algae. Biological growth can induce corrosion and human health concerns.

4.6.1.4 Disease Micro-Organisms

It is critical to provide consistent and effective biocide addition, such as chlorine, bromine, ozone, or hydrogen peroxide, to the cooling tower water. Untreated cooling tower water may contain legionella and other microorganisms brought in by the circulating air or water. Legionella grows easily in water were algae and scale are present and can be dispersed with aerosolized drift. Moreover, studies have linked legionnaire disease to cooling tower aerosol exposure. Therefore, water sampling is critical to determine the presence of legionnaire disease bacteria (LDB).

The Cooling Technology Institute (CTI) recommends:

- Continuous application of halogens (chlorine or bromine). Note that non-oxidizing biocides may be needed to control bio-film and planktonic organism.
- Intermittent use of halogens, if continuous is not possible.
- Hyper halogenation, which is the practice of maintaining a minimum of 5 ppm of free halogen residual for at least 6 hours.
- Emergency disinfection when legionella count is greater than 1,000 Colony Forming Units (CFU) per Milliliter (ml).

4.6.1.5 Bleed Rate

The bleed rate is determined by the hardness of local water. Once the bleed is established, a discharge permit is required. Additionally, the bleed rate should not be changed unless system conditions or water testing show that the rate is wrong. If it is apparent that the treatment program is ineffective, contact the district and regional office.

4.6.2 Systems Over 30 Tons

4.6.2.1 Contract Treatment

When complete water-treatment services are contracted, use Service Contracts for Packaged and Unitary Units, Central Heat and chilled Water Plant(s), Boilers and Cooling Tower Water Treatment and Filtration, and Distribution Systems (SECTION 7) this specification covers all phases of water treatment required in a postal installation.) All required treating and testing equipment and all necessary chemicals should be furnished by the contractor. The type and size of the system determines the method and type of treatment. Since the specification requires the contractor to warrant the system conditions, fair and competitive bids can be obtained from all major water-treatment companies.

4.6.2.2 Continuing Existing Programs

Offices that currently run their own water-treatment programs with proven success and that would not benefit from a contract (SECTION 7 SERVICE CONTRACTS) may continue their present method, if there is no objection from the regional office.

4.6.2.3 Contracting for Full Service

4.6.2.3.1 Requirements

When a contract for water treatment is being planned, all systems should be considered for inclusion in the contract. If possible, the contract should cover a two-year term with option for renewal. Either party should have the option of breaking the contract upon 30 day notice to the other party. Failure of the contractor to fulfill all contract requirements should be called to the attention of the contracting officer. (See SECTION 7 for Statement of Work).

4.6.2.3.2 Problems

All problems concerning water treatment must be reported in writing to the contractor and a copy of the letter sent to the district office. A follow-up letter should be sent, within one month of the initial letter, to the district office detailing what action was taken by the contractor to remedy the problem and if the action taken is judged to be satisfactory.

4.6.3 Scale Removal

4.6.3.1 General

Scaling is a common problem that occurs in most plants where a good water-treatment program is not carried out. When scale is formed in the condenser, the heat-transfer rate between the hot refrigerant gas and the condenser water is reduced and the system capacity decreases. Scale formation within the condenser tubes may restrict flow and increase pressure. As long as the scale exists in the condenser, the system will work harder and produce less cooling. As the scale increases, the system tonnage goes down and the electricity consumption goes up. The cost of water treatment is insignificant compared to the overall cost incurred as a result of untreated water. Therefore, it is paramount to appropriately treat all make-up water systems.

4.6.3.2 Removers

4.6.3.2.1 General

Generally, acids only remove soft scale build up. Hard scale build up may be removed mechanically or by blast cleaning. There are many types of acid used to remove scale. Many factors must be considered before using an acid; cost, danger (both to personnel and equipment), time, method, and ease of operation. As a means of introduction to the wide field of available acids. Table 4-4 lists the three general types of acids and the individual acid under each group used to remove material from equipment. Each of the acids is used to some extent in chemical cleaning. However, in air-conditioning systems, three of these acids, hydrochloric, sulfuric, and sulfamic, are usually relied upon for removal of all types of scale or fouling. Table 4-4 lists the commercial concentration and specific gravity of three acids listed. These acids are not inhibited against metal attack.

Table 4-4. Acids

A. Classifications and Formulas		
Group	**Acid**	**Formula**
Mineral	Hydrochloric (Muriatic)	HCl
	Sulfuric	H_2SO_4
	Nitric	HNO_3
	Phosphoric	H_3PO_4
Dry	Sulfamic	H_2NSO_3H
	Sodium Bisulfate	N_aHSO_4
Organic	Formic	HCOOH
	Acetic	$C_2H_4O_2$
	Citric	$C_6H_8O_7$
B. Concentration and Gravity		
Acid	**Concentration %**	**Specific Gravity Degree Baume**
Hydrochloric HCl	28-38	18-23
Sulfuric H_2SO_4	78-93	60-66
Sulfamic H_2NSO_3H	Dry Powder	Dry Powder

WARNING

Heat is produced when acid is mixed with water. Use caution and proper safety gear when working with acids. Never pour water into acid--always pour the acid into water. Adding water to acid is similar to adding water to boiling oil. The hot oil causes the water to flash into steam and explosively splash out the hot oil. Dry acids such as sulfamic, used as a descaler, will burn bare skin because of skin moisture. Treat dry acids the same as liquid acids. When acid is used to control the pH in a cooling tower or atmospheric condenser system, the acid must be automatically pumped directly from an acid carboy into the system. Sulfuric acid must not be handled, mixed, or otherwise used except in approved acid carboys as received from the chemical company. Failure to comply may cause injury or death.

WARNING

Acidizing of equipment is inherently hazardous. Only trained and competent individuals using the proper permits, SDS, and PPE shall perform acidizing of equipment. Disposition of the wastewater shall adhere to the Clean Water Act. Failure to comply may cause injury or death and/or equipment damage, including punitive legal action.

4.6.3.2.2 Hydrochloric Acid (HCl)

Hydrochloric acid is a mineral acid in a water solution containing 28 to 38 percent hydrogen chloride. Hydrogen chloride is a gas, but is easily dissolved in water. The solution is very aggressive, and effective buffers must be added to the acid solution to make it useful as a descaler.

WARNING

Proper ventilation is required when using any type of chemical or acid. Carbon dioxide gas (CO_2) is formed when acid is used to remove scale. Never inhale the fumes from any chemical or acid. Failure to comply may cause injury or death.

4.6.3.2.3 Sulfuric Acid (H_2SO_4)

CAUTION

Sulfuric acid cannot be buffered sufficiently to make it harmless to metal when used in the low pH range. Do not use sulfuric acid (H_2SO_4) as a scale remover. Failure to comply may cause equipment damage.

WARNING

Heat is produced when acid is mixed with water. Use caution and proper safety gear when working with acids. Never pour water into acid--always pour the acid into water. Adding water to acid is similar to adding water to boiling oil. The hot oil causes the water to flash into steam and explosively splash out the hot oil. Dry acids such as sulfamic, used as a descaler, will burn bare skin because of skin moisture. Treat dry acids the same as liquid acids. When acid is used to control the pH in a cooling tower or atmospheric condenser system, the acid must be automatically pumped directly from an acid carboy into the system. Sulfuric acid must not be handled, mixed, or otherwise used except in approved acid carboys as received from the chemical company. Failure to comply may cause injury or death.

Sulfuric acid is used as an alkalinity reducer. When it is the main acid used in an acid-treating system, it is easy to protect the system metal in the pH range of 6.0 to 7.5 (the range normally used in acid-treated systems). The acid costs less per pound than other acids and the cost of using H_2SO_4 in the tower water is usually recovered by the water saved as a result of increased cycles of concentration.

4.6.3.2.4 Sulfamic Acid (H_3NO_3S)

Sulfamic acid is a dry, crystalline material, readily soluble in water to give acid solutions. The dry acid is easy to handle, mixed with solid inhibitors and surfactants, and packaged as a dry descaler. The acid solution is less aggressive than the mineral liquid acids and the cost is almost double the cost of HCl. However, this is more than offset by the increased safety, ease of transportation and ease of use. All dry acid descalers sold to remove common scale buildup are blends of sulfamic acid, inhibitors, and surfactants, plus other material added for specific uses. Ammonium bifluoride is added to sulfamic acid for removal of silica scale. These same substances are also used with HCl.

4.6.3.3 Descaling Methods

Descaling can be accomplished mechanically or chemically. Mechanical descaling falls under a host of activities such as grinding, brushing, sanding, sandblasting, water blasting, ice blasting, jetting, and polishing. Chemical descaling could be acidic or basic depending on the composition of the scale. However, both methods have disadvantages. Mechanical cleaning may require extensive equipment dismantling and all scale may not be removed. Chemical cleaning may corrode the equipment, cause stress cracking, or adversely affect elastomers. Additionally, it may create disposal problems. Therefore, it is important to carefully analyze the scale, so that the best method of descaling may be selected.

4.6.3.4 Scale Composition

4.6.3.4.1 Determining Scale Type

With the hot end of the condenser opened, check for any scale. There are many possibilities for scale composition but, if the scale is white and powdery-looking, it is probably calcium carbonate. If it is brown and resembles a mixture of dirt and sand, it may be phosphate scale. A hard, flinty scale is probably silica scale. Sulfate scale color may vary, but it is a hard scale and easy to distinguish from a carbonate scale. Iron deposits are easy to identify. The best method for identifying scale is to take a sample of the scale material and see if it is readily dissolved in a small amount of acid solution. If gas bubbles are evident, calcium carbonate is present, and a reaction is taking place. A true sulfate scale will prove hard to remove and will be very slow to dissolve in the acid. Silica scale also shows very little reaction. Scale can also be tested at a qualified laboratory.

4.6.3.4.2 Removal

Calcium carbonate accounts for over 80 percent of all scale. The thickness of the scale shows the amount of scale in the system. The more scale there is in the system, the more acid it will require to remove the scale. The following items affect the amount of acid needed to remove scale from a system; number of gallons of water in system; temperature of water; type of scale; amount of scale; pH of water; other chemicals used in the system; cleanliness of system (other than scale); type of acid descaler; and concentration of acid in descaler.

4.6.3.5 Acid Type

4.6.3.5.1 Dry Sulfamic

Unless a special acid is required, use the dry sulfamic acid descaler. It is safer than other acids.

4.6.3.5.2 Solution pH

Since all descalers work their best in the lower pH range, pH is used as a control point for acid solutions. A pH of 1.5 is fairly standard for best results. This means some method is needed for checking pH. An electric pH meter is very useful, but pH test strips work as well. As the acid is used up, it must be replaced until all the scale has been consumed or has reacted with the acid.

WARNING

Explosive gases, such as hydrogen, may be produced when chemicals react with certain metals. Keep fire, sparks, etc., away from any descaling operation. Failure to comply may cause injury or death and/or equipment damage.

4.6.3.5.3 Determining Solution Amount

As a general guide for carbonate scale, one gallon of HCl descaler is recommended for every 15 gallons of water and 5 pounds of sulfamic descaler for every 10 gallons of water. This is the initial charge only; additional acid is necessary to maintain the pH level. Another rule of thumb method for determining acid needs is to add 15 pounds of dry acid or 2 gallons of liquid HCl for every 10 tons of system capacity. More acid is needed for heavily scaled systems. However, consultation with a cleaning service provider is highly recommended.

4.6.3.6 Acidizing Methods

4.6.3.6.1 General

There are two methods used to acidize a system. General acidizing requires keeping the system in operation. Acid is fed into the tower sump, and the entire system is acidized. If the amount of water in the system is very large and, if necessary valves are installed, the condenser can be sealed off from the remainder of the system and acidized, thereby reducing treatment cost. This method is referred to as local acidizing.

4.6.3.6.2 Local Acidizing

In local acidizing, the air-conditioning system must be shut down and the condenser valves closed to isolate the condenser from the rest of the system. Connections must be available in the inlet and outlet pipes to connect circulating hoses and valve impervious to the acid solvent. A tank or drum equipped with a small circulating pump impervious to acid is also required to circulate the solution through the condenser (Figure 4-1). This method of acidizing has both good and bad points, and local conditions must be taken into consideration before deciding on using it.

The advantages of local acidizing are: less acid is required, resulting in less cost; less metal, gaskets, and elastomers are exposed to the acid; and there is no danger of foaming over and causing damage to private property.

The disadvantages are: the system must be shut down; the temperature cannot be maintained, resulting in longer time to complete the job; special equipment is needed; and acidizing produces CO_2 gas, making adequate ventilation a necessity. It is also possible that the cooling tower itself may need cleaning and this method does not provide any cleaning of the tower. The waste acid solution must be properly disposed and may require the National Pollution Discharge Elimination System permit.

4.6.3.6.3 General Acidizing

WARNING

Acid solutions are hazardous. Never use acid solutions (descalers are acid) over 160°F. Never agitate acid solutions with air. Failure to comply may cause injury or death.

General acidizing uses the solution in the entire system as a cleaning solvent. The condenser-water pump is used to circulate the solution.

The advantages of general acidizing are: less trouble; the system is in operation during the acidizing; the entire system including the tower is cleaned; no extra equipment is needed; and all CO_2 gas produced is released in the tower.

The disadvantages are: the high cost (more acid required), and the danger of tower drift blowing on personnel or private property. This danger can be reduced by using an antifoam material. Some companies supply small packages of antifoam with their descalers, but the material can be purchased from any chemical company or refrigerant supply house.

The time required to acidize a system depends mainly on the amount of scale in the system, the pH of solvent, and most important, the temperature of the acid solution. Generally, acids are most effective at a temperature of 150 to 160°F. It is not considered safe to exceed 160°F, as the inhibitors are not effective above this temperature. Maintaining the temperature of the solution as high as possible without exceeding 160°F increases the effectiveness of the acid and reduces the time necessary to complete the job.

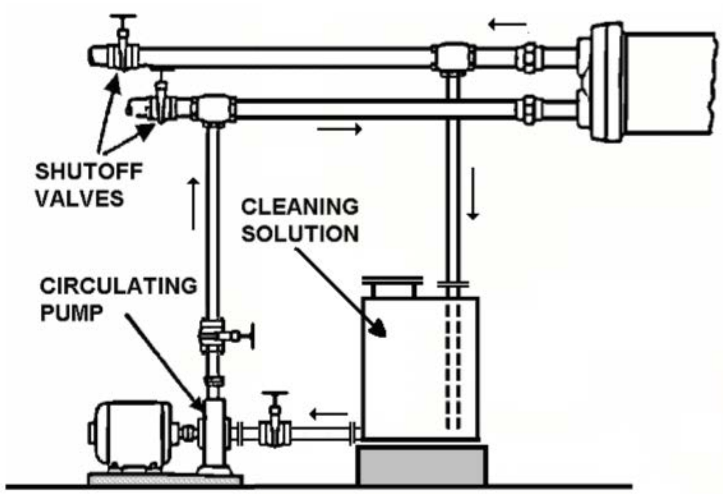

Figure 4-1. Local Acidizing

A descaler works by ion exchange, whereby the negative acid combines with the positive scale and an ion of each is given up or cancels out another. This is similar to the action of a zeolite water softener where sodium chloride (which is negative) removes positive ions from the water (scale-forming minerals) and makes the water soft. The calcium ions are replaced with sodium ions that are not scale-forming.

Some descalers remove a pound of scale per pound of acid and others require 3 pounds of acid to remove a pound of scale. This is due mainly to the ratio of acid to other ingredients. A cheaper acid may end up costing more than a higher priced acid.

Due to an increase of negative ions, when the acid is added to the water the pH drops. As the acid reacts with scale, the negative ions are cancelled out by positive ions so the pH starts back up. As long as more acid is added, the low pH is maintained. When the scale is all dissolved, there is no further reaction, and the pH stabilizes or remains at the low level. This means that all the scale is removed.

However, the job is not finished until the system is drained, refilled, and checked to make sure that all equipment is operating satisfactorily. The pump strainer should be checked for loose material; a check should be made for piping leaks; and the float valve should be adjusted in the tower basin.

Acidizing or chemical cleaning is not complicated or difficult, if a few simple rules are applied. The following procedures can be used:

- Gathering Information. The necessary data should include: system conditions; what needs cleaning; type of scale; best method to use (local or general acidizing); gallons of water in system (as close an estimate as possible); and whether the system contains oil or grease. This information should determine if acidizing is necessary; if the system should be pretreated to remove any oil or grease; what type of scale is in the system; the best acid and method to use to clean the system; and an idea of the amount of acid descaler needed and appropriate disposal method.
- Pre-cleaning the system. If an oil film is present in the system, it can be removed by adding a low-foaming household detergent to the system. One and one-half pounds of detergent for every 100 gallons of water circulated at normal operating temperature for 15 to 20 minutes should remove all traces of oil. The tower should be cleaned before any acidizing is started. The basin should be cleaned of all loose material and as much algae as possible removed, since acidizing will kill all algae loose in the system. If local acidizing is to be used, the tower would not have to be cleaned, but it is recommended that the entire system be cleaned before the job is finished. If the system is cleaned with detergent to remove all residue, it is not necessary to drain the system to start the acidizing.

4.6.3.7 Acidizing Procedures

4.6.3.7.1 Local Acidizing

If local acidizing is the best method, and the system is equipped with the necessary drain and block valves, proceed as follows: shut down the system; use the condenser block valves to isolate the condenser from the system; and drain the condenser. Connect the acid hoses, drum, and pump to the condenser (Figure 4-1). Fill the drum with hot water and the recommended amount of descaler material. Circulate the solution through the condenser while checking the pH of the returning solution and adding more descaler material to maintain a pH of between 1.0 and 2.0 in the drum. ($C0_2$ gas bubbles from the solution indicate that carbonate material is being removed from the condenser, but the pH test is the best method to determine when the job is finished). Frequently check all joints to determine if leakage is occurring.

WARNING

Employees must be trained and competent to work with chemicals. The drum or tank containing the chemical solution should be clearly marked and secured. Proper PPE shall be worn at all times. Failure to comply may cause injury or death.

4.6.3.7.2 Heating

If the acid solution can be heated, it will speed up the descaling action and reduce the time required. It is possible to use live steam or electric heating cables to increase the temperature of the drum solution. Fire or an open flame must be kept away from the operation.

WARNING

Steam can scald and electricity can cause electrocution. Use proper safety precautions at all times. Failure to comply may cause injury or death.

4.6.3.7.3 Heavy Scale

For extremely heavy scale, it is necessary to properly dispose of the wasted solution and start over with a fresh mix, since the removed scale will slowly build up in the solution until it is saturated with solids. Before disposing of the acid solution, allow the pH to rise to at least 6.0 and follow the Clean Water Act, as well as state, federal and USPS disposition guidelines. If the pH does not raise enough, any type of alkaline material, such as soda ash or caustic soda, can be used to raise the pH. This prevents corrosion of drain lines. Do not spill or flush the used solution to the environment, except if legally permissible.

4.6.3.7.4 General Acidizing

If the general method is used, the acid descaler is added to the tower-basin intake while the system is operating. The initial charge should be added and the pH checked to determine if the pH is between 1.0 and 2.0. It may be necessary to shut off the tower fan to increase the temperature of the circulating solution. The pH level should be held by adding acid until the pH level stabilizes between 1.0 and 2.0 without additional feed. The pH then should be raised to 6.0 and the system drained. Follow the Clean Water Act, state, federal, and USPS guidelines for draining, containment, and disposal of all used solution. The tower basin should be checked for material and flushed out if necessary. If the system is to be put back into operation, it is not necessary to flush the system. If the system is to be laid up, it should be filled, the pH checked to make sure it is above 7.0, and the water allowed re-circulate for 30 minutes before the system is shut down and drained for lay-up.

4.6.3.8 Safety Requirements

NOTE

This is not a complete list of safety regulations. Good common sense plus the required technical knowledge goes hand-in-hand to produce and maintain a safe work environment.

Personnel should be trained in the handling of chemicals and always follow these procedures:

- If liquid descaler is used, make sure 1-gallon, unbreakable, labeled, and closeable plastic containers are specified.
- If dry-powder acid is used, keep completely dry until mixed for use. Mixing container should be labeled and dry-powder should not disperse in the environment.
- Use and wear safety gear. Long sleeve shirt, long pants, rubber aprons, gloves, and goggles are a must. Obtain and review SDS.
- Pour acid into water; never pour water into acid.
- Do not permit acid to contact bare skin or eyes.
- Keep all fire, sparks, etc., away from descaling operation.
- Do not spill solution. Keep solution from concrete floors or other material that might be damaged, as well as drains.
- Explosive gases may be produced, depending upon reaction of acid on different metals in system. Ensure that metals that would induce explosive gases are not present in the system.
- Make sure proper ventilation is supplied. When using local acidizing, special care is necessary to prevent accumulation of CO_2 gas.
- Always fill closed units from the bottom up.

- Check for leaks before acidizing. Do not acidize systems known to have leaks.
- When using a pump for local methods, make sure the pump is checked for proper material of construction, that it is grounded and all wiring is safe.
- Check drum and pump before using. Acid will slowly destroy both.
- Do not agitate acid solutions with air.
- Never acidize systems with aluminum parts.
- If tower is galvanized steel, use local method if possible.
- Do not dump chemical solutions in sewer or drain on ground.
- Use antifoam if necessary and prevent foam or tower drift from blowing on personnel, cars, etc.
- Dispose of used acid solutions. Never store acid in metal containers.
- Never use acid solutions over 160°F.
- Keep unauthorized persons away from descaling operation.
- Make one person responsible for entire operation and do not leave equipment until the operation is finished.
- Complete all acidizing operations the same day. Do not leave acid in system unless responsible person is present.
- Keep constant watch for plugged pump strainer or blocked lines during operation.
- Use good common sense at all times.

4.7 GLYCOL ANTIFREEZE IN CHILLED-WATER SYSTEMS

WARNING

Glycol solution may be classified as a hazardous material. Check with environmental engineering to determine if the glycol solution is classified as a hazardous material. If so, at disposal it becomes a hazardous waste subject to Environmental Protection Agency guidelines for proper storage, handling, disposal, and documentation. Follow all legal requirements for proper disposal. Failure to comply can cause environmental damage and/or result in criminal prosecution.

4.7.1 General

The toxicity of glycol solutions requires that any system using glycol be isolated from potable-water systems. The system using glycol must not have any cross-connection between it and the potable-water system that is not in accordance with local codes. If the systems are cross-connected, there are two acceptable methods of repair; removing the connecting piping or installing a reduced-pressure zone-type backflow preventer between the systems. Check valves are not suitable for this application.

4.7.2 Inhibitors

Ethylene glycol is corrosive and toxic and requires the use of inhibitors and buffers. The inhibitors normally used with glycol exhaust themselves, due to contact with oxygen and heat. Periodic tests should be run to ensure proper levels of inhibitor. Galvanized surfaces in particular are prone to attack by glycol solutions. Glycol should not be used with such types of water treatment as oxidants. The water-treatment chemical manufacturer should be consulted about compatibility before using glycol in the chilled-water system.

4.7.3 Use

Using ethylene glycol in a chilled-water system results in decreased system efficiency and capacity. This decrease in efficiency and capacity is a result of changes in the viscosity and specific heat of the mixed water and glycol. Increasing the percentage of glycol in the solution increases the problem. If glycol is used, it should be mixed in the lowest percentage that offers adequate freeze protection to minimize the reduction in efficiency and capacity.

4.7.4 Actual Tons

4.7.4.1 General

When figuring actual tons of refrigeration on Form 4994, Operating Log for Centrifugal Refrigeration Plants, two corrections must be made in the formula.

4.7.4.2 Evaporator Flow

The chilled-water flow reading in gallons per minute (gpm) requires correction due to the increase in viscosity of the solution. The manufacturer of the flow meter used in the system should be consulted for flow-correction factors. This factor must then be used when figuring evaporator flow in gpm.

4.7.4.3 Specific Gravity and Heat

The changes in specific gravity and heat of the solution also require correction. A chart supplied by the chemical manufacturer is used to find the correction factor when the specific gravity of ethylene-glycol solution in the system is known. When the percentage of ethylene glycol in the solution is known, use the chemical manufacturer’s chart to determine the correction factor (The factor is always less than one). The following formula is then used:

$$\text{Tons} = \frac{GPM x TD}{24} \text{ x Correction Factor}$$

NOTE

Where gpm is corrected flow rate in gallons per minute, TD is temperature difference in °F of the solution entering and exiting the evaporator.

4.8 WATER TESTING

4.8.1 General

Water treatment testing is the review of the water treatment program performance on a continuing basis to determine whether the program is achieving the established objectives. The importance of water treatment testing is to control overfeeding or underfeeding of water treatment chemicals and to detect water impurities. Failure to test and monitor the water treatment system will result in adverse consequences.

4.8.2 Controls

Due to constantly changing conditions, it is necessary to keep strict control on chemical levels and to recognize danger signs in water analysis reports. Water testing is used here to describe the required tests made locally to maintain set limits on conditions or chemicals. Water analysis is used to describe a series of tests made to show the entire water makeup.

4.8.3 Water Tests

Frequent water tests, and test follow-ups, enhances the quality of the water treatment program. On a once-through water system, where the water is in the system for a total of perhaps 5 minutes, a monthly test would show what the condition of the water was at the time the sample was taken, but it would not show what occurred between tests. If any phase of the treatment is critical, it must be checked often enough to ensure that treatment levels are being maintained.

4.8.4 City-Water Analysis

4.8.4.1 General

Although the system may be in perfect operating condition, a city-water analysis report is very important and has a direct effect on the treatment of the cooling-water system where city water is used as makeup water.

4.8.4.2 Analysis

The process of water evaporation leaves minerals behind in the circulating water. The term cycles of concentration compares the level of impurities in the circulating water to the level of impurities of the original raw make up water. If the circulating water has four times the impurity concentration than that of the make-up water, then the cycles are 4. Where city water is used, a complete water analysis can be obtained by calling the local water department.

4.8.4.3 Analysis Results

Water analysis results are stated in parts-per-million (ppm). One part-per million means one part in a million parts. Since ppm, as defined in water treatment work, is a measure of proportion by weight and is equal to a unit weight per million unit weights of solution, the units (pounds, gallons, etc.) must be defined to know what is being compared. Hardness or total hardness is listed in ppm and expressed as calcium carbonate ($CaCO_3$).

4.8.5 Water Testing For Control

Although a complete water analysis is very important in water treatment, there is no need to make unnecessary tests when checking chemical levels in the system. If it is necessary to operate a zeolite water softener by hand, based on water tests, the hardness of the outlet water would have to be known to determine when to recharge the unit, and the chloride content of the rinse water would have to be known to determine when to end the rinse cycle. Other tests would be of no value. Control tests are made to determine that a certain level of treatment or condition exists, and if the treatment should be altered to stay within the control range. Control testing should be backed up by frequent complete analysis to ensure that all conditions are satisfactory and to verify the control check accuracy. When a water-treatment program is determined for a particular plant, a control range for each condition is also determined and it then becomes the responsibility of Plant Maintenance to maintain the condition in the system within the approved or recommended level.

4.8.6 Testing Methods

4.8.6.1 Acceptable Methods

There are many types and methods of testing water. A chemical laboratory uses equipment that gives very accurate results, but this accuracy is not necessary in the field for control purposes. Control tests should be conducted with equipment that is easy to use. The tests should require little time to conduct and should give fairly accurate results when used by persons with no formal chemical training. Titration and colorimetric are the most common types of testing used in the field, although some offices make use of electric pH meters and conductance meters when the testing is required to be accurate or is required frequently. Titration is the process of adding a standard solution to a prepared sample until a color change or endpoint is reached. The amount of standard solution used determines the ppm of the desired test. Colorimetric analysis is a procedure where a measured sample is prepared and matched to a color standard. The easiest test kit to use is referred to as a drop-test kit. The standard solution is added one drop at a time from a small plastic bottle and the drops are counted until the endpoint is reached. Some drop-test kits give results in grains per gallon (gpg). This reading can be changed to ppm by multiplying by 17.1. Testing requirements are determined by the type of system, treatment used, makeup water, and degree of control necessary to obtain the proper results. Drop-test kits should be used at all offices where it is necessary to control system water by adjusting chemical treatment.

4.8.6.2 Unacceptable Methods

Efficacy claims for most non-chemical devices have not been independently validated. However, some firms have been promoting these devices as an effective substitute for chemical treatment. They indicate that non-chemical devices require little or no chemical treatment to solve or prevent water related problems, such as scale, corrosion, slime, odor, and even biological growth. Accordingly, these devices function by electronic, electrostatic, magnetic, ultrasonic, and other physical principles. Findings from a non-peer review study, Chemical vs. Non-chemical Cooling Water Treatment - a Side-by-Side Comparison, indicated that non-chemical towers delivered more consistent microbiological control for aerobic and anaerobic planktonic organisms as compared to chemical tower. Nonetheless, the Department of Defense Unified Facility Criteria recommends against using non-chemical devices as a comprehensive water treatment or trials.

4.9 CONTRACTING FOR WATER TREATMENT

See SECTION 7 for contracting water treatment services.

Additional information from reputable organizations, such as American Society of Heating, Refrigerating & Air-Conditioning Engineers may be used to augment the information in this Handbook.

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SECTION 5

HEATING

5.1 GENERAL

5.1.1 Scope

This chapter covers the recommended procedures for the safe, economical operation and maintenance of automatically fired boilers. It is not intended to serve as operating instructions for any specific heating plant. Due to the wide variety of types and makes of equipment used, this chapter should be supplemented with the manufacturers' specifications concerning maintenance, care, and specific written operating instructions for each system.

5.1.2 Inspection of New Boilers

Before any new heating plant (or boiler) is accepted for operation, a final (or acceptance) inspection must be completed and all items of exception must be corrected. In addition to determining that all equipment called for is furnished and installed in accordance with the plans, specifications, and applicable codes, all controls must be tested by a person familiar with the control system. Boiler design must be based on ASME *Boiler and Pressure Vessel Code* Section I for Power Boilers and Section IV for Heating Boilers, and good engineering practices. Additionally, United States Postal Service (USPS) policy is to upgrade associated equipment to meet current code requirements (*AS-530-2004-9*).

5.1.3 Safety

5.1.3.1 General Guidelines

WARNING

Ensure personnel operating boilers fully understand the operating characteristics of each particular boiler as described in the manufacturer’s documentation before attempting to place the boilers into service. The manufacturer’s manual must be studied and personnel must be trained before operating a boiler. Proper ventilation requirements must be met to avoid breathing hazards. Water chemistry requirements must be monitored to avoid equipment damage which may result in hazardous leaks or explosions. Pressure relief valves often require periodic tests or certifications for proper functionality which must be performed as described in the manufacturer’s documentation. Never exceed operational limits contained in the manufacturer’s documentation. Failure to follow directions and warnings can result in property damage, serious injury, or death.

Safety is very important in boiler operation and should be foremost in the minds of those who operate and maintain heating systems. Only properly trained, qualified personnel may work on or operate mechanical equipment. Adequate supervision must be provided.

5.1.3.2 Lighting

The boiler room must be well lighted and equipped with an emergency light source in case of power failure. If a flashlight is used for this purpose, it must be maintained in working order and protected against removal from the boiler room.

5.1.3.3 Ventilation

The boiler room must have an adequate air supply that permits clean, safe combustion and minimizes soot formation. An unobstructed air opening must be provided. It may be sized on the basis of 1 square inch free area per 2,000-Btu maximum-fuel input of the combined burners located in the boiler room, or as specified for the particular job conditions in the National Fire Protection Association (NFPA) standards for oil-and gas-burning installations. The boiler room air supply openings must be kept clear at all times. Additionally, boiler rooms must be monitored for the critical hazards of combustible and toxic gas conditions. The key gases of concern are combustible gases and carbon monoxide.

5.1.3.4 Fire Protection

Fire-protection apparatus and fire-prevention procedures for boiler room areas should conform to recommendations of the NFPA.

5.1.4 Water and Drain Connections

5.1.4.1 Water Connections

Proper and convenient water-fill connections must be installed. Provisions should be made to prevent boiler water from back feeding into the service water supply. A convenient water supply that can be used to flush out the boiler and to clean the boiler room floor should be provided in every boiler room.

5.1.4.2 Drain Connections

Proper and convenient drain connections should be provided for draining boilers. Unobstructed floor drains properly located in the boiler room will make proper cleaning of the boiler room easier. Floor drains that are used infrequently should have water poured into them periodically to prevent the entrance of sewer gases and odors. If there is a possibility of freezing, an antifreeze mixture should be used in the drain traps. Discharges to drains shall abide by the Clean Water act.

5.1.5 Housekeeping

Generally, a neat boiler room indicates a well-run plant. The boiler room should be kept free of all material and equipment not necessary to the operation of the heating system. Good housekeeping should be encouraged, and procedures should include routine inspections to maintain the desired level of cleanliness.

5.1.6 Posting of Certificates and/or Licenses

Boiler safety inspection certificate PS *Form 279A* must be mounted as follows:

Boilers - On the wall closest to the front of the burner of the boiler.

Unfired Pressure Vessels - On the pressure vessel or the closest wall.

5.1.6.1 Posting Emergency Shut-down Procedures (ESP)

The site's Integrated Emergency Management Plans (IEMP) and OSHA 1910.38 should include a step-by-step Emergency Shutdown Procedure (ESP) available to use as a checklist to verify that ESP on the boiler was completed per procedure. The checklist should contain information regarding the desired status of equipment following the ESP (OSHA 1910.38 for additional requirements).

5.1.6.2 Evacuation

There should be procedures covering evacuation of the area and a method for accounting for personnel.

5.1.7 Record Keeping and Logs

5.1.7.1 Schematics, Diagrams, and Instructions

All drawings, wiring diagrams, schematic arrangements, manufacturers' descriptive literature, and spare parts lists, and written operating instructions should be kept permanently in the boiler room or other suitable location so they are available to those who operate and maintain the boiler. Where space permits, drawings and diagrams should be framed or sealed in plastic and hung adjacent to the related equipment. Other material should be assembled and enclosed in a suitable binder. When changes or additions are made, the data and drawings should be revised accordingly.

5.1.7.2 Log Book

A permanent log book should be provided in each boiler room to record maintenance work, inspections, certain tests, and other pertinent data. Brief details of repairs or other work done on a boiler plant (including time started, time completed, and signature of person in charge) should be recorded. Performance and results of tests, inspections, or other routines required by codes or laws, insurance company inspection reports, and initial acceptance test data should be recorded. In addition to a permanent log book required by ASME Section VI, boiler daily log sheets PS Form 4846 Steam and PS 4846-A Hot Water are also required on **boilers over 400,000 Btu/hr**. Log sheet samples are shown in Appendix A.3 Low Pressure Heating Boiler Operating Log (Hot Water) (Form 4846-A) and Appendix A.4 Low Pressure Heating Boiler Operating Log (Steam) (Form 4846). Form 4846 and Form 4846-A are available online from the USPS PolicyNet Forms Webpage ((https://blue.usps.gov/formmgmt/forms/4846.pdf) and (https://blue.usps.gov/formmgmt/forms/4846A.pdf)).

5.1.7.3 Maintenance Schedules and Records

A suggested chart-type log for scheduling and recording maintenance work, testing, and inspection performed during any one period is shown in Appendix A.5, Maintenance, Testing, and Inspection Log; Heating Boilers. The routine work normally performed on heating boilers is listed. As each portion of the work is completed, the initials of the person performing the work and the date should be entered in the appropriate space.

5.1.8 Fuels

5.1.8.1 General

Gas and Electricity are the principal fuels used in boilers. Oil is also a source of heat.

5.1.8.2 Gas

5.1.8.2.1 Heating Values

Gas used for fuel comes in the form of natural, manufactured, mixed, or liquefied petroleum (LP) gas. Natural, manufactured, and mixed gases are normally distributed through underground piping, and require no storage facilities. Heating values of these gases in Btu per cubic feet are:

	Low	**High**
Natural Gas	950	1150
LP Gas	2500	3300
Manufactured Gas	350	600
Mixed Gas	600	800

5.1.8.2.2 Natural Gas

Natural gas, commonly referred to as gas, is a gaseous fossil fuel consisting primarily of methane. It is found in oil fields and natural gas fields, and in coal beds. Natural gas is an excellent boiler fuel and requires only simple equipment for burning. Most suppliers now add a chemical to the gas which results in an objectionable odor so that leaking gas will be noticed before the concentration of gas becomes dangerous. The composition of the gas varies according to the source. However, methane is always the major part and usually is combined with ethane and nitrogen.

5.1.8.2.3 Standard Heating Value

Gas suppliers have a standard heating value that they agree to maintain. Although most maintain a 1,000-Btu/Ft^3 rating, the local gas office should be contacted if the exact rating is unknown. When the Btu rating is available, a simple time check using a stopwatch and the meter reading while the boiler is operating at full load will determine the number of cubic feet per minute (cfm) of gas used in the boiler. This is the method used to check Btu input of a burner, and the local gas company will usually provide assistance in making this test.

5.1.8.2.4 Efficiency Tests

The amount of heat extracted from fuel depends on the efficiency of the combustion process, which can be determined by a flue gas analysis. A flue gas analysis requires special equipment and tests samples of the flue gases leaving the boiler. This is performed by inserting a probe into the flue of the boiler, or furnace, between the last heat exchanger and draft diverter or any source of dilution air that could enter the flue that did not pass through the combustion process. This is known as 'in-situ' testing. It is also necessary to take a combustion air temperature measurement or ambient temperature if that is the source of combustion air. Results of a good test would show no carbon monoxide present, approximately 20 percent excess air, and a carbon dioxide reading between 7 and 11 percent at a stack temperature between 400 and 500°F. By using the above readings as an example, a fuel-efficiency table should show an efficiency rating of 78 to 82 percent. This means that for each cubic foot of gas used in the burner, 78 to 82 percent of the heat content is absorbed into the boiler. The remaining heat content is lost by heating of the air required for combustion, and heat going up the stack. Output of individual boilers and burners may vary somewhat from these figures; the manufacturer's operator's manual should be used to determine the exact figures pertaining to a certain burner or boiler.

5.1.8.2.5 Liquefied Petroleum Gas (LPG)

Liquefied petroleum gas is normally stored in tanks at high-pressure so that it will remain in a liquid state. Storage may be either above or below ground. Storage of LPG within buildings is prohibited and storage outside building shall conform to distance requirements (OSHA 1926.153). Storage and handling requirements should be in accordance with NFPA Pamphlet #58, OSHA 1910.110 and OSHA 1926.153, and local regulations (To obtain *Pamphlet #58*, write to National Fire Protection Association; 1 Batterymarch Park; Quincy, MA 02269-7471; ATTN: Publications--Sales Division). Welding to any part of the LPG container subject to pressure shall comply with the code under which the vessel was fabricated. The liquefied fuel is reduced in pressure and its state is changed to a gas at the required pressure for the burner. Propane or butane gas has a heating value of 2,500 to 3,300 Btu/cu ft. Modification of the fuel-burning equipment is necessary when changing from liquefied petroleum gas to other gases or from other gases to liquefied petroleum gas.

5.1.8.3 Fuel Oils

5.1.8.3.1 Classification

Fuel oils are liquid mixture produced from petroleum and mainly used for industrial and domestic heating, and for the production of steam and electricity in power plants. They are hydrocarbons containing between 84 and 85 percent carbon, 12 to 14 percent hydrogen, and small amounts of oxygen, nitrogen, and sulfur, with traces of moisture and solid material. Fuel oils are graded in accordance with the specifications of the American Society for Testing Materials (ASTM D 396). There are six grades of fuel oil; however, grade 3 is no longer manufactured. Oils are classified by their viscosities, as well as flash point, pour point, water and sediment content, sulfur content, ash, and distillation characteristics. Fuel oils are prepared for combustion in most low-pressure boiler burners by atomization (spraying). Types of atomization commonly used are:

high-pressure mechanical atomization, low-pressure mechanical atomization, centrifugal atomization (rotary cup), compressed-air atomization, and steam atomization.

5.1.8.3.2 Use

Fuel oil may be the only fuel used in a boiler or, where natural gas is the primary fuel, fuel oil may be used as a standby fuel. In some sections of the country where the natural gas supply is critical or subject to interruption, large users of gas are required to maintain a standby fuel so gas service can be interrupted without loss of heating capabilities. Fuel oil is procured from local suppliers and stored on-site in storage tanks for use as needed. Most plants cannot store a normal year's supply of fuel and, where experience has shown a fuel oil shortage to be possible, fuel oil usage must be anticipated and storage tanks refilled so that an adequate supply is available during a heavy usage period.

5.1.8.3.3 Specifications

Fuel oil specifications must show the Btu heating value, specific gravity, sulfur content, viscosity, and allowable sediment, so that all oil purchased is consistent in quality and usage. No replacement burners shall be installed on fuel oil fired boilers without first evaluating the feasibility of modification to an alternate fuel source. In addition, this same evaluation must be performed prior to any major modifications and repairs to the boilers. Oil burners are designed and adjusted to fire with certain grades of oil; care must be exercised to ensure that all fuel oil used meets a particular air requirement. Air adjustments may be necessary every time a change is made from one oil tank or type of oil to another. A flue-gas analysis should reveal a carbon dioxide reading of 8 to 13 percent without smoke or carbon monoxide. A range of 10 to 13 percent is normal for most burners. Excess air should range from 3 to 15 percent, and the stack-gas temperature should be between 400 and 650°F. Efficiency figured by a combustion slide chart will normally range from 80 to 82 percent. A stack-gas temperature less than 380°F above room temperature may cause the moisture in the stack gases to condense and cause what resembles fly ash to leave the stack. Any sulfur in the fuel combines with the moisture to form sulfuric acid, causing corrosion of the stack and breeching. Outside air inlets for combustion air should provide at least one square inch of inlet area open space for each 2,000 Btu input. That would mean about 70 square inches for each gallon of fuel used per hour. Smoke level should not exceed No. 1 when checked by the conventional spot-type smoke tester.

5.1.8.3.4 Fuel Oil Grades

Fuel oil grades are as follows:

- Grade Number 1 is light-viscosity distillate oil intended for vaporizing pot-type burners. The heating value is approximately 135,000 Btu/gal. It has little or no lubricating qualities, and should not be used exclusively on systems where the oil pump receives lubrication from the oil it pumps. It can, however, be used to reduce viscosity of other oils.

- Grade Number 2 is distillate oil used for general purpose heating. This oil grade is most commonly used in low-pressure boiler oil burners. It does not require preheating before burning and is easy to ignite and control. Almost all boilers with burners that use oil as a standby fuel use No. 2 oil because it is easy to store and use. Specifications for No. 2 fuel oil are as follows: 7.0 to 7.3 pounds per gallon; 137,000 to 141,800 Btu heating value per gallon; and 30 to 38 specific gravity degrees as per American Petroleum Institute (API). The oil grade alone does guarantee a certain quality. The average heating value for No. 2 oil is 139,400 Btu/gal (Table5-1).
- No. 3 Grade fuel oil is lower quality space heating oil. However, the price difference between No. 2 and No. 3 was marginal. As a result, No. 2 was purchased and No. 3 has not been produced since 1948.
- Grade Number 4 is heavier than No. 2, but not heavy enough to require preheating facilities. Because the oil is no longer available in many locations as a straight-run distillate, and is a mix of No. 2 and heavier oils, it may be necessary in Northern states to provide tank heaters or small recirculating preheaters to ensure delivery of the blended fuel to the burner. If the fuel is not blended properly, the No. 2 oil and the heavier oil may separate eventually. Many dealers blend the two grades of oil in the tank truck while delivering the oil to the location. This may result in the physical separation of the two grades if they stand in the tank for any length of time. The heating value of grade 4 is approximately 147,000 Btu/gal. API gravity ranges from 20 to 28 and its weight varies from 7.4 to 7.8 pounds per gallon.
- Grade Number 5 has been divided into hot No. 5 and cold No. 5. The hot grade requires preheating; the cold may be burned, as is, from the tank but because of the increased demand for distillate products, the residual oils may be lower in quality and may require necessary preheating for good results. Sometimes Grade No. 5 is a mix of Grade No. 2 and Grade No. 6. The usual heating value is approximately 152,000 Btu/gal.
- Grade Number 6 is the heaviest grade of fuel oil and is commonly referred to as "Bunker C" oil. The Btu/per gallon is the highest of the five common fuel oils and the cost is the lowest. Due to the weight and consistency of the oil, it must be heated before it can be burned. If stored outside, the storage tanks must have heaters to maintain a high enough oil temperature to allow the oil to be pumped. Air pollution is another problem associated with using No. 6 oil but, since it is more plentiful than the higher grades of fuel oil, it may become necessary to convert some boilers to burn No. 6 fuel oil. The usual heating value is approximately 153,000 Btu/gal.

Table5-1. Gravity and Heating Value of Fuel Oils

GRADE NO.	GRAVITY API	WEIGHT, LB PER GALLON	HEATING VALUE Btu PER GALLON
1	38 - 45	6.675 - 6.95	132,900 - 137,000
2	30 - 38	6.690 - 7.29	137,000 - 141,800
4	20 - 28	7.396 - 7.78	143,100 - 148,100
5	17 - 22	7.686 - 7.94	146,800 - 150,000
6	8 - 15	8.053 - 8.44	151,300 - 155,900

5.1.8.3.5 Preheating Requirements

The correct temperature range must be used for each grade of preheated oil. Improper preheating causes poor combustion, smoke, and high fuel consumption. The oil delivered to the burner must be preheated to the temperature recommended by the burner manufacturer for the grade of fuel used.

5.1.8.4 Electricity

Although electricity is not a fuel, it is used as a source of heat for heating boilers. The two general methods of application are electrodes and immersed direct-resistance elements. When electrodes are used, the boiler water serves as the heating element by offering resistance to the passage of current between the immersed electrodes. Direct-resistance elements create heat by the resistance offered to the passage of electric current through the immersed element.

5.1.8.5 Combination Fuels

In all cases where natural gas is the primary fuel and a secondary fuel is required. Generally, No. 2 oil is specified as the standby fuel. A reduced gas rate is usually obtainable when a secondary or standby fuel is required.

Fuel oils stored in the tanks for extended periods of time can develop organic. It is recommended that stored oil be used and replenished at regular intervals.

5.1.9 Combustion

5.1.9.1 How Fuels Burn

In boilers, burning or combustion is a form of oxidation (the union of a substance with oxygen). Oxygen combines rapidly with a fuel and releases heat. To produce combustion, in addition to the fuel and oxygen, some type of flame or heat is needed to vaporize part of the fuel and start the burning process. Under certain conditions, combustion may be self-starting. All fuels must be changed into a gas before they will burn. To do this, the surface temperature must be raised to a point where some of the fuel will vaporize or become a gas. Some fuels such as gasoline, propane, etc., vaporize at a low temperature and are extremely easy to ignite. Others, such as coal and wood logs, require much higher temperatures before they will vaporize enough to ignite.

5.1.9.2 Gas Combustion

Since all fuels burn as gases, combustion mixtures must be considered. Before vaporized gases from the fuel will burn, they must be mixed with air. The temperature of the mixture then must be raised to the ignition point and held there while combustion takes place. The gas/air mixture is very important and is one of the items controlled by the operator. In all fuels, the two basic elements are hydrogen and carbon. Other elements such as sulfur may be present and give off heat, but these are considered impurities.

5.1.9.3 Air Requirements

The amounts of hydrogen and carbon that appear in any fuel are very important to burning, and the proper amount of oxygen must be supplied to each type of fuel to have complete combustion. By computing a fuel/air ratio, it is easy to determine exactly how much air is needed for perfect combustion of any type of fuel. The ratio is usually expressed in terms of weight and simply means that for a unit weight of a certain type of fuel, a certain weight of air is required for combustion. The fuel and air must be mixed in the proper proportion for complete combustion to take place.

5.1.9.4 Ignition Temperature

In addition to fuel and air, a third factor--heat--is required for combustion. If heat is added gradually, a point will be reached where the fuel is producing enough heat to maintain its own combustion. This is called the ignition temperature; from this point on, no external heat is needed to produce combustion. Below this point, the fuel will not burn freely and continuously unless some form of heat is supplied to it. Actual ignition temperature is affected by surrounding conditions. For each type of gas, a certain amount of air is required; poor combustion will result if the fuel/air mixture is too lean or too rich. The range between the two limits is known as the "limits of flammability."

5.1.9.5 Proper Mixing

In a boiler, the mixing of fuel and air is a complicated process. The separate streams of fuel and air entering the boiler must be accurately mixed and heated to start and maintain combustion. The manner in which this is accomplished is one of the main factors in boiler and burner design and may be the determining factor in whether or not a boiler is effective and economical.

5.1.9.6 Incomplete Combustion

Incomplete combustion is the unfinished burning of fuel that leaves carbon deposits. When fuel is burned without sufficient oxygen, carbon particles in the form of smoke or soot are produced as is carbon monoxide (CO), a lethal gas. Incomplete combustion results in higher fuel costs; the carbon deposits reduce heat transfer through the boiler tubes, which increases the overall operating and maintenance costs. See Appendix A.6 Effect of Soot on Fuel Consumption for examples of the effect of soot on fuel consumption.

5.1.9.7 Excess Air

Excess air ensures complete combustion. However, air used in excess of that required for complete combustion represents a loss in operation; the heated excess air is exhausted through the chimney. The sensible heat lost through the chimney represents a big loss in operation and should be minimized whenever possible. Every 10 percent increase of excess air results in a loss of 1 percent efficiency. Excess air also causes or promotes corrosion in a boiler using fuel oil or coal as a fuel. Most boiler manufacturers specify required air supply at full-rated load and these specifications should be followed; however, the best check is to ensure that the flue gas contains a small amount of excess oxygen. The lower this excess can be maintained, the more efficient the boiler will be. The only danger is in burner modulation, where the ratio of fuel to air may not be controlled and the possibility of insufficient air could be encountered. If natural gas is used as the fuel, the local gas company will sometimes perform flue-gas analysis without charge. It is standard practice to set air requirements for natural gas burners at approximately 20 percent over the required amount. Regardless of the amount of air going through a boiler, incomplete combustion will result unless the air is adequately mixed with the fuel. Many burners have primary air that is mixed directly with the fuel and secondary air that enters the combustion chamber to supply the air needed to complete the process of combustion. A certain amount of time is required for fuel to burn completely; this takes place while the fuel and air mixture is traveling through the combustion chamber or firebox. If air leaks are not repaired or boiler doors are left open or do not close tightly, air could enter the boiler but not be usable or unburned fuel products could escape into the boiler room creating a carbon monoxide hazard.

5.2 CENTRAL HEATING SYSTEMS

5.2.1 Steam Systems

5.2.1.1 General

Some buildings are heated by steam radiators, air handlers with steam-heating coils, or a combination of both. The most common steam radiator systems are the one-pipe, condensate-return, and combination systems.

5.2.1.2 One-Pipe System

In a one-pipe system, the boiler operates with a steam pressure of 1 to 3 psig and is connected to the radiators by a single pipe 1-1/2 to 3 inches in diameter. The pipe must be slightly sloped so that all condensate returns directly to the boiler or to a condensate-return tank where the condensate is pumped back into the boiler. The steam and condensate travel in opposite directions in the same pipe in the take-off from the main to the radiator. Each radiator and riser pipe is equipped with an air-vent valve. When there is no steam pressure on the system, the supply lines and the radiators are filled with air. One of the problems encountered with the one-pipe system is its inherent tendency to store water in the radiators and cause the boiler to shut down because of low water. This problem is increased when the radiators are controlled manually. The supply line must be either wide open or closed. When it is partially closed, the steam pressure will not allow the condensate to leave the radiator. The radiator fills up with water until it is forced out through the air-vent valve. Boilers used with one-pipe heating systems should not be equipped with automatic makeup valves to maintain boiler water level. Makeup water should be added by hand when necessary. Two low water cutoffs are required and must be checked weekly for proper operation.

5.2.1.3 Condensate Return System

5.2.1.3.1 Operation

Steam boilers depend on steam condensate-return systems to maintain the boiler water level. Untreated raw water is used to replace any lost steam or condensate. Low-pressure, steam-heating boilers should operate with over 85 percent of condensate return. Some boiler water is lost by blowing down external attachments such as the water column, water-level controller, and low-water fuel cutoff. Water loss from the system is minor if the return system is maintained in top condition and all condensate is returned to the boiler.

5.2.1.3.2 Types

The condensate-return system may be a vacuum system that maintains a vacuum on the entire return system up to the individual steam traps, or it may be a gravity-return system, where the condensate drains into an atmospheric-type return tank. A steam trap is required in the outlet from each radiator. Supply lines and headers are equipped with traps to prevent condensate returning through the steam outlet to the boiler. In systems with condensate-return tanks, the condensate is pumped back into the boiler each time the level rises high enough in the tank to trip a float switch. Makeup water may be added to the boiler itself, or it may be added at the condensate-return tank. The condensate may be pumped back into the boiler as it returns from the system, or it may be pumped into the boiler when the boiler water level controller signals that the water level is low. Regardless of the type of return system, it is important to determine that no water or steam is being needlessly lost from the system and the condensate-return system is functioning as designed.

5.2.1.4 Combination System

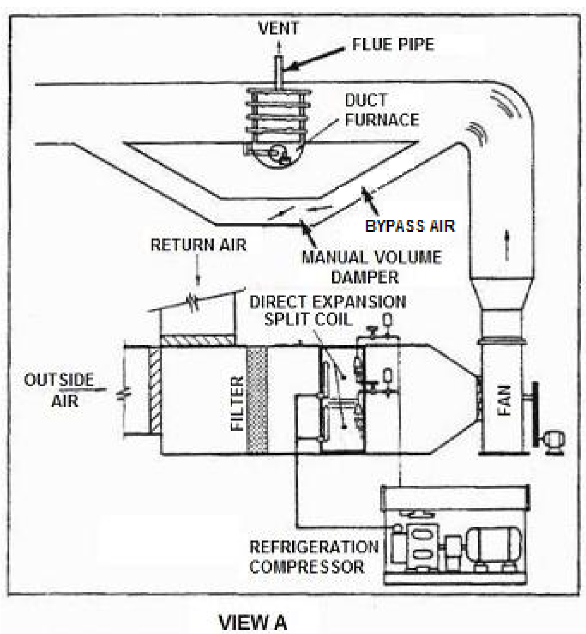
When a radiator or convector system is used in conjunction with air handlers, separate controls are used to regulate the two systems. The air handlers are designed to maintain room temperature until it is cold enough outside to require additional heat from the wall units located on outside walls. The wall units are intended to offset heat loss through the walls only, not to heat the room. However, the two systems will fight for control if thermostats controlling radiators or convectors are not set lower than thermostats controlling discharge air temperature from air handlers. Higher temperature settings can cause overheating and loss of both efficiency and comfort.

5.2.2 Hot-Water Systems

New facilities generally use low-temperature, pressurized hot-water heating systems; pressurized systems minimize air infiltration. These systems are designed to be pressurized and, ideally, should not allow infiltration. Hot water heating uses convectors and air handler to supply heat. Convectors are normally used only under outside windows. Interior spaces are heated by warm air, forced-circulation systems that use hot-water heating coils in the air-handlers. These systems are usually total environmental control systems that both heat and cool as required. The hot water temperature is regulated through a by-pass mixing or diverting valve. The mixing valve is located to blend boiler supply and return water to achieve desired water temperature according to outside air temperature. This temperature-regulated hot water is then pumped to the air handler and convector units where additional temperature controls maintain individual room or zone conditions. Some older buildings have modified systems where original steam radiators have been converted to hot-water radiators. These systems become closed-loop systems, and it is essential that no air enters the system. Expansion tanks are installed to allow for expansion of the hot water, and all air vents or vacuum breakers originally installed as part of the steam system are removed or closed off with a petcock to prevent any loss of water from, or influx of air into, the system.

5.2.3 Direct-Fired Systems

A direct-fired system consists of small unitary (package) units for heating, or for both heating and cooling, that are usually supplied with gas-fired heaters called duct furnaces (Figure 5-1). The heating section or duct furnace may be built into the same housing that enclosed the fan, filters, and cooling coil or it might be installed in the discharge duct of a packaged chiller unit. The duct furnace is a gas-tight enclosure where the hot combustion gases pass through a series of small flue pipes that are enclosed by the ductwork carrying the system air supply. The control unit uses a time-delay, spark-ignited pilot light, a flame-sensing element, combustion airflow switch, and high-temperature safety thermostat. The burner unit is ignited depending on a predetermined temperature of the room or return air. When the air requirement for the system exceeds the cubic feet per minute (cfm) capacity of the furnace section, it is customary to install a bypass duct around the furnace section. Bypass air can then be adjusted with a manual volume damper to ensure maximum permissible airflow through the furnace. Small direct-fired space heaters are used to some extent in small buildings that usually require no heat or that do not have a central system. This type of heater is usually ceiling-hung in the space to be heated and consists only of a fan, furnace, burner, and simple control system.



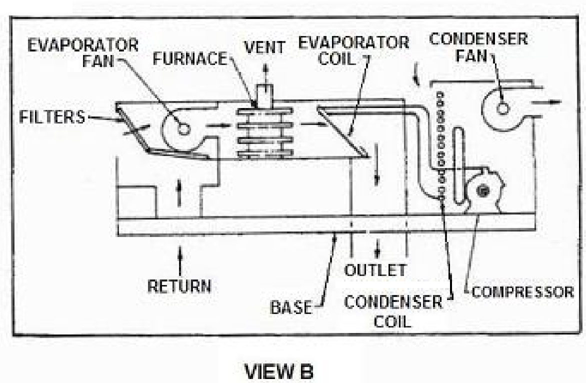


Figure 5-1. Direct-Fired System with Duct Furnace

5.3 UNFIRED PRESSURE VESSELS

5.3.1 General

A pressure vessel is an American Society of Mechanical Engineers (ASME) certified container designed to hold gases or liquids at a pressure different from the ambient pressure. An unfired pressure vessel is a pressure vessel not heated by combustion. If superheated steam or high-temperature hot water is used to heat low-pressure steam or hot water, the heat exchanger is classified as an unfired pressure vessel. The storage tank for an air compressor and the evaporator and receiver in an air-conditioning system are all unfired pressure vessels and may require periodic inspections.

5.3.2 Construction

Design and construction of pressure vessels shall adhere to ASME codes. Pressurized vessel heads, per ASME VIII Div 1, are flanged and dished, elliptical, hemispherical or tori conical. All pressure vessels are designed, constructed, and inspected according to strict codes; the American Society of Mechanical Engineers (ASME) code is accepted almost worldwide. A pressure vessel is built for a particular application or requirement and is checked, tested, and stamped by authorized code inspectors before it leaves the factory.

WARNING

Pressure vessels are designed for a specific purpose. Do not use a pressure vessel for other than its intended purpose. Do not alter or change the pressure vessel or safety device in any manner. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

5.3.3 ASME Approval

5.3.3.1 Code Stamp

The ASME code stamp should always be visible. It should never be defaced or removed. Code stamping on the vessel usually shows the following data:

- Operating pressure is the pressure normally expected in the system.
- Maximum allowable working pressure (MAWP) is the maximum pressure that can be safely contained by the vessel. The setting of the pressure relief device must never be higher than the MAWP.
- Design pressure may be shown and may be the same as MAWP or lower, depending on construction. Pressure differential between vessel operating pressure and valve set pressure should be at least 5 psi on systems with valves set 70 psi and below. For valves set above 70 psi, the differential should be at least 10 percent of the valve set pressure.

5.3.3.2 Temperature

Temperature affects the strength of vessel material and as it increases, MAWP goes down. If the vessel is under hydrostatic pressure (no gas), the MAWP will decrease as the temperature of the liquid goes above 60°F.

5.4 BOILER PRINCIPLES

5.4.1 Application

Boilers are devices where water absorbs heat from hot products of combustion with or without direct radiation from the burning fuel. Boilers are generally classified as high-pressure or low-pressure types. Steam boilers are not completely filled with water; the vapor space is above the water level. Hot-water boilers are filled with water; they do not have a steam-disengaging space. Heating boilers are of the fire-tube type if the combustion gas passes through the tubes, which are submerged in water. For water-tube boilers, the arrangement is reversed; the combustion gas is outside the tubes and the water inside the tubes. High-pressure steam boilers are used if high-pressure steam is needed to operate equipment such as steam turbines for air-conditioning or large kitchens. Hot-water systems are specified for new post office buildings, and many older facilities have been converted to hot water. Most of these boilers are the fire-tube type and are bought as package boilers. The maximum allowable working pressure of a standard boiler shall in no case exceed the ASME MAWP stamped on the boiler.

5.4.2 Alternative Fuel Source Feasibility-fuel-oil Fired Boilers

No replacement burners may be installed on fuel-oil fired boilers without first evaluating the feasibility of modifying the boiler to an alternate fuel source. This same evaluation must be performed prior to any major modification or repair of the boilers.

5.4.3 Low-Pressure Boilers

Boilers classified as low-pressure boilers must not exceed 15 psig steam pressure or 160 psig water pressure when used as hot-water boilers. Low-pressure boilers are further classified according to the material from which they are fabricated and are either steel or cast-iron boilers. Steel boilers are also classified by the position of the combustion gases with respect to the tube surface and are either fire-tube or water-tube.

5.4.4 High-Pressure Boilers

Boilers rated to operate at steam pressures above 15 psig and water pressures above 160 psig, and/or at temperature over 250°F are classified as high-pressure boilers by ASME and are referred to as power boilers. These boilers require inspection by a National Board Certified Inspector. They may be of either fire-tube or water-tube design. Cast-iron boilers are not used for high-pressure. Although there are a few high-pressure steam boilers in postal facilities, they are not covered in this handbook. Manufacturers' manuals and operating instructions should be consulted on high-pressure boilers.

5.4.5 Hot-Water Boilers

New heating systems in postal facilities are generally designed for hot-water heating. Hot water is pumped throughout the building without the use of large steam lines and the consequent problem of returning the condensate to the boiler. Hot water is easier to control than steam and results in a more smoothly balanced system. A hot-water boiler is the same as a steam boiler, except that it is part of a closed system and is entirely under a constant water pressure. There is no water column or gauge glass on the boiler as the entire boiler is flooded. The water is heated as it circulates through the boiler. An expansion tank is required because of the difference in total volume of water between the hot and cold conditions. Enough pressure must be maintained on the entire system to ensure a few pounds of pressure at the highest point in the system when the hot-water circulating pump is off. With closed expansion tanks, the pressure is maintained by a charge of air or nitrogen that expands or compresses as the water contracts or expands. The charge of air or nitrogen is contained in the expansion tank.

Hot-water systems are classified according to the water temperature maintained and are divided into three ranges. Low-temperature hot-water (LTHW) systems range from 180 to 250°F; medium-temperature hot-water systems range from 251 to 300°F; high-temperature hot-water systems range from 301 to 400°F. All postal installations having hot-water heating systems operate in the LTHW range and normally operate at 210°F or lower.

5.4.6 Basic Terminologies

5.4.6.1 Saturated Steam

Saturated steam or “Wet Steam” is steam composed of water vapor mixed with droplets of liquid water and is in equilibrium with heated water at the same pressure meaning it has not been heated above the boiling point for its pressure. This is in contrast to superheated steam, which is heated beyond the boiling point for its pressure to ensure all water droplets vaporize creating “dry steam”. The condensed water droplets found in saturated steam can cause serious damage to steam turbine blades or other engine parts because the water droplets are not compressible.

5.4.6.2 Superheated Steam

Superheated steam is steam that has reached a temperature higher than the saturation or boiling temperature for the existing pressure. This is accomplished by further heating the saturated steam after it is separated from the boiler water. As long as the steam is in contact with the water, additional heat added will boil more water into saturated steam and will not raise the temperature of the steam. Super heaters are common on high-pressure boilers but are seldom used or needed on low-pressure units.

5.4.6.3 Boiling and Circulation

5.4.6.3.1 Boiling

A liquid boils at a temperature at which its vapor pressure is equal to the pressure of the gas above it. The lower the pressure of the gas above the liquid, the lower the temperature at which the liquid will boil. Steam is formed in bubbles along the heat transfer surface that is exposed to the boiler heat. This is called boiling. The greater the temperature difference between the heated surface and the water, the faster the heat will transfer to the water and the faster the steam will be formed.

5.4.6.3.2 Circulation

One of the main considerations in boiler design and construction is the circulation cycle. The boiler must be designed and built so that all phases of the circulation cycle work together to create a system that is safe in operation and is as efficient and economical as possible. Due to differences in water temperature within the boiler, a definite circulation pattern is established which results in completion of the following three steps common to all steam boilers:

1. Flow of water to heated areas
2. Flow of steam and heated water to upper areas
3. Release of steam

The design of hot water systems must accommodate effective circulation. Water-tube boilers often require proof of circulation by incorporating a flow switch with or in lieu of a low water cut off.

5.4.6.4 Btu Input

Btu input is a measure of the amount of fuel the boiler can burn safely per unit of time. Every type of fuel has a definite heat content or Btu rating per pound, gallon, or cubic foot. The operator should know the Btu rating for the fuel being burned. Input rating is usually given in Btu per hour. It is also called combustion rate.

5.4.6.5 Btu Output

The amount of steam produced per hour is measured and converted to Btu by the use of a steam chart. A pound of steam contains a certain number of Btu depending on its temperature and pressure.

5.4.6.6 Boiler Horsepower

A boiler horsepower is equal to the evaporation of 34.5 pounds of water at a temperature of 212°F into steam at a temperature of 212°F. This is 34.5 times the latent heat of vaporization of one pound of water at atmospheric pressure or 33,472 Btu/hr.

5.4.6.7 Pounds of Steam per Hour

WARNING

A boiler is normally rated in boiler horsepower, Btu per hour, pounds of steam per hour or MBH (one MBH equals 1,000 Btu per hour). A boiler must never be fired higher than its rating. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

In addition to horsepower, boilers may also be rated in Btu per hour, "pounds of steam per hour" or "MBH." One "pound of steam" or one MBH equals 1,000 Btu per hour."

5.4.6.8 Square Foot Heat Transfer Area

This is a measure of the boiler surface area that is used to transfer heat into the boiler water. The tube surface area constitutes the majority of this area. It was common practice years ago to rate 1 boiler horsepower as 10 square feet of heating surface. However, due to engineering progress, improvements in heat utilization such as enhanced heat transfer surfaces, and better circulation of water and combustion products, the present evaporation rate may be as high as 19.2 pounds of steam per hour per square foot or higher. This results in a design criterion of 1.44 to 5 square feet of heating surface per boiler horsepower.

5.4.7 Low-Pressure Boiler Designs

5.4.7.1 General

Low-pressure boilers are used to heat water that is used for space heating purposes, or they are used to produce saturated steam at a pressure under 15 psig. Basically, a low-pressure steam-heating boiler produces steam at a pressure just high enough to do a satisfactory job. The steam is saturated but should not contain the droplets of water known as priming or carryover. The steam condensate is returned to the boiler with as little loss of condensate as possible. Makeup water is added to the boiler to replace any loss of steam or condensate. Some type of fuel is mixed with air and burned in the boiler to produce the heat that is transferred to the boiler water. The true efficiency of the boiler is determined by comparing the total heat in the steam produced to the total heat in the fuel used. How the fuel is burned, how the heat is transferred to the boiler water, how efficient the boiler is, etc., are all related to the type of boiler, how it is designed and built, the type of fuel used, the pressure maintained in the boiler, and how it is operated and maintained. Figure 5-2 illustrates a typical low-pressure boiler. Figure 5-3 illustrates a modern boiler that requires about half the floor space allocated to a typical boiler.

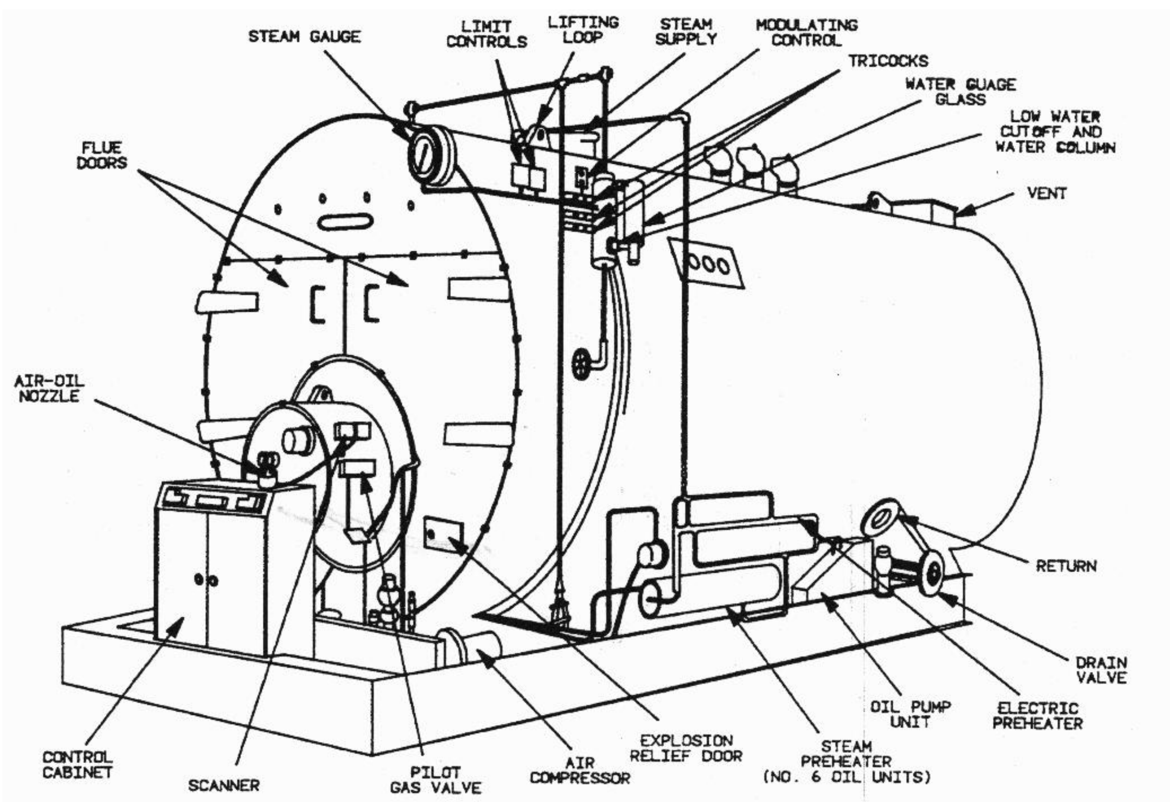


Figure 5-2. Typical Low-Pressure Package Boiler

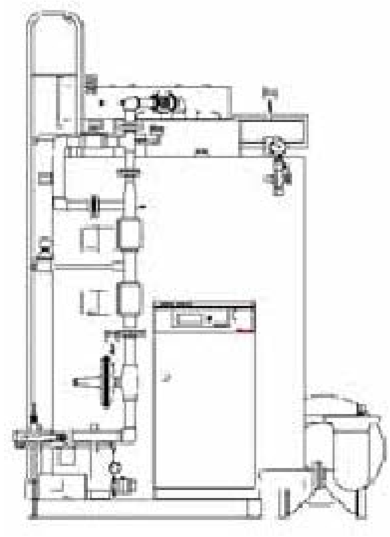


Figure 5-3. Low NOx Hot Water Boiler

5.4.7.2 Basic Types

The most common boilers are fire-tube multipass internal combustion package hot-water boilers (Figure 5-4). Some types are: two-pass firebox boilers, horizontal return-tube boilers, two-pass portable firebox boilers, and locomotive boilers. Each name is descriptive of a certain type of boiler and provides a fairly good description of a heating plant when included with boiler rating and type of fuel used.

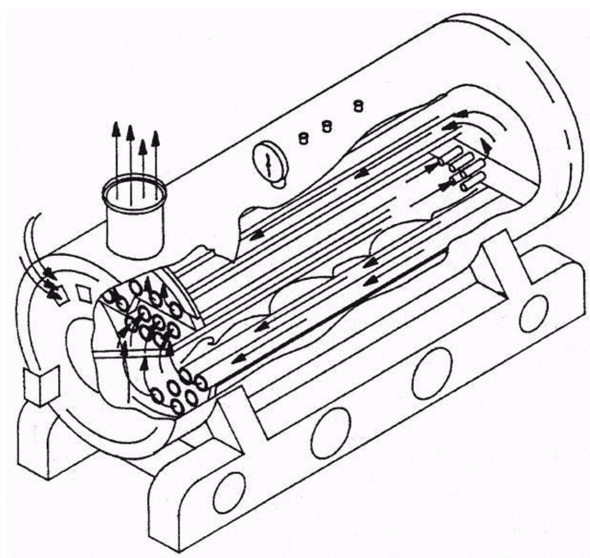


Figure 5-4. Package Fire-Tube Boiler

5.4.7.3 Boiler Appearance and Construction

5.4.7.3.1 Simple Drum Boiler

The first boiler used was a simple shell or drum with a feed water line and a steam outlet mounted on a brick setting with a firebox underneath. Fuel was burned on a grate, and the heat was directed over the lower shell surface before most of it went out the flue. It was soon determined that this method was very inefficient, and it was necessary to bring more of the water into better contact with the hot surface(s) to reduce heat loss and to boil water faster.

5.4.7.3.2 Fire-tube Boilers

The fore-runner of modern fire-tube boilers and the first boiler to use fire-tubes is commonly called the horizontal return-tube (HRT) boiler (Figure 5-5). Tubes were installed through the boiler shell, and the flue installed on the front of the boiler. The heat was directed over the bottom of the shell and then passed through the fire-tubes back to the flue at the boiler front. This was the forerunner of modern fire-tube boilers.

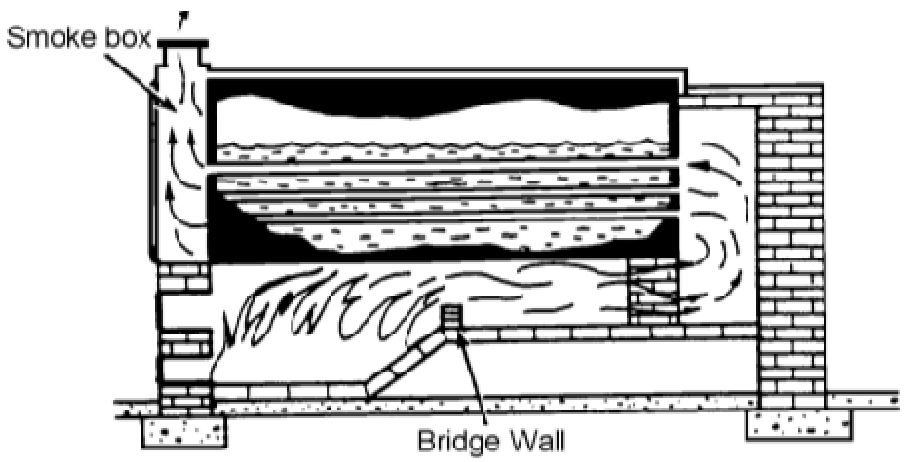


Figure 5-5. HRT Boiler

5.4.7.3.3 Firebox Boiler

Firebox boilers are steel boilers. They may be single or multiple pass that usually has the firebox built in at the factory. The firebox or combustion area may be enclosed with a water leg on the sides or may have some type of water wall tube arrangement for reducing waste heat. The burners and boiler fittings are installed at the facility after the boiler is installed. Another firebox-type boiler has the firebox built from firebrick after the boiler is set in place (Figure 5-6).

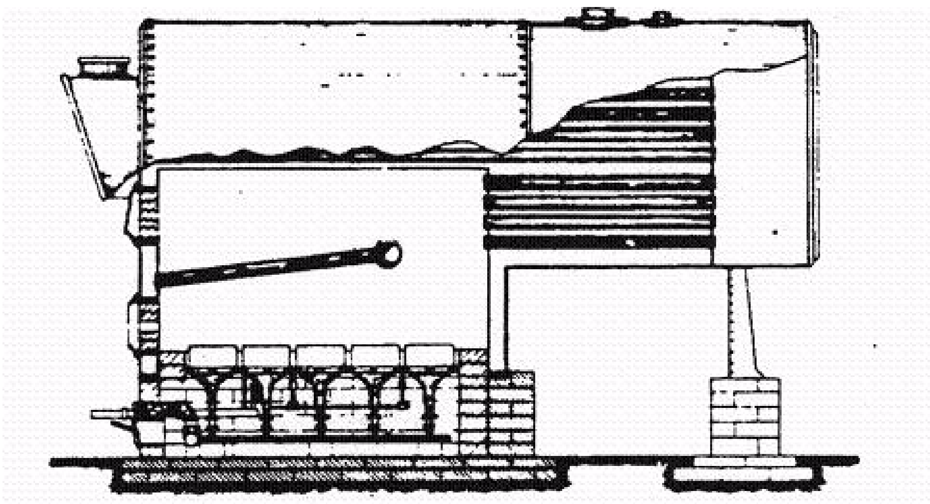


Figure 5-6. Short Firebox Boiler

5.4.7.3.4 Internal Furnaces and Marine Boilers

These boiler types represent the largest number of boilers being sold for building heating systems. They are also referred to as package boilers, since they usually come completely equipped with burner, controls, and all auxiliaries. These boilers are prefired and tested before shipment and are built with two to four passes. These boilers are fired on gas or liquid fuels, and combustion takes place in the first pass of the boiler. They are built with a dry back, refractory-lined rear chamber or with a wet back where the rear chamber is covered by a water shell that is an extension of the boiler drum. The Scotch boiler incorporates a large fire-tube as the combustion chamber. This design allows the combustion chamber to be surrounded by water, thus aiding the transfer of heat. It comes in both the dryback and wetback designs (Figure 5-7). The number of passes of flue gas through a boiler does not necessarily dictate its efficiency. Improvements in design of both boilers and burners allow for greater heat transfer. Two-pass boilers are now capable of extracting most of the heat from the flue gas. This makes the two-pass boiler some
hot-water b

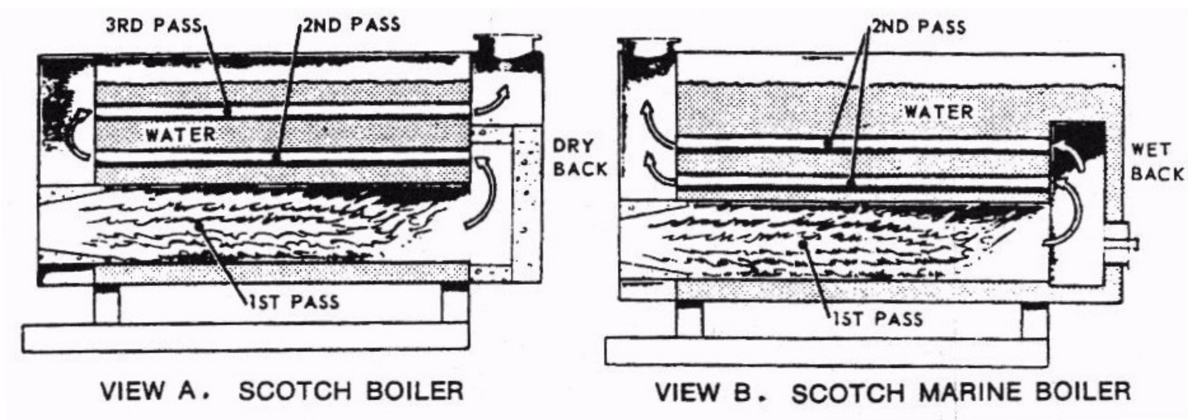


Figure 5-7. Scotch Boiler Designs

5.4.7.3.5 Vertical Boilers

Vertical boilers are fire-tube boilers used for small system applications. Figure 5-8 depicts tubeless and tube vertical boilers. Modern vertical boilers are very efficient in operation; they require very little floor space. The fire-tubes in these boilers are usually either equipped with helical inserts that spiral the gas against the tube surface or constructed with internal fins to increase the heating surface. One type is a two-pass boiler with forced-draft burner.

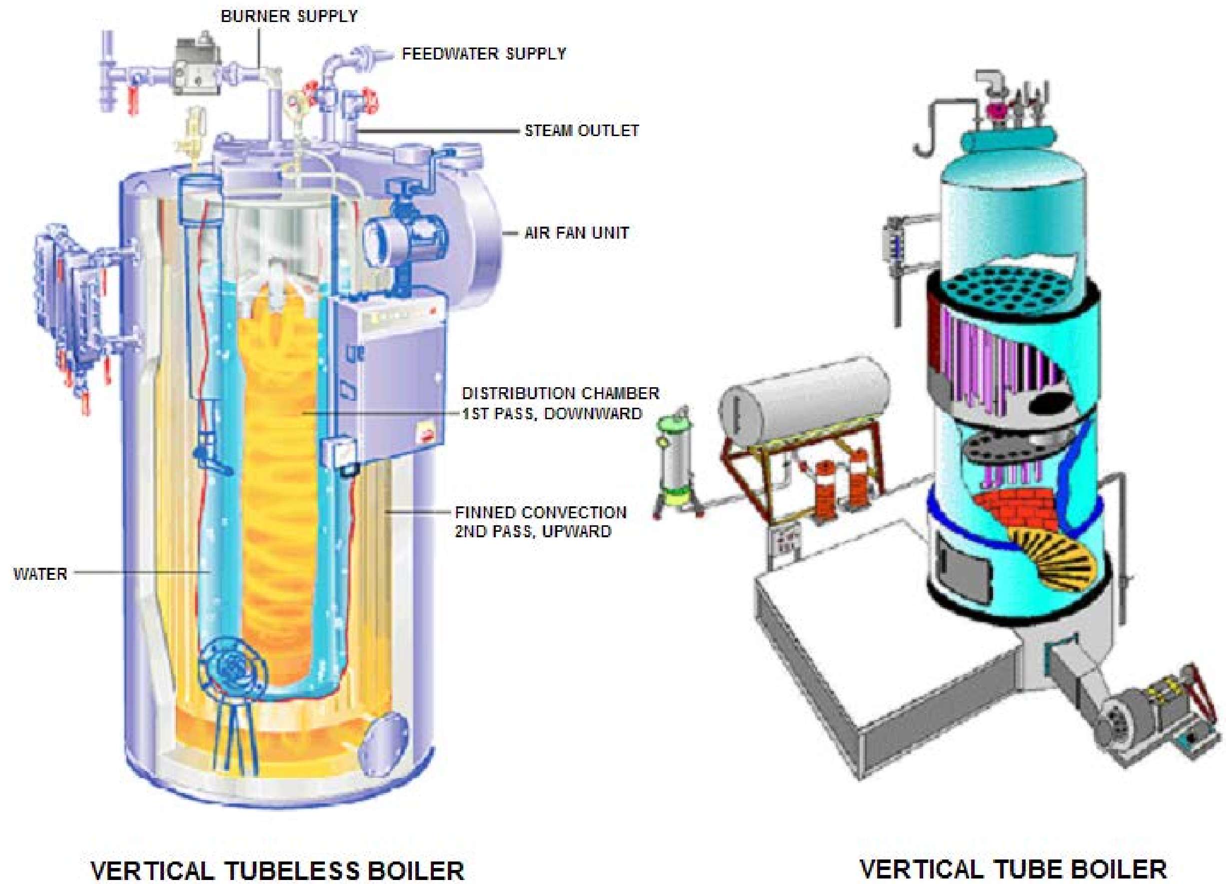


Figure 5-8. Vertical Fire-Tube Boiler

5.4.7.3.6 Electric Boilers

Electric boilers are also used for small plants or for special applications. They are usually constructed of a vertical shell-type design. Heat is generated by metal electrodes submerged in the water using the boiler water as the conductor. Low-water protection is automatic, because current will not flow above the water level. These boilers are usually used as auxiliary heating units in total electric systems using the heat-pump principle. Water-treatment to improve the conductivity of the water is usually required to maintain maximum output.

5.4.7.3.7 Hot-Water Boilers

The fire-tube hot-water boilers are very similar to steam boilers in appearance and, except for a few differences, are basically constructed and operated the same way. Instead of controlling steam pressure with a pressurestat, temperature is controlled with an aquastat. The water column, water glass, and gauge cocks are not needed since the boiler is completely filled with water. Likewise, dry pipe baffles are not needed. In place of a steam outlet pipe, provisions are made for plumbing a water inlet and outlet. The interior of the boiler is designed so that water will circulate through the boiler and not short-circuit from the inlet to the outlet connections.

5.4.7.3.8 Cast-Iron Sectional Boiler

A cast-iron sectional boiler is commonly used for small buildings to generate steam or hot water within the scope and service restrictions of ASME Section IV. Section IV service restrictions limit steam boilers to pressures not exceeding 15 psi and hot water boilers to pressures not exceeding 160 psi and/or temperatures not exceeding 250°F. This type of boiler is constructed of one or more sections of hollow castings. Multiple castings may be connected internally with push or Swedge nipples, polymer "o- ring" seals or gaskets, or connected externally with French nipples. The sections may stand vertically like slices of a loaf of bread or lay horizontally like pancakes. Combustion takes place below the boiler itself, and hot gases pass up and through the cast-iron sections.

There will be two pieces of information missing from a cast-iron boiler nameplate: a National Board registration number and the year built. Cast-iron boilers are not registered with the National Board, and ASME Section IV makes no provisions for a year of construction to appear on the nameplate. Since most inspection forms ask for a year of construction, the inspector will have to estimate. If the boiler is original to the building, the age of the building would directly correspond to the age of the boiler. If the boiler is a replacement, the inspector will have to question the owner to determine its age.

Cast-iron boilers typically have a few inherent problems. The inspector should always look for water leaks at the connecting joints of sectional boilers. The inspector should request the removal of the sheet metal casing any time there is evidence of leakage and the leakage cannot be traced to an external source.

Overheating or thermal shock can cause cast-iron boilers to crack. Overheating occurs when the boiler is allowed to operate with low-water conditions or poor circulation. Thermal shock can occur when a boiler is overheated and cold water is added in an attempt to raise the water level. Under those circumstances, cracking is usually the least that can happen. The worst that can happen is an explosion that shatters the cast-iron boiler into many pieces and causes destruction and injury.

5.4.8 Boiler Classifications and Components

5.4.8.1 Classifications

The two general classifications of heating boilers pertain to the method of manufacture: casting or fabrication. Cast boilers are usually made of iron, bronze, or brass. Fabricated boilers are generally made of steel but can also be copper or brass.

5.4.8.2 Fabricated Boilers

5.4.8.2.1 General

Boiler design can be classified in three main divisions: fire-tube, water-tube, and electric boilers. There are two basic types of industrial boilers: fire-tube and water-tube. In fire-tube boilers, the combustion gas passes through the tubes and the water circulates around them. In water-tube boilers, the water passes through the tube and the combustion gases pass around them.

5.4.8.2.2 Fire-Tube Boilers

Types of fire-tube boilers are as follows:

- External-Furnace Boilers. In this type of boiler, the furnace is external and may be brick-set or steel jacketed. It is surrounded essentially by a refractory rather than by water.
- Scotch Boilers. The scotch boilers used in modern heating systems are similar to those originally designed for shipboard installation and are sometimes called scotch marine boilers. The furnace is a cylinder completely surrounded by water. Most scotch boilers are of the dry back or partial wet back design and are arranged for multiple gas passes.
- Firebox Boilers. Firebox boilers have a firebox integral with the boiler, such as the oil field- or locomotive type, and may be single or multiple pass. The furnace of this boiler is usually enclosed in a water-cooled upper sheet called a "crown sheet." Various tube and shell configurations characterizing different manufacturers' designs complete the boilers.
- Vertical Fire-Tube Boilers. In vertical fire-tube boilers, the products of combustion pass up through tubes surrounded by water.

The boiler drum of steam fire-tube boilers must have an open space for steam above the top row of fire-tubes. The water level is maintained in the drum so that the fire-tubes are always covered by water. If the water level is allowed to drop to a point where tubes are not covered by water, they will overheat and burn out or rupture.

5.4.8.2.3 Water-Tube Boilers

Water-tube boilers are made in a variety of configurations with respect to tube and drum arrangement. They are classified as straight-, curved-, or bent-tube boilers. They are also classified according to the number of drums used: single-drum, two-drum, three-drum, or multi-drum boilers. Field maintenance personnel must not "pop test" water-tube boilers by firing the unit unless USPS boiler inspectors are contacted for technical advice.

5.4.8.3 Cast-Iron Boilers

5.4.8.3.1 General

Cast-iron boilers are made in three general types: horizontal-sectional, vertical-sectional, and one piece. Most of the sectional boilers are assembled with push nipples, but some are assembled with external headers and screwed nipples.

5.4.8.3.2 Horizontal-Sectional

Horizontal-sectional, cast-iron boilers are made up of sections stacked one above the other, like pancakes

5.4.8.3.3 Vertical-Sectional

Vertical-sectional, cast-iron boilers are made up with sections standing vertically like the slices in a loaf of bread. Vertical cast-iron boilers may also be connected externally with French Nipples

5.4.8.3.4 One-Piece

One-piece, cast-iron boilers are those in which the pressure vessel is made as a single casting.

5.4.8.4 Components

5.4.8.4.1 Boiler Body

Older boilers were constructed in a cylindrical form with flat tubesheets at both ends where fire-tubes were attached. The metal was high-grade steel commonly referred to as boiler plate steel. Modern boilers are usually in a cylindrical form but have many configurations due to modern methods of welding and internal bracing. The old lap joints used for joining metal with rivets have been replaced with stronger, welded joints. All boiler construction methods are rigorously governed by codes and ordinances. The most important code used in construction of pressure vessels is the one sponsored by ASME. All boilers in postal facilities must be manufactured according to the ASME code and stamped with the code stamp indicating code compliance.

5.4.8.4.2 Fire-Tubes

The fire-tubes act as braces for the flat tubesheets to which they are attached and are either rolled, welded, or both. In any case, they extend through holes in the tubesheet and are either rolled and flared, rolled and beaded or rolled and welded on the outside of the tubesheet so that any individual tube can be replaced as needed. Tubes in fire-tube boilers are sometimes called flues; however, it is the usual practice to use this term only for large pipes found in older boilers. Flues are usually 6 inches or larger in diameter, whereas the small tubes are 2 to 3 inches in diameter. There are no standard sizes for fire-tubes; therefore, many different sizes exist. When it is necessary to replace a tube for any reason, follow these procedures:

1. Remove the tube without cutting or defacing the tubesheet in any way.
2. Check inside the boiler by looking through the tube opening to determine the condition of the other tubes in the same area.
3. Check the removed tube to determine exactly what caused the failure and to see if scaling or corrosion is taking place in the boiler. If the tube shows evidence of pitting corrosion, it is more likely that the surrounding tubes are also pitted and should be replaced before they fail.
4. If the tubes are rolled, use a special reamer to clean, deburr, and countersink the tube opening before any new tubes are installed.

5. Clean the new tubes inside and out before installing unless it is intended to boil out the entire boiler before it is put back into service.
6. Use special tube expanders and beading tools for different size tubes. It is very important that the person doing the work use the right tools and fully understand their usage. Otherwise, the tube may leak.
7. Only a company in possession of a valid "R" stamp is authorized to repair pressure vessels.

5.4.8.4.3 Bracing

Boilers require internal bracing to withstand pressure and temperature changes. Drum ends and tubesheets are usually the weak links in fire-tube boilers and they require most of the bracing. As mentioned in Paragraph 5.4.8.4.2, the tubes act as bracing for the flat tubesheets, but additional bracing is usually required. Threaded through-stays are used on older boilers, and these must be checked and kept tight. These staybolts may also be "drilled stays" that have a small hole drilled in the center of the staybolt, extending 6 inches into the bolt. The drilled hole will leak if the staybolt cracks within the drilled area. Newer boilers use welded stays. Although all supporting members are called stays, a "brace" is usually defined as a large stay. Stayrods are used like staybolts on older boilers and may be equipped with turnbuckles for adjustment. Other types of stays used are gusset, palm, diagonal, jaw, crowfoot, radial, etc. All stays and bracing should be checked when a boiler is given an internal cleaning or inspection.

5.4.8.4.4 Dry Pipe

Dry pipe is a term used to describe the steam-collection piping at the top of the boiler drum and above the open space over the water level. Most boilers have some type of piping arrangement that acts to prevent drops of water being carried by the steam into the steam-line outlet. The arrangements vary from a simple pipe drilled with holes for the steam to enter to a complicated baffle arrangement that acts as a water trap.

5.5 BOILER AND BOILER ROOM ACCESSORIES

5.5.1 Safety and Piping Controls

WARNING

Safety valves and safety relief valves are designed for a specific purpose. Do not use a safety valve or a safety relief valve for other than its intended purpose. Do not alter or change the safety device in any manner. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

Safety valve and safety relief valves are the most important valves on a boiler. Failure of these valves can result in catastrophic accidents, such as boiler explosion.

5.5.1.1 Safety Valve

Safety valve and safety relief valves are the most important safety device on a boiler. The safety valve is attached directly to the boiler steam drum and relieves excess boiler pressure when it exceeds the boiler-control settings and reaches the pressure setting of the valve. Safety valves must be stamped in accordance to ASME code and capacity must be certified by the National Board of Boiler and Pressure Vessel Inspectors. The safety valve(s) must be capable of relieving steam pressure from the boiler fast enough to prevent the pressure from rising above the valve-popping pressure. If the boiler is operating at 100 percent of capacity and the main-stream stop valve is closed, all the steam produced can be relieved by the safety valve, if it is designed and operating properly. A safety valve is an automatic pressure-relieving device actuated by the pressure generated within the boiler. It is used primarily on steam boilers. Valves of this type are of the spring-loaded pop type with a factory-sealed pressure setting (Figure 5-9).

Figure 5-9. Safety Valve (Provides Steam Pressure Relief)

5.5.1.2 Safety-Relief Valve

This valve is attached directly to the drum of a hot-water boiler to relieve excess boiler pressure when it exceeds the boiler-control settings and reaches the pressure setting of the valve. The steam boiler safety valve must relieve steam pressure from the boiler and the safety-relief valve must relieve excess water volume from the hot-water boiler. Although the two valves have the same basic purpose, they are not identical valves and must be used only for their intended purposes (Figure 5-10).

Figure 5-10. Safety Relief Valve (Provides Excess Water Volume Relief)

Manufacturers or assemblers of safety valve and safety relief valves must hold an ASME certification of authorization to use a "V" or "HV" code symbol stamp. Likewise, National Board of Boiler and Pressure Vessel Inspectors offers the Certificate of Authorization and "R" symbol stamp for the repair and/or alteration of boilers, pressure vessels, and other pressure-retaining items. Only holders of an "R" stamp are authorized to repair or modify boilers and safety or safety relief valves.

5.5.1.3 Water-Level Controllers

Although some older boilers still depend on a manually opened valve to add water to the boiler, most boilers are equipped with some type of automatic water-level control. The function of a water level controller is to maintain the required amount of water in the steam generator. One controller is a float-type that admits makeup water directly to the boiler. Other float-types are used to open valves or close contacts that start up a pump or energize some device to admit water to the boiler. An electric probe or set of probes is the other main type of water-level controller. When the water level drops enough to uncover a probe, the electric current is stopped between the probes or between a probe and the boiler metal. This interruption in current is a signal to add water to the boiler until the probe is again covered by the water and the current is again established.

5.5.1.4 Low-Water Fuel Cutoffs

5.5.1.4.1 Types

A low-water cutoff is very similar to the water-level controller and, in many cases, may be combined with the level controller to perform both functions. The low-water fuel cutoff may be float-operated or may be the electric-probe-type, but the purpose of the device is the same. Low-water fuel cutoffs are designed to provide protection against hazardous low-water conditions in heating boilers. Records indicate that many boiler failures result from low-water conditions. Low-water fuel cutoffs may be generally divided into two types: float and probe (Figure 5-11 and Figure 5-13).

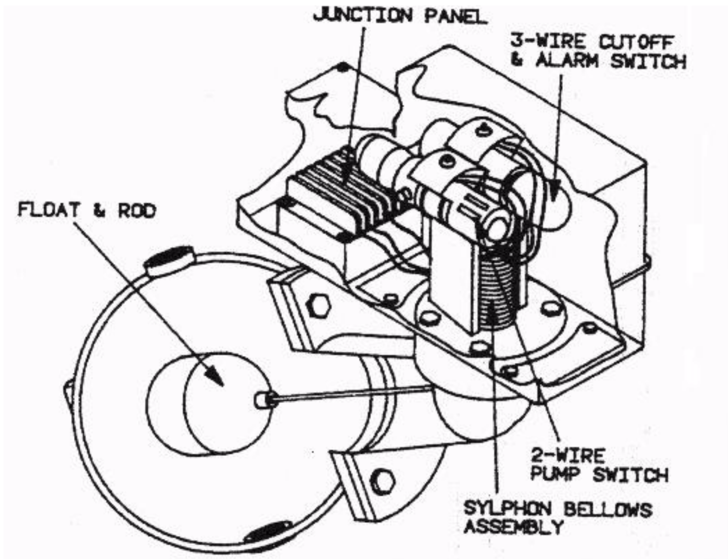


Figure 5-11. Float-Type Low-Water Fuel Cutoff with Manual Reset

5.5.1.4.2 Combination Low-Water Cutoff and Boiler Feeder

Float-type, low-water fuel cutoffs may be combined with a water feeder or built as a separate unit. The combination feeder cutoff units are generally used on steam boilers, while the cutoff units are sometimes installed on hot-water boilers or as a second cutoff on steam boilers. A feeder-cutoff combination adds water as needed to maintain a safe minimum water level and stops the firing device if the water level falls to the lowest permissible level. Both operations are accomplished by the movement of the float, linked to the water valve or pump control and burner-cutoff switch. The units serving as fuel cutoffs only are basically the same as the combination unit, but without the water-feeder valve (Figure 5-12). A water-feeder installation normally acts as an operating control to maintain a predetermined safe water level in the boiler. If the installation is designed to maintain a safe water level with the safety or safety relief valve discharging at capacity (steam and/or hot-water boilers), it can be considered a safety control.

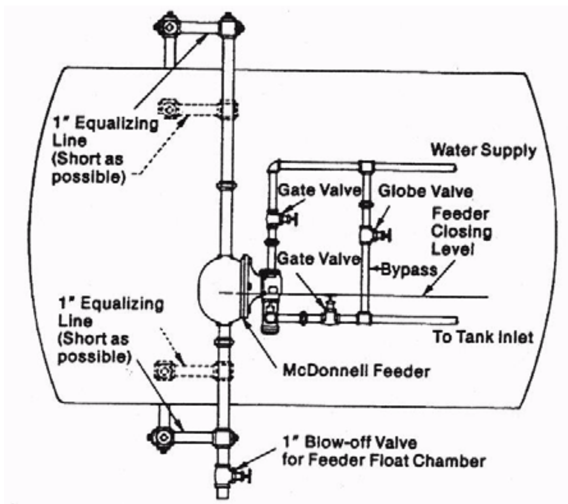


Figure 5-12. Installation of Combination Low-Water Fuel Cutoff and Boiler Water Feeder

Combination water feeder control and low-water cutoff operating from one sensor or float are prone to developing low water if the sensing element becomes disabled or stuck in deposits. As a result, most jurisdictions require a second independent low-water fuel cutoff to prevent total failure. Additionally, most low-water fuel cutoffs require annual dismantling and cleaning.

5.5.1.4.3 Electric Probe-Type, Low-Water Fuel Cutoffs

Electric probe-type, low-water fuel cutoffs are either contained in the water column mounted externally on the boiler or mounted on the boiler shell. Some consist of two electrodes (probes) that, under normal conditions, are immersed in the boiler water with a small current being conducted from one electrode to the other to energize a relay. Others use one probe, and the boiler shell, in effect, becomes the other probe. If the water level drops low enough to uncover the probes, the current flow stops and the relay operates to shut off the burner (Figure 5-13).

Figure 5-13. Electric-Probe Low-Water Control

5.5.1.5 Traps

A steam trap is an automatic valve that releases condensed steam and non-condensable gases from a steam space while preventing the loss of live steam. Steam traps are designed to maintain steam energy efficiency for performing specific tasks. They are commonly classified by the physical process causing them to open and close. The three major categories are:

- Thermodynamic (Figure 5-14)
- Thermostatic (Figure 5-15)
- Mechanical (Figure 5-16)

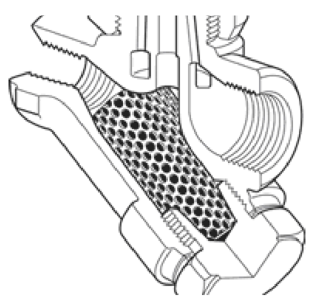


Figure 5-14. Thermodynamic Trap

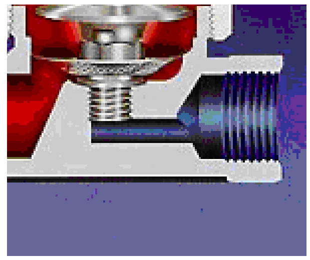


Figure 5-15. Thermostatic Trap

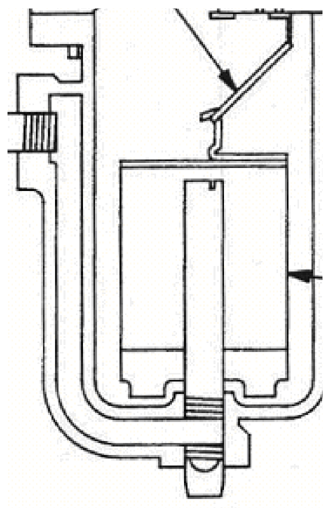


Figure 5-16. Bucket Trap

5.5.1.6 Air Eliminators

Air eliminators are installed on hot-water boilers to eliminate air from the system as it is released from the water within the boiler (Figure 5-17). Air in modern heating and cooling systems can lead to corrosion, noise, and reduced efficiency of pumping systems.

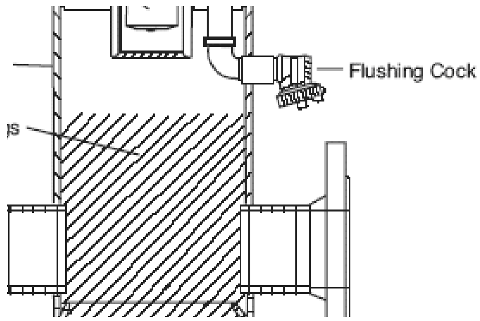


Figure 5-17. Air Eliminator

5.5.1.7 Condensate-Return Pumps and Return Loop

Condensate-return pumps are used on either one- or two-pipe steam systems to return condensate to the boiler when this cannot be done by gravity. They are generally used in conjunction with a reservoir (condensate-return tank) and a float-operated switch for starting the pump motor. Where two boilers are connected together and served from one condensate-return pump, a vacuum breaker may be required on the idle boiler to prevent the formation of a vacuum that would affect the functioning of the feed valve.

Each boiler of a steam-heating system must have the return-pipe connections that supply a gravity return arranged to form a loop as shown in Figure 5-18. This ensures that the water in each boiler cannot be forced below the safe water level. The loop is required in gravity systems and is desirable in pump-return systems.

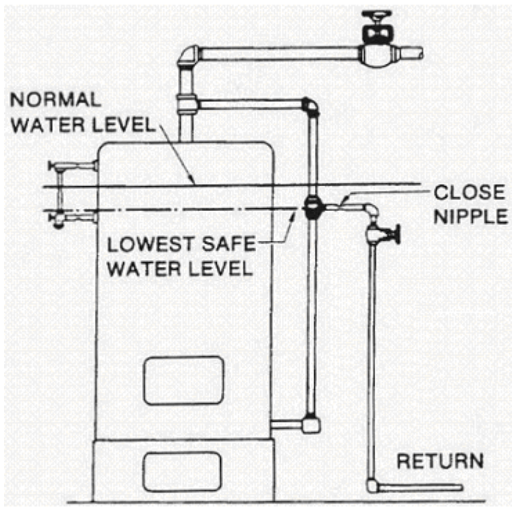


Figure 5-18. Typical Return

5.5.1.8 Vacuum-Return Pump

The vacuum-return pump is used in larger systems to create a partial vacuum in the return lines of the heating system and to assist in condensate return, air elimination, and steam distribution.

5.5.1.9 Other Controls

5.5.1.9.1 Circulators (Circulating Pumps)

Circulators are basically centrifugal-pump units used on hot-water heating systems to force the flow of water through the system.

5.5.1.9.2 Expansion Tanks

Expansion tanks are used on hot-water systems to allow for the expansion of heated water. An air cushion in the tank is compressed by the expanding water. Hot-water heating systems are classified as closed-loop systems. This means the system is airtight and water or air cannot enter or leave the system. The entire piping system must be completely filled with water, and a minimum pressure of 2 or 3 psig is maintained at the highest point in the system when the water in the system is cold and the circulating pump is off. This ensures that no air pockets may develop at high points in the system.

If any container is filled completely with water, sealed, and then heated, the water expands and the pressure increases rapidly until the container ruptures; the same will happen in a hot-water system unless the system has some type of expansion tank with an air cushion. Water will not compress; the air in the expansion tank will. This allows heated water to expand by compressing the air in the tank.

The pressure in the system increases as the water is heated. An expansion tank must be properly sized for the system and properly installed to do its intended job. It should be located higher than the hot-water boiler and connected into the system between the boiler's water discharge and the circulating-pump suction. This location helps stabilize the pressure throughout the system and increases the pump-suction pressure, making the pump more efficient. Expansion tanks may lose air to the system and need to be recharged. This can be accomplished by isolating and draining the expansion tank completely with the system off. This will require opening of the vent port on the dip tube to break the vacuum. After closing the drain and opening the valve between the tank and the system, the air in the tank will compress. If the tank needs to be recharged often, it may be losing air out through a small leak at the sight glass or other opening. This needs to be determined and corrected. Air cushion bladder-types or types employing a top dip tube may be mounted anywhere.

5.5.1.9.3 Oil Preheaters

Oil preheaters are used to condition the heavier grades of fuel oil for handling and burning. They are used in the oil storage tank or at the burner (or at both locations), depending upon the grade of oil burned.

5.5.1.9.4 Fuel-Oil Storage and Supply Systems

A fuel-oil storage and supply system may consist of a tank connecting piping and necessary strainers only, or it may require a transfer pump, depending upon the location of the tank and the grade of oil being used. In cold climates where outside fuel-storage tanks are used for oils of Grades 4, 5, or 6, hot-water or steam-heating coils, insulation, pumps, and transfer lines must be an integral component of the fuel storage system. The fuel-oil temperature should be controlled to permit satisfactory flowing or pumping in the presence of low outside air temperatures.

5.5.1.9.5 Temperature and Pressure Controllers

Boilers must have some way to maintain a constant pressure or temperature inside the boiler shell. One good method is to adjust or turn off the burner when the pressure reaches the desired point and turn the burner back on or increase the firing rate when the pressure starts to drop. This is the method used on modern boilers, and the devices used are called the pressurestat and aquastat. Steam boilers require pressurestats to keep boiler pressure within the desired range. Hot-water boilers require aquastats to maintain a proper temperature range. These controls are used either as a simple ON/OFF electric switch to make or break the burner circuit or to modulate or adjust the burner up or down to maintain constant pressure or temperature.

Some modern boilers use Micro Computer Boiler Control Systems that identify problems and suggest solutions in plain English; these systems also provide better control over steam pressure and water temperatures. Moreover, the Micro Computer Control can operate many boilers and can be accessed remotely.

5.5.2 Fuel-Burning Equipment and Fuel-burning Controls

5.5.2.1 Gas-Burning Equipment

5.5.2.1.1 Types

Gas burners are either premix or nozzle mix depending on how the air and gas are brought together. In premix gas, air and gas are mixed upstream from the burner port. Premix gas burners fall into two general classes: atmospheric and power. Nozzle mix or combination, burners can be designed for a variety of flame shapes and allow for greater burner turndown. Turndown is the ratio of the maximum to minimum firing rates.

5.5.2.1.2 Atmospheric Gas Burners

Atmospheric gas burners depend upon natural draft for combustion air. There are several types of atmospheric gas burners, most of which are either single or multiport-type (Figure 5-19).

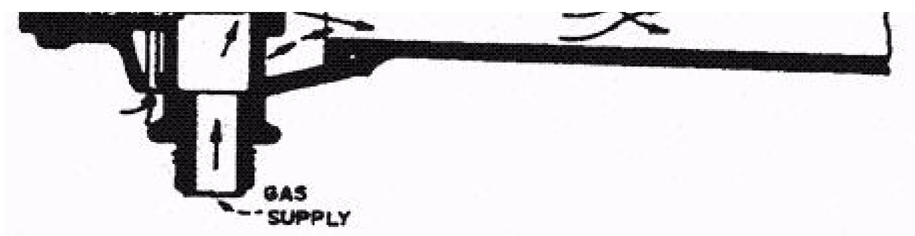


Figure 5-19. Atmospheric Gas Burner

5.5.2.1.3 Power Gas Burners

Power gas burners depend upon a blower to supply combustion air. They fall into two general classifications:

- Induced/natural-draft burners. These operate with a furnace pressure slightly less than that of atmospheric burners. The proper draft condition is maintained by an induced-draft fan.
- Forced-draft burners. These are designed to operate with a furnace pressure higher than that of atmospheric burners. Forced-draft burners are equipped with sufficient blower capacity to force products of combustion through the boiler without the help of natural or induced draft.

5.5.2.1.4 Combination Fuel Burners

Most boilers have combination or nozzle mix burners because premix burners have limited turndown and cannot easily adapt to dual fuel configuration. If a burner has a maximum output of 1,000,000 Btu/hr at high fire and a minimum output of 200,000 Btu/hr at low fire, the turndown ratio is 5 to 1. Combination fuel burners are designed to burn more than one fuel, with either a manual or an automatic switch over from one fuel to another. The combinations of fuel generally used are natural gas/liquefied petroleum gas, or natural gas/oil (Figure 5-20).

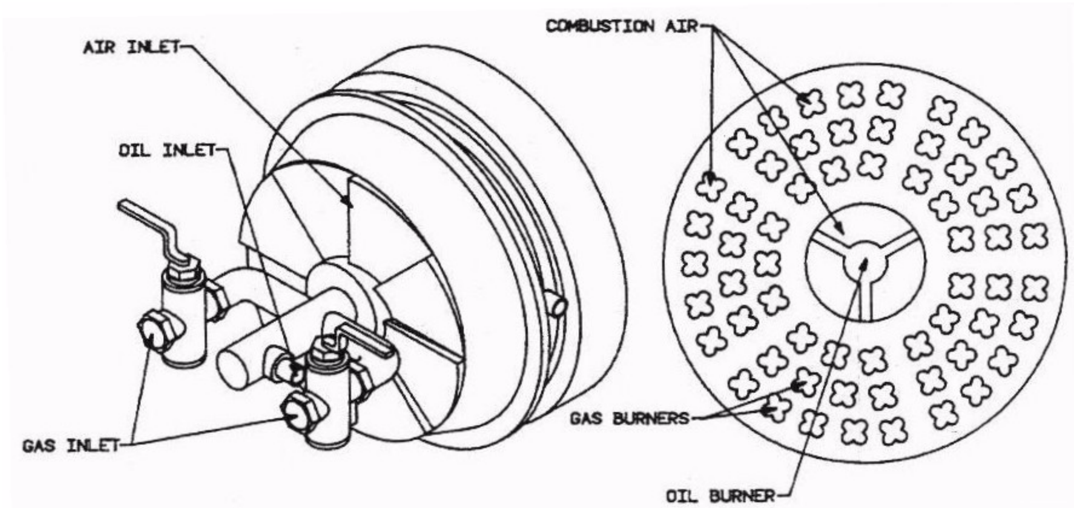


Figure 5-20. Combination Fuel Burners

5.5.2.2 Oil-Burning Equipment

5.5.2.2.1 General

The fundamental principles that govern all burners are the same. Liquid fuel must be vaporized before they can be burned; the oil must be mixed with air; the temperature of the mixture must be above the ignition temperature; there must be a continuous supply of fuel and air; and products of combustion must be removed from the combustion chamber. An oil burner mechanically mixes fuel oil and air for combustion under controlled conditions. The term oil burner is a misnomer, because the device does not actually burn the oil. Small capacity burners vaporize liquid in a single step, larger burners require two steps: atomization and vaporization. Ignition is accomplished by an electric spark, electric resistance wire, gas pilot flame, or oil pilot flame. The five main types of oil atomizers are (1) mechanical, (2) steam or compressed air, (3) low-pressure air, (4) rotary cup, and (5) supersonic.

5.5.2.2.2 Pressure-Atomizing Burners (Gun-Type)

Pressure-atomizing (gun-type) burners are divided into two classes:

- High-Pressure Mechanical Atomization. The high-pressure mechanical atomizing burner is characterized by an air tube, usually horizontal, with a pressurized oil delivery system centrally located in the tube (Figure 5-21). The entire system is designed so that a spray of atomized oil is introduced at approximately 100 psig and mixed in the combustion chamber with the air stream emerging from the air tube. The oil is supplied to the burner by a fuel delivery unit serving as a pressure-flow regulating device as well as a pumping device. If electric ignition is used, a high-voltage transformer supplies approximately 10,000 volts to create an ignition arc across a pair of electrodes located above the nozzle. Where gas ignition is employed on a larger burner, a gas pilot is used with the firing rate governed by the size of the nozzle used. Multiple nozzles are used on some of the larger burners and variable-flow nozzles are used on others. A low fire start on a modulating burner with a variable flow nozzle is accomplished by supplying the oil at a reduced pressure. A low fire start on a multiple-nozzle burner is accomplished by permitting oil flow to only one or two of the nozzles.
- Low-Pressure Mechanical Atomization. The low-pressure atomizing burner differs from the high-pressure-type mainly by its ability to supply a mixture of oil and primary air to the burner nozzle. The air meeting the mixture in the furnace is secondary air and provides for complete combustion. The air pressure before mixing and the pressure of the air/oil mixture vary with different makes of burners, but are in the low range of 1 to 15 psig for air and 2 to 7 psig for the air/oil mixture. Capacity of the burners is varied by making pump stroke or orifice changes on the oil pumps.

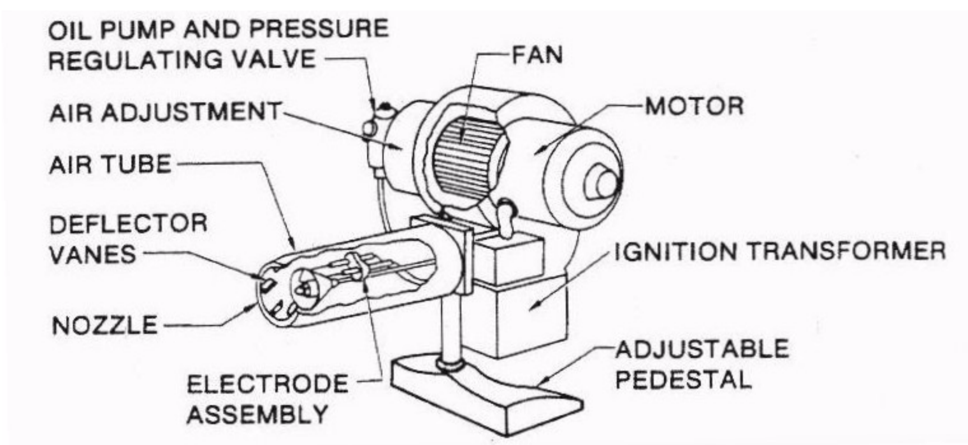


Figure 5-21. High-Pressure Atomizing Burner

5.5.2.2.3 Steam-Atomizing Burners

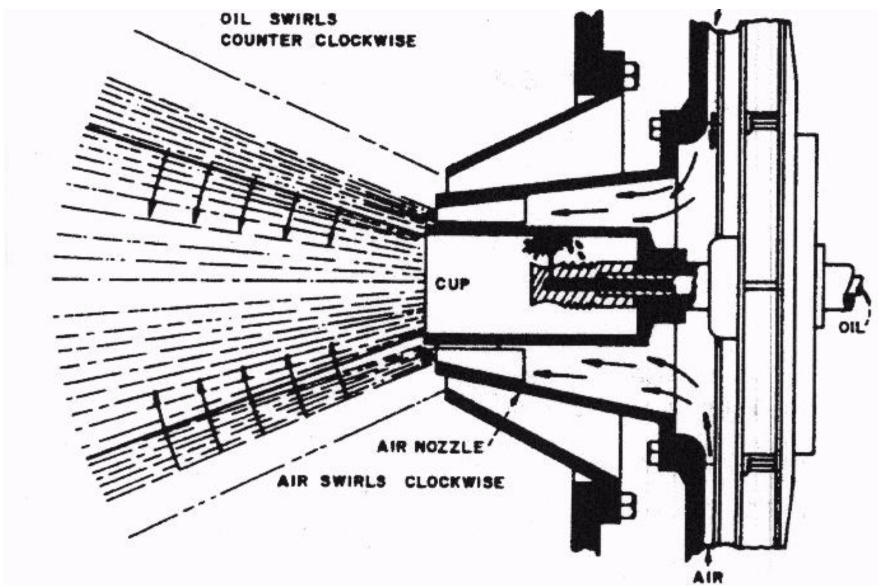
Steam-atomizing burners use steam to atomize heavy grade fuel oil. Two types of steam atomizers are available: internal (oil flows around the steam) and external (steam flows around the oil). With the external steam atomizer there is no mixing of steam and oil; there is mixing of steam and oil with the internal steam atomizer. The steam is usually supplied by the boiler being operated.

5.5.2.2.4 Air-Atomizing Burners

In this burner, the compressed air or steam is the atomizing medium. An air compressor is usually provided as part of the burner, but air may be supplied from another source.

5.5.2.2.5 Horizontal Rotary-Cup Burner

The horizontal rotary-cup burner (Figure 5-22) utilizes the principle of centrifugal atomization.



The oil is prepared for combustion by centrifugal force. It spins off a cup that is rotating at high speed into an air stream that breaks up the oil into a spray. Modulated firing may be provided on these burners. This type of burner is primarily used with heavy oils, as it is harder to control fire when lighter oils are used.

5.5.2.3 Natural Gas Burners

5.5.2.3.1 General

Natural gas is a clean-burning fuel, easy to control from minimum to maximum usage. It gives constant heat, and it is easy to mix with air for good combustion.

5.5.2.3.2 Natural Gas Piping and Controls

Public Law 104-304 requires the U.S. Department of Transportation (DOT) to develop and enforce minimum safety regulations for the transportation of gases by pipeline. The safety regulations became effective in 1970, and are published in Title 49 of the *Code of Federal Regulations (CFR*), Parts 190, 191, 192, and 199. The gas pipeline safety regulations apply to natural gas systems and operators of natural gas master meter systems. The regulations require operators of natural gas systems to deliver gas safely and reliably to customers; provide training and written instruction for employees; establish written procedures to minimize the hazards resulting from natural gas pipeline emergencies; and, keep records of inspection and testing based on suggested forms found in Paragraph 7.4.6.

Natural gas operators who do not comply with the safety regulations may be subject to civil penalties, compliance orders, or both. If safety problems are severe, a "Corrective Action Order" may be issued by Office of Pipeline Safety (OPS). This could result in the shutdown of the system.

State agencies may enforce pipeline safety regulations under certification by OPS. The state agency is allowed to adopt additional or more stringent safety regulations for intrastate pipeline transportation as long as such regulations are compatible with the federal minimum regulations. However, if a state agency is not certified, the DOT retains jurisdiction over intrastate pipeline systems.

The operation of gas-fired equipment presents an element of danger, due to flame extinction and continued gas flow, or due to the danger of leakage. Therefore, natural gas controls and piping arrangements must meet the required codes. Contact your USPS boiler inspector when remodeling or installing equipment. Required controls vary according to size of boiler and burner, but all gas-supply controls must ensure that reliable positive shutoff will occur when the burner cycles off. Gas explosions have occurred as a result of failure of the valve to close tightly. The skills and knowledge of the boiler operator is the first line of defense for preventing explosions; for instance, before starting a fire in a cold boiler or reigniting a flame that may have been accidentally extinguished, the entire fireside of the boiler must be thoroughly ventilated (purged). The second automatic line of defense is a properly functioning burner management system (BMS); it prepares the burner for light-off and includes a flame monitoring safety ignition system to safely light and prove pilot before allowing the main gas valve to operate. New and repaired gas piping must be pressure tested before placed into service. Compressed air at 1.5 times the highest operating pressure in the main fuel gas piping and the duration of the test is contingent on the length and total volume of the pipe. Gas-pressure regulators are required on all gas burners to maintain maximum pressure to the burner. Burner pressure is usually expressed in ounces per square inch (OSI) or inches of water; all burners have an operating range that must be maintained. Required pressure for the maximum firing rate is the highest pressure that should be on the system.

5.5.2.3.3 Atmospheric Burners

The older firebox boilers are usually equipped with natural-draft burners, where injected gas entrains air for combustion. These are either upshot burners installed on the floor, and the gas leaves the burners in a vertical direction, or inshot burners mounted outside the firebox at the front of the boiler and the gas shoots horizontally into the firebox. Both types are atmospheric-injection burners similar to the type used in kitchen gas stoves. They require both primary and secondary air for proper combustion. The burners have both minimum and maximum gas-pressure limits and must be operated within these limits. Too much gas pressure will result in poor combustion, and not enough pressure will result in the gas burning inside the burner. The burners are usually cast-iron or steel and are not designed to withstand the heat of a direct flame. They will either crack open or warp and must be replaced. The air supply is regulated by air dampers, and the damper linkage is connected to the gas-regulator valve by a lever and chain. As the gas-regulator valve opens or closes, the linkage opens or closes the air dampers. The gas-regulator valve may be a two-position valve, either open or shut, or it may be a modulating-type valve that ranges anywhere between open and closed, depending on load demands. The two-position, or ON/OFF valve is the simplest type of valve, but the modulating-type is much preferred since it minimizes ON/OFF cycling and is usually more economical.

5.5.2.4 Power Burners

5.5.2.4.1 Description

Burners that provide forced or induced air for fuel mixing, flame direction control, and secondary air are referred to as power burners. The fan or blower supplying the air is combined with the burner to supply a mixture of gas and primary air leaving the burner tip. The secondary air is supplied in a pattern around the burner tip, and the final mixing and combustion takes place as the mixture travels through the firebox or furnace. This type of burner is usually operated by an automatic control system, where the pilot light is ignited and checked each time the burner is started and cuts off after the main burner starts operating.

5.5.2.4.2 Air Supply

The air supply is traditionally provided, in proportion to the gas supply, by a modulating motor that operates linkage connections to each supply. Some newer control systems have eliminated the single modulating motor with linkages to fuel and air supplies and replaced it with two individual modulating motor for fuel and air. These motors can be configured to open at different rates to allow for different flow characteristics of valves and dampers. Moreover, they can be electronically linked to assure accuracy and repeatability. Adjustment of the air-to-fuel ratio is very critical and, when the burner is of the modulating-type, it is necessary to find a setting that provides the proper amount of air through the full modulation cycle. This requires checking the flue gas with proper instruments and adjusting the air volume while operating the burner at many points from low- to high-fire positions.

5.5.2.4.3 Classification

Burners are classified as either induced-draft or forced-draft. Draft is the force that moves the gases up the stack to get rid of them. Draft can be either atmospheric or forced. Draft in atmospheric burners is cause by pressure differential due to the height of the stack and the heat of combustion. Forced-draft burner uses a blower to supply enough air to pressurize the furnace and force the combustion gases through the boiler.

5.5.2.5 Combination Gas and Oil Burners

Combination gas and oil burners use either fuel or both together. They are normally used in postal installations where natural gas is the main fuel, but must be backed up by a secondary or standby fuel. The standby fuel is usually No. 2 fuel oil that does not require preheating. The burner is a power burner combining a gas burner and an oil burner into one unit, using the same blower and control. The switch over is either manual or automatic. The oil burner may be either a gun-type, mechanical-pressure atomizing burner or an air-atomizing burner. Normally, postal installations specify the mechanical-pressure atomizing burner.

5.5.3 Auxiliary Equipment

5.5.3.1 Induced Draft Fan

Boilers installed on top floors of buildings or in locations where a tall stack is not feasible may be equipped with an induced-draft fan so the stack height can be reduced or the stack eliminated. The fan produces the required draft through the boiler when otherwise it would be created by the height of the stack. This type of fan might also be required to increase the boiler draft when converting from one fuel to another. The fan is usually mounted in a special housing that is part of the stack itself. The motor and drive are located outside the stack for protection from the high temperatures in the stack. The fan must be in operation before the burner comes on and must continue operating until after the burner is shut off. It is connected with the burner-control system to provide a boiler pre-purge and post-purge to clear the boiler of all gases.

5.5.3.2 Barometric-Draft Regulators

This is a simple control item designed to maintain a predetermined airflow through a boiler. It is used on systems where the stack influences the draft through the boiler. The regulator is a simple sheet metal butterfly valve installed in the boiler breeching between the boiler and the smokestack. It has an arm with an adjustable weight that is positioned to determine the amount of draft in the boiler. If the stack draft increases, the weight on the regulator arm is overcome by the increased draft and the damper opens to add dilution air thus reducing draft. The draft through the boiler never exceeds the setting of the regulator.

5.6 GENERAL BOILER OPERATIONS AND LAYUP

5.6.1 General

When it is the responsibility of the USPS to either fire a boiler for the first time or fire a boiler which has been laid up for a period in excess of 24 months, the following procedures should be conducted by the installing contractor. However, local personnel must watch the procedure.

5.6.2 Firing a New Steam Boiler

All boiler auxiliary equipment requires operator attention during start up. When a boiler is to be fired for the first time:

1. The boiler must be checked internally and externally for material, tools, equipment, etc., which might have been left by laborers.
2. All firing equipment and controls, such as low water cut off, high limit control switch, gauges, gasket, etc. must be checked as thoroughly as possible without actually firing the boiler.
3. Fill the boiler to the normal water line, place all auxiliary equipment in the operating position, and start the boiler on low fire. The boiler may have a high- or low-fire switch of some type, or the hand firing valve may be used to limit the burner to low fire.

WARNING

Boiler doors present a hazard during burner light-off. Do not stand in front or back of boiler doors during this time. In case of furnace explosion, the doors could be blown off or thrown open. Failure to comply may cause injury or death.

4. As soon as the burner is firing, check the condition of the fire, burner operation, boiler stack, and the venting system.
5. Check all safety controls and as many limit and operating controls as possible. Controls must be checked individually.
6. The operator must monitor the boiler while pressure is increased and all equipment, piping, etc., must be constantly observed during this period.
7. Before the system is placed in general service, all controls must be checked for proper operation. Additionally, the pressure must be raised to check limit controls and the safety valves, which may require placing a jumper wire on operating and limit controls.
8. The entire steam and return system must be checked for proper operation and inspected for leaks or any evidence of potential trouble.
9. The system must be operated for 3 days at normal pressure. This will allow time for any oil, dirt, etc., in the system to be flushed back to the boiler.
10. The boiler must be shut down and the manhole cover removed for internal inspection. The water must be drained and the boiler checked for accumulation of oil and other foreign material on the waterside. If no evidence of oil or grease is found, the boiler can be returned to normal service by filling the boiler to the normal water line and heating the water until it is steaming. The boiler water must be treated with the prescribed boiler-water treatment, and then the boiler can be closed up and returned to service.

5.6.3 Cleaning a Steam Boiler

After the boiler has operated for 3 days and has been checked (Paragraph 5.6.2), or if evidence of oil or grease is found inside the boiler shell, the following procedure must be followed:

1. Prepare a boil out compound by mixing caustic soda and trisodium phosphate in the proportions of 1 pound of each chemical per 50 gallons of boiler water.

WARNING

Caustic soda is harmful to eyes and skin. Do not permit the dry material or the concentrated solution to come in contact with skin or clothing. Use rubber gloves, apron, and goggles when handling caustic material. Always mix dry chemicals with water before putting them in the boiler. Failure to comply may cause injury or death.

WARNING

Trisodium phosphate causes irritation to respiratory track and skin. Do not digest and use proper protective equipment as recommended by the SDS. Failure to comply may cause injury or death.

2. Remove the manhole cover and add the boil-out compound to the water in the boiler. Fire the boiler and bring the water to a slow boil, without producing excessive steam. Maintain the slow boil for at least 4 hours.
3. Shut down the boiler, slowly drain the boiler, and wash the interior with high-pressure water.
4. Refill the boiler, fire the boiler to boiling point so oxygen will be driven out of the water, add recommended boiler-water treatment, close the manhole opening, and return the boiler to service.
5. If the boiler is not clean after the first boiling-out period, the procedure may be repeated a second time following the same program.

5.6.4 Firing a New Hot-water Boiler

The following procedure must be followed when placing a new hot-water boiler into operation:

1. The boiler must be checked internally and externally for material, tools, equipment, etc., which might have been left by laborers, as well as for missing components.
2. Check all firing equipment and controls as thoroughly as possible without actually starting a fire.

3. If the boiler shows evidence of excessive oil or grease, it can be cleaned separately (Paragraph 5.6.3.) It is usually sufficient to clean the boiler and piping system at the same time by using trisodium phosphate as a cleaning agent. Partially fill the boiler with water, and the trisodium phosphate is added at the rate of one pound for each 50 gallons of water. Close up the boiler. Fill and vent the entire system, except for the expansion tank. A pressure gauge at the highest point in the system will show a pressure of 2 to 3 psig when the system is filled and vented. At this point, consider the pressure in the boiler to be the minimum pressure for the system.
4. Start the circulating pump and check to see that water is circulating to all parts of the system. Fire the boiler on low fire and allow the water to slowly rise to operating temperature (between 180 and 210°F). As soon as the burner is firing, check the flame condition, burner operation, boiler stack, and venting system.

WARNING

Boiler doors present a hazard during burner light-off. Do not stand in front or back of boiler doors during this time. In case of furnace explosion, the doors could be blown off or thrown open. Failure to comply may cause injury or death.

5. Check all safety controls and, as the temperature and pressure increase to operational values, check all operating and limit controls.
6. The operator must monitor the boiler while pressure is building, and all equipment, piping, etc., must be constantly observed during this period.
7. The system must be operated at normal temperature for 4 hours and then shut down and drained. The boiler must be opened and washed out with a high-pressure stream of water.
8. Close up the boiler, refill and vent the system, fire the boiler, and bring the system water up to normal operating temperature. Treat the system water as recommended, and make water tests to determine if proper conditions have been are obtained.
9. Before the system is placed in general service, all controls must be checked for proper operation, and the temperature and pressure must be raised to check the limit controls and safety-relief valve(s). All handhole and manhole covers must be tightened while the boiler is hot, but not under pressure.
10. Check the flue-gas CO and CO_2 content. After final adjustments are made on air-to-fuel ratio, the system can be put in regular service or on standby.

5.6.5 Laying Up a Boiler

5.6.5.1 General

Boilers should be laid up for storage when not in use. This may be during the summer months or for a full year. The type of boiler and the expected period of layup determine the method of layup used.

5.6.5.2 Steel Hot-Water Boilers

Unless the boiler is to remain out of service for over 1 year, nothing is done to the boiler. It must be left filled with treated, preferably deaerated, water. If the boiler is to remain out of service for over 1 year, it must be laid up in the same manner as a steam boiler is laid up for a long period (Paragraph 5.6.5.3.3).

5.6.5.3 Cast-Iron Boilers

5.6.5.3.1 General

All cast-iron boilers (steam and hot-water) are laid up in the same way. When the layup period is for less than 1 year, they are laid up using the wet method; when layup exceeds 1 year, they are laid up by the dry method.

5.6.5.3.2 Wet Method

When a boiler is not needed for a period of 1 month to 1 year, it must be placed in storage or in layup to prevent corrosion of the boiler metal. The recommended method is the wet-type, where the boiler is removed from service, drained, and given an internal inspection and cleaning. All manhole and handhole covers must be removed for cleaning, and new gaskets must be installed when the covers are replaced. After the internal cleaning and inspection is completed, the boiler is filled with water to within a few inches of the top of the boiler. The boiler is fired with a low fire, raising the water to boiling temperature and allowed to steam for 30 minutes to eliminate most of the oxygen in the water. The boiler water must be treated as recommended in Paragraph 4.2 while the boiler is steaming. After the steaming period, the manhole cover can be replaced, and the boiler made tight. A vent valve or the safety valve should be opened, if possible, and the boiler-water level raised until water comes out the vent. The boiler should be checked at least once a month to determine if leakage into or out of the boiler has occurred. With all steam and return valves closed, any leakage out of the boiler will lower the pressure and the water level. When the boiler is needed, the water is dropped to operating level and the boiler fired.

5.6.5.3.3 Dry Method

When a boiler will not be used for a period exceeding 1 year, it should be laid up using the dry method. When one boiler is removed from service and the system is still in use, all valves connecting the boilers must be closed to provide a watertight seal. When a boiler is laid up dry, there must be no moisture inside the drum, or oxygen corrosion will result. When a boiler is laid up dry, the following tasks must be performed:

1. Drain the boiler while it is warm, remove all handhole and manhole covers, and clean the interior (waterside) of the boiler.

2. Make a complete inspection of the waterside, checking for evidence of scale, corrosion, blisters, damaged metal, or loose tubes or bracing.
3. Any needed repairs must be made as soon as possible.
4. The boiler should not be dry-fired in an effort to remove moisture.
5. A similar result can be achieved with proper application of desiccant.
6. Replace the handhole covers.
7. Place a tray of lime or other moisture-absorbing material, such as silica gel, inside the manhole opening. Seal the boiler.
8. Check the boiler periodically and replace the absorbing material as necessary.
9. Regardless of the method used to lay up a boiler, the fireside is treated the same.
10. The tubes must be cleaned when the boiler is removed from service.
11. If humidity is high in the boiler room, the tubes must be coated with mineral oil to prevent corrosion.
12. The fireside must be checked for loose or damaged firebrick or other insulating material.
13. All metal, such as tubes, drum, bracing, etc., must be checked for evidence of leaking, overheating, or other irregularities.
14. The burner tips should be checked for evidence of overheating or clogged passages.
15. Air should be allowed to circulate through the fireside to keep the metal dry.
16. If moisture is a problem, the fireside should be closed up and a tray of moisture-absorbent material placed in the furnace.

5.6.6 Returning a Boiler to Service

5.6.6.1 From Wet Storage

Lower the water level to its normal operating level by using the boiler blow down valve. Check water quality and if acceptable, the boiler is then ready to fire. The length of time a boiler is out of service determines the amount of checking and preparation necessary to ensure that the boiler is ready to fire. When the boiler has been out of service for a period of 3 months or longer, the procedure in Paragraph 5.6.6.2 should be followed disregarding Paragraph 5.6.6.2, Step 3 and Paragraph 5.6.6.2, Step 4 concerning the boiler waterside.

5.6.6.2 From Dry Storage

Returning a boiler to service after a lengthy period in dry storage demands that a competent person familiar with the boiler and system supervise the preparation and actual firing of the boiler. Although most boilers and systems differ in some respects, the following procedure provides a guide that can be used on all boiler installations:

1. Review manufacturer's operating instructions handbook for startup of boiler and equipment.
2. Do not take anything for granted. Because a valve is supposed to be open does not mean that it is open. All items must be checked and verified.
3. Handhole and manhole openings should be checked and new gaskets installed.
4. The interior of the drum should be checked and moisture-absorbent trays removed.
5. Reinstall all handhole covers and add water to the boiler until normal water level is reached.
6. Make sure combustion air to boiler room is unobstructed and boiler flue draft damper is open.
7. Check fuel supply and all equipment to determine that fuel is available at burner.
8. Check burner programmer with fuel off and with a clean flame detector.
9. Turn all switches to ON and set burner on low-fire position or use hand-firing cock to regulate fire to low-fire position.
10. Start burner and allow low fire to bring water temperature up slowly.

WARNING

Boiler doors present a hazard during burner light-off. Do not stand in front or back of boiler doors during this time. In case of furnace explosion, the doors could be blown off or thrown open. Failure to comply may cause injury or death.

11. Bring water up to boiling temperature, for steam boiler; allow it to steam slowly for 30 minutes to drive off oxygen in the water.
12. If water, bring temperature up to 180°F for at least 4 hours.
13. Shut down the burner, treat the boiler water, install the manhole cover (use new gasket), and open all appropriate valves to the system.
14. Check all valves on makeup water supply and on condensate-return system, if applicable, to ensure that they are open.
15. Test condensate-return pumps for proper operation by physically raising floats or by energizing control circuits.

16. Fire boiler and raise pressure to normal level. Make sure pressure or temperature controller functions properly.
17. While pressure is building, test all safety and operating controls for proper operation.
18. Lift safety or safety-relief valve by hand when pressure is normal. Check all boiler and burner auxiliaries.
19. Observe flame condition and check flue gas for CO and CO_2.

5.6.7 Boiler Operating Tests and Inspections

WARNING

Boiler testing is inherently hazardous. Observe all safety precautions when conducting any boiler tests. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

5.6.7.1 Responsibility

All testing and inspection requirements presented in this part are meant to be conducted by the boiler operator or the operator's supervisor. These are routine operational tests and inspections that do not take the place of required formal boiler inspections. Only qualified personnel may perform the tests. Record the tests on Form 4846 or 4846-A, Low-pressure Heating Boiler Operating-Log.

5.6.7.2 Tests

5.6.7.2.1 Try-Lever Test

Once a month during the heating season, the safety valve or safety-relief valve must be manually checked, (try lever test). This is done using a chain or rope long enough to be reached by a person standing on the floor and attached to the handle on the valve. The valve is opened for a period of at least 5 seconds and allowed to snap shut. If steam simmers from the valve or if water drips from the safety-relief valve, the valve should be quickly rechecked and if defective, it should be replaced. Only authorized repair shops with a Certificate of Authorization ("VR" Stamp) shall be used to repair or recondition relief valves. A steam boiler should have a minimum of 5 psig steam pressure when the test is performed. A hot-water boiler should be at its normal operating temperature.

5.6.7.2.2 Pop Test

The pop test determines the actual opening pressure and temperature of safety or safety relief valves. It is performed by local personnel once a year and must be conducted just prior to the start of the heating season. For boilers that are operated 12 months a year, the test must be made when the boiler is shut down for cleaning and inspection. A pop test creates conditions that actually force the valve to operate as it would in an emergency. The steam-pressure controls must be adjusted or jumpered electrically to allow the pressure to reach the setting of the safety valve. The hot-water boiler pressure is raised by expansion of the water in the boiler. The expansion tank must be open to the boiler so that an air cushion is provided; otherwise, the boiler could be damaged due to uncontrollable rising pressure. Except for large multistory buildings, most hot-water boilers have safety-relief valves set for 30 psig. For either hot-water or steam boiler, the system must be isolated from the boiler during the test. At least two persons knowledgeable in boiler testing must be present, and provision must be made to allow safe discharge of water and steam from the safety valves or safety-relief valves. The water discharge from safety-relief valves creates a considerable amount of steam, and this should be anticipated. If the safety valve or safety-relief valve does not pop at the set pressure, the test must be discontinued and the valve replaced or returned to the manufacturer for repair. The pressure gauge must be checked and calibrated before conducting the test.

Pop and capacity tests on water-tube heating boilers should be performed as follows:

1. Isolate the boiler and raise the pressure using a hydrostatic test pump (or city water pressure, if adequate) until the valve relieves.

WARNING

Pop Tests shall be conducted in presence of a certified Boiler Inspector. Failure to follow proper procedures may result in damage to equipment, personal injury, or death.

WARNING

Boiler testing is inherently hazardous. Observe all safety precautions when conducting any boiler tests. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

2. Remove the valve and send it to an authorized safety valve test facility laboratory for the test. Care shall be exercised to assure that the valve is not damaged during reinstallation.

It is highly recommended to replace the relief valves with new or reconditioned valves in lieu of pop tests.

5.6.7.3 Inspection

Although controls are referred to as operating, safety, or limit controls, they all perform a safety function. All controls should be visually checked daily, but once a month they must be inspected to determine that they are actually working. Such inspection involves creating conditions that allow the controls to operate. Although not all boilers have identical controls, most have some type of the following:

- Operating Controls. These controls maintain normal boiler operation and include the pressurestat, aquastat, fuel valves, modulating valves, level controllers, water-pressure regulator, etc.

- Limit Controls. These controls maintain both high and low limits for steam or water pressure, water level, stack temperature, fuel pressure, and temperature, and include low-water level controller, pressure-limit stats, and temperature-limit stats (both high and low).
- Safety Controls. These controls shut down the burner when a dangerous mechanical failure occurs and include flame failure, ignition failure, mechanical-draft failure, and circuit-failure controls.
- Programmer System Controls. The burner should be stopped and started while watching the programmer control to ensure that the correct timing and sequence is carried out and that all phases operate correctly.

5.6.7.4 Preparing Boiler for Internal Inspection

The local office should prepare the boiler for internal inspection in the following manner:

1. Water must be drawn off and the boiler washed thoroughly.
2. Manhole and handhole plates, washout plugs, and inspection plugs in water-column connections must be removed.
3. The boiler and combustion chamber must be thoroughly cooled and cleaned.
4. The furnace, combustion chamber, and fireside tubes must be cleaned.
5. All grates of internally fired boilers must be removed.
6. At each inspection, brickwork must be removed as required by the inspector in order to determine the condition of the boiler, headers, furnace, supports, or other parts.
7. The pressure gauge must be removed for testing.
8. Any leakage of steam or hot water into the boiler must be prevented by disconnecting the pipe or valve connecting the boiler to steam or another source of hot water.
9. The person responsible for preparing the boiler for inspection must be present at the inspection.

5.6.7.5 Boiler Logs

5.6.7.5.1 Low-Pressure

Forms 4846 and 4846-A, Low-Pressure Heating Boiler Operating Logs, establish a standard for recording the operation of low-pressure boilers in order to improve safety, fuel economy, and maintenance. (See Appendix A.3 Low Pressure Heating Boiler Operating Log (Hot Water) for an example of hot-water boiler logs, Form 4846-A, and Appendix A.4 Low Pressure Heating Boiler Operating Log (Steam), Form 4846). Record each boiler operation on the proper form in accordance with instructions on the reverse of the form (Paragraph 5.6.7.7 for exception).

5.6.7.5.2 High-Pressure Boilers

The operation of high-pressure boilers (defined as steam boilers over 15 psig or hot-water boilers over 160 psig or 250°F) requires a unique, more comprehensive log than Form 4846 or Form 4846-A. A special log must be developed and used at each location where high-pressure boilers are used.

5.6.7.5.3 Retention

Completed logs will be retained for 3 years. After three years, one typical form for each heating season must be retained indefinitely.

5.6.7.6 Boiler Malfunction

The headings on Form 4846 and Form 4846-A provide a place for the name(s) of the person or persons who are qualified to troubleshoot the boiler in case of emergency or malfunction. Since many boiler explosions are caused by persons manipulating controls in an effort to fire a boiler, only qualified personnel following the control manufacturer's instructions should attempt to correct control malfunctions.

5.6.7.7 Small Domestic-Type Boilers

Use of Form 4846 and Form 4846-A is not required on small, domestic-type boilers with less than 400,000 Btu/hr input. However, all other maintenance operating and testing procedures prescribed in this handbook, MS-1, and MS-49 must be followed.

5.6.8 Preventive Maintenance

Each facility manager must verify that all preventive maintenance being performed on boiler and water heaters in facilities is in accordance with the preventive maintenance that is prescribed in the current MMO titled Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Preventive Maintenance Checklists. Boilers must display a current certificate of inspection at all times.

5.7 OPERATION, MAINTENANCE, AND REPAIR OF STEAM BOILERS

5.7.1 General

The boilers covered in this section are steel, fire-tube, low-pressure steam boilers. The information presented here is general in nature, but there should be no problem in relating this information to a specific piece or type of equipment. The manufacturer's handbook covering a particular boiler or system should be used in conjunction with this handbook to ensure that proper operation and maintenance procedures are followed.

5.7.2 Starting a Steam Boiler and Heating System

5.7.2.1 Cleaning and Filling

5.7.2.1.1 Inspection for Foreign Objects

Before starting a new boiler, an inspection must be made to ensure that specified components have been properly installed and no foreign objects such as tools, equipment or rags, are left in the boiler.

5.7.2.1.2 Checks before Filling

Before putting water into a new boiler, to the extent that it is possible without lighting a fire in the empty boiler, make certain that the firing equipment is in operating condition. This is necessary because in order to drive off the dissolved gases that might otherwise corrode the boiler, raw water must be boiled (or heated to at least 180°F promptly after it is introduced into the boiler.

5.7.2.1.3 System Cleaning

No chemicals should be added to the boiler until the hydrostatic test has been completed and the burner has been checked to ensure a low fire flame can be established. Fill the boiler to the proper waterline and operate the boiler for a few days with steam in the entire system to bring the oil and dirt back from the system to the boiler. This is not necessary if the condensate is to be temporarily wasted to the sewer, in which case the system should be operated until the condensate runs clear.

5.7.2.2 Starting After Layup

(Single Boiler Installation)

When starting a boiler after layup, proceed as follows:

1. Review the manufacturer's procedure for startup of burner and boiler.
2. Set the control switch in the OFF position.
3. Make sure the path of fresh air to the boiler room is unobstructed.
4. Check the availability of fuel.
5. Check the water level in the gauge glass. Make sure the gauge-glass valves are open.
6. Use try cocks, if provided, to double-check the water level.
7. Vent the combustion chamber to remove unburned gases.
8. Clean the fire scanner glass, if provided.
9. Open the main steam shutoff valve.
10. Open the cold-water supply valve to the water feeder, if provided.
11. Open the suction and discharge valves on vacuum or condensate pumps and set electrical switches for desired operation.
12. Vent the boiler to remove air when necessary.
13. Check the operating pressure setting of the boiler.
14. If provided, check the manual reset on the low-water fuel cutoff and high-limit pressure controls to determine if they are properly set.
15. Open the manual fuel-oil supply or manual gas valve.
16. Turn on the circuit breaker or fused disconnect switch.
17. Turn on all boiler emergency switches.
18. Turn on the boiler control starting switch.

WARNING

Boiler doors present a hazard during burner light-off. Do not stand in front or back of boiler doors during this time. In case of furnace explosion, the doors could be blown off or thrown open. Failure to comply may cause injury or death.

19. Slowly raise the pressure and temperature. Stand by the boiler until it reaches the established cutout point to ensure that the operating control shuts off the burner.
20. During the pressure buildup period, walk around the boiler frequently to observe that all associated equipment and piping is functioning properly. Check for proper over-the-fire draft.
21. Immediately after the burner shuts off, inspect the water column and open each try cook (if provided) individually to determine true water level.
22. Enter the following in the log book:
    a. Date and time of startup
    b. Any irregularities observed and corrective action taken
    c. Time when controls shut off burner at established pressure, tests performed, etc.
    d. Signature of operator
23. Check the safety valve for evidence of simmering. Perform a try-lever test (Paragraph 5.6.7.2).

5.7.2.3 Abnormal Conditions

CAUTION

Operating a boiler with known abnormal conditions is dangerous and forbidden. Do not attempt to restart unit until all deficiencies have been identified and corrected. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

If any abnormal conditions occur during lightoff or pressure buildup, immediately open the emergency switch. Do not attempt to restart unit until difficulties have been identified and corrected.

5.7.2.4 Condensation

Following a cold start, condensation (sweating) may occur in a gas-fired boiler to such an extent that it appears the boiler is leaking. This condensation should stop after the boiler is hot.

5.7.2.5 Cutting in an Additional Boiler

NOTE

> When the stop valve at the boiler outlet is closed, the stop valve in the return line of that boiler must also be closed.

When placing a boiler on the line with other boilers already in service, start the boiler using the procedures in Paragraph 5.7.2.2; however, keep the supply stop valve and the return stop valve closed. If one is provided, open the drain valve located between the stop valve at the boiler outlet and the steam main. When the pressure within the boiler is approximately the same as the pressure in the steam main, open the stop valve very slightly. If there is no unusual disturbance, such as noise, vibration, etc., continue to open the valve slowly until it is fully open. Then open the valve in the return line.

5.7.3 Operation

5.7.3.1 Water Level

5.7.3.1.1 Checks and Tests

Check the water gauges regularly, determining by trial the required frequency. The check should be made when there is steam pressure in the boiler. Close the lower gauge-glass valve, then open the drain cock located on the bottom of the valve and blow the glass clear. Close the drain cock and open the lower gauge-glass valve. Water should return to the gauge glass immediately. If water return is sluggish, leave the lower gauge-glass valve open and close the upper gauge-glass valve. Then open the drain cock and allow water to flow until it runs clear.

5.7.3.1.2 Leaks

Close the drain valve and repeat the test described in Paragraph 5.7.3.1.1 with the lower gauge-glass valve closed. If leaks appear around the water gauge glass or fittings, correct the leaks at once. Steam leaks may result in a false water line and may also damage the fittings.

5.7.3.1.3 Blow Down

If water disappears from the water gauge glass, blow down the gauge glass to see if water appears. If it does not appear, stop the fuel supply immediately. Close off feedwater to prevent water from being added until the boiler cools. Likewise, the safety valve should not be opened. Let the boiler cool until the crown sheet or combustion chamber is below 120°F. Then add water to the boiler until 1 inch shows in the gauge glass. Do not put the boiler back into service until the condition responsible for the loss of water has been identified and corrected. Intended and unintended discharge of boiler water requires an National Pollutant Discharge Elimination System (NPDES) permit.

5.7.3.2 Steaming Pressure

5.7.3.2.1 Set Pressure

A common danger in steam-heating boilers comes from the failure of the safety valve(s) to open at the set pressure. This is usually due to the buildup of a corrosive deposit between the disk and the seat of the safety valve that is caused by a light leakage or weeping of the valve. Frequent safety valve inspection will mitigate this danger.

5.7.3.2.2 Pressure Differential

The snap-action opening of a safety valve occurs when the boiler steam pressure on the underside of the valve disk overcomes the closing force of the valve spring. As the force of the steam pressure approaches the counteracting force of the spring, the valve tends to leak slightly and, if this condition is permitted to exist, the safety valve can stick or freeze. Therefore, the safety valve should not be set close to the boiler operating pressure. On low-pressure heating boilers, the pressure differential between the safety valve set pressure and the boiler operating pressure should be at least 5 psi (35 kiloPascals kPa)), i.e., the boiler operating pressure should not exceed 10 psig (70 kPa). If, however, the boiler operating pressure is greater than 10 psig (70 kPa), it should not exceed 15 psig (100 kPa) minus the blow down pressure of the safety valve.

5.7.3.3 Blow Down

CAUTION

Valve opening and closing must be performed in the proper sequence. Do not open the slow-opening blow off valve first and then pump the lever-action blow off cock open and closed. The water hammer is apt to break the valve bodies or pipe fittings. Failure to comply may cause equipment damage.

Where low-pressure steam boilers are used solely for heating and where practically all of the condensate is returned to the boiler, blow down only as often as concentration of solids require. Boilers used for process steam that require high makeup must be blown down as required to maintain chemical concentrates at the desired level and to remove precipitated sediments. Boilers equipped with slow-opening blow off valves and a quick-opening blow off cock must have the levers or cocks opened first. The slow-opening valve must then be gradually opened and closed. When the slow-opening valve has been shut tightly, close the lever valve or cock.

5.7.3.4 Rust

If rust appears in the water gauge glass, it indicates corrosion and must not be ignored. Check the boiler water to ensure that the water-treatment compound is at proper strength and make sure the boiler is not using considerable quantities of makeup water. Check the return line and other parts of the system for evidence of corrosion.

5.7.3.5 Waterline Fluctuation

A wide fluctuation of water line may indicate that the boiler is foaming or priming. This may be due to a very high rate of steam, especially in low- pressure boilers, or due to the water level in the boiler being carried too high. Foaming may also be caused by dirt or oil in the boiler water. Foaming can sometimes be cured by blowing the boiler down, draining 2 or 3 inches of water, and then refilling the boiler a few times. If foaming persists, it may be necessary to take the boiler out of service, drain, and wash out thoroughly as described in Paragraph 5.7.2.1. The boiler is then refilled and put back into service.

5.7.3.6 Abnormal Water Loss

The requirement of large amounts of manually fed makeup indicates abnormal water loss. Boilers operated with automatic water feeders requiring an increase in water treatment must be immediately investigated to determine the cause of increased water usage. Prompt and proper repair or replacement of parts must be made at once to correct the abnormality. If the operator cannot determine the cause of the water loss, a competent contractor should be contacted.

5.7.3.7 Makeup Water

When makeup water is needed and neither the boiler nor the condensate tank is equipped with an automatic water feeder, manually add water to the steam boiler following these procedures:

1. Use every practical means for excluding oxygen from the boiler water. One source of oxygen is makeup water; therefore, hold makeup to a minimum. If the boiler loses more than 3 inches of water per month, this indicates a probable leak in some part of the system. The leak must be found and corrected.
2. If the system includes a pump for returning condensate or adding feedwater, be certain that the air vent at the receiver is operating properly.
3. If large quantities of feedwater are required, de-aerating equipment is recommended to remove dissolved gases, thereby reducing oxygen corrosion.

5.7.3.8 Low-Water Cutoff

5.7.3.8.1 Inspection

Check the operation of the low-water cutoff, pump control, and the water feeder (if one is installed). Follow the manufacturer's blow down instructions on the tag or plate attached to each control (if provided).

5.7.3.8.2 Tests

Periodically, the low-water cutoff may be tested under actual operating conditions. With the burner operating and the boiler steaming at the proper water level, close all the valves in the feedwater and condensate-return lines so the boiler will not receive any replacement water. Then carefully observe the water line to determine where the cutoff switch stops the burner in relation to the lowest permissible water line established by the boiler manufacturer. The lowest visible part of the sight glass must be mounted at least 1" above manufacturer's lowest permissible level. Each low water fuel cutoff must cut off fuel supply automatically prior to the fall of the surface of the water below the level of the lowest visible part of the gage glass.

5.7.4 Removal of Steam Boiler from Service

5.7.4.1 Procedure

NOTE

For treatment of laid up boilers, see SECTION 4.

To remove a steam boiler from service at the end of the heating season or for repairs, proceed as follows:

1. While maintaining boiler-water temperature (180 to 200°F), drain off the water from the bottom drain until it runs clear.
2. Refill water to the top of the boiler and add sufficient water-treatment compound to bring the treatment up to strength.
3. After all the dissolved gases are released (approximately 1 hour), shut down the firing equipment, then open the main disconnect switch.

5.7.4.2 Cleaning

When the boiler is cool, thoroughly clean the tubes and other fireside heating surfaces. Scrape the heating surfaces down to clean metal. Clean the smokeboxes and other areas where soot or scale may accumulate. Soot is not corrosive when it is perfectly dry, but can be very corrosive when damp. For this reason, all soot must be removed from a boiler at the beginning of the non-operating season or any extended non-firing period.

5.7.4.3 Corrosion Protection

Swab the fireside heating surfaces with neutral mineral oil to protect against corrosion. If the boiler room is damp, place a tray of calcium chloride or unslaked lime in the combustion chamber and replace the chemical when it becomes mushy.

5.7.4.4 Water Level

Drain a steam boiler back to the normal water level before putting the boiler back in service.

5.7.4.5 Periodic Checks

Check the boiler occasionally when it is idle to ensure it is not corroded.

5.7.5 Maintenance

5.7.5.1 Cleaning

Clean the boiler tubes, smokeboxes, and other heating surfaces as needed. The frequency of the cleaning is best determined by trial, but must be done at least annually. A general prediction of the frequency of cleaning applicable to all boilers cannot be made.

5.7.5.2 Draining

A clean, properly maintained steam-heating boiler should be drained if there is a possibility of freezing, if the boiler has accumulated a considerable amount of sludge or dirt on the waterside, or if it is necessary to make repairs to the waterside. Very little sludge should accumulate in a boiler where little makeup water is added and where appropriate water treatment is maintained at the proper strength.

5.7.5.3 Antifreeze

WARNING

Automotive and undiluted antifreeze are not designed for boiler use. Do not use automotive or undiluted antifreeze. Do not use ethylene glycol as it presents a poison inhalation hazard. Failure to comply may cause severe injury or death.

Antifreeze solutions, when used in heating systems, shall be environmentally friendly and should be tested from year to year as recommended by the antifreeze manufacturer. Antifreeze solutions should not be circulated through the boiler. The antifreeze solution should be heated in an indirect heat exchanger. If antifreeze is used, check to ascertain that elastomeric seals and gaskets are not adversely affected.

5.7.5.4 Fireside Corrosion

5.7.5.4.1 General

The causes of waterside corrosion and procedures to remove it are discussed in Paragraph 4.2.2.3.

Boilers also corrode on the fireside. Some fuels contain substances that cause fireside corrosion. Sulfur, vanadium, and sodium are among the materials that may contribute to this problem. Boilers that operate continuously are less prone to fireside corrosion.

5.7.5.4.2 Sulfur

Deposits of sulfur compounds may cause fireside corrosion. The probability of trouble from this source depends on the amount of sulfur in the fuel and on the care used in cleaning the fireside heating surfaces. This is particularly true when preparing a boiler for a period of idleness. Preventing fireside corrosion also depends on keeping the boiler heating surfaces dry (or coated with mineral oil) when a boiler is out of service.

5.7.5.4.3 Vanadium

Deposits of vanadium or vanadium and sodium compound also cause fireside corrosion. Some heavier fuel oils have these compounds in trace amounts. While this can be controlled with fuel oil additives, MTSC should always be consulted before using such additives. These compounds may be corrosive during the season when boilers are in service.

5.7.5.4.4 Cleaning and Inspection

The person responsible for boiler maintenance should be certain that the fireside surfaces of the boilers are thoroughly cleaned at the end of the firing season. Operating a boiler with water temperatures too low can cause abnormal corrosion on the fireside. This is due to condensation of the stack gasses. Maintain water cut-out temperatures at 180°F or above to eliminate this problem. If signs of abnormal corrosion are discovered, a reputable contractor should be engaged.

5.7.5.5 Safety Valves

Every boiler manufactured to ASME Code Section I and IV shall be protected by a safety valve. The safety valve shall be manufactured per ASME code, sized appropriately for the boiler, and National Board Certified. Defective safety valves can lead to catastrophic damage to facility and injury or death to personnel. Replace safety valves only with ASME coded and National Board certified valves of the required capacity. Safety valves on steam boilers must be tested for proper operation as outlined in Paragraph 5.6.7.

5.7.5.6 Burner Maintenance

5.7.5.6.1 Oil Burners

Oil burners require annual maintenance to retain their operational safety and combustion efficiency. Inspect burner and appliance for signs of soot, overheating, fire hazards, corrosion, or wiring problems. Verify that all oil-fired heaters are equipped with a barometric draft control, unless they have high-static burners. Each oil furnace or boiler should have a dedicated electrical circuit. Assure that all 120-volt wiring connections are enclosed in covered electrical boxes. Inspect fuel lines and storage tanks for leaks. Inspect heat exchanger and combustion chamber for cracks, corrosion, or soot buildup. Check and clean the oil-line strainers. Inspect and check the nozzle and check the oil level in the gear cases. Check and clean filters, air-intake screens, blowers, and air passages. Check all linkages and belts, adjust as required, and lubricate in accordance with the manufacturer's recommendations. Check to see if flame ignition is instantaneous or delayed. Flame ignition should be instantaneous, except for pre-purge units where the blower runs for a while before ignition. Sample undiluted flue gases with a smoke tester, following the smoke-tester instructions. Compare the smoke smudge left by the gases on the filter paper with the manufacturer's smoke-spot scale to determine smoke number. Analyze the flue gas for O_2 or CO_2, temperature, CO, and steady-state efficiency (SSE). Sample undiluted flue gases between the barometric draft control and the appliance.

5.7.5.6.2 Gas Burners

Check gas burners for causes of CO and soot, such as over-firing, closed primary air intake, flame impingement, and lack of combustion air. Remove dirt, lint, rust, and other debris that may be interfering with the burners. Clean the heat exchanger, if necessary. Take action to improve draft, if inadequate because of improper venting, obstructed chimney, leaky chimney, or depressurization, as well as seal leaks in vent connectors and chimneys. Adjust gas input if combustion testing indicates over firing or under firing. Linkages, belts, and moving parts on power burners should be checked for proper adjustment. On combination oil and gas burners, after prolonged periods of oil firing, the gas outlets may become caked with carbon residues from unburned fuel oil and will require cleaning. Any required lubrication must be in accordance with the manufacturer's specifications. Check the pilot burners and ignition equipment for proper flame adjustment and performance.

5.7.5.7 Low-Water Fuel Cutoff and Water-Feeder Maintenance

Qualified personnel must annually dismantle low-water fuel cutoffs and water feeders to the extent necessary to ensure freedom from obstructions and proper functioning of the working parts. Inspect connecting lines to the boiler for accumulation of mud, scale, etc., and clean as required. Examine all visible wiring for brittle or worn insulation and make sure electrical contacts are clean and functioning properly. Give special attention to solder joints on the bellows and float if this type of control is used. Check the float for evidence of collapse, and check the mercury bulb (where applicable) for mercury separation or discoloration. Do not attempt to repair mechanisms in the field. Complete replacement mechanisms, including necessary gaskets and installation instructions, are available from the manufacturer. Mercury must be treated as a toxic waste material.

5.7.5.8 Flame Safeguard Maintenance

Flame safeguard control, called the primary control or the programmer, ensures safe light-off, operation, and shutdown of the burner; it regulates purging the boiler of all gases prior to trial for ignition and verifies that there is no flame in the boiler prior to lightoff, and checks for a pilot before allowing the main flame to light. The control provides proof that the main flame has ignited before releasing the boiler to the run (modulation) mode. Most importantly, it does not allow any action to occur if operating controls, limits, or safety interlocks are open.

The flame safeguard control also initiates a post purge upon shutdown to remove all gases from the boiler. And it often provides a means for detecting a problem elsewhere in the system. Although the flame safeguard is designed for fail-safe operation and is quite reliable, a faulty device can be catastrophic and should not be ignored.

5.7.5.8.1 Thermal-Type Detection Device

Check the device for electrical continuity and satisfactory current generation in accordance with the manufacturer's instructions. After completing maintenance, test as per Paragraph 5.9.2.

5.7.5.8.2 Electronic-Type Detection Device

Replace the vacuum tubes or transistors annually with the type recommended by the manufacturer. Check operation of the unit in accordance with manufacturer's instructions and examine for damaged or worn parts. Do not attempt to repair these units in the field. Replacement assemblies are available from the manufacturer on an exchange basis.

5.7.5.9 Limit-Control Maintenance

Maintenance on pressure-limiting controls is generally confined to a visual inspection of the device for evidence of wear, corrosion, checking wiring for loose connections or damaged wires, etc. If the control is a mercury bulb-type, check for mercury separation and discoloration of the bulb. If the control is defective, replace it. Do not attempt to make field repairs. Mercury is a toxic and should be handled appropriately.

5.7.6 Cast-Iron Boiler and Steel Boiler Maintenance

5.7.6.1 Cast-Iron Boiler Maintenance

5.7.6.1.1 Heating Surfaces

Check the firebox gas passages and breeching for soot accumulation. If required, use a wire brush and vacuum cleaner to remove the soot or other dirt accumulations.

5.7.6.1.2 Internal Surfaces

If there is considerable foreign matter in the boiler water, the boiler must be allowed to cool, then drained and thoroughly flushed out. Remove the blow down valves and plugs from the front and rear sections, and with a high-pressure water stream wash through these openings. This will normally remove any sludge or loose scale. If hard scale has formed on the internal surfaces, the boiler must be cleaned by chemical means, as prescribed by a qualified water-treatment specialist.

5.7.6.2 Steel Boiler Maintenance

5.7.6.2.1 Heating Surfaces

WARNING

Refractory ceramic fibers (RCF) may, when exposed to extremely high temperature (>1800°F), change into a known human carcinogen. The fibers present an inhalation hazard when disturbed. Do not remove or replace previously fired RCF (combustion chamber insulation, target walls, canopy gasket, flue cover gasket, etc.) or attempt any service or repair work involving RCF without ascertaining composition of the RCF material. Failure to comply may cause injury or death

Remove all accumulations of soot, carbon, and dirt from the fireside of the boiler. Use a flue brush to clean the tubes. Clean the breeching and stack as required. Inspect the refractory and make any necessary repairs. Note, however, that refractory ceramic fibers (RCF) may, when exposed to extremely high temperature (>1800°F), change into a known human carcinogen. When disturbed as a result of servicing or repair, RCF becomes airborne and, if inhaled, may be hazardous to your health.

5.7.6.2.2 Internal Surfaces

Blow down the boiler as required. If water does not run clear, the boiler must be cleaned. Allow the boiler to cool, vent and drain it; remove all manhole and handhole covers, and wash the inside of the boiler with a high-pressure water stream. Loosen any solidified sludge, scale, etc., with a hand scraper. Start at the top of the boiler and work down. Flush thoroughly after cleaning. Where access is limited or where scale buildup is difficult to remove, it may be necessary to clean the boiler chemically, as prescribed by a qualified water-treatment specialist. The discharge water is regulated under the Clean Water Act and requires a permit for disposition.

5.7.6.3 Tubes

NOTE

Do not use sealant in boilers.

If one tube in a boiler develops a leak due to corrosion, it is likely that other tubes are corroded. Have the boiler examined by a capable and experienced inspector before ordering any replacement tubes. If all the tubes will need replacement soon, it is preferable and less expensive to have all the work done at one time.

5.7.6.4 Periodic Tests

5.7.6.4.1 Daily (for Maintenance Capable Facilities without BAS)

1. Observe operating pressures, water level, gauge glass, test low water cut off and water hardness, complete blow down, and other conditions listed on the daily log sheet.
2. Observe the flame on oil burners; if the flame is smoky or if the burner starts with a puff, correct.
3. Determine and correct the cause of any unusual noise or condition.

5.7.6.4.2 Annually

See guide in current Guidelines for Creating Detailed Local Building and Building Equipment Preventive Maintenance Checklists MMO.

5.7.6.4.3 Internal Inspection

When practical, use a flashlight rather than an extension light for internal inspections. If an extension light is taken into a boiler, ensure that the cord is rugged, in good condition, and properly grounded, use GFI. It should be equipped with a vapor-tight globe, substantial guard, and nonconducting holder and handle.

5.7.6.5 Steam-Pressure Gauge

A steam-pressure gauge should never be used without a water trap or siphon tube, sometimes referred to as a pigtail, to protect the gauge from the high temperature of the steam. The steam gauge needle should return to zero when the system is off or when the gauge is removed. All pressure gauges must be equipped with a gauge cock valve so the gauges can be removed while the system is under pressure. An inspector's gauge test port should be provided. The gauge cock is also used to damp out any fluctuation in the pressure to prevent the gauge needle from jumping or moving. Rapid movement of the needle will result in a wearing action on the pinion gear in the gauge and will render the gauge useless. Steam pressure must never be carried higher than necessary; a constant pressure should be maintained, if possible. A low-pressure steam boiler has safety valves that open at 15 psig. The normal operating pressure should never be over 10 psig steam pressure.

5.7.6.6 Maintenance of Condensate-Return Systems

Inspect and clean the strainer upstream from of the pump. Drain and flush the condensate tank. Check pump packing or mechanical seal, float switches, and vacuum switches, as applicable. For detailed instructions, refer to manufacturer's maintenance data and specifications.

5.7.7 Boiler Repairs

5.7.7.1 Safety

Never attempt to repair a boiler while it is in service or under pressure. When the boiler is shut down for repairs, all sources of energy should be isolated using lock out/tag out procedures. Only authorized boiler repair personnel from an approved R or NR-stamp shop shall repair boilers. Take every precaution necessary to ensure the safety of employees working in the boiler room and particularly of those working inside the steam space or in the combustion chamber of the boiler. Entry into a boiler shall be treated as a confined space (i.e., vapor space testing, harnesses, radios, and watcher). Therefore, postal employees may not enter the space. Pull the main burner switch, lock it out, and tag it with Form 4707, Out of Order. Swing the burner out of place, if possible. Close and lock valves, etc. Someone must always be standing by outside the boiler when anyone works inside the boiler.

5.7.7.2 Notification

When repair work is required, notify the authorized boiler and pressure vessel inspector and be guided by the inspector's recommendations.

5.7.7.3 Welding Requirements

All welding performed on pressure-containing parts of boilers or unfired pressure vessels must be done by a shop that holds a valid "R" stamp certificate from the National Board of Boiler and Pressure Vessel Inspectors or other acceptable certification recognized by the ASME. Additionally, welders should be qualified to perform specified requirements.

5.7.8 Tests and Inspections

NOTE

The tests recommended for burner efficiency, combustion safeguards, safety controls, operating controls, limit controls, safety valves, and safety-relief valves are included in Paragraph 5.6.7.

5.7.8.1 Purpose

Periodic inspections ensure protection against loss of or damage to the pressure vessel because of corrosion, pitting, etc. These inspections also provide protection against unsafe operating conditions possibly caused by changes in piping or controls or lack of testing of safety devices. Inspections must be thorough and complete. So that all important elements may be checked, the following recommended directions and instructions for such inspections are given.

5.7.8.2 Preparing Boilers for Inspection

Each boiler shall have a written boiler inspection plan. The inspection scope should include the necessary steps for scheduling, work permits, and plans for shutdown, inspecting, and restarting the boiler. Inspection is centered on critical boiler components, whose failure will directly affect safety and/or boiler reliability. The work scope should also incorporate each unit's operating and failure histories for critical parts, and shall include hydrostatic testing observed by the boiler inspector.

Before inspection, every accessible part of a boiler must be opened and properly prepared for examination, both internally and externally. In cooling down a boiler for inspection or repairs, the water must not be withdrawn until the setting is sufficiently cooled. This avoids damage to the boiler. When possible, the boiler should be allowed to cool down naturally.

1. Prepare a boiler for internal inspection in the following manner:
2. Water must be drained and the boiler washed thoroughly.
3. All manhole and handhole plates, washout plugs, and water-column connections must be removed and the furnace and combustion chambers thoroughly cooled and cleaned.
4. All grates in internally fired boilers should be removed.
5. Brickwork should be removed as required by the inspector in order to determine the condition of the furnace, supports, or other parts.
6. Any leakage of steam or hot water into the boiler should be cut off by disconnecting the pipe or valve at the most convenient point.

It is not necessary to remove insulation material, masonry, or fixed parts of the boiler unless defects or deterioration are suspected. Where there is moisture or vapor showing through the covering, the covering must be removed at once and a complete investigation made to find the cause. Every effort must be made to discover the true condition without compromising the pressure vessel. If it means drilling holes or cutting away parts, this should be coordinated with the postal boiler inspector.

5.7.8.3 Inspection

5.7.8.3.1 Procedure

All inspections must be performed by an inspector commissioned by the National Board of Boiler and Pressure Vessel Inspectors or the postal boiler inspector. The inspector should get as close as possible to the parts of the boiler in order to obtain the best vision of the surface. The inspector should use a good artificial light, if natural light is inadequate. Whenever the inspector deems it necessary to test boiler apparatus controls, etc., these tests should be made by a plant operator in the presence of the inspector unless otherwise ordered.

5.7.8.3.2 Corrosion

Types of harmful materials are as follows:

- Surfaces. The inspector should examine all surfaces of the exposed metal inside the boiler to detect any corrosion caused by treatment, scale solvents, oil, or other substances that may have entered the boiler. Any evidence of oil should be noted carefully, since even a small amount is dangerous. Immediate steps must be taken to prevent the entrance of any more oil into the boiler. Oil or scale on plates above the boiler fire is particularly dangerous, often causing sufficient weakening to bag (bulge) or rupture the plates.
- Seams and Joints. Corrosion along or immediately adjacent to a seam is more serious than a similar amount of corrosion in the solid plate away from the seams. Grooving and cracks along longitudinal seams are especially significant, since they are likely to occur when the material is highly stressed. Severe corrosion is likely to occur at points where the circulation of water is poor; such places should be examined very carefully.

5.7.8.3.3 Stays, Manholes, and Openings

Inspection of stays, manholes, and openings should be as follows:

- Stays. All stays, diagonal or through, should be examined to see if they are in even tension. All fastened ends should be examined to note if cracks exist where the plate is punched or drilled. If stays are not found in proper tension, then proper adjustment must be made.

- Manholes and Openings. The man-hole(s) and other reinforcing plates, as well as nozzles and other connections flanged or screwed into the boiler, must be examined both internally and externally to determine if they are cracked or deformed. Whenever possible, observation should be made from the inside of the boiler to check the thoroughness with which the pipe connections are made to the boiler. All openings to external attachments, such as water column connections, openings in dry pipes, and openings to safety valves, should be examined to ensure their freedom from obstructions.

5.7.8.3.4 Fire Surfaces, Lap Joints, and Tubes

Inspection of fire surfaces, lap joints, and tubes should be as follows:

- Fire Surfaces. Particular attention should be given to any plate or tube surface exposed to fire. The inspector should observe whether or not any part of the boiler has become deformed (bulging or blistering) during operation. If bulges or blisters are large enough to seriously weaken the plate or tube, especially if water is leaking from such a defect, the boiler should be removed from service until the defective part or parts have been repaired. Never plug fire-tubes, and do not operate a fire-tube boiler with a plugged tube. Carefully watch for leakage from any part of the boiler structure, particularly in the vicinity of seams and tube ends. Fire-tubes sometimes blister but rarely collapse; the inspector should examine the tubes for blistering and require replacement, if necessary.
- Lap Joints. Lap-joint boilers are apt to crack where the plates lap in the longitudinal or straight seam. If there is any sign of leakage or other distress at this joint, it must be investigated thoroughly to determine if cracks exist in the seam. Any cracks noted in shell plates are usually dangerous.

NOTE

Staybolts should be tested by tapping one end of each bolt with a hammer. When possible, holding a hammer or other heavy tool at the opposite end makes the test more effective. A dull sound may indicate deterioration of the staybolt.

- Tubes. Tubes in horizontal fire-tube boilers deteriorate more rapidly at the ends near the fire. These ends should be carefully tapped on their outer surface with a light hammer to determine if there has been a serious reduction in thickness. Without water cooling, the tubes of vertical tubular boilers are more susceptible to deterioration at the upper ends when exposed to fire or heat. They should be inspected by reaching as far as possible through the handholes (if any) as well as inspected at the ends. Tube surfaces should be carefully examined to detect bulges, cracks, or any evidence of defective welds. If exposed to a strong draft, tubes may become thinned by the erosion produced by the impingement of particles of fuel and ash. Document tube wall thickness. A leak from any tube frequently causes serious corrosion on a number of neighboring tubes. The ligaments between tube holes in the heads of all fire-tube boilers and in shells of water-tube boilers must be examined. If any leakage is noted, broken ligaments are probably the reason. Corrective action is necessary.

5.7.8.3.5 Pipes

Inspection of pipes should be as follows:

- The steam and water pipes, including connections to the water columns, must be examined for leaks. If any are found, it must be determined whether they are the result of excess strain due to expansion, contraction, or some other cause. The general arrangement of the piping in regard to provisions for expansion and drainage, as well as adequate support at the proper points, should be carefully noted. The location of the various stop valves should be observed to see that water will not accumulate when the valves are closed and cause water-hammer action.
- The arrangement of connections between individual boilers and the main steam header should be especially noted to ensure that any change in position of the boiler (due to settling or other causes) has not placed an undue strain on the piping.
- Determine if all pipe connections to the boiler have the proper strength in their fastenings, whether tapped into or welded to the boiler shell. The inspector should ensure that there is proper provision for the expansion and contraction of the piping and that there is no undue vibration that could damage parts (this includes all steam and water pipes). Special attention must be given to the blow off pipes and their connections and fittings, because their expansion and contraction due to rapid changes in temperature and water-hammer action cause a great strain upon the entire blow off system. The freedom of the blow off and drain connections on each boiler should be tested, whenever possible, by opening the valve for a few seconds, at which time it can be determined whether there is excessive vibration.
- Carefully inspect the piping to the water column to ensure there is no chance of water accumulating in the pipe that forms the steam connection to the water column. The steam pipe preferably should drain toward the water column. The water pipe connection to the water column must drain toward the boiler. Check the position of the water column relative to the fire surfaces of the boiler to determine whether or not the column is placed in accordance with code requirements. Examine all attachments to determine their operating condition (steam only).

- If the examination is performed while steam is in the boiler, observe the water column and gauge glass to see that the connections to the boiler are free of obstruction, as shown by the action of the water in the glass. The water columns and gauge glasses should be blown down on each boiler to definitely determine the freedom of the connections to the boilers, as well as to see that the blow off piping from the columns and gauge glasses are free. The gauge glasses should be examined to see that they are clean and properly located to permit ready observation. The freedom of the gauge glass should be determined by test (steam only).

5.7.8.3.6 Low-Water Cutoff and Water Feeder

Inspection of low-water cutoffs and water feeders should be as follows:

- Each automatically fired low-pressure steam or vapor system boiler shall have at least two automatic low water fuel cutoffs, one of which may be a combined feeder/cutoff device. Each device shall be attached to the boiler by separate pipe connections below the waterline. Each cutoff device shall be installed to prevent startup and to cut off the boiler fuel supply automatically, prior to the fall of the water surface below the level of the lowest visible part of the gage glass.

Exception: In lieu of the requirements for low water cutoffs in Paragraph 5.7.8.3.6, a water-tube or coil-type boiler, requiring forced circulation to prevent overheating and failure of the tubes or coils, shall have an accepted device to prevent burner operation at a flow rate inadequate to protect the boiler unit against overheating.

- The fuel or feedwater control device may be attached directly to the boiler shell or to the tapped openings provided for attaching a water glass directly to a boiler. If the connections from the boiler utilize piping, nonferrous crosses should be used at all right angles to facilitate cleaning and inspection of the pipes.
- Designs with a float and float bowl must have a vertical straightway-valve drainpipe. The drainpipe is located at the lowest point in the water-equalizing pipe connections through which the bowl and the equalizing pipe can be flushed and the device tested.

NOTE

A stop valve must not be placed between a steam boiler and its Low Water Cutoff.

5.7.8.3.7 Safety Valves

WARNING

Safety valves and safety relief valves are designed for a specific purpose. Do not use a safety valve or a safety relief valve for other than its intended purpose. Do not alter or change the safety device in any manner. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

Safety valves and safety relief valves present an explosion hazard if a malfunction occurs. They must be carefully inspected per the specifications listed below. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

Since the safety valve is the most important safety device on the boiler, it must be inspected with utmost care. There should be no rust, scale, or other foreign substances in the body of the valve that would interfere with its free operation. The valve must not leak under operating conditions. The opening pressure and freedom of operation of the valve should be tested, with the try lever in accordance with the procedure in Paragraph 5.9.5.2 and the pop test in accord with the procedure in Paragraph 5.9.5.3. If the valve has a discharge pipe, determine at the time the valve is operating whether or not the drain opening in the discharge pipe is free and in accordance with all required codes. If necessary, in order to determine the freedom of discharge from a safety valve, the discharge connection may be removed.

NOTE

A stop valve must not be placed between a steam boiler and its safety valve or between the safety-relief valve and the discharge opening of the pipe. The end of the discharge pipe should be cut at an angle or notched to prevent the installation of a valve or threading of the pipe.

5.7.8.3.8 Steam Gauges

A test gauge connection should be provided on the boiler so that the steam gauge on the boiler can be tested under operating pressure. The steam gauge should not be exposed to excessively high ambient temperatures and should be mounted with a siphon or trap between it and the boiler. Provisions should be made for blowing out the piping leading to the steam gauge.

5.7.8.3.9 Other Inspection Factors

Other inspection factors include:

- In water-tube boilers, it should be determined whether or not the proper baffling is in place. The absence of baffling often causes high temperatures on portions of the boiler structure not intended for such temperatures and, from this, a danger may arise. The location of combustion arches with respect to tube surfaces should be noted to make sure they do not cause the flame to impinge on a particular part of the boiler and produce overheating and consequent rupture of the material of the particular part.
- Localization of heat brought about by improper or defective burner or stoker installation or operation creates a blowpipe effect upon the boiler and is cause for shutdown of the boiler until the condition is corrected.
- If boilers are suspended, the supports and setting should be examined carefully, especially at points where the boiler structure comes near the setting walls or floor. At such points, make sure that ash and soot will not bind the boiler structure and produce excessive strain on the structure due to expansion of the parts under operating conditions.

5.7.8.4 Inspecting Repairs

When repairs have been made, especially tube replacements, determine if the work has been done safely and properly. Pay special attention to excessive rolling in accessible tubes and, under-rolling in difficult-to-reach tubes. These always cause separation of the parts.

5.7.8.5 Hydrostatic Tests

If there is any doubt about the extent of a defect found in a boiler, a hydrostatic test should be performed by a qualified USPS Inspector or contractor. It is critical for the person performing inspection to know what they're looking at and for. A hydrostatic pressure test must not exceed 1-1/2 times the maximum allowable working pressure. During the test, the safety valve must be removed, or isolated, from the boiler. It is suggested that the minimum temperature of the water be 70°F and the maximum 160°F. All controls and appurtenances unable to withstand the test pressure without damage must be removed during the test.

5.8 OPERATION, MAINTENANCE, AND REPAIR OF HOT-WATER BOILERS

5.8.1 Starting a New Boiler

5.8.1.1 Cleaning and Filling

5.8.1.1.1 Inspection for Foreign Objects

See Paragraph 5.7.2.1.

5.8.1.1.2 Check before Filling

Before putting water into a new boiler, make certain to the extent possible without actually lighting a fire in the empty boiler that the firing equipment is in operating condition. This is necessary because raw water must be boiled (or heated to at least 180°F) promptly after it is introduced into the boiler in order to drive off the dissolved gases that might otherwise corrode the boiler. In a hot-water heating system, the boiler and entire system (other than the expansion tank) must be full of water for satisfactory operation. The red, or fixed, hand on the combination altitude gauge and thermometer is normally set to indicate the amount of pressure required to fill the system with cold water. Water should be added to the system until the black hand registers the same as or more than the red hand. To ensure that the system is full, water should come out of all air vents when the vents are opened.

5.8.1.2 Abnormal Conditions

If any abnormal conditions occur during lighting off or temperature buildup, immediately open the emergency switch.

WARNING

Operating a boiler with known abnormal conditions is dangerous and forbidden. Do not attempt to restart unit until all deficiencies have been identified and corrected. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

5.8.1.3 Condensation

Following a cold start, enough condensation may occur in a gas-fired boiler that it will appear the boiler is leaking. This condensation should stop after the boiler is hot.

5.8.1.4 Cutting in an Additional Boiler

NOTE

When the stop valve at the boiler outlet is closed, the stop valve in the return line of that boiler must also be closed.

When placing a boiler on line with other boilers already in service, start the boiler using the above procedures, but close the supply-stop valve and the return-stop valve. Bring the boiler to the same temperature as the operating boiler and partially open the supply valve(s). If there is no unusual disturbance, such as noise, vibration, etc., slowly open the supply valve until it is fully open. Open the valve in the return line.

5.8.2 Operation

5.8.2.1 Preliminary Checks

The first things checked when going on duty are the pressure and temperature in all operating boilers.

5.8.2.2 Combination Gauge

When the boiler is cold, the stationary and moveable hands of the combination altitude/pressure gauge should be together; when the boiler is hot, the moveable hand should be above the stationary hand. The stationary hand should be aligned with the moveable hand at the time the system is initially filled, or it may be set to indicate the minimum pressure under which the system can operate and still maintain a positive pressure at the highest point in the system.

5.8.2.3 Operating Temperature and Pressure

5.8.2.3.1 Operating Temperature

The maximum operating temperature of the boiler water should never exceed 250°F and should be as low as possible to heat the space adequately under design conditions. Higher temperatures will accelerate any corrosion process.

5.8.2.3.2 Operating Pressure

WARNING

Safety valves and safety relief valves are designed for a specific purpose. Do not use a safety valve or a safety relief valve for other than its intended purpose. Do not alter or change the safety device in any manner. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

WARNING

Boilers have a maximum allowable working pressure that varies depending on the design of the boiler. The safety valve set pressure shall not exceed the boiler maximum allowable working pressure. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

The failure of the safety-relief valve(s) to open at the set pressure frequently causes dangerous conditions in hot-water boilers. This failure is usually due to buildup of corrosive deposits between the disk and seat of the valve that are caused by a slight leakage or weeping of the valve. The safety-relief valve opens when the boiler water pressure on the underside of the valve disk overcomes the closing force of the valve spring. As the force of the water pressure approaches the counteracting force of the spring, the valve tends to leak slightly and, if this continues, the safety-relief valve can stick or freeze. For this reason, the pressure between the safety-relief valve set pressure and the boiler operating pressure should be at least 10 psi or 25 percent of the boiler operating pressure, whichever is greater. The following are examples that show how to determine pressure differentials:

- The operating pressure of a hot-water heating boiler, where the safety-relief valve is set to open at 30 psig, should not exceed 20 psig.
- If the safety-relief valve on a hot-water heating boiler is set to open at 100 psig, the boiler operating pressure should not exceed 75 psig.

5.8.2.3.3 Differential Limits

To ensure that the safety-relief valve closes tightly after popping and the boiler pressure is reduced to the normal operating pressure, these pressure differentials between the valve-set pressures and operating pressures must not be exceeded.

5.8.2.4 Testing

Periodic testing of safety-relief valves must be carried out in accordance with Paragraph 5.9.6.

5.8.3 Removal from Service

5.8.3.1 Procedures

Annually drain water from the bottom of the boiler while it is still hot (180°F to 200°F) until the water runs clean, then refill the boiler to the normal water-fill pressure and refire to drive off any dissolved gasses. If water treatment is used in the system, sufficient treatment compound should be added to condition the additional water. Any boiler water discharge should adhere to the CWA.

5.8.3.2 Cleaning

When the hot-water boiler (any of those referred to previously) is cool, thoroughly clean the tubes and other heating surfaces, and scrape the surfaces down to clean metal. Clean the smokeboxes and other areas where soot or scale may accumulate. When dry, soot is not corrosive but it can be very corrosive when it is damp. All soot must be removed from a boiler at the beginning of the non-operating season or any extended non-firing period.

5.8.3.3 Protection against Corrosion

Swab the fireside heating surfaces with neutral mineral oil to protect against corrosion. If the boiler room is damp, place a tray of calcium chloride or unslaked lime in the combustion chamber and replace the chemical when it becomes mushy.

5.8.3.4 Periodic Checks

During the idle period, check the boiler occasionally to ensure that corrosion is not occurring. This is also an opportune time to repaint the exposed metal parts of the boiler, and inspect and service the firing equipment and combustion chamber.

5.8.4 Maintenance

5.8.4.1 Cleaning

5.8.4.1.1 General

Clean the boiler tubes and other heating surfaces as required.

A general prediction applicable to all boilers cannot be made, so the frequency of the cleaning is best determined by trial. Clean the smokeboxes as required.

5.8.4.1.2 Backwashing of Water Heater

Any water heater installed in or connected to a boiler should be backwashed periodically, using valves to reverse the direction of flow through the heater. This backwashing reduces the amount of scale accumulated at the outlet side of the heater. Continue the backwashing until the water runs clear. The backwashing may be done frequently, and the maximum interval should be determined by trial.

5.8.4.2 Draining

A clean, properly maintained heating boiler should not be drained unless there is a possibility of freezing, the boiler has accumulated a considerable amount of sludge or dirt on the waterside, or draining is necessary to make repairs. Very little sludge should accumulate in a boiler where little makeup water is added and where an appropriate water treatment is maintained at the proper strength. If it is necessary to drain the boiler and heating piping to do repair work and the various parts of the system cannot be isolated to avoid such draining, consider the installation of valves and drains at that time to prevent having to drain again. Considerable time and expense can be saved the next time repairs are necessary, and the amount of raw water required is also reduced.

5.8.4.3 Antifreeze

WARNING

Antifreeze solution is harmful or fatal if swallowed. Antifreeze solutions may be used only in closed circulating systems entirely separated from potable-water supply systems. Furthermore, disposal shall adhere to the CWA. Failure to comply may cause injury or death.

5.8.4.3.1 Type

Antifreeze solutions used in heating systems must have an ethylene-glycol base and an added inhibitor. The antifreeze should be environmentally friendly.

5.8.4.3.2 Concentration

Antifreeze concentrations must not be less than 33 percent or greater than 66 percent. (100 percent antifreeze has a freezing point of about -6°F, while a concentration of 68 percent has a freezing point of about -92°F, and a 50 percent solution has a freezing point of about -34°F.)

5.8.4.3.3 Service Life

The service life of an antifreeze solution depends on such factors as heating system design and condition, hours of operation, solution and metal temperatures, aeration, and the rate of contamination. Therefore, the antifreeze solution should be tested at least annually and as recommended by the antifreeze manufacturer. High metal temperatures accelerate depletion of the antifreeze inhibitors. For maximum service life, the metal temperature in contact with the solution should be kept under 350°F. The fluid temperature should not exceed 250°F.

5.8.4.3.4 Expansion

Antifreeze solutions expand more than water per given rise in temperature (i.e., a 50 percent by volume solution expands 4.8 percent by volume with a temperature increase from 32 to 180°F, while water expands 3 percent with this same rise in temperature). Allowance must be made for this expansion when an antifreeze solution is used in a heating system.

5.8.4.4 Fireside Corrosion

5.8.4.4.1 General

Chapter 4 highlighted some of the causes of waterside corrosion and recommended mitigating procedures. Boilers can also corrode on the fireside. Some fuels contain substances that cause fireside corrosion. Sulfur, vanadium, and sodium are among the materials that may contribute to this problem.

5.8.4.4.2 Sulfur

Deposits of sulfur compounds cause fireside corrosion. The amount of sulfur in the fuel and the care used in cleaning the fireside heating surfaces determines the probability of corrosion. Particular care must be taken when preparing a boiler for a period of idleness. In an idle boiler, keeping the boiler heating surfaces dry will also prevent this problem.

5.8.4.4.3 Vanadium and Sodium

Deposits of vanadium, or vanadium and sodium compound, also cause fireside corrosion. These compounds may be corrosive during the season that boilers are in service.

5.8.4.4.4 Cleaning

The person responsible for boiler maintenance must be certain that the fireside surfaces of the boilers are thoroughly cleaned at the end of the firing season. Also, the maintenance person should observe the fireside surfaces and, if signs of abnormal corrosion are discovered, a reputable consultant should be engaged.

5.8.4.5 Safety-Relief Valves

WARNING

Safety valves and safety relief valves are designed for a specific purpose. Do not use a safety valve or a safety relief valve for other than its intended purpose. Do not alter or change the safety device in any manner. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

All pressure vessels must be equipped with appropriate relief devices, stamped in accordance to ASME code and capacity must be certified by the National Board of Boiler and Pressure Vessel Inspectors. Safety-relief valves on hot-water heating and hot-water supply boilers should be tested for proper operation in accordance with Paragraph 5.9.6. When replacement is necessary, use only ASME certified valves of the required capacity.

5.8.4.6 Burner Maintenance

5.8.4.6.1 Oil Burners

Oil burners, refer to Paragraph 5.7.5.6.1.l

5.8.4.6.2 Gas Burners

Maintenance on gas burners is performed as follows: Refer to Paragraph 5.7.5.6.2.

5.8.4.7 Low-Water Fuel Cutoff and Water Feeders

Maintenance procedures for low-water fuel cutoffs and water feeders are as follows:

1. Low-water fuel cutoffs and water feeders must be dismantled when necessary, but no less than annually by qualified personnel to the extent necessary to ensure freedom from obstructions and the proper functioning of all working parts.
2. Inspect the connecting lines to the boiler for mud, scale, etc., and clean as required.
3. Examine all visible wiring for brittle or worn insulation and ensure the electrical contacts are clean and functioning properly.
4. Give special attention to solder joints on the bellows and float (when this type of control is used).
5. Check the float for evidence of collapse and the mercury bulb (where applicable) for mercury separation or discoloration.

NOTE

Do not attempt to repair these units in the field.

Complete replacement mechanisms, including necessary gaskets and installation instructions, are available from the manufacturer.

6. Reassemble and test without draining water from the entire system.

5.8.4.8 Flame Safeguard Maintenance

5.8.4.8.1 Thermal-Type Detection Device

See Paragraph 5.7.5.8.1.

5.8.4.8.2 Electronic-Type Detection Device

See Paragraph 5.7.5.8.2.

5.8.4.9 Limit-Control Maintenance

See Paragraph 5.7.5.9.

5.8.4.10 Use of Sealants

Sealants in the boiler water have a detrimental effect on boilers, pumps, safety-relief valves, etc. Their use is prohibited in hot water heating or hot water supply boilers. This does not prohibit taking the necessary steps to attach a gasket.

5.8.4.11 Circulating Pumps and Expansion Tanks

Inspect and lubricate the circulating pump(s) in accordance with the manufacturer's instructions, and check operation of all associated controls, switches, etc. Examine expansion tank for dirt, leaks, and corrosion. Clean and repair as required. For detailed instructions, refer to the manufacturer's literature, instructions, and data.

5.8.4.12 Maintenance Schedule of Boilers in Service

5.8.4.12.1 General

Listed below are suggested frequencies for the various routines and tests to be performed in connection with boiler inspection and maintenance.

5.8.4.12.2 Daily Procedures

See Paragraph 5.7.6.4.1.

5.8.4.12.3 Annual Maintenance

See Paragraph 5.7.6.4.2.

5.8.5 Tests and Inspections

5.8.5.1 Purpose

5.8.5.1.1 Installation Inspection

This inspection differs from the inspection during manufacture, which pertains primarily to conforming to code construction requirements. This inspection determines if boiler supports, piping arrangements, safety-relief valves, other valves, water columns, gauge cocks, altitude gauges, thermometers, controls, and other apparatus on the boiler meet code and/or other jurisdictional requirements.

5.8.5.1.2 Low Water Cutoff

All automatically fired hot-water heating or supply boilers must be equipped with an automatic low-water fuel cutoff that is located where it can automatically cut off the fuel supply when the surface of the water falls below the lowest safe water line. Such a fuel-control device may be attached directly to the boiler shell or to the tapped openings provided for attaching a water glass directly to a boiler. Designs having a float and float bowl must have a vertical straightway-valve drainpipe through which the bowl and the equalizing pipe can be flushed and the device tested. The drainpipe is located at the lowest point in the water-equalizing pipe connections.

5.8.5.1.3 Combination Temperature and Pressure Gauges

A test-gauge connection should be provided on the boiler so that the gauge on the boiler can be tested under operating conditions. The gauge must not be exposed to excessively high ambient temperatures.

5.9 BOILER TESTING

5.9.1 General

Periodic testing of all important boiler components is required to maintain good working conditions and ensure safety. Testing requires proper definition of the boiler envelop to properly isolate boiler components. Furthermore, it is essential to examine the boiler before testing to correct irregularities and to setup adequate safety precautions prior to testing. Safety precautions must protect personnel conducting the tests, building occupants, and equipment.

In addition to the usual mechanic tools, one or more test leads, a test pressure gauge, a test thermometer, and volt-ohm-meter will be required in connection with certain tests. The test leads should consist of approximately 3 feet of insulated No. 14 gauge stranded wire equipped with properly insulated alligator clips. The test gauge should be a good quality inspector's gauge, graduated in increments of not more than 1 pound each. These gauges require periodic calibration. This can be done only in a properly equipped laboratory. The thermometer should read at least as high as 400°F, with no more than 2 degrees per graduation.

5.9.2 Flame-Safeguard Device Testing

NOTE

All service work on flame safeguard devices shall be performed by competent Flame Safeguard personnel.

It is recommended to test the flame safeguard system at least once a month to verify flame failure shutdown and positive fuel cutoff when the fuel valves are de-energized. However, modern flame guard management systems can test themselves for failure and report internal circuit faults.

5.9.2.1 Gas-Thermal-Type

Follow these procedures:

1. While the burner is in operation, shut off the manual gas valve.

2. Turn off the pilot gas cock and time the interval for the automatic gas valve to close. This time must not exceed that recommended by the manufacturer.
3. If test result from Step 2 above is okay, relight the pilot, turn on the main gas valve, and allow the burner to fire.
4. Check the burner for proper operation.

5.9.2.2 Oil-Thermal-Type, Stack Switch

Follow these procedures:

NOTE

The manual shutoff must be a gate valve installed just ahead of the oil solenoid valve.

1. Shut off the manual valve in the oil supply line and time the interval required for the oil solenoid valve to close. Check this time against that recommended by the manufacturer.
2. If the test result in Step 1 is okay, refire the burner, and observe its operation.

5.9.2.3 Gas-Electronic Flame Rod with Standing Pilot

Follow these procedures:

1. With the burner firing normally, turn off the main gas cock.
2. Turn off the pilot gas cock and time the interval required for the safety shutoff gas valve to close (should be 4 seconds or less); check with the manufacturer's data.
3. If the test result in Step 2 is okay, relight the pilot, reset the controls, and fire the boiler. Observe the boiler operation.

5.9.2.4 Gas-Electronic Flame Rod with Interrupted Ignition (and Gas Electronic Flame Scanner)

Follow these procedures:

1. With the burner firing normally, turn off the main gas cock and time the interval for the shutoff gas valve to close (should be 4 seconds or less); check with the manufacturer's data.
2. If the test result in Step 1 is okay, open the main gas cock, reset controls and fire the burner. Observe the boiler operation.

5.9.2.5 Oil or Gas-Electronic Flame-Scanner

Follow these procedures:

1. With the burner firing normally, shut off the manual valve in the oil- or gas-supply line and time the interval for the solenoid valve to close (should be 4 seconds or less); check with the manufacturer's data.
2. If the test result in Step 1 is okay, open the manual valves, reset the controls, and refire the burner. Observe the boiler operation.

5.9.2.6 Oil or Gas-Electronic-Type with Proven Pilot-Flame Detection

Follow these procedures:

1. With the burner in OFF cycle, manually shut off the fuel to the main burner and the pilot burner.
2. Operate the necessary control to start the main burner.
3. After the prepurge period, the pilot assembly will be energized but, because no flame is detected, the automatic pilot valve will shut off in about 10 seconds, and the main automatic fuel valve will not be energized.
4. If the test result in Step 3, above is okay, open the manual valve to PILOT and reset the controls. Test the main burner for flame detection.
5. Test gas as per Paragraph 5.9.2.4.
6. Test oil as per Paragraph 5.9.2.5.

5.9.2.7 Pilot Turndown Test

Following is information for the pilot turndown test:

- This test is required to prove that the main automatic fuel valve cannot be energized if the pilot cannot light it safely.
- This test is accomplished by reducing the pilot to the smallest flame recognized by the flame detector. This flame must be adequate to light the main burner. If it is not, the flame detector must be repositioned to assure that it will only detect pilot flames that can safely light the main. When the test is complete, the pilot flame must be restored to its normal size.
- Since each device may require different procedures, consult the manufacturer's instructions for making this test.

5.9.3 Combustion-efficiency Tests

5.9.3.1 General

Combustion efficiency is a calculation of how well the boiler is burning a specific fuel, shown in percent. A combustion-efficiency test must be made on each fuel-burning unit at least once each year; on gas-fired units with nonadjustable secondary air, only the draft and stack temperature need be checked. More frequent tests should be made on large units and on boilers burning preheated oil. If burners have variable firing rates, their efficiency must be checked at the different rates.

5.9.3.2 Oil Burners

5.9.3.2.1 Over-the-Fire Draft

Over-the-fire draft is the air pressure in the boiler furnace during occurrence of the main flame. Measure the over-the-fire draft and compare it to that recommended by the burner manufacturer. Adjust the secondary air as required. This reading should range from 0.02 to 0.05 inches of water negative pressure for natural or induced-draft installations up to 5 gallons/hour. Readings for forced-draft installations will be somewhat higher and will be positive pressure readings. If necessary, a small hole may be drilled in the firebox door to accommodate the draft gauge. On forced-draft units, the hole must be plugged when not in use.

5.9.3.2.2 Smoke Readings

Run new boilers 30 to 60 minutes before taken smoke readings. Follow manufacturer's instructions and use a smoke-measuring instrument to obtain a smoke reading. No unit should be allowed to operate with a smoke density in violation of local codes. Air adjustments, nozzle conditions, nozzle location, combustion chamber size, and air leakage all affect the fuel combustion.

5.9.3.2.3 Carbon Dioxide (CO_2) Readings

Using the CO_2 analyzer, take a reading in the breeching ahead of any openings (barometric dampers, cleanouts, etc.). A small hole may be drilled for this purpose. The theoretical percent of CO_2 ranges from 15 percent for No. 1 and No. 2 oil to 16.5 percent for No. 6 oil. Actual readings should range from 9 to 12 percent for light oil and from 10 to 14 percent for heavy oil. Adjustments should be made to provide the highest CO_2 reading without smoke. Reduced secondary air resulting from a dirty fan or a change in barometric conditions may cause smoking at the higher CO_2 readings.

5.9.3.2.4 Stack Temperature

Measure the stack temperature at the same point that the CO_2 readings were taken. Subtract the room temperature from this reading; the result will be the net stack temperature. The net stack temperature should range from 400 to 600°F. About 500°F is desirable for modern units designed to burn oil. Units converted from coal will run somewhat higher. Low stack temperatures cause condensation and deterioration of the brickwork, whereas high stack temperatures indicate that the heat of combustion is not being absorbed by the heat-transfer surfaces of the boiler. Insufficient draft may cause low stack temperature and poor combustion, whereas excess draft can result in high stack temperature. The result in either case is a loss in boiler efficiency. If problems are encountered with boilers having nonadjustable secondary air inlets and draft hood, consult the manufacturer.

5.9.3.2.5 Adjustments

After the tests are made in the order listed above, adjustments should be made to bring the readings within the proper range; however, do not sacrifice one measurement to improve another beyond practical limits. After correcting one reading, recheck the others to determine that they are still within the proper range. The draft, percent of CO_2, and stack temperature must be regulated to provide the best overall safe boiler efficiency.

5.9.3.3 Gas Burners

5.9.3.3.1 Over-the-Fire Draft

See Paragraph 5.9.3.2.1.

5.9.3.3.2 Carbon Dioxide (CO_2) Readings

Using the CO_2 analyzer, take a reading in the breeching ahead of any openings (barometric dampers, cleanouts, etc.). A small hole may be drilled for this purpose. The theoretical percent of CO_2 for natural gas is approximately 12 percent. Actual readings should range from 7 to 10 percent, depending on the amount of excess combustion air. Adjustments should be made to provide the highest CO_2 reading while maintaining proper flame color and shape. This test is not required for boilers with nonadjustable secondary air inlets and draft hoods.

5.9.3.3.3 Stack Temperature

See Paragraph 5.9.3.2.4.

5.9.3.3.4 Adjustments

See Paragraph 5.9.3.2.5.

5.9.3.4 Draft Measures at the Boiler Breeching

To check the accuracy of the draft measurement, an additional reading may be taken at the breeching on the furnace side of any draft regulators, cleanouts, etc. This reading will probably range from 0.07 to 0.10 inches of water negative pressure for natural- or induced-draft installations. For forced-draft units, the reading will be less than the over-the-fire draft, but should be a positive pressure. Both readings must be recorded when the heat transfer surfaces are clean and the boiler properly adjusted. They can then be compared to later periodic readings. For example, if the readings at the breeching remained constant, and the over-the-fire reading changed, this would indicate a possible inaccuracy in the over-the-fire measurement. If the difference between the two readings increased, this would indicate a soot buildup or other restriction in the combustion chamber or gas passages (tubes). This is helpful in determining the need for cleaning the heat transfer surfaces of the boiler. This measurement is primarily used to check oil-burning units and large forced-draft, gas-fired units.

5.9.4 Limit-Control Tests

5.9.4.1 General

All limit controls must be tested periodically. Consult the manufacturer's data for complete details. A test gauge should be used to check the operation of all pressure controls. In general, the tests are to be performed as follows.

5.9.4.1.1 High Limit Steam Pressure Control

The high limit steam pressure control turns off the burner when the boiler pressure exceeds a preset level. The high limit steam pressure control shall be tested per manufacturer's specifications for proper operation and manual reset function. The boiler's controls must be adjusted to force the boiler pressure high enough to operate the high-pressure control. Then, without resetting the manual reset switch, return the controls to the desired operating pressure. The boiler should not restart until the manual reset is actuated. If, however, the pressure exceeds this limit setting and has tripped the manual reset, do not reset the control, but immediately take the boiler out of service until the cause of the problem is identified and corrected.

5.9.4.1.2 Draft Limit Control

The draft limit control must cause burner shutdown and prevent startup when an inadequate air volume is supplied to the burner(s). It must be tested to ensure proper operation. Burner shut off should occur when over-the-fire draft falls below the minimum allowable 0.02 inches of water. Using a draft gauge to measure the over-the-fire draft, restrict the flow of secondary air until the draft drops slightly below 0.02 inches of water. At this point, the burner should cut off. Do not completely shut off the secondary air during this test. If the control shuts down the burner, reset the controls and refire the boiler. If the control does not shut off the burner, adjust or replace it as required. On natural- or induced-draft installations, the draft gauge will measure a negative pressure difference, the pressure over the fire being less than room pressure; whereas, for forced-draft installations, the gauge will measure a positive pressure.

5.9.4.1.3 Boiler Room Temperature-Limit Switch Control

Some installations have a temperature-limit switch control or other device that will shut down the burner in the event of a rise in temperature in the vicinity of the boiler. These devices protect against flashbacks, oil fires, and overheated boilers. If possible, trip the device manually while the burner is firing; the burner should shut down. If the burner does shut down, reset the device, refire the boiler, and check operation. If the device cannot be operated manually, shut down the boiler, disconnect the power, and open the control-circuit at the device. Attempt to refire the boiler; it should not operate. If the boiler does not operate, reconnect circuit, fire boiler, and check operation.

5.9.4.1.4 Electrical-Current Limit Controls

All electrical-current limiting or overload devices, including fuses and thermal overload elements, must be inspected to determine if they are properly sized and in good condition. Switches, starters, and relays must be checked for proper operation.

5.9.4.1.5 Low Gas-Pressure Control

Check the manufacturer's data to determine the minimum allowable operating gas pressure to the burner. Connect a manometer to the gas manifold just ahead of the burner. With the burner firing normally, close the main gas cock gradually until the pressure drops to the minimum specified by the manufacturer. The burner should shut off. If the burner shuts off, reset the controls, refire the boiler, and check burner operation. If the burner does not shut off, shut it off and repair or replace.

5.9.4.1.6 High Gas-Pressure Control

NOTE

For systems where high-pressure gas over 1 psi is furnished upstream of the regulator.

Check the manufacturer's instructions for the maximum operating pressure of the burner. Connect a manometer to the gas manifold just downstream of the pressure regulator. With the burner shut down, adjust the pressure regulator to provide pressure slightly in excess of this maximum operating pressure. Operate the burner controller to call for heat; the burner should not start. If the burner does not start, readjust the pressure regulator to normal burner operating pressure and check burner operation. If the burner starts, shut it off and repair or replace.

5.9.4.1.7 Oil Pressure Supervisory Switch

NOTE

On installations with separate pump set.

Manually turn down the burner cock until the oil pressure drops below the minimum recommended by the burner manufacturer. The burner should shut off. If the burner performs as expected, reset the burner cock, restart the burner, and check burner operation.

5.9.4.2 Air-Pressure Supervisory and Emergency Disconnect Switch

5.9.4.2.1 Air-Pressure Supervisory Switch

Check the manufacturer's instructions for the minimum static pressure required. Adjust the air damper to decrease air to the burner; the burner should shut off when the pressure drops below the minimum recommended air pressure. If the burner shuts off, readjust air damper to desired air pressure and check burner operation.

5.9.4.2.2 Emergency Disconnect Switch

All boilers must be equipped with a clearly visible emergency disconnect switch located outside the boiler room door. Instructions next to the emergency disconnect should indicated required emergency boiler shutdown steps. To test the disconnect switch, throw the switch to the OFF position while the boiler is operating. This should kill all power to the controls and the boiler should shut down completely. If the boiler shuts down completely, restore the switch, refire the boiler, and observe for proper burner operation. On units equipped with program controls, the burner controls should completely recycle before refiring.

5.9.5 Safety Valve Test (Steam Boilers)

5.9.5.1 Safety

Safety relief valves are the last line of defense against catastrophic boiler failure. Therefore, personnel conducting a pop or capacity test must be qualified, briefed on the location of all shutdown controls in the event of an emergency, and at least two people must be present during the test. Additionally, personnel must be protected.

The most practical relief valve test, however, is usually the bench test alternative in a controlled environment. Here, the valve is transported to a central shop were consistent test procedures can be applied and documented. Relief valves should be tested for proper lift, correct set pressure, and acceptable leakage after re-close to comply with the National Boiler Inspection Code (NBIC). Repairs to any ASME coded relief valves require a holder of a NBIC VR certificate. Consult NBIC paragraph RB-8400 for detailed testing and operation inspection guidelines and paragraph RB-8410 for recommended inspection and test frequencies.

5.9.5.2 Try-Lever Test

Only boilers low enough in pressure should be considered safe for try-lever test. Every month that the boiler is in operation or after any period of inactivity, a try-lever test should be performed. However, the boiler pressure should be 5 psig and provisions must be made to route the escaping steam to an area where it will not cause injury.

1. Lift the try lever on the safety valve to the wide-open position and allow steam to be discharged for 5 to 10 seconds.
2. Release the try lever and allow the spring to snap the disk to the closed position. If the valve simmers, operate the try lever two or three times to allow the disk to seat properly.
3. If the valve continues to simmer, it must be replaced, or repaired by an authorized repair shop (R/UV stamp).
4. Visually inspect the valve and discharge piping for evidence of scale or encrustation.
5. Do not disassemble the valve or attempt to adjust internal or external parts. The date of the test must be entered into the boiler log book.

5.9.5.3 Pop Test

An open pop test of a safety valve is conducted to determine if the valve will open under boiler pressure at operating temperatures within the allowable tolerances. It must be conducted annually, preferably at the beginning of the heating season if the boiler is used only for space-heating purposes. Below is a recommended procedure for conducting the pop test.

1. Establish the necessary trial conditions at the particular location. Make sure that the safety valve discharge piping is properly supported and discharges to a safe location. Review the preparation for the test with all personnel involved. At least two people must be present at all such tests.
2. Install a temporary, calibrated test-pressure gauge to check the accuracy of the boiler pressure gauge.
3. Isolate the boiler, if possible, by shutting the stop valves in the steam supply and condensate-return piping.
4. Temporarily place test leads across the appropriate terminals on the operating control to demonstrate the ability of the high-limit pressure control to function properly. After this has been checked, place another set of test leads across the high-limit pressure control terminals to permit continuous operation of the burner.
5. The safety valve should pop open at an acceptable pressure; i.e., 15 psig plus or minus 2 psig. A simmering action will ordinarily be noticed shortly before the valve pops to the open position.
6. If the valve does not open in the 13 to 17 psig range, it should be replaced or repaired. It is not necessarily a dangerous situation if the valve opens below 13 psig, but it could indicate a weakening of the spring, improper setting of the spring, etc. If the valve does not open at 17 psig, shut off the burner and dissipate the steam to the system by slowly opening the supply valve. When the pressure has dropped sufficiently, open the valve using the try-lever test method. If this releases the disk from the seat, continue with the pop test procedure as previously described. If the valve still does not open at or below 17 psig, it must be replaced with a new valve, returned to the manufacturer for repair, or field repaired by the manufacturer.
7. If the valve pops open at an acceptable pressure, immediately remove the test leads from the high-limit pressure control. The burner main flame should cut off as soon as the test leads are removed.
8. The safety valve will stay open until the pressure in the boiler drops sufficiently to allow the valve to close, usually 2 to 4 psig below the opening pressure. This pressure drop (blow down) is usually indicated on the safety valve nameplate.
9. Relieve the higher pressure steam to the rest of the system by slowly opening the steam-supply valve. After the boiler and supply piping pressures have become equalized, open the return valve.

10. Remove the test leads from the operating control and check to make certain that the control functions properly. This is best done by allowing the control to cycle the burner on and off at least once.
11. Enter the necessary test data into the boiler log book.

5.9.5.4 Capacity Test

Capacity tests must be performed on safety valves on all new boiler installations or on existing boilers when any modification changes the output of the boiler (i.e. changing the size of the burner, the rate of fuel flow, or the grade or type of fuel not previously fired), and when any safety valve is repaired or replaced. Follow these procedures:

1. Establish the necessary trial conditions at the particular location. Make sure that the safety valve discharge piping is properly supported and discharges to a safe location. Review the preparation for the test with all personnel involved. At least two people must be present at all such tests.
2. Install a temporary, calibrated test-pressure gauge to check the accuracy of the boiler pressure gauge.
3. Isolate the boiler, if possible, by shutting the stop valves in the supply and return piping of the boiler. The water feeder should be able to operate during the test, if it is necessary to do so. It may be necessary to manually feed 1 or 2 inches of water to the boiler to prevent the low-water fuel cutoff from shutting down the burner.
4. Set the burner to operate at its maximum capacity and ensure that combustion is complete with proper over-the-fire draft.
5. When the operating control has shut off the burner, place test leads across the control terminals to switch the control to the high-pressure cutout.
6. When the high-pressure cutout has demonstrated its ability to shut off the burner, place another set of test leads across its terminals, reset it if it has this feature, and allow the burner to continue running without control.
7. The safety valve should pop open at the set pressure (15 psig, plus or minus 2 psig) or within the range of 13 to 17 psig. If it opens below 13 psig or does not open at 17 psig, it should be replaced or repaired by the authorized representative of the safety valve manufacturer.
8. If the safety valve opens within this range, continue running the burner. If the pressure continues to rise, allow it to reach a maximum and hold it for a minimum of 30 seconds. The maximum reached must not exceed 20 psig.
9. If the pressure continues to rise above 20 psig, the burner should be stopped by removing the test leads from the high-pressure cutout. If the boiler room is filled with steam, the disconnect switch at the door may be used. The safety valve must be replaced by one that demonstrates its ability to maintain a pressure of not more than 20 psig in the boiler.

10. If the safety valve does maintain a maximum pressure of 20 psig or below, the burner should be stopped by removing the test leads from the high-pressure cutout. Observe the pressure at which the safety valve closes.
11. Remove the test leads from the operating control and let the burner cycle once to determine whether or not it is functioning properly.
12. Enter all pertinent data in the boiler room log-date, time, personnel present, opening pressure, maximum pressure, closing pressure, and any other pertinent information.

5.9.6 Safety-Relief Valve Tests (Water Boilers)

WARNING

Safety valves and safety relief valves are designed for a specific purpose. Do not use a safety valve or a safety relief valve for other than its intended purpose. Do not alter or change the safety device in any manner. Failure to comply may cause injury or death and/or equipment damage, including general equipment and area destruction.

5.9.6.1 Try-Lever Test

Only boilers low enough in pressure should be considered safe for try-lever test. Every month that the boiler is in operation or after any prolonged period of inactivity, a try-lever test must be performed as follows:

1. Lift the try lever to the open position and hold it open for at least 5 seconds or until the water discharged runs clear.
2. Release the lever and allow the spring to snap the disk to the closed position. If the valve leaks, operate the try lever two or three times to clear the seat of any object that is preventing proper seating. As safety-relief valves are normally piped to the floor or near a floor drain, it may take some time to determine if the valve has shut completely.
3. If the safety-relief valve continues to leak, it must be replaced with a new valve, returned to the manufacturer for repair, or field repaired by the manufacturer.
4. Visually inspect the valve and discharge piping for evidence of scale or encrustation.
5. Do not disassemble the valve or attempt to adjust internal or external parts. The date of the test must be entered into the boiler log book.

5.9.6.2 Pop (Pressure Relief) Test

A pop (pressure-relief) test must be performed annually, preferably at the beginning of the heating season if the boiler is shut off during the summer months. Follow these procedures:

1. Establish the necessary trial conditions at the particular location. Make sure that the safety valve discharge piping is properly supported and discharges to a safe location. Review the preparation for the test with all personnel involved. At least two people must be present at all such tests.
2. If possible, calibrated test gauges and thermometers should be temporarily installed to check the accuracy of the boiler pressure gauge and thermometer during the test.
3. Isolate the boiler, if possible, by shutting the stop valves in the steam supply and condensate-return piping.
4. If an automatic water feeder is provided, the water inlet valve should be closed.
5. Shut the valve to the expansion tank. Drain all the water from the tank to ensure that an air cushion is provided. Open the valve to the tank. The expansion tank must not be isolated from the boiler during the pop test.

NOTE

Prepressurized expansion tanks do not require draining.

6. Make sure that all personnel are clear of the safety-relief valve discharge.
7. Drain all the water from the boiler through the safety-relief valve to reduce boiler pressure to not more than 50 percent of the safety-relief valve set pressure. Disposition of the boiler discharge must comply with the CWA.
8. Place test leads across the appropriate terminals of the operating control to demonstrate the ability of the high-temperature cutout to function properly. After this has been checked, place test leads across the high-temperature cutout to permit continuous operation of the burner.
9. Observe that the pressure and temperature of the boiler water are rising. If an adequate air cushion is provided, the water temperature may rise to 274°F in a system with a safety-relief valve set to open at 30 psig and as high as 370°F in a system with a safety-relief valve set to open at 160 psig.
10. ASME certifies the capacity of relief valves and the maximum overpressure. Relief valves certified on water, gal/min water at 70°F, should not exceed their set pressure by more than 10 percent or 3 psig, whichever is greater, except for a fire case where overpressure should not exceed 21 percent. Moreover, the relief valve set pressure should not exceed the vessel maximum allowable working pressure (MAWP).
11. The valve should open and discharge a mixture of water and vapor.

12. If the valve does not open between the allowable pressures in Step 10 (above), it must be replaced with a new valve, returned to the manufacturer for repair, or field-repaired by the manufacturer.
13. If the valve does open satisfactorily, remove the test leads from the high-limit control. The valve will remain open and discharge water and steam until the closing pressure is reached. This may be 10 to 50 percent below the set pressure of the valve. There are no blow-down requirements for safety-relief valves.
14. After the safety-relief valve has closed, the remainder of the stored energy may be dissipated by slowly and carefully opening the boiler supply valve. The return valve may be opened after the pressures between the boiler and the supply systems have been equalized.
15. Allow the high-limit control to cycle the burner at least once to determine if it functions properly
16. Remove the test leads from the operating control and allow it to cycle the burner on and off at least once to determine if it functions properly.

5.9.6.3 Capacity Test

A capacity test must be performed on safety-relief valves on all new boiler installations or on existing boilers when any modification changes the output of the boiler (i.e. changing the size of the burner, the rate of fuel flow, or the grade or type of fuel not previously fired), and when any safety-relief valve is repaired or replaced. Hydrostatic (water pressure) testing is not an acceptable means of determining the capacity of a safety-relief valve. As with safety valves, the capacity of a safety-relief valve is measured in pounds of steam per hour or Btu per hour. Follow these procedures:

1. Establish the necessary trial conditions at the particular location. Make sure that the safety valve discharge piping is properly supported and discharges to a safe location. Review the preparation for the test with all personnel involved. At least two people must be present at all such tests.
2. It is recommended that calibrated test gauges and thermometers be temporarily installed to check the accuracy of the boiler pressure gauge and thermometers. It should be determined that all controls, gauges, etc., are designed to withstand the temperatures that will be experienced during this test.
3. Isolate the boiler from the supply and return piping by shutting respective valves. If a water feeder is provided that can feed water to the boiler during the test, it should remain operable.
4. Set the burner to operate at its maximum capacity. Ensure that combustion is complete with proper over-the-fire draft, cutting back on fuel supply if necessary to accomplish this. It would be advantageous to be able to meter the fuel flow to calculate the output of the boiler. On gas burners, this can be done by shutting off all other gas appliances in the building and using the gas and vapor. All personnel should keep clear of the end of the discharge pipe.

5. If the safety-relief valve does not open (flow equals 24 cu in/min) within its opening tolerances, or if the relief pressure exceeds that which is allowable, immediately shut down the burner and make the boiler inoperative until a new valve is installed and passes the tests as prescribed herein. All pressure vessels other than unfired steam boilers shall be protected by a pressure relieving device that shall prevent the pressure from rising more than 10 percent or 3 psi, whichever is greater, above the maximum allowable working pressure, except when multiple devices are provided, or where an additional hazard can be created due to fire or other external sources (UG-134).
6. If the valve opens within its opening tolerances, keep the burner running until maximum pressure is reached, unless the pressure exceeds those specified in Step 5 above. If the maximum pressure is within acceptable limits, hold it there for 30 seconds to check for further rise. If there is no further pressure rise, shut down the burner by pulling test leads from the high-temperature cutout.
7. The safety-relief valve will continue to discharge until the boiler pressure is below the relief valve set pressure.
8. After the valve has closed, the residual pressure in the boiler may be dissipated through the safety-relief valve by using the try lever or by slowly opening the stop valve in the supply line. After the supply valve has been opened, the return valve and valve in the piping to the expansion tank must be opened.
9. Allow the high-limit control to operate and shut down the burner at least one time to check its function. After this has been done, remove the test leads from the operating control and check to make certain it is functioning properly.
10. Enter all pertinent data in the log book.

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SECTION 6

CENTRAL AIR CONDITIONING SYSTEMS

6.1 GENERAL

Central air-conditioning systems differ from self-contained or package-type air-conditioning units. They are custom designed for a building with primary and secondary components. Primary components are central plant equipment such as water chillers, direct expansion (DX) equipment, cooling tower, condensers, boilers, and pumps. Secondary components include air handlers, ducts, plenums, terminal units, controls, and refrigerants.

In central air-conditioning systems, hot water or steam for heating and chilled water for cooling are produced at a central location and piped to the individual fan-coil units (referred to as air handlers). Air handlers are equipped with heating and/or cooling coils. In the central system, temperature, humidity, cleanliness, and air distribution are controlled to meet the requirements for the conditioned space. The air to be conditioned is taken from outside the building, recirculated from the conditioned space, or supplied from both of these sources. From any source, the air to be conditioned is moved across cooling and/or heating coils by the action of the fan.

6.2 TYPES OF CENTRAL AIR-CONDITIONERS

6.2.1 General

Four basic types of central air-conditioning are: all-air, air-water, all-water, and direct-expansion. Each type has its own functional and economic advantages and is designed for specific applications. Each name indicates the controllable medium that is supplied to the space to be conditioned.

6.2.2 All-Air Systems

6.2.2.1 General

With the all-air system, the air-treating and refrigeration plants may be located in a central station some distance from the space to be conditioned. Only the final cooling/heating medium (air) is brought into the conditioned space through ducts and distributed within the space through outlets or mixing terminal outlets. Common names for some of the all-air systems are as follows:

- Single-duct, variable air volume (VAV)
- Single-duct, constant volume (CV)
- Dual-duct
- Single-duct with reheat
- Multi-Zone
- Double-duct, constant volume

6.2.2.2 Single-Duct, Variable Air Volume System

This type of central system supplies a single stream of either hot or cold air at normal velocity. Volume is adjusted by automatic, thermostatically controlled dampers (Figure 6-1).

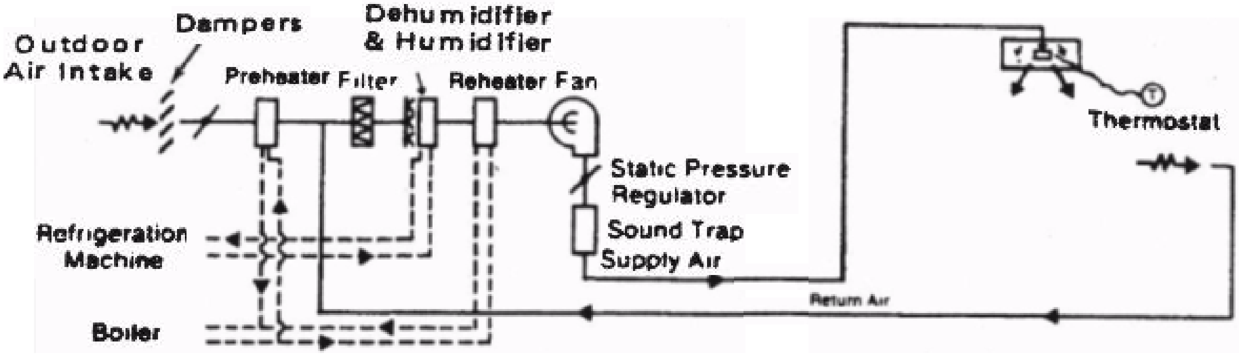


Figure 6-1. Single-Duct Variable Volume System

6.2.2.3 Single-Duct, Constant Volume System

This type of central system supplies a single stream of either hot or cold air at constant volume. The layout of the system is the same as that shown Figure 6-1, except for the absence of a static pressure regulator.

6.2.2.4 Dual-Duct System

This is a high-velocity system with a central air-conditioning plant supplying two air streams to each room. The primary air supply is constant-volume, variable temperature; the secondary supply is variable air volume, constant temperature adjusted by thermostatically controlled dampers (Figure 6-2).

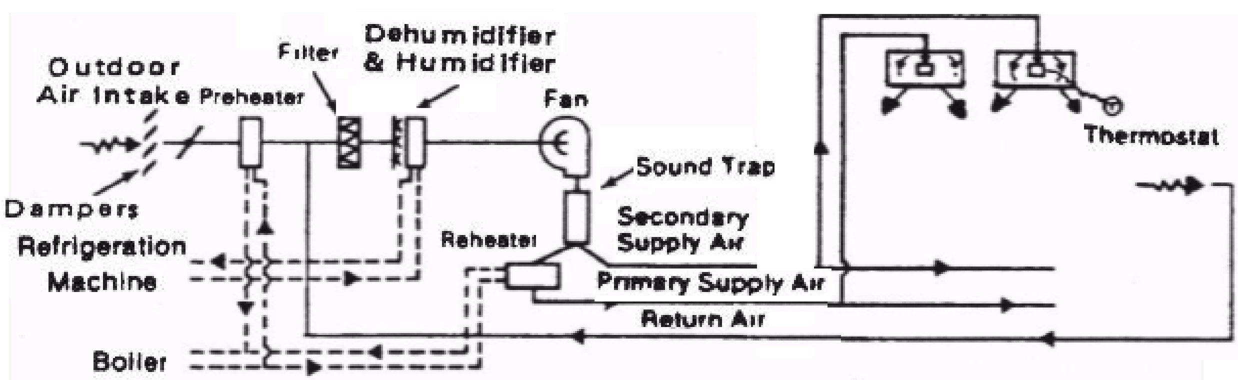


Figure 6-2. Dual-Duct System

6.2.2.5 Single-Duct with Reheat System

This system consolidates all major equipment in the machine room except for the reheat element, which is located near the room or area to be conditioned.

Primary treated air is supplied at constant volume from this central plant through a single duct to rooms. Each room is equipped with a small steam or hot-water coil, or a strip heater that is positioned either in the supply air stream or in an inducted-air position (Figure 6-3).

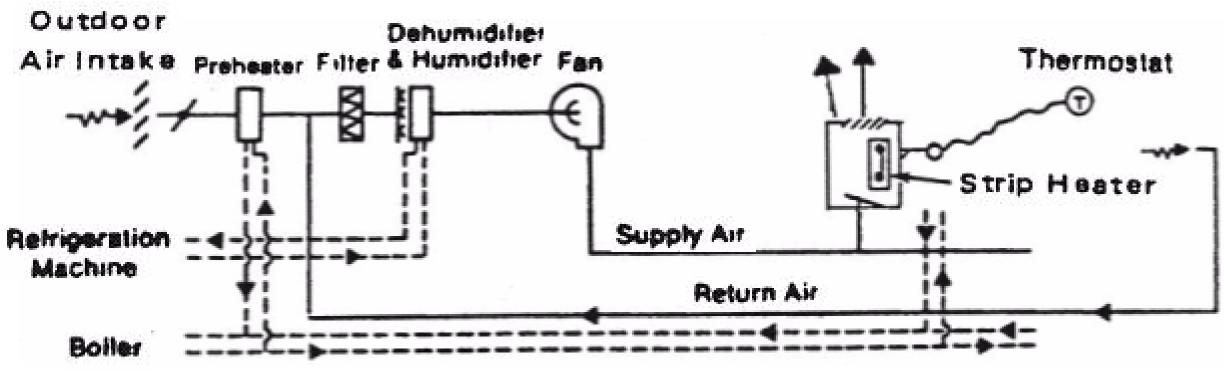


Figure 6-3. Single-Duct System with Reheat

6.2.2.6 Multi-Zone System

This system distributes a single air stream to each room through ducts at normal velocity.

Central air-treating apparatus includes dampers that premix the cold and warm air supplies controlled by the room thermostats (Figure 6-4).

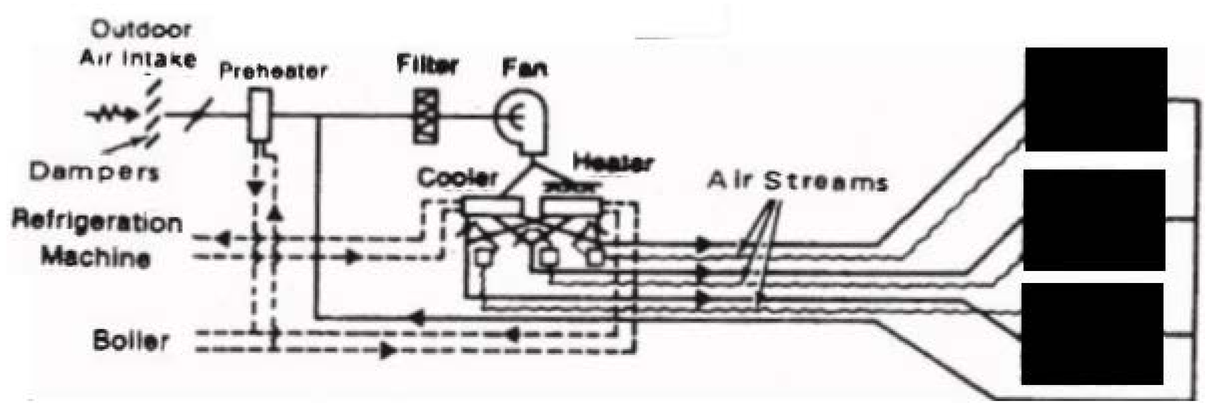


Figure 6-4. Multi-Zone System

6.2.2.7 Double Duct, Constant Volume System

This type of system supplies treated air through a pair of ducts to room terminals of special design and function. These terminals automatically mix air to maintain proper temperature and volume (Figure 6-5).

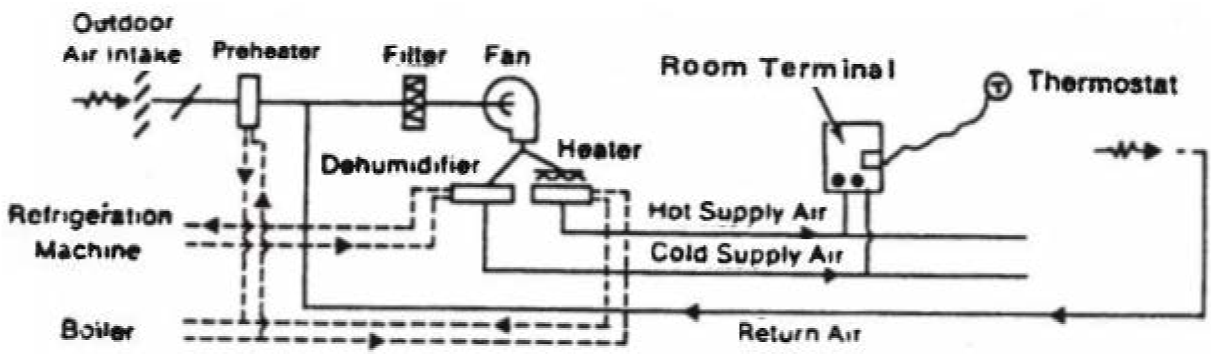


Figure 6-5. Double-Duct Constant Volume System

6.2.3 Air-Water Systems

6.2.3.1 General

An air-water system is the result of conditioning transferred by a combination of heated/cooled air and hot/chilled water. Like the all-air systems, the air apparatus and refrigeration plants are separate from the conditioned space. The cooling and heating to the conditioned space, however, is affected in only a small part by air brought from the central apparatus. The major part of the room's thermal load is balanced by warm or cool water circulated through either a coil in an induction unit or a radiant panel. The different air-water types are as follows:

- Induction
- Fan-coil with supplementary air
- Radiant panels with supplementary air

6.2.3.2 Induction System

This system uses a high-velocity, high-pressure, constant-volume air supply to an induction terminal. Inducted air from the room is either heated or cooled within the terminal as required. Capacity control is accomplished by water flow or air bypass (Figure 6-6).

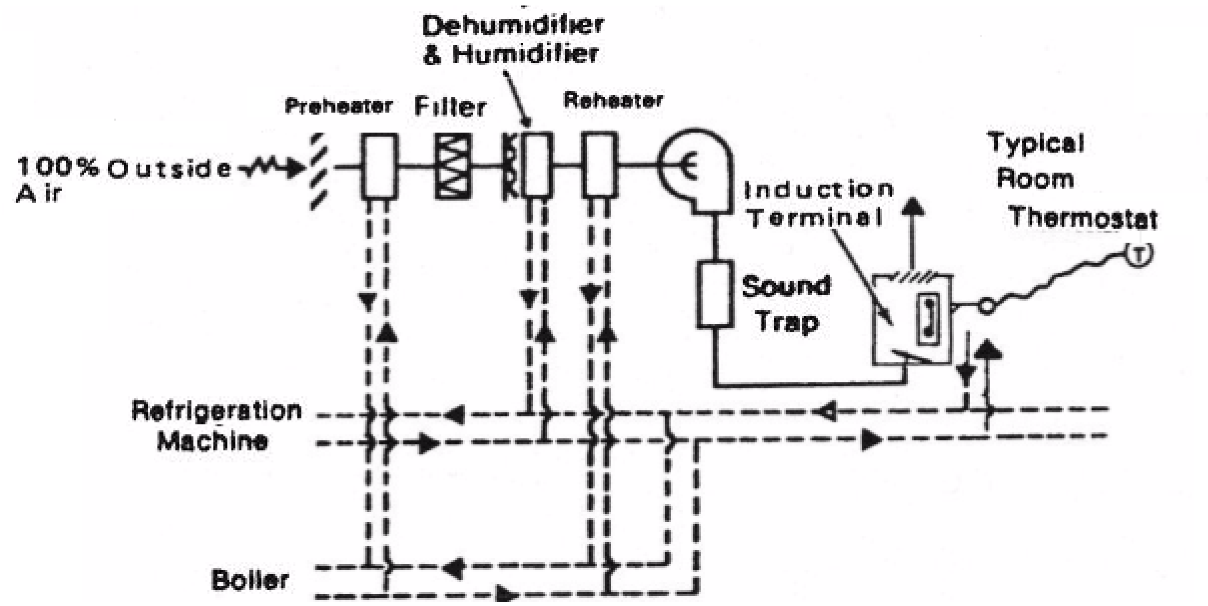


Figure 6-6. Induction System

6.2.3.3 Fan-Coil with Supplementary Air System

The fan-coil terminal provides direct heating or cooling of the room air. A supplementary constant-volume air supply provides the necessary ventilation (Figure 6-7).

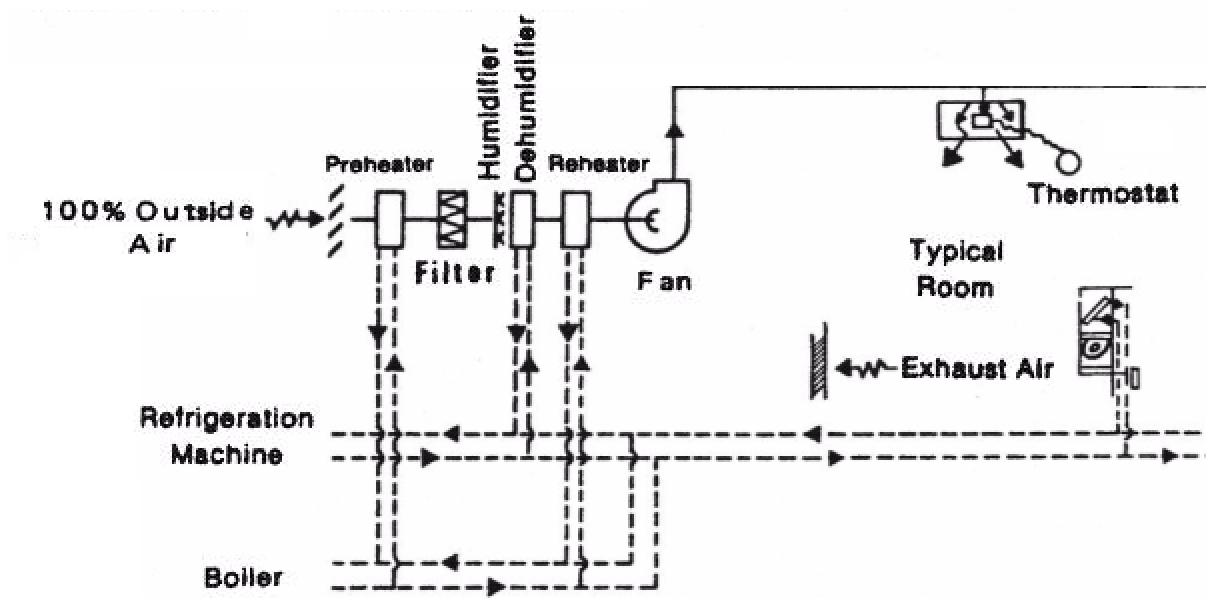


Figure 6-7. Fan Coil with Supplementary Air System

6.2.3.4 Radiant Panels with Supplementary Air System

Ceiling or wall, radiant-panel terminals provide radiant heating or cooling. A constant-volume air stream is supplied for dehumidification and ventilation (Figure 6-8).

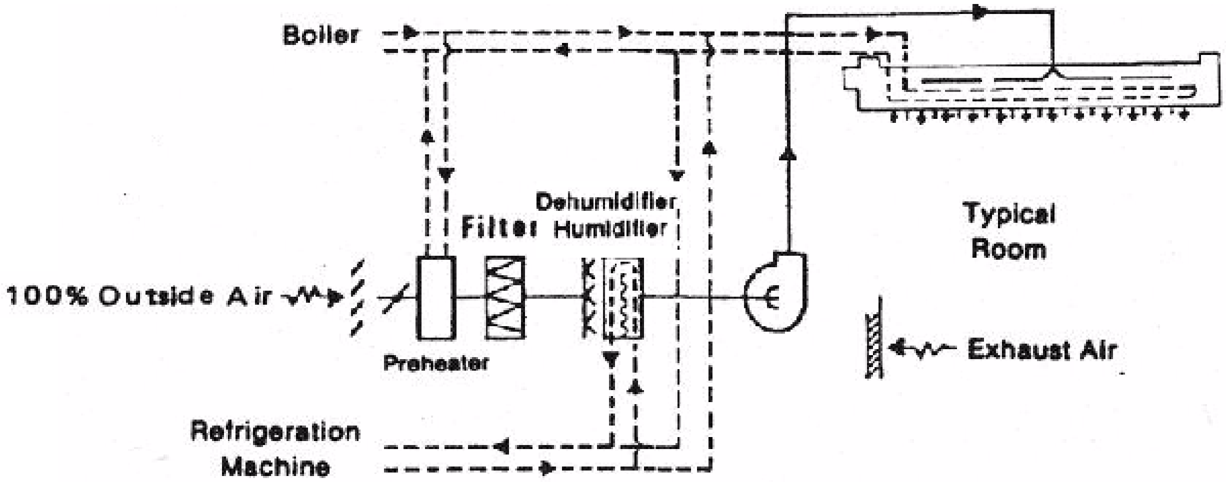


Figure 6-8. Radiant Panels with Supplementary Air System

6.2.4 All-Water Systems

An all-water system is the result of conditioning transferred only by means of hot and chilled water. They are fan-coil room terminals connected to one or two water circuits. Chilled and hot water are supplied from a remote source and circulated through the coils in the fan-coil unit located in the conditioned space. Ventilation is accomplished by separate means. The various types of piping arrangements are discussed in Paragraph 6.6.2.1.

6.2.5 Direct-Expansion Systems

In direct-expansion (DX) systems, liquid refrigerant from a remote condensing unit is piped to an evaporator coil in an air handler. These are usually referred to as DX coils and are used primarily in small systems (50 tons and less).

6.3 AIR HANDLERS

6.3.1 General

There are two basic types of air handling units (AHU): constant air volume (CAV) and variable air volume (VAV) units. In CAV AHU the air supply and return fan capacities are constant; in VAV AHU the fan capacities are variable. A basic air handling unit consists of the various components shown in Figure 6-9. To follow the air pattern, start with the outside air intake to the building. Outside air, or fresh air, is normally required in at least some minimum quantity to meet building codes during occupancy periods. The air passes through a normally closed outside air damper and mixes with the return air. This is mixed air supply. The air is then conditioned through any required filtering and passed through the heating or cooling coils. Discharge air from the supply fan then feeds all parts of the system.

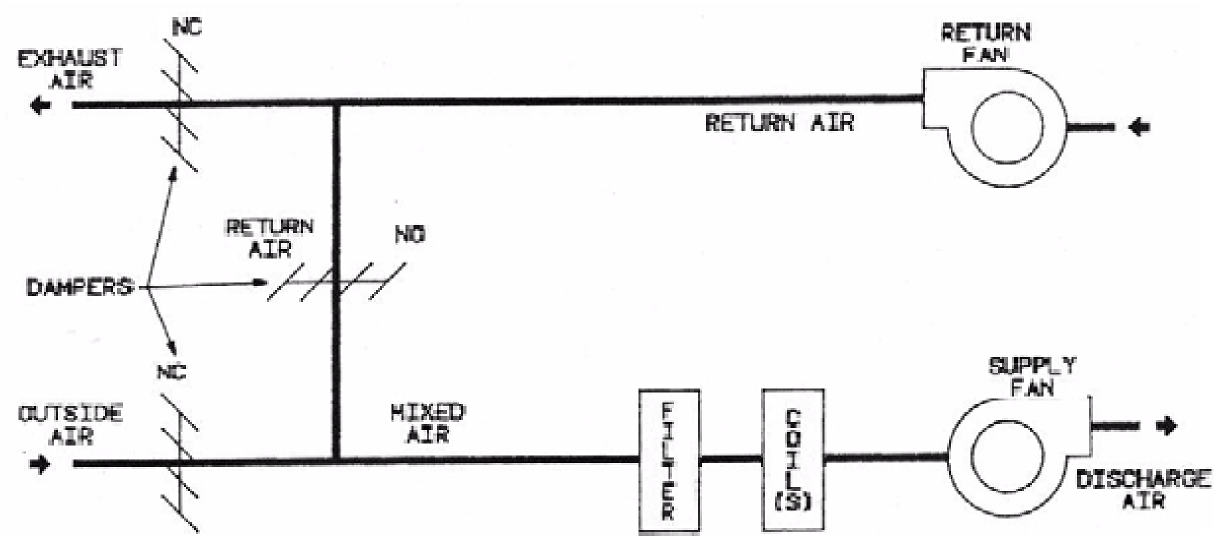


Figure 6-9. Basic Air Handling Unit

If the system includes a return air fan, air from the controlled space may be exhausted to the outside. In other instances, some or all of the return air may be routed through the return-air damper. The direction of the return air flow is determined by the mixed air controls that position the outside return and exhaust air dampers. The amount of exhaust air from a building is usually less than the outside air drawn in because of the desire to maintain a slightly positive pressure within the building. A slightly positive pressure is desired inside the building to help prevent drafts, heat gain or loss, and infiltration of dirt and dust from outside. Maintaining a positive pressure requires that consideration be given to the normal routes of air exiting the building through doors, windows, cracks, etc.

6.3.2 Air Handling System Applications

The way in which AHUs operate may be classified as follows:

- Single-zone
- Terminal reheat

- Multi-Zone
- Dual-duct
- Variable air volume
- Induction
- Economizer cycle

6.3.2.1 Single-Zone

6.3.2.1.1 General

The simplest form of air handling system is the single zone system. The AHU supply conditioned air to an entire building or to a discrete section of the building that can be controlled as a single zone. Only one coil operates at a time, either hot or cold. The system is controlled by modulating the supply of air or by turning the unit on and off.

Many air handlers used by the Postal Service are face and bypass damper systems (Figure 6-10). These are used for workroom floor areas in buildings designed prior to the oil embargo of 1973. These units may have a cooling coil or both a cooling coil and a heating coil. Only the final control element (air) is brought into the conditioned space.

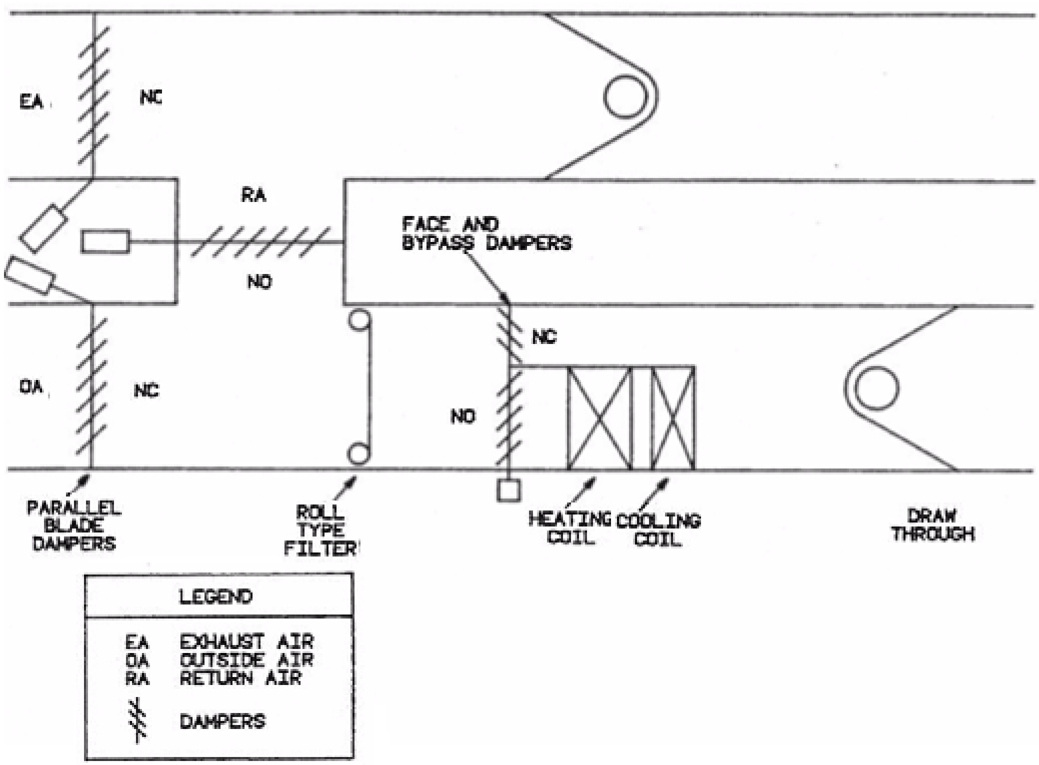


Figure 6-10. Face and Bypass Damper System

The single-zone system with sequenced valves and dampers has replaced the face and bypass damper system in newer buildings. It is generally used for workroom floor applications; this air handler has a heating cycle, ventilation cycle, and cooling cycle operating in sequence. The heating valve is a normally open valve that closes on a temperature rise in the space. Following closure of the heating valve, outside air dampers start opening on a temperature rise in the space, providing the enthalpy limit controller allows for it. When temperature and humidity of the outside air prohibits its use for cooling, the outside air dampers close and the cooling valve begins to open. Figure 6-11 illustrates a typical sequenced valve and damper air handler.

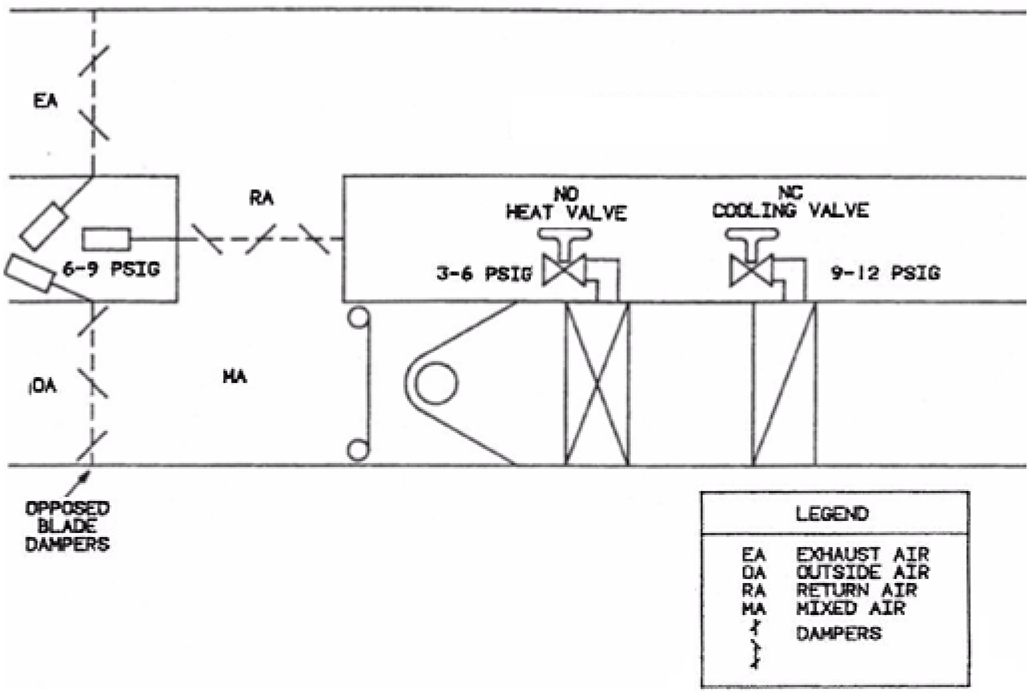


Figure 6-11. Single Zone with Sequenced Valves and Dampers

6.3.2.2 Terminal Reheat System

A reheat system is a modification of a single-zone single-duct system. Air is transferred to all spaces at the same temperature. A terminal box reheats the air as needed. Although good for humidity control, reheat systems are energy inefficient; they use heating and cooling simultaneously for all spaces that have demand below that of the zone with the peak load.

6.3.2.3 Multi-Zone with Discharge Air Control

Single zone, terminal reheat, and multi-zone systems provide a constant volume of air to each zone served. However, with multi-zone heating and cooling control is accomplished by separately varying the temperature of the air supplied in each zone. The multi-zone air handler is used in office areas. The system distributes a single air stream to each room through ducts at a normal velocity. Central air-treating apparatus includes zone-controlled dampers that premix cold and warm air supplies controlled by room thermostats. System control design may incorporate outside air reset of a hot deck and a cold deck controller. Figure 6-12 illustrates a typical multi-zone air handler.

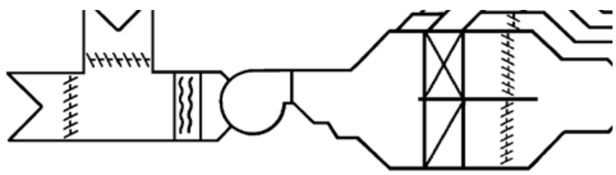


Figure 6-12. Multi-Zone with Discharge Air Control

6.3.2.4 Dual-Duct

The dual-duct air handler is normally a high-velocity system with central air-conditioning being supplied in two air streams throughout the building. Room terminals, called mixing boxes, premix the cold and warm air supplies for each designated area. Rooms may have one or more mixing boxes depending on room size and use. Figure 6-13 illustrates a typical dual-duct air handler.

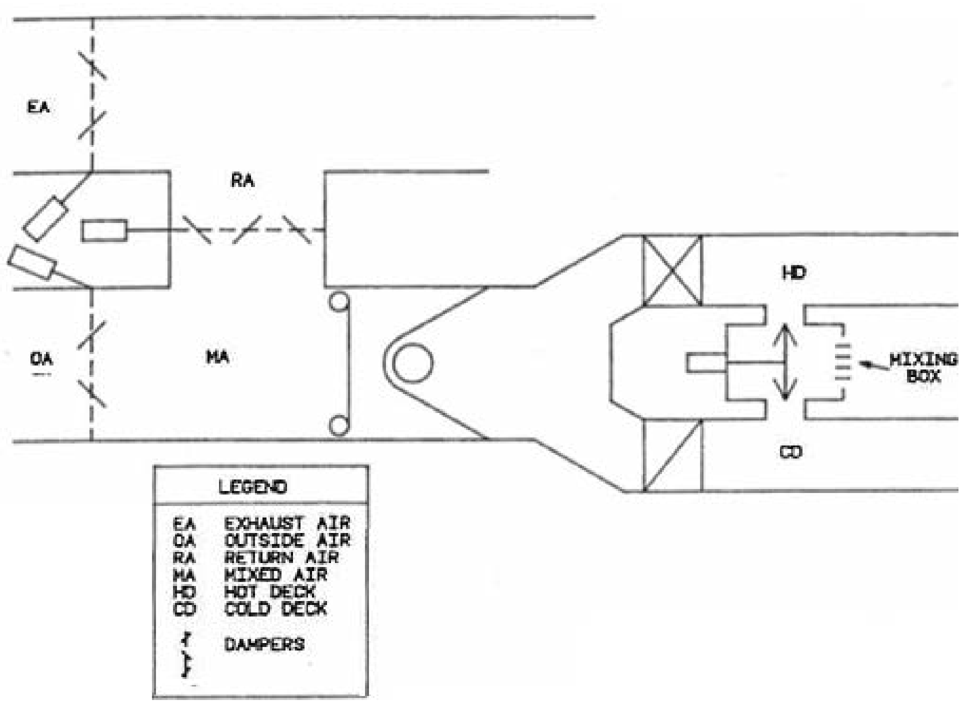


Figure 6-13. Dual-Duct Air Handler

6.3.2.5 Variable Air Volume

In a variable air volume system, the air temperature is held constant and the air volume is varied. The simplest control system for varying the air is On-Off control of the fans. However, damper controls (opening and closing) are more common and varying fan motor speed is the most effective method for controlling air volume.

6.3.2.6 Induction System

An induction system uses terminal units at the exterior perimeter of the building. Outdoor air is cooled, heated, humidified, or dehumidified, depending on the season, and delivered at high velocity through a small circular duct.

6.3.2.7 Economizer Cycle

An economizer cycle is a control sequence that adjusts motorized dampers to draw in outside air when advantageous for minimizing cooling energy.

6.3.3 Scheduling, Cycling, and Variable Volume

Air handlers should be scheduled to turn on or off as the heat load changes in the building. Air handlers used to maintain mail processing areas should be secured during downtime.

Air handlers should be cycled on and off as the load changes. This cycling could be set up on intervals of 30 minutes on and 30 minutes off. Cycling should be developed in the "W" shape to control peak power usage.

Variable volume is an alternative to cycling. As the load decreases, variable vanes located on the blower intake close, or the motor is slowed by a variable frequency drive unit, causing the motor to unload. This operation uses less amperage and saves energy.

6.3.4 Filters, Coils, and Blower Section

Filters should be monitored on a daily basis. ASHRAE Standard 52.2 defined minimum efficiency reporting value (MERV) to describe filter performance. MERV values of 8 and higher correspond to dust spot efficiencies of more than 30 percent, MERV values of 13 and higher to dust spot efficiencies of more than 80 percent, MERV values of 15 and higher to dust spot efficiencies of more than 95 percent. Inclined manometers or magnehelic gauges should be maintained to ensure accurate readings. Coils should be kept clean and the blower section checked for dirt or dust accumulation on fan blades. Chemical coil cleaners are available from several manufacturers. Caution should be used when applying coil-cleaning chemicals; chemicals can contaminate the environment, as well as adversely affect the coils. Upon completion of cleaning, coils should be checked with a manometer for an indication of airflow through all passes of the coil.

6.3.5 Filters

6.3.5.1 Roll-Type Filters

At present, fiberglass, noncleanable, roll-type filters are the predominant type of filter installed in postal air handlers. Advanced technology has allowed for the development of tackified, dual-ply, polyester filter media. This media, which have a greater density than fiberglass, eliminate much of the pull-through. Roll-type filters must function properly in the air handler mechanisms and provide adequate dust trapping and holding capacity. The manufacturer should furnish certification that the filter has been tested and is on the qualified product list. Movement of the filter is automatically controlled by an advancing mechanism such as follows:

- Timer. Advances the filter media in increments at a predetermined rate.
- Pressure Switch. Advances the filter media when the buildup of dust causes a pressure drop across the media that exceeds a set value. The pressure range is usually between 0.30 and 0.45-inches of water.
- Timer and Pressure Switch. Operates as described in previous paragraph. However, a pressure switch overrides the timer if an unusually dusty condition causes the pressure drop to exceed the set value before the timer calls for advancement of the media.
- Photocell Advance Switch. The photocell has been adapted to filter systems as an advance mechanism. With a light bulb in the return air plenum and the photocell placed after the filter, the filter is advanced as the light fades.

6.3.5.2 Sectional Throw-Away Filters

When dirty, these should be removed, discarded, and replaced. They may be vacuum-cleaned ONLY in an emergency, and used only until a replacement is available. When not available locally, postmasters should try to obtain them through the refrigeration service contractor (if the local office has such a service contract) or through the assistance of a larger, nearby post office.

6.3.5.3 Sectional Cleanable Filters

These should be washed in a solution of mild detergent and water. A supply of spare filters should be kept on hand so that the air handlers need not be shut down while the filters are being cleaned. For installations with a large number of filters, a contract for cleaning and servicing should be considered. Clean, efficient filters are necessary to remove dust, lint, and other foreign material from the air, as well as to ensure efficient transfer of heat between the heating or cooling coil and the air as it is blown across the coils. Where air is found to bypass a filter because of poor installation, necking, or holes in the filter, the condition should be corrected immediately. Failure to do so can result in a clogged or frozen coil and unwarranted, additional expenses incurred to clean or replace the coil.

CAUTION

Filters must be clean, serviceable, and in place for efficient system operation. Under no circumstances may air handlers be operated without filters or while changing filters. Lock out/Tag out and confined space procedures may apply. Failure to comply may cause equipment damage.

6.3.6 Operation

6.3.6.1 General

The single-zone air handler will be used as an example to explain in detail how the temperature of the air leaving the discharge duct of the unit is automatically controlled (Figure 6-14).

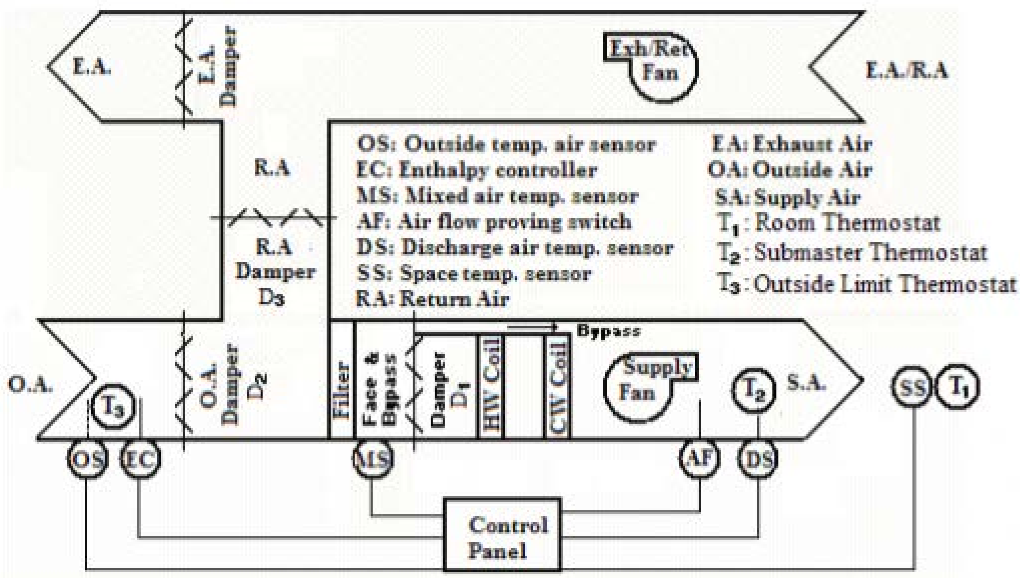


Figure 6-14. Typical Single-Zone Air Handler

6.3.6.2 Electronic Temperature Sensing

Electronic temperature sensing is normally performed by a thermistor, a variable resistance sensor. When the temperature sensed by the thermistor changes, the resistance value of the thermistor also changes. The thermistor is a passive analog input to the digital controller, in which the wired resistance values can be converted to actual temperatures information that can be processed by the controller.

6.3.6.3 Sensors Application

Figure 6-14 depicts a space sensor (SS), which is located in the space served by the air handler; a discharge air sensor (DS), mounted in the supply duct; a mixed air sensor (MS), installed in the mix air chamber; an outside air sensor (OS), mounted next to the intake vent. Additionally, a return air sensor (RS) can be mounted in the return air duct. Other devices, such as static pressure transmitters and humidity transmitters use active electronics to produce a control signal. The thermistor for the SS is a small solid state electronic device, mounted on an enclosed printed circuit. The DS, MS, OS, and RS are often constructed as a probe that is inserted securely into the duct.

6.3.6.4 Fresh Air for Cooling

MS-49, *Energy Conservation and Maintenance Contingency Planning*, requires that outside air be used for cooling when it is suitable. Enthalpy controls (EC) have been installed at many locations to achieve this (Figure 6-14). However, when air-conditioning or heating is required, keeping fresh air intake to a minimum prevents unnecessary heating and/or cooling load. The percent of outside air brought into the facility can be estimated by using the following equation:

$$\text{Percent Outside Air} = \frac{\text{(Return Air Temp) - (Mixed Air Temp)}}{\text{(Return Air Temp.) - (Outside Air Temp.)}}$$

NOTE

The accuracy of the equation depends on the accuracy of the temperature calculations and uniformity across the air flow.

Dampers are difficult to set up and control. A slightly opened damper can allow significant air intake; a damper positioned of 10 percent physically opened may pass as much as 50 percent air. Therefore, properly maintained dampers will control leakage, so that minimum outside air is obtained. American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Standard 62.1-2016, *Ventilation for Acceptable Indoor Air Quality* provides guidance on the minimum acceptable levels of outside air. A copy of Standard 62 can be purchased from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle NE, Atlanta, GA 30329-2305.

6.3.6.5 Fresh-Air Intake Damper

6.3.6.5.1 Purpose

The outside air damper, when provided, is always open to its set position when the fan is operating and is always closed when the unit is not operating. They are designed to provide a specific minimum air ventilation rate in order to maintain acceptable air quality. Excessive ventilation wastes energy and low ventilation affect air quality. To ensure proper damper operation, they should be inspected as per current MMO Guidelines for Creating Detailed Local Building Equipment Maintenance Preventive Maintenance Checklist.

6.3.6.5.2 Ventilation Rate

If the actual flow rate of the air handler is known, the ventilation rate is:

$$\text{Ventilation Rate} = \frac{(\text{Total Air Flow}) \times (\text{Percent Outside Air})}{\text{Occupancy}}$$

where,
Total Air Flow = air handler flow rate, cfm
Percent Outside Air = value from the above equation
Occupancy = number of people in area served by th

6.3.6.6 Return-Air Damper

This damper is normally closed when the unit is not operating. When the fan is turned on, the damper automatically assumes its set position. As the outside air damper gradually opens, as described in Paragraph 6.4.7.5, the return-air damper gradually closes. When the outside air damper is wide open, the return-air damper is fully closed.

6.3.6.7 Mechanical Cooling Cycle

Assume the system is providing cooling instead of heating and the plant is being operated on the mechanical cooling cycle instead of the heating cycle used for the example in Paragraph 6.4.3.7.4. This means that the refrigeration plant is being operated and chilled water is circulating through the cooling coil in the air handler. When operating, the face and bypass dampers perform in the same manner as described in Paragraph 6.4.3.7.5 to hold the temperature in the zone at the set point. In the case of cooling, OS causes the outside fresh-air intake damper to return to its minimum opening whenever the outside temperature exceeds a set point.

6.3.6.8 Ventilation Cycle

If the difference between the outdoor and supply air temperature is not significant, the exhaust and outdoor air dampers are fully opened and the return damper is fully closed. During this cycle, there is no hot water in the heating coil or chilled water in the cooling coil. Thus, all effective control would be through the fresh-air intake damper.

6.3.7 Hot-Water Temperature Control

6.3.7.1 General

For installations using a hot-water coil (rather than a steam coil), the temperature of the water circulating through the heating coil is varied in accordance with the outside temperature through the use of an outside control and a three-way water-mixing valve.

6.3.7.2 Outside Control

The outside control activates a water-mixing valve whereby the amount of water taken from the boiler is mixed with the return water to produce a circulating-water temperature inversely proportional to the outside temperature. This means that the higher the outside temperature, the lower the temperature of the circulating water in the heating coil, and the lower the outside temperature, the higher the circulating-water temperature.

6.3.7.3 Three-Way Mixing Valve

The change in water temperature is accomplished through a three-way mixing valve. Mixing valves combine the flow of two or more inlets into a single outlet. Three-way thermostatic valve has an internal thermostatic element that senses temperature of the fluid leaving its mixed outlet ports and maintains outlet temperature close to the target set temperature. They are used in hydronic systems, so water may either flow through the coil or bypass it. Additionally, it could be configured to circulate water directly to the heating coil, or mix it with return water in any proportion, and circulate the mixture through the coil or circulate only return water through the coil (Figure 6-15). The valve is completely closed off to the boiler at an outside temperature of 65ºF and completely open to the boiler at an outside temperature of 0ºF.

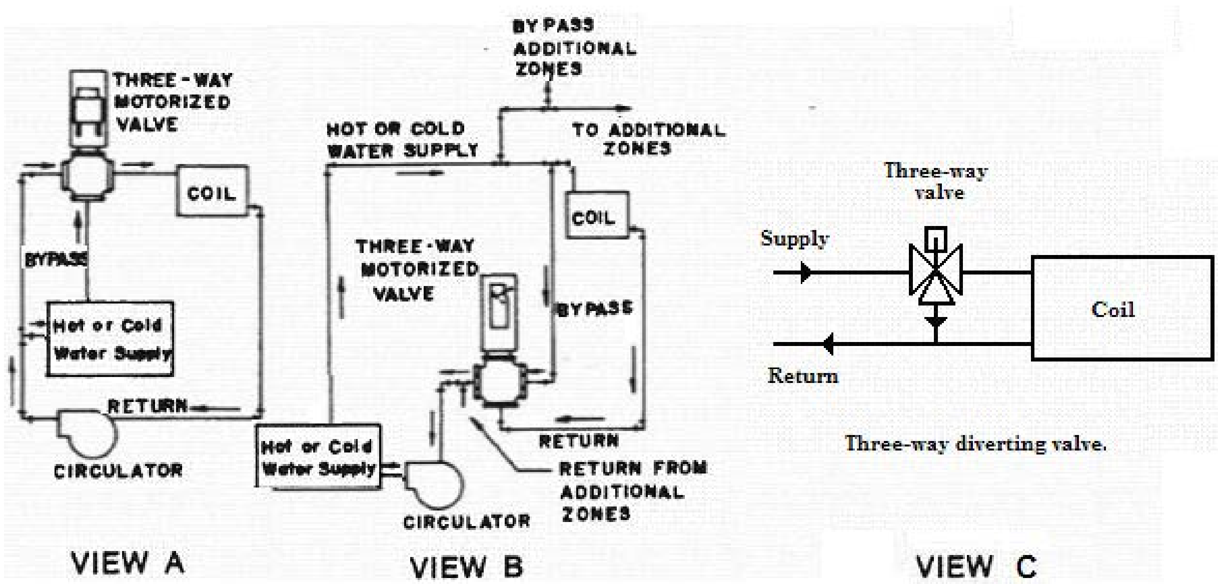


Figure 6-15. Three Methods of Piping Three-Way Mixing Valves

6.3.7.4 Water Temperature Relation Table

In the design stage, heating plant capacity is based on the outside design temperature, taking into account the lowest temperature on record for a locality. In actual operation, the temperature at which the boiler water is maintained is an additional factor. For the operator of a heating plant to determine that the heating plant and related controls are operating properly, temperature relation tables are furnished. Table 6-1 shows the relationship between outside temperature and the corresponding temperature at which the water should be leaving the mixing valve. Table 6-1, view A is based on a boiler water temperature maintained at 190ºF, Table 6-1, view C is based on a temperature of 210ºF. Each table is designed for the three most commonly used design temperatures, namely -10ºF, 0ºF, and +10ºF. To see if the heating plant and controls are operating properly, an operator determines the design temperature for the installation, selects the proper boiler water temperature table, and then checks the temperature of the water leaving the mixing valve.

Table 6-1. Water Temperature Relation Figure

TEMPERATURE OF WATER LEAVING MIXING VALVE			
Outside Temperature	**Design Temperature -10°F**	**Design Temperature -0°F**	**Design Temperature +10°F**
A. 190°F Boiler Water			
Above 65°F	Circulating pump off. No water flowing.		
65°F	80°F	80°F	80°F
60°F	88°F	89°F	90°F
55°F	95°F	97°F	100°F
50°F	102°F	106°F	110°F
45°F	110°F	114°F	120°F
40°F	117°F	122°F	130°F
35°F	124°F	131°F	140°F
30°F	131°F	139°F	150°F
25°F	139°F	148°F	160°F
20°F	146°F	156°F	170°F
15°F	153°F	164°F	180°F
10°F	161°F	173°F	190°F
5°F	168°F	181°F	--
0°F	175°F	190°F	--
-5°F	183°F	--	--
-10°F	190°F	--	--
B. 200°F Boiler Water			
Above 65°F	Circulating pump off. No water flowing.		
65°F	80°F	80°F	80°F
60°F	88°F	89°F	90°F
55°F	96°F	99°F	102°F
50°F	104°F	108°F	113°F
45°F	114°F	118°F	125°F

TEMPERATURE OF WATER LEAVING MIXING VALVE			
Outside Temperature	**Design Temperature -10°F**	**Design Temperature -0°F**	**Design Temperature +10°F**
40°F	120°F	126°F	134°F
35°F	128°F	135°F	145°F
30°F	136°F	145°F	156°F
25°F	144°F	154°F	167°F
20°F	152°F	163°F	178°F
15°F	160°F	172°F	189°F
10°F	168°F	181°F	200°F
5°F	176°F	190°F	--
0°F	184°F	200°F	--
-5°F	192°F	--	--
-10°F	200°F	--	--
C. 210°F Boiler Water			
Above 65°F	Circulating pump off. No water flowing.		
65°F	80°F	80°F	80°F
60°F	89°F	90°F	92°F
55°F	98°F	100°F	102°F
50°F	106°F	110°F	115°F
45°F	115°F	120°F	127°F
40°F	123°F	130°F	139°F
35°F	132°F	140°F	150°F
30°F	141°F	150°F	162°F
25°F	150°F	160°F	174°F
20°F	158°F	170°F	186°F
15°F	167°F	180°F	198°F
10°F	176°F	190°F	210°F
5°F	184°F	200°F	--

TEMPERATURE OF WATER LEAVING MIXING VALVE			
Outside Temperature	**Design Temperature -10°F**	**Design Temperature -0°F**	**Design Temperature +10°F**
0°F	193°F	210°F	--
-5°F	201ºF	--	--
-10°F	210°F	--	--

6.3.8 Maintenance of Air Handlers

Preventive maintenance is the route to energy management. Mixed air plenums should be kept clean. Dust, dirt, pollen, and mold spores tend to collect in the plenum where outside air and return air are mixed, resulting in an unhealthy situation. Dirty filters allow pull-through causing a dirt buildup on the blowers and the coils. This buildup can reduce efficiency by as much as 70 percent. A maintenance guide for supply/return fans and associated equipment is shown in, the current MMO Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Checklists.

6.4 AIR-CONDITIONING CONTROLS

6.4.1 Definitions

Three elements are necessary for a control system: a sensor, a controller, and a controlled device. The sensor measures the temperature in the environment and passes the information to the controller. The controller compares the environment temperature with the set point and sends a signal to open or close the heating/cold water valve as required to maintain the set point. The basic air-conditioning cycle control is a device that starts, stops, regulates, and/or protects the heating and cooling systems and their components. It does this by sensing and measuring changes in the heating or cooling medium (air or water). The impulse received from a sensing and measuring device meters the energy used in the control circuit. The metered energy actuates the control equipment that then initiates a change or prevents a further change in the heating or cooling medium. Abbreviations necessary to understand automatic controls are listed in Table 6-2.

Table 6-2. Abbreviations

Acronym	Definition
ACU	Air-Conditioning Unit
AHU	Air Handling Unit
C	Coil
C	Common

Acronym	Definition
Dpr.Act.	Damper Actuator
Dprs.	Dampers
DSPT	Differential Static Pressure Transmitter
EA	Exhaust Air

Acronym	Definition
CC	Cooling Coil
CD	Cold Deck
Ch.WR	Chilled Water Return
Ch.WS	Chilled Water Supply
Com.HW	Common Hot Water
CWS	Cold Water Supply
CWV	Cold Water Valve
DA	Direct Acting
DPC	Differential Pressure Controller
DPDT	Double-Pole Double-Throw
M	Main
MA	Mixed Air
NC	Normally Closed
NO	Normally Open
OA	Outside Air
PE	Pneumatic/Electric
R	Relay
R	Resistor
RA	Reverse Acting
RA	Return Air
RC	Receiver-Controller

Acronym	Definition
EP	Electric/Pneumatic
GLB	Globe
h	Enthalpy
HC	Heating Coil
HD	Hot Deck
HL	High Limit
HVU	Heating and Ventilating Unit
HWR	Hot Water Return
HWS	Hot Water Supply
HWV	Hot Water Valve
SP	Set Point
SPC	Static Pressure Controller
SPRC	Static Pressure Receiver-Controller
SPST	Single-Pole Single-Throw
St.V.	Steam Valve
Sw.	Switch
T	Thermostat
T	Transformer
T	Transmitter
TR	Throttling Range
TT	Temperature Transmitter

Acronym	Definition
RH	Relative Humidity
RR	Reversing Relay
S	Sensor

Acronym	Definition
UN	Union
UV	Unit Ventilator
VAV	Variable Air Volume

6.4.2 Types of Control Systems

A variety of control systems are used with chiller, boiler, and air handler installations. Control systems may be manual, electric, electronic, pneumatic (using compressed air), hydraulic, and self-generated energy. Another way of classifying automatic control systems is by defining their action as two-position, floating, or proportional. Two-position control provides full-on or full-off operation of the controlled device with no intermediate positions. Floating controls reposition the controlled device as required only when an extreme has been reached. This maintains room conditions near the control set point. They also permit the operator to stop at any position between full-on and full-off. With proportional control, the controlled unit assumes a position proportional to the change in room conditions. Proportional action is accomplished through feedback linking the controlled unit to the sensing unit. If automatically controlled, these units may include sensing devices, relays, motor-operated valves, or timing devices. Examples are thermostats, humidistats, aquastats, ductstats, water-control valves, and solenoids. The majority of USPS installations use electronic controls in conjunction with pneumatically operated valves or damper motors. The simplest automatic control system uses a sensing device and an operating device; a complex control system is a combination of the two. Using electronics, it became possible to reset and monitor control loops for the whole building from a central computer. A number of buildings could then be monitored from a remote location. This most comprehensive development of a building control system became known as a building management system.

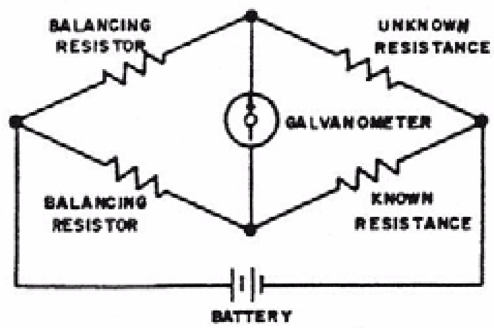
6.4.3 Electronic Controls

6.4.3.1 Description

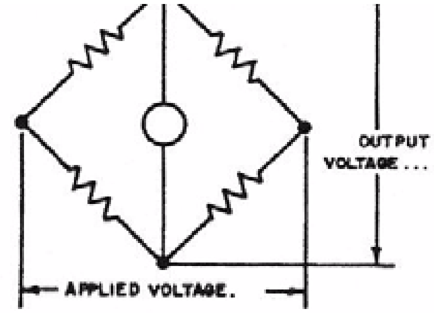
A control system has three basic elements: sensor, controller, and a control device. The sensor measures the control variable, which could be temperature, pressure, or humidity. Direct digital control electronic systems are being used to control dampers, valves, start-stop functions, sensing temperatures, flow, pressures, and other HVAC devices. Electronic control can be hard wired with low voltage or line voltage wiring, or they can be wireless using FM transmitters and receivers.

6.4.3.2 Wheatstone Bridge

The basic component in an electronic circuit, as applied to heating, ventilating, and air conditioning, is the Wheatstone bridge (Figure 6-16). This unit is a specific arrangement of electrical resistances connected in a network. The bridge is made of two resistive dividers R1-R4 and R2-R3 and a source potential, such as the battery, excites the circuit; and the galvanometer measures the output. The bridge is balanced when all four resistors have the same resistance. In a typical bridge configuration, the resistors are active and change in value as a result of the application of the measured physical phenomenon.



VIEW A. TYPICAL WHEATSTONE BRIDGE



VIEW B. ELECTRONIC CONTROL BRIDGE

Figure 6-16. Typical Wheatstone Bridge

6.4.3.3 Direct Digital Control

Modern technology has evolved into the direct digital control (DDC) system. These systems use a microprocessor as the controller and either electric actuators or transducers to pneumatic actuators to control the medium. Resistance temperature detectors/devices (RTD) have been developed to replace thermistors as the most accurate temperature sensors. Thin-film capacitors are the newest in technology for humidity sensors; they use Complementary Metal-Oxide Semiconductor (CMOS) "micro-machined" chip technology.

6.4.3.4 Digital Control Advantages

These systems, through the use of programmable interface panels, can be used for total control of large postal facilities. They offer energy management reports such as a record of peak power usage, load shedding, and scheduling and cycling of air handlers and lighting throughout the building. Use of these systems for energy conservation has proven effective.

6.4.3.5 Thermistors

Solid-state technology has changed the electronic control industry. Most electronic controls must receive a regulated direct current (DC) voltage from a power supply. The exact value of this regulated voltage will change from manufacturer to manufacturer. The normal temperature transmitter is a temperature-sensitive resistor known as a thermistor. Thermistors may increase or decrease resistance on a temperature increase. The amount of resistance increase or decrease varies and the manufacturer's literature should be consulted for exact figures.

6.4.3.6 Electronic Controls

Most solid-state electronic control systems use electric controllers for high limits or a sliding-scale high-limit enthalpy controller. Electric relays are installed between the limit controllers and the electronic single- or dual-input controllers. The electronic controllers can be used as either direct acting or reverse acting to match the application. Electronic relays used in these systems include: reversing, signal selecting, sequencing and paralleling. Complex applications may use several electronic relays. Actuators may be electric motors equipped with actuator drives, electro-hydraulic actuators, transducers, silicon control rectifiers (SCR) electric heat controllers, and single- or two-stage relays. The devices can control electric heat, direct-expansion refrigeration systems, rooftop air handling units, and all other types of air handlers used in postal facilities. Figure 6-17 illustrates a complex application.

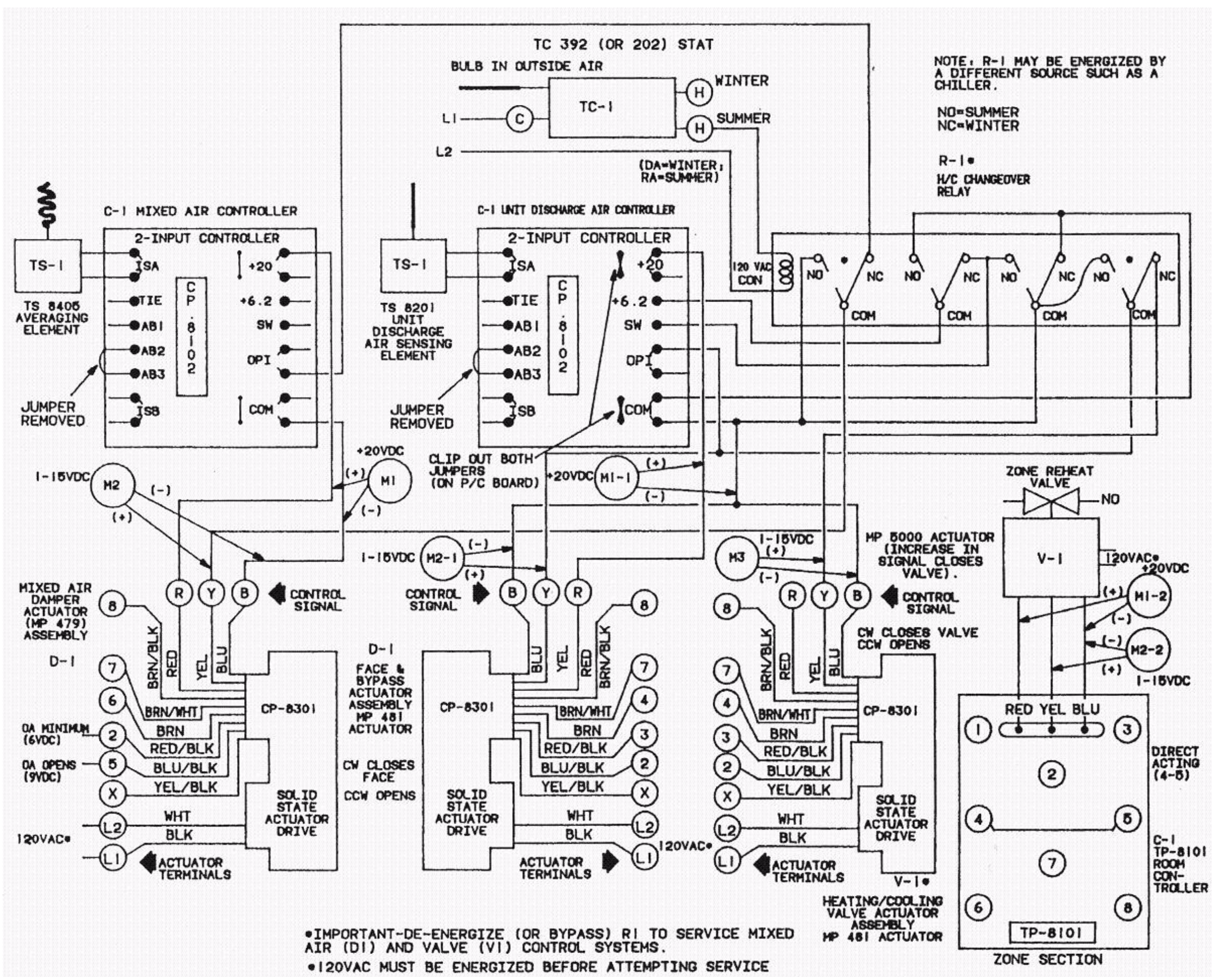


Figure 6-17. Heating/Cooling Face and Bypass Multi-Zonewith Hot Water Zone Reheat Service Wiring Diagram

6.4.3.7 Electronic-Pneumatic

6.4.3.7.1 Description

Electronic controllers are designed for fast, accurate sensing. Pneumatic actuators, used in conjunction with positioning relays, offer the fastest movement of dampers or valves. A combination of the electronic control and pneumatic movement is used in several postal facilities. The system is a complex application that offers the best of both systems. Transducers are used to convert the electronic signal to a usable pneumatic signal. Generally, application and operation of electronic-pneumatic-control systems are described in terms of temperature control. Humidity and other variables are controlled by a similar electronic system in the same way.

6.4.3.7.2 Wheatstone Bridge

In Figure 6-18, T1 represents a room or zone thermostat. The sensing element of the thermostat is a coil of wire acting as resistance in the bridge circuit. If all the resistances in the bridge had the same value, there would be a null current flow through the galvanometer (G), when the switch (S) was closed. If the resistor in T1 experiences a lower temperature, AD will have a lower resistance than AC. This will make point D positive with respect to point C and current will flow from C to D through the galvanometer (G). If the resistor in T1 experiences a higher temperature, AD will have a higher resistance than AC. This will make point C positive with respect to D, and current will flow in the opposite direction, from D to C.

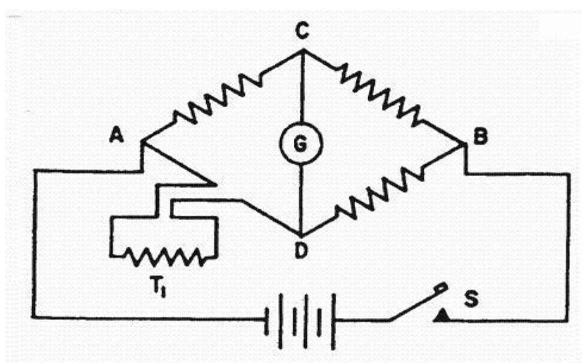


Figure 6-18. Basic Wheatstone Bridge

6.4.3.7.3 Two-Bridge Network

Two bridges are used to establish the relationship between T1 (room or zone thermostat) and T2 (duct discharge or submaster thermostat), (Figure 6-19). One bridge is referred to as the main bridge and the other as the auxiliary bridge (Figure 6-20). The resistance wire in the T1 thermostat forms one leg of the main bridge. Any change in the room or zone temperature causes an imbalance in the main bridge circuit. This imbalance produces a signal of a few millivolts that is impressed across the terminals of the amplifier. The resistance wire in the discharge duct or submaster thermostat is in an averaging tube that senses temperature variation across the discharge duct. The sensing element forms one leg of the auxiliary bridge. This bridge is connected in parallel with the main bridge and the two, in turn, are connected by a ratio adjustment potentiometer. The potentiometer in the circuit determines the number of degrees change T2 must make for each degree change in T1. It is connected with the amplifier to balance out the phase and strength of the incoming signal. The potentiometer makes the damper motor capable of proportional operation. The adjustment is determined by design and operating conditions; upon installation, any required adjustment is made by the control company. When the temperature of the discharge air is such that space conditions are satisfied, the voltage between the two bridges becomes balanced. With no signal across the amplifier terminals, a null point is reached.

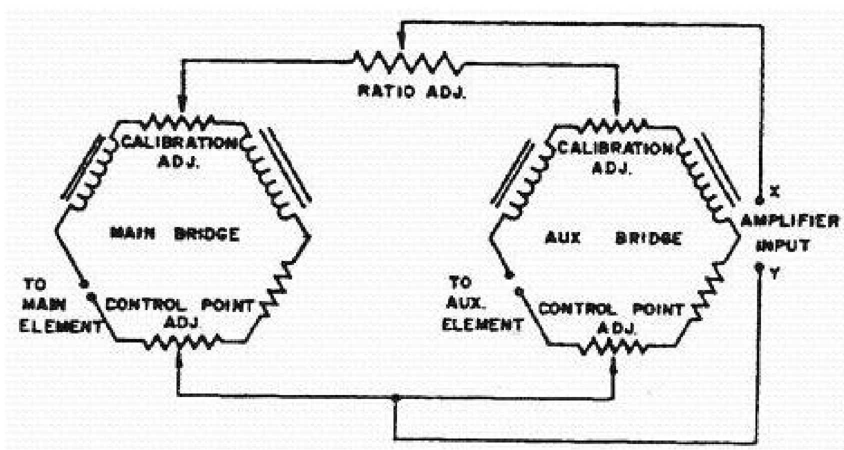


Figure 6-19. Two-Bridge Network

6.4.3.7.4 Single-Zone Heating-Cycle Control

Single-zone heating-cycle operation is as follows:

1. The chilled-water pump is off. No water is flowing through the chilled-water coil. The hot-water pump is running heated water from the boiler through the hot-water coil (Figure 6-14).

2. As the temperature in the room represented by T1 decreases, there is a decrease in resistance in T1. A negative phase signal is impressed across an amplifier, and T2 calls for sufficient heat to satisfy space requirements and rebalance the bridge system. The dampers react as follows:

a. Decreasing voltage on the control-system solenoid coil opens the restrictor on the air bypass that, in turn, lowers the pressure on the piston and starts the face damper opening and bypasses damper closing.

b. Controlled by a reversible shaded-pole motor, the return damper D3 moves toward the open position.

3. As the temperature in the room represented by T1 increases, there is an increase in resistance in T1. A positive phase signal is impressed across the amplifier. T2 calls for sufficient cooling to satisfy space requirements and rebalance the bridge system. The dampers react as follows:

   a. Increasing voltage on the solenoid coil in D1 closes the restrictor on the air bypass that, in turn, raises the pressure on the piston and starts the face damper moving toward the closed position. As continued cooling is needed the face damper moves to a completely closed position and the bypass damper to a fully open position.

   b. Should more cooling be needed, the outside fresh-air damper motor starts the damper moving toward the open position as soon as the face damper is fully closed. The motor is a reversible, shaded-pole type, with the shaft spring loaded to close the damper in case of power failure. This prevents freezing of the coil.

   c. In an overheated situation, the D3 return damper moves toward its minimum open position. The return damper remains in this minimum position as long as the fresh-air intake damper is open.

6.4.3.7.5 Cooling-Cycle Control

Cooling-cycle operation is as follows:

1. The hot-water pump is normally off. No water is flowing through the hot-water coil. The chilled-water pump is running chilled water from the refrigeration plant through the chilled-water coil. As the temperature in the room represented by T1 increases, there is an increase in resistance in T1. A positive phase signal is impressed across the amplifier. T2 calls for sufficient cooling to satisfy space requirements and rebalance the bridge system. The dampers react as follows:

   a. Increasing voltage on the solenoid opens the restrictor on the coil bypass that, in turn, lowers the pressure on the piston and starts the face damper (D1), moving toward the open position and the bypass damper to the closed position. In the single-zone unit, the reversing relay reverses connections to the motor's starting windings and has the same sequence of operation on the face and bypass dampers D1 in both heating and cooling seasons. This is only true for the single-zone unit.

   b. When operating under the mechanical cooling cycle, damper D2 is controlled by the outside limit thermostat, T3. Since the setting of T3 is normally 78°F, damper D2 will be in the minimum position (or closed position when separate minimum-position damper is provided) when the outside temperature exceeds 78ºF.

   c. Since D3 operates inversely in relation to D2, D3 will be in its normal, open position.

2. As the temperature in the room represented by T1 drops, there is a decrease in resistance in T1. A negative phase signal is impressed across the amplifier. T2 calls for sufficient heat to satisfy space requirements and rebalance the bridge system. The dampers react as follows:

   a. Decreasing voltage on the solenoid coil for D1 starts closing the restrictor on the air bypass that, in turn, raises the pressure on the piston and starts the face damper (D1) moving toward the closed position. As continued heating is needed, (D1) moves the face damper to a completely closed position with the bypass damper fully open.

   b. D2 (fresh-air intake damper) remains in minimum or closed position.

   c. D3 (return damper) remains in open position.

6.4.3.7.6 Outside Cooling Cycle (Economy Cycle)

This cycle is used when the building can be cooled with outside air instead of using the mechanical cooling plant. This is particularly true during the late fall, early spring, and certain days and nights during the summer. Under this cycle, there will be no hot water flowing through the heating coil or chilled water flowing through the cooling coil. In the interest of economy, this cycle should be used whenever possible.

Damper control is accomplished through the T1-T2 relationship referred to in Paragraph 6.4.3.7.3. With the refrigeration plant shut off, the fresh-air damper (D2) is under control of the T2 submaster thermostat in the discharge duct. Since the outside dry-bulb temperature will be less than 78°F, the outside fresh-air intake damper may open when T1, the room thermostat, calls for cooling. The action of the face and bypass dampers (D1), the fresh-air intake damper (D2), and the return damper (D3) is the same as that described in Paragraph 6.4.3.7.5.

6.4.3.7.7 Multi-Zone Cycle Control

With the exception of the face and bypass dampers (D1) the control sequence for the multi-zone unit is the same as that for the single-zone described in Paragraph 6.4.3.7.4. In the multi-zone unit, there is no reversing relay as described in Paragraph 6.4.3.7.5. Dampers (D1) perform the same for both the heating and mechanical cooling cycles (Figure 6-20).

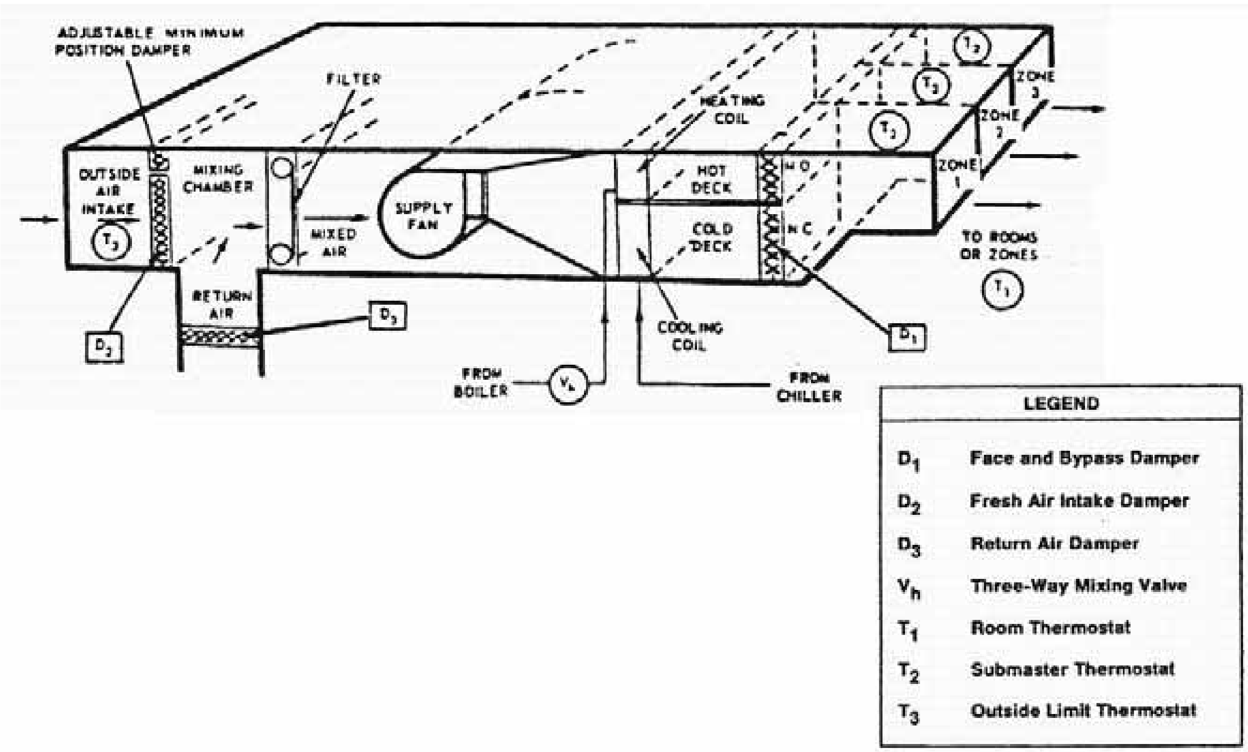


Figure 6-20. Two Bridge Network

6.4.4 Electric Controls

6.4.4.1 General

Electrical energy is sometimes used to transmit the controller's measurement of a change in a controlled condition to other parts of the system and to translate that measurement into the mechanical movement necessary to adjust the travel of the control element. The relatively weak impulse received from the sensing element is readily amplified to produce a usable voltage.

The amplified electrical power may then do the mechanical work of opening or closing valves or dampers and starting and stopping machinery. Electric systems are commonly used in small buildings such as satellite facilities. Modern control techniques have produced the programmable controller. Manufacturers of such controllers have designed these devices to include features such as night setback, night setup, weekend setback, and weekend setup. These features can be used to conserve energy.

6.4.4.2 Operating Principles

In automatic electric control, two voltages are used. The term low voltage applies to wiring and electrical devices using 25 volts or less. In most low-voltage applications, the device is normally a control unit or actuator using relatively little power. It may be a relay, a solenoid or motorized-type valve, or a damper motor. The other voltage is line voltage, generally either 115 or 230 volts. A line-voltage controller directly operates a major piece of equipment such as a fan motor, a line-voltage valve, or a control motor. It is also connected to the primary side of a step-down transformer to provide power for a low-voltage circuit. Besides starting and stopping current flow, electric control circuits require that the magnitude of the current be regulated. This function is carried out by means of a variable resistor called a potentiometer.

6.4.4.3 Relays

To do mechanical work, an electric-control system must include some means of transforming electrical energy into mechanical energy. For actual control work, the usual method is through a magnetic coil or solenoid. The solenoid is used for operating a valve or a coil-and-armature mechanism with contacts (relay) to control airflow.

6.4.4.4 Electric Control Circuits

6.4.4.4.1 Classifications

Like electronic circuits, electric control circuits are classified as two-position (full-on or full-off), floating, or proportional. Two-position circuits are further classified into two- and three-wire circuits, using line and low voltage. Figure 6-21 shows line-voltage and low-voltage, two-wire circuits. In each case, the contacts are essentially a switch that turns the electric power on or off to operate some device. In low-voltage applications, the operated device may be a relay, a solenoid, a motorized valve, or a damper motor. The contacts in these circuits return to their normal de-energized position without electrical assistance. Some use spring action to return to their normal position, while others use the weight of the coil core. Three-wire, two-position, control units consist of either single-pole, double-throw (Figure 6-22), or sequence single-throw contacts (Figure 6-23). The three-wire, two-position control has a common contact and a high and low contact. These terms, in the case of a heating-control thermostat, refer to the temperatures at which the contacts close. The sequence single-throw unit also has a common contact on a flexible blade that bends with temperature change and allows the high contact to be made first. Additional movement engages the low contact.

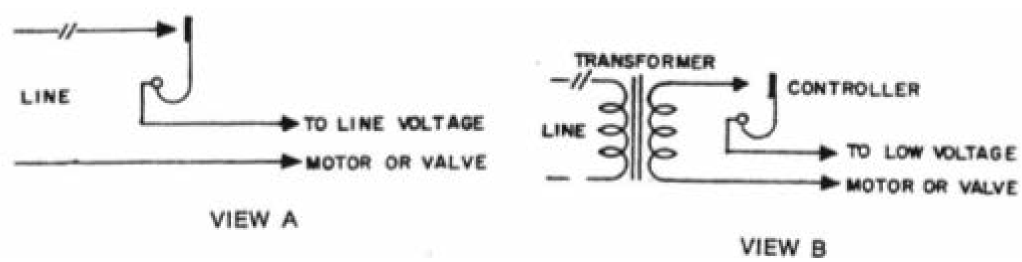


Figure 6-21
Two-Wire Control Circuits

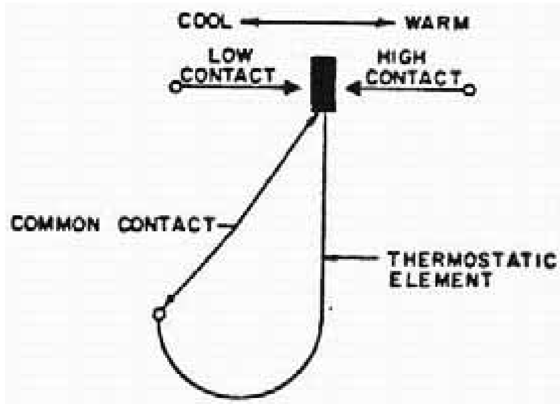


Figure 6-22. Double-Throw Three-Wire Controller

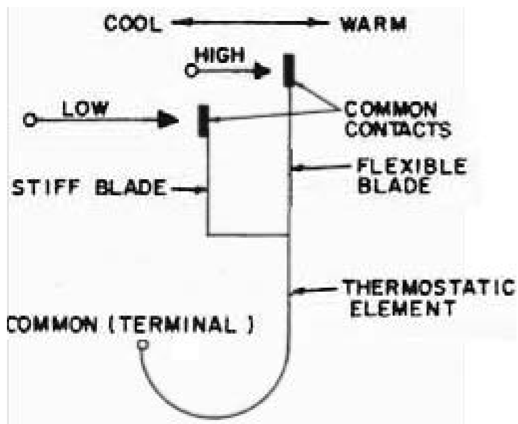


Figure 6-23. Single-Throw Three-Wire Controller, Sequence Contacts

The contacts close in sequence as the controlled condition reaches two predetermined points. The first contact closes the starting circuit and the second contact closes a holding circuit to prevent chattering action of the control. The contacts disengage in reverse sequence when environmental conditions are satisfied.

6.4.4.4.2 Floating Control

The floating-control circuit has no fixed number of positions, but allows the controlled element to assume any position from one extreme of motion to the other. This is possible as long as the room temperature or other controlled variable condition stays within the limits of the controller. Figure 6-24 shows a typical floating circuit using a low-voltage supply and a double-throw, three-wire controller. Line voltage can also be supplied to a floating control. When the common contact engages the high contact, power is supplied to motor field coil W1 and to coil W2 through capacitor M. The motor then rotates in the proper direction to make the necessary corrections. When conditions change in the opposite direction, the common contact engages the low contact. The connections to W1 and W2 are reversed, and the motor rotates in the opposite direction until the circuit is broken again. When the common contact does not contact either the low or high contact, conditions are satisfied and the motor remains stationary. Proportional-control circuits are so designated because they provide variable control (temperature, humidity, or pressure) proportional to changes in demand. They operate to position the controlled device at any point between fully open and fully closed, and then proportion the delivery to the need as dictated by the controlled device. Proportional-control circuits may be applied to motorized valves, motorized dampers, and sequence-switching mechanisms.

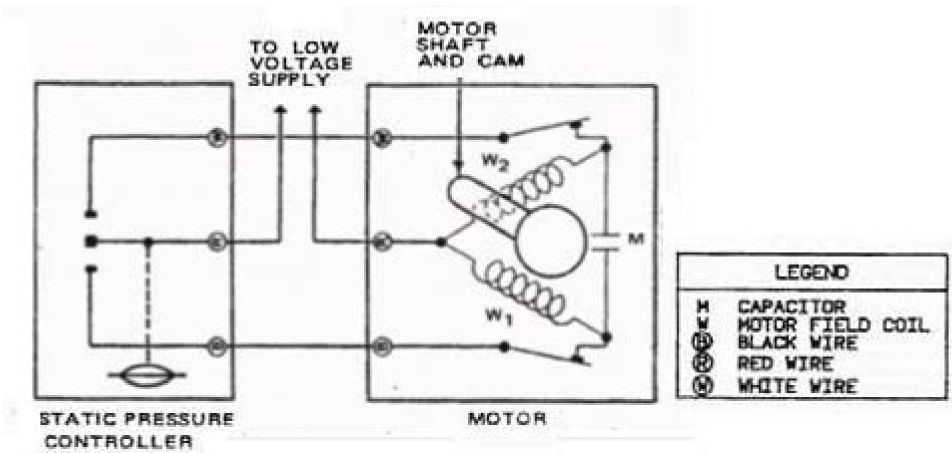


Figure 6-24. Floating-Control Circuit

6.4.4.4.3 Controller Components

Controllers for proportioning circuits have a variable potentiometer on which the contact finger is actuated by a mechanism sensitive to temperature, pressure, or humidity. Other components making up the control are a reversible-power unit, a balancing relay, and a balancing potentiometer (Figure 6-25). The power unit is a reversible, capacitor-type motor connected to either line- or low-voltage circuits. The motor drives the output shaft through a gear train. Limit switches are operated by the shaft to limit its rotation to 90 or 160 degrees. The power unit is started, stopped, and reversed by the single-pole, double-throw contacts of a balancing relay (Figure 6-26). The balancing relay consists of an armature pivoted on one end and swinging between two electromagnetic coils. As the magnetism of the two coils changes due to changes in current flow, the armature moves toward the stronger coil. The swinging armature usually has a two-contact arm set to contact two stationary contacts to complete the circuits involved at certain armature positions.

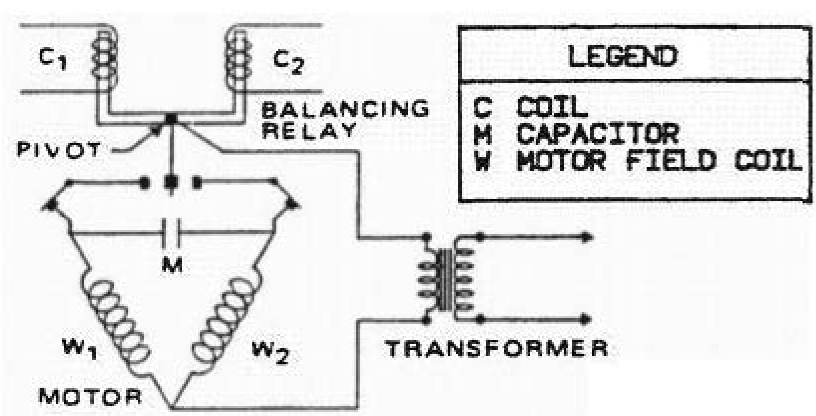


Figure 6-25. Diagram of Balancing Relay and Motor Circuit

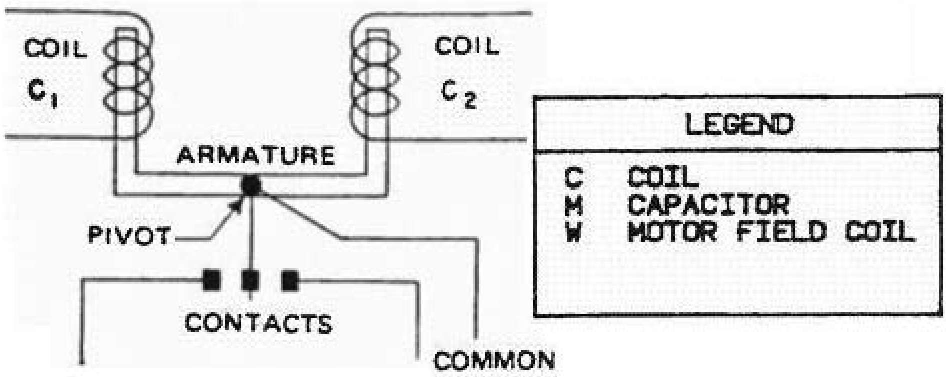


Figure 6-26. Diagram of Balancing Relay

This relay, usually mounted in the motor, is a low-voltage installation. The function of the balancing relay is illustrated in Figure 6-27. A balancing potentiometer is also built into the motor housing. This potentiometer is identical to the controller potentiometer, except that the contact finger is operated from the motor shaft.

6.4.4.4.4 Current Flow

Figure 6-27 shows a typical circuit. When the current reaches the potentiometer winding of the controller, the current is evenly divided with half of it flowing down the right leg and the other half down the left leg. The current flows through the controller potentiometer, the balancing relay coil, the balancing potentiometer coil, and then back to the transformer. The resistances of coils C1 and C2 are identical; therefore, the amount of current flowing in the two legs depends upon the total potentiometer resistance in each leg at any given time. Figure 6-27 shows a static and balanced condition of the system.

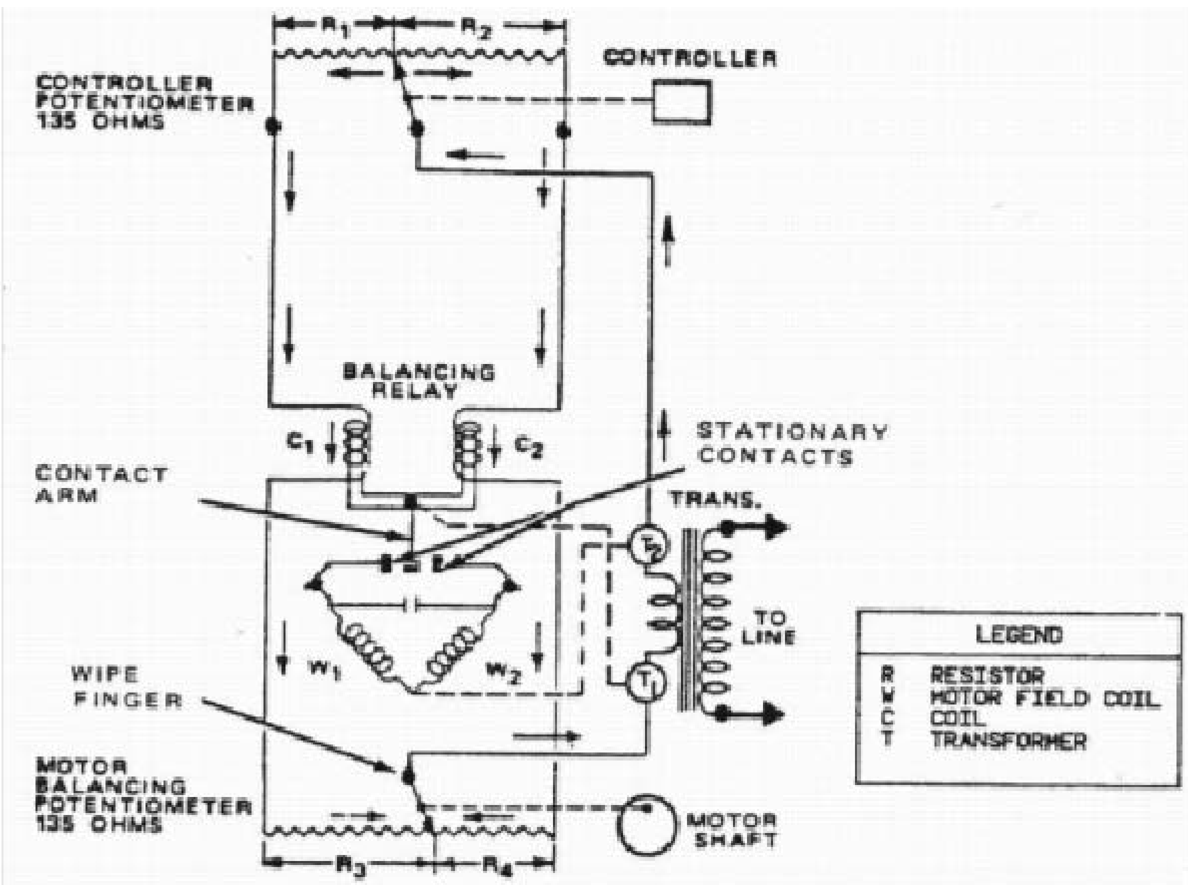


Figure 6-27. Typical Balancing Relay Circuit with Proportional Motor

NOTE

The above descriptions of electric control circuits are used in a general way. There are variations to these descriptions, but the fundamentals are the same.

6.4.5 Pneumatic Controls

NOTE

The pressures used in the examples in this section are examples only. Different manufacturers use various pressures in their controls. That information should be checked prior to adjusting the controls.

6.4.5.1 Basics

Pneumatic controls are commonly used for controlling heating and air-conditioning equipment in Postal Service applications. They use compressed air to supply energy for the operation of valves, relays, operators, and other pneumatic-control equipment. Generally, these systems detect a change in environmental conditions (temperature, relative humidity, or pressure) and act to position a controlled device to maintain the environmental conditions at the desired level. The air used to power these controls is supplied by an electrically driven air compressor. Air is supplied to the control system at 20-25 psig. Certain control systems employ dual-element (day/night or summer/winter) thermostats, and the air supply to those devices is switched from 13-15 psig to 20-25 psig depending on the operation desired. Air lines that lead from the air supply to the controlling devices are labeled as main or supply air. Air lines that lead from the controlling device to the controlled device are designated branch or output.

6.4.5.2 Typical Pneumatic Control System Components

6.4.5.2.1 Pneumatic-Control System

Figure 6-28 shows a typical pneumatic-control system. The air compressor should produce control quality air and be dedicated only to the pneumatic-control system. It must supply air that is clean, dry, and free of oil. The compressor must be maintained according to manufacturer's recommendations. Particular attention must be paid to cleaning the air intake filters and keeping the receiver tank free of excess moisture. Cross-connection with the plant or process air system or the use of a screw-type compressor is not recommended due to the possibility of oil contamination. Air receivers are classed as pressure vessels and must be inspected and maintained in accordance with current postal regulations. Standard filters in the air lines remove particulate matter, coalescing filters remove aerosol oil particles, and refrigerated air dryers remove moisture by cooling the supply air below its dew point and draining off the resulting condensate. Most control manufacturers recommend that the supply air contain less than 1 part per million of oil. Excessive oil can block the internal passages and orifices of the pneumatic controls and rot away their rubber parts. Control compressors should run approximately one-third to one-half of the time to allow adequate cooling time between operating cycles. Excessive compressor running time may be caused by numerous leaks in the control system, an undersized compressor, or a worn or defective machine. The air receiver is usually operated at 80 to 120 psig and a reducing valve lowers the pressure to 20 to 25 psig to supply the controls.

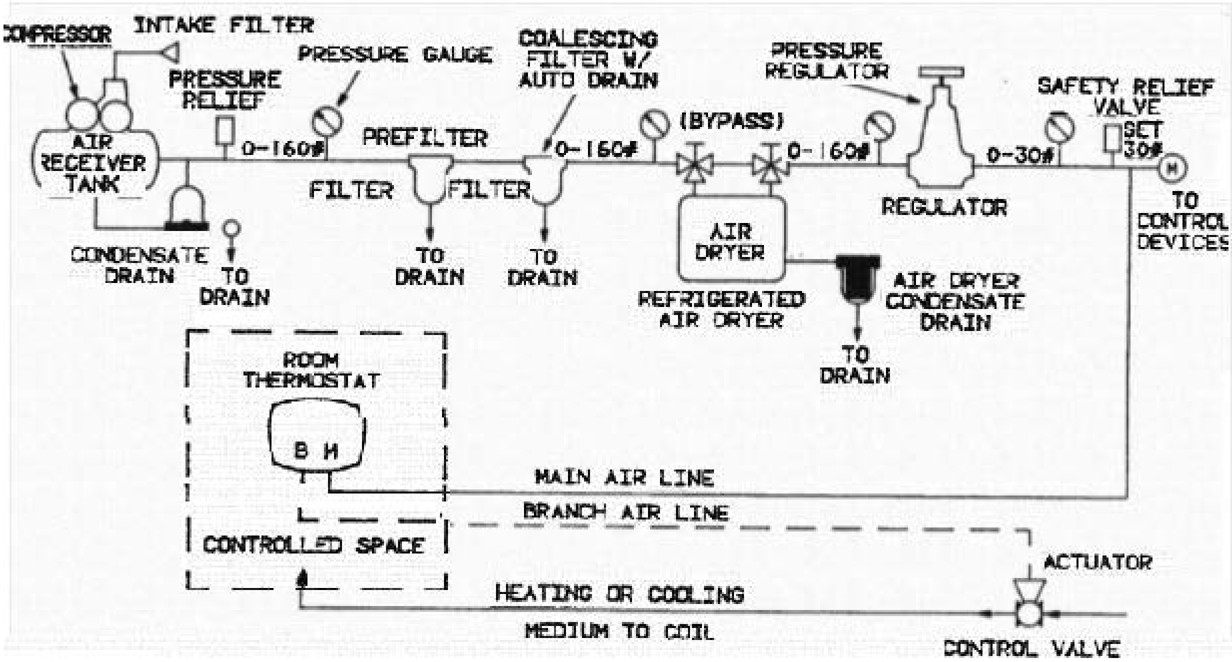


Figure 6-28. Typical Pneumatic System

6.4.5.2.2 The Controlling Device

The controlling device may be classified as a thermostat or a receiver-controller. The thermostat has some type of temperature-sensing element, generally a bimetal or refrigerant-filled bulb, attached to the device while a receiver-controller utilizes a remote sensing element that transmits a pressure proportional to the quantity being sensed. Both the thermostat and the receiver-controller meter out air pressure to the controlled device in response to a change in the measured condition. If the change in branch or output pressure is gradual, the device may be said to operate proportionally. If the branch line changes rapidly from zero to maximum with no intermediate operation, a two-position or positive operation is provided. Pneumatic-control systems utilize proportional control in all but a few applications.

6.4.5.3 Thermostats

6.4.5.3.1 Single-Element Room Thermostat

Figure 6-29 shows a typical, single-element, room thermostat. The room thermostat may be used to position a water valve supplying a fan coil unit, a heating zone valve, a zone or discharge air damper, or face and bypass dampers. All modern room thermostats utilize a bimetal-sensing element and most are high-volume relay type. Relay-type thermostats are accurate, fast-acting devices and will give years of satisfactory service, if properly maintained. Regardless of manufacturer, all pneumatic-room thermostats have several test and adjustment points. The SET POINT dial is used to adjust the thermostat, to maintain a desired temperature. The OUTPUT ADJUSTMENT is used to set the output pressure of the thermostat and the SENSITIVITY or THROTTLING RANGE adjustment is used to select the number of degrees above and below the set point through which the controlled device will operate.

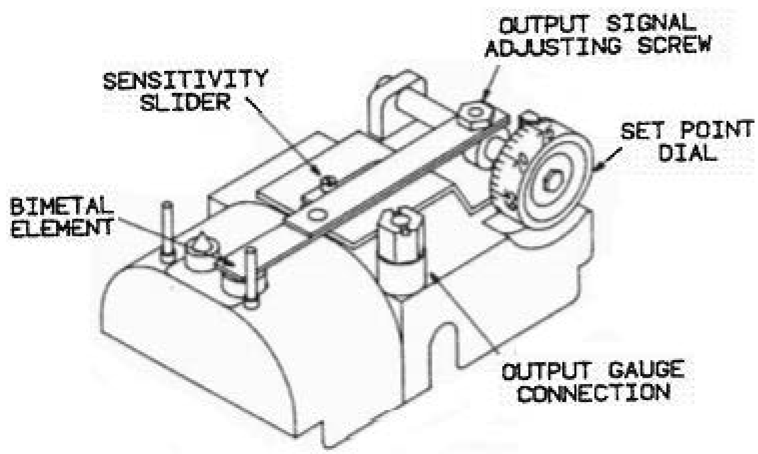


Figure 6-29. Single-Element Room Thermostat

6.4.5.3.2 Temperature Range

Most control manufacturers suggest that a room thermostat should operate the controlled device over a fairly narrow range of temperature. If the thermostat is set to move its valve or actuator over a small change of temperature (for example, one degree), the controlled device will cycle rapidly between open and closed, and this will greatly lessen the life span of the controlled device. If the throttling range is set to operate over a very wide range of temperature, the system will not be able to respond fast enough to changes in load. Experience has shown that throttling ranges of three to four degrees are satisfactory in room temperature control applications. If a room thermostat is controlling a fan coil valve that operates over an 8-13 psig pressure range and the desired throttling range is four degrees with a 65ºF winter set point, the valve should be fully open (8 psig) at 63ºF and fully closed at 67ºF (13 psig). The throttling range or sensitivity adjustment should be set to produce the required five pound change in pressure over the four degree change of temperature.

6.4.5.3.3 Room Temperature

If the room temperature is found to be outside of the desired throttling range and if conditions warrant (for example, room temperature above 65ºF with heat still being added during winter operations), it may be necessary to calibrate the thermostat. While manufacturer's literature and operating instructions should be consulted for specific information, the general steps of calibration may be outlined as follows:

1. Take the ambient temperature in the space using an accurate dial, bulb, or electronic thermometer. Thermometers provided in the thermostat covers are not accurate enough for this purpose.
2. Adjust set point dial to the ambient temperature.
3. Adjust output pressure of the thermostat to the middle of the controlled device's operating range (midspring).
4. Adjust set point dial to desired temperature.

6.4.5.3.4 Output Pressure

Single-element thermostats may be either direct or reverse-acting. Direct-acting thermostats (commonly abbreviated D. A. or DIR) increase their output pressure as the temperature being sensed increases. Reverse-acting (R. A. or REV) devices decrease the output pressure as the temperature increases.

6.4.5.3.5 Dual-Element Thermostats

Summer/winter thermostats utilize a direct-acting and reverse-acting element and are used to control face and bypass air handlers or single pipe, fan-coil units that utilize the same normally open valve for heating and cooling. Since face and bypass dampers are normally open to the face of the coils, winter operation requires the thermostat to close the face dampers and shut off the heat on a temperature rise in the space (direct action). The same thermostat must be reverse-acting in the summer to open the face dampers and admit cool air to the space on a temperature rise. The thermostat is internally switched from a direct- to reverse-acting, temperature-sensing element by switching the supply pressure of the thermostat from (typically) 13-15 psig for direct action to 20-25 psig for reverse action. Other features of dual-element thermostats are as follows:

- Day/night thermostats also utilize two sensing elements. These thermostats are used for automatic lowering of heating set points during unoccupied hours. The day element is set for the "occupied" set point of 65ºF degrees. The night element has a set point that is usually ten degrees below the day set point and maintains the space at a minimal level of heating during unoccupied hours. Day/night thermostat set points are switched by changing the supply pressure of the thermostat.
- Supply lines to dual-element thermostats must be separated from the rest of the control system supply mains. Other pneumatic-control devices such as receiver-controllers, temperature transmitters, and relays must operate on a constant 20-25 psig supply. They become inaccurate or inoperative if the supply pressure drops to 15 psig.

6.4.5.3.6 Dead-Band Thermostats

Air handlers using the sequenced valves and dampers method of operation can be controlled by dead-band thermostats. These thermostats are designed to operate all year without seasonal changes of set point as they control the building's heating system when the space temperature is below 65°F and operate the cooling apparatus when the space temperature exceeds 78°F. Between 65°F and 78ºF a dead- or free- energy band exists where the building is operating without the use of any heating or cooling energy. Some dead-band thermostats have an adjustable, free energy band while others are fixed at 13°F (Figure 6-30).

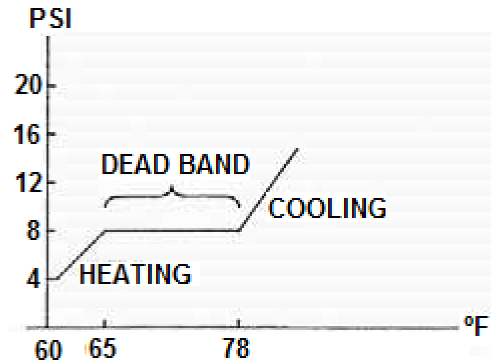


Figure 6-30. Dead-Band Thermostat Output Pressure vs Temperature

6.4.5.3.7 Remote-Element and Insertion Thermostats

Older or less complex systems often utilize remote-element or insertion thermostats (Figure 6-31). These thermostats are mounted at or near the location where temperature is sensed and detect temperature changes through the use of a refrigerant-filled bulb and capillary tube or a rod-and-tube-type, insertion element. These devices are reliable and easy to calibrate, but lack temperature indication and remote set point capability. Typical applications would include high limits (economizers) or steam valve control on steam to hot water converters.

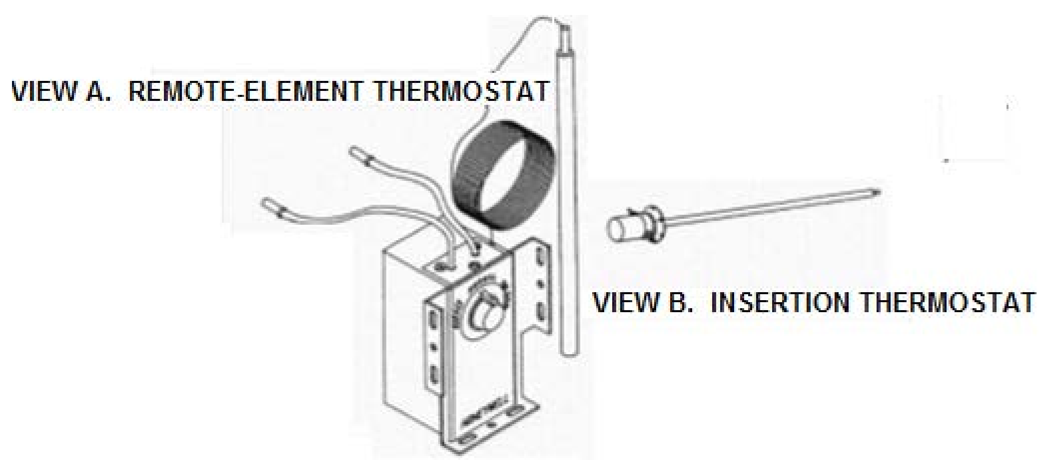


Figure 6-31. Thermostats

6.4.5.4 Receiver-Controllers

6.4.5.4.1 Modern Pneumatic-Control

Systems use various combinations of remote, temperature-sensing elements and receiver-controllers to operate valves and dampers in the control system. The controller/transmitter system allows for remote temperature indication through the use of analog gauges, central location of all controls in a cabinet or on a panel, and for the use of remote set point adjustment from a building monitoring computer (Figure 6-32).

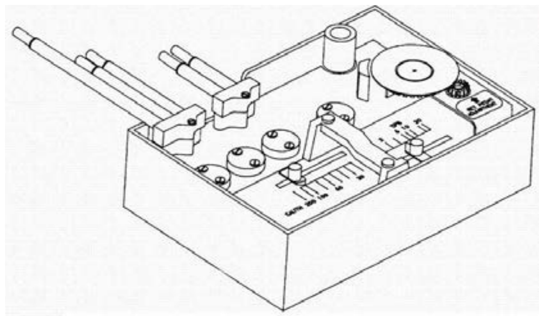


Figure 6-32. Receiver-Controller

6.4.5.4.2 Temperature Transmitters

Temperature transmitters or remote sensing elements (Figure 6-33) are used for temperature detection in receiver-controller systems. These remote sensors operate over fixed temperature spans, which are marked on the device, and over a 3 to 15 psig pressure span regardless of manufacturer. Remote sensors may be easily checked for accuracy by comparing a known temperature to the output pressure of the transmitter. These devices are constant-bleed-type instruments and require air supplied through an orifice or restriction of a definite size. The restrictor may be located inside the receiver-controller or it may be mounted in the air line connecting the transmitter and controller.

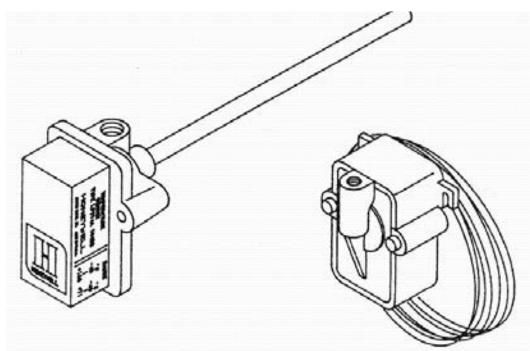


Figure 6-33. Temperature Transmitters

6.4.5.4.3 Analog Gauges

Analog gauges are often found in the sensor lines. These gauges provide direct temperature indication by converting the 3 to 15 psig sensor pressure to the proper temperature. If these gauges are used, the gauge scale must match the range of the temperature transmitter being used. For example, a 0 to 100°F range analog gauge must be used with a 0 to 100°F temperature transmitter.

6.4.5.4.4 Single-Input Receiver-controllers

Single-input receiver-controllers utilize one remote temperature transmitter and operate the controlled device to maintain a particular desired temperature. The single-input controller has two adjustments: sensitivity and set point. Sensitivity can be expressed as gain, percent proportional band, or percent throttling range. The percent throttling range expresses the desired throttling range of the controller as a percent of the sensor span. Set point is used to select the desired operating temperature of the system. Control manufacturer's literature should be consulted for specific instructions on calibrating the set point and throttling range of a single-input controller.

6.4.5.4.5 Master/Sub-master Controllers

Dual-input or master/sub-master controllers use two temperature inputs. They are found in systems where it is necessary to vary the set point of one temperature in response to a change in another temperature. For example, a building hot water radiation system may be controlled by a dual-input controller. As the outside air temperature drops, hotter water should be supplied to the radiation system to compensate for increased heat losses through the building envelope. Master/sub-master systems are also used to control the temperature of the air supplied to a space in response to changes in outside air temperature or the room temperature itself.

6.4.5.4.6 Operating Schedule

A predetermined range of temperature operations, known as an operating schedule, must be decided upon and set into the controller. Schedules may be found on building control prints or may be developed by the building operators. Schedules shall be developed in accordance with USPS energy conservation guidelines and should be checked at least annually and whenever Postal Operations at the facility change to maximize energy conservation.

6.4.5.4.7 Percent Authority

The relationship between the master (outside air) and control or sub-master (hot water) temperature is expressed as ratio or percent authority. The desired operating schedule causes sensor line pressure changes that must be considered when calculating ratio or percent authority; manufacturer's literature should be consulted for the proper method of calculation. Dual-input controllers also have a throttling range setting that refers to the change in the controller's output in response to a change at the control sensor, and a set point adjustment. To find the desired set point of a master/sub-master controller, the master temperature is first checked and the control set point is found by the use of a set point graph. See Figure 6-34 for a typical schedule and set point graph.

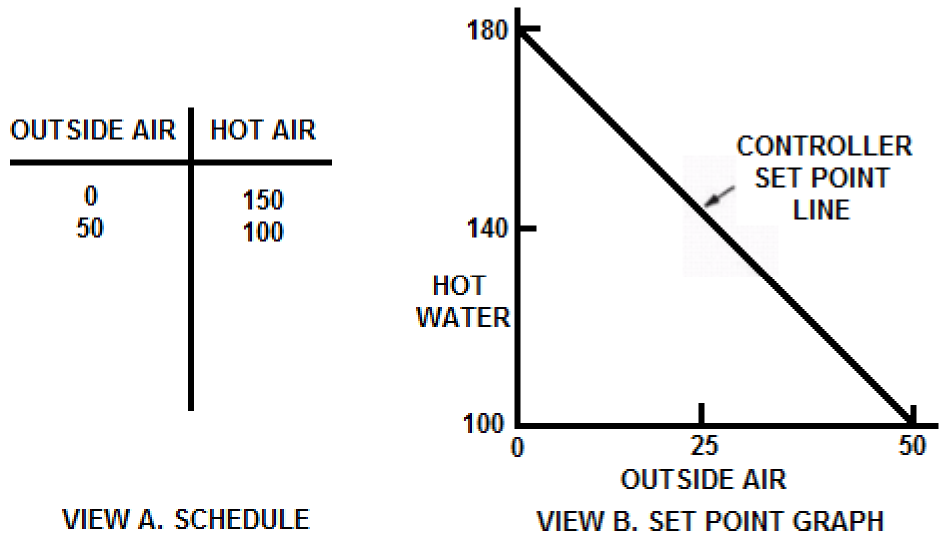


Figure 6-34. Typical Schedule and Controller Set Point Graph

6.4.5.4.8 Remote Set Point Adjustment

Certain systems, particularly those originally fitted with a building monitoring computer, have a capability for remote set point adjustment. These systems use an extra port on the single-or dual-input receiver-controller and a pressure change to that port shifts the set point of the controller over a predetermined range. Remote set point adjustment may be made through the use of an electro pneumatic transducer or a gradual switch.

6.4.5.5 Relays and Auxiliary Devices

6.4.5.5.1 Typical Relay Types

Relays and auxiliary devices generally may be considered to be any device that changes the output signal of a controller. Some typical relay types and applications are listed below:

- Reversing relay. Used to reverse the output signal of a controller. Often found in face and bypass damper systems to convert the direct-acting (winter), output signal of a controller to a reverse-acting signal for summer operation.
- Minimum position relay. Maintains a minimum air pressure to outside air dampers. This allows outside dampers to remain open to meet ventilation requirements while the air handler is running.
- High or low-pressure selecting relay. Often found in multi-zone systems. This relay allows the warmest zone to operate the cooling valves and dampers and the coldest zone to operate the heating devices.
- Electric/pneumatic (E-P) relay. Serves as an interface between the electric and pneumatic portions of the control system. Often used as a switch or as a bleed-off device for fail-safe operation or system interlock.

6.4.5.5.2 Volume-booster relays

Volume-booster relays are used to compensate for pressure losses or time delays in long runs of control tubing. These relays are also used to amplify the output of low-volume, nonrelay-type controllers.

6.4.6 Control Maintenance

6.4.6.1 Scheduling

Inadequate or improperly used HVAC control systems, as well as poorly balanced systems adversely affect efficiency and energy usage. Studies of pneumatic and electronic HVAC controls by the Construction Engineering Research Laboratory (CERL) and the National Bureau of Standards (NBS) showed that controls must be tested and calibrated on a regular schedule. The CERL study reported that controls may drift out of calibration significantly over very short periods of time. The NBS reported that a 1°F error in the mixed-air controller of an air handler may increase energy usage as much as 11 percent above normal. Calibration errors, in addition to increasing energy usage, may cause damage by short cycling the equipment or by not responding to damaging conditions. As a general rule, pneumatic controls will require more frequent calibration than electronic controls. Controls that are exposed to adverse environmental conditions, e.g., heat, cold, vibration, and dust, will require more frequent service than controls not subjected to these conditions.

NOTE

> All maintenance managers should review their HVAC control maintenance to ensure that it is adequate.

6.4.6.2 Calibration Tests

Controls that are maintained in-house should be tested for proper calibration on an annual basis as required by MMO Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Checklists.

Where HVAC controls are not maintained in-house, control maintenance should be contracted out to qualified professional service companies. For specifications for this service, see SECTION 7.

6.4.6.3 Inspection

Look for missing parts, damaged sensors, loose wires, or air leaks when inspecting controls. Additionally, damper actuators and associated hardware should be checked for bent or loose connecting rods. To prevent dirt contamination, covers should be removed only when servicing the control. Sensor elements should be cleaned periodically so that the dirt and oils do not form an insulating layer.

6.4.6.4 Cleaning

Pneumatic control air compressors require periodic bleeding of the accumulated water and cleaning of the filter to ensure proper operation. A coalescing-type filter should be installed between the compressor and the pneumatic system to remove oil from the air. Refrigerated air dryers or desiccant-drying systems may be used if water in the lines is a problem. Polycarbonate bowls on filters should have the pressure released prior to maintenance being performed. These have been known to fracture after having been exposed to certain solvents.

6.4.7 Applications

6.4.7.1 Single-Zone

6.4.7.1.1 Single-Zone System

This system (Figure 6-35) provides simple control of space temperature. The temperature is controlled by the direct-acting room thermostat that controls a hot water supply valve and a chilled water supply valve in response to changes in room temperature.

In operation, the branch line from the thermostat provides a 2-13 psig signal to the hot and chilled water valves. When the thermostat requires an increase in room temperature, the hot water valve opens. As the temperature increases, the branch pressure increases; at the set point temperature, the branch pressure increases to close the hot water valve.

Should the space temperature continue to rise, the direct-acting thermostat will continue to increase the branch line pressure. If the temperature rises above the set point, the normally closed, chilled water valve will begin to open. The chilled water valve has a spring range of 8-13 psig, thus it will throttle to the fully open position as temperature continues to increase.

Both valves will be closed between 6 and 8 psig branch pressure. This dead band between the two spring ranges ensures that the heating valve is fully closed before the cooling valve opens and vice versa.

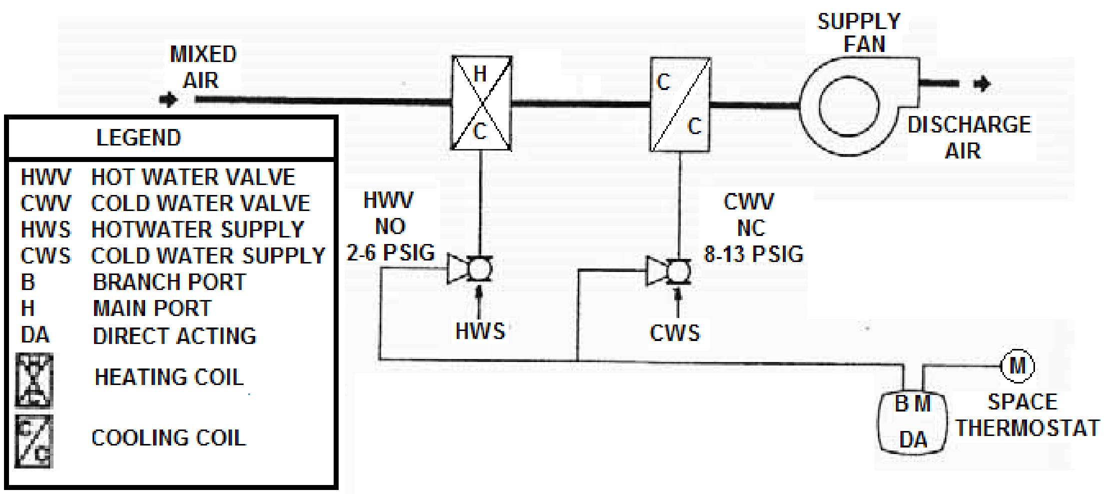


Figure 6-35. Single-Zone Space Control

6.4.7.1.2 Single-Zone System with Low-Limit, Freezestat, and Outside Air Control

In this system (Figure 6-36), the same function is being performed by the space thermostat as in the previously discussed single-zone system. However, additional controls that are often found in conjunction with the thermostat and coil controls in a system like this are added. This system also includes control of the outside air damper, the electric/pneumatic (EP) relay that ties into the fan starter circuit to provide failsafe, and low-limit and freeze protection controls.

In this sequence of operation, the fan starter is tied to the EP relay controlling the branch line airflow to the outside air damper actuator. When the fan is off, the EP relay exhausts the branch line to the outside air damper, allowing it to fully close. Also tied into the control circuit for the fan starter is a freezestat, which is another electrical device. The other pneumatic device shown is the low-limit control. This is a bleed-type device and is located directly downstream from the heating coil and becomes active only when the mixed air temperature leaving the heating coil drops below a nominal 50-55°F. The additional restrictor shown is an adjustable restrictor in the line ahead of the low-limit control and the hot water supply valve. This restrictor limits the amount of airflow, to the devices downstream and, in the event that the low-limit control senses a decreased mixed air temperature, the low-limit will bleed off branch line air, allowing the hot water supply valve to open further than the space thermostat may be allowing.

The freezestat previously mentioned would come into action if the low-limit control was not able to compensate for the drop in temperature by providing sufficient flow through the heating coil to enable the coil to recover. If the mixed air temperature leaving the heating coil continues to drop, the freezestat would break the control circuit to the fan starter, shutting off the fan to prevent the possibility of coil freeze up. This is a safety control that generally has a manual reset. The temperature range of this device is from 35 to 45ºF. The device must be reset manually if it breaks the fan control circuit.

Other controls may be used in conjunction with this type of system, but this provides the basics. There potentially could be a minimum-position control on the outside air damper and control of return air and exhaust air dampers.

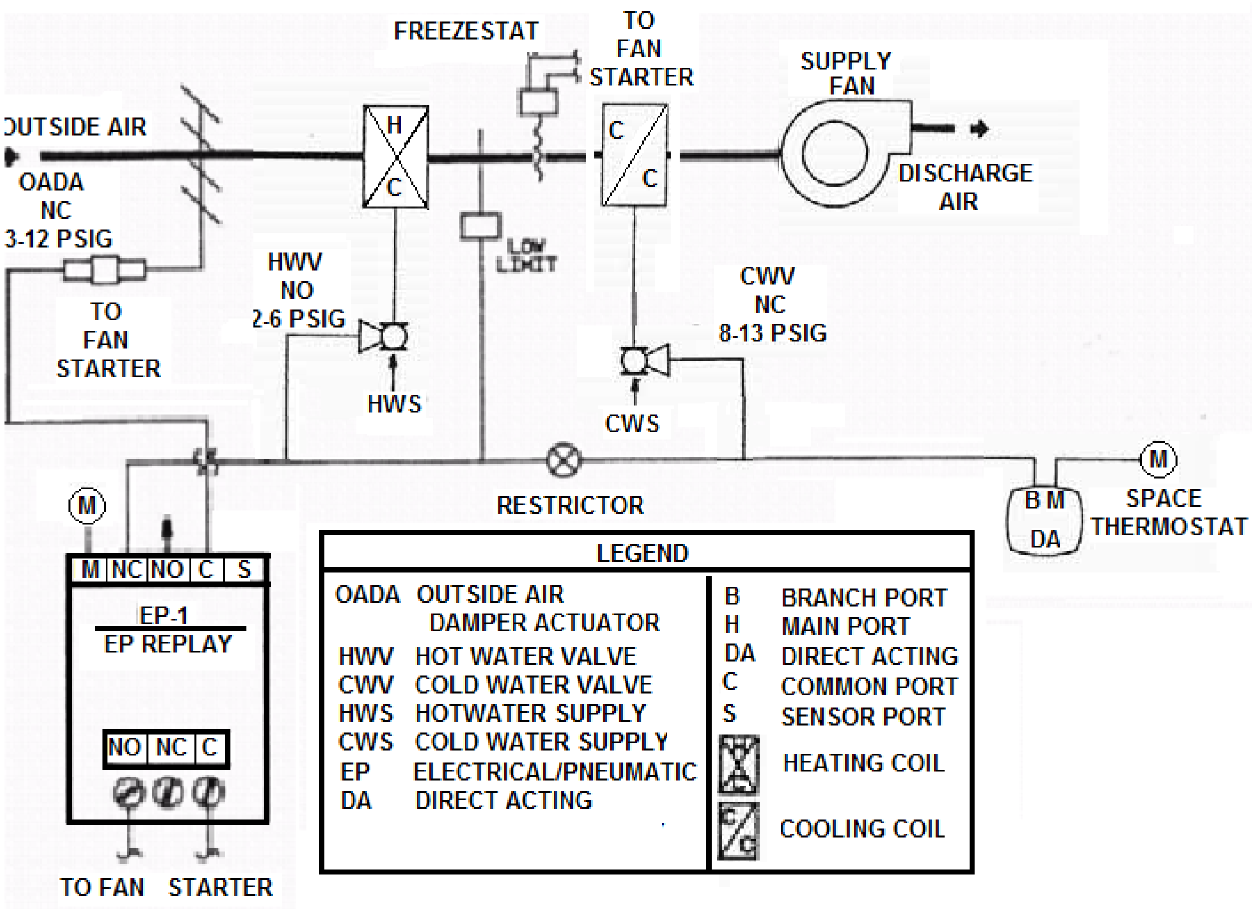


Figure 6-36. Single-Zone Space Control with Low-limit and Outside Air Control

6.4.7.1.3 Single-Zone Control of Space Temperature and Humidity

This system (Figure 6-37) is similar to the previous single-zone systems that have been discussed, but has some additional control functions. This system provides humidity control in addition to the temperature control of the previous system. To facilitate humidity control, face and bypass dampers control flow through the cooling coil, and the heating coil provides reheat capability.

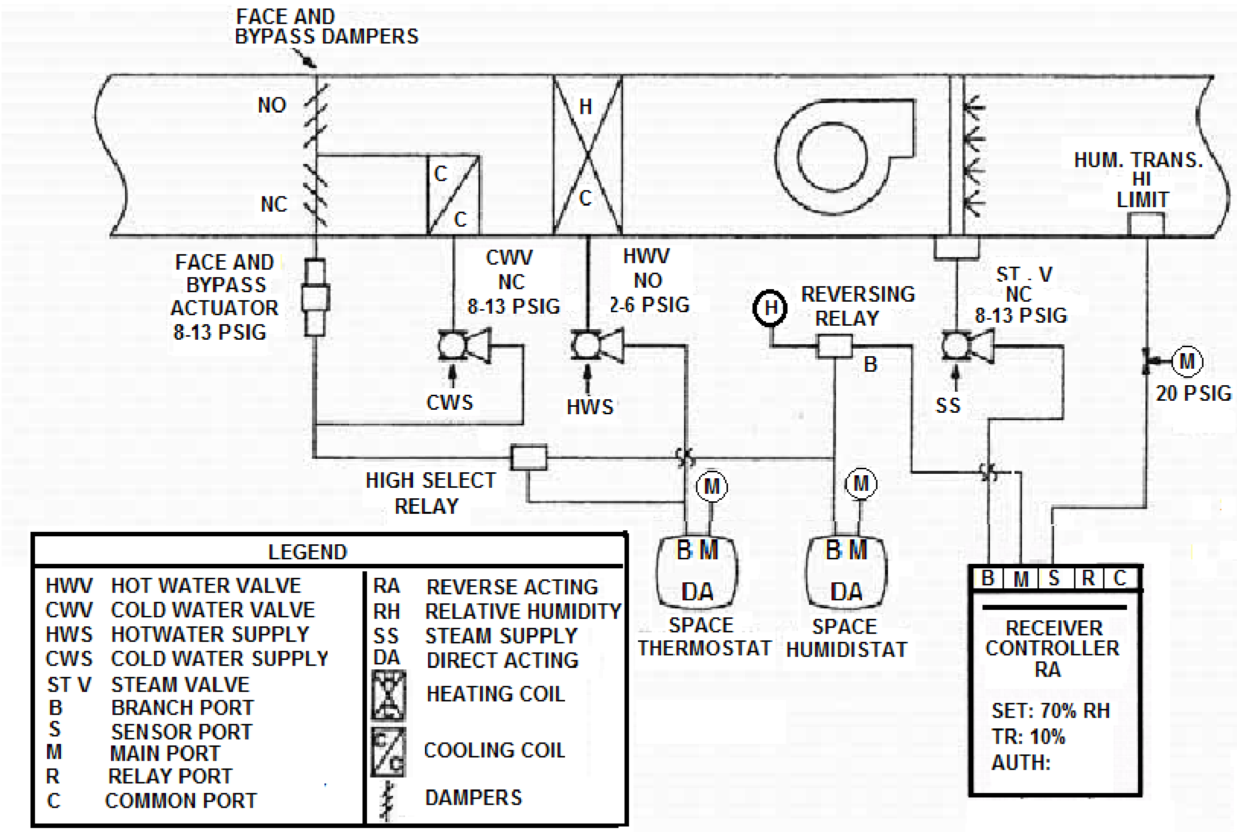


Figure 6-37. Single-Zone Space Temperature and Humidity Control

Basic temperature control in this system is done by the direct-acting, space thermostat, which controls the hot water supply valve, the chilled water supply valve, and the face/bypass actuator sequence. Control of the hot water supply valve is direct-acting. As temperature rises in the space, branch line pressure from the thermostat increases, closing off the hot water supply valve. As pressure continues to increase in response to rising space temperature, a signal passes through the high select relay and starts to drive open the chilled water supply valve. It then closes off the bypass damper and opens the normally closed face damper.

At the same time, the space humidistat, which is also direct-acting, is sensing the humidity level in the space. Its branch line feeds the S port of the high select relay. If the humidity in the space rises above set point and the branch line pressure of the humidistat exceeds that of the branch line pressure of the thermostat, the humidistat branch line pressure will actuate the face and bypass damper and the chilled water supply valve to provide cooling to dehumidify the space.

At the same time, the branch line of the humidistat goes to the reversing relay which, in turn, is fed to the main air port of the reverse-acting receiver-controller. The humidity transmitter located in the duct and the receiver-controller, serve as a high limit. Should the humidifier output increase above 70 percent it will close the steam valve by reducing the branch line pressure to the normally closed steam valve.

This type of system would be used in an area where low humidity in the winter could present a problem, as well as a need for dehumidification during mild weather if the humidity were too high. As mentioned, it would be possible to open the cooling coil valve and face damper thereby cooling the air because of a high humidity condition (even though the wall thermostat might be calling for some heat). In this case, the air would be reheated by the heating coil and supplied at a temperature necessary to satisfy the demands of the space.

6.4.7.2 Mixed Air Control

6.4.7.2.1 Mixed Air Control, Economizer

The purpose of this application is to provide the maximum amount of free cooling available from the outside air. Commercial systems generally are cooling oriented because of load conditions in the controlled space. As such, it is advantageous to maximize the use of outside air for cooling whenever possible. The type of economizer system will vary depending on geographical areas. In the past, some of the milder climate areas utilized no economizer system at all, or outside air dampers were in a fixed position at all times. The conversion to economizer systems has been a popular energy saving tactic. Pneumatic systems have tended to be more sophisticated because of their use in larger buildings, whereas most electric-or electronic-control systems generally did not include economizer systems if the buildings were built in the fifties and early sixties. A number of things can be done to enhance the operation of an economizer system. Several of these options are covered elsewhere in this handbook.

The operation of the economizer cycle shown in Figure 6-38 involves a mixed air transmitter that sends a signal to the direct-acting, mixed air receiver-controller, RC-1. This branch line signal is sent to the normally closed (NC) port of EP-1. The coil of EP-1 is wired so that it is activated when the fan is running. When the fan is energized, EP-1 is energized, the NC and C ports are connected, and the branch line signal from RC-1 is sent to the outside, return, and exhaust damper actuators. When the fan is deenergized, the NC port of EP-1 is blocked, the C port is connected to the NO port, and the signal is exhausted to atmosphere, allowing the outside air, return air, and exhaust air dampers to return to their normal condition. As long as the supply fan is energized, the dampers will adjust in response to changing mixed air temperatures and will attempt to maintain a mixed air temperature of 55°F.

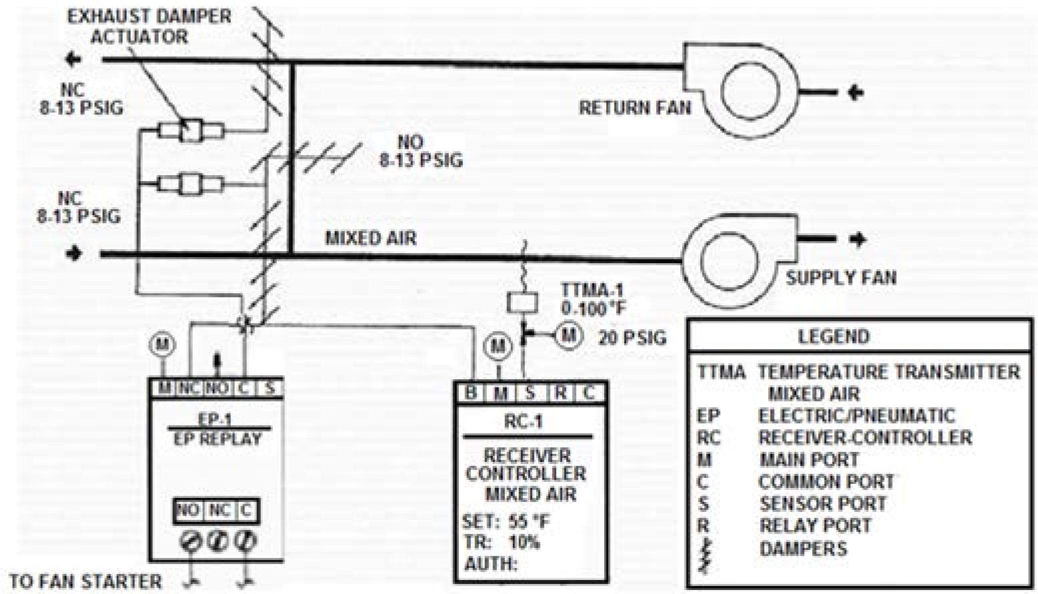


Figure 6-38. Mixed Air Control, Economizer

6.4.7.2.2 Mixed Air Control, Economizer with High-Limit and Minimum-Position Control

In this system (Figure 6-39), two functions are added to the economizer system. These functions are a high-limit control to deactivate the outside air intake if the temperature rises above a given set point, and a minimum-position switch so that the outside air damper will remain open at a minimum position to satisfy ventilation requirements in the building, irrespective of other conditions (such as low or high mixed air temperature during occupied hours).

The gradual switch (SP-1) that controls minimum position is capable of providing a fixed signal that is adjustable or passing a higher signal that is provided at port S-1. The set point on SP-1 is 9 psig. As long as the pressure at port S-1 (which originated from the branch output of RC-1) is greater than 9 psig, this pressure will be transmitted out of port B to the NC port of EP-1. So long as EP-1 is energized, this pressure is passed on through C to the outside, return, and exhaust dampers, allowing them to adjust in response to the changing, mixed air temperature.

As outside air temperature increases, the mixed air controller, which is direct-acting, will increase its signal, adjusting the outside and exhaust dampers toward the open position and the return air damper to the closed position. If the outside air transmitter TTOA-1 senses a temperature rising above 70°F, it will trigger the diverting relay (HL-1) that is used as a high-limit control, blocking the output of RC-1 and exhausting the common port out the NC port. This reduces the pressure at S-1 below 9 psig. The gradual switch (SP-1) will maintain a minimum 9 psig signal in the branch line, maintaining a minimum position on the outside, return, and exhaust dampers. In the example shown on Figure 6-39, the minimum position is shown as 8 psig (which corresponds to the range of the damper actuator) and the set point is 9 psig. In this case, 9 psig represents a movement of the outside air damper that will allow enough outside air to enter the building while the fan is running to meet minimum air requirements.

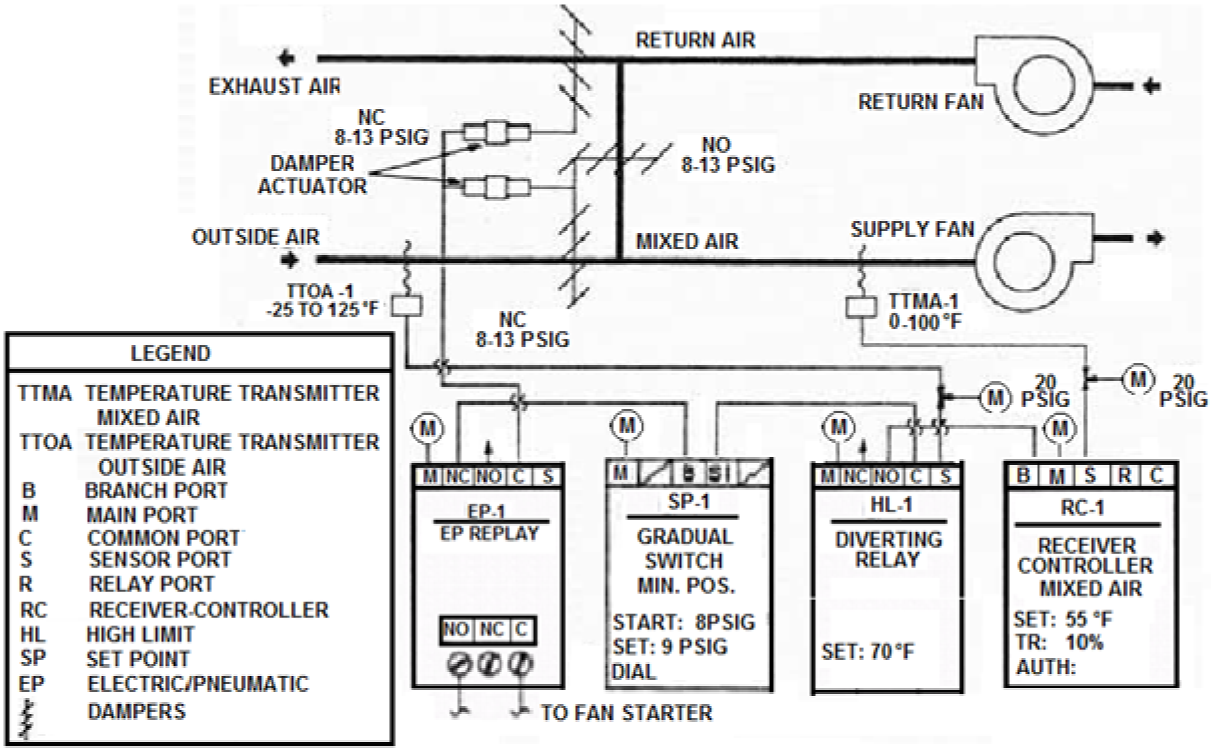


Figure 6-39. Mixed Air Control, Economizer with High-Limit and Minimum-Position Control

6.4.7.2.3 Mixed Air Control, Economizer with High-Limit, Minimum-Position, and Warm-Up Control

For this economizer application, warm up control has been added (Figure 6-40). Warm up control allows the building to warm up to the set temperature on morning startup before energizing the economizer system. Upon fan startup, EP-1 is energized as in the other systems and the signal from RC-1 (the mixed air controller) passes through HL-1 and SP-1 to the NC port of the diverting relay used as a warm up control (WU-1). Until the return air temperature sensed at TTRA-1 rises above the set point in the warm up relay, which is 70°F, the branch output of the mixed air controller is blocked at the warm up relay. Once the return air temperature rises above 70°F, the relay switches and connects NC and C. This allows the branch signal to pass through to position the dampers in response to either the signal from the mixed air controller or, in the case of minimum position, in response to the gradual switch (SP-1).

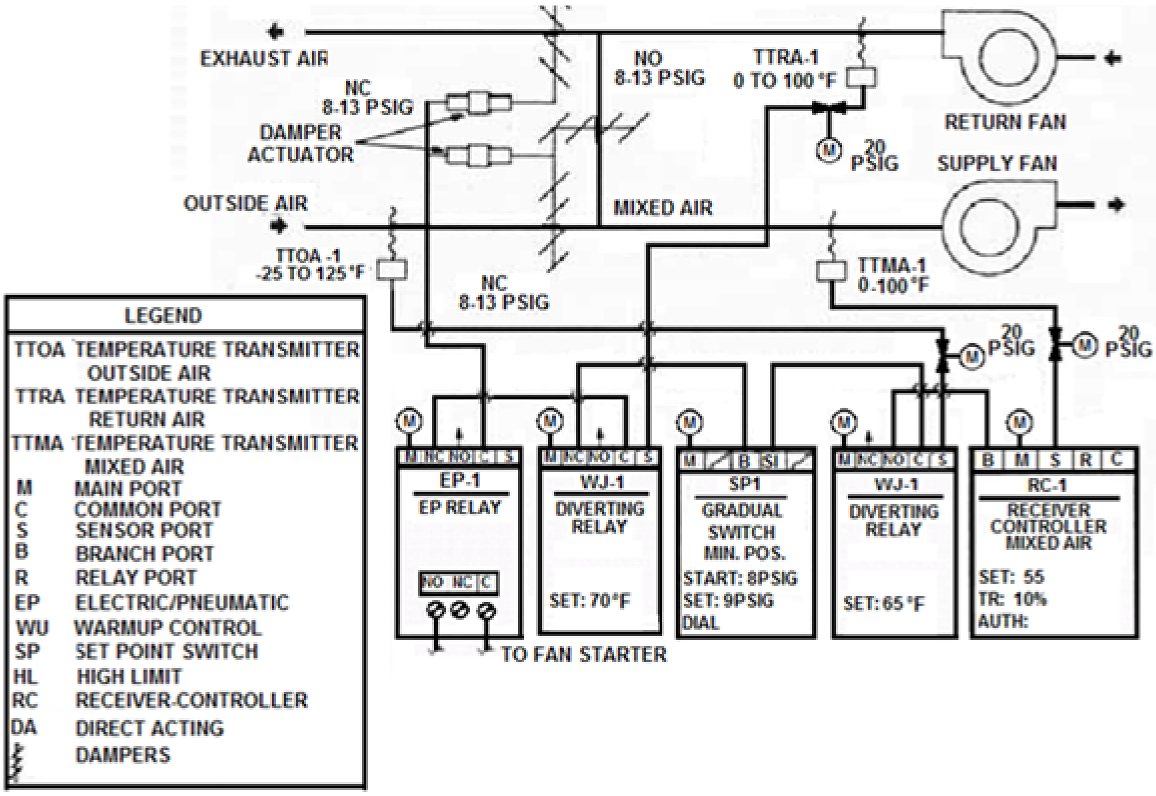


Figure 6-40. Mixed Air Control, Economizer with High-Limit, Minimum-Position, and Warm-Up Control

6.4.7.2.4 Mixed Air Control, Economizer with Enthalpy Changeover and Minimum-Position Control

In this application, an enthalpy-controlled changeover point is used to monitor whether there is free cooling available from the outside air.

This is in contrast to the previous systems where a fixed changeover point or high-limit control to lock out outside air was utilized. The amount of cooling energy needed is determined by the enthalpy content of the air that varies with both temperature and humidity. It is often more economical to cool warmer outside air with a lower enthalpy content than it is to cool return air with higher enthalpy content.

In Figure 6-41, a signal comparing relay, with two signal inputs from an outside air enthalpy transmitter (hTOA-1) and a return air enthalpy transmitter (hTRA-1), is used. As long as the signal from hTOA-1 is less than the signal from hTRA-1, the NO and C ports of hL-1 are connected and the mixed air, receiver-controller provides a signal to position the dampers. When the outside air enthalpy rises above that of the return air enthalpy, hL-1 switches and blocks the NO port to exhaust the damper control signal back through C to NC that allows the outside, return, and exhaust dampers to return to the minimum position as governed by SP-1. The final control, of course, is through EP-1, which is in series with the fan starter. When the supply fan is deenergized, EP-1 exhausts the control signal that positions the dampers to their normally closed or normally open position.

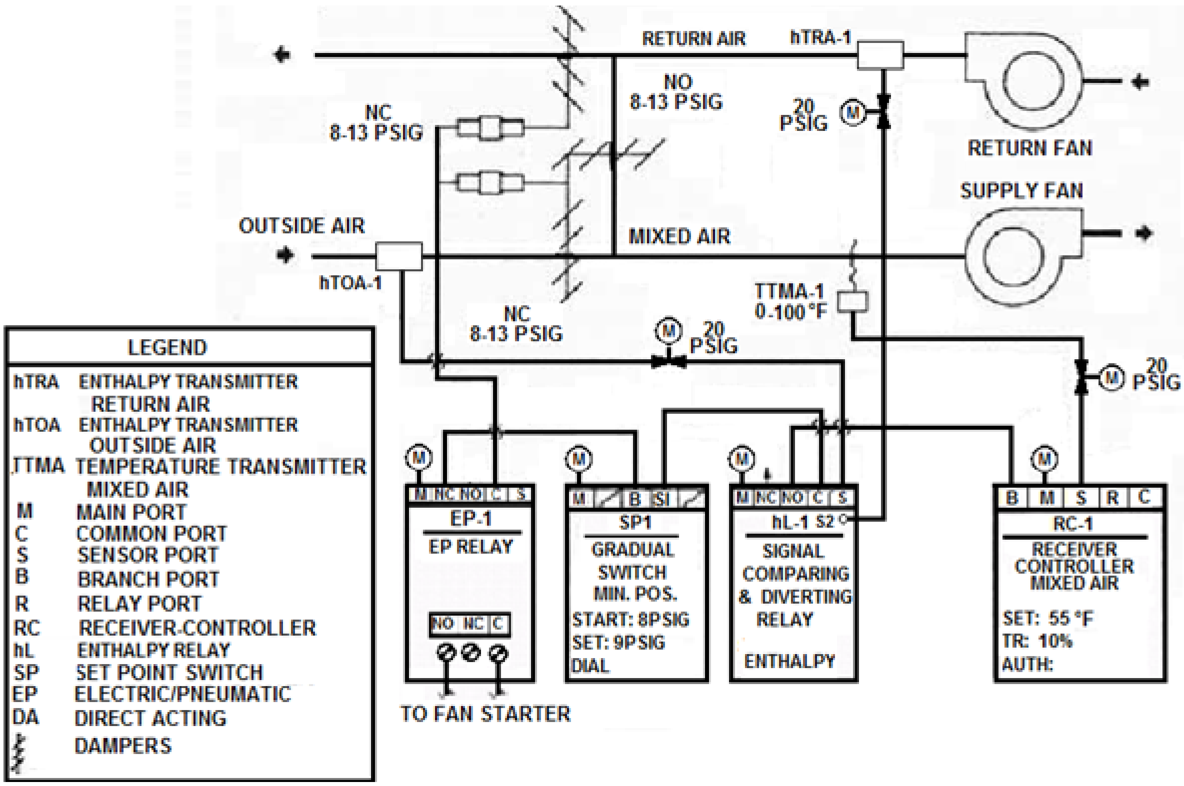


Figure 6-41. Mixed Air Control, Economizer with Enthalpy Changeover and Minimum-Position Control

6.4.7.3 Unit Ventilator

Figure 6-42 depicts a unit ventilator. The unit ventilator is a self-contained unit except for a hot water supply from a central boiler. It does not rely on any central air handling system. It is generally located beneath the windows on an outside wall where the normally closed outside air dampers would bring in air for ventilation from the outside and the normally open return air dampers would be able to recirculate the return air after mixing it with the outside air.

When the fan is energized, the EP relay allows the thermostat signal to position the coil valve and the damper actuator. The fan draws the two air supplies through the heating coil to the space. The thermostat generally is direct acting and, as shown in Figure 6-42, is used to position a normally open heating valve. At the same time, whenever the fan is energized, the branch signal of the thermostat will also be fed to the damper actuators. In this application, the damper actuator has a dual spring range of 1 to 4-psig and 8 to 12 psig.

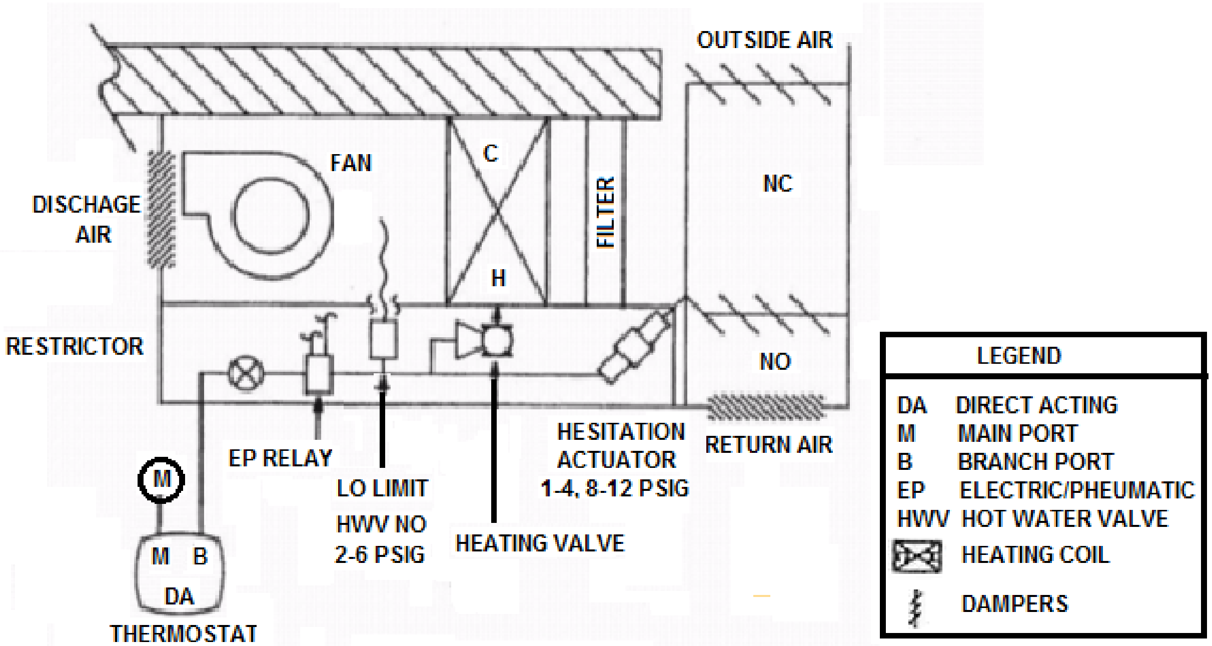


Figure 6-42. Unit Ventilator

When the temperature in the space is below set point, the thermostat branch pressure will be low and the position of the dampers will be normally closed or at a minimum position to the outside air and open to return air. This will allow maximum recirculation of return air. At the same time the heating valve will be open, supplying additional heat to warm the space as the discharged air temperature is raised to achieve set point. As the room temperature approaches set point, the branch pressure will rise and throttle the normally open hot water supply valve toward the closed position. If the outside air temperature is quite cold and the discharged air temperature is lower than 55 to 60°F, the low-limit control would bleed down the branch pressure, opening the heating valve, and allowing the damper motor to close off outside air. This could occur regardless of the room temperature being satisfied.

The hesitation stroke, damper actuator utilizes two separate springs internally. The first of these is actuated between 1 and 4 psig. This provides a minimum amount of damper movement upon system startup. This allows the outside air damper to open to a minimum position to provide the required ventilation air. Nothing happens between 4 and 8 psig and the system operates on the return air. This is to prevent reheating of cold outside air as the hot water supply valve is closed through this range. After the room temperature is satisfied and the hot water supply valve is closed, the damper actuator will fully stroke between 8 and 12 psig, closing off the return air damper and opening the outside air damper to get a maximum amount of outside air to provide ventilation.

6.4.7.4 Multi-Zone

6.4.7.4.1 Multi-Zone System with Hot and Cold Deck Control

This is a relatively simple system (Figure 6-43) utilizing two transmitters, two receiver-controllers, and a zone thermostat and damper actuator for each zone in the space. The receiver-controllers control three-way mixing valves that control flow to the hot and cold deck coils. Both receiver-controllers are direct-acting. The flow through the heating coil in the hot deck is normally open to heating, and the flow through the cold deck is normally closed to cooling. Spring ranges for these valves are selected for close-off ratings that would correspond to their application.

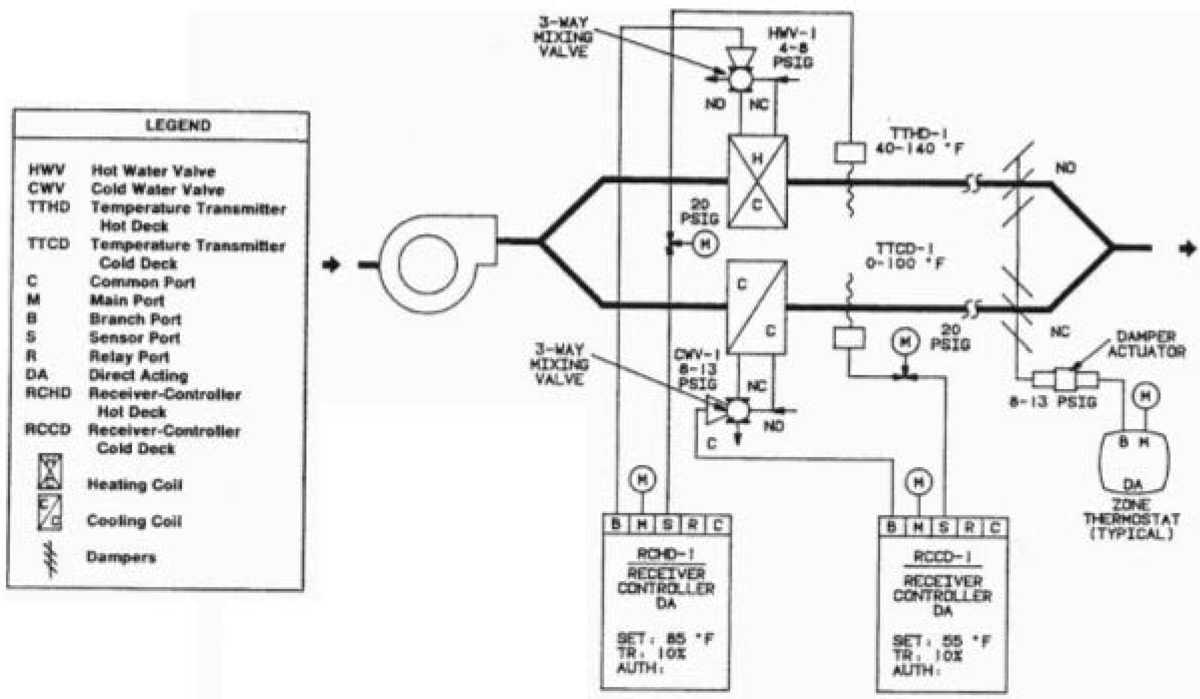


Figure 6-43. Multi-Zone Hot and Cold Deck Control

6.4.7.4.2 Multi-Zone System with Hot and Cold Deck Control with Hot Deck Reset

This system (Figure 6-44) is essentially the same as the system in Figure 6-45, with the addition of a temperature transmitter in the outside air duct. The signal from the temperature transmitter is piped to port R of the receiver-controller (RCHD-1). The reset schedule shown represents the design temperature ranges of 30 to 70ºF outside air temperature. Over this outside air temperature range, it is determined that a range of from 75 to 90ºF hot deck temperature will be sufficient to offset the heat losses that these temperature changes cause. The authority setting of this application works out to be 75 percent, utilizing a 10 percent throttling range with the transmitters as shown.

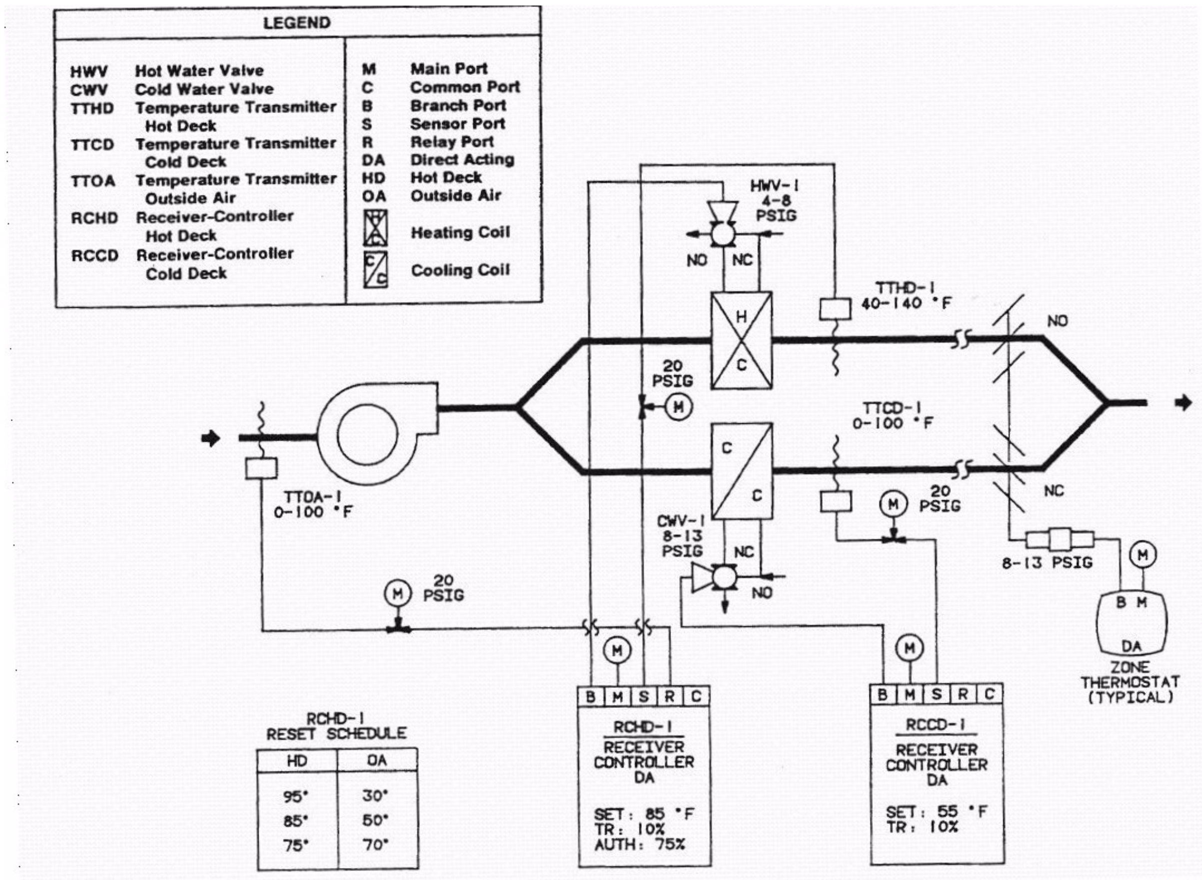


Figure 6-44. Multi-Zone Hot and Cold Deck Control with Hot Deck Reset

6.4.7.4.3 Multi-Zone System with Hot and Cold Deck Control with Hot and Cold Deck Reset

In this system (Figure 6-45), the additional step of adding cold deck reset from space temperature has been taken so that cold deck temperatures are maintained only at a level required by demand in the various zones. A high/low multi-input selector relay is included which will accept the branch input from up to six individual zones and pass through the highest input to reset RCCD-1 per the cold deck reset schedule.

This type of system allows the temperature of the cold deck to be reset upwards as demand decreases in the space. The zone of highest demand is represented by the highest output passed through to reset the receiver-controller so that the system will effectively compensate for worst case demand. The advantage here is that the cold deck supply temperature may be reset upwards to reduce cost of cooling, as space demand decreases.

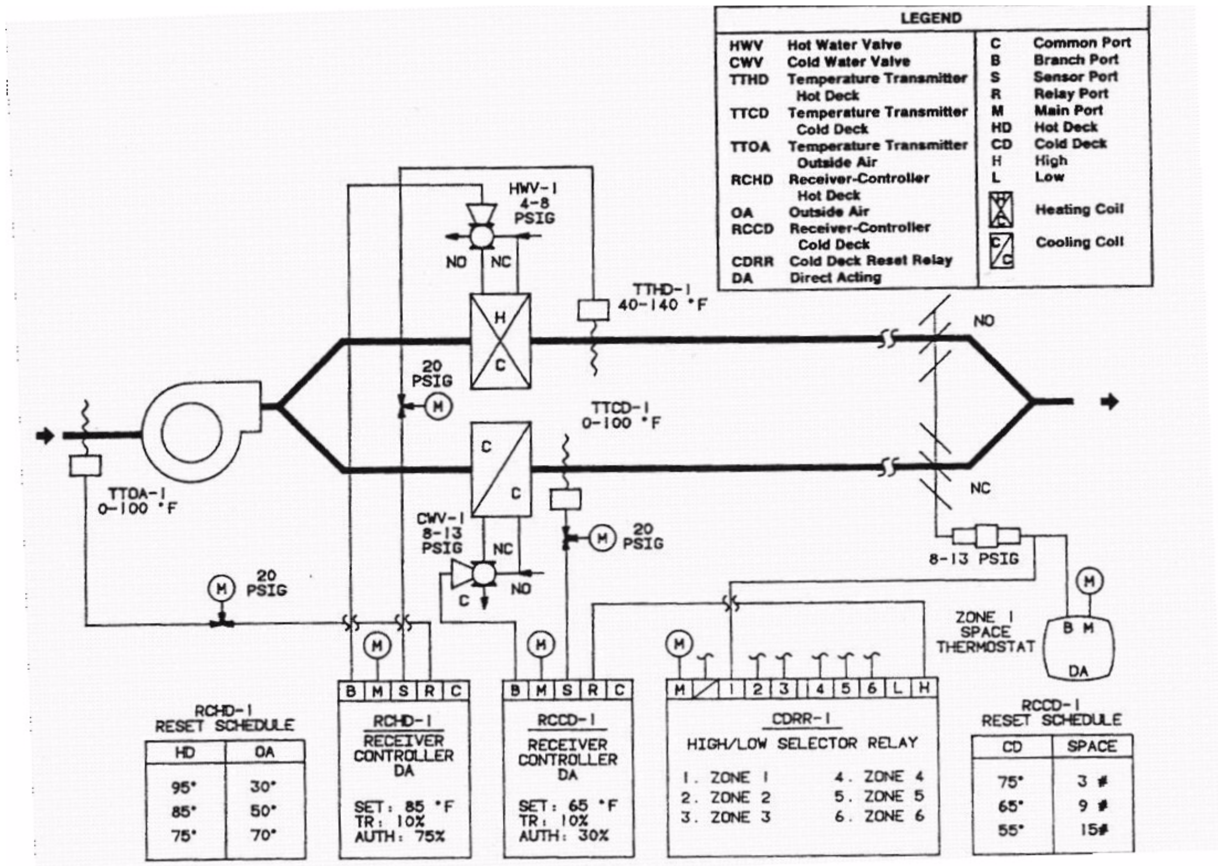


Figure 6-45. Multi-Zone Hot and Cold Deck Reset

6.4.7.5 Hot and Cold Duct or Dual-Duct System Control

This system (Figure 6-46) is very similar to the basic hot deck/cold deck or multi-zone control that has already been described. The primary difference is in the delivery of the hot and cold air supply to the spaces. Dual-duct systems are relatively rare and are generally considered not to be energy efficient. They were originally designed to provide a continuous supply of hot deck temperature and cold deck temperature to each space. The terminal units for each space would mix these two air supplies as necessary to provide a discharge air temperature that would satisfy space conditions. These systems are used very rarely today; many older systems have been retrofitted to lock out the hot or cold deck during the inappropriate season. In doing so, the necessity of reheating or re-cooling air is eliminated.

Some of these systems may also utilize hot deck reset (probably the most common) and, occasionally, cold deck reset. These functions most probably would have been added on as an energy-saving measure. As stated earlier, most of these systems predate the common application of both of these functions.

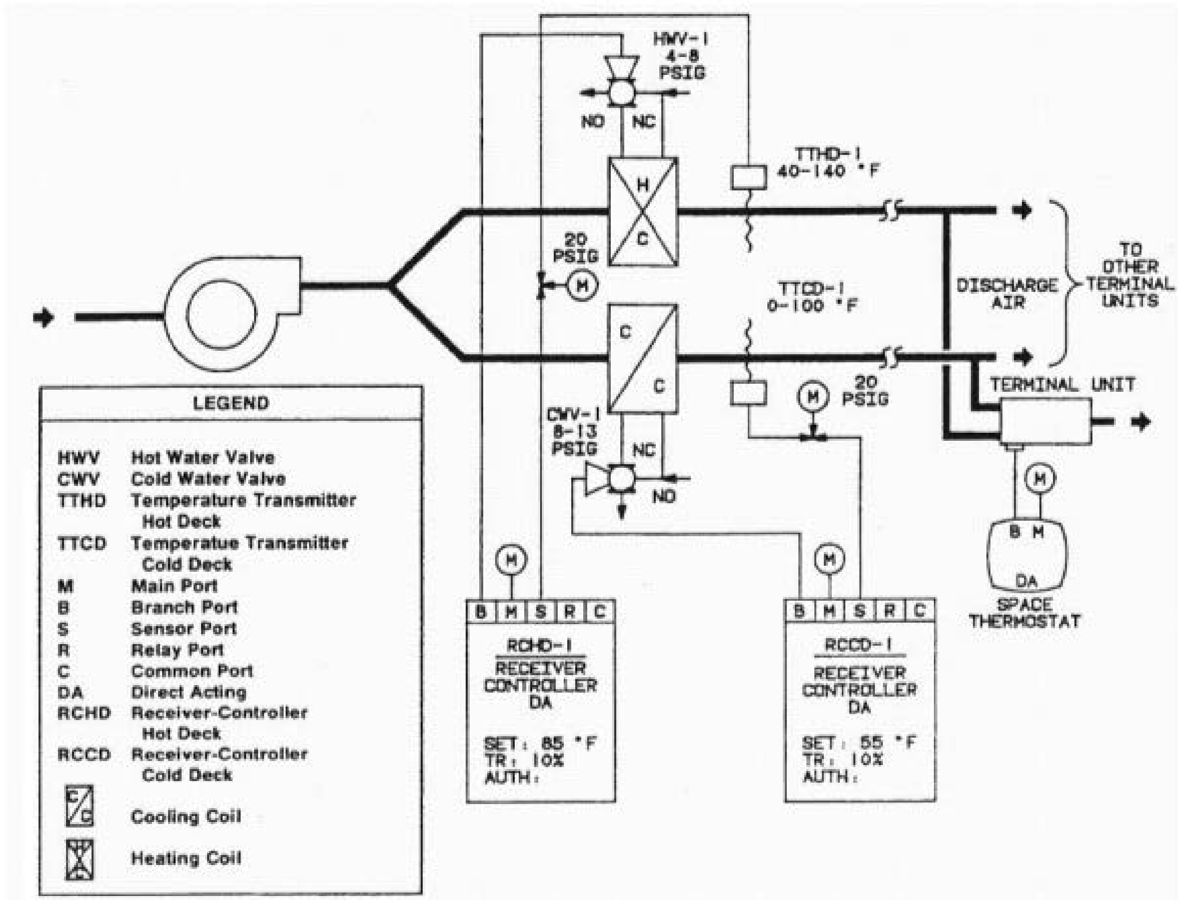


Figure 6-46. Dual-Duct Control

6.4.7.6 Variable Air Volume (VAV) Terminal Unit

6.4.7.6.1 Terminal Unit, Variable Air Volume (VAV)

The terminal unit shown in Figure 6-47 is a typical variable air volume (VAV) unit. In the example shown, the terminal is supplied with cooling air and the terminal dampers are in the normally open position. The thermostat controlling the space temperature is reverse-acting. The damper position is normally open. As the temperature rises, the terminal dampers open to allow greater air flow into the space. This terminal could also be supplied with warm air and utilize a direct-acting thermostat that would close the dampers to minimum on a rise in temperature. Units of this type usually have a mechanical stop for minimum and/or maximum volume adjustment. Volume varies as the inlet duct static pressures vary.

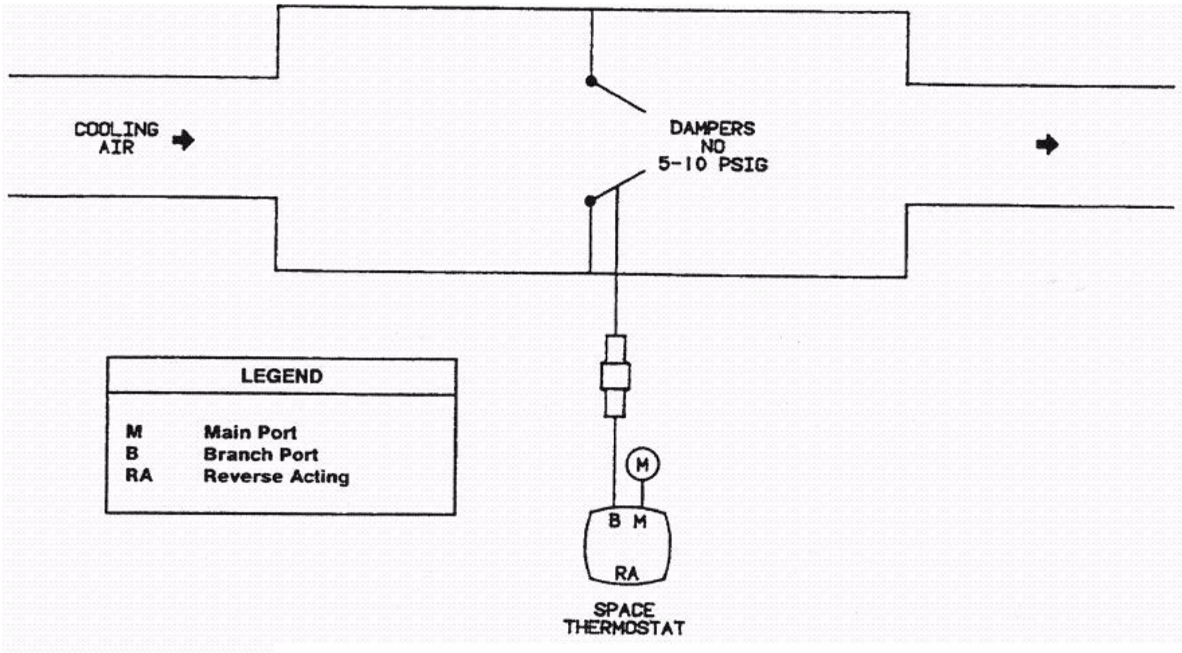


Figure 6-47. AV Terminal Unit

6.4.7.6.2 Terminal Unit, VAV with Reheat

This is a variable volume, throttling-type terminal as previously discussed, except a reheat coil and hot water valve are included to operate in sequence with the volume damper. In Figure 6-48, a reverse-acting thermostat and a normally open volume damper are being used. As the temperature decreases, the volume damper is closed by an increase in branch line pressure. As the pressure continues to rise in the branch line, the VAV unit goes to a minimum flow that is mechanically set. As the pressure continues to rise, the normally closed hot water valve starts to open. The hot water valve will throttle to full flow upon sufficient demand in the space and, on a decrease in demand for heat, will throttle toward the closed position. It will be fully closed before the terminal unit starts to open to allow a greater flow of cooling air to the space.

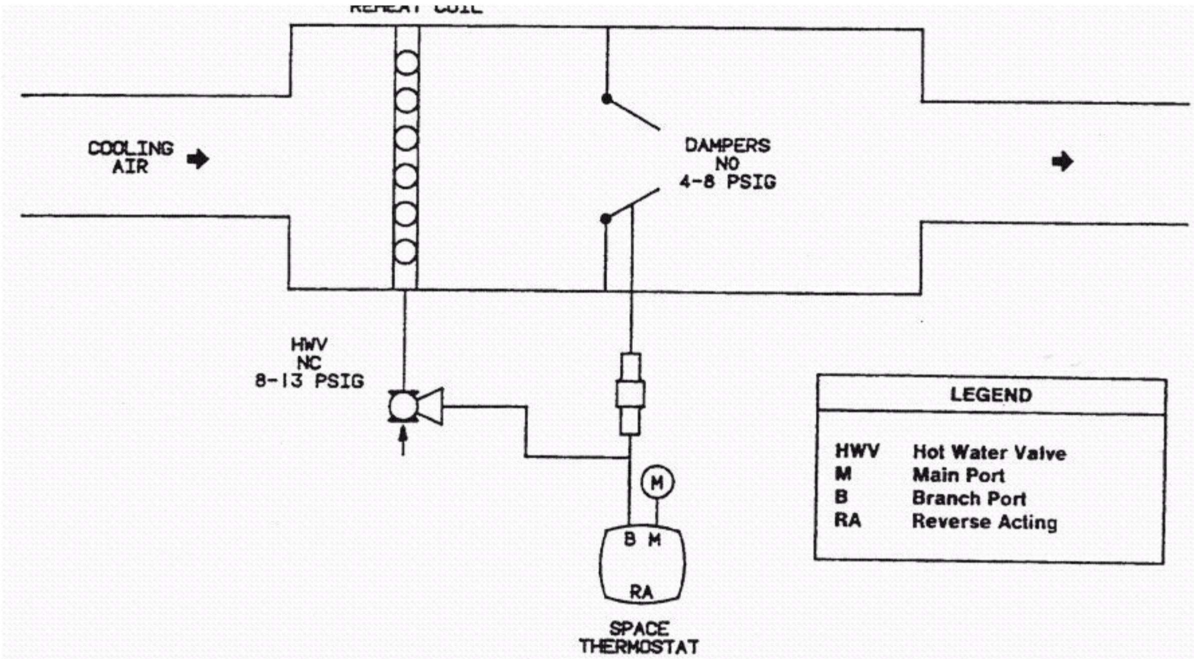


Figure 6-48. VAV Terminal Unit with Reheat

6.4.7.6.3 Terminal Unit, VAV with Strip Reheat

In Figure 6-49, a strip heater in the duct is used. It is controlled in sequence with the VAV damper. The reverse-acting thermostat responds to an increase in space temperature by decreasing the branch line pressure, thus opening the VAV box to increase flow to meet demand in the space. As space temperature decreases, output of the controller increases, driving the terminal dampers toward the minimum position. If this action is not sufficient to maintain space temperature at a comfortable level, decreasing temperature will cause the room thermostat to increase the branch line pressure. This will close the normally open contacts in the PE switch that is controlling the electric strip heater.

This will reheat the incoming air to the space until the space temperature reaches set point.

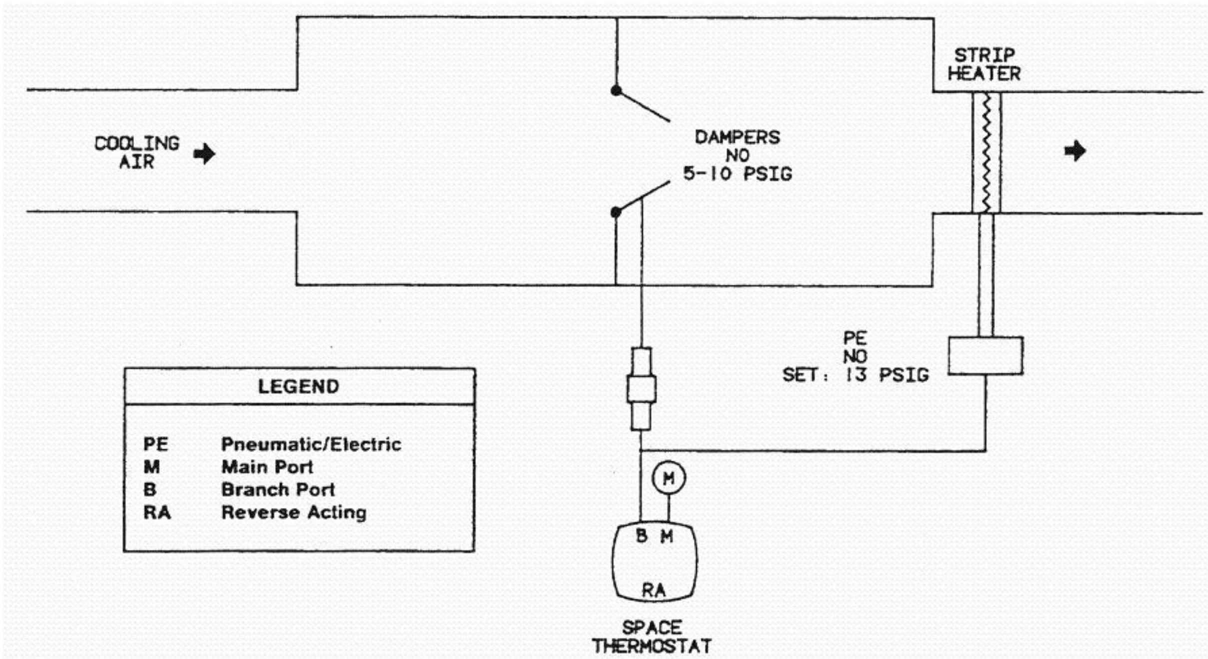


Figure 6-49. VAV Terminal Unit with Strip Reheat

6.4.7.6.4 Variable Volume Diffuser

This is a slightly different type of terminal unit (Figure 6-50) with the terminal unit being part of the space diffuser. This unit would encompass mechanical limits for minimum and maximum volume and, as shown, would be normally open to cooling with a reverse-acting thermostat.

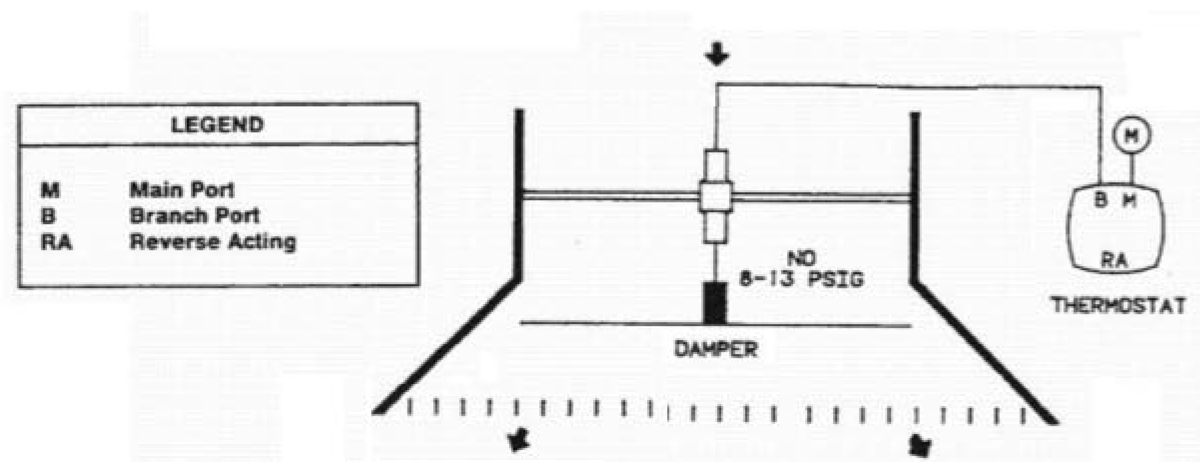


Figure 6-50. VAV Diffuser

6.4.7.6.5 Terminal Unit, VAV with High-Limit Control

This terminal unit (Figure 6-51) is controlled by a thermostat in the space to be conditioned and a constant volume/VAV controller. These sense flow through the terminal unit. The controller contains a built-in high-limit control that limits flow through the terminal unit to a maximum setting established by the manufacturer (or upon application in the field by air balance specialists).

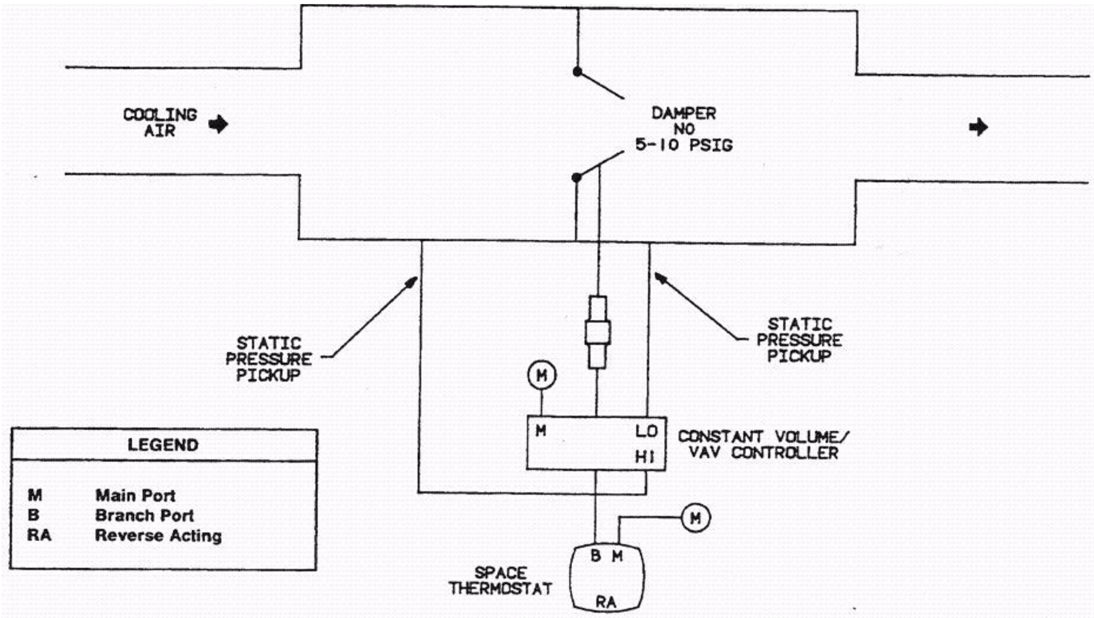


Figure 6-51. VAV Terminal Unit with High Limit Control

The terminal unit is supplied with cooling air and utilizes a normally open damper and a reverse-acting thermostat. The space thermostat controls the action of the damper. As the space temperature increases, the branch line pressure decreases allowing flow to increase through the terminal unit. As flow increases, the sensed pressure from the low and high static pressure pickups is sensed and, at the predetermined high limit, the direct action of the controller will take over through the high select relay built into the controller. The constant volume/VAV controller will maintain flow at that fixed maximum setting.

This type of terminal unit control responds to changing supply pressures. The duct supply pressure may vary either upward or downward in response to demand in other zones within the building. If demand increases in other zones of the building, other terminals will open and decrease the total available static pressure. The constant volume controller will respond by allowing the actuator to open further and add air volume into the space to meet the desired demand.

The other situation that may occur is an increase in static pressure due to one or more terminal units closing down on a decrease in demand in other areas of the building, which increases the static pressure, and, therefore, increases flow through other terminal units. The static pressure sensors will pick up this increased flow and compensate for it by closing the terminal damper in each unit to maintain flow at the preset high limit.

6.4.7.6.6 Terminal Unit, VAV Pressure Independent

This type of terminal unit (Figure 6-52) utilizes a slightly different type of volume controller that maintains a constant volume of flow into the space to be conditioned in response to space demand. The controller used is a reset volume controller with a control output range of 8 to 13 psig. This matches the spring range of the actuator that it is controlling. The reset volume controller has minimum and maximum flow set points. The device in this particular application is a reverse-acting controller used in conjunction with a direct-acting space thermostat. The space thermostat resets the set point of the controller up or down between 8 to 13 psig in response to changing space temperature. As the space temperature goes up, the branch line pressure from the thermostat goes up, resetting the set point of the controller downward to allow a greater volume of air to flow through the terminal unit into the space. At any given control point the volume controller will respond to changes in inlet flow, opening or closing the damper to maintain a flow rate that corresponds to the set point needed to satisfy space temperature.

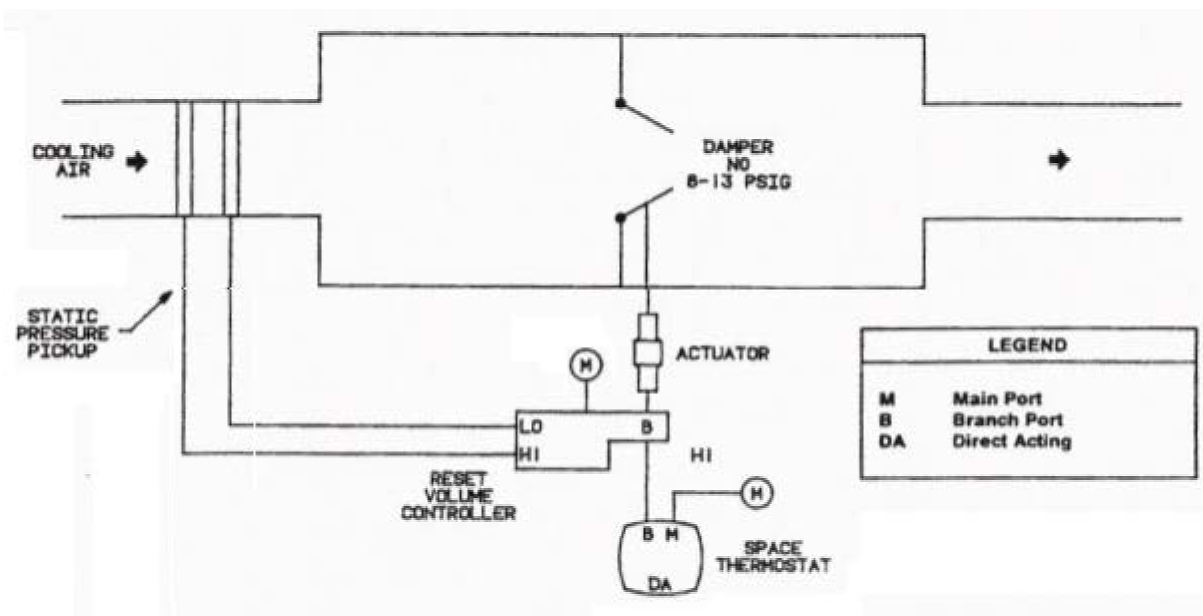


Figure 6-52. VAV Pressure Independent Terminal Unit

This type of system is rarely used as a retrofit application, but has become quite common in new applications. The primary reason for it not being used in a retrofit situation is that the action of the thermostat and actuator must be changed in most applications to be used with this type of controller.

6.4.7.7 VAV Induction Unit

6.4.7.7.1 VAV Induction Box

Induction units as shown in Figure 6-53 use primary system air discharged through the terminal unit, and secondary air inducted from the controlled space.

A typical unit is shown with thermostatically controlled operators varying the primary and secondary dampers. On a demand for less cooling, the primary air dampers throttle, reducing primary air volume. The inducted air dampers are simultaneously opened. Primary air discharges into a mixing section while inducting return air flow from the surrounding space. Mixed air is redirected into the supply duct and out of the diffuser.

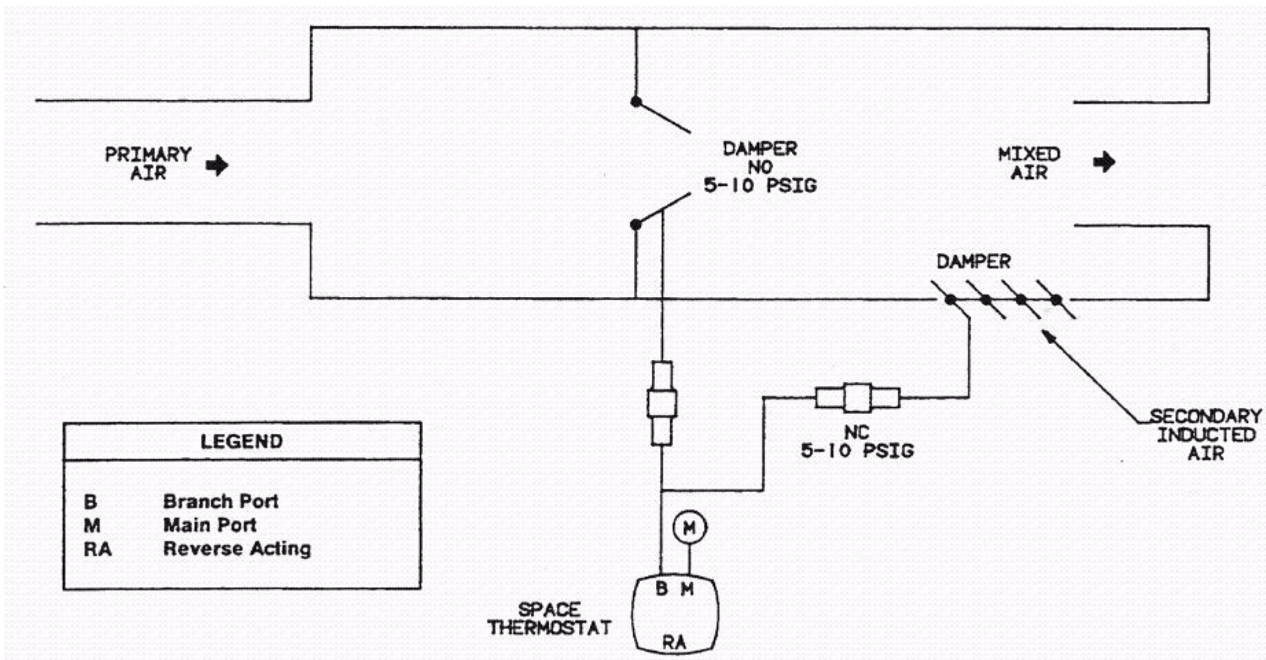


Figure 6-53. VAV Induction Box

6.4.7.7.2 VAV Induction Box with Reheat

Figure 6-54 is essentially the same as the induction box described in Paragraph 6.4.7.7.1, but with the important additional feature of a reheat coil in the primary air supply. This type of unit is used primarily in perimeter areas. It provides additional heat capability in those areas that have a greater demand for heat, such as perimeter zones.

Note that the actuator spring ranges are slightly different here to accommodate the sequencing of the hot water supply valve. Instead of 5 to 10 psig actuators, they have a range of 4 to 8 psig so that the normally open primary volume damper is at its minimum-flow position, and the secondary air dampers are fully open before the normally closed water supply valve starts to open.

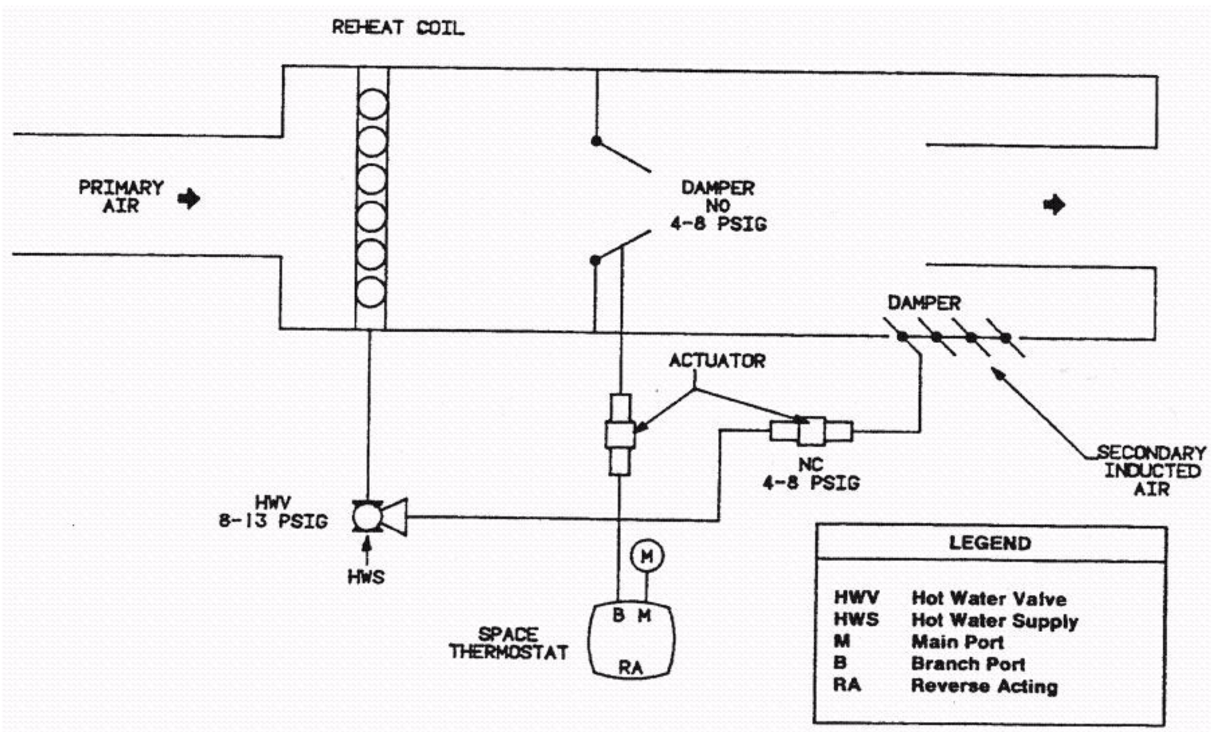


Figure 6-54. VAV Induction Box with Reheat

6.4.7.8 Supply Fan Volume Control

6.4.7.8.1 General

The purpose of fan volume control is to maintain a preset system static pressure. As shown in Figure 6-55, static pressure is sensed with a differential static pressure transmitter by referencing space static pressure and a point two-thirds downstream from the fan in the supply duct. The transmitter signal is sent to the reverse-acting receiver-controller, which moves the normally closed supply fan vortex damper to maintain the desired static pressure level.

A common problem with the fan volume control is that the vortex vanes may overshoot the control point. Some systems are so sensitive that hunting problems may occur even though the receiver-controller is set at its widest proportional band setting. In such cases, it is recommended that a variable restrictor be used between the branch output of the receiver-controller and the damper actuator. This will slow the actuator response until stable control is achieved.

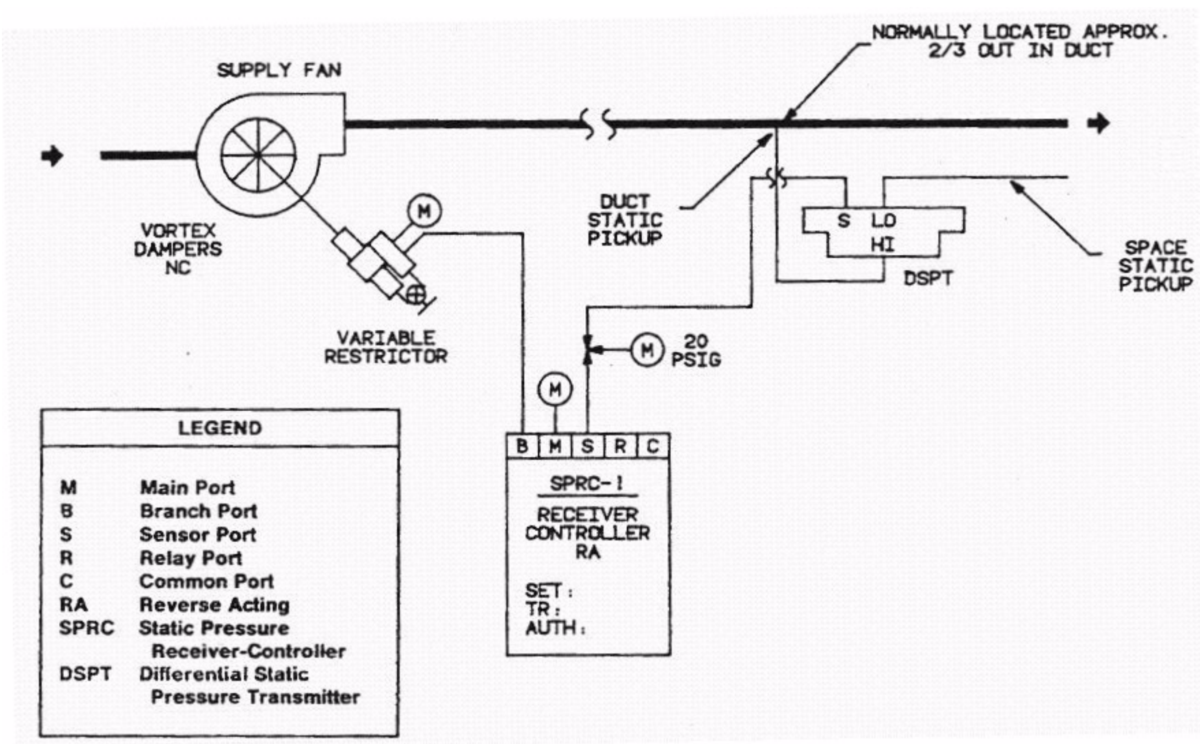


Figure 6-55. Supply Fan Volume Control

6.4.7.8.2 Supply Fan Volume Control with Reset

A major consideration in controlling static pressure is hunting as the controller seeks its set point. On the other hand, if the throttling range is too wide, an objectionable offset to the control point could occur.

With the addition of an integral reset relay as shown in Figure 6-56, the offset problem can be substantially overcome. This relay (RR-1) provides integral reset to the proportional control of the receiver-controller. Although the offset may not be eliminated totally, it will be reduced substantially.

As explained in the example in Paragraph 6.4.7.8.1, the problem remains that the vortex vanes may overshoot their control point. By placing a variable restrictor between the branch output of the integral relay and the actuator, the actuator movement will slow in order to achieve stable control.

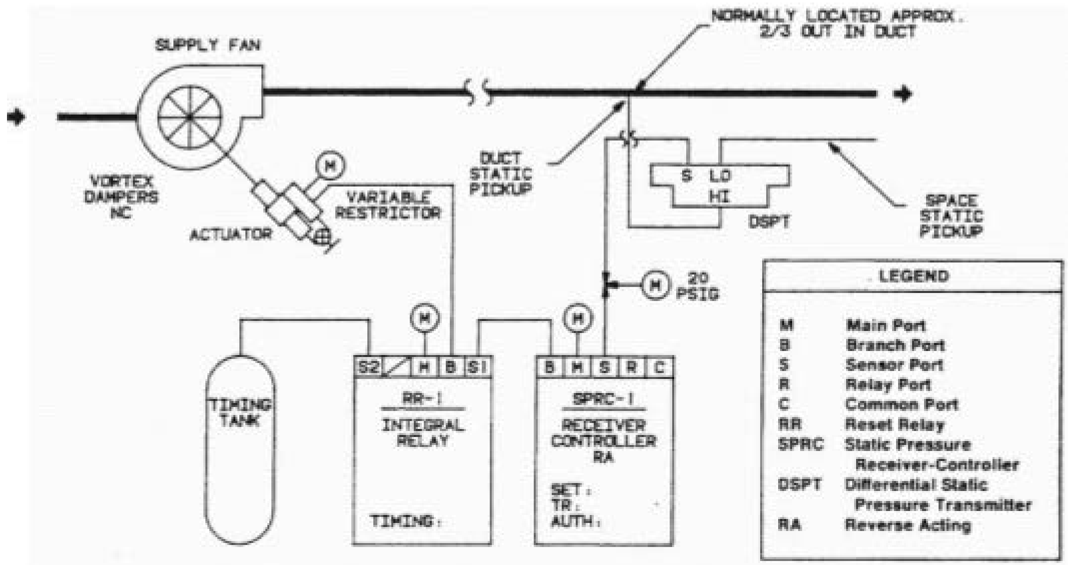


Figure 6-56. Supply Fan Volume Control with Reset

6.4.7.9 Open Loop Supply and Return Fan Capacity Control

6.4.7.9.1 General

This control system (Figure 6-57) is similar to the basic supply fan capacity control system, except that the control signal moves the vortex dampers on the supply and return fans. The objectives are to maintain the supply static pressure at a preset level as system demand varies, and to maintain a fixed volume differential between the supply and return fans to maintain building static pressure at a fixed level. This method is widely used because of its simplicity.

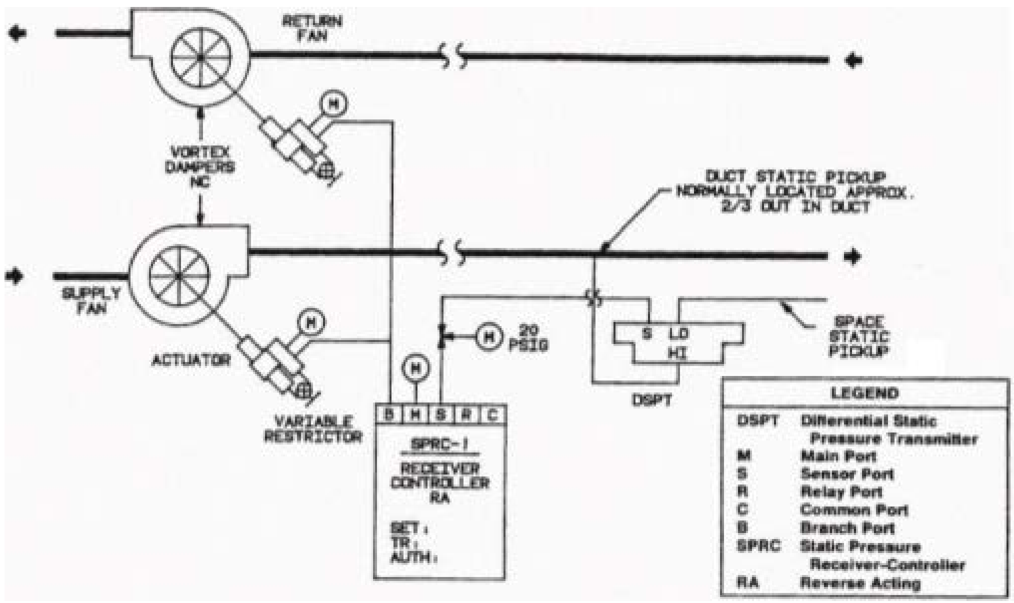


Figure 6-57. Open Loop Supply and Return Fan Capacity Control

The differential static pressure transmitter signal is sent to a reverse-acting receiver-controller, which moves the supply fan vortex damper to maintain static pressure at a preset level as system demand varies. The receiver-controller also moves the return fan vortex damper to maintain a relatively constant cfm differential between the supply and return fans. This is accomplished by using a damper actuator with a positive positioner on it to adjust the start point and effective spring range of the return fan vortex damper at minimum and maximum flow conditions. This adjustment ensures that the desired cfm differential is present at both ends of the demand curve and assumes that the fan curves are matched closely enough to minimize errors as the flow varies from maximum to minimum.

The accuracy of this control method in maintaining a fixed differential between supply and return fans depends on linear damper characteristics and matching fan curves. This may be difficult to obtain. However, this mismatch is not usually serious if the fans are of the same type. The fans are sized to operate at approximately the same percent of flow on their curves, and system flow reduction is limited to approximately 50 percent.

If the system load varies significantly between major zones in the supply system, the return system resistance may not vary in direct proportion to supply system resistance. This control method does not sense the effect of resistance variations between supply and return systems. Therefore, the building pressure may vary when major load variations occur.

Again, on this system, it is recommended that variable restrictors be installed between the positioner and the damper actuators to slow down response and aid in balancing the system.

6.4.7.9.2 Open Loop Supply and Return Fan Capacity Control Reset

Figure 6-58 is a duplication of the example in Paragraph 6.4.7.9.1 with the addition of reset control.

Again, this is accomplished by adding the integral reset relay (RR-1).

As in the previous capacity control sequences, it is imperative that system stability be obtained before adding reset function.

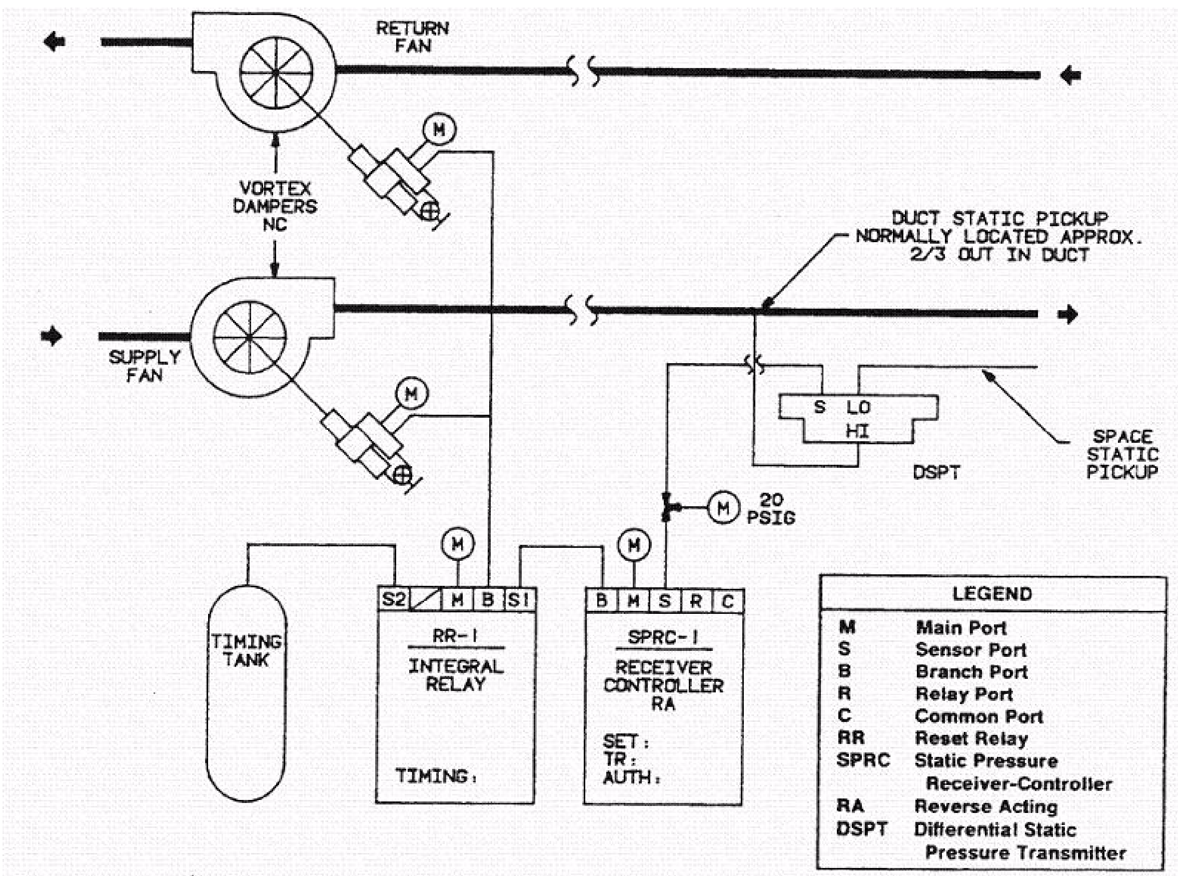


Figure 6-58. Open Loop Supply and Return Fan Capacity Control Reset

6.4.8 Building Automation System (BAS)

6.4.8.1 General

In large central air-conditioning installations, environmental conditions are monitored and controlled by a Building Automation System (BAS). These systems provide total building automation and energy management functions. Standard features are as follows:

- Comprehensive energy management
- High-level programming language
- Maintenance management
- On-line data base generation
- Trend logging
- Continuous self-diagnostics
- Multilevel password access
- Universal analog inputs
- Alarm actions with message text
- Auto restart after power failure
- Forty-eight hour, rechargeable battery backup to protect programs

Time of day scheduling, duty cycling, start/stop time optimization, electrical demand limiting, night temperature setback/setup, and outside air optimization are normally addressed by energy management systems.

6.5 PUMPS

6.5.1 Centrifugal Pump

The Hydraulic Institute lists centrifugal pumps as a kinetic type of pump (ANSI/HI 1.1 - 1.2). A centrifugal pump is a kinetic machine converting mechanical energy into hydraulic energy through centrifugal activity. It consists of a stationary pump casing (housing) and an impeller mounted on a rotating shaft that imparts velocity to a fluid transforming the fluid exit velocity energy into pressure energy. The head developed is approximately equal to the velocity energy at the periphery of the impeller. The pump casing has suction and discharge opening for the fluid entry and exit. The casing suction guides the fluid to the eye of the impeller. The vanes of the rotating impeller impart radial and rotary motion to the fluid forcing it to the outer part of the pump casing, the volute region. The volute is an expanding area of the casing that collects the fluid emanating from the tip of the impeller and gradually causing a reduction in high velocity to convert the velocity energy to pressure energy and discharge it through the discharge connection (Figure 6-59).

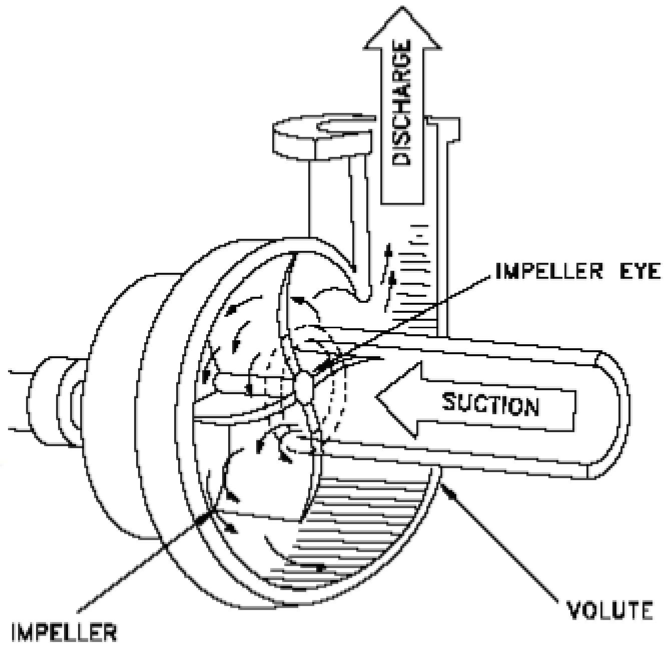


Figure 6-59. Centrifugal Pump

6.5.2 Types of Centrifugal Pumps

6.5.2.1 General

Centrifugal pumps can be classified by impeller type or casing configuration, end application of the pump, specific speed or mechanical configuration. Pumps with volute casings are called volute pumps; those with diffusion vanes are called diffuser pumps; and vertical diffuser turbine pumps as well as regenerative pumps are called turbine pumps. Impeller classifications are radial flow, mixed flow, and axial flow pumps. They are also classified in terms of group as volute, diffuser, turbine, and propeller pumps.

6.5.2.2 Radial Flow Pump

A radial flow pump is a centrifugal pump that uses only centrifugal force to develop pressure; the fluid enters the impeller axially and is discharged at right angles to the shaft. Two types of radial flow pumps are available: single suction and double suction. In a single-end suction pump, fluid enters the impeller from one side. The shaft does not extend into the suction passage, and because of this, rags and trash do not clog the pump. For a double suction pump, fluid enters the impeller from both sides; however, the shaft extends into the suction passage, thereby limiting its use to handling only clear water.

6.5.2.3 Mixed Flow Pump

Mixed-flow pumps are ideal for low-head, large-capacity applications. Although some horizontal units are built, the pumps are usually vertical with a single impeller. Mixed-flow units develop pressure partly by centrifugal force and partly by the force of guide vanes on the fluid.

6.5.2.4 Axial Flow or Propeller Pump

Axial-flow units, often called propeller pumps, develop most of their head by the lifting action of guide vanes. These pumps are usually vertical and best suited for low heads and large capacities. Axial-flow pumps direct the fluid along the same axis as the pump shaft.

6.5.2.5 Volute Pump

The volute pump is so named because the impeller rotates in a spiral-shaped housing, called the volute. In this pump, fluid is discharged by the impeller into a progressively expanding spiral casing that is proportioned to gradually reduce fluid velocity. Thus, velocity energy changes to pressure energy in the volute.

The majority of centrifugal pumps built in the United States today are volute pumps. These include horizontal and vertical pumps, and single stage or multistage pumps for wide ranges of flow and pressure.

6.5.2.6 Diffuser Pump

The diffuser pump uses nearly the same housing as the volute pump but has stationary guide vanes built into the housing and surrounding the runner. These gradually expanding passages change the direction of fluid flow and convert velocity energy to pressure energy. This pump was originally more efficient than the volute pump; however, efficiency of both types is now about equal. Diffuser pumps have many uses as multistage high-pressure units.

6.5.2.7 Turbine Pump

The regenerative turbine pump is characterized by a unique impeller design. The impeller shroud has a large number of blades machined into its periphery. Generally, a blade row exists on each side of the shroud to minimize axial thrust. In a traditional centrifugal pump, fluid enters the impeller adjacent to the shaft centerline and is then accelerated outward, exiting the impeller at its outside diameter. A regenerative turbine pump differs in that the fluid enters near the impeller outside diameter, is accelerated through approximately 330 degrees of rotation, and exits the pump discharge at, or near, the same radius as the inlet. A sector of about 30 degrees separates the inlet from the outlet. In this sector, the casing walls parallel to the impeller shroud are positioned in very close proximity to the rotating impeller to minimize leakage between the high-pressure exit and the impeller inlet.

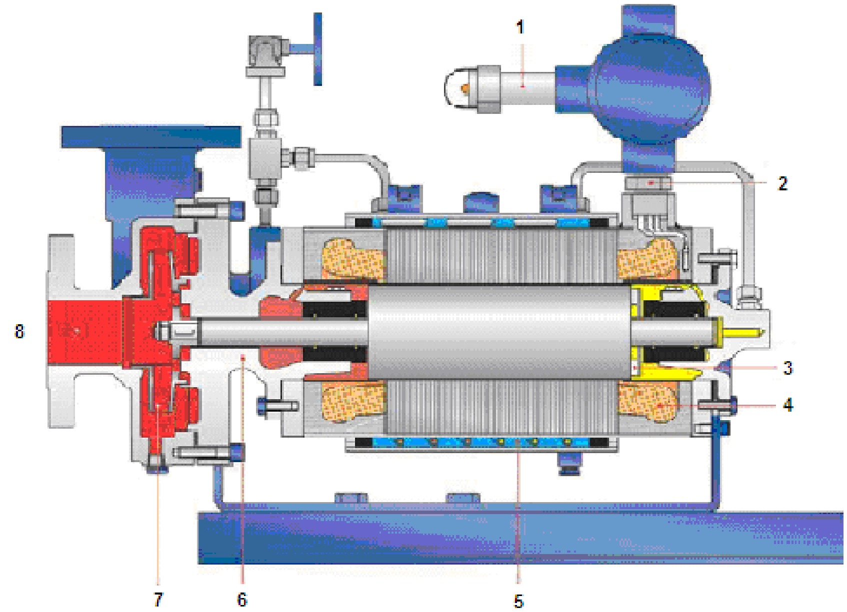
6.5.3 Centrifugal Pump Structure

6.5.3.1 Basic Components

All centrifugal pumps are constructed with the same basic components: an impeller to increase the velocity of the fluid; a casing and a casing gasket to contain and direct the flow of the fluid; a shaft on which to mount and rotate the impeller; power end with bearings to support and permit free rotation of the shaft; a rear cover or stuffing box with packing and lantern ring or with single or double mechanical seal to keep the liquid in and the air out of the casing; wear rings in the casing and on the impeller to reduce costly wear on these components; and a shaft sleeve to protect the shaft from wear, corrosion, or erosion.

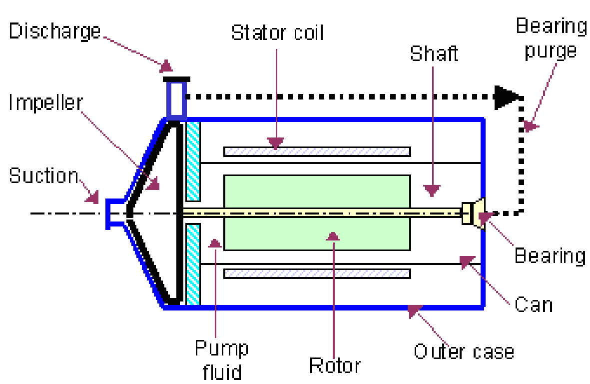
Some centrifugal pump are sealless, they do not used packing or mechanical seal. Two of these are the magnetic pump and the canned pump. The magnetic pump uses an outer casing with magnets and inner magnet rotor; an electric motor turns the magnets around the inner casing and the magnetic field turn the inner rotor/impeller. The canned pump uses an electric motor stator attached to the shaft and magnet fields outside the "can"; current flows from the winding to the stator causing it to rotate. Sealless pumps are generally used when there is a need to contain dangerous fluids (Figure 6-60). Although all pumps using centrifugal force as the moving force are classed in the broad centrifugal pump class, the intended application is a major factor in impeller and casing design, materials used, and other mechanical and hydraulic features.

Canned Sealless Pump



1. Rotation indicator
2. Double containment
3. Auxiliary impeller
4. Solid encapsulation
5. Heat exchanger
6. Hot neck
7. Impeller
8. Casing

Magnetic Sealless Pump



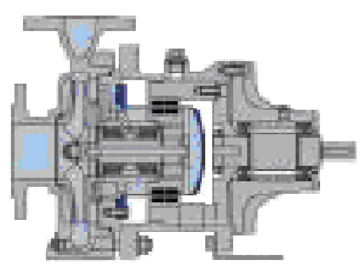


Figure 6-60. Sealless Pumps

6.5.3.2 Impellers

Impellers are classified according to their structure, how the liquid enters, and the detail of the vanes. Impellers can be single or double suction (Figure 6-61), as well as open, semi-open, or closed. Single suction impellers allow fluid to enter the center of the blade only from one direction. Double suction impellers allow fluid to enter the center of the impeller blades from both sides simultaneously. Figure 6-62 shows seven different types of impellers:

- Open. An impeller with relatively small shrouds and vanes attached to a central hub.
- Semi-Open. An impeller with shroud or wall on one side only.
- Closed. An impeller, single suction, with shrouds on both sides to enclose liquid passages and with liquid inlet on one side only.
- Closed. An impeller, double suction, similar to the one above with liquid inlets both sides.
- Mixed-flow.
- Axial-flow.
- Mixed-flow.

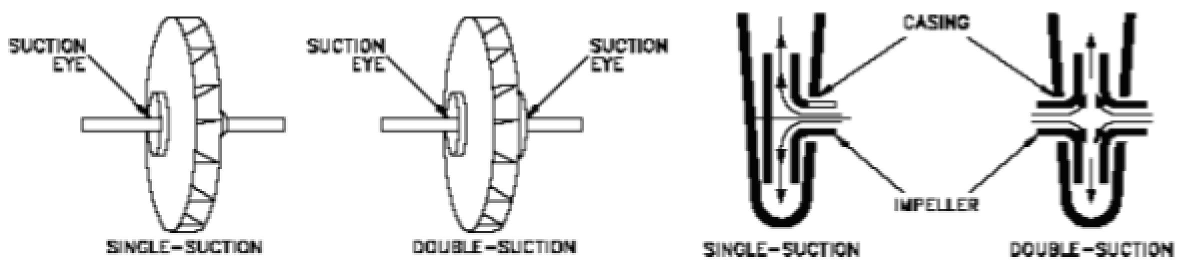


Figure 6-61. Single and Double Suction Pump Impellers

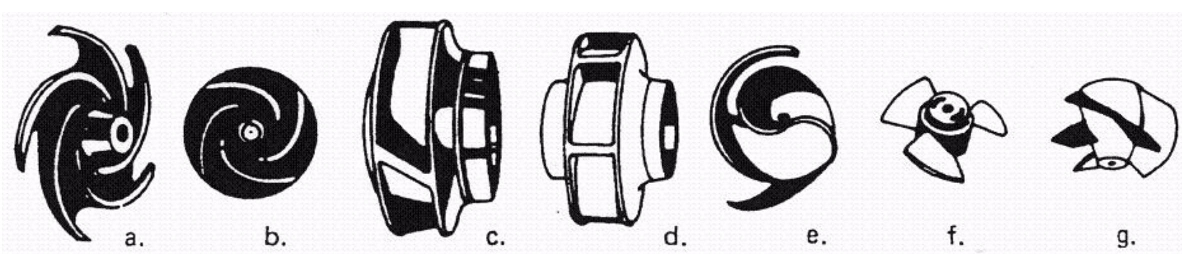


Figure 6-62. Pump Impellers

6.5.3.3 Casings

6.5.3.3.1 Function

The pump casing provides a pressure boundary for the pump, an entry and exit for the fluid, as well as channels to direct the suction and discharge flow. The pump casing performs three basic functions:

- Directs the flow of liquid in the volute
- Provides a space to house the impeller
- Contains the fluid

6.5.3.3.2 Types

A variety of pump casings are available. The volute casing collects liquid discharged from the impeller and converts velocity energy into pressure. Solid and split casings made of two or more parts fastened together describe pumps divided by the horizontal plane through the shaft center line and usually with suction and discharge nozzles in the same half. Likewise, radially split refers to a pump divided in a plane perpendicular to the axis of rotation. End-suction single-stage pumps are made of one piece solid casings; although one side of the casing must be open to accommodate the impeller. Thus, a solid casing requires a rear cover with an integral stuffing box for the open side and rear cover gasket to prevent leakage between the rear cover and the solid casing. Barrel casings are used to avoid difficulty in maintaining a tight joint between the halves of axially and radially split casings. Barrel casing is basically an inner casing fitted to an outer casing.

6.5.3.4 Bearings

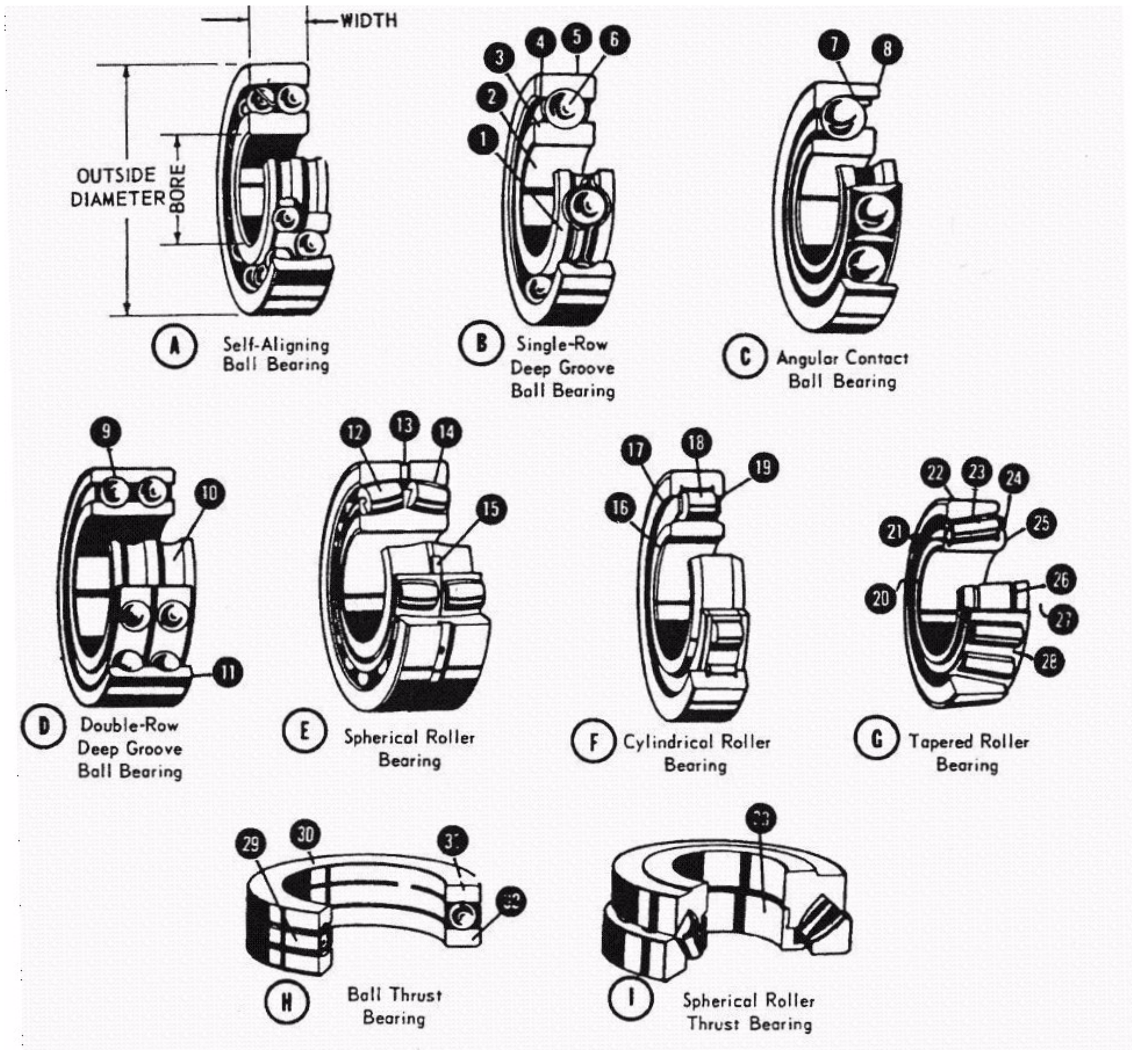
The function of bearing in centrifugal pumps is to keep the shaft or rotor in proper alignment with the stationary parts under the action of radial and transverse loads.

6.5.3.4.1 Types

Centrifugal pumps use many kinds and types of bearings. The most common are antifriction, sleeve, and Kingsbury.

6.5.3.4.2 Antifriction Bearings

Antifriction bearings minimize friction by removing any possible sliding between bearing surfaces and replacing all contacts with rolling interfaces, either balls or cylinders, and may be single- or double-row type (Figure 6-63). Ball bearings are widely used for large shafts. Two angular-contact matched bearings mounted back to back are used on many units to carry the thrust load in either direction as well as the radial load.



1. Inner Ring
2. Inner Ring Corner
3. Inner Ring Land
4. Outer Ring Land
5. Outer Ring
6. Ball
7. Counter Bore
8. Thrust Face (Face)
9. Outer Ring Raceway
10. Inner Ring Raceway
11. Outer Ring Corner
12. Spherical Roller
13. Lubrication Feature
14. Spherical Outer Ring Raceway
15. Guide Ring
16. Inner Ring Side
17. Outer Ring Side
18. Cylindrical Roller
19. Locating Rib
20. Cone Front Face
21. Cone Front Face Rib
22. Cup (Outer Ring)
23. Tapered Roller
24. Cone Back Face Rib
25. Cone Back Face
26. Under Cut
27. Cone (Inner Ring)
28. Cage
29. Ball Cage
30. Face
31. Small Bore Washer
32. Large Bore Washer
33. Sleeve

Figure 6-63. Common Parts of Antifriction Bearings

6.5.3.4.3 Sleeve Bearings

Sleeve bearing, also called journal bearing, is a simple device for providing support and radial positioning while permitting rotation of the shaft. Common industrial materials for plain bearing are Babbitt, bronze, cast iron, graphite, and other modern materials. Two basic journal bearing designs are prevalent: sleeve and tilting pad. Sleeve bearings have no moving parts and a fixed geometry, so direct measurement of the bore is possible. Tilting pad bearing tilts to accommodate the oil film making bore determination difficult. There are two subcategories of tilt pads: Rocker back and spherically seated. Two types of sleeve bearings are discussed as follows:

- Plain Sleeve Bearings. Plain sleeve bearings usually consist of babbitt-faced sleeves placed around the shaft. In some instances, especially in vertical pumps, the bearing material may be bronze. This bearing carries radial loads only.
- Spherically Seated Sleeve Bearings. The spherically-seated, self-aligning sleeve bearing shown in Figure 6-64 consists of a normally constructed sleeve bearing mounted in bushings having spherical contact with the bearing body. The bearing can thus assume perfect alignment with the shaft. The bearing bodies for these bearings are separate and are bolted and doweled to the lower half casing. The bushings are cast iron and babbitt-lined with no adjustment for wear. When these bearings have worn, unless the spherical seat of the bushings or body has been damaged, it is necessary only to replace both halves of the removable linings.

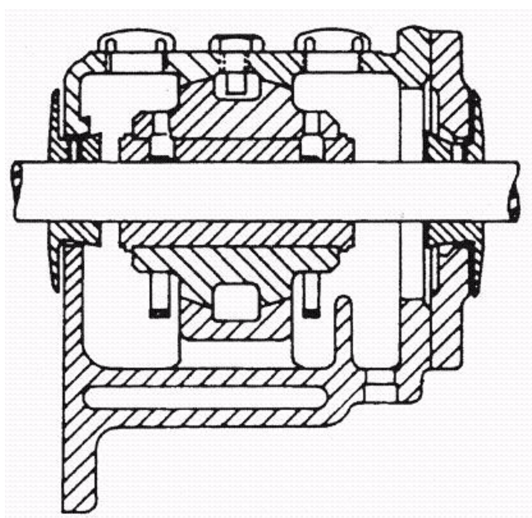


Figure 6-64. Spherically Seated Plain Bearing

6.5.3.4.4 Kingsbury Thrust Bearing

This bearing uses stationary, segmental, babbitted thrust shoes that ride on an oil film carried by a thrust collar revolving with the shaft. All of the thrust is supported by the oil film. Any failure of this film permits metallic contact, and burns out the thrust shoes. Figure 6-65 shows the Kingsbury babbitted thrust shoes supported so that they lift slightly at one end (facing the direction of collar rotation) and slide on the oil film surface. Each set of thrust shoes is held in place by a spherically-seated aligning washer, so that the shoes can adjust themselves to the thrust collar. The thrust collar is an integral part of a long sleeve that is keyed to the shaft. True collar rotation is thus ensured.

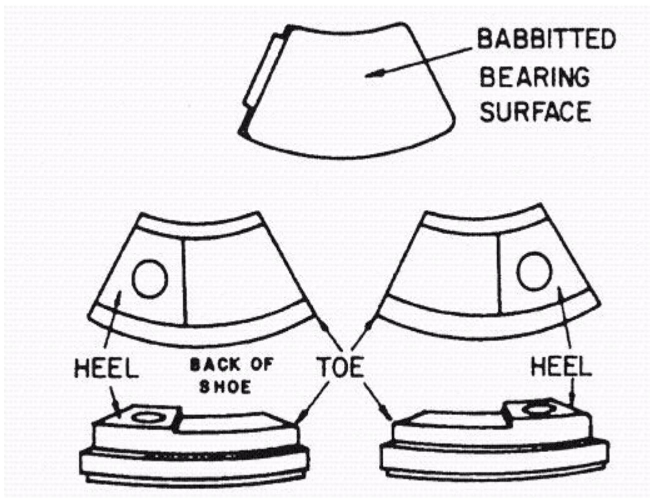


Figure 6-65. Kingsbury Thrust Shoes

6.5.3.5 Shafts and Sleeves

Pump shafts not only transmit power from the driver to the impeller but must also withstand the radial load imposed on the impeller. Shafts are machined and ground to close tolerances at critical points. Shafts of some small pumps are stainless steel and do not require shaft sleeves. Shafts for larger pumps are made of steel and require some form of shaft sleeve to protect the shaft at critical wear points. Shaft sleeves are bronze for standard noncorrosive applications.

6.5.3.6 Shaft Seals

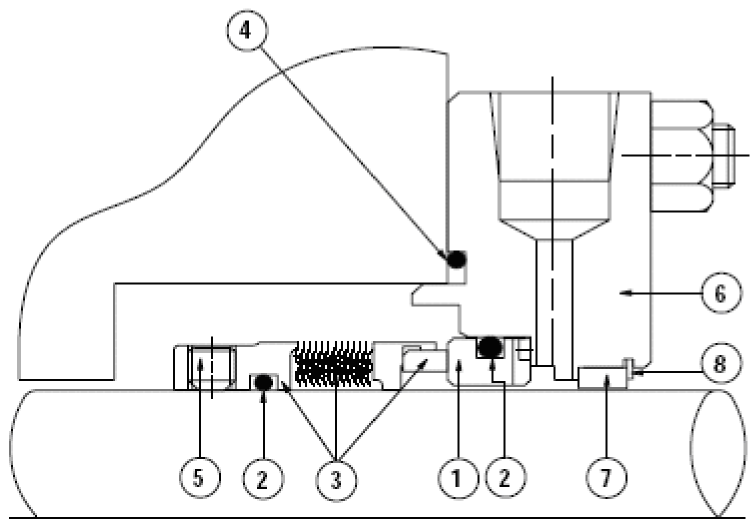
6.5.3.6.1 General

The shaft seal on centrifugal pumps keeps the air out and the fluid in the pump. Two basic systems are used to accomplish this: the mechanical seal and the packing gland.

6.5.3.6.2 Mechanical Seal

Technically, there is always leakage across the stationary and rotating mechanical seal faces. The incremental leakage is meant to lubricate the sealing surfaces. In the absence of this leakage, the sealing surfaces would quickly wear out. Mechanical seals minimize fluid leakage by having two matched, extremely flat, mated faces: one stationary in a gland and the other rotating with the pump shaft. Machining procedures, including shaft support, of the larger pump manufacturers are such that misalignment of the seal parts is practically nonexistent. Customarily, one of the sealing surfaces is softer than the other; for instance a carbon ring rotating against a hard material such as cast iron, ceramic, or tungsten carbide. The carbon ring always shows the greatest amount of wear, being softer than any of the hard materials. Figure 6-66 shows a mechanical seal within a stuffing box.

Typical Bellows Seal Arrangement



Part Name	Part Name
1 Mating Ring	5 Set Screws
2 O-Ring	6 Gland Plate Assembly
3 Rotary Seal Assembly	7 Bushing
4 O-Ring or Gasket	8 Retaining Ring

Figure 6-66. Mechanical Seal Installation

The function of the stuffing box is to create a structure that reduces the leakage around the pump shaft to a minimum by using packing rings or mechanical seal. Packing rings are fitted around the pump shaft and squeezed together with the packing gland/follower. The more pressure put on the rings by the gland, the tighter the rings fit around the shaft. However, when the packing is too tight fretting of the shaft or sleeve can occur, which will cause leakage. Additionally, packing, as a shaft seal, always requires some leakage to lubricate the shaft and minimize shaft fretting.

Figure 6-67 shows a packed stuffing box, with throat bushing, 5 rows of packing, lantern ring, and a stuffing box gland. There are many different types of stuffing box packing materials. Asbestos, however, should not be used as packing materials. Some of the most common packing materials are graphite, Teflon, aramid, etc.

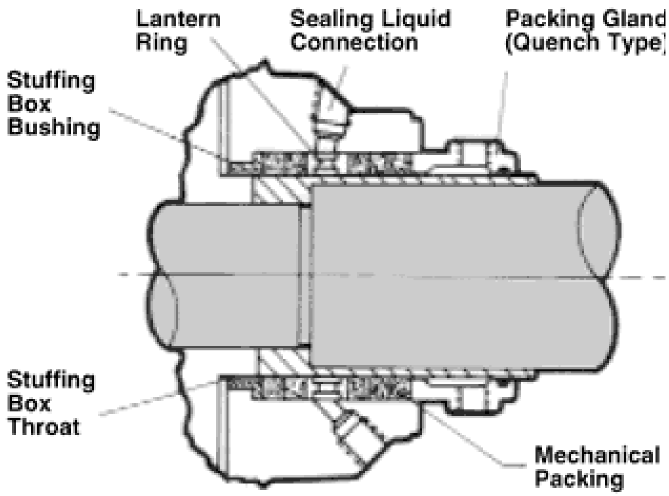


Figure 6-67. Stuffing Box

NOTE

Asbestos has been used as a Class 1 packing. Care should be used when working on older (pre-1972) packed valves and pumps.

6.5.4 Centrifugal Pump

Centrifugal pump imparts velocity to a liquid transforming it to pressure energy as it leaves the pump.

6.5.4.1 Rating Curve

Any centrifugal pump has, for a particular speed and particular diameter impeller, a rating curve which indicates the relationship between the head (or pressure) developed by the pump and the flow through the pump.

6.5.4.2 Operating Curves

Operating curves give actual pump figures for the following:

- Total head (in feet)
- Capacity (in gallons per minute)
- Required horsepower at different heads and capacities
- Net positive suction head (npsh)

The total head in feet shown on the vertical scale by the manufacturer is the amount of head (static and friction) in feet that a pump will overcome at any given capacity. It will be noted on the curves that the highest head developed is at the "0" capacity mark. This head is obtained by closing off the discharge valve on a centrifugal pump so that there is no flow through the pump.

NOTE

When the pump is running, the suction and discharge valves should be open.

6.5.4.3 Power and Efficiency

The work performed by a pump is a function of total head and weight of the liquid pumped in a given time period. Pumps should be selected with highest efficiency rating. The efficiency curve is depicted as concave upward. The brake horsepower is on the lower right hand portion of the graph. The pump input or brake horsepower is the actual horsepower delivered to the pump shaft. The pump output or hydraulic horsepower is the liquid horsepower delivered by the pump.

6.5.4.4 Net Positive Suction Head

The net positive suction head (npsh), is the head (in feet) required at the eye of the pump impeller to prevent cavitation. Cavitation is the formation of small bubbles in the liquid entering the pump. If the available npsh is less than the required, the pump will experience cavitation, or less flow than anticipated.

6.5.5 Selection of Pump

The selection of a pump for a given application is influenced by system requirements and layout, fluid characteristics, intended life, energy cost, code requirements, material of construction, and so on. Thus, the pump must be able to deliver the desired capacity in a given length of time and overcome the head resistance on the system. Additionally, the behavior of the system affects the choice of pump. For instance, the head and capacity may change at different loads.

A change of speed always results in a change in capacity, head, and horsepower. If the ratio of the new speed to the old speed doubles, say 3500 rpm/1750 rpm which is equal to 2, then the old capacity is multiplied by 2 (New Q = old Q x 2). The head, however, increases by the square of the speed ratio. Hence, the new TDH is equal to the old THD x (22), which is the old TDH x 4.

6.5.6 Monitoring Pump Operation

6.5.6.1 General

Never operate a pump without an appropriately installed coupling and stuffing box guard. Always perform lockout/tag out before working on rotating equipment. The mechanical condition of a pump can be determined by periodically monitoring its performance. The data obtained from various instrument readings is compared to the operating (performance) curves provided by the pump manufacturer and to previous instrument readings. The results of the comparison are then analyzed and a determination made, based on experience or the manufacturer's recommendation, whether or not the pump should be opened for inspection and overhaul. There are six parameters that should be monitored to understand pump performance: suction pressure, discharge pressure, flow, pump speed, fluid properties, and power. Additionally, it is also important to monitor the cost incurred for operating and maintaining the pump.

6.5.6.2 Gauge Check

Total discharge head (TDH) on a pump can be determined from the suction and discharge pressures. Pressure is measured by gauges permanently installed on the suction and discharge sides of the pump. If possible, the gauges should be installed at the pump's suction and discharge flanges. To apply the TDH data to the performance curves, the impeller diameter or the pump capacity must be known. Non intrusive well calibrated flow meter can be used to determine flow.

6.5.6.3 Prime-Mover Load Check

A change in power input to the pump motor at a given capacity is an indication of trouble. The load on the motor is usually measured with an ammeter. If, for the same amount of water, more amperage is required to operate the pump than when the pump was new, the pump needs attention. It is recommended that the performance of the pumps be checked periodically. The data obtained from the checks should be plotted on graph paper, with total head and horsepower plotted against capacity in gpm. The resulting curve will show the progress of wear or other factors of deterioration in the pump. When plotting the test data, be sure to use the same capacity reading on which the new pump performance was based.

6.5.7 Pump Maintenance

6.5.7.1 Mechanical Seals

6.5.7.1.1 Failure and Causes of Failure

There are many types of mechanical seals. However, the most common are pusher and bellows types; they are either single or double acting seals. Pusher seals are spring loaded and use dynamic secondary O-rings to prevent fluid from escaping between the shaft and the rotary seal. Bellows seals use a bellow configuration with a rotating face to exert pressure on the stationary face; the O-ring seal between the rotary assemble and the shaft is not subject to movement. Failure of a mechanical seal can be due to poor specification, inappropriate installation, poor material of construction, shaft movement, unbalanced impeller, pump cavitation, bad bearings, stuffing box not square, incompatible gland gasket, axial movement of the shaft, poor lubricity of the fluid, etc. It is not recommended to remove the seal for inspection, since reassembling it would change the wearing pattern and may cause it to fail.

6.5.7.1.2 Replacing Seals

Because of the many types of seals, no general instructions for replacing seals can be included in this handbook. However, instructions are provided by the seal and pump manufacturers and should be followed carefully. It is important that seals be installed in the correct position to avoid excessive pressure on seal faces causing leakage past the seal.

6.5.7.2 Pump Gland Packing

6.5.7.2.1 Failures and Causes

Failure of pump gland packing is indicated by excessive leakage. This type of failure is usually caused by over tightening of the stuffing box gland, which causes the premature wearing of the packing and fretting of the shaft or shaft sleeve or by installing packing that is not compatible with the pumped fluid.

6.5.7.2.2 Replacing Packing

Replace packing as follows:

1. First, unbolt and remove the packing gland. With the use of a packing hook, remove all the old packing and lantern ring, if any, without scratching the shaft. Also, remove, inspect, and replace throat bushing, if any.
2. Clean the inside of the stuffing box, as well as the shaft sealing area, so that the new packing can move easily.
3. Make sure that the new packing is the correct type and size. If the packing is cut from a roll, cut the length slightly shorter than the inside circumference of the stuffing box when the ends are butted together. The cut ends should be square and clean with no loose strings hanging from them. However, Skive joints are cut at a 45 degree angle.

4. Insert each packing ring separately as far as possible into the box, seating it firmly. Stagger the butted ends 90° or 180° apart. Tap each new packing ring into place in the box. If a seal cage (lantern ring) is used, be sure to locate it under the hole that supplies the seal cooling water.
5. When the required number of rings has been inserted, install the gland and tighten it by hand. Back off until the gland is loose. Turn the shaft by hand in the normal direction of rotation to level off any high spots in the packing. Tighten the gland just enough to prevent excessive leakage before starting the pump.
6. It is a good practice to start the pump with the stuffing box gland quite loose. As the packing adjusts itself to the shaft, and after the pump has been running for about 10 to 15 minutes, gradually tighten the gland until leakage is reduced to the desired number of drops per minute. Keep the gland square with the pump shaft at all times. If the gland becomes too hot to touch while the pump is operating, it is probably too tight. If it is impossible to add the last ring of packing in the box and still insert the gland, omit the ring and tighten the gland as described. Continue to tighten the gland daily, allowing for proper leakage, until the packing has seated itself enough to allow the last ring to be inserted.

6.6 PUMPING SYSTEMS

6.6.1 General

Pumping systems, as applied to heating and air-conditioning, are used to circulate and feed water to air-handler coils. They also transfer heat from the condenser to the cooling tower. Pumping systems fall into two main categories. One system is known as the open type, such as that installed between the condenser and cooling tower system. The other is known as the closed type, as applied to piping hot and cold water to and from the air-handling coils. It differs from the open system in that it is sealed off from the atmosphere. The open system is open to the atmosphere at the cooling tower.

6.6.2 Heating System Piping Arrangements

6.6.2.1 Types of Piping Arrangements

Heating systems can be 1 or 2 pipe. One pipe systems are exclusive to steam-heating and the steam moves toward the steam device while the condensate moves by gravity toward the boiler. Two pipe heating systems can be steam or hot water.

Chilled water cooling systems are generally two pipes. If the building has hydronic systems for both heating and cooling, this is called a four pipe system. It is the preferred layout when a central plant is used.

There are two and three pipe systems which try to share piping for both heating and cooling. These systems usually experience difficulties in switching from heating to cooling and also when switching back to heating. Care must be taken to prevent warm water entering the air conditioning evaporator or cool water entering the boiler.

6.6.2.2 Diagrams

In large facilities where the demand for heat varies from one part of the building to another, separate pump systems are required on the same boiler using the same expansion tank. To efficiently maintain complex pumping systems, it is recommended that a drawing of the installation's piping be kept readily available. Piping diagrams are useful in determining what units are included in a given pump system. They also ensure the correct size of pipe and fittings when replacement is required.

6.6.3 Cooling System Piping

6.6.3.1 Chilled-Water Systems

Chilled-water pump systems are similar to the heating systems. One difference is the use of a smaller expansion tank in the chilled-water system because of the lower change in water temperature, which results in a reduced amount of expansion. Also, the pressure in the tank is maintained by either a solenoid or a pressure-regulated water line. The tank could be open, closed or bladder type. Closed tanks may have entry at the bottom and this type is usually suspended from the ceiling of the equipment room. It may also have entry at the top with the use of a dip tube. This type is usually standing on the equipment room floor. The water compresses the trapped air in the top of the tank to a predetermined pressure.

6.6.3.2 Condenser-Water Systems

A typical condenser-water pump system is illustrated in Figure 6-68. It is a single-pipe, open-pumping system, because the circuit is broken at the cooling tower. The suction head on the pump depends on the vertical distance from the pump inlet to the free water surface in the tower sump. The column of water standing in the pipe between the pump and the tower sump is the only way of pressurizing this system to provide the pump with positive pump suction. The condenser and the height to which the water must be pumped provide the only resistance to flow and the ability of the pump to produce the necessary flow. The size of the piping is such that it offers negligible resistance.

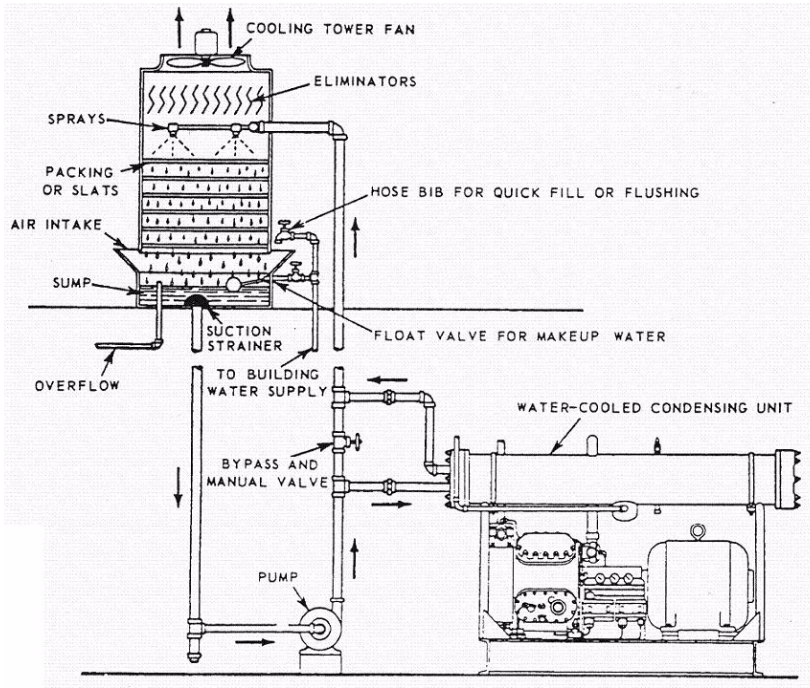


Figure 6-68. Typical Cooling-Tower System

6.6.4 System Head

6.6.4.1 General

The system head is the algebraic sum of the static head on the pump discharge, minus the static head on the pump suction, plus the friction losses through the entire system of fluid flow. The relationship between head (in feet of liquid) and pressure measured in psi is shown in the following equation:

$$H = 2.3p$$

where:

H = head, in feet
p = pressure, in psi

Pressure caused by resistance of the piping, pipe fittings, and actual lift of the water, added to the pressure required to force the water through the coils, equals the Total Dynamic Head.

6.6.4.2 Static-Pressure Head

Static-pressure head is the height to which the water can be raised by a given pressure. In other words, it is the weight of the entire column of water that the pump normally pumps against converted to feet of water head.

6.6.4.3 Friction Head

In any pipe through which a fluid is flowing, there is a loss of pressure. The loss of pressure (or friction head) depends on the velocity of the water, the pipe diameter and length, and the degree of roughness of the inside pipe surface.

6.6.4.4 Suction Head

Suction head is the pressure measured at the suction port of the pump. When the source of supply is below the pump, the condition is known as static suction lift. When the source of supply is above the pump, it is known as static suction head. One characteristic of a pump is that a certain amount of energy is needed to fill a pump on the suction side and overcome the friction and flow losses from the suction connection to that point in the pump at which more energy is added, such as the pump shaft. The amount of energy in the water at the pump inlet is known as the net positive suction head (npsh). In a centrifugal pump, the required npsh is that pressure, in feet of water, required to overcome friction losses between the suction opening and the impeller vanes and to create the desired velocity of flow into the vanes.

6.6.5 System Checks

6.6.5.1 General

To detect existing or pending failures in a pump system, periodic checks should be made. First, it must be assumed that the system has been balanced. Balancing of the system consists of properly metering the flow through each coil so that it gets its share of the total amount of flow. Once the system is in balance and the amount of flow in each coil and total flow is charted, any deviation from the normal should be followed by a check to determine the reason for the change.

6.6.5.2 Gauges

System checks are made by measuring pressures and flow throughout the system. This is done through the use of pressure gauges strategically installed in the system. Gauges are normally installed on both the suction and discharge side of the pump. Because of variations in pressure and flow that exist in the system due to branch circuit demands, the net positive suction head (npsh) will be affected. A lack of the required amount of npsh, measured in feet of water, will cause the pump to operate improperly. This data is obtained from the suction side pressure gauge. The reason the gauge is installed on the discharge side of the pump has been discussed in Paragraph 6.5.6.2. Other pressure gauges are installed, some permanently and others temporarily, at each of the coils. They are installed one on each side of an orifice flange and used to measure the pressure drop across the orifice. This data, by graph or calculation, is converted to quantity of water flowing through that particular leg of the system.

6.6.5.3 Pump Curves

The data obtained from pressure gauge readings are applied to the pump-performance curves. Any deviation from the standards, as established by the curves for a given capacity and total head, is cause for further inspection of the system. A troubleshooting guide, Table 6-3, has been provided to aid in identifying some of the causes of abnormal operation.

6.6.5.4 Pressure Levels

All centrifugal pumps have a rating curve, as stated in Paragraph 6.5.4.1, that indicates the relationship between the head (or pressure) developed by the pump and the flow through the pump. The rating curves establish the pressure limitations within which the pump will operate satisfactorily. By consulting the net positive suction head curve, the minimum suction pressure can be determined. The head-capacity curve determines the best discharge pressure for a particular required rate of flow.

6.6.5.5 System Inhibitors

6.6.5.5.1 Algae and Slime

Algae consist of tiny plant cells that multiply and produce large masses of plant material in a short time. Slime growth consists of a gelatinous mass that clings to practically all surfaces in the condenser system, trapping organic matter, debris, and scale-forming material. When the microbiological growths break loose from the tower, they clog lines, pumps, and heat exchangers. The key to combating algae and slime is mechanical cleaning followed by chemical treatment. Good housekeeping requires the periodic cleaning of the condenser-pump system to remove mud, silt, leaves, twigs, algae, slime, etc., that may have collected.

6.6.5.5.2 Scale

The evaporative process used to cool water in the condensing-water circulating system results in the concentration of dissolved solids in the water. Scale-forming salts are produced and deposited on surfaces in contact with the water. Deposits of calcium carbonate from the condensing water are normally the chief scale problem, although deposits of calcium silicate, magnesium silicate, and calcium sulphate may also be encountered. Since the solubility of calcium carbonate decreases as the temperature increases, the deposits usually show up first in the hottest part of the system, the tubes of the condenser. A buildup of scale in the condenser lowers the rate of heat transfer, reduces the efficiency of the refrigeration machine, results in an increase in consumption of electricity, and may cause the refrigeration machine to cut out because of high head pressure. In some water (such as that fairly low in hardness), the deposit of scale can be minimized by adequate bleed at the tower. In cooling towers, bleed, along with chemical treatment, is required.

6.6.5.5.3 Corrosion

Corrosion is generally the result of dissolved oxygen and acid gases in the water. The chief offenders among the acid gases are carbon dioxide and sulfur dioxide picked up from the atmosphere. The means and effect of cleaning water in a pumping system are described in Chapter 4.

6.6.6 General Startup and Follow-up

After it is determined that a pump is in good condition, certain steps must be taken before it is placed in operation. Many pumps require steps unnecessary in other pumps. For example, for radial-type impellers, the discharge valve should be closed at startup. For the mixed-flow or propeller-type pumps, the valve should be fully opened and the following steps taken:

1. Check that the bearings are filled with lubricant according to the manufacturer's recommendations.
2. With the coupling disconnected, test for correct direction of rotation and freedom of rotation.
3. Turn on the cooling-water system for the pump bearings, stuffing boxes, and mechanical seals, if these parts are liquid cooled or lubricated.
4. Prime the pump (follow the manufacturer's recommendations).
5. Close or open the discharge gate valve, depending on the starting procedure.
6. If the pump should not be started against a dead shutoff, open the recirculating valve.
7. Start the motor and allow the pump to come up to speed.
8. Open the discharge valve slowly.
9. Check the leakage from the stuffing boxes. Adjust the sealing-liquid valve for proper flow to ensure the lubrication of the packing. If the packing is new, do not tighten up on the gland immediately. Let the packing run in before reducing the leakage through the stuffing boxes.
10. Check the general mechanical operation of the pumps and motor.
11. Close the recirculating valve once there is sufficient flow through the pump to prevent overheating.
12. Check the pump suction, discharge, lube-oil, cooling-water, and sealing-water pressures and temperatures against the manufacturer's specifications.
13. Check the electric motor amperage to ensure that the motor is not overloaded.

NOTE

If the pump is started with the discharge valve open, the steps are the same, except that the discharge valve is opened sometime before the motor is started.

6.6.7 Recording Pump Data

While the pump is running, periodic checks should be made on suction and discharge pressure, stuffing box leakage, and bearing temperatures. No record is necessary for these readings, but the operator should report any discrepancy in pump operation. It is recommended that maintenance cards be kept on each pump. The cards should identify the pump, the date maintenance was performed, and the condition of the parts to be repaired or replaced. This data, plus the operating hours, help to make future decisions as to whether it is more economical to repair or replace the entire pump.

6.6.8 Preventive Maintenance

Guides can be found in the current MMO Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Checklists .

6.6.9 Troubleshooting Guide

NOTE

While performing troubleshooting procedures, observe all normal precautions for safeguarding personnel and equipment.

Table 6-3 lists the most common troubles occurring in centrifugal-type pumps. It includes the probable causes and recommended remedies for correction. Data in this guide is of a general nature and is intended to provide a standard approach to identifying and analyzing the most common troubles. It is recommended that this guide be reviewed at the local level and expanded, if necessary, to include the results of local experience.

Table 6-3. Troubleshooting Guide for Centrifugal-Type Pumps

SYMPTOM	CAUSE	REMEDY
1. No water is being delivered.	a. Pump not primed	a. Refer to text paragraph on Startup.
	b. Speed too low	b. Check whether motor is directly across the line and receiving full voltage. In case of steam turbine, check governor and determine if receiving full steam pressure.
	c. Discharge head too high	c. Check operating conditions. See that pipe friction and suction and discharge heads are as specified.
	d. Suction lift too high	d. Check with gauges. Normal suction should not exceed 15 feet.
	e. Impeller and/or piping plugged	e. Inspect piping, suction strainer, and impeller.

SYMPTOM	CAUSE	REMEDY
(continued)	f. Impeller rotating in wrong direction	f. Check shaft rotation against pump case direction arrows or manufacturer's literature.
2. Not enough water is being delivered.	a. Air leaks in suction line or stuffing box	a. Plug inlet and pressurize. A gauge in line will indicate leakage with a drop in pressure. A 1 percent leak may cause the capacity to decrease 10 percent.
	b. Speed low	b. Refer to text paragraph on starting.
	c. Discharge head higher than anticipated	c. Check operating conditions. See that pipe friction and suction and discharge heads are specified.
	d. Suction lift too high	d. Check with gauges. Normal suction should not exceed 15 feet.
	e. Impeller or suction line partially plugged	e. Inspect piping, suction strainer, and impeller.
	f. Not sufficient suction head for hot liquid	f. Hot liquids in almost all cases must flow by gravity and have sufficient thread or submergence to eye of impeller. Refer to pump manufacturer for complete information on suction piping, size, and type of liquid, and amount of submergence available.
	g. Wearing rings worn	g. Refer to text paragraph on bearings.
	h. Impeller damaged	h. Repair or replace.
	i. Foot valve too small	i. Inspect. Net area should be at least equal to area of pump suction but preferably larger. Suction-strainer area should be at least three of four times the area of suction pipe.
	j. Casing packing defective	j. Replace all worn packing.

SYMPTOM	CAUSE	REMEDY
(continued)	k. Foot valve or suction opening not submerged enough	k. Submerge entrance of suction pipe at least three feet below surface of the liquid.
3. There is not enough pressure.	a. Speed too low	a. Check whether motor is directly across the line and receiving full voltage. In case of steam turbine, check governor and determine if receiving full steam pressure.
	b. Air in the water	b. Plug inlet and put line under pressure. A gauge in line will indicate leakage with a drop in pressure. A 1 percent air leak may cause the capacity to decrease 10 percent.
	c. Wearing rings worn	c. Refer to text paragraph on bearings.
	d. Impeller damaged	d. Repair or replace.
	e. Casing packing defective	e. Replace all worn packing.
4. Pump works for a while and then loses suction.	a. Leak in the suction line	a. Plug inlet and put line under pressure. A gauge in line will indicate leakage with a drop in pressure. A 1 percent air leak may cause the capacity to decrease 10 percent. (An 8 to 10 percent air leak will cause pump to lose its prime.)
	b. Water seal plugged	b. Inspect line and position of seal cage in stuffing box.
	c. Suction lift exceeds 15 feet	c. Check for obstruction in suction line and for low water level.
	d. Air or gas found in the liquid	d. Vent suction back to source of supply.
5. Pump takes too much power.	a. Speed too high	a. Check speed of driver or, in case of belt drive, sheave, or pulley diameters.

SYMPTOM	CAUSE	REMEDY
(continued)	b. Mechanical defects, such as a bent shaft	b. Check run out of shaft. Total run out allowed depends upon pump design and speed. Approximately 0.003 inch for high-speed and 0.006 inch for low-speed units.
	c. Rotating elements binding	c. Check for too tight stuffing boxes, wearing-ring fit, and defective packing.

SECTION 7

SERVICE CONTRACTS

7.1 AUTHORITY

This handbook does not delegate contracting authority. Refer to Facility Services CMC for all service contracts. All service contracts shall give due consideration to article 32 factors prior to issuance.

7.2 SERVICE CONTRACTS

Prior to beginning any request visit the CMC website @
https://blue.usps.gov/supplymanagement/fscmc-hvac-maint.htm

Service contracts for heating ventilation and air conditioning (HVAC) equipment, such as package and unitary units, central heat and chilled water plants, and boilers; and for cooling tower water treatment and filtering; as well as water distribution systems are permissible for those installations where maintenance personnel are not qualified to perform routine preventive maintenance on USPS assets. For instance, in some USPS locations mechanics are not qualified to operate and maintain refrigeration systems, energy management systems, boilers, water treatment and water filtration processes, and other specialized facility maintenance equipment and processes. Paragraph 7.4.6 provides a partial list of some of the specialized equipment and processes that may need service contracts. However, prior to determining the need for a service contract due consideration must be given to all of the Article 32 factors.

7.3 TECHNICAL ASSISTANCE

If technical assistance is needed regarding service or maintenance requirements, contact the Area Maintenance Support office. If assistance in procurement and contracting is needed, contact the appropriate Commodity Management Center (CMC).

7.4 STATEMENT OF WORK

This Statement of Work (SOW) applies to the operation, maintenance, and repair of package and unitary refrigeration units, central plant heat and chilled water systems, boiler and cooling tower water treatment and filtration, and distribution systems.

The requestor must complete the SOW worksheet found on the CMC website. It should be understood that frequencies of work should align with frequencies approved in the current Guides can be found in the current MMO Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Checklists.

However, prior to subcontracting any work due consideration must be given to all factors contained in Article 32 of the National Agreement. If guidance is needed the Lead Maintenance Manager should be consulted.

7.4.1 General Information

The contractor shall provide all management, tools, supplies, equipment, and labor necessary to repair, maintain, service, and safely operate the central heat plant with chilled/hot water and steam, and the associated distribution systems, as well as any packaged and unitary units, water treatment for boilers, cooling towers and distribution systems, and Building Automation System (BAS). The contractor shall equip boilers, cooling towers, and other assets needing water treatment with automatic feeding devices to effectively treat and/or filter the water. The automatic feeding devices and all chemicals furnished and installed at each location by the contractor shall remain the property of the contractor except as noted. Nonetheless, the contractor shall specify the initial acquisition cost and United States Postal service (USPS) option purchase price at the expiration or termination of the contract, which shall be less than the acquisition cost, and shall provide manufacturer's invoices, drawings, operation, and maintenance manuals to USPS contracting officer within 30 days of contract signing. Furthermore, at the expiration or termination of the contract, all such devices and all chemicals, which were installed or stored by the contractor on USPS premises, shall be removed at the contractor's expense and the system restored to its original condition except if USPS desires to exercise the option to purchase the equipment at the price stated in the contract. Electrical outlets and electricity to operate the devices shall be provided by USPS at no cost to the contractor. However, any installed water meter in the makeup water lines, or elsewhere, are the property of USPS. Bypass feeders and/or pot feeders shall be used in closed loop systems and will remain property of the USPS. The contractor shall furnish and install pot or bypass feeders when no such feeders are presently installed. The contractor shall maintain all records and reports required to operate and maintain the central heat and chilled water systems and all other designated equipment.

NOTE

> USPS makes no representation or guarantee as to the condition of existing equipment, specified in Paragraph 7.4.6, on the start date of the contract. USPS strongly encourages the contractor to visit each site, inspect all equipment, and perform water testing to determine current conditions.

All work requirements shall be completed and accepted by the USPS prior to any payments disbursement for services performed during the month.

7.4.2 Basic Services

The contractor shall operate, service, and maintain BAS, packaged and unitary units, central heat and chilled water systems, including cooling towers, boilers, and water treatment and filtration processes, and chemically fed equipment for systems listed on Paragraph 7.4.6, and other designated equipment in accordance with the contract, the appropriate equipment manufacturer's recommendations, and best commercial practices. The contractor shall operate and/or service all assets under their control with qualified (and when applicable by law, regulation, or standard, with certified) managers, supervisors, operators, mechanics, and inspectors. USPS approved quality control, operation, maintenance, and inspection methods shall be employed. Furthermore, the contractor shall provide twenty-four hour call desk coverage. Additionally, the contractor shall conduct and document failure modes and effect analysis (FMEA) and reliability centered maintenance (RCM) in order to develop appropriate and effective maintenance programs. FMEA is a technique that identifies potential failure modes and their criticality. The preventive maintenance (PM) programs should address and eliminate, or mitigate, the effects of identified failure modes and RCM is a systematic approach for identifying the most cost effective maintenance regime for an asset or system. Furthermore, the contractor's maintenance procedures shall include work permits and safety procedures for start-up, control, operation, shutdown and all required personal protective equipment (PPE), including scaffolding and safety barriers. The contractor shall ensure that the HVAC system (or systems) produces the appropriate thermal demands and remains environmentally compliant during production and distribution of steam, chilled/hot water, and refrigeration. Likewise, water treatment should not produce any detrimental effects, such as equipment corrosion, scaling, or biological growth; scaling and fouling inhibits heat transfer. The contractor shall ensure proper inspection and maintenance of primary and ancillary equipment and system functions, including but not limited to production, production control, distribution, pumping, emission control, cooling towers, water treatment, fuel supply, and plant effluent refrigerants. Piping, distribution, pressure valves, boilers, and other items shall be maintained according to the appropriate craft and utility code: the American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME), the National Board of Boiler and Pressure Vessel Inspectors (NBBI), and the American Society of Heating, Refrigeration, & Air Conditioning Engineers (ASHRAE) standards, and all other applicable standards and governing regulations. Pressure vessels shall only be repaired by an R-Stamped repair shop and proper documentation shall be provided to USPS. All records shall be readily available for use by USPS and all reports shall be timely submitted. A list of packaged, unitary, and central heat, chilled water, water treatment and filtration, distribution systems, and related equipment with available workload data is included in Paragraph 7.4.6.

The contractor shall visit each site within the first 30 days of the contract to analyze conditions and recommend changes in equipment and procedures. The contractor shall notify the USPS location of leaks in systems so they can be repaired.

7.4.2.1 Preventive Maintenance (PM) Program

The contractor shall be required to accomplish PM in accordance with the current Guides which can be found in the current MMO Guidelines for Creating Detailed Local Building and Building Equipment Maintenance Checklist.

7.4.2.1.1 Preventive Maintenance Reports

The contractor shall develop and submit to the USPS a summary of preventive maintenance work and inspections completed during each visit to the facility. The report shall also identify maintenance tasks and inspections that were not performed. Justification for nonperformance of scheduled tasks should be unambiguously documented. The contractor shall also document and maintain preventive maintenance records for the major equipment included in the contract. Equipment records shall contain a complete history of maintenance, including dates scheduled and completed, and name of technician(s) who performed the work.

7.4.2.2 Corrective Maintenance (CM)

The contractor shall provide all necessary equipment, parts, permits, safety locks, PPE, material and labor to perform repairs and corrective maintenance services to return heat and cooling systems and related support equipment, including piping, and water treatment, to their proper operating condition. Corrective maintenance requirements shall reflect deficiencies identified during PM inspections or other service work. Corrective maintenance shall be accomplished concurrent with other service tasks or as soon as possible to sustain full operation of plant functions; it shall include corrosion control and touch-up painting of all equipment. Corrective maintenance reports shall also be submitted to USPS contracting officer no later than the 5th workday of the month.

7.4.2.3 Service Calls

The FSSP Response Line 1 855 444 6375/Facility Response Line Self Service desk will be the primary office to contact the contractor for service calls concerning corrective maintenance and repair services for heating and cooling systems in small facilities. Service calls may be classified as emergency, urgent, or routine. The appropriate classification will be given to the contractor along with the job order or service request.

7.4.2.4 Emergency Service Calls

Emergency service involves the correction of conditions that constitute an immediate danger to personnel, threaten property, and/or action required to restore essential service. The contractor shall be at the job site within two hours after receipt of an emergency service call and shall work continuously until the required service is completed or the condition is arrested.

7.4.2.5 Urgent Service Calls

Urgent service calls are used when a reported condition will not immediately endanger personnel or threaten property; nonetheless, if not corrected soon, the condition could affect the health or the well-being of personnel. Urgent service calls shall be accomplished during normal working hours, or on the second or split shifts within the capability of the contractor. The contractor shall respond to the work site within 24 hours and shall complete the task within five days after the initial receipt of the service request.

7.4.2.6 Routine Service Calls

Routine service calls are for work that is not classified as emergency or urgent. Routine work requests shall be responded to within 72 hours and completed within 15 days of the service request.

7.4.2.7 Operation Procedures

The contractor shall establish and maintain written instructions for the heat/chilled water plant operation, packaged and unitary units, water treatment and filtration, and water distribution systems. These procedures shall comply with the appropriate standards, Federal, State and Local codes, and the equipment manufacturer's recommendations. The plan shall address startup/shutdown, operational adjustments, safety precautions and emergencies for all major equipment; and shall include posted visible shutdown and start up procedures. Additionally, the contractor shall ensure that shutdowns and equipment overhauls, such as boilers, hot water generators, pressure vessels, and so on occurs during a USPS scheduled plant shutdown. The contractor shall request approval from the USPS contracting officer to deviate from any procedure within the contract.

7.4.2.8 Water Testing and Treatment

The contractor shall provide, operate and maintain all water treatment and filtration equipment affecting packaged units, the central plant, including boilers, and distribution system and shall provide sampling and analysis/test services to meet the various requirements, such as algae and bacteria containment, minimization of scale and corrosion to HVAC equipment and related components. Thus, all automatic feeding devices shall be provided by the contractor. Additionally, the contractor shall ensure that procedures used to conduct tests (water and corrosion coupons) are in accordance with applicable directives and best industry practices, and shall maintain appropriate laboratory records for all tests performed. Test files shall include the type of test, related equipment, results, date, and time performed, and name of person who performed the test. Samples for laboratory testing must be delivered to a reputable and certified laboratory within 20 hours of sample collection or sooner, so that analysis can commence within 24 hours. However, if Legionella is suspected sample delivery, analysis, and reporting of results to USPS contracting representative shall occur without any delay.

NOTE

USPS reserves the rights to perform independent sampling and laboratory analysis to ensure that performance thresholds are being met by the contractor.

Chemicals used by the contractor must not violate Federal, State, or Local regulations. Contractor shall submit proposed chemical treatment with Safety Data Sheets (SDS) prior to initiation of the contract to USPS contracting officer for approval. Normally, it is not necessary to chemically treat closed-loop water systems for pH control. However, steam boiler water should be kept between a pH of 10 to 11.5 and cooling tower water between a pH of 7 to 8. If a steam boiler is used, condensate return should be monitored for carbonic acid. The contractor shall supply and store all chemicals used in the contract in solid form and encased in protective plastic containers. The contractor shall not use chemicals considered toxic or heavy metals that have been identified as hazardous to humans or the environment by government agencies, refer to Environmental Protection Agency (EPA) CFR Part 63. The contractor is responsible for cleanup and remediation of all spills during filling/refilling at the site(s). Cleanup shall follow all EPA, Federal, State, and Local requirements. If any spills occur, the contractor shall immediately notify area personnel and the USPS contracting offices and provide immediate cleanup at no additional expense to USPS. The contractor shall, at the end of the contract performance period or upon termination of the contract, remove at no additional expense to USPS, any and all chemical feeding equipment, chemicals, and storage containers as directed by the USPS contracting officer or designated representative.

7.4.3 Service Delivery Summary

Table 7-1 lists performance objectives and thresholds for heating, ventilation, and air conditioning (HVAC) equipment. This includes package and unitary units, central heat and chilled water plants, boilers, cooling tower water treatment and filtering, as well as water distribution systems. These objectives and thresholds may be used in specifying service contracts.

Table 7-1. Performance Objectives and Thresholds for HVAC Equipment

Performance Objective	SOW Para	Performance Threshold
Basic Services, PM Program, and Operation Procedures Plant operates properly. System functions efficiently. Customers are satisfied with environmental controls. All records and reports are accurate and current. Reports are submitted on time.	7.4.2 7.4.2.1 7.4.2.1.1 7.4.2.7	Notice of Violation (NOV) is not permitted. Receipt of NOV results is failure of all performance objectives until NOV is resolved. 90% of all scheduled PMs are properly and timely completed. 100% of all reports are accurate. 90% of all reports are submitted timely. Approval of deviations from written procedures is obtained 100% of the time.
Corrective Maintenance (CM) All system components are in good working order. Any repairs are made immediately. Contractor makes progressive effort to keep system efficient and technologically current.	7.4.2.2	Response to and completion of service calls are timely 90% of the time.

Performance Objective	SOW Para	Performance Threshold
Service Calls Service calls are handled appropriately and professionally. Customers are satisfied with system operations.	7.4.2.3 7.4.2.4 7.4.2.5 7.4.2.6	90% of emergency service called answered within 2 hours. 90% of urgent service called answered within 24 hours. 90% of routine service called answered within 72 hours.
Operate and Maintain EMS Equipment Comfort levels maintained. Energy goals are met. Metrics are maintained on system efficiencies. All systems are balanced. System is fully operational. System defects are identified for timely repair.	7.4.2	EMS downtime shall not exceed two hours during the month.
Additional Clauses: Contractor performed a minimum of twelve (12) monthly scheduled inspections on all HVAC equipment.	7.4.2	12 monthly inspections were performed on all HVAC equipment 100% of the time.
Replace HVAC Filter Filter replacements are made in a timely manner; USPS is informed of filter replacement in writing. Replacement is made within the specified time.	7.4.2	Replacement schedule is submitted and followed 95% of the time.

7.4.4 USPS Furnished Property and Services

USPS will not supply the contractor any property or services.

7.4.5 General Information

7.4.5.1 Safety Requirements

Contractor personnel must notify USPS contract officer of their presence on USPS premises, sign in and obtain appropriate identification, failure do so is a violation of the contract. Furthermore, prior to work initiation contractor personnel must review USPS safety and emergency procedures, complete and signed needed permits; and all applicable work permits must be duly completed and approved by USPS supervisory personnel. Additionally, all safety precaution shall be reviewed with contract personnel prior to initiating any work. Local Energy Control procedures shall apply to work on all rotating and energized equipment.

The contractor shall provide safety controls and protection to the life and health of employees, customers, and all others, as well as for preventing damages to property, materials, supplies, and equipment. The contractor shall comply with all U.S. Department of Labor Occupational Safety & Health Administration (OHSA) and Environmental Protection Administration (EPA) standards in the performance of this contract as well as any other applicable Local, State or Federal agencies.

7.4.5.2 Hours of Operation

The requestor shall provide the hours of access for the contractor in its request to CMC.

7.4.5.3 Security Requirements

Contractor personnel shall display USPS visitor badge at all times when working on USPS premises and legible identification of the contractor's company, badge, or name on their uniform or clothes. Prior to any servicing during normal duty hours the contractor is required to report to the Senior Postal Official and sign in a logbook the date, time, company name, and name of mechanic(s). Work performed after normal duty hours shall be accomplished at no additional cost to USPS and work will continue until equipment is returned to normal working condition.

Keys issued to contractor, if any, by the USPS contracting officer shall only be used for official business under this contract. All keys lost or stolen shall be reported immediately to the contracting officer. The contractor shall not duplicate any keys issued by USPS.

7.4.5.4 Special Qualifications

Contractor personnel such as but not limited to HVAC Master Mechanics, HVAC Journeymen, and water specialists shall be licensed by the state the work is being performed. The contractor shall provide a copy of employees' licenses to the contracting office prior to the contract start date.

7.4.5.5 Equipment under Manufacturer's or Installer's Warranty

Equipment, components, and parts, other than that installed under this contract, shall not be removed or replaced, or deficiencies corrected while under warranty of the manufacturer or the installer without prior approval from the USPS contracting officer. All defects in material or workmanship, defective parts, or improper installation and adjustments found by the contractor shall be reported to the USPS contracting officer so that necessary action may be taken. The contractor shall be knowledgeable of the equipment, parts, and components that are covered by warranty. The contracting officer will furnish all available warranty information to the contractor.

7.4.5.6 Replacement, Modernization, and Renovation

During the term of the contract, USPS may replace, renovate, or improve equipment, systems, and components at the USPS' expense and by means associated with this contract. All replaced, improved, updated, modernized, or renovated equipment, components, and systems shall be maintained, operated, and/or repaired by the contractor at no additional expense to USPS.

7.4.6 Statement of Work Planning Guide

NOTE

The following Statement of Work Planning Guide is a sample. Acquire current forms from Supply Management.

STATEMENT OF WORK – PLANNING GUIDE

CONTRACTING FOR OPERATION, MAINTENANCE, AND REPAIR OF PACKAGED AND UNITARY UNITS CENTRAL HEAT AND CHILLED WATER PLANT(S), BOILER AND COOLING TOWER WATER TREATMENT AND FILTRATION, AND DISTRIBUTION SYSTEMS

Installation: ____________________

Street Address: ____________________

City, State, ZIP + 4: ____________________

1. **Reason for Request:**

   ☐ Current contract expires on ___ (date)

   ☐ No contract exists.

2. **Current/former contract information, (if applicable):**

   a. Name of Contractor:

   b. Contract Number:

   c. Notice ☐ is/ ☐ is not required for termination.

   d. If notice is required, how many days?

3. **Requested effective date that service should begin:**

4. **Provide a list of company names, addresses, telephone numbers and contact individuals of any local professional Water Treatment service firms that might be interested in providing these services.**

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APPENDIX A

SAMPLE MAINTENANCE CHECKLISTS

A.1 OPERATING LOG FOR RECIPROCATING TYPE REFRIGERATION MACHINES

OPERATING LOG FOR RECIPROCATING TYPE REFRIGERATION MACHINES
(Cooling Season)

BUILDING | MONTH AND YEAR

MACHINE NUMBER AND DATE	TIME CHECKED	OUTSIDE CONDITIONS				COMPRESSOR									CONDENSER		CHILLER	
		TEMPERATURES		SUNSHINE (Check one) (5)		HIGH SIDE HEAD		LOW SIDE SUCTION		OIL GEAR BOX					WATER TEMPERATURE		WATER TEMPERATURE	
		D.B.	W.B.	YES	NO	PRESSURE	TEMPERATURE	PRESSURE	TEMPERATURE	PRESSURE	TEMPERATURE				IN	OUT	IN	OUT
(1)	(2)	(3)	(4)			(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
	____ A.M.																	
	____ A.M.																	
(No.)	____ P.M.																	
	____ P.M.																	
(Date)	____ P.M.																	
	____ P.M.																	
	____ A.M.																	
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(No.)	____ P.M.																	
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(Date)	____ P.M.																	
	____ P.M.																	
	____ A.M.																	
	____ A.M.																	
(No.)	____ P.M.																	
	____ P.M.																	
(Date)	____ P.M.																	
	____ P.M.																	

INSTRUCTIONS

GENERAL—Where 1 machine is installed, use the form to cover 4 days operation; where 2 machines are installed, use the form to cover 2 days operation; and, where 3 or 4 machines, use to cover each day of operation.

COLUMN (1)—Show the number of the machine in operation and the date. If machine is not in operation, so indicate.

COLUMN (2)—Readings are to be taken at the end and middle of each tour.

COLUMN (11)—Applies to open units only where they have gear box.

COMMENTS—Use reverse for comments or notes deemed necessary or of interest.

PS Form 4990
June 1971

Figure A-1. Operating Log For Reciprocating Type Refrigeration Machines

A.2 OPERATING LOG FOR CENTRIFUGAL REFRIGERATION PLANTS

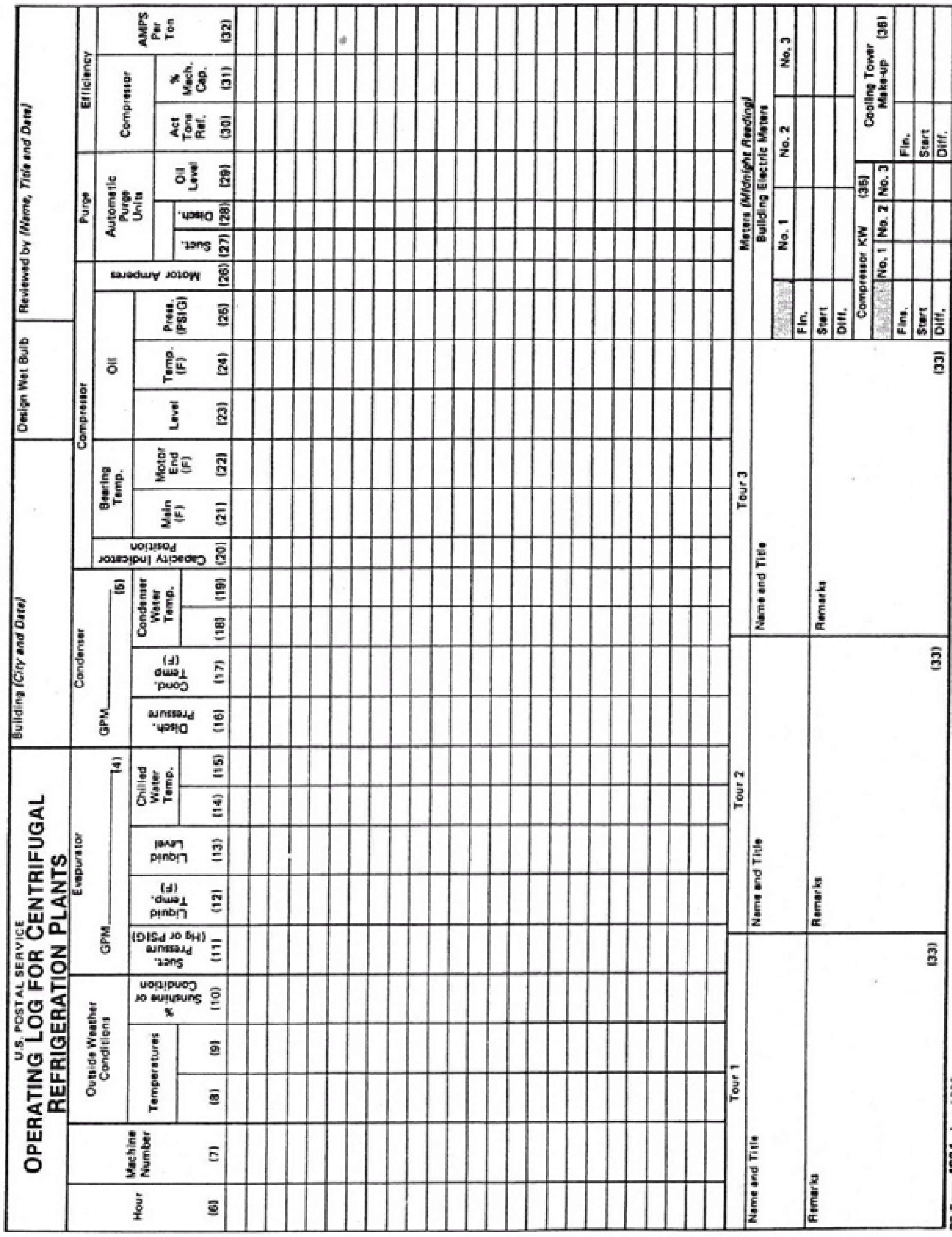

Figure A-2. Operating Log For Centrifugal Refrigeration Plants

A.3 LOW PRESSURE HEATING BOILER OPERATING LOG (HOT WATER)

U.S. POSTAL SERVICE LOW PRESSURE HEATING BOILER OPERATING LOG (HOT WATER)	BUILDING:	MONTH:	YEAR:
	ADDRESS:	FUEL TYPE:	
PERSON(S) TO BE NOTIFIED IN EMERGENCY (NAME & TELEPHONE NO.)		BOILER NO.:	

Daily Checks

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1) RECORD PRESSURE	1ST READING																															
	2ND READING																															
2) RECORD BOILER WATER TEMP	1ST READING																															
	2ND READING																															
3) RECORD FLUE GAS TEMP	1ST READING																															
	2ND READING																															
4) OPERATOR'S INITIALS	1ST READING																															
	2ND READING																															

Weekly Checks (Enter Date)

	WEEK 1	WEEK 2	WEEK 3	WEEK 4
1) OBSERVE FLAME CONDITION				
2) TEST LOW WATER CUT-OFF				
3) OBSERVE CIRCULATING PUMPS				

Monthly Checks (Enter Date)

1) MANUAL LIFT SAFETY RELIEF VALVE				
2) REVIEW CONDITION OF OR TEST EACH ITEM	A. FLAME DETECTION DEVICES		F. REFRACTORY	
	B. LIMIT CONTROLS		G. STOP VALVES	
	C. OPERATING CONTROLS		H. CHECK VALVES	
	D. FLOOR DRAINS		I. DRAIN VALVES	
	E. FUEL PIPING		J. LINKAGES	
3) OBSERVE GAGE GLASS ON EXPANSION TANK				
4) COMBUSTION AIR ADEQUATE/UNOBSTRUCTED				

GENERAL COMMENTS:

PS Form 4846-A, March 1985 (INSTRUCTIONS ON REVERSE)

Figure A-3. Low Pressure Heating Boiler Operating Log (Hot Water)

A.4 LOW PRESSURE HEATING BOILER OPERATING LOG (STEAM)

U.S. POSTAL SERVICE LOW PRESSURE HEATING BOILER OPERATING LOG (STEAM)	BUILDING:	MONTH:	YEAR:
	ADDRESS:	FUEL TYPE:	
PERSON(S) TO BE NOTIFIED IN EMERGENCY (NAME & TELEPHONE NO.)		BOILER NO.:	

Daily Checks

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1) RECORD PRESSURE	1ST READING																															
	2ND READING																															
2) OBSERVE WATER LEVEL	1ST READING																															
	2ND READING																															
3) RECORD FLUE GAS TEMP	1ST READING																															
	2ND READING																															
4) OPERATOR'S INITIALS	1ST READING																															
	2ND READING																															

Weekly Checks (Enter Date)

	WEEK 1	WEEK 2	WEEK 3	WEEK 4
1) OBSERVE FLAME CONDITION				
2) TEST LOW WATER CUT-OFF				
3) TEST GAGE GLASS				

Monthly Checks (Enter Date)

1) MANUAL LIFT SAFETY VALVE				
2) REVIEW CONDITION OF OR TEST EACH ITEM	A. LINKAGES		F. FLOOR DRAINS	
	B. DAMPER CONTROLS		G. FLAME DETECTION DEVICE	
	C. STOP VALVES		H. LIMIT CONTROLS	
	D. REFRACTORY		I. OPERATING CONTROLS	
	E. FLUE-CHIMNEY BREECHING		J.	
3) INSPECT FUEL PIPING				
4) COMBUSTION AIR ADEQUATE/UNOBSTRUCTED				

GENERAL COMMENTS:

PS Form 4846, March 1985 (INSTRUCTIONS ON REVERSE)

Figure A-4. Low Pressure Heating Boiler Operating Log (Steam)

A.5 MAINTENANCE, TESTING, AND INSPECTION LOG; HEATING BOILERS

MAINTENANCE, TESTING, AND INSPECTION LOG
HEATING BOILERS

YEAR________
CITY OR DIVISION________ BLDG.________
BOILER NO________ GAS ( ) OIL ( ) STEAM ( ) WATER ( )

	ROUTINE TO BE PERFORMED	FREQ	JAN.	FEB.	MAR.	APR.	MAY	JUNE	JULY	AUG.	SEPT.	OCT.	NOV.	DEC.	
1	OBSERVE PRESSURE & WATER LEVEL OR TEMP.														1
2	REPORT UNUSUAL NOISES OR CONDITIONS	D													2
3															3
4	OBSERVE CONDITION OF FLAME, REPORT IF	W													4
5	SMOKEY OR BURNER STARTS WITH PUFF														5
6															6
7	TEST LOW WATER FUEL CUT-OFF & WATER FEEDER	W													7
8	TEST GAUGE GLASS OR WATER COLUMN	W													8
9															9
10	OBSERVE CONDENSATE OR CIRCULATING PUMPS	W													10
11															11
12															12
13	CHECK CONDITION OF HEATING SURFACES	SA													13
14															14
15	TRY LEVER TEST - SAFETY OR RELIEF VALVE	M													15
16	TEST FLAME DETECTION DEVICES	M													16
17	TEST LIMIT CONTROLS	M													17
18	TEST OPERATING CONTROLS	M													18
19	INSPECT BOILER ROOM FLOOR DRAINS	M													19
20	INSPECT FUEL SUPPLY SYSTEM IN BOILER ROOM	M													20
21															21
22	SLUDGE BLOWDOWN	Q													22
23															23
24															24
25	COMBUSTION EFFICIENCY AND DRAFT TESTS	A													25
26															26
27	INTERNAL AND OR EXTERNAL INSP. AND CLEANING	A													27
28	ROUTINE BURNER	A													28
29	ROUTINE LOW WATER FUEL CUT-OFF	A													29
30	BLOWDOWN TEST - LOW WATER FUEL CUT-OFF	A													30
31	POP TEST - SAFETY OR RELIEF VALVE	A													31
32	ROUTINE CONDENSATE OR VACUUM PUMP	A													32
33	ROUTINE ENTIRE CONTROL SYSTEM	A													33
34	INSPECT BOILER ROOM AIR INTAKE	A													34
35	INSPECT GAS PIPING	A													35
36															36
37															37
38															38

D - DAILY W - WEEKLY M - MONTHLY Q - QUARTERLY SA - SEMI-ANNUALLY A - ANNUALLY AD - AS DIRECTED

Figure A-5. Maintenance, Testing, And Inspection Log; Heating Boilers

A.6 EFFECT OF SOOT ON FUEL CONSUMPTION

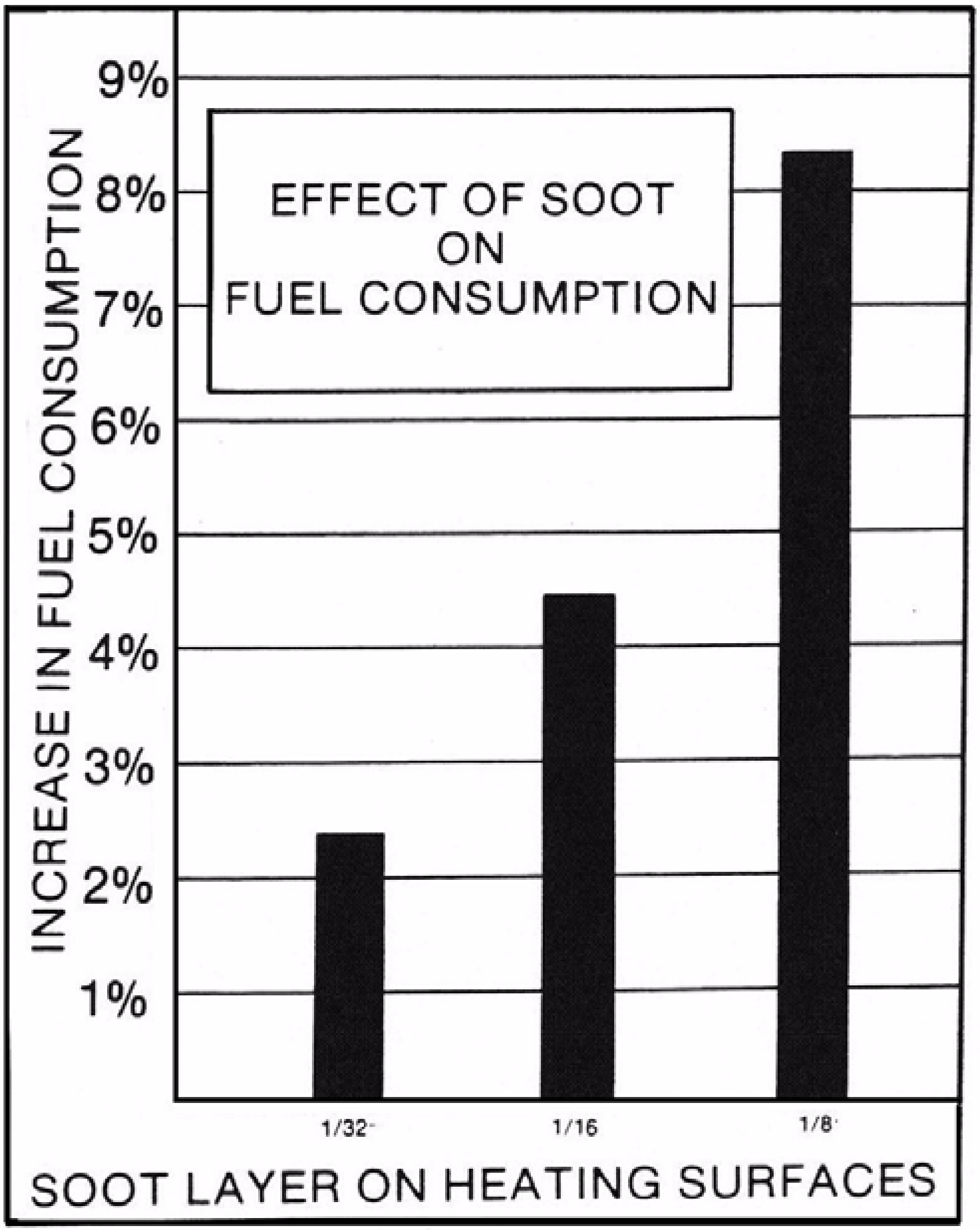

Figure A-6. Effect Of Soot On Fuel Consumption